

Investigation of the  
potable water  
contamination incident  
at Ranger mine  
March 2004



Supervising Scientist



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## **Executive summary**

At approximately 10.00 am on 24 March 2004 the Supervising Scientist was advised by the General Manager Operations of the Ranger mine that the potable water system at the mine had been contaminated, probably by process water. As a result, all operations at the mine and mill had been shut down, the potable water system had been isolated and all non-essential staff had been sent home. In addition, he advised that, since Jabiru East (but not the township of Jabiru) received its potable supply from the mine, the potable supply to Jabiru East had been shut down and all businesses in the Jabiru East region, including the Airport, the Supervising Scientist's Jabiru Field Station and the Gagudju Workshop, had been advised that water remaining in their systems should not be consumed.

The Hon Dr David Kemp MP, the then Minister for the Environment and Heritage, was informed of the occurrence of the incident and Dr Kemp requested that the Supervising Scientist should conduct a comprehensive investigation into the incident and provide a report to him at the conclusion of the investigation.

Late on 25 March 2004, Energy Resources of Australia (ERA) advised the Supervising Scientist that it had now been established that, during the night of 23–24 March 2004, contaminated potable water from a holding tank adjacent to Jabiru Airport had discharged to the environment. This additional information was subsequently provided to Dr Kemp who reiterated his request for a comprehensive report from the Supervising Scientist.

This report contains the results of the Supervising Scientist's investigation of the incident, including his assessment of the likely impact on the health of workers at the mine site, on the health of people living in the vicinity of the mine and on the environment of Kakadu National Park.

## **Causes of the incident**

This investigation has concluded that the primary cause of the contamination of the potable water system at the Ranger mine in March 2004 was that an operator, at about 9.40 pm on 23 March, opened a valve connecting the water manifold at the Fine Ore Bin (FOB) Scrubber to a one inch hose. At the time of this connection, the manifold was also connected to the process water system. Unknown to this operator, the other end of the one inch hose was connected to the potable water system and the valve at that end of the hose was open. The higher pressure in the process water system caused water to flow from the process water system into the potable water supply system.

It has not been possible to determine when, or by whom, the valve at the potable water end of the hose was opened. Nor has it been possible to determine precisely when the hose was connected to the potable water system but it occurred some time between 11.45 am on 20 March 2004 and 6.30 pm on 23 March 2004.

We have concluded that supplementing the process water supply to the FOB scrubber with potable water (that is, simultaneous supply of process water and potable water to the scrubber) has probably not occurred in the past, is not a standard ERA procedure and is not a practice knowingly adopted by any ERA operators. However, it is likely that a hose has been connected between the FOB scrubber and the potable water hosepoint in the past and that, contrary to ERA stated policy, potable water may have been used by some staff to supply water to the FOB scrubber when process water was unavailable.

It is concluded that the primary conditions that enabled the incident to occur were:

- The existence of the same type of connectors, albeit of different size, on the process and potable water systems;
- The lack of a system for early warning of contamination in the potable water system; and
- The absence of non-return valves in the potable water system.

ERA has made commitments to address these issues but it is recommended that measures to address these issues should be made requirements of the company under legislation.

However, it is the Supervising Scientist's view that the underlying cause of the incident was the poor condition of the process water distribution system at Ranger.

During the conduct of this investigation, it was identified that the Control Room Log at Ranger contains about 30 entries related to the failure of, or repairs to, various parts of the process water distribution system at Ranger in the period 1 March to 24 March 2004. A general inspection of the mill noted that leaking pipes were common, valves were broken and corroded, temporary hose connections were present, and the colour coding of pipes was in many instances obscured by rust and grime. On this basis, it was obvious that a major refurbishment of the process water system was required to bring it up to a satisfactory standard.

Discussions with staff revealed that the condition of the process water system and the need for frequent repairs led to a situation where staff were forced to use alternative water supplies to keep the scrubber operational. While accepted practice, it is clear that such a switch did not require the formal change management procedure to be followed. Staff considered that these breaches of change management procedures were necessary to keep the plant operating.

ERA had previously identified the condition of the process water system as a significant risk and had begun, and has continued to implement, a process water system refurbishment program. Part of this, the Process Water Pipe Replacement Project, remains to be completed. This project needs to be completed and it is recommended that the condition of the process water distribution system should be audited before the end of 2004. It is also recommended that steps be taken at Ranger to tighten up procedures for the management of changes to the water systems on site and to address the culture of staff that has arisen as a result of the poor condition of the current system.

In public discussion on this incident, it has been noted that the incident occurred only a few months after ERA received certification under the International Standard ISO 14001. Many have questioned the efficacy of this standard in the light of the occurrence of the incident. It should be noted that the ISO 14001 standard is designed to address environmental issues and, despite the secondary but important leak of contaminated water at Jabiru East, the primary risk associated with this incident was an Occupational Health and Safety (OHS) issue. OHS risks are not addressed in the systems implemented at Ranger under ISO 14001. It is recommended that this should be rectified.

## **Environmental Requirements and the Ranger Authorisation**

It is the role of the Northern Territory Government to assess whether or not ERA has been in breach of the *Mining Management Act 2001* and the Ranger General Authorisation. In addition to the Ranger General Authorisation, there may be breaches of provisions of the *Mining Management Act 2001* related to ERA's duty of care to provide a safe work environment. This report has noted that the Northern Territory Minister for Mines and Energy announced on 19 May 2004 that the report of his Department on the incident had been

referred to the Northern Territory Department of Justice to consider whether a case existed for prosecution of ERA.

Energy Resources of Australia (ERA) is required to comply with the Commonwealth Environmental Requirements (the ERs) for the Ranger mine as attached to the Authority issued under Section 41 of the Commonwealth *Atomic Energy Act 1953* and to the export permit for uranium granted under the *Customs (Prohibited Exports) Regulations 1958*.

This report has reviewed the extent to which ERA may have been in breach of the Ranger Environmental Requirements. We have concluded that ERA was in breach of ER 3.4 as a result of its failure to ensure that process water is contained within a closed system. We have also concluded that ERA has been in breach of ER 5.1 as a result of its failure to ensure that radiation doses to company employees and contractors must be kept as low as reasonably achievable. It is recommended that the Commonwealth Minister for Industry, Tourism and Resources should assess whether or not action should be taken by the Commonwealth in response to the established breach of Environmental Requirements 3.4 and 5.1.

## **Responsibilities of the Supervising Scientist and the Northern Territory Government**

The Commonwealth Government decided, in June 2000, that the inspectorial activities of the Supervising Scientist, which had ceased in 1995, should be reinstated. In making this decision, the Government made it clear that this inspectorial role should be limited, in a manner similar to that in place prior to 1995 and consistent with the Supervising Scientist's functions under the *Environment Protection (Alligator Rivers Region) Act 1978*, to assessing issues that could be relevant to off-site environmental protection.

The mechanism for implementing this decision was the commencement of Routine Periodic Inspections (RPI). These are carried out monthly and, while organised by the Supervising Scientist, are conducted jointly with the NT Department of Business, Industry and Resource Development and the Northern Land Council. These inspections focus on the environmental protection mechanisms in place at Ranger including the condition and adequacy of containment structures and bunds. They do not involve inspections of plant inside the bunds nor do they address Occupational Health and Safety issues other than radiation safety. Those are issues that are the responsibility of the Northern Territory Government. This focus on off-site environmental protection issues is the reason why the RPI process did not identify the primary conditions that gave rise to this incident

The Supervising Scientist does not review in detail the Northern Territory Government's conduct of its responsibilities for the day-to-day regulation of mining of uranium at Ranger. However, in his report on the investigation of the leak of tailings water at Ranger in 2000, the Supervising Scientist recommended that the Northern Territory Department of Mines and Energy should undertake a comprehensive review of its site inspection regime in the light of deficiencies identified in the report, and design and implement a new proactive inspection regime within a risk management framework.

The Supervising Scientist is aware that the NT Department of Business, Industry and Resource Development (DBIRD) now carries out a much more comprehensive inspection and audit program at Ranger than applied in 2000. The results of these inspections and audits are not normally conveyed to the Supervising Scientist where they do not relate to environmental issues. The Commonwealth Government may wish to be satisfied that the occurrence of this incident can not be attributed to a lack of vigilance on the part of the Northern Territory Government in the discharge of its responsibilities in the day-to-day regulation of the mining

of uranium at Ranger. It is recommended that the Commonwealth Minister for Industry, Tourism and Resources should seek advice on this issue from the Northern Territory Government

### **Contamination of the Jabiru East potable water supply**

A faulty valve at a holding tank at Jabiru East caused contaminated potable water to flow from the mine towards Jabiru East. Water quality data at Jabiru East businesses on the morning of 24 March are limited but we have been able to conclude that water consumed at the Jabiru Field Station and the Gagudju Workshop on the morning of 24 March met all drinking water guidelines and that it is highly likely that this was also true at the Jabiru East Airport.

The consumption of water from the Jabiru Field Station (JFS) of the Supervising Scientist by staff of the Supervising Scientist and Aboriginal Traditional Owners on 5 April 2004 arose from a misunderstanding by a member of staff and from the lack of tagging of potable water outlets within the JFS. We have concluded that the water from the Jabiru Field Station consumed by SSD staff and by Aboriginal Traditional Owners on 5 April met drinking water guidelines and did not represent any health risk. The Supervising Scientist will develop and implement an emergency response plan to ensure that the circumstances that led to this incident are not repeated.

### **Assessment of human health implications for ERA staff and contractors**

A detailed assessment has been carried out on the potential for adverse long-term health effects arising for workers at the Ranger mine who were exposed to contaminated water as a result of this incident. Such long-term effects could arise, in principle, as a result of chemical exposure and radiation exposure.

For radiation exposure, it has been concluded that, even under the worst-case scenario considered, the risks arising from radiation exposure of ERA staff and contractors who consumed contaminated water at the Ranger site on 23–24 March 2004 are very low and that long-term effects on their health would not be expected. It is considered that no follow-up radiation exposure monitoring is required.

The risks to workers from chemical exposure were assessed by two different approaches. The first approach used risk assessment methods that combine information on the exposure of workers to chemicals in the Ranger incident with data on effects of such chemicals on human health in the medical and scientific literature to draw conclusions on the likely effects on people who were exposed to contaminated water. The second approach involved the measurement of a range of chemical and biological response indicators in samples of blood and urine from workers who were exposed to contaminated water, and the expert medical assessment of the results to assess the likelihood of adverse long-term effects.

These two different approaches were adopted in two separate investigations conducted on behalf of ERA and the Supervising Scientist. While the two investigations were independent and produced separate reports, they used common data sets (for example chemical data sets on the extent of water contamination and health testing analyses of blood and urine) provided by ERA and SSD as appropriate.

The principal conclusion of both investigations, supported by both the risk assessment and the medical assessment methods, was that it is most unlikely that there will be any longer-term or delayed health effects on target organs such as the brain, liver and kidney because of the brief period of exposure to the contaminated water.

Both of the health investigation reports, however, adopted a precautionary approach to their conclusions and recommended that a follow-up health monitoring program for affected workers be considered. It is recommended that ERA implements such a program following consultation with affected workers and their doctors.

## **Assessment of environmental impact**

Two approaches have been adopted in this report in assessing the potential impact on the downstream environment of Kakadu National Park arising from the discharge of contaminated water from the water storage tank at Jabiru East on 24 March 2004.

The first approach was based upon modelling of the flow of contaminated water from the mine site to the Jabiru East tank, mixing in the tank, and overflow from the tank towards the Magela Creek. The model used very conservative assumptions and represented a worst case scenario. The results indicated that, of all the constituents present in process water, only manganese, uranium and possibly copper could have been present in Magela Creek at concentrations that would be measurable above background. Taking into account the measured attenuation of metals during overland flow towards Magela Creek, we have concluded that environmental impact downstream from the Ranger mine would not be expected.

The second approach was based upon assessment of a range of monitoring data. These included data from the Supervising Scientist's routine biological and chemical monitoring programs conducted in the vicinity of the Ranger mine, including continuous monitoring of electrical conductivity, as well as additional sampling conducted as part of this investigation. Assessment of all the chemical analyses of water samples obtained during the period of the incident demonstrate that no change occurred in the chemistry of Magela Creek downstream from the Ranger mine as a result of the incident. The creekside biological monitoring program using fish and freshwater snails was underway throughout the week in which the incident occurred. No change was observed in fish larval survival or snail reproduction at the monitoring site downstream from the mine compared to results obtained upstream.

Based on all of these data, the overall conclusion has been drawn that the potable water contamination incident should not have given rise to any impact on the ecosystems of Kakadu National Park and that there should be no impact on the health of people who consume water or food from the creek or billabongs downstream from the mine.

## **Recommendations**

The recommendations arising from this investigation are listed below.

### **Recommendation 1:**

*The Commonwealth Minister for Industry, Tourism and Resources should advise the Northern Territory Minister for Mines and Energy that ERA should be required, either through approval of an appropriately submitted Mining Management Plan for the Ranger mine or by required revisions to such a Plan, to:*

- a) Ensure that the fittings used throughout the Ranger potable water system should always remain incompatible with all other fittings used on the site to prevent the connection of the potable water system to any other system.*
- b) Install a water contamination probe within the Ranger potable water system. The probe should measure electrical conductivity and acidity continuously and should trigger an alarm alerting operators if the value of either of these variables changes significantly from pre-set values.*



- c) *Install non-return valves at points in the potable water system where connections may be made to other water systems. A risk analysis of the potable, process and pond water systems should be used to determine where non-return valves are required.*

**Recommendation 2:**

*The Commonwealth Minister for Industry, Tourism and Resources should advise the Northern Territory Minister for Mines and Energy that, by the end of 2004, an independent audit of the process water distribution system at Ranger should be carried out to determine whether the Process Water Pipe Replacement Project has been completed and to identify further work required to address any remaining deficiencies in the process water system.*

**Recommendation 3:**

*ERA should introduce a permit system requiring authorisation by a Superintendent for changes to water systems and should implement a program designed to improve the standard of housekeeping on site. ERA should determine the minimum competency standards required for operators, and implement a training system that ensures that operators meet those standards.*

**Recommendation 4:**

*The Commonwealth Minister for Industry, Tourism and Resources should advise the Northern Territory Minister for Mines and Energy that ERA be required to implement a Workplace Safety System consistent with, or equivalent to, Australian Standard 4801 and that the operation of this system be the subject of an annual independent audit.*

**Recommendation 5:**

*The Commonwealth Minister for Industry, Tourism and Resources should consider whether action should be taken by the Commonwealth in response to the established breach of Environmental Requirements 3.4 and 5.1.*

**Recommendation 6:**

*The Commonwealth Minister for Industry, Tourism and Resources should seek advice from the Northern Territory Minister for Mines and Energy on the nature and extent of the audit and inspection regime at the Ranger mine and, in particular, should seek details of any concerns expressed by the Department of Business, Industry and Resource Development on the condition of the process plant and on related OHS issues.*

**Recommendation 7:**

*ERA should provide copies of the two health risk assessments contained within the Supervising Scientist's report to affected workers, should counsel these workers to seek advice from their doctors on their possible participation in the proposed voluntary monitoring program and should facilitate the implementation of this program for those workers who choose to participate, including the provision of the advice of an independent consultant neurotoxicologist. When the results of the program become available, they should be assessed by both the Rio Tinto occupational physician and the Supervising Scientist's independent expert group and these assessments should be provided to the affected workers and their doctors.*

## **Preface**

This report on the contamination of the potable water system at the Ranger mine in March 2004 has been prepared by the Supervising Scientist at the request of the then Minister for the Environment and Heritage, Dr David Kemp.

The Northern Territory Government, through the Department of Business, Industry, and Resource Development (DBIRD), conducted its own parallel investigation into the incident. Whilst this was a separate, independent investigation, DBIRD officers cooperated fully with my staff when relevant information was sought. Importantly, DBIRD openly discussed its findings with me and my staff. The findings of the two independent investigations were remarkably similar and discussions enabled minor differences to be resolved based on discussions on the evidence.

The preparation of this report would not have been possible without the full cooperation of Energy Resources of Australia (ERA), the operator of the Ranger mine. ERA provided full and open access to key personnel at the mine who needed to be interviewed, to all documents and computer logs that were sought and to all data collected by ERA that might be relevant to my investigation.

I wish to thank the group of experts from the Australian Centre for Human Health Risk Assessment who provided me with advice on the difficult issue of assessing whether or not delayed or longer-term health effects could be expected for those workers at the Ranger mine who were exposed to the chemicals in the contaminated water through drinking and showering.

I wish to acknowledge the cooperation of the Gundjehmi Aboriginal Corporation and the Northern Land Council in facilitating meetings with the Mirrar Traditional Owners and with the broader Aboriginal community in the region.

Finally, I wish to thank the staff of the Supervising Scientist Division who assisted me in the conduct of my investigation and in the preparation of this report. A large number of staff have been involved and they worked diligently and tirelessly on the tasks they were allocated.

Dr Arthur Johnston

Supervising Scientist

August 2004

# **Investigation of the potable water contamination incident at Ranger mine March 2004**

## **Supervising Scientist**

### **1 Introduction**

At approximately 10.00 am on 24 March 2004 the Supervising Scientist was advised by the General Manager Operations of the Ranger mine that the potable water system at the mine had been contaminated, probably by process water. As a result, all operations at the mine and mill had been shut down, the potable water system had been isolated and all non-essential staff had been sent home. In addition, he advised that, since Jabiru East (but not the township of Jabiru) received its potable supply from the mine, the potable supply to Jabiru East had been shut down and all businesses in the Jabiru East region, including the Airport, the Supervising Scientist's Jabiru Field Station and the Gagudju Workshop, had been advised that water remaining in their systems should not be consumed.

The Hon Dr David Kemp MP, Minister for the Environment and Heritage, was informed of the occurrence of the incident and Dr Kemp requested that the Supervising Scientist should conduct a comprehensive investigation into the incident and provide a report to him at the conclusion of the investigation.

Late on 25 March 2004, ERA advised the Supervising Scientist that it had now been established that, during the night of 23–24 March 2004, contaminated potable water from a holding tank adjacent to Jabiru Airport had discharged to the environment. This additional information was subsequently provided to Dr Kemp who reiterated his request for a comprehensive report from the Supervising Scientist.

This report contains the results of the Supervising Scientist's investigation of the incident, including his assessment of the likely impact on the health of workers at the mine site, on the health of people living in the vicinity of the mine and on the environment of Kakadu National Park.

### **2 Description of the incident**

#### **2.1 Discovery of the contamination of the potable water system and the immediate response**

Prior to 7.30 am on 24 March 2004, a number of ERA employees noted a change in the taste or quality of drinking water at Ranger. Similarly, a number of ERA employees noted that they felt itchy after showering at Ranger after shift changeover at 7.00 am and/or that showering left an oily film on their skin or hair. It appears that these observations remained, on the whole, unreported to ERA managers until later in the morning. However two reports were made that resulted in investigation of the potable water system.

At approximately 6.40 am, an administrative employee reported to a Shift Supervisor that drinking water tasted unpleasant. Chlorine levels in the potable water tank at Ranger were

checked and found to be appropriate. At this stage, contamination of the potable water system with process water was not suspected.

At approximately 7.30–7.45 am on Wednesday 24 March 2004, the Day Shift Supervisor at the Ranger mine took a drink of water from a water cooler located in the Grinding Building Crib (lunch) Room at the Ranger minesite. The water tasted very bitter and he suspected that process water had contaminated the potable water system.

The Day Shift Supervisor informed the Production Superintendent of his suspicions by phone, then went to the Fine Ore Bin (FOB) Scrubber on the second level and found a 1 inch hose connected to the manifold with the valve open. He closed the valve, returned to the Grinding Building Crib Room, and advised the Production Superintendent by phone that the process water system had been connected to the potable water system. At the request of the Production Superintendent, the Day Shift Supervisor tagged the water cooler 'Out of Service' and took a sample of water from it to the ERA laboratory on site for analysis.

At about this time, after being advised of the problem by the Day Shift Supervisor, Day Shift Operator A left the Grinding Building and found a 1 inch hose connected between a potable water hose point on the ground level and the FOB Scrubber manifold on the second level. He closed the valve at the potable water hosepoint and returned to the Grinding Control Room.

At approximately 8.20 am, Day Shift Operator A attempted to connect the 1 inch hose to the process water hosepoint on the ground level outside the Fine Ore Bins but could not do so because the process water hose point had a 2 inch fitting and the hose had a 1 inch fitting. He went to the pyrolusite thickener located at the back of the Grinding Building where he found a 1 inch to 2 inch connector and used it to connect the hose to the process water hosepoint. Upon returning to the Grinding Control Room, Day Shift Operator A noted that the FOB scrubber low flow alarm continued to activate and return repeatedly.

Shortly before 8.00 am the ERA laboratory determined that the pH of the water sampled from the water cooler in the Grinding Crib Room was 4.5, its electrical conductivity was 5900  $\mu\text{S}/\text{cm}$  (microSiemens per centimetre) and it contained uranium at a concentration of approximately 8000 ppb (parts per billion). The ERA laboratory advised the ERA Maintenance Manager who subsequently advised the Production Manager of the analysis. The analysis confirmed that process water had contaminated the potable water system at Ranger. At 8.10 am, an announcement was made on the Ranger intercom system (GAI phone) advising ERA staff not to drink water as the potable water system had been contaminated with process water. ERA commenced sending non-critical staff and contractors home at 8.30 am and shortly before 9.00 am shutdown of the plant commenced.

At approximately 8.15 am, the water supply to Jabiru East was isolated by closing a valve on the Jabiru East line on the minesite. Between 9.00 am and 9.15 am, ERA's Environment, Safety and Health Manager visited businesses and the Jabiru Field Station (JFS) of the Supervising Scientist at Jabiru East advising that there were problems with the potable water and that the supply had been shut down.

At approximately 9.30am water from the JFS header tanks was tested for electrical conductivity (EC) and found to have an EC of 338  $\mu\text{S}/\text{cm}$ . This is well within the normal range for potable water at the Field Station. A number of samples were taken from taps and the tanks at the JFS and dispatched to the commercial laboratory in Darwin for analysis (results in Appendix 1). The main isolation valve at the front of the JFS was closed but not locked or tagged. All staff were advised not to drink or use JFS water.

## **2.2 The Jabiru East discharge**

As described in Section 3.1.1, potable water for Jabiru East is supplied via the Jabiru East line from the Ranger minesite. Users at Jabiru East include the Supervising Scientist's Jabiru Field Station, businesses at the airport and the Gagudju workshop. The supply also maintains a tank at Jabiru East as an emergency supply for Jabiru East and the minesite in the event that there is a failure of the primary supply from the Brockman Borefield. The tank's size is 1.2 ML and is intended to be maintained full.

At approximately 8.15 am on 24 March, after ERA staff were advised of the suspected contamination of the potable water supply, a member of the ERA Services Maintenance team drove to the isolation valve on the Jabiru East line adjacent to Retention Pond 2 (RP2) and isolated the Jabiru East line to avoid further contamination of the water supply at Jabiru East. At approximately 9.30 am the same employee drove to the Jabiru East tank to further isolate the supply to Jabiru East and the tank through valving located near and adjacent to the tank. Once isolation had occurred, the employee walked around the back of the tank where he observed water flowing from the tank overflow pipes. These pipes discharge into a concrete ditch drain at the base of the tank. Water discharged into this short concrete drain would flow into an earthen drain then overland towards Magela Creek, approximately 600 m away along the path of flow.

The Jabiru East tank had ceased overflowing by the mid to late afternoon of that day (24 March), when ERA commenced pumping the contents of the Jabiru East tank back to Ranger.

The significance of the overflow from the Jabiru East tank (ie that the water being released to the environment may be contaminated with process water) was not recognised at the time, and was not reported to ERA managers until the following day, 25 March 2004. ERA's General Manager Operations subsequently advised the Assistant Secretary Office of the Supervising Scientist at approximately 10.15 pm on 25 March after the Assistant Secretary Office of the Supervising Scientist had completed interviewing night shift staff at Ranger. The Assistant Secretary Office of the Supervising Scientist and the ERA Environment, Safety and Health Manager inspected the Jabiru East tank later that night.

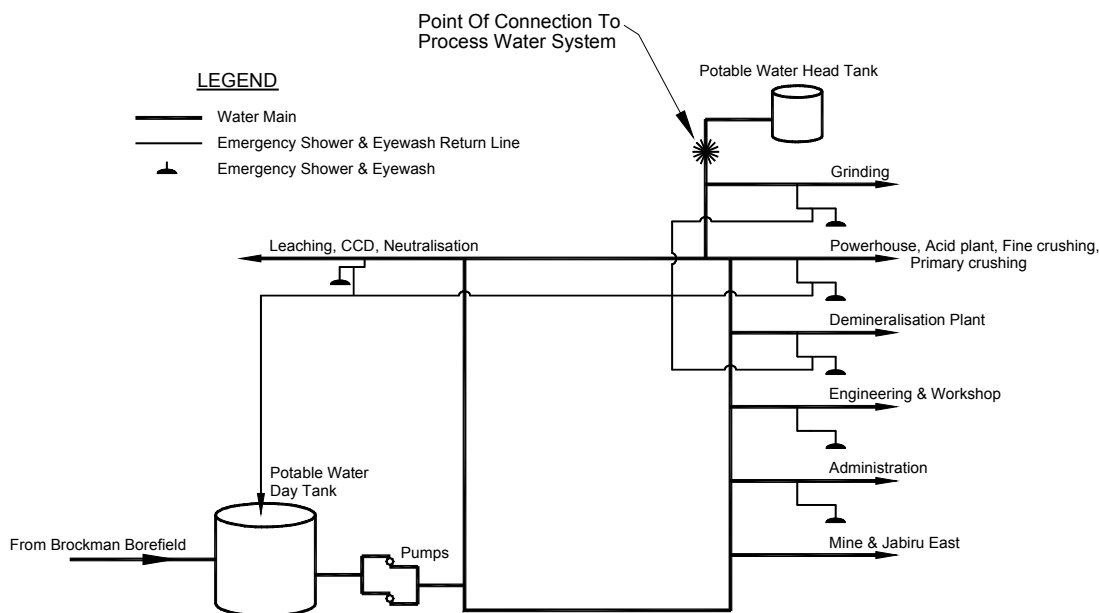
## **3 Investigation of the incident**

### **3.1 Ranger Project Area water systems**

Before describing the investigation of the incident, it is necessary to briefly outline the three water systems on the Ranger Project Area (including Jabiru East). They are, in order of decreasing water quality, the potable water system, the pond water system and the process water system.

#### **3.1.1 The Ranger potable water system**

The potable water system at Ranger supplies drinking water and water for facilities such as ablutions for the Ranger minesite and also to Jabiru East. Water is pumped from the Brockman Borefield on the Ranger Project Area into the potable water tank located adjacent to the administration building at Ranger. A simplified conceptual diagram of the Ranger potable water system is shown in figure 1.



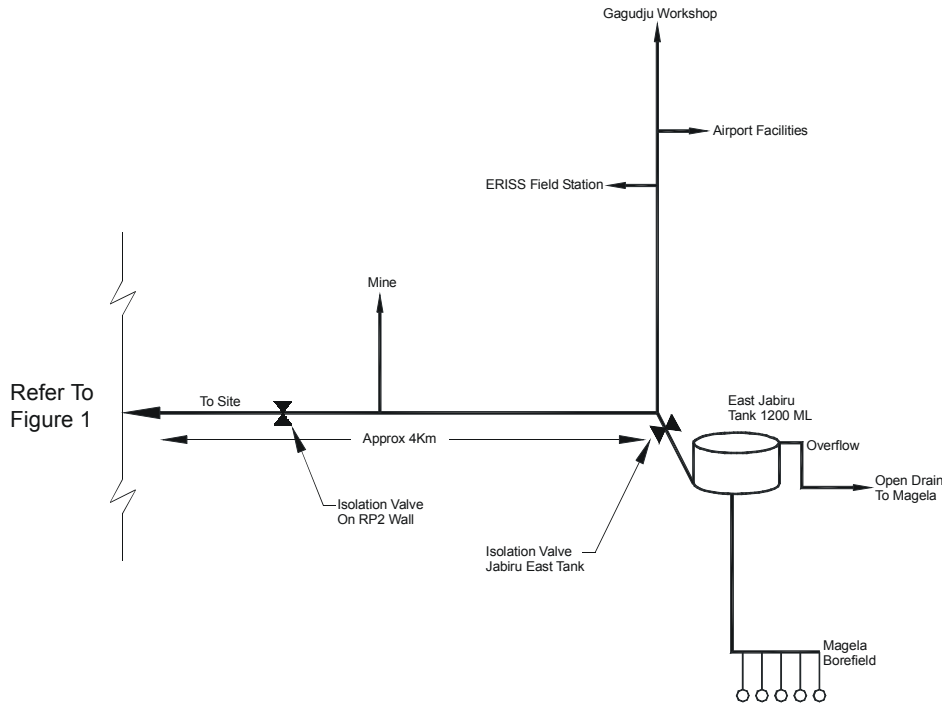
**Figure 1** Simplified conceptual diagram of the Ranger potable water system

A water main from the potable water day tank distributes potable water around the minesite. Connected into this main via a pipe is the potable water head tank. The purpose of the head tank, located on top of the Fine Ore Bins, is to pressurise the water main and, hence, the entire potable water system.

When the level of water in the head tank drops below a certain level, water is automatically pumped from the potable water day tank via the water main into the potable water head tank. When the water level in the potable water day tank falls below a certain level, water is automatically pumped from the Brockman Borefield into the potable water day tank.

There are numerous emergency showers and eye washes located around the mill and process plant at Ranger. These are connected to the water main and, where located outside buildings, are also connected to a smaller diameter return line that returns water to the potable water day tank. The purpose of the return line is to maintain water movement in the pipes that supply the emergency showers and eye washes preventing water from becoming heated by the sun during the day.

Potable water for Jabiru East and the Mine (Pit 3) is supplied via the Jabiru East line that is connected to the water main very close to the potable water tank at Ranger. Hence, the Jabiru East water reticulation system is part of the same system that supplies the minesite, deriving its pressure from the potable water head tank located on top of the fine ore bins. The Jabiru East line passes the Mine (Pit 3) then proceeds to Jabiru East supplying water to the Supervising Scientist's Field Station, the businesses located at Jabiru Airport, and the Gagudju Workshop. A simplified conceptual diagram of the Jabiru East potable water system is shown in figure 2.



**Figure 2** Simplified conceptual diagram of the Ranger and Jabiru East potable water system

The town of Jabiru derives its drinking water from separate borefields located approximately 25 km west of the town and is not connected in any way to the Jabiru East or the Ranger potable water system.

Located at Jabiru East are two 1.2 ML potable water tanks, one of which has been decommissioned. The purpose of the Jabiru East tank that remains in service is to provide an emergency water supply for Jabiru East and/or the minesite in the event that there is a failure of some sort in the primary supply from the Brockman Borefield. It does not supply water to Jabiru East or the minesite in normal circumstances. There is a small (25 mm) pipe between the Jabiru East line and the Jabiru East tank that provides a small constant flow into the tank to compensate for losses due to evaporation and to maintain movement of water through the tank to avoid stagnation. Consequently, the Jabiru East tank remains full at all times.

The Jabiru East tank is also equipped with overflow pipes that feed into a concrete ditch drain at the base of the tank. The concrete ditch extends away from the tank for several metres, after which water would flow in an earthen drain for several tens of metres and then overland towards Magela Creek. The travel path for water between the tank and Magela Creek is approximately 600 m.

There is also a larger (200 mm) pipe incorporating a pressure relief valve between the Jabiru East line and the Jabiru East tank. This valve is designed to remain closed unless the pressure in the line becomes excessive, whereupon it opens and dumps water into the Jabiru East Tank, relieving the pressure in the Jabiru East line, and preventing a blow-out in the potable water system.

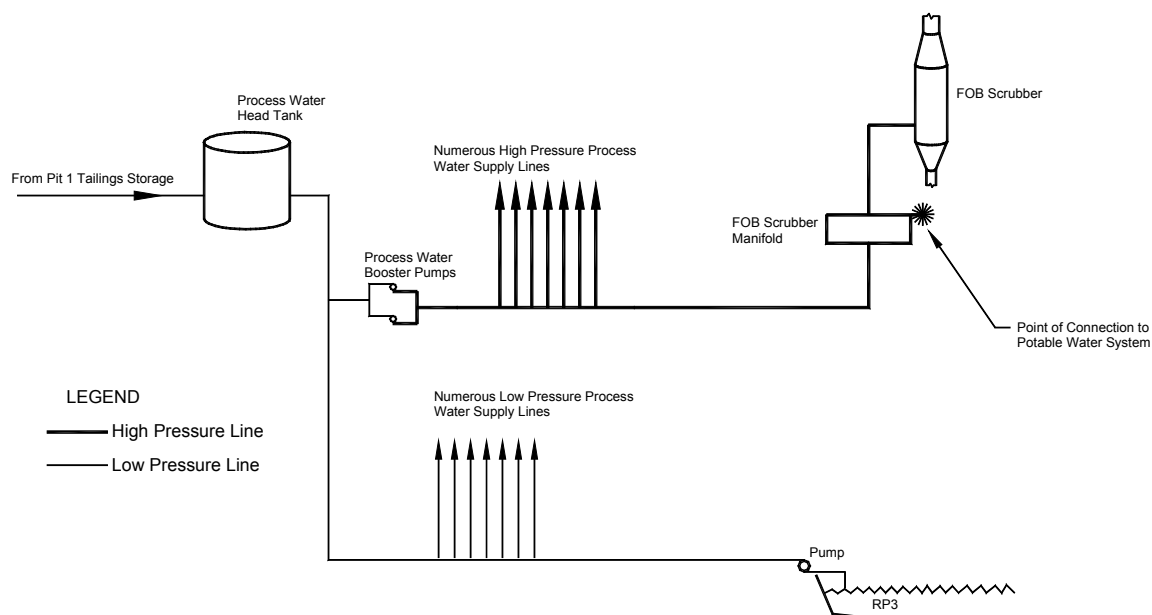
### 3.1.2 Pond water system

The pond water system at Ranger is designed to manage rainfall runoff and seepage from stockpiles, rainwater that is collected in Pit 3 and storm water from the process plant area and other potentially contaminated areas onsite. The main repository of pond water at Ranger is Retention Pond 2, although Pit 3 and Djalkmara Billabong each serve as temporary repositories during the wet season each year and there are various sumps that collect and store seepage that are pumped to Retention Pond 2 as required.

Pond water is water that has been in contact with ore but has not been affected by the extraction process at the Ranger mill. It does not, for example, meet drinking water standards and is disposed of by a combination of evaporation, direct irrigation and release/irrigation following treatment through wetland filters. The pond water system includes a network of pipes and pumps to facilitate the movement of pond water around the site as required. Pond water is used wherever water is required to make slurries that can be pumped around the site, and for other purposes including fire fighting, electric motor cooling, and dust suppression including all scrubbers except Fine Ore Bin Scrubbers 1 and 2. Scrubbers are devices that remove dust entrained in air passing through flues or stacks. Water is sprayed into the airflow and the resultant water/dust mixture is collected and retained.

### 3.1.3 Process water system

The process water system contains water that has been in contact with uranium ore or tailings during the uranium extraction process. It is very poor quality water that is never allowed to be released (unless treated so that it is no longer of a quality which characterises process water). It is contained primarily in the tailings repositories (that is, Pit 1 and the Tailings Dam) on site and is returned to the mill for re-use in the mill and process plant. Retention Pond 3 provides surge storage capacity of process water for the mill and process plant. A simplified conceptual diagram of the Ranger process water system is shown in figure 3.



**Figure 3** Simplified conceptual diagram of the Ranger process water system



Process water is pumped from Pit 1, which has been used as a tailings repository since 1996, to the Process Water Head Tank located at the eastern end of the Tailings Dam Corridor. Low pressure lines, operating under the head provided by the Process Water Head Tank carry process water to various parts of the process plant and mill. A separate high pressure line, pressurised by two booster pumps that usually operate individually, draws process water from the Process Water Head Tank and supplies parts of the process plant and mill that require process water at a higher pressure.

One of the purposes for which process water is used in the mill is in Fine Ore Bin Scrubbers 1 and 2. These scrubbers are connected to the high pressure process water line.

### **3.2 Supervising Scientist Field Station Potable Water System**

As described previously, the Gagudju Workshop and the businesses at the Jabiru Airport derive their potable water supply directly from the Jabiru East line.

The Supervising Scientist's Jabiru Field Station (JFS) has a slightly different arrangement, whereby water from the Jabiru East line is first piped into tanks located at the field station through a valve at the entrance to the JFS. Valves at the tanks open and close automatically maintaining the water level in these tanks between preset levels. Potable water is supplied to the Field Station from these tanks via pressure sets that provide the pressure for the JFS potable water system.

The fire fighting facilities at the Field Station are comprised of two independent systems. The first is the fire hose reels located around the field station that are connected into the potable water system. The second is a fire hydrant main supplying several fire hydrants located at the Field Station. The fire hydrant main is pressurised by its own pump that is only activated in the event of a fire at the Field Station, drawing water from the Field Station's potable water tanks.

The fire fighting system at the Field Station has been designed to remain operational when there is a failure in the potable water system. The potable water system (including the fire hose reels) draws water from half-way up the tanks whilst the fire hydrant main draws water from the bottom of the tanks. This ensures that the tanks always remain at least half full, and makes this water exclusively available for fire fighting purposes. The fire hydrant main has its own dedicated pump, and so is not dependent on the pressure sets that pressurise the potable water system.

Further, after the valve at the entrance to the JFS there is a direct connection between the Jabiru East line and the Field Station potable water system that bypasses the Field Station tanks. The valve on this connection is normally closed but opens automatically when there is no pressure in the field station potable water system. Thus, if the pressure sets at the Field Station fail, pressure for the fire hose reels (and the entire potable water system) is supplied via a direct connection to the Jabiru East Line provided that the valve at the entrance to the JFS is open.

### **3.3 Investigation of the potable water contamination incident**

#### **3.3.1 Investigation methodology**

Shortly after 9.00 am on 24 March 2004, the Manager of the Jabiru Field Station was advised by an ERA employee that the potable water supply to Jabiru East had been shut off due to a problem with the potable water. The Manager then advised the Assistant Secretary Office of the Supervising Scientist by telephone of the situation, adding that he suspected that the

potable water system had been contaminated by process water. At the request of the Supervising Scientist, the Assistant Secretary Office of the Supervising Scientist departed Darwin for Jabiru at approximately 10.00 am to commence an investigation.

The following chronology (table 1) is a summary of the actions taken by the Assistant Secretary Office of the Supervising Scientist in the investigation into the circumstances surrounding the contamination of the potable water system at Ranger.

**Table 1** Chronology of investigation

Date (2004)	Approximate Time	Action
24 March	Afternoon	Water samples collected by the Manager JFS from a fire Hydrant at Jabiru East and from the Administration, Engineering and Grinding buildings on the Ranger minesite.  Initial briefing on the incident received from the ERA Environment Safety and Health Manager  Fine Ore Bin Scrubber and potable water hosepoint to which it was connected inspected (the point of the contamination)
25 March	Morning	Further discussions with ERA Environment, Safety and Health Manager & Senior Occupational Health & Safety Adviser
	Afternoon	Commence compiling relevant ERA documentation  ERA Maintenance Manager interviewed  Discussions with ERA Production Manager  ERA Day Shift Operator A interviewed
	Evening/night	ERA Night Shift Operator A interviewed  ERA Night Shift Operator B interviewed  ERA Night Shift Supervisor interviewed  Discussions with ERA Environment Safety and Health Manager and General Manager Operations  General Manager Operations advises of overflow of Jabiru East Tank  Jabiru East Tank inspected
26 March	Morning	ERA Day Shift Supervisor interviewed
	Afternoon	ERA Production Superintendent Processing interviewed  Discussions with ERA Maintenance Manager and ERA Maintenance Superintendent  General inspection of Grinding Building, Leaching area CCDs including process water booster pumps and Clarifier area.
	Evening	Brief discussion with ERA Chief Executive Officer  ERA Environment, Safety and Health Manager and General Manager Operations interviewed  Heavy Equipment Workshop/Engineering inspected
29 March	Morning	Discussions with ERA Manager Development re potable water sampling and testing
	Afternoon	Discussions with ERA Project Engineering Coordinator re potable water system drawings  Review ERA potable water sampling points and inspect <ul style="list-style-type: none"><li>• Simon Carves Yard</li><li>• Water Management Yard</li><li>• Old Neutralisation Area</li></ul>

		<ul style="list-style-type: none"> <li>• CCDs</li> <li>• Area 42 'Pond Water' Area</li> <li>• Acid Plant Control Room and Crib Room</li> <li>• Acid Storage Tanks (from outside area)</li> <li>• Water Demineralisation Plant</li> <li>• Clarifier</li> </ul>
30 March	Morning	Senior Occupational Health and Safety Adviser interviewed
	Afternoon	ERA Manager Strategy interviewed
		Fine Ore Bin Scrubber and potable water hosepoint to which it was connected re-inspected
		Potable water hosepoints in process plant area inspected
		Additional ERA documentation received
29 April		Return to Ranger to clarify issues associated with the operation of the potable, process and pond water systems

### 3.3.2 The contamination event

The following account of the events related to the contamination of the potable water system at Ranger is based upon interviews and discussions with various ERA employees, the review of relevant documentation supplied by ERA and held by the Supervising Scientist, and inspections conducted during the course of the investigation.

Throughout the Day Shift (7.00 am to 7.00 pm) on 23 March 2004, the low flow alarm on the Fine Ore Bin (FOB) scrubber activated and returned repeatedly. The alarm indicates that the flow of process water supplied to the scrubber is below a pre-set point but not so low as to 'trip', that is, automatically shut the scrubber and the mill down. The alarm is said to 'return' when the flow of water to the scrubber returns to above the pre-set point. The Day Shift Operators continually acknowledged the alarm throughout the day, which silences the audible signal, however the alarm continues to show on the control screen.

At approximately 6.30 pm on 23 March 2004, Day Shift Operator A decided to attempt to supplement the flow of water supplied to the scrubber to stop the low flow alarm from activating. He left the control room and went to a potable water hose point (tap) on the ground level outside the Fine Ore Bins to which a 1 inch hose was already connected. The other end of this hose was connected to the hosepoint on the manifold of the FOB scrubber, also a 1 inch fitting. The handle on the valve of the potable water hose point was broken and the valve was very difficult to open.

The operator attempted to open the valve by hitting it with a piece of 'Besser Brick'. However, before succeeding, he realised that he should not open the valve as there was a risk of process water from the scrubber contaminating the potable water system through the hose, so he returned to the control room after ensuring the valve was closed, but left the 1 inch hose connected as he had found it. Note that the above account of the actions of Day Shift Operator A is based upon interviews with Day Shift Operator A and the Day Shift Supervisor conducted by the Assistant Secretary Office of the Supervising Scientist on 25 and 26 March 2004. ERA has since advised that Day Shift Operator A has stated to ERA interviewers more recently that he did not attempt to open the valve at the potable water hosepoint.

Shift change occurred at 7.00 pm, as usual, and the low flow alarm on the FOB scrubber continued to activate and return several times per minute. The following summarises the

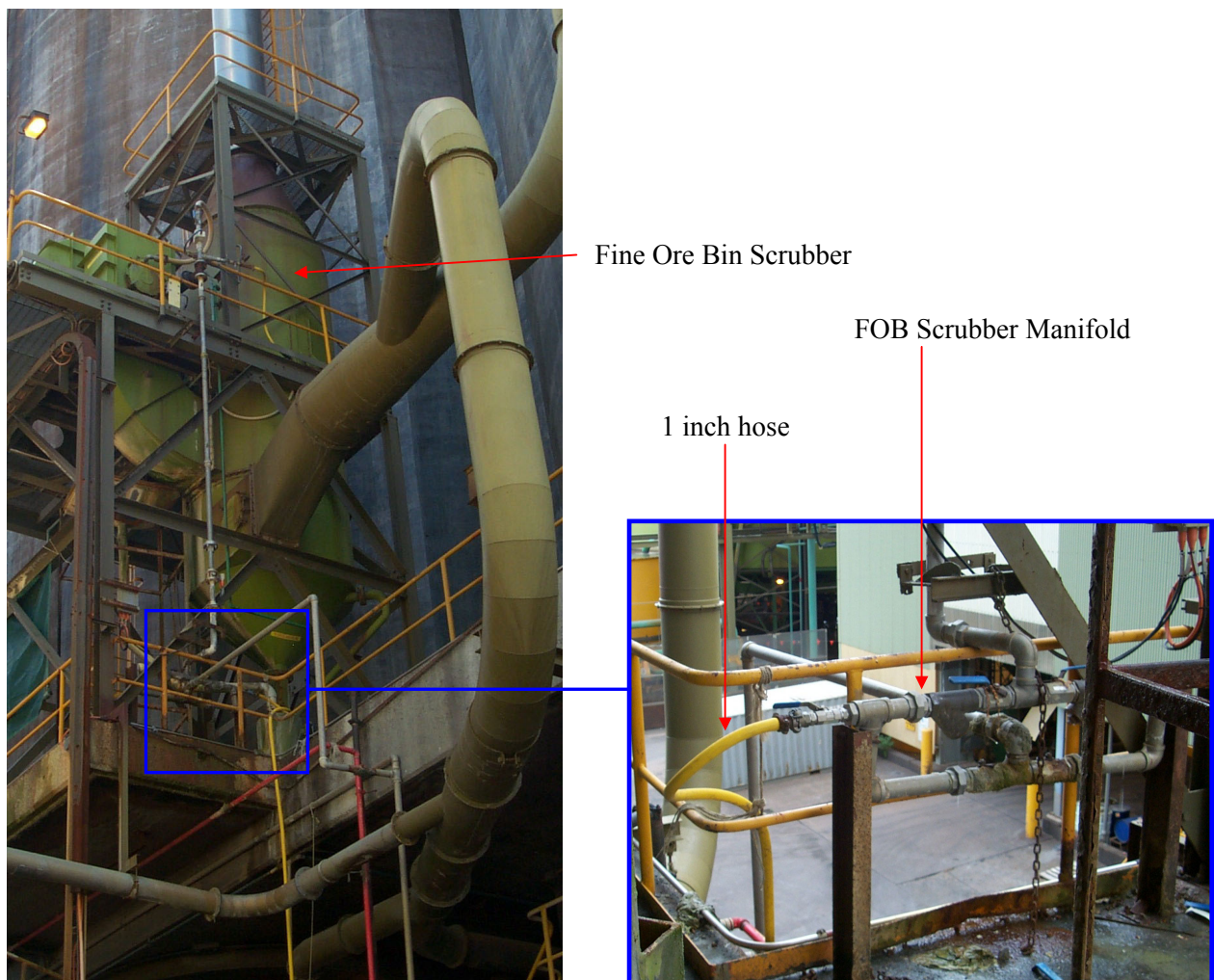
measures taken by the night shift operators in an attempt to resolve the repeated activation of the low flow alarm in the FOB scrubber:

- Night Shift Operators A and B checked the filters in the process water line that supplies the FOB scrubber on the second level of the Fine Ore Bins. At that time they observed that the 1 inch hose was connected to the hose point on the manifold of the FOB scrubber and that the valve was closed. Night Shift Operator B checked the 1 inch hose in order to determine if it was pressurised. If it was, he intended to open the valve to supply additional water to the FOB scrubber. However, it appeared that the 1 inch hose was not pressurised so he did not open the valve at the scrubber. The filters were clean and were not the cause of reduced flow of process water to the FOB scrubber.
- Night Shift Operator B contacted the shift electrician/technician and requested that he check the flow meter in the process water line that feeds the FOB scrubber to ensure that it was not malfunctioning. The electrician/technician was busy on another job and was unavailable.
- Night Shift Operator B asked a Shift Plant Technician to open a valve on the second process water booster pump so that it could be activated from the control room to increase the pressure/flow in the high pressure process water line and hence increase supply of process water to the FOB scrubber. The Shift Plant Technician went to the booster pump but found that the valve was jammed closed and could not be opened. The second pump was never started.
- After being advised by the Shift Plant Technician that the valve to the second process water booster pump could not be opened, Shift Operator B asked him to connect an additional process water line to the hose point on the manifold to the FOB scrubber to supply additional water. The Shift Plant Technician could not attend to this task immediately.
- After some time, Night Shift Operator B instructed Night Shift Operator A to connect an additional process water line to the hose point on the manifold to the FOB scrubber. Night Shift Operator A went to the FOB scrubber on the second level of the Fine Ore Bins and opened the valve on the inlet to which the 1 inch hose was already connected. Night Shift Operator A assumed that the other end of the hose was connected to the process water hose point on the ground level, but did not check. It is not possible to see the potable water hosepoint or the process water hose point on the ground level outside the Fine Ore Bins from the FOB Scrubber on the second level.
- At this point, Night Shift Operator B noted that the FOB Scrubber alarm ceased alarming and returning. He contacted the Shift Plant Technician advising him that he need not connect the additional process water line to the FOB scrubber as Night Shift Operator A had already done so. Night Shift Operator B recalls that the control screen indicated that the alarm remained active (that is, did not return). As the alarm was no longer constantly re-activating accompanied by the audible buzzer, requiring acknowledgement each time, and the FOB scrubber did not trip, he took no further action on the matter for the remainder of the shift.

The FOB scrubber alarm log shows that prior to 9.38 pm on 23 March 2004, the low flow alarm was activating and returning several times per minute indicating that the process water flow to the FOB scrubber was oscillating around the alarm set point. Each time the alarm activated, the operator acknowledged the alarm by pushing a button on the control panel, silencing the audible buzzing sound. The alarm would then appear on the control screen.

At 9.38 pm, the low flow alarm remained activated for 9 minutes before returning at 9.47 pm. The low flow alarm activated and returned again during that minute, however, after 9.48 pm, the low flow alarm remained constantly activated only returning for three periods lasting between 5 and 31 seconds. Thus, the low flow alarm changed from a pattern of activating and returning several times per minute to remaining active with only short return periods at 9.38 pm, indicating that something happened that reduced flow of process water to the FOB scrubber.

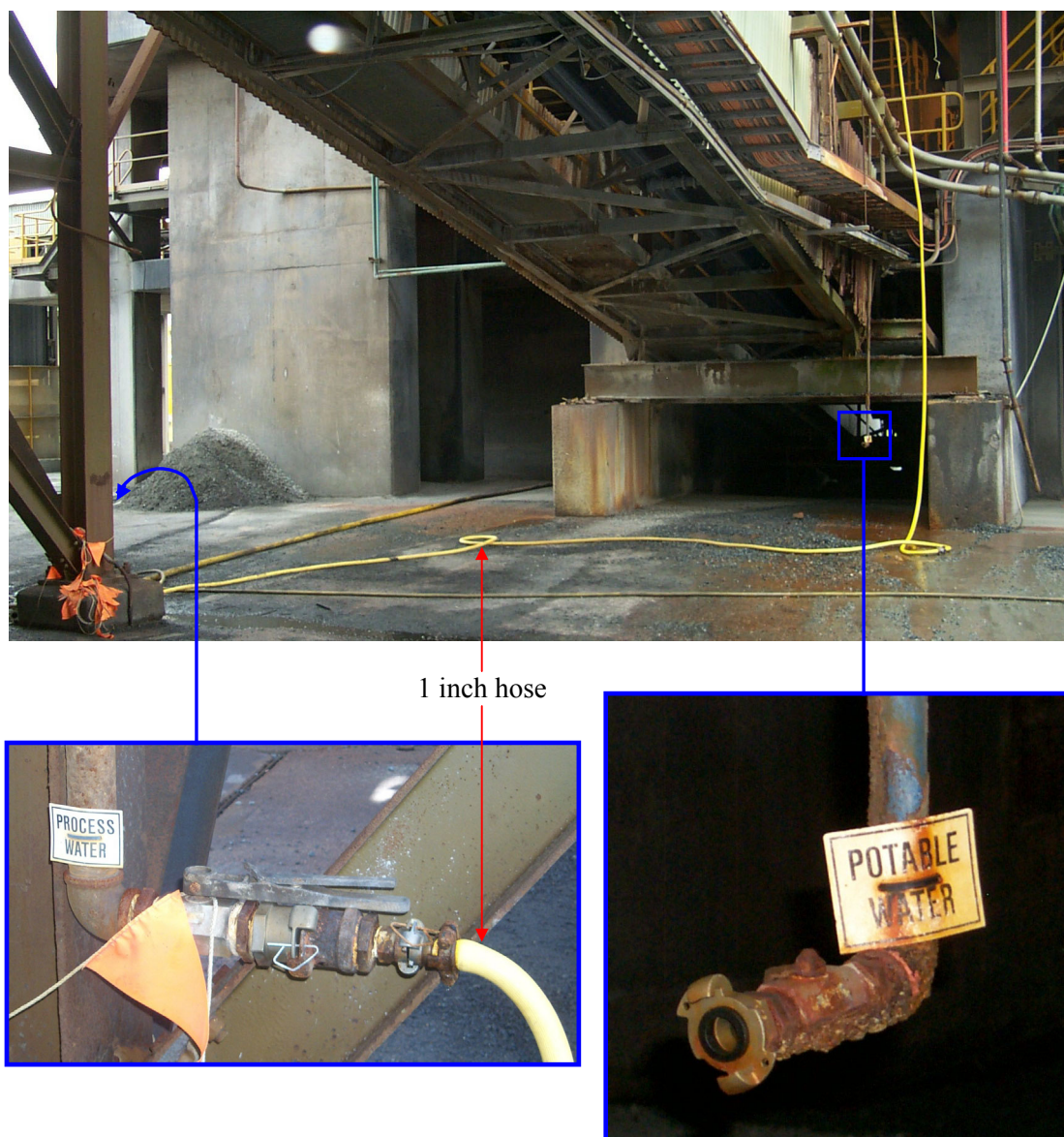
We have concluded that at 9.38 pm on 23 March 2004 the potable water system became hydraulically connected to the process water system at the FOB scrubber. The intent, according to the operators, was to supplement the flow of water to the FOB scrubber with process water to stop the low flow alarm from activating, however a connection to the potable water system was made by mistake, taking process water away from the FOB scrubber into the potable water system and hence slightly reducing the flow of process water to the FOB scrubber.



**Figure 4** Fine Ore Bin Scrubber – Inset: Fine Ore Bin Scrubber Manifold with 1 inch hose connected

There is an inconsistency in the statements of the operators. It is clear that the 1 inch hose was connected between the potable water hosepoint on the ground level and the FOB scrubber on the second level. It is also clear that both valves were open at 9.38 pm on 23 March 2004 allowing contamination of the potable water system with process water and that Night Shift Operator A opened the valve at the FOB scrubber. However, it has not been possible to determine conclusively who opened the valve on the potable water hose point on the ground level and precisely when this occurred.





**Figure 5** Ground Level Outside Fine Ore Bins – Insets: Potable Water Hose Point through which process water entered the potable water system and the Process Water Hose Point to which the FOB scrubber was intended to be connected.

### 3.3.3 Duration of the connection resulting in the contamination event

The Supervising Scientist was contacted by a contractor who had seen media reports of the incident. The contractor had worked at Ranger during the day shift on 22 March 2004, during which time he filled his water bottle with water from the water cooler located at the back of the heavy equipment workshop. Fortunately, he had not emptied his water bottle and provided it to the Supervising Scientist for analysis noting that he thought the water tasted ‘funny’.

The chemical analysis of this sample is consistent with normal potable water indicating that the contamination event had not yet occurred during the day shift (ending at 7.00 pm) on 22 March 2004. There is no evidence of contamination of the potable water system with process water the day before the incident.

Considering when ERA staff started observing changes in the quality of the potable water, the statements of ERA operators and the alarm and control room logs, we can conclude with a

high degree of certainty that the potable water system became contaminated with process water at 9.38 pm on 23 March 2004. It is not possible to be as definitive in relation to the period of time over which the potable water hose point was connected to the FOB scrubber via the 1 inch hose. If the hose is connected between these two points, contamination of the potable water system will only result if the valve at the potable water hose point and the valve at the FOB scrubber are open simultaneously while the scrubber is operating on process water, as was the case during the night of 23 March 2004. The absence of contamination of the potable water system on 22 March 2004 does not necessarily mean that the potable water hose point was not connected to the FOB scrubber via the 1 inch hose on 22 March 2004.

The statements of key ERA staff in relation to how long the 1 inch hose was connected between the potable water hose point outside the Fine Ore Bins and the FOB scrubber are summarised in table 2.

**Table 2** Summary of ERA Employee Statements

Employee	Statement
Day Shift Operator A	<p>The 1 inch hose was connected between the potable water hose point and the FOB scrubber at about 6.30 pm 23 March when he attempted to open the valve on the potable water hose point. Before he succeeded in opening the valve, he realised that there was a risk of contamination of the potable water system, and so did not proceed. He left the hose connected but ensured that the valve was closed.</p> <p>The 1 inch hose was connected between the potable water hose point and the FOB scrubber on the morning of 24 March and the valve on the potable water hose point was open. He closed the valve and disconnected the 1 inch hose from the potable water hose point.</p> <p>The 1 inch hose has been connected between the potable water hose point and the FOB scrubber a few times over the past two months. Potable water has been used in place of process water in the past when the process water system has been unavailable.</p>
Day Shift Supervisor	<p>The 1 inch hose was connected between the potable water hose point and the FOB scrubber at about 6.30 pm 23 March when he observed Day Shift Operator A attempting to open the valve on the potable water hose point, then realising that there was a risk of contamination of the potable water system and ceasing his attempt to open the valve, but leaving the hose connected.</p> <p>The 1 inch hose has been connected between the potable water hose point and the FOB scrubber for months although he has never seen the valves open before.</p> <p>Approximately two weeks before March 23, he disconnected the 1 inch hose from the potable water hose point and connected it to the 2 inch pond water hose when the process water system failed.</p>
Night Shift Operator A	<p>The 1 inch hose was already connected to the FOB scrubber during the evening of 23 March when he checked the filters in the process water line with Night Shift Operator B and also later in the shift when he opened the valve on the FOB scrubber manifold. He assumed the other end of the 1 inch hose was connected to the process water hose point but did not check.</p> <p>The 1 inch hose has always been connected to the process water hose point except when he first commenced employment with ERA about 4 weeks prior to the incident, when it was connected to the potable water hosepoint.</p> <p>The FOB scrubber was connected to the pond water system hose point the previous week due to a failure of the process water system.</p>
Night Shift Operator B	<p>The 1 inch hose was already connected to the FOB scrubber but the valve at the scrubber was closed when he checked the filters in the process water line with Night Shift Operator A.</p> <p>He has never had to supply additional water to the FOB Scrubber when it is operating on process water. When the process water system fails, pond water is used in place of process water.</p> <p>During the week leading up to his last shift prior to the incident (Friday 19 March 2004) the FOB scrubber was running on pond water due to a failure in the process water system.</p>
Night Shift Supervisor	<p>He was not on duty on 23/24 March 2004 as he had attended a training course during the day shift.</p> <p>During his last shift prior to the incident (Friday 19 March 2004) the FOB scrubber was running on pond water, via a hose connected to the pond water hose point in the Grinding building due to the failure of the process water system.</p>

The statements summarised in table 2 are in conflict with regard to the period of time before the incident. Day Shift Operator A and the Day Shift Supervisor both recall the 1 inch hose being connected between the potable water hose point and the FOB scrubber over a period of months. Night Shift Operator A recalls that the 1 inch hose has always been connected to the process water hose point, except when he first commenced employment with ERA about four weeks prior to the incident when it was connected to the potable water hose point. Night Shift Operator B and the Night Shift Supervisor do not recall the 1 inch hose ever being connected to the potable water hose point, adding that pond water is used to replace process water when the process water system fails.

The operators maintain a record of maintenance undertaken, problems encountered and other significant events that occur during each shift in a computer based Control Room Log. During the month of March 2004, the log does not include any references specifying the connection of potable water to the process water system.

In addition to the computer based log, the Shift Supervisors maintain a similar hand-written log of significant events. It also contains no reference during the month of March 2004 to the connection of potable water to the process water system. The relevant entries from the computer log and the Supervisors' handwritten log are listed in table 3.

The entries in table 3 indicate that the process water line that supplies Ball Mill 1, Ball Mill 2, the Rod Mill and the scrubbers (including the FOB scrubber) failed during the Day Shift on 8 March. Pond water was supplied to the mills and scrubbers during the same shift and both ball mills and the rod mill were restarted that afternoon.

During the night shift on 8 March, repair work on the process water line to restore lubricating/cooling water to pump glands in the mill caused the process water line to fail again. All mills were shut down, the process water line that failed was sealed closed to stop the process water leak and the mills and scrubbers remained on pond water. On 16 March, both scrubbers automatically shut down due to low flow of pond water.

An adjustment to the hoses supplying pond water to the scrubbers (since 8 March) was made in an attempt to increase the supply of pond water. Repairs on the failed process water line were completed during the Day Shift on 19 March, however there were problems with the pumps that supply process water from the pit back to the mill and the plant remained on pond water (water from retention pond 2) until 11.45 am on Saturday 20 March. During the Night Shift on 19 March and the day shift on 20 March, an electrical fault cut power supply to the potable water pump at the Brockman Borefield.

A generator was moved to the borefield to power the pump and restore the supply of potable water to the potable water day tank at the minesite. During the Night Shift on 23 March, a 1 inch water hose was connected to the FOB scrubber in response to a low flow alarm on the scrubber. This has since been confirmed to be the connection between the process and potable water systems that allowed contamination of the potable water system.

The Supervisor's hand-written log and the Control Room Log are consistent. Table 4 compares the Control Room Log with the statements of the ERA operators and supervisors who were interviewed.

An aspect common to the Control Room Log and the statements of the operators and supervisors is that the process water supply to the FOB scrubber was unavailable in the week ending 19 March. The Control Room Log, Supervisors hand-written log and all Operators and Supervisors interviewed except Night Shift Operator A have stated that the FOB scrubber was running on pond water during that period. The Control Room Log, and the Night Shift



Supervisor indicate that pond water was supplied to the FOB scrubber via a connection between the FOB scrubber and the pond water hose point in the Grinding Building.

**Table 3** Log extracts

Shift	Operators Control Room Log (computer based)	Supervisors Hand-Written Log
Monday 8 March Day Shift	P/W line burst at back of Mills. Lost water to both Scrubbers and Pyro Mill. All mills off feed  BM2 on feed @15.20  RM BM1 on feed @16.05	Burst water line, bottom floor grinding. Lost flow to both scrubbers. Ball mill 2 & rod mill down. Pond water set up to both. Mills away again.
Monday 8 March Night Shift	De-isolated water to mills to bring gland seal water on. Patched process line blew out again. Ground floor flooding and process water head tank struggling to maintain level.  0145hrs- Feed off and mills shut down for process water leak repairs. Blank inserted in process water line before leak and temporary water lines and fittings hooked up to pyro mill water addition and BM2 feed seal.  0300hrs- Feed on to rodmill. Down time 75min  0310hrs- Feed on to BM 2. Down time 85min.	Process water line blows out when line was deisolated.  Install blind in process water line at back of mill to enable seal water to be brought back onto pumps. Plumb hoses to pyro pipes for this mill. Scrubbers still on pond water
Tuesday 16 March Night Shift	Feed off Rod mill @ 2347—2356 lost scrubber  Feed of B/M #2 @ 2233—0018 lost scrubber	Both scrubbers tripped on low water flow. Both mills down. Re-routed hoses to scrubbers
Friday 19 March Day Shift	Repaired process water line behind ball mill 1	Repairs completed process water line behind BM1.  Inpit pumps also out of action due to fault with mine feeder. Running pond water (RP2)
Friday 19 March Night Shift	22-15. Ball mill 2 scrubber water flow low  Plant on RP2 water, no power on mine feeder  Generator set up on potable water pump supplying site.	Unable to obtain enough water pressure to run rodmill circuit scrubber. On inspection, found a valve had not been opened.  No potable water due to elect fault. In the process of setting up Jenni @ bore field
Saturday 20 March Day Shift	Plant back on process water @1145	Confine movement of personnel onsite due to no potable water. (IE NO SAFETY SHOWERS) Powerhouse operator sourced to repair insulator on pole by the mine. Pond water is off.
Tuesday 23 March Night Shift	F.O.B scrubber alarming low flow check filters ok, attached 1" water line to scrubber water feed line ok.	
Wednesday 24 March Day Shift	RM and BM2 shut down at 0855 hrs due to potable water contamination incident of 23 March.	Potable water contaminated. Drinking and wash water U/S.  Rod Mill down @ 8.55  Ball Mill 2 down @ 8.55

Table 4 Comparison Between Control Room Log and ERA Employee Statements

Control Room Log		ERA Operator & Supervisor Statements	
Date	Extract from Log	Statements generally consistent with the Control Room Log	Statements generally not consistent with the Control Room Log
<b>Monday 8 March Day Shift</b>	PW line burst at back of Mills. Lost water to both Scrubbers and Pyro Mill. All mills off feed  BM2 on feed @15:20  RM BM1 on feed @16:05	Approximately two weeks before March 23, he disconnected the 1 inch hose from the potable water hose point and connected it to the 2 inch pond water hose when the process water system failed. (Day Shift Supervisor)	The 1 inch hose has always been connected to the process water hose point except when he first commenced employment with ERA about 4 weeks prior to the incident, when it was connected to the potable water hosepoint. (Night Shift Operator A)
<b>Monday 8 March Night Shift</b>	De-isolated water to mills to bring gland seal water on. Patched process line blew out again. Ground floor flooding and process water head tank struggling to maintain level.  0145hrs- Feed off and mills shut down for process water leak repairs. Blank inserted in process water line before leak and temporary water lines and fittings hooked up to pyro mill water addition and BM2 feed seal.  0300hrs- Feed on to rodmill. Down time 75min 0310hrs- Feed on to BM 2. Down time 85min.	During the week leading up to his last shift prior to the incident (Friday 19 March 2004) the FOB scrubber was running on pond water due to a failure in the process water system (Night Shift Operator B)  During his last shift prior to the incident (Friday 19 March 2004) the FOB scrubber was running on pond water, via a hose connected to the pond water hose point in the Grinding building due to the failure of the process water system. (Night Shift Supervisor)  When the process water system fails, pond water is used in place of process water. (Night Shift Operator B)	The FOB scrubber was connected to the pond water system hose point the previous week due to a failure of the process water system. (Night Shift Operator A)  The 1 inch hose has been connected between the potable water hose point and the FOB scrubber a few times over the past two months. Potable water has been used in place of process water in the past when the process water system has been unavailable. (Day Shift Operator A)  The 1 inch hose has been connected between the potable water hose point and the FOB scrubber for months. (Day Shift Supervisor)
<b>Friday 19 March Day Shift</b>	Repaired process water line behind ball mill 1		
<b>Friday 19 March Night Shift</b>	Plant on RP2 water		

Green text: statement is fully consistent with Control Room Log

Orange text: Control Room Log neither supports nor refutes the statement

Red text: statement is inconsistent with Control Room Log

<b>Saturday 20 March Day Shift</b>	Plant back on process water @1145		
<b>Tuesday 23 March Night Shift</b>	F.O.B scrubber alarming low flow check filters ok, attached 1" water line to scrubber water feed line ok.	<p>The 1 inch hose was connected between the potable water hose point and the FOB scrubber at about 6.30pm 23 March (Day Shift Supervisor &amp; Day Shift Operator A)</p> <p>The 1 inch hose was connected between the potable water hose point and the FOB scrubber on the morning of 24 March (Day Shift Supervisor &amp; Day Shift Operator A)</p> <p>The 1 inch hose was already connected to the FOB scrubber when the filters in the process water line were checked early in the 23 March night shift. (Night Shift Operator A &amp; Operator B)</p>	

Green text: statement is fully consistent with Control Room Log

Orange text: Control Room Log neither supports nor refutes the statement

Red text: statement is inconsistent with Control Room Log

The Control Room Log also records that process water supply was reinstated at 11.45 am on 20 March. Before that time, the 1 inch line could not have been connected between the FOB scrubber and the potable water hose point because it was connected to the pond water hose point. Both the Day Shift Supervisor and Day Shift Operator A stated that the 1 inch hose was observed to be connected between the potable water hose point and the FOB scrubber at approximately 6.30 pm on 23 March. It has not been possible to determine who made this connection or precisely when it was made.

Thus we have concluded that the one inch hose was connected between the potable water hose point on the ground level outside the Fine Ore Bins and the Fine Ore Bin Scrubber on the second level of the Fine Ore Bins sometime between 11.45 am on 20 March 2004 and approximately 6.30 pm on 23 March 2004. As noted previously, the potable and process water systems did not become hydraulically connected until 9.38 pm on 23 March when the valve at the FOB scrubber end of the 1 inch hose was opened.

### 3.3.4 ERA policy and practice for a backup water supply

The potable and process water systems at Ranger should be completely separate systems. Temporary connections between the two systems should never be made because of the risk of contamination of the potable water system with process water. This, however, was what occurred on the evening of 23 March 2004. A question that arises following this incident is whether connections between the process and potable water systems have been made in the past with or without cross-contamination, and if so, whether such connections were ERA policy or practice. There are two broad scenarios to be considered: *supplementing* the supply of process water to the scrubber with potable water, and *operating* the scrubber on potable water only. This section discusses these scenarios.

#### *Supplementing the supply of process water with potable water*

As the pressure of the process water system is significantly higher than the potable water system, any attempt to *supplement* the supply of process water to the FOB scrubber by connecting an additional supply of potable water would actually reduce the supply of water to the FOB scrubber through loss of process water to the potable water system, resulting in the contamination of the potable water system. This is what occurred on 23 and 24 March. If this had occurred in the past, it may have been detected by the statutory program of potable water sampling undertaken by ERA. Under the Authorisation issued by the Northern Territory Department of Business, Industry and Resource Development, ERA is required to sample and test its potable water according to the following schedule (table 5).

**Table 5** Statutory potable water quality monitoring program

A.2 Potable Water	Measurement	Frequency
Mine Site (Jabiru East Supply)	pH, EC, turbidity, dissolved sulfate	Monthly
	Total coliform, E. coli & faecal Streptococci, gross- $\alpha$ and gross- $\beta$	Quarterly
	Alkalinity, total sodium, potassium, calcium, magnesium, chloride, nitrate, sulfate, copper, lead, manganese, uranium & zinc	November

Given the very high salinity of process water, any significant contamination of the potable water system would be readily observed as an increase in electrical conductivity (EC) and dissolved sulfate. The Office of the Supervising Scientist reviewed ERA potable water quality

data reported by ERA back to the year 1980. There is no evidence in that dataset of contamination of the potable water system with process water.

There is a record of another incident involving the contamination of the potable water system with process liquor (as opposed to process water) in July 1983. The description of this incident included in the Supervising Scientist's 1983–84 *Annual Report* is reproduced in full below.

During July 1983 an unauthorised temporary modification to connections for the mill process water and potable water systems resulted in some radioactive material (ammonium diuranate) being deposited in a section of the potable water supply serving the mill area. Although the section was isolated and cleaned under supervision, some residue had remained in the blind ends of the potable system and was detected during modification to the system on 23 September. Subsequent investigations determined that there had not been any significant exposure of workers through ingestion or contact with the water. All pipework for potable water in the section of the mill involved was replaced.

The description of the 1983 incident states that the potable water system was contaminated with ammonium diuranate (process liquor) indicating that the contamination occurred in a different area of the Ranger process plant to the current incident and did not involve recycled process water. Process water is a waste product that is recycled in the mill whereas process liquor contains the uranium which is precipitated out of solution as ammonium diuranate (yellow cake) prior to calcining to form  $U_3O_8$ , the product exported by ERA. Consequently, the 1983 incident, although similar to the current incident in nature, is not related to it other than at the most general level. It appears from the text of the Supervising Scientist's 1983–84 *Annual Report* that the 1983 incident was much less significant than the current incident, resulting in the contamination of only a small section of the potable water system. Potable water monitoring data for the period appears normal supporting the conclusion that the extent of the contamination was very limited.

It is clear, from the interviews with ERA employees, that ERA staff were aware that the potable water system should not be used to supplement the process water feed to the FOB scrubbers; that is, the systems should not be simultaneously be connected to the scrubbers. ERA documentation examined by SSD staff in the course of this investigation makes it clear that the backup water supply for the FOB scrubbers is the pond water system, not the potable system.

There is no evidence to suggest that the Ranger potable water system has been contaminated with process water prior to 23 March 2004, although it should be noted that potable water monitoring is only conducted monthly and it is possible that relatively minor and short-lived contamination events may have escaped detection. Whilst there are inconsistencies between the statements of the ERA employees interviewed, none of them indicated that they were aware of potable water being used to supplement the primary process water supply to the FOB scrubber (except of course in relation to this incident where the connection was erroneous) although Day Shift Operator A did state that he thought other operators had used potable water in place of process water when process water was not available. After considering all the evidence available, we have concluded that supplementing the process water supply to the FOB scrubber with potable has probably not occurred in the past, is not a practice adopted by any ERA operators, and is not a standard ERA procedure.

#### *Operating the scrubber on potable water*

It has been established (by DBIRD and confirmed by ERA) during this investigation that the pressure of the potable water system is sufficient to run the FOB scrubber in place of process water when the process water system is unavailable. This would not result in contamination of the potable water system as no process water is being supplied to the FOB scrubber if it is

running exclusively on potable water. So, considering only the absence of past contamination of the potable water system, no conclusions can be drawn regarding whether the scrubber has been operated on potable water when process water was unavailable. Other evidence needs to be considered.

ERA documentation describing the process and pond water systems clearly state that scrubbers operate on pond water, except the FOB scrubbers which operate on process water. As noted previously, this documentation further notes that the FOB scrubbers may be operated on pond water if there is a loss of process water to the plant.

The Control Room Log and Supervisors handwritten log indicate that pond water is supplied to the FOB scrubber in place of process water when there is a failure of the process water system. Each ERA employee interviewed was asked whether there was a written procedure describing the connection of the FOB scrubber to potable water for any reason. Every ERA employee interviewed responded that there was no such procedure. In summary, all documentary evidence examined throughout this investigation indicates that the FOB scrubber is operated on pond water when the process water system is unavailable.

However, both the Day Shift Supervisor and Day Shift Operator A stated that the connection between the potable water hose point and the FOB scrubber had been in place during preceding months but neither had seen the valves open and the connection actually in use. Day Shift Operator A also stated that potable water has been used in place of process water in the past and the Day Shift Supervisor stated quite specifically that approximately two weeks prior to the incident, he disconnected the 1 inch line connected to the FOB scrubber from the potable water hose point (valve was closed at that time) and connected the 1 inch line to the pond water hose point. This is partly corroborated by the Control Room Log, the Supervisors hand-written log and the statements of other operators that confirm that the FOB scrubber was operating on pond water at that time. In addition, the ERA staff who observed, on 23 March 2004, that the potable water system was connected to the FOB scrubber input, albeit with the valves closed, did not immediately disconnect the potable water system and report their observations to senior management. This would be consistent with these employees having seen that connection before and therefore not considering it to be abnormal. We have, therefore, concluded that it is likely that a hose has been connected between the FOB scrubber and the potable water hosepoint in the past and that, contrary to ERA stated policy, potable water may have been used by some staff to supply water to the FOB scrubber when process water was unavailable.

### **3.4 Investigation of the extent of contamination of potable water at Jabiru East**

#### **3.4.1 Drinking water quality at Jabiru East businesses**

Following the discovery of contamination of the potable water system on the mine site on 24 March 2004, the Jabiru East potable water pipeline was isolated at about 8.15 am by closing a valve at the distribution manifold near Retention Pond 2 (RP2). Between 9.30 am and 9.45 am ERA staff closed isolation valves at the Jabiru East potable water tank that was found to be overflowing (see figure 2).

As described in section 3.2, the potable water supply to both the Jabiru Field Station (JFS) and the Gagudju Workshop is provided through storage tanks. These tanks were sampled by ERA on the morning of 24 March before any remedial action had been taken by ERA related to the tanks. Full details of the analyses of these water samples are given in the Appendix 6 of the ERA Investigation Report (Appendix 5 to this report). The results for a number of key

constituents are shown in table 6 and a comparison is drawn with corresponding results for Brockman Borefield water and with the Australian Drinking Water Guidelines.

Samples were also collected by SSD staff at four locations at the JFS on the morning of 24 March 2004. The full analyses for these samples are given in Appendix 1a and the results for the same key variables are also shown in table 6.

A limiting factor for the assessment of the initial/preflush water quality in Jabiru East against the Australian Drinking Water Guidelines is that only the filterable fraction<sup>1</sup> of the samples was analysed instead of the total fraction. However, a comparison of the filterable and total fractions of samples collected after the flushing of the Jabiru East reticulation system between 2 April 2004 and 8 April 2004 in Jabiru East, showed that for uranium concentrations of the order of 10 ppb (the approximate concentration of the samples in question), the filterable and total fraction had similar uranium results. Based on this observation it is likely that all samples collected from the consumer outlets would have satisfied the Australian Drinking Water Guidelines.

It is clear from these all of the data in table 6 that the water at the JFS and the Gagudju Workshop had not been contaminated by process water from the Ranger mine and that there would have been no health impact on people who consumed water at the JFS or the Gagudju workshop on the morning of 24 March 2004.

Since the supply line to Jabiru East had been isolated at 8.15 am, samples of potable water could not be taken from the airport businesses on the morning of 24 March before remedial action commenced. The quality of any water consumed at the Airport on that morning needs to be inferred from less direct evidence.

**Table 6** Drinking water quality (filtered) at Jabiru East on the morning of 24 March 2004

Sample Description	Sample Number	Sample date/time	EC (µS/cm)	pH	Fe (ppb)	Mn (ppb)	SO4 (ppm)	U (ppb)
Brockman Borefield (ERA)	100309	24/03/04 09.13	400	–	<20	0.06	0.9	8.36
JFS Potable Water Tank (ERA)	100306	24/03/04 11.30	338	–	<20	1.88	1.2	8.23
Gagadju Workshop Water Tank (ERA)	100308	24/03/04 10.00	411	6.88	<20	0.27	0.9	8.05
JFS Header Tank Outlet (SSD)	A00307	24/03/04 09.30			<20	0.49	0.6	8.2
JFS Header Tank Top (SSD)	A00308	24/03/04 09.30	338		<20	1.3	1.2	8.24
JFS Men's washroom (SSD)	A00309	24/03/04 09.30			<20	0.04	0.8	8.17
JFS Tearoom (SSD)	A00310	24/03/04 09.30			<20	0.03	0.8	8.04
Australian Drinking Water Guidelines (1996), health aspects				6.5 – 8.5	300	500	500	20

<sup>1</sup> The filterable fraction of a sample is obtained via filtration through a membrane (with a pore size of 0.45 µm), which removes particulates from the water sample for the purpose of allowing a faster analysis. The filterable fraction is considered to be more bioavailable than the particulate matter. The total fraction contains both the filterable fraction and the particulate matter, and requires an acid digestion prior to analysis. The Australian Drinking Water Guidelines state that the total fraction should be analysed for assessment of drinking water quality.

Water use at Jabiru Airport, the Jabiru Field Station and the Gagudju workshop on the night of the incident was limited to irrigation at the field station. This use is conservatively estimated at approximately 1 L/s over a one-hour time period.

Using this assumption and knowing the pipe diameter of 100 mm and length from the Jabiru East tanks of 800 m, modelling has indicated that at worst, the contamination plume would have travelled approximately 400 m towards the Airport and Field Station (that is, only half way) prior to the line being shut down. Thus, modelling indicates that contamination did not reach the Airport prior to the flushing of the lines. This is consistent with the results obtained for water at the JFS which is fed from the Jabiru East line before the Airport, noting that the water used in irrigation would have drawn water from the main Jabiru East line into the field station.

It is our understanding that the only water use at the Airport and the Gagudju Workshop in the early hours of the morning of 24 March was consumption of water for tea/coffee by a few individuals. This usage would not have been sufficient to draw water located at the junction of the JFS/Jabiru East line junction to the Airport. Hence the small amount of water consumed at the airport could not have been contaminated by process water.

We have concluded that water consumed at the Jabiru Field Station and the Gagudju Workshop on the morning of 24 March met all drinking water guidelines and that it is highly likely that this was also true at the Jabiru East Airport.

### 3.4.2 Water quality at the Jabiru East tank

On the first day of the incident, 24 March, ERA and the Supervising Scientist Division (sample A00315, Appendix 1) each collected a water sample from a fire hydrant located close to the Jabiru East potable water tank (at 12.00 am and 1.30 pm respectively). These two samples are the only samples collected within the vicinity of the Jabiru East tank prior to any remedial action. However, they may not be representative of water quality in the pipeline because it is likely that the hydrant result represents the dead space between the hydrant and the main line. This is confirmed by comparison (see table 7) with results for water samples (A00323, A00324) at the sump between the tank and the hydrant on the following day (see below).

**Table 7** Water chemistry data for the Jabiru East reticulation system on the first 2 days after the incident, for the most contaminated sample collected on the minesite, for tank source water, and guideline values. Total metal concentrations are given in parts per billion (ppb) or parts per million (ppm); sulfates are given for filterable fraction in ppm.

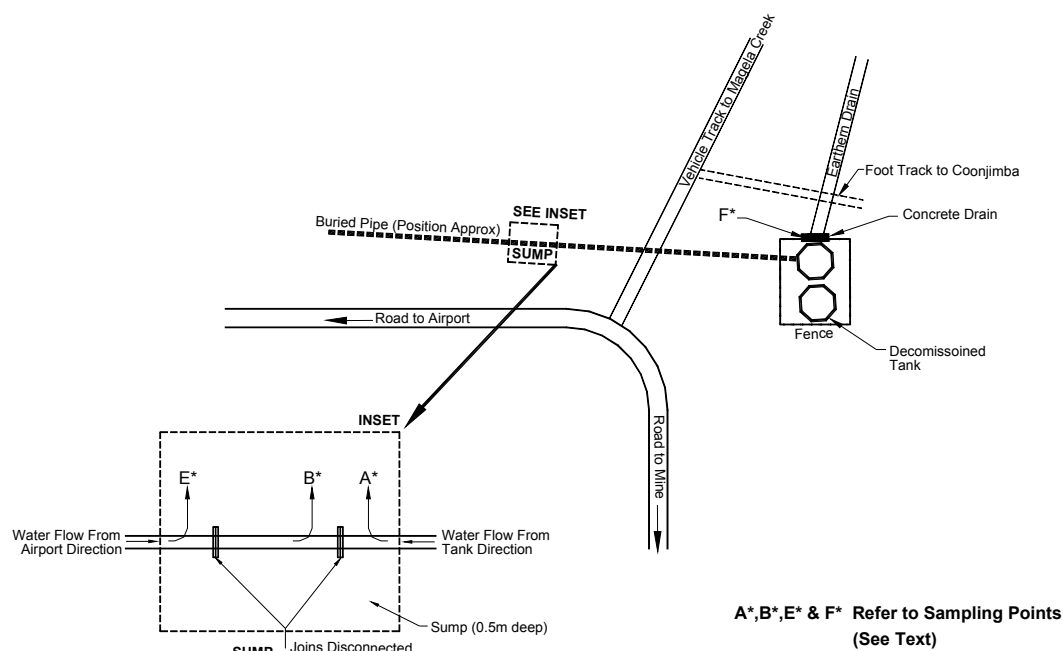
Sample Description	Sample Number	Sample date/time	EC (µS/cm)	pH	Fe (ppb)	Mn (ppm)	SO <sub>4</sub> (ppm)	U (ppb)
Hydrant close to Jabiru East tank	A00315	24/03/04 13.30	1045	6.9	120	29.7	410	125
Sump; flow from tank direction (A*)	A00323	25/03/04 10.05	776	6.05	1200	75.9	1060	414
Sump; flow from airport direction (B*)	A00324	25/03/04 10.10	1476	6.54	1000	73.6	1180	460
Sump; flow from airport direction (E*)	A00328	25/03/04 10.30	850	7.02	560	20	330	461
Grinding area ground floor toilet cistern	A00322	24/03/04 15.50	8710	4.2	1842	607	6940	7060
Brockman Borefield (ERA)	100309	24/03/04 09.13	400	-	<20	.00006	0.9	8.36
Australian Drinking Water Guidelines (1996), health aspects				6.5 – 8.5	300	500	500	20

1: only concentrations in the filterable fraction available



As part of the remedial action undertaken by ERA, and after the water out of the Jabiru East potable water tank was pumped up to the mine site, the Jabiru East reticulation system was drained at a low point in a sump between the Jabiru East potable water tank and the Jabiru East Airport buildings on 25 March 2004. While the pipeline was opened ERA and SSD staff collected water samples (see figure 6).

Two distinct flows of water were observed with different EC and pH values (see table 7); one coming from the direction of the tank (sample A00323, 'A\*') and one coming from the direction of the Jabiru East airport (A00324, 'B\*'). Water from the direction of the Jabiru East potable water tank was of better quality. This was, we believe, due to the presence of residual clean water in the tank remaining from prior to the incident (dilution effect) and the start of remedial action at the tank having improved the water quality.



**Figure 6** Sampling from the Jabiru East reticulation system on 25 March 2004

Sample A00328 ('E\*') was taken after the second join was opened at about 10.30 am when water was only coming from the direction of the Jabiru East airport.

The highest total uranium concentration measured was 461 ppb (sample E\*). However, losses of uranium and other key variables via precipitation in the reticulation system over the previous 26 hours (since the isolation of the pipeline from the mine site on 24 March 2004 at 8.15 am) can not be excluded.

The investigation of the Jabiru East potable water system was limited by several factors.

Firstly, direct comparisons between the Supervising Scientist and ERA potable water quality data are complicated by the differing sample preservation<sup>2</sup> and analysis techniques employed. The Supervising Scientist had the total fraction analysed whilst ERA had the filterable

<sup>2</sup> The 'Standard Methods for the Examination of Water and Wastewater' (APHA) require acidification of the sample as a preservation step. This procedure was followed during sample collection by Supervising Scientist staff.

fraction analysed. The Supervising Scientist's analyses were undertaken to allow a comparison with the drinking water guidelines<sup>3</sup> (NHMRC & ARMCANZ 1996) whilst ERA's analyses, in the early stages of the incident, were focussed on identifying the presence of process water in the potable water system.

Secondly, a systematic sampling program was hindered due to uncertainties regarding pipeline connections in Jabiru East, and the low water pressure in the pipelines after the isolation of the main pipeline from the mine site to Jabiru East. It is, therefore, difficult to assess the exact extent of contamination of the Jabiru East reticulation system.

Thirdly, the sample collected from the hydrant located close to the Jabiru East potable water tank shows contamination with analytes characteristic of process water, but at concentrations significantly lower than the samples collected in the sump the following day. As the hydrant is located at a distance of the order of 10 m from the main pipeline, it is probably not representative of the extent of contamination in the main pipe. Compared to samples collected during drainage, the next day, it has a significantly lower level of contamination.

Lastly, remedial action to clean the Jabiru East potable water line between the Jabiru East potable water tank and the minesite had started in the afternoon of 24 March 2004 (see Section 4.2) before a full investigation could be conducted. This will have affected the water quality in the pipes close to the Jabiru East tank. Thus, samples collected after 4.00 pm on 24 March 2004 are likely to have lower contaminant concentrations than were present on the day of the incident.

Based on the limited amount of representative samples available, we can conclude that the total uranium concentration in the potable water line in the vicinity of the Jabiru East potable water tank, some 800 m from the Jabiru East airport, was above 460 ppb on 25 March 2004, the day after the incident. On the day of the incident, when this water would have fed into the overflowing Jabiru East potable water storage tank, it would possibly have been significantly higher.

We have concluded, therefore, that the available water quality data are inadequate to determine the quality of water in the Jabiru East tank when it was overflowing and that 'worst case' scenario modelling is needed to allow estimates to be made of contaminant concentrations in the tank during overflow.

### 3.5 Environmental Requirements and Ranger Authorisation

#### 3.5.1 Commonwealth Environmental Requirements for Ranger Mine

The Commonwealth Environmental Requirements (the ERs) for the Ranger mine are attached to the Authority issued under Section 41 of the Commonwealth *Atomic Energy Act 1953*, to the export permit for uranium granted under the *Customs (Prohibited Exports) Regulations 1958* and are incorporated, as appropriate, into regulatory instruments issued by the Northern Territory Department of Business, Industry and Resource Development (the Regulator). They articulate the Commonwealth's expectations of ERA in relation to environmental and human health protection and ERA is legally obliged to comply with them.

The Commonwealth Minister for Industry, Tourism and Resources administers the *Atomic Energy Act 1953* and the *Customs (Prohibited Exports) Regulations*.

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<sup>3</sup> Water samples collected by SD immediately after the incident and in the following weeks were analysed for the relevant inorganic parameters of the Water Quality Guidelines – see Appendix 1A for results and comparison with Guideline values.

Sections of the ERs that are directly relevant to this incident are ERs 3.4 and 5.1.

ER 3.4 is reproduced below:

*3.4 Process water must be totally contained within a closed system except for:*

- (a) losses through natural or enhanced evaporation;*
- (b) seepage of a quality and quantity that will not cause detrimental environmental impact outside the Ranger Project Area; and*
- (c) subject to clauses 3.1, 3.2 and 3.3, process water which has been treated to achieve a quality which:*
  - i) conforms to a standard practice or procedure recommended by the Supervising Scientist; and*
  - ii) is not less than that of the water to which it is to be discharged.*

It has been established that during the evening of 23 March 2004 and the morning of 24 March 2004, process water left the process water system and entered the potable water system. For the purpose of ER 3.4, the Ranger Minesite Technical Committee has determined that the 'closed system' is comprised of the process water system (Pit 1, tailings dam, Retention Pond 3 and pipes and pumps connected to these storages) and the bunds and drains designed to collect spillages from the process water system. Retention Pond 2 is also included to the extent that it may collect infrequent spillage of small volumes outside the primary containment bunds. When process water entered the potable water system, it was not totally contained within the defined closed system and the losses from the closed system were not due to evaporation or seepage. It is the Supervising Scientist's view that this constitutes a breach of ER 3.4.

In addition, it has been established that the contaminated water moved through the potable water system to Jabiru East where it discharged to the general environment from the Jabiru East tank. It is the Supervising Scientist's view that this discharge constitutes a second breach of ER 3.4.

ER 5.1 is reproduced below:

*5.1 The company must implement a system to control the radiological exposure of people and the environment arising from its mining and milling activities. The system and the dose limits applied must comply, at the minimum, with relevant Australian law taking into account the most recently published and relevant Australian standards, codes of practice, and guidelines. Subject to clause 5.3, the company must achieve the following outcomes:*

- a) Radiation doses to company employees and contractors must be kept as low as reasonably achievable and must always remain less than the dose limit for workers.*
- b) Radiation doses to people who are not company employees or contractors must be kept as low as reasonably achievable and must always remain less than the dose limit for members of the public.*
- c) Ecosystems surrounding the Ranger Project Area must not suffer any significant deleterious radiological impacts.*

The contamination of the potable water system resulted in ERA employees and contractors drinking and showering in water containing elevated concentrations of radionuclides. Whilst the radiation doses received by the employees and contractors as a result of this exposure were below the dose limit for workers (and for members of the public), it is our view that

ERA has not met the requirement stipulated in ER 5.1(a) to keep doses to employees and contractors as low as reasonably achievable. It is the Supervising Scientist's view that this constitutes a breach of ER 5.1 (a).

It could be argued that ERA has, as a result of this incident, also breached ERs 1.1 (c), 1.2 (c), 3.1, 6.1, 10.1(b), 12.1, 14.1 and 18.4. The Supervising Scientist has assessed the potable water contamination incident in the context of each of these ERs. He has concluded that it would probably be difficult to demonstrate that these ERs have been breached. In the light of his firm conclusions on the breach of ERs 3.4 and 5.1, this matter has not been pursued further.

### **3.5.2 The Ranger General Authorisation**

The Ranger General Authorisation (RGA) is issued by the Northern Territory Minister for Mines and Energy under the *Mining Management Act 2001*.

The RGA sets out the conditions with which ERA must comply and incorporates, as appropriate, the Commonwealth's Environmental Requirements. Some of these conditions are stipulated in detail in the Authorisation. However, most of the detailed procedural requirements are contained in the reports or plans which are required under the General Authorisation and assessed by the Regulator.

It is the role of the Northern Territory Government, particularly the Department of Business, Industry and Resource Development, to assess whether or not ERA has been in breach of the *Mining Management Act 2001* and the RGA. In addition to the Ranger General Authorisation, there may be breaches of provisions of the *Mining Management Act 2001* related to ERA's duty of care to provide a safe work environment. The Northern Territory Minister for Mines and Energy announced on 19 May 2004 that the DBIRD report on the incident had been referred to the Northern Territory Department of Justice to consider whether a case existed for prosecution of ERA.

## **3.6 Conclusions on the occurrence of the incident**

### *The contamination event*

Some time between 11.45 am on 20 March 2004 and approximately 6.30 pm on 23 March 2004, a 1 inch hose was connected between the potable water hose point outside the Fine Ore Bins and the Fine Ore Bin Scrubber at the Ranger mine. It has not been possible to determine precisely when or by whom the connection was made.

At approximately 9.38 pm on 23 March 2004 an operator opened the valve at the Fine Ore Bin Scrubber believing that the other end of the 1 inch hose was connected to a process water hose point outside the Fine Ore Bins.

The intent of the operators was to increase the supply of process water to the Fine Ore Bin scrubber in response to an alarm indicating low flow of process water to the scrubber. The valve at the potable water hose point was already open at this time so opening the valve at the Fine Ore Bin scrubber hydraulically connected the potable water system to the process water system allowing process water to enter the potable water system.

It has not been possible to determine precisely when or by whom the valve at the potable water hose point was opened.

The contamination of the potable water system with process water was discovered the following morning at about 7.30 am – 7.45 am on 24 March 2004 when the Day Shift Supervisor at the Ranger mine took a drink of water from a water cooler located in the Grinding Building Crib (lunch) Room at the Ranger minesite. The water tasted very bitter.

Shortly before 8.00 am, analysis by the ERA laboratory of a water sample taken from the cooler confirmed the presence of process water in the potable water system. At 8.10 am, an announcement was made on the Ranger intercom system (GAI phone) advising ERA staff not to drink water as the potable water system had been contaminated with process water.

The potable water supply to Jabiru East was isolated at the Ranger minesite at approximately 8.15 am, ERA commenced sending non-critical employees and contractors home at about 8.30 am, and workers at Jabiru East were advised that the water supply had been cut off, that there was a problem with the water and not to drink it between 9.00 am and 9.15 am.

We have concluded that supplementing the process water supply to the FOB scrubber with potable water (that is, simultaneous supply of process water and potable water to the scrubber) has probably not occurred in the past, is not a practice adopted by any ERA operators, and is not a standard ERA procedure. However, it is likely that a hose has been connected between the FOB scrubber and the potable water hosepoint in the past and that, contrary to ERA stated policy, potable water may have been used by some staff to supply water to the FOB scrubber when process water was unavailable.

#### *Cause of the incident*

The immediate cause of the contamination of the Ranger potable water system with process water was the connection of the two systems between the potable water hose point on the ground level outside the Fine Ore Bins and the Fine Ore Bin Scrubber on the second level of the Fine Ore Bins. However, it is the Supervising Scientist's view that the underlying cause of the incident was the poor condition of the process water distribution system at Ranger.

The Control Room Log contains between 20 and 30 entries (depending on interpretation) related to the failure of or repairs to various parts of the process water system at Ranger in the period 1 March to 24 March 2004. The great majority of these entries describe relatively minor issues such as repairs to minor holes in pipes or pump boxes. However, the number and nature of these entries indicates that the process water system is in poor condition requiring constant repairs in order to keep the mill operating.

This view is supported by the issues that have been identified in recent months by the Routine Periodic Inspections (RPIs) conducted by the Office of the Supervising Scientist, the Northern Territory Department of Business, Industry and Resource Development (DBIRD) and the Northern Land Council. The RPIs are focussed on environmental protection infrastructure and contaminant containment structures around sources of contamination such as stockpiles, the mill and process plant rather than the plant itself. Even so, the RPIs have identified general housekeeping at the site as an area requiring improvement. Leaking pipes are a common example of poor housekeeping.

In general, ERA has responded by addressing each of the housekeeping issues raised in the RPIs, although the priority given by ERA to addressing these has not been as high as the RPI team would have preferred. ERA has justified its position by referring to the systems it has built to consider and prioritise housekeeping issues, based on risk. It is true that the issues identified have been relatively minor when considered in isolation. However, similar to the entries in the Control Room Log, considered together, they represent evidence of a plant in need of refurbishment. In general, we have not been satisfied with the timeliness of ERA's response to issues raised in RPIs. There has been discussion between ERA and the Office of the Supervising Scientist directly, and also in the Ranger MTC about how to adjust the RPI process such that it directly and transparently considers the outputs of risk assessment systems employed by ERA. This would allow the RPI team, including the Office of the Supervising Scientist, to systematically test the risk assessment processes employed by ERA against our

expectations and also afford ERA the opportunity to demonstrate to the RPI team that its risk assessment systems were producing acceptable results. Changes to the RPI process as described above were discussed and agreed, subject to further refinement, by the Ranger MTC at a meeting held on 19 February 2004.

A general inspection of the mill was undertaken as part of this investigation. The poor condition of the process water system and associated infrastructure was immediately obvious upon entering these areas. Leaking pipes were common. The FOB scrubber itself had a significant process water leak. The valve handle on the potable water hosepoint was broken and corroded to the extent that one needed to hit it with a brick to open or close it. What appeared to be a temporary hose connection, that was leaking quite significantly, was observed in the Grinding Building. The colour of some pipes, necessary to identify what they contain, was very difficult to determine due to a build up of rust and grime on them.

In summary, it was obvious that a major refurbishment of the process water system was required to bring it up to a satisfactory standard.

(An obvious question that arises is whether or not the unsatisfactory condition of the process water system should have been identified in the Routine Periodic Inspections (RPIs). The Commonwealth Government reinstated the Supervising Scientist's inspectorial role in June 2000 but stated that this role should concentrate 'on issues that have a potential to cause offsite impact'. The mechanism for implementing this decision was the commencement of RPIs. These are carried out monthly and, while organised by the Supervising Scientist, are conducted jointly with the NT Department of Business, Industry and Resource Development and the Northern Land Council. These inspections focus on the environmental protection mechanisms in place at Ranger including the condition and adequacy of containment structures and bunds. They do not involve inspections of plant inside the bunds. Thus the RPIs would not be expected to identify the deficiencies in the process water system that were found in the conduct of the current investigation.)

Given the above context, the ERA mill operators and supervisors have been required to routinely implement work-around solutions to failures in the process water system in order to minimise plant down-time. By their very nature, it is not possible to develop procedures that describe a work-around solution for every potential failure. That is where change management procedures become relevant.

Change management procedures are designed to ensure that risks of all types are assessed and adequately addressed prior to taking an action that is a deviation from normal procedures or a change to the normal operation of a system. That is, they provide a framework for the development and approval of appropriate procedures to enable specific actions for which there are no existing applicable procedures. Implementing work-around solutions has become almost 'the norm' rather than the exception and change management procedures have not been applied rigorously. The more experienced operators have obviously become very skilled at implementing work-around solutions to maintain the operation of the plant and have a record of success. However, given the condition of the plant, the frequency of failures requiring work-around solutions, and the failure to implement change management procedures, it was only a matter of time before a mistake was made.

It is worth noting that at least two experienced ERA staff observed the connection between the potable water hose point and the FOB scrubber prior to the contamination incident. Both were aware of the potential for contamination of the potable water system (one commented on the risk in the presence of the other), but as the valve was closed, neither thought it necessary to disconnect the hose or to advise senior management of the existence of the connection.

This is indicative of the hose having been connected between these two points in the past; neither of the ERA employees were alarmed or concerned that the hose was connected between these two points so neither disconnected it.

This apparent lack of concern regarding an abnormal and inherently risky connection is consistent with a workplace where the staff have become used to operating under abnormal conditions and have become somewhat complacent in relation to risk management. The failure to implement change management procedures when making temporary connections to the process water system is consistent with this being required frequently, and thus not being perceived by the operators as constituting a deviation from normal operating conditions. It has not been possible to rule out the previous deliberate connection of the FOB scrubber to potable water by some operators to keep the scrubber running when the process water system was unavailable.

There are many factors that have directly contributed to this incident relating to such things as operational procedures or training of operators. However, it is our conclusion that the poor condition of the process water distribution system established over time an environment and a culture that exposed deficiencies in other areas that allowed the incident to occur.

#### *Measures to address the cause of the incident*

ERA has previously identified the condition of the process water system as a significant risk, and had already commenced a program to replace the entire process water distribution system with new High Density Polyethylene (HDPE) and stainless steel pipes prior to the incident.

This arose from the assessment of environmental risk required in order to achieve ISO 14001 certification. The main line between the process water head tank and the booster pumps had already been replaced and funding had been allocated in the 2004 calendar year ERA Maintenance Capital Budget to replace the remainder of the process water distribution system. The FOB scrubber has been refurbished in the annual maintenance shutdown of the plant in May 2004 and preparatory work for the replacement of the entire process water distribution system has been undertaken. The replacement of the process water distribution system is planned to be completed by September 2004 as it could proceed whilst the plant was operating. These activities are progressing according to a schedule that was determined prior to the incident.

ERA has trialled a program in the Ranger Workshop designed to improve housekeeping. The program, called 5S (an acronym for *Sort, Store, Shine, Standardise, Sustain*) is planned to be rolled out across the entire site. The pilot program achieved excellent results in the Workshop. A cursory inspection of the Workshop was undertaken on 26 March 2004 as part of this investigation and housekeeping appeared to be exemplary.

Prior to the incident occurring, ERA already had plans in place to address what we consider to be the underlying cause of the incident – the poor condition of the process water distribution system. Implementation of these plans will greatly reduce the frequency of failures of the process water system, and similarly greatly reduce the need for work-around solutions to keep the mill operating.

ERA was also commencing a program to address general housekeeping on site. This, in combination with the replacement of the process water distribution system, will set a higher standard for the operation of the mill and partly address any complacency that might exist amongst operators.

ERA has advised that it has established a permit system for changes to water systems. In effect this is a change management procedure developed for the specific purpose of ensuring any change to water systems is properly assessed and approved prior to implementation.

ERA's Investigation Report (Appendix 5) identifies a range of initiatives in response to this incident including changing the couplings on all potable water hose points in the mill to a system that is not compatible with that employed on the process or pond water systems, installing an electrical conductivity probe in the potable water system to detect contamination with saline water, and installing non-return valves in the potable water system to ensure that water can not flow into the system via hosepoints.

#### *Contamination of the Jabiru East potable supply*

A faulty valve at the Jabiru East tank caused contaminated potable water to flow from the mine towards Jabiru East. Water quality data at Jabiru East businesses are limited but we have been able to conclude that water consumed at the Jabiru Field Station and the Gagudju Workshop on the morning of 24 March met all drinking water guidelines and that it is highly likely that this was also true at the Jabiru East Airport.

The quality of water in the Jabiru East tank when it was overflowing towards the Magela Creek has also been difficult to assess because remedial action was commenced prior to full characterisation of the water quality in the tank. Based on the limited number of representative samples available, we can conclude that the total uranium concentration in the potable water line in the vicinity of the Jabiru East potable water tank, some 800 m from the Jabiru East airport, was above 460 ppb on 25 March 2004, the day after the incident. On the day of the incident, when this water would have fed into the overflowing Jabiru East potable water storage tank, it would possibly have been significantly higher. Hence, the assessment of possible environmental impact will require the use of 'worst case' scenario modelling.

## **4 Recovery of the potable water system**

### **4.1 Remedial action undertaken at Ranger**

ERA commenced activities to recover the potable water system at Ranger on the afternoon of 24 March. Taps were opened around the Ranger site to drain the potable water system and the Potable Water Day Tank was emptied to Retention Pond 2. All water coolers and hot water urns were disconnected for disposal and on Saturday 27 March, the Potable Water Day Tank was internally cleaned. In summary, the strategy adopted by ERA to recover the Ranger potable water system was to flush the system with clean potable water and analyse water samples from various potable water outlets around the minesite to determine whether the flushing process had been successful. In addition to recovering the potable water system, ERA implemented various measures to ensure that the source of contamination had been removed and that the risk of such contamination recurring was minimised. This was a lengthy process involving a staged return to operations with the final approval to resume milling activities at Ranger granted by DBIRD on 6 April 2004.

The rationale adopted by the Supervising Scientist in relation to determining conditions under which he would support the resumption of activities at Ranger was twofold.

Firstly, in order to recover the potable water system and to undertake the necessary maintenance, repair and modifications to the plant required in response to the incident, ERA needed to have its staff available on site. The return to Ranger of the ERA workforce was thus required before all necessary steps to recover the potable water system could be completed.



With that context, the Supervising Scientist sought assurance that ERA would put in place measures to reduce the risk to its employees from the consumption of potentially contaminated water to a very low level. The measures included the supply of bottled drinking water to ERA employees (consumption from the Ranger potable water system was not acceptable without demonstrating compliance with water quality guidelines) and water from all occupied areas meeting water quality screening targets. The source of the contamination had already been identified and removed on the morning of 24 March.

Secondly, prior to supporting the resumption of mining and milling activities, the Supervising Scientist stipulated that measures to prevent the recurrence of a similar incident and to rapidly detect contamination of the potable water system with process water should be undertaken and that the potable water system must be demonstrated to meet all drinking water guidelines. The resumption of milling activities represented the return to normal operating conditions at Ranger and the Supervising Scientist determined that full compliance with the drinking water guidelines was appropriate. ERA subsequently requested permission to re-commence mining activities prior to milling activities, noting that mining could proceed without any involvement of the process water system such that there was no risk of a similar incident recurring. ERA further noted that potable water at the mine facilities had met drinking water guidelines in terms of chemical/toxicological contaminants. The Supervising Scientist supported ERA's request.

The correspondence between the Supervising Scientist, DBIRD and ERA, which identifies the conditions required and met throughout this process is summarised in table 8. Copies of the correspondence appear at Appendix 2 to this report.

**Table 8** Summary of correspondence related to the resumption of activities at Ranger

Date	Author	Summary of Content
30 March	Supervising Scientist	<p>Conditions for the return to Ranger of ERA staff for maintenance purposes only (ie not mining or milling) specified:</p> <ul style="list-style-type: none"> <li>the potable water system in areas to be occupied is flushed and meets electrical conductivity and pH screening targets</li> <li>drinking water points remain tagged 'out of service' and bottled drinking water is supplied for use on site</li> <li>water for use in emergency showers and eye wash stations meets electrical conductivity and pH screening targets</li> </ul>
30 March	DBIRD	DBIRD supports the resumption of activities at Ranger from 7.00 pm on 30 March subject to the conditions stipulated by the Supervising Scientist above.
31 March	Supervising Scientist	<p>Conditions for re-commencement of mining and milling activities specified:</p> <ul style="list-style-type: none"> <li>analysis of 2 consecutive samples from representative points throughout the potable water system meet drinking water guidelines for chemical/toxicological contaminants</li> <li>analysis of one representative water sample meets drinking water guidelines for microbiological contaminants</li> <li>analysis of one representative water sample meets drinking water guidelines for radiological contaminants</li> <li>appropriate measures are taken to prevent the recurrence of the incident</li> <li>monitoring of EC and pH in the potable water system to identify any further contamination with process water commences</li> </ul>
31 March	ERA	Request to re-commence mining (but not milling) immediately on the basis that mining does not impact upon the process water circuit and two consecutive water samples from the mine have met drinking water guidelines.

Date	Author	Summary of Content
31 March	Supervising Scientist	Supervising Scientist supports the immediate resumption of mining (but not milling) subject to the conditions stipulated in his letter dated 30 March (see above)
31 March	DBIRD	DBIRD supports the resumption of mining (but not milling) activities at Ranger subject to the conditions stipulated on 30 March
2 April	Supervising Scientist	Supervising Scientist identifies information gaps in data provided by ERA comparing water quality in the Ranger potable water system to drinking water guidelines
6 April	ERA	Proposal to re-commence milling activities addressing the conditions stipulated by the Supervising Scientist on 31 March
6 April	Supervising Scientist	Supervising Scientist supports the immediate resumption of milling activities at Ranger
6 April	DBIRD	DBIRD approves the immediate resumption of milling activities at Ranger
20 April	Supervising Scientist	Summarises Supervising Scientist position on reinstatement of Jabiru potable water supply
22 April	ERA	Proposal to return water supply to Jabiru East for industrial purposes
22 April	Supervising Scientist	Supervising Scientist supports return of water supply to Jabiru East for industrial purposes
7 June	ERA	Final proposal for reinstatement of the potable water system in Jabiru East
9 June	Supervising Scientist	Supervising Scientist supports reinstatement of the potable water system in Jabiru East
11 June	DBIRD	DBIRD approves full reinstatement of the potable water system in Jabiru East

## 4.2 Remedial Action at Jabiru East

### 4.2.1 Flushing of the Jabiru East potable water supply system

The flushing of the potable water system at Jabiru East was planned and performed by ERA and is described in detail in appendices to the ERA Investigation report which is attached as Appendix 5.

A summary of the chronological order of events is given in table 9.

During the flushing process between 31 March 2004 and 8 April 2004 about 70 drinking water samples from Jabiru East were sampled by ERA. Drinking water samples collected on 1 April 2004 and 2 April 2004 from several points at Jabiru East had an average filterable uranium concentration of 12.4 ppb. Trends for filterable uranium were decreasing between 31 March 2004 and 4 April 2004. Most samples collected in Jabiru East after 2 April 2004 were analysed for metal and major ions concentrations in the total fraction. All of those total concentrations were below the Australian Drinking Water Quality Guidelines with the total uranium concentrations being below 12.6 ppb.

### 4.2.2 Requirements for the reconnection of the potable water supply to Jabiru East

On 16 April 2004 ERA submitted a proposal to re-instate the Jabiru East potable water supply. After discussion including staff from Earth Water Life Sciences Pty Ltd, SSD and DBIRD, the Supervising Scientist requested (see Appendix 2 – Correspondence) that prior to the reconnection of the potable water supply to Jabiru East additional samples are collected and analysed as follows:

- Samples: Samples should be collected from the Jabiru Field Station, the Tourist Centre at the Airport (two representative samples), the Gagudju Workshop and a suitable point on

the line as it enters Jabiru East (for example, at the corner opposite the storage tanks at the eastern end of the Airport runway);

- Essential analyses: Before re-instatement of the supply, the samples should be collected and treated as specified in the Australian Drinking Water Standards and analysed for (a) the full suite of inorganic elements including Nitrates, Nitrites and Ammonia and (b) microbiological analysis; and
- Secondary analyses: In addition to the above analyses, arrangements should be put in place for (a) Gross alpha and Gross beta and (b) Total Petroleum Hydrocarbons. In a duty-of-care and risk assessment framework, given the known characteristics of water currently in the drinking water system at the mine, the results of these analyses need not be available at the time of re-instatement of supply but should be reported as soon afterwards as possible.

The Supervising Scientist also reiterated his earlier advice of involving the Department of Health and Community Services to ensure that all procedures would be supported by the responsible Northern Territory authorities.

**Table 9** Summary of remedial flushing activities for the Jabiru East potable water system

Date	Action
24 March – 25 March	Contaminated water from the Jabiru East potable water tank pumped back to the mine
9.00 am on 25 March 2004	Magela bore water pumped into the Jabiru East potable water tank and subsequently used to flush the pipeline from the Jabiru East potable water tank back to mine site
10.00 – 11.00 am on 25 March	The pipeline from the Jabiru East potable water tank to the businesses in Jabiru East was drained into a sump (see figure 6)
25 March	<p>The main lines of the reticulation system in Jabiru East were flushed by pumping clean water from the Gagudju workshop storage tank through the system back to the Jabiru East potable water storage tank.</p> <p>A sample was taken from the tank at 4.50 pm and showed a filterable uranium concentration of 11.1 ppb (sample # 100593, at Appendix 1A). A similar attempt to pump water from the Supervising Scientist field station tank back through the system to the Jabiru East potable water tank was unsuccessful due to a closed valve.</p>
26–28 March	The pipeline between the Jabiru East potable water tank and the minesite was repeatedly flushed with Magela bore water until criteria for EC and pH values were met at the outlet on the minesite (EC less than 400 $\mu\text{S}/\text{cm}$ and pH greater than 7.3).
28 March	A water sample was collected at the outlet on the mine site (ERA sample # 100505) and sent for analysis some days later. The concentration of uranium was 11 ppb, of arsenic 1.3 ppb and of manganese 239 ppb in the filterable fraction; all other results were comparable to the Brockman bore water. No data for the Magela bore water are available.
30 March – 8 April	Flushing of the Jabiru East outlets with Magela bore water fed via the Jabiru East potable water tank. The flushing was performed in three stages: first all accessible taps in Jabiru East were flushed for between 10 and 20 minutes, then two major outlets at the extremities in Jabiru East were flushed for 12 hours and finally likely drinking points were flushed for one hour and until the EC was less than 400 $\mu\text{S}/\text{cm}$ and the pH greater than 7.3.
22 April	ERA submits a proposal to reinstate the Jabiru East supply for industrial purposes only. Supported by Supervising Scientist and approved by DBIRD.
22 April – 7 June	Ongoing repairs of leaks in the Jabiru East system, flushing of the system and water quality analyses for microbiological indicators
7 June	ERA submits a final proposal for reinstatement of the potable water system in Jabiru East.
9 – 10 June	Proposal was supported by the Supervising Scientist on 9 June 2004 and by DHCS on 10 June 2004
11 June	DBIRD approves full reinstatement of Jabiru East potable water system.

Following receipt of the Supervising Scientist's advice, DBIRD met with ERA and the Department of Health and Community Services (DHCS) to discuss appropriate conditions for reinstatement of the Jabiru East potable water supply. DBIRD reported that DHCS concurred with the Supervising Scientist's advice on the requested testing for inorganic and organic pollutants. DHCS requested, however, that, following full flushing of the reticulation system after the repair of all leaks in the system, three consecutive samples complying with the microbiological Australian Water Quality Guidelines should be required before reinstatement of the supply for drinking purposes.

On 22 April 2004, ERA submitted a proposal to reinstate the Jabiru East water supply for industrial purposes (toilets, garden sprinklers and equipment washing facilities) only. The Supervising Scientist supported this request and approval was given by DBIRD.

Following repairs to various leaks in the Jabiru East water system, further flushing of the system and water quality analyses, ERA submitted a final proposal for reinstatement of the potable water system in Jabiru East on 7 June 2004. This proposal was supported by the Supervising Scientist on 9 June 2004 and by DHCS on 10 June 2004. Approval for reinstatement of the supply was given by DBIRD on 11 June 2004.

### **4.3 Jabiru Field Station Incident**

Early on the morning of 5 April 2004, final preparations for a 9.00 am helicopter flight were completed by Supervising Scientist Division staff at the Jabiru Field Station (JFS). The helicopter flight was required to access creeks around the Jabiluka lease from which samples of macroinvertebrates were to be collected as part of the Supervising Scientist's biological monitoring program.

The sampling field team consisted of three Supervising Scientist Division (SSD) staff members and two Aboriginal Traditional Owners. During these preparations one of the Supervising Scientist's staff found that the potable water supply was available, assumed that it had been cleared for drinking, and used it to fill drinking water bottles for consumption in the field by the team throughout the day. His assumption that the water had been cleared was based on the following:

- Initial testing of water from the Jabiru Field Station water tanks indicated that the water was of potable quality;
- More comprehensive analyses of water samples taken from Jabiru East businesses and the Jabiru Field Station met drinking water guidelines;
- The automatic garden watering system at the Jabiru Field Station had operated; and
- An ERA employee indicated during a casual conversation midway through the previous week that the potable water supply should be restored by the end of the week.

Three containers (20 L, 5 L and 1 L) were filled with ice made at the Jabiru Field Station some months before the incident. The containers were then filled with water from the tap in the preparation room of the Jabiru Field Station. At the end of the day, all the water in the 1 L container, and about one quarter of the water in the 5 L container had been consumed by one SSD staff member and the two Aboriginal Traditional Owners (the other members of the field team drank only other drinks). The 20 L container was used as an 'ice bucket' throughout the day to cool other drinks taken by the team and none of the water it contained was consumed.

At approximately 10.30 am on 5 April 2004, it was brought to the attention of the Jabiru Field Station Manager that the potable water system was operational and that water was available

from all taps. He investigated and found that the main isolation valve (see figure 7) at the front gate was open. As no communication had been received from ERA regarding a change in the status of the potable water, he closed the valve and opened the taps in the men's toilet. An e-mail message was sent to staff directing them not to use the water.



**Figure 7** Jabiru Field Station main isolation valve

The Jabiru Field Station Manager contacted ERA by telephone to seek information on the status of the Jabiru East potable water system. The ERA employee to whom the Jabiru Field Station Manager spoke was not aware of the status of the potable water system at that time but committed to find out and report back. A second call to ERA later in the day was similarly unsuccessful in confirming the status of the potable water system.

On returning from the field in the evening, the SSD staff member who had filled the water bottles that morning read the e-mail message from the Jabiru Field Station Manager indicating that the water had still not been cleared to drink. He immediately responded to all recipients of the message indicating what had occurred.

At approximately 12.30 pm the following day (6 April) the Jabiru Field Station Manager returned to the Jabiru Field Station after spending the morning collecting routine environmental water samples. After reading the e-mail message advising that water from the Jabiru Field Station had been consumed by the field team the previous day, the potable water system was investigated to try and establish the source of the water.

The water level in the Jabiru Field Station tanks was below the potable water system outlets, the valves at the outlets of the pressure pumps were closed and the pressure pumps were turned off. It was clear that the Jabiru Field Station tanks could not have been the source of the water.

The Supervising Scientist was notified of the situation. The Supervising Scientist asked the Jabiru Field Station Manager to try and determine the source of the water and to collect some samples from strategic places for analysis. Samples were collected from 5 locations around the Jabiru Field Station site for analysis.

It was at this stage that the direct connection between the Jabiru East Line and the Jabiru Field Station potable water system that bypasses the Jabiru Field Station tanks was discovered, although its purpose and method of operation (described in Section 3.2) were not clarified until the following day with advice from contractors familiar with the Jabiru Field Station. As there was no pressure in the Jabiru Field Station potable water system, the valve in the direct connection to the Jabiru East Line opened when the main isolation valve was opened, pressurising the Jabiru Field Station potable water system directly from the Jabiru East Line. Water samples from the Jabiru Field Station were collected and sent to Darwin for urgent analysis.

ERA was advised of the incident and several ERA staff went to the Jabiru Field Station to investigate. At the request of the Jabiru Field Station Manager, ERA locked out the main isolation valve. It was established that ERA staff opened the Jabiru Field Station main isolation valve during the morning of Friday 2 April to obtain a water sample and did not close it again. Thus, the Jabiru Field Station potable water system was connected directly to the Jabiru East Line from that time until the morning of 5 April when the Jabiru Field Station Manager found the Jabiru Field Station main isolation valve open and closed it.

On Wednesday 7 April ERA staff opened the Jabiru Field Station main isolation valve, opened all taps at the Jabiru Field Station, placed 'Out of Service' tags on the taps and measured the EC and pH of water from each. Fifteen taps at the Jabiru Field Station were selected from which water samples were collected for comprehensive analysis in order to characterise the water in the Jabiru Field Station potable water system.

#### **4.3.1 Health risks associated with the Jabiru Field Station incident**

In addition to measurements of EC and pH conducted on water samples collected from the Jabiru Field Station at various times after the potable water contamination incident (all returning normal results), there are two key datasets that are relevant to the determining whether the SSD staff and the Traditional Owners who drank water taken from the Jabiru Field Station have been subject to any health risk. They are the analysis of:

- the samples collected from the Jabiru Field Station on 6 April – although collected the day after the field team consumed the water, these samples are representative of the water consumed because the potable system had not been fully drained and most of these samples were collected from areas other than the men's toilet; and
- the samples collected by ERA and SSD after the contamination incident but before 5 April.

Together, these data cover the period before and immediately after the consumption of water from the Jabiru Field Station.

The results of analyses of water collected on 6 April are summarised in table 10 (a full set of results is in Appendix 1A). These results show that the water was of drinking water quality with respect to inorganic parameters (microbiological analyses was not carried out on these samples).

Similarly, a review of water quality analyses for all other samples collected either by ERA or SSD from taps/pipes etc at or immediately outside the Jabiru Field Station or from the Gagudju workshop that is at the end of the line that supplies the Jabiru Field Station reveals that every sample met drinking water guidelines in respect of the constituents measured. Table 11 summarises the results of those analyses, and more SSD results are available in Appendix 1.

Thus, we have concluded that the water from the Jabiru Fields Station consumed by SSD staff and by Aboriginal Traditional Owners on 5 April met drinking water standards and did not present any health risk.

**Table 10** A summary of key indicators of process water in samples collected from JFS potable outlets on the 6 April 2004, and the Drinking Water Guidelines

	EC ( $\mu\text{S}/\text{cm}$ )	Mn ( $\mu\text{g}/\text{L}$ )	U ( $\mu\text{g}/\text{L}$ )
A00516	390	7.39	11.6
A00517	388	3.46	11.5
A00518	N.A.	7.13	11.6
A00519	389	3.48	11.4
A00520	NA	4.49	11.4
Drinking Water Guideline (total)	NA	500	20

Note: N.A. – result not available or guideline not available

**Table 11** Summary of the key indicators of process water in (i) a sample of JFS potable water prior to the contamination incident, and (ii) ERA and SSD samples collected from potable outlets and fire hydrants in the Jabiru East system (not including the Jabiru East tank area) between the time of the contamination incident and the JFS drinking incident; and the relevant drinking water guidelines

	pH	EC ( $\mu\text{S}/\text{cm}$ )	SO <sub>4</sub> (mg/L)	Mn ( $\mu\text{g}/\text{L}$ )	U ( $\mu\text{g}/\text{L}$ )
(i) Potable water at JFS prior to 24/3/04 incident (filtrate)	NA	NA	0.9	0.16	8.02
(ii) SSD samples, n = 4 (filtrate)	NA	NA	0.6 – 1.2	0.03 – 1.3	8.04 – 8.24
(ii) ERA samples, n = 43	7.6 – 8.5	371 – 457	0.7 – 44 (filtrate)	0.04 – 173 (filtrate)	7.45 – 19.5 (filtrate)
				0.61 – 39.7 (total)	10.7 – 12.6 (total)
Drinking Water Guideline (total)	6.5 – 8.5 aesthetic	N.A.	250	500	20

Note: NA – result not available or guideline not available

#### 4.3.2 Discussion of Jabiru Field Station incident

There are two primary factors that contributed to the consumption of water from the Jabiru Field Station before the process of clearing the water for drinking was complete. The first was the incorrect assumption that the Jabiru Field Station potable water system was supplied solely via the Jabiru Field Station tanks. The presence of the direct connection between the Jabiru Field Station potable water system and the Jabiru East Line (described in Section 3.2) was not known. So, when ERA isolated the inlet to the Jabiru Field Station tanks and placed ‘Out of Service’ tags on them on 30 March, it was assumed that the entire system had been isolated.

The second, which is related to the first, is that unlike at the Ranger mine site, every tap at the Jabiru Field Station was not tagged with an ‘Out of Service’ tag. The absence of anything indicating that the potable water system had still not been cleared, and the presence of water in the system was interpreted, along with other considerations, by an SSD employee as meaning that the water had been cleared for consumption.

This incident had the potential to very significantly damage the relationship between the Mirarr people and the Supervising Scientist. The Supervising Scientist Division has been developing this positive relationship over a number of years and the employment of Mirarr people to assist in field work has proven to be a very important and mutually beneficial activity. This incident could have destroyed the trust that has grown between the Mirarr and SSD.

The Supervising Scientist met with Ms Yvonne Margarula, Senior Traditional Owner, on 14 April to brief her on the incident, to assure her that the incident did not put anyone's health at risk, and to apologise for the incident. Ms Margarula was clearly very concerned about the incident but accepted the assurances offered by the Supervising Scientist that the health and safety Aboriginal Traditional Owners working with the Supervising Scientist's staff had not been harmed and agreed that the employment of Mirarr people by SSD could continue.

#### **4.4 Conclusions on recovery of the potable water system**

Recovery of the potable water system at the Ranger mine site took place in stages on the basis of approvals from the NT Department of Business, Industry and Resource Development (DBIRD). First, staff were allowed to return to site to carry out maintenance under conditions that ensured their safety. Mining staff were then allowed to return to work on the same basis. Resumption of milling was only allowed when it had been established that the potable water system met the Australian Drinking Water Guidelines and measures had been implemented that would ensure that a similar incident could not recur.

The Jabiru East potable water supply was reinstated to a standard appropriate for industrial purposes on 22 April 2004.

Following repairs to various leaks in the Jabiru East water system, further flushing of the system and water quality analyses, ERA submitted a final proposal for reinstatement of the potable water system in Jabiru East on 7 June 2004. This proposal was supported by the Supervising Scientist on 9 June 2004 and by DHCS on 10 June 2004. Approval for reinstatement of the supply was given by DBIRD on 11 June 2004.

A faulty valve at the Jabiru East tank caused contaminated potable water to flow from the mine towards Jabiru East. Water quality data at Jabiru East businesses are limited but we have been able to conclude that water consumed at the Jabiru Field Station and the Gagudju Workshop on the morning of 24 March met all drinking water guidelines and that it is highly likely that this was also true at the Jabiru East Airport.

The consumption of water from the Jabiru Field Station of the Supervising Scientist by staff of the Supervising Scientist and traditional owners on 5 April 2004 arose from a misunderstanding by a member of staff and from the lack of tagging of potable water outlets within the Jabiru Field Station. We have concluded that the water from the Jabiru Field Station consumed by SSD staff and by Aboriginal Traditional Owners on 5 April met drinking water standards and did not represent any health risk.



## 5 Assessment of human health implications for ERA staff and contractors

### 5.1 Modelling of the process water contamination of the potable water system

#### 5.1.1 Estimates of the volume of process water entering the potable line

Given the complexities of the potable and process water distribution system, estimating the quantity of process water that entered the potable water line cannot be accurately determined. A lack of flow metering in the vicinity of the connection means that any estimation of flow has to be based on assumptions of the various pressures of both systems relative to the location of the connection. The following assumptions have been used in the estimate:

- Pressure of the high pressure process water line – 680 kpa ( $\approx$  69 m of water);
- Pressure of the high pressure process water line at the manifold where the connection was made approximately +10.5 m relative to the process water pressure gauge – 58.5 m;
- Pressure of the potable water line at the manifold where the connection was made – 23.5 m (worst case with header tank almost empty);
- Diameter of hose connecting the two systems – 25 mm;
- Length of hose connecting the two systems – 20 m;
- Losses due to friction in the hose only. This is a conservative assumption as there would be potentially quite large losses due to friction elsewhere, but these would be difficult to estimate for the network;
- The potable water system is an open system. Given the leak of up to 18 L/s at Jabiru East, this is a fair assumption.

Using these assumptions, the pressure difference between the two systems at the manifold would have been approximately 35 m as a worst case. Flow at this pressure through 20 m of 25 mm hose is approximately 2.5 L/s, which over the 10.5 hours duration of the incident would have resulted in approximately 95 m<sup>3</sup> of process water entering the potable system.

As stated above, it is very difficult to determine with certainty what quantity of process water entered the potable system as pressures and demands would have varied continuously throughout the duration of the incident. For the purposes of this investigation we will assume a quantity approaching 100 m<sup>3</sup> entered the potable water system. In reality the volume is likely to have been much less.

Modelling work undertaken by EWLS for ERA included in ERA's Investigation Report into the Potable Water Contamination Incident (Appendix 2), concludes that process water would have entered the potable system at a rate of 1.72 L/s which is comparable to 2.5 L/s calculated above. Work undertaken on site by DBIRD also indicated a total volume of process water entering the potable system approaching 5.9 tonnes/hr which equates to approximately 1.6 L/s.

#### 5.1.2 Flow within the potable water system

The Ranger potable water system (see figure 1) consists of a ring main, which circles the mine site, off which supply is taken to various parts of the operation. The main items linked to this line are the potable water header tank, the potable water day tank, the Jabiru East supply

line, and the various sections of the mine and mill such as the Demineralisation Plant, the workshop, the mill, and administration.

Unlike most water distribution systems, the header tank is only used to maintain pressure rather than providing the supply for the system.

The header tank is linked to the ring main near the Fine Ore Bins via a single pipeline. Supply to the system is provided through the potable water day tank which resides near the Administration building. Water is pumped into the ring main from the potable water day tank when levels in the header tank indicate that pressure in the line is dropping.

On the night of the incident the major user of potable water on site was the Demineralisation Plant which used approximately 11.8 t (11.8 m<sup>3</sup>) of water per hour between 9.30 pm and 3.00 am. This equates to approximately 3.3 L/s. Amenities uses such as showering, toilets and drinking were insignificant and only totalled approximately 10 m<sup>3</sup> for the whole night. By far the largest user of potable water was Jabiru East where a leak at the Jabiru East tank, thought to have been as large as 18 L/s (see section 6.1.2), discharged water via an overflow pipe to the surrounding land.

With such a large draw on the system, water throughout the potable water system would have preferentially followed the path of least resistance from the header tank to the Jabiru East line whilst the potable day tank pumps were off, and directly from the potable day tank to the Jabiru East line whilst the pumps were in operation.

The potable day tank is filled from the Brockman bore field periodically. Water is then pumped into the potable system. The only return from the system back into the potable day tank is via the potable return lines which bring water back from select emergency showers and eyewashes to ensure circulation is maintained and water temperatures do not become elevated. The return flows at approximately 0.6 L/s. Given that the day tank has a volume of 300 m<sup>3</sup>, this flow is minor and would take 140 hours to totally fill the day tank. Given that recharge from the Brockman Borefield occurs approximately every 1–1.5 hours for 1–1.5 hours, modelling suggests that under the extreme circumstance of the return line containing pure process water, the day tank would stabilise at a contamination level of around 300 ppb uranium.

However, the return line is likely to have contained relatively clean water for a majority of the incident as the return volume is a combination of small flows from selected emergency shower and eye washes. These small flows would have bled clean water contained within the pipes supplying the emergency showers and eye washes for some time before contaminated water reached the return line. Using this realistic assumption, the day tank cannot be seen as a major source of contamination distribution throughout site.

Logs of the potable water day tank heights on the night of the incident indicate that the potable water pumps operated every 20 to 30 minutes for approximately 15 minutes to recharge the pressure in the potable water line. When this occurred, flow would have reversed in the ring main with fresh water flushing back through the system until the header tank pressure was such that the pumps were shut off. The process water pumps operate at a rate of approximately 24 L/s. The combined effect of the demands of the Jabiru East line drawing contaminated water from the potable water ring main interspersed with the injection of relatively fresh water into the system when the potable water pumps were operational would have resulted in what can be best described as packets of water with varying qualities moving around the system throughout the duration of the incident.

Determining through modelling what the quality of potable water would have been at any one time throughout the night would be impossible. Nor can it be assumed that any one sample

taken in the moments following the incident would represent the contamination in the system during the incident. These samples are merely indicative of the quality of water passing the sampling point at the time of sampling, or in the case of samples taken from toilet cisterns, the quality of the water passing the cistern at the time of the last flush.

## 5.2 Characterisation of the contaminated potable water

Only a small number of samples could be collected from the potable system at the Ranger mine site on 24 March 2004 by ERA and SSD prior to the system being flushed. ERA samples were analysed for the relevant components of the Australian Drinking Water Inorganic suite, initially for filterable components and later for total fraction. The SSD samples were analysed for radionuclides (total fraction), relevant components of the Australian Drinking Water inorganic suite (filtrate and total fractions) and in some instances (where volume allowed) were characterised by ICPMS Total Quant Scan<sup>4</sup> for 69 elements including heavy metals and rare earth elements (pseudo-total fraction, ie acidified and unfiltered). The results of SSD analyses are given in Appendix 1, with a summary of the key indicators of process water contamination measured in those samples provided in table 12. Radionuclide results are discussed in Section 5.4.

Because the potable water system at Ranger had been disconnected when contamination had been established, water sampling was opportunistic rather than systematic and the small number of samples plus the limited distribution of locations sampled does not provide a good representative coverage of the whole potable water system on site. However, even with the limitations of the sampling design and the limited data set, conclusions can be drawn from the results.

The range of results presented in table 12 shows that the level of contamination across the site was variable. ERA staff measured uranium as high as 8000 µg/L using an XRF instrument (this method has ~ 50% uncertainty). SSD sample H (A00322) from a toilet cistern in the grinding room and ERA sample 100323 from the potable tank on top of the fine ores bin, show the greatest contamination; about a 1:3 and a 1:10 dilution of process to potable water in the SSD and ERA samples respectively. Other samples show no, or little, indication of contamination; for example, SSD sample D (A00318). The samples with high contamination were from locations close to the processing plant. Further away from the plant or in other flow directions the pattern of contamination is difficult to infer, eg compare SSD samples C (A00317) and D (A00318) collected from taps close to each other.

Contaminants were attenuated in the reticulation system by effects other than dilution. ERA has carried out laboratory studies of mixtures of process water and potable water (contained in Appendix 5 to the ERA Investigation Report which is attached to this report as Appendix 5) which show that the decrease in metal concentrations at a pH greater than 4.8 (which applies to all except the most contaminated samples) are likely to occur due to co-precipitation of metals, particularly with amorphous aluminium compounds.

Independent experts employed by ERA and the Supervising Scientist have assessed the health risk to workers exposed to the contaminated waters. The outcome of these assessments is described in the next section.

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<sup>4</sup> To quickly characterise the water SSD samples (where volume allowed) were initially analysed by an ICPMS Total Quant scan. Results for samples 'E' (A00319) and 'H' (A00322) were provided to the human health experts engaged by SSD. Fully quantitative results for these samples were later forwarded to the consultants. For this reason earlier versions of data for these samples may contain different values.

**Table 12** Summary of the key indicators of process water in samples collected at the mine site on the day of the contamination incident (24 March). Results are for the total fraction unless indicated otherwise

Sample ID	Description	pH	EC (µS/cm)	SO4 (mg/L) filterable	Mn (µg/L)	U (µg/L)
	Process water	3.8	20100	20070	1630000	24000
	Drinking Water Guideline (total)	6.5 – 8.5 aesthetic	N.A.	250 (total) aesthetic	500	20
SSD – A00316 'B'	Urn in crib room d/s main building			1.1	1.2	0.6
SSD – A00317 'C'	Downstairs mill lab taps	7.5	1516	0.8	0.4	7.1
SSD – A00318 'D'	Downstairs mill lab taps			30.8	709	9.6
SSD – A00319 'E'	Engineering shower block	6.7	1505	913	64200	366
SSD – A00320 'F'	Eng toilet tap shower block			1080	75700	156
SSD – A00321 'G'	Engineering crib room			3420	197000	527
SSD – A00322 'H'	Grinding area ground floor toilet cistern	4.2	8710	6940	607000	7060
ERA – 'GCR' no sample ID	Grinding Room Crib	4.50	5900			8000 (by XRF)
ERA – 'MLT' no sample ID	Mill laboratory tap	4.50	5900			3000 (by XRF)
ERA – 100305	Potable Water from Admin Crib Room	5.8	2740	345	23700	263
ERA – 100323	Potable Water Header Tank (on the fine ore bins)			2570	195000 (filterable)	2355
Earlier sample same site			5380			3000 (by XRF)
ERA – 100324	Admin Potable Water Tank Discharge			110	8330	69.2
Earlier sample same site		7.45	650			*
ERA – 100326	Potable Water - Underground pipe to Jabiru East			178	17310	115
Earlier sample same site		7.44	770			*

Note – uranium measured by XRF may have an error as high as 50%

\* Undetectable by XRF

## 5.3 Chemical exposure

### 5.3.1 ERA assessment of human health risks

On 25 March, a day after the incident was reported, ERA contacted Rio Tinto's Group Occupational Physician, Dr Richard Gaunt, to investigate the health aspects of the incident, specifically in relation to chemical toxicity (ERA had separately undertaken an initial risk

assessment for ionising radiation). Dr Gaunt immediately flew from the United Kingdom to Jabiru to commence his investigation.

The major aim of the investigation, as it is understood by the Supervising Scientist, was to determine the likely health risks to the exposed employees and contractors and, based on this information, propose and oversee a program of urine and blood sampling and analysis to enable further understanding of exposure and health effects. The following description of the investigation is based on Dr Gaunt's final report, which is provided as Appendix 8 of the ERA Investigation Report (Appendix 5).

Initially, Dr Gaunt undertook a rapid, 1<sup>st</sup> Level assessment of the risks of a worst-case contamination scenario of 1 part process water to 3 parts potable water, which was based on the ratio of the concentration of uranium measured in the potable water sample that first alerted mine staff to the contamination incident (~ 8 mg/L) to the typical uranium concentration in process water at the time (~ 25–30 mg/L). Calculated exposures were based on an assumed consumption of 2 L of the worst-case quality water. Following this, a 2<sup>nd</sup> Level risk assessment was undertaken using actual chemistry data for the most contaminated potable water sample collected by ERA on 24 March. This water sample reported a substantially lower level of contamination than the most contaminated potable water sample collected by SSD (ie sample H; A00322; see Section 5.2 and Appendix 1A and 1B) and used as the worst-case scenario for the SSD human health risk assessment (see Section 5.3.2). Dr Gaunt undertook confidential one-on-one interviews with all concerned individuals to determine the likely extent of exposure levels and initial physical symptoms. Information was obtained from employees and contractors on their estimated consumption of water and location(s) of consumption, whether they showered on-site and symptoms. This information is appended to the SSD human health risk assessment report at Appendix 3C. The 1<sup>st</sup> and 2<sup>nd</sup> Level risk assessments arrived at two key conclusions:

- Exposures to various contaminants (eg sulfates, copper and probably manganese) were sufficiently high to cause the acute skin and gastric symptoms reported; and
- The overall short-term nature of the exposure was probably insufficient to cause long-term health effects, however, they could not be excluded for uranium and manganese.

Further consideration was given to the potential, albeit unlikely, effects of uranium and manganese, in particular renal proximal tubule damage from uranium and neurological damage from manganese, and means of testing for such effects. Consequently, a health (urine and blood) testing program for all individuals who had expressed concern was undertaken on 4 April, 10 days after the contamination incident. The program focused on indicators that provided information on kidney function, liver function, general haematological parameters and concentrations of key metals in either blood or urine. In general, the majority of the results were within the acceptable range. In particular, Dr Gaunt and a consultant toxicologist retained by ERA (Dr Roger Drew, Toxikos) concluded that urinary N-acetylaminoglucosaminidase (NAG), which is known to be a sensitive indicator of renal tubular damage, were not elevated and, thus, confirmed a lack of effect on renal function. While some individuals returned results for various markers that were outside the normal reference range, Dr Gaunt concluded that these were not related to exposure to the contaminated water.

As a final, 3<sup>rd</sup> Level assessment, Dr Gaunt considered the results of the blood and urine testing program and a revised worst-case contamination scenario predicted by Klessa (2004) as detailed in Appendix 5 of the ERA Investigation Report (Appendix 5 to this report), of 1 part process water in 2 parts potable water. This scenario represented a similar level of contamination to the SSD sample H. The key conclusions of the 3<sup>rd</sup> Level risk assessment

supported but also elaborated on those of the 1<sup>st</sup> and 2<sup>nd</sup> Level assessments and can be summarised as follows:

- The predicted worst-case concentrations of various contaminants are consistent with the acute, temporary symptoms reported by some workers;
- The results of the initial medical testing program provide considerable reassurance that there will be no long-term health effects from exposure to the contaminated water;
- Clinically significant renal damage from the uranium intake has not occurred, nor are there likely to be any sub-clinical effects of uranium ingestion on the kidneys that might increase the susceptibility of exposed workers to future renal disease;
- Adverse long-term effects from manganese and aluminium are unlikely;
- Adverse long-term effects from other contaminants present in the potable water supply do not represent a concern to health; however
- Notwithstanding the available literature information and initial health testing results, the possibility of adverse long-term health effects of uranium (kidney function) and manganese and aluminium (neurological effects) cannot be excluded entirely at this stage.

Consequently, to increase confidence in the conclusions of the risk assessment, Dr Gaunt made a number of recommendations. The most significant of these was for a further voluntary testing program over a 3 month period extended to all workers and contractors who advised exposure to contaminated water on site on 23/24 March 2004, after which the ERA and SSD health experts again assess the risk of long-term health effects and consider the need for further testing, research and monitoring. The details of Dr Gaunt's recommended monitoring program are as follows:

- Blood and urine samples to be taken from subjects over a single period of time (one to two days);
- Blood samples to be analysed for:
  - serum B2M, manganese, glucose, liver function and lead;
- Urine samples to be analysed for:
  - uranium and ratio of U:creatinine, NAG content relative to creatinine excretion, protein, calcium, phosphate and glucose; and
- MRI scans to be conducted for manganese and aluminium levels for workers with high potential or reported exposures.

In relation to the proposed monitoring program, Dr Gaunt recommended that ERA engage an experienced neurotoxicologist to provide advice on the testing program for assessing long-term health effects of manganese and aluminium, in particular the recommendation to conduct MRI scans.

Finally, additional significant recommendations by Dr Gaunt included:

- That ERA commission a further detailed review of the properties of the contaminants in the Ranger potable water system; and
- That ERA commission a detailed review of the scientific literature on the kidney changes caused by uranium exposure with particular attention being given to the clinical significance of any changes.

### 5.3.2 SSD assessment of human health risks

Following advice from the Office of Chemical Safety within the Therapeutic Goods Administration and the Commonwealth Department of Health and Ageing on appropriate human health and toxicology experts<sup>5</sup>, the Supervising Scientist engaged a team of senior human health/toxicology and environmental chemistry scientists from the Australian Centre for Human Health Risk Assessment (ACHHRA) and the National Research Centre for Environmental Toxicology (EnTox).

ACCHRA is a consortium of Monash University, the University of Queensland, Griffith University and Flinders University, and includes EnTox, a centre of excellence collaboration between the University of Queensland, Griffith University, Queensland University of Technology, and Queensland Health, as a partner organisation. The details of the expert group are provided in Appendix 3A.

The Terms of Reference under which the ACCHRA/EnTox project team worked are provided at Appendix 3B. The objectives were to:

- Undertake an assessment of the short- and long-term health risks/impacts (arising due to chemical toxicity) to workers at Energy Resources of Australia's (ERA) Ranger mine, following exposure to potable water contaminated with mine process water;
- Provide advice on the most appropriate procedures (for example, what types of samples – urine, blood, bile, hair, etc – and what type of analytes/biomarkers) for testing for exposure to/presence of and effects of the key contaminants within the exposed workers; and
- Provide advice on appropriate long-term procedures for monitoring effects on and health status of the exposed workers.

The project team was requested to undertake a preliminary, 'first-pass' assessment of the likely health risks in order to provide timely initial advice to the Supervising Scientist on points one and two, above. Following this, a detailed human health risk assessment of the incident was to be prepared, addressing all three points above.

#### *Preliminary risk assessment*

In order to undertake the initial assessment, the project team was provided with the following information (in addition to background/contextual information):

- Chemical analysis results for potable water samples A00319 and A00322. It is important to note that these samples correspond to samples E and H, respectively, as identified in Section 5.2 and 5.4, and are referred to as such through the remainder of this section. The history of these samples was detailed in Section 5.2. Sample E was representative of a moderate level of contamination and sample H represented a high, or 'worst-case' level of contamination. The chemistry of both samples can be seen in table 12 and Appendix 1A and 1B (and also in the human health risk assessment report at Appendix 3C); and
- A copy of a spreadsheet containing incomplete information gathered by ERA on estimates by employees and contractors of consumption of potable water and location(s) of consumption, whether they showered on-site and symptoms.

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<sup>5</sup> Advice was received from Dr Utz Mueller (Team Leader, Review, Chemical Assessment Group, Office of Chemical Safety, Therapeutics Goods Administration) and Dr Helen Cameron (Director, Environmental Health, Population Health Division, Australian Government Department of Health and Ageing)

Based on the above information, a range of exposure scenarios was recommended by SSD to the project team (table 13). The estimated maximum volume of water ingested of 5 L was based on the maximum volume of water estimated (at the time that this assessment was undertaken) by a worker to have been ingested over the period in question. Given that no details on shower length were available, an upper duration of 20 minutes was assigned as a worst-case exposure.

Given the short timeframe to complete the preliminary risk assessment (ie less than 1 week from commencement of the project), the project team focused only on the likely health risks from the first ingestion scenario, this being the worst-case scenario. The preliminary report concluded that although long-term effects were unlikely, some effects from uranium (on the kidneys) and from manganese (on the nervous system) could not be excluded at that stage. Following the provision of the preliminary report to the Supervising Scientist, a scope and plan for the detailed risk assessment was prepared.

**Table 13** Exposure scenarios recommended by SSD to be used for first-pass human health risk assessment

Pathway	Scenario	
Ingestion (drinking water) over <12-h period	1.	5 litres water @ the water quality provided for sample H
	2.	500 mL @ the water quality provided for sample H
	3.	5 litres water @ the water quality provided for sample E
	4.	500 mL @ the water quality provided for sample E
Dermal contact (showering water)	1.	20 minute shower @ the water quality provided for sample H
	2.	5 minute shower @ the water quality provided for sample H
	3.	20 minute shower @ the water quality provided for sample E
	4.	5 minute shower @ the water quality provided for sample E

#### *Detailed risk assessment*

The detailed risk assessment, which is provided in Appendix 3C, built upon the start made by the preliminary assessment. The Scope of Works for the detailed risk assessment was as follows:

- Complete detailed health risk evaluation on manganese, uranium and other highly ranked substances;
- Provide advice on health risks from skin irritation and showering from substances;
- Expand document to complete gaps for lower ranked substances and include discussion on other possible health risks (organics, microbiological etc); and
- Provide recommendations for biological monitoring and interpretation of data for Ranger workers.

Key information provided to the project team to undertake the analysis included:

- A final and agreed set of chemical analysis results for potable water samples E (A00319) and H (A00322);
- A completed copy of the spreadsheet containing information on estimates by employees and contractors of consumption of potable water and location(s) of consumption, whether they showered on-site and symptoms;



- Results of voluntary blood and urine tests arranged by Dr Gaunt for individuals with high levels of concern and/or reported exposures;
- Results of voluntary urine tests arranged by Mr Ian Marshman (Senior Radiation Officer, ERA) for individuals with high levels of concern and/or reported exposures; and
- The ERA Investigation Report.

The approach and key outcomes of the risk assessment are summarised below, but are discussed in full detail in the final report (Appendix 3C).

Acknowledging the difficulties in accurately estimating individual exposures of contaminated water, the risk assessment considered scenarios of ingestion of either 500 ml or 5 L of water corresponding to potable water samples E and H. However, it was considered unlikely that all water ingested by workers who estimated consumption of up to 5 L, was contaminated, at least to the extent indicated by sample H. Furthermore, water intake may have been limited by the taste and gastrointestinal irritation associated with the rising metal and salt concentrations. Exposures through showering or washing with the contaminated water were likely to be much less than the ingested exposures, and other than being identified as a potential cause of acute (and transient and reversible) effects including skin itchiness and irritation as reported by some workers, was not further addressed by the risk assessment.

The extent to which the potable water contamination (as represented by samples E and H) exceeded the Health Guideline Values (HGVs) of the Australian Drinking Water Guidelines (NHMRC & ARMCANZ 1996) was used as a screening tool to prioritise those metals that warranted further attention in the risk assessment. Consequently, the assessment focused mainly on eight metals or metalloids (ie manganese, uranium, lead, nickel, copper, aluminium, selenium and arsenic) that achieved relatively high concentrations in some samples of the contaminated water, and that have toxicological properties that merit attention to possible acute and delayed toxic effects. However, caution must be used in interpreting these 'exceedances', since HGVs are conservative estimates of a safe level of exposure over a lifetime, and the short-term exposure (<12 hours) in the Ranger incident would not necessarily have affected the same target organs, or could require much longer term exposure to produce adverse health effects. Consequently, where possible, the 'worst-case' intake estimates in this incident were also compared with animal and/or human studies where exposures occurred acutely or over a short time span.

Acute health effects reported by 21 of the exposed workers (gastrointestinal distress; two cases of vomiting; skin itchiness on washing or showering) were consistent with the known irritant effects of some of the metals. The available information suggested that the levels of sulfate and some of the metals (eg magnesium, copper) could have been high enough to produce such acute symptoms based on a 'worst-case' estimated oral intake. The fact that most of the potentially exposed workers reported no adverse health effects, nor noticed any changes in the taste of the water, further suggested that such 'worst-case' estimates of intake are probably overestimates of the actual exposures.

The potential for systemic toxicity arising from the Ranger incident is more difficult to predict since the availability of quantitative data on short-term systemic toxicity is quite limited for many of the analytes. Nevertheless, the risk assessment was able to collate and analyse sufficient information and literature on the contaminants of most concern to conclude that it is most unlikely that the short-term exposures would result in any delayed (or longer-term) adverse health effects, beyond the acute skin and gastrointestinal irritation reported by some workers. Supporting this, the results of health studies undertaken on some of the

workers, including blood and urine tests of various clinical chemistry parameters and measurements of blood and urinary levels of selected metals, were quite consistent with the predicted low risk of systemic toxicity. Significantly, these results appear to show there were no adverse effects on the kidney, a significant target organ for uranium, lead and copper. However, some clinical chemistry values in individual workers were marginally above the normal range. In particular, samples from three individuals returned marginally high NAG values of 20.2, 18.4 and 15.2 IU/L, with the third individual also showing some other clinical chemistry values outside the normal range. The risk assessment recommended that health testing should be repeated at least for these three individuals.

While the risk assessment concluded that the potential for the exposures to result in systemic toxicity is very low, such a possibility cannot be completely ruled out, and the merits of follow-up blood/urine biomonitoring or organ function program focusing on the kidney and the brain should be considered. However, it needs to be appreciated that biomarkers of renal disease or brain dysfunction may not be specific to metal-induced toxicity and may be difficult to interpret in the absence of baseline data for individual workers. A decision on the need for, and nature of any follow-up medical assessment for individual workers should be made by their attending medical professionals and based on their individual medical histories. This decision should take into account other potential risk factors and their need for reassurance relating to the Ranger incident.

#### *Evaluation of ERA health risk assessment*

Following the completion of the ERA health risk assessment, the ACCHRA/EnTox project team was requested to provide comment on the ERA report's conclusions and recommendations. The project team's response is provided at Appendix 3D and is summarised below.

Although the ERA report and SSD report adopted slightly different risk assessment approaches and used slightly different exposure scenarios, both reports drew very similar conclusions with regards to the observed acute skin and gastrointestinal symptoms being consistent with exposure to acidic water with high concentrations of irritant metals, and the low likelihood of long-term, or delayed health effects on target organs such as the brain, liver and kidney.

The most significant difference between the two reports was that the ERA report made firmer recommendations about follow-up health testing, although it is noted that this is a precautionary approach that should be considered and supported by the workers' doctor(s). The SSD report canvassed the use of some possible biomarkers relating to renal effects and neurotoxicity, but it cautioned that the results of such tests might be difficult to interpret on an individual basis, and a decision for such testing should be made by the attending medical professional of individual workers, informed by the level of concern expressed by those workers, and by other possible risk factors from their individual medical histories. It was noted that the ERA report proposed MRI testing for workers assessed to have the highest potential exposure to manganese and aluminium. The ACHHRA/EnTox report did not make such a recommendation because such tests may only be useful in showing deposition of these metals at selected sites in the brain, which may be difficult to interpret on an individual basis. It is considered unlikely that such MRI testing could provide evidence of brain dysfunction arising from the incident. However, it was acknowledged that the ERA report recommended that the need for such MRI testing should be further assessed by a consultant neurotoxicologist.

In summary, both the ERA and SSD reports on the Ranger incident reach essentially the same conclusions about the reported short-term health effects, and the low likelihood of there being any longer-term effects associated with the incident. Both reports could be provided to relevant stakeholders with the expectation that the differences in approach and the differing emphasis on responsibility for follow-up testing should not result in conflict between the findings.

## 5.4 Radiological exposure

Several samples collected by SSD personnel were sent to the SSD radioanalytical laboratories for radionuclide analysis. In the period immediately following the incident, rapid analysis was required, and so the analyses were performed on the samples without acid digestion. The results obtained are given in table 14, and show that sample A00322('H') had the highest Ra-226 concentration; this sample also had the lowest pH, the highest electrical conductivity and the highest concentrations of other contaminants such as manganese (see table 11). Other samples with somewhat elevated Ra-226 concentrations were sample A00319 from the Ranger site, and samples A00315, A00324 and A00330 from the vicinity of the Jabiru East tank. The radionuclide concentrations for the Magela Creek samples were within the ranges previously recorded for Magela Creek water samples.

**Table 14** Electrical conductivity, Ra-226 and Po-210 results obtained for some samples collected on 24 March 2004. Radionuclide analyses were performed on unfiltered, acidified samples.

	Code	Field pH	EC ( $\mu\text{S}/\text{cm}$ )	Ra-226 (Bq/L)	Po-210 (Bq/L)
<i>Ranger site samples</i>					
Mill lab tap A	A00317	7.5	1516	$0.009 \pm 0.002$	$<0.0013$
Mill lab tap B	A00318	7.5	1516	$0.009 \pm 0.002$	$<0.0012$
Engineering shower block shower rose	A00319	6.7	1505	$0.694 \pm 0.014$	$0.138 \pm 0.009$
Grinding area ground floor toilet cistern	A00322	4.2	8710	$15.0 \pm 0.4$	–
<i>Jabiru East samples</i>					
Hydrant close to Jabiru East tank	A00315	6.9	1045	$0.357 \pm 0.011$	$0.024 \pm 0.002$
Tank Jabiru East – B	A00324	6.5	1476	$0.145 \pm 0.004$	$0.143 \pm 0.009$
Tank Jabiru East – F	A00330	8.2	801	$0.181 \pm 0.005$	$0.016 \pm 0.001$
Eriss Jabiru Field Station tank outlet	A00307	–	–	$0.0088 \pm 0.0005$	$0.0009 \pm 0.0001$
<i>Magela Creek samples</i>					
MG009C	A00312	6.5	17	$0.0023 \pm 0.0003$	$0.0033 \pm 0.0003$
MG009W	A00313	6.4	18	$0.0022 \pm 0.0004$	$0.0035 \pm 0.0003$
Mudginberri billabong inlet	A00331	6.7	17	–	$0.0028 \pm 0.0002$
<i>Other samples</i>					
Jabiru Town	A00331	7.4	438	$0.0048 \pm 0.0007$	–

- 1 The samples for radionuclide analysis were not completely digested, as these analyses were required as soon as possible after sample collection.
- 2 Radionuclide analyses were performed by alpha-particle spectrometry at the eriss laboratories.
- 3 Indicated errors are the estimated analytical uncertainties ( $1\sigma$ ) due to counting statistics. Other systematic and random errors are also present and are estimated to be of the order of 10% for Ra-226 and 3% for Po-210.

More complete analyses are now available on a 'total' (that is, acid-digested sample) basis for radionuclides on several of these samples. These results are summarised in table 15.

**Table 15** 'Total' radionuclide concentration results for some samples collected on 24 March 2004

Sample code	U-238 (Bq/L)	U-234 (Bq/L)	Th-230 (Bq/L)	Ra-226 (Bq/L)	Pb-210 (Bq/L)	Po-210 (Bq/L)
A00322	81.6 ± 3.5	78.9 ± 3.4	291 ± 12	13.4 ± 0.3	18 ± 3	0.8 ± 0.1
A00315	1.36 ± 0.06	1.36 ± 0.06	2.7 ± 0.1	0.406 ± 0.011	–	0.078 ± 0.003
A00324	4.95 ± 0.39	4.60 ± 0.39	20.9 ± 1.0	0.210 ± 0.006	–	–
A00330	1.31 ± 0.06	1.29 ± 0.06	0.86 ± 0.04	–	–	–

1 Analyses were performed by alpha-particle spectrometry at the eriss laboratories, using an acid digest of the sample.

2 Indicated errors are the estimated analytical uncertainties ( $1\sigma$ ) due to counting statistics. Other systematic and random errors are also present and are estimated to be of the order of 10% for Ra-226, and 3% for the other radionuclides.

The following dose assessment assumes an intake of 5 L of water similar to that of sample A00322 ('H') as a worst-case scenario, and an intake of 500 mL as a more realistic scenario. Dose conversion factors for ingestion by an adult, based on ICRP publication 72, have been used. This gives committed effective dose in  $\mu\text{Sv}$ .

The detailed results of the dose assessment are given in table 16. For the worst-case scenario of 5 L intake, the estimated committed effective dose is approximately 430  $\mu\text{Sv}$ , most of this being due to ingestion of Th-230. For the scenario of 500 mL intake, the dose is proportionally smaller at approximately 43  $\mu\text{Sv}$ . These doses are lower than either the work-related dose limit for a radiation worker of an average of 20 000  $\mu\text{Sv}$  per year, or the dose limit for a member of the public of 1000  $\mu\text{Sv}$  per year. The predicted doses for drinking of Jabiru East water are even lower due to its lower radionuclide concentrations (table 15). (Note that these samples were collected near the Jabiru East tank and water of this type was not consumed by members of the public.) It has been concluded, therefore, that these dose limits were not exceeded for either workers or members of the public who may have drunk water from either the Ranger site or from Jabiru East water supply on the day of the incident.

**Table 16** Worst case dose estimation for a worker at the Ranger mine, assuming an intake of 5 L or 500 mL of water with a radionuclide content similar to that of sample A00322 (table 15)

	Assumed concentration (Bq/L)	Dose conversion factor for intake ( $\mu\text{Sv/Bq}$ )	Committed Effective Dose for 5 L intake ( $\mu\text{Sv}$ )	Committed Effective Dose for 500 mL intake ( $\mu\text{Sv}$ )
U-238	81.6	0.045	18	1.8
U-234	78.9	0.049	19	1.9
Th-230	291	0.21	306	30.6
Ra-226	13.4	0.28	19	1.9
Pb-210	18	0.69	62	6.2
Po-210	0.8	1.2	5	0.5
Total			429	43

Dose conversion factors from ICRP 1996

Based upon these dose estimates we have concluded that the risks arising from radiation exposure of ERA staff and contractors who consumed contaminated water at the Ranger site on 23–24 March 2004 are very low and that long-term effects on their health would not be expected.

## 5.5 Conclusions on the risk to worker health

A detailed assessment has been carried out on the potential for adverse long-term health effects arising for workers at the Ranger mine who were exposed to contaminated water as a result of this incident. Such long-term effects could arise, in principle, as a result of chemical exposure and radiation exposure.

For radiation exposure, it has been concluded that, even under the worst-case scenario considered, the risks arising from radiation exposure of ERA staff and contractors who consumed contaminated water at the Ranger site on 23–24 March 2004 are very low and that long-term effects on their health would not be expected.

The risks to workers from chemical exposure were assessed by two different approaches. The first approach used risk assessment methods that combine information on the exposure of workers to chemicals in the Ranger incident with data on effects of such chemicals on human health in the medical and scientific literature to draw conclusions on the likely effects on people who were exposed to contaminated water. The second approach involved the measurement of a range of chemical and biological response indicators in samples of blood and urine from workers who were exposed to contaminated water and the expert medical assessment of the results to assess the likelihood of adverse long-term effects.

These two different approaches were adopted in two separate investigations. One investigation was carried out for ERA by the Rio Tinto occupational physician from the UK, assisted by a consultant toxicologist retained by ERA. The second investigation was carried out for the Supervising Scientist by a group of experts in the Australian Centre for Human Health Risk Assessment (ACHHRA) and the National Centre for Environmental Toxicology (EnTox). While the two investigations were independent and produced separate reports, they used common data sets (for example chemical data sets on the extent of water contamination and health testing analyses of blood and urine) provided by ERA and SSD as appropriate.

The principal conclusions of both investigations, supported by both the risk assessment and the medical assessment methods, were that:

- The short-term (or acute) effects that were reported by some exposed workers, skin irritation and/or gastrointestinal distress, were consistent with effects that would be expected from contact with water that was slightly acidic and that contained relatively high concentrations of the metals present in process water at Ranger; and
- It is most unlikely that there will be any longer-term or delayed health effects on target organs such as the brain, liver and kidney because of the brief period of exposure to the contaminated water.

Both the ERA and the SSD reports, however, adopted a precautionary approach to their conclusions.

Firstly, both reports noted that some clinical chemistry values were marginally above the normal range. In particular, kidney function tests for three individual workers showed slightly elevated results in the first set of tests and it was recommended that, on the basis of discussion between individual workers and their medical professionals, these tests could be repeated after 3–6 months.

Second, both reports noted that, even although longer-term or delayed effects are considered to be most unlikely, they cannot be completely ruled out. For this reason, both reports state that a more extensive longer-term monitoring program should be considered for the exposed workers.

The ERA report recommends a voluntary monitoring program consisting of:

- A specified blood and urine sampling and analysis program; and
- Subject to further assessment by a consultant neurotoxicologist, Magnetic Resonance Imaging (MRI) scans to be conducted for manganese and aluminium levels for workers with high potential or reported exposures.

The SSD report canvassed the use of some possible biomarkers relating to renal effects and neurotoxicity but it cautioned that the results of such tests might be difficult to interpret on an individual basis. In particular, MRI scans for manganese and aluminium were not recommended in the SSD report because such tests may only be useful in showing deposition of these metals at selected sites in the brain and the significance of such deposition may be difficult to interpret on an individual basis. For these reasons, the SSD report recommends that any decision to engage in a follow-up testing of individual workers should be made by their doctors and should be based upon their individual medical histories and factors such as their level of concern and the need for reassurance relating to the Ranger water contamination incident.

It is the Supervising Scientist's view that the precautionary approach recommended in both medical risk assessment reports should be adopted. ERA should provide copies of both health assessment reports to affected workers, should counsel these workers to seek advice from their doctors on whether or not they should take part in the proposed voluntary monitoring program recommended in the ERA report and should facilitate the implementation of this program for those workers who choose to participate, including the provision of the advice of an independent consultant neurotoxicologist. When the results of the program become available, they should be assessed by both the Rio Tinto occupational physician and the Supervising Scientist's independent expert group and these assessments should be provided to the affected workers and their doctors.

## **6 Environmental impact investigation**

Impact on the environment as a result of the potable water contamination incident could have arisen in two ways. First, water which overflowed from the tank at Jabiru East moved towards Magela Creek and could have affected downstream ecosystems. This issue is addressed in sections 6.1 through modelling and in 6.2 through examination of monitoring data. Second, contaminated potable water at the minesite could have entered the external environment following its use in amenities (sinks, toilets, showers etc). This issue is assessed in section 6.3.

### **6.1 Assessment of environmental impact using modelling – Jabiru East discharge**

#### **6.1.1 Summary of environmental investigations conducted in the vicinity of the Jabiru East Tank Area**

Physico-chemical measurements of surface waters in the vicinity of the Jabiru East Tank Area were collected by both ERA and Supervising Scientist staff. A chronological sequence of events and the main findings are described below.

##### *Chronology of events*

On the morning of 24 March, the tank overflowed to the environment adjacent to and beyond the tank (details of the volume and duration of the overflow are discussed in section 6.1.2).

Staff of the Supervising Scientist were informed of the full extent of this overflow by ERA staff on 25 March.

On 25 March, unaware that the tank had overflowed beyond the drainage system of the tank, staff of the Supervising Scientist commenced an investigation to determine the extent of the contaminated plume in the tank's reticulation system (refer to Section 3.4.2). SSD staff measured the EC and pH of water in a concrete drain near the base of the tank, confirming the presence in the drain of contaminated water (sample A00330 Appendix 1A). SSD staff then followed the potential drainage path toward the creek but did not find evidence of contaminated water away from the tank.

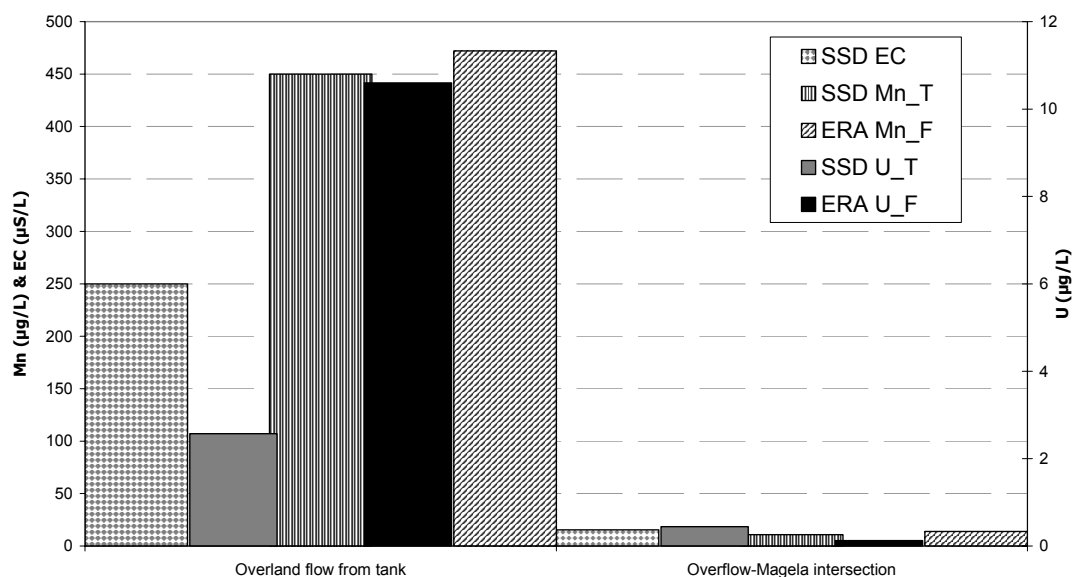
Heavy rain occurred during the night of 25 March causing overland flow of contaminated water between the tank and the creek on 26 March.

On 26 March SSD and ERA staff measured general *in situ* water quality parameters and collected samples of overland flow water from sites between the tank and Magela Creek (ERA samples were collected several hours earlier than the SSD samples). These samples were analysed for uranium and the relevant inorganic components of the Drinking Water Suite of analytes (results contained in Appendix 1C).

On 27 March, when conditions allowed, ERA and SSD collected soil samples from the area between the tank and Magela Creek. ERA collected 27 samples in a transect between the tank and the creek.

#### *Attenuation of contaminants between the tank and creek*

Dilution from heavy rains and standing water, as well as chemical/physical processes, decreased the concentration of contaminants in the overflow water on its passage to the creek. The change in EC measurements and manganese and uranium concentrations between the tank and the edge of Magela Creek is shown in figure 8.



**Figure 8** Concentration changes of key process water indicators between the Jabiru East tank and Magela Creek on 26<sup>th</sup> March (SSD and ERA data)

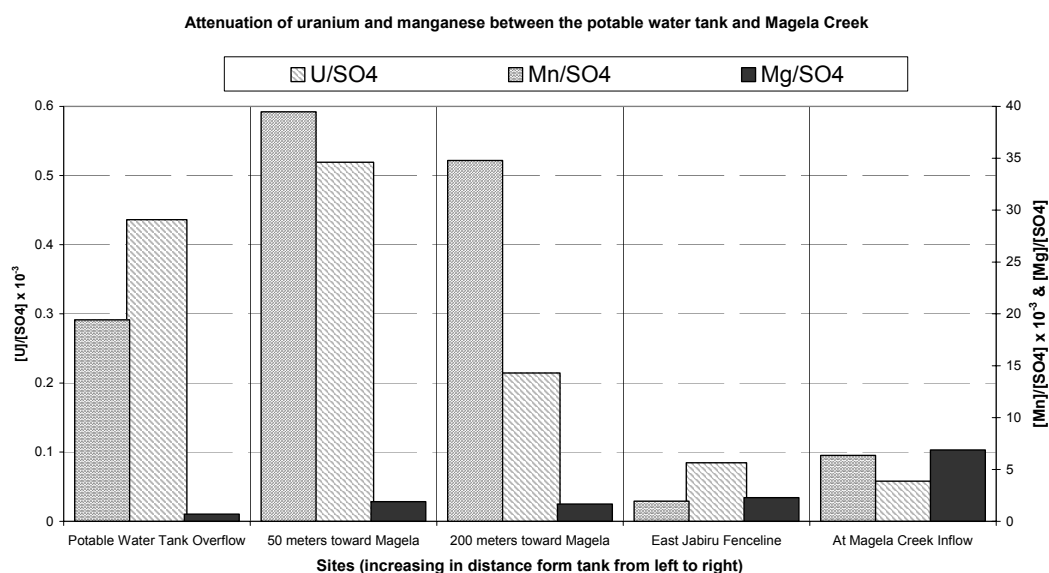
While ERA data are higher than SSD data<sup>6</sup> for some parameters, the same trend of decreasing contaminant concentration towards the creek can be seen.

The decrease in EC (from 250  $\mu\text{S}/\text{cm}$  to 15.4  $\mu\text{S}/\text{cm}$ ) between the overland flow and at the intersection of the potential route of overland flow with Magela Creek indicates that the process water that overflowed from the tank was highly diluted by the time it reached Magela Creek. An even larger reduction in metal concentrations occurred between the tank and the creek; ~99% for uranium and ~97% for manganese.

Attenuation of the metals is evidenced by the ratios of metal and sulfate concentrations. Figure 9 shows that relative to sulfate, the heavy metals uranium and manganese were greatly reduced (by 80–90%) before the overland flow reached the creek. Sulfate remains in solution and generally only decreases through dilution, whereas metals are removed from the water through reactions such as adsorption to, and formation of, particulates that settle out of the water column and by adsorption to soils. Results of ERA's soil analyses show that of the 27 sites sampled, only the site close to the tank had an excess of uranium compared to background levels (see Jones et al in Appendix 6 of the ERA Investigation Report: Appendix 5 to this report). This also indicates that attenuation of the metals occurred mostly within a short distance from the tank.

### 6.1.2 Modelling of environmental impact

It was concluded in section 3.4.2 that the water quality in the Jabiru East tank on 24 March 2004 when the tank was overflowing to Magela Creek can not be reliably determined from the measurements taken on that date. For example, the uranium concentration on 25 March, the day after the incident, was about 460 ppb but the concentration could have been greater on 24 March. For this reason it has been necessary to model a worst case scenario for concentrations in the tank during the period of overflow.



**Figure 9** Changes in metal to sulfate ratios indicating the attenuation of metals along a transect between the Jabiru East tank and Magela Creek (ERA data)

The Jabiru East tank is used as an emergency storage for water in case of supply interruptions from the mine or for use in fire fighting. The tank is maintained full and holds approximately

<sup>6</sup> The ERA results are for a sample closer to the tank than the SSD 'overland flow' sample.



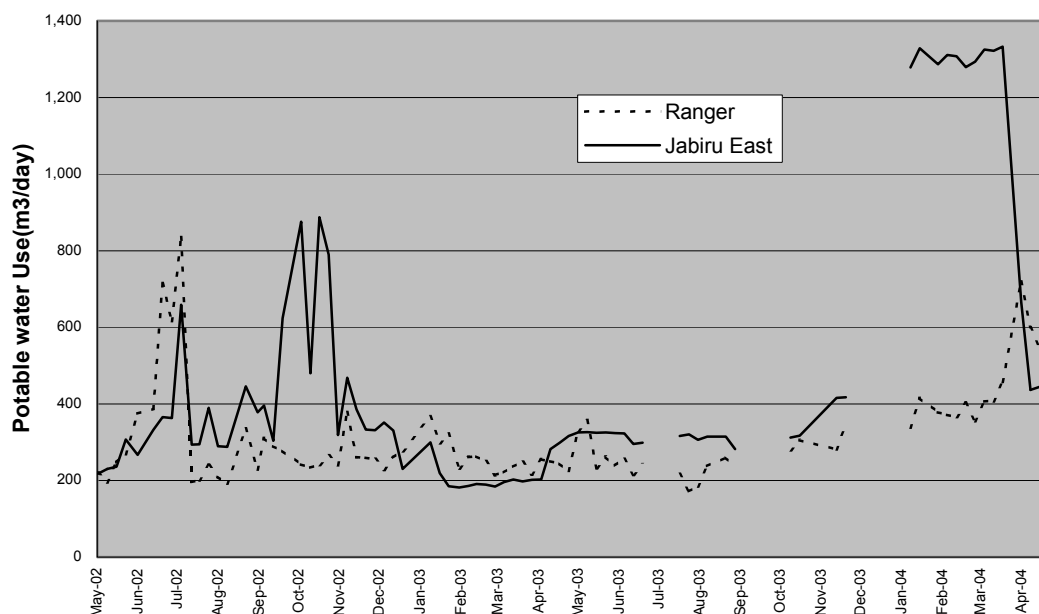
1.2 ML. Supply to the tank is taken via an off-take from the Jabiru East line via a pressure relief valve that is normally set to maintain equal pressure in the Jabiru East line. On the night of the incident this valve was leaking, subsequently overfilling the tank and causing water to flow from the tank overflow pipes, uncontained, towards Magela Creek.

According to flow meter readings taken by ERA (figure 10), the usage of water along the Jabiru East line had been high since at least January 2004 indicating that the valve had been leaking for some time. Analysis of these data indicates a continual leak over the period of 7 January 2004 until the morning of the incident when the line was closed (24 March 2004). From the data in figure 10, calculated losses vary between 11.3 L/s and 12 L/s over this period. There were no flow data readings taken during the week of the incident or on the night of the incident so an actual value of discharge from the tank during the incident cannot be determined.

The fact that such a large potable water usage had been metered, the data recorded by ERA staff and yet the large discrepancy was not noticed, or if noticed, not acted upon is of concern, and highlights a potential issue with the management of such data.

When ERA staff discovered the overflow, the discharge rate was estimated to be approximately 8 L/s. This however was at least 1.5 hours after the supply to Jabiru East had been shut off. At this point in time there would have been no flow into the tank so the 8 L/s would have been an under estimate of the flow from the tank during the period of the incident.

Based on the volumes used on site, and an estimation of flow into the Jabiru East tank once the system was turned back on, the supply to Jabiru East has been estimated to have been closer to 18 L/s. Apart from a small amount used for irrigation at the Jabiru Field Station, the remainder would have entered the Jabiru East tank and would have subsequently discharged via the overflow pipe at the same rate. The figure of 18 L/s is higher than historical data indicates but it has been adopted for the purposes of modelling to ensure conservatism. Given the extra pressure added to the potable system due to the connection of the process line during the incident, it is likely that the true leak rate on the night of the incident lies somewhere between 12 L/s and 18 L/s.



**Figure 10** Historical potable water usage on site (Ranger) and Jabiru East (data collected by ERA and provided by DBIRD)



**Figure 11** Jabiru East Potable Water Tank – overflow pipes and concrete drain

The volume of the supply line to Jabiru East is approximately 135 m<sup>3</sup>. At a rate of 18 L/s, water from site during the incident would have reached the Jabiru East tanks in 2 hours.

On site, the volume of pipe work from the contamination point to the Jabiru East off take is approximately 2.4 m<sup>3</sup>. At a demand rate of 18 L/s from the Jabiru East line, water could have travelled from the contamination point to the Jabiru East off take in 2.5 minutes which is insignificant compared to the time taken to travel to Jabiru East. It can, therefore, be assumed that contaminated water potentially reached the Jabiru East tanks 2 hours after the start of the incident.

Water discharging from the tanks is assumed to have travelled down a path and entered Magela Creek just downstream of Coonjimba billabong. Inspections of this path following the incident have shown the presence of wetland vegetation suggesting that the leak from the tank has probably occurred for some time. The presence of this wetland vegetation would have aided the attenuation of contamination discharged from the tank. Measurements reported in the previous section indicated that about 80 - 90% of the metals would have been attenuated along this path.

Using the following assumptions, a worst case has been modelled of the potential discharge of contaminants to the environment via the leak at the Jabiru East tank.

- Time taken for contaminated water to reach the Jabiru East tanks – 2.3 hours;
- Contamination of the Jabiru East tank is homogeneous;
- The worst case concentration of water heading to Jabiru East is based on a contamination rate of 2.5 L/s and a flow rate to Jabiru East of 18 L/s. This assumes that all of the process water entering the potable water system travelled directly to the Jabiru East tanks which is a highly conservative assumption;

- Duration of the contamination event on site is approximately 10.25 hours prior to the Jabiru East line being shut off;
- Volume of water in the Jabiru East tank – 1.2 ML (1200 m<sup>3</sup>);
- There was no attenuation of contaminants prior to entering Magela Creek; and
- The flow in Magela Creek at 8.15 am on 24 March was approximately 10.7 m<sup>3</sup>/s.

Using these conservative assumptions, the concentrations of a range of process water constituents have been calculated. The results are presented in table 17. The results indicate that, of all the constituents listed in the table, only Mn, U and possibly Cu could have been present in Magela Creek at concentrations that would be measurable above background.

**Table 17** Modelling of concentrations in the Jabiru East Tank and Magela Creek due to contamination of potable water supply under a worst case scenario

Analyte	Units	Typical # Process Water	Supply to tank Concentration	Leak from tank Concentration	Magela Concentration
Ca	mg/L	460	57.5	34.9	0.060
Mg	mg/L	3190	398.	168.	0.284
SO <sub>4</sub>	mg/L	20070	2508.	901.	1.52
Al	µg/L	423000	52800	18100	32.0
As	µg/L	100	12.5	4.48	0.01
B	µg/L	1760	220	78.88	0.13
Be	µg/L	99	12.3	4.44	0.01
Br	µg/L	564	70.5	47.09	0.08
Cd	µg/L	23.2	2.9	1.17	0.00
Cr	µg/L	320	40	14.34	0.02
Cu	µg/L	22500	28100	1008	1.70
Fe	µg/L	6480	810	290.	0.49
I	µg/L	70	8.75	3.14	0.01
Mn	µg/L	1630000	204000.	73050	123
Ni	µg/L	4690	586.	210.	0.35
Pb	µg/L	3970	496.	177.	0.30
Se	µg/L	398	49.7	17.8	0.03
U	µg/L	24000	3000	1070	1.80
Zn	µg/L	5750	718.	347.50	0.59

# Sample of process water provided by ERA . Job number EL03471

The predicted maximum concentration of U, 1.8 µg/L, is below the ecological limit for uranium in Magela Creek, 5.8 µg/L, and would not be expected to give rise to any significant biological effects. The Australian Drinking Water Guideline for uranium is 20 µg/L. The maximum total load of uranium that could have entered the Creek under this scenario is about 0.07 kg. This value is very low compared to the Additional Annual Load Limit of uranium of about 3.6 t/year allowed into Magela Creek under the Authorisation. If, however, we use the assumption that 80–90% of metal contamination is attenuated along the path to Magela Creek (see previous section), the concentration of uranium in the creek would have been approximately 0.2–0.4 µg/L and 0.06 kg of uranium could have been attenuated along the path to the creek.

The limit for Mn in Magela Creek, based only on the statistical distribution of naturally occurring concentrations, is 32 µg/L and this concentration would have been exceeded under the worst case scenario modelled above which gives a Mn concentration in Magela Creek of about 120 µg/L. This issue will be addressed in the next section on monitoring results but it should be noted that, as shown in figure 9, attenuation of metals, including manganese, during overland flow towards the Magela Creek was observed to be about 80–90%. Such attenuation would have reduced the predicted increase in manganese concentrations to a value that is within the natural range. In addition, the Australian Drinking Water Guideline for manganese is 500 µg/L and the ecological guideline in the Water Quality Guidelines for Australia and New Zealand is 1200 µg/L.

The worst case prediction for the Cu concentration in Magela Creek is about 1.7 µg/L. However, it is known that Cu speciation is pH dependent and it was observed that the ratio of Cu to SO<sub>4</sub> is lower in water at the Jabiru East Tank by a factor of about 5 compared to the same ratio in process water. This reduction would reduce the maximum predicted concentration of Cu in Magela Creek to background values.

In conclusion, even using the worst case scenario, we would conclude that environmental impact downstream from the Ranger mine would not be expected.

## **6.2 Assessment of environmental impact using monitoring – Jabiru East discharge**

### **6.2.1 Monitoring programs conducted**

As part of its routine surface water quality monitoring program, the SSD had in place:

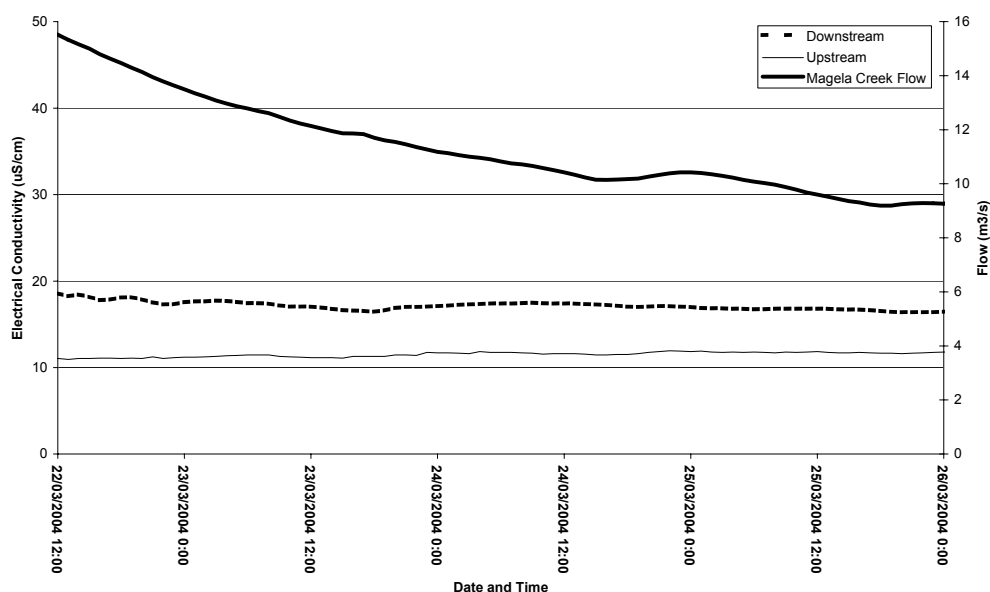
- Biological (creekside) monitoring upstream and downstream of the mine spanning the period two days prior to the incident and a further eight days of continuous testing and exposure of test fish and snail species;
- At the Magela Creek creekside monitoring stations, both upstream and downstream of the Ranger mine, dataloggers were deployed in tanks holding creek water. Measurements of pH, EC, temperature and dissolved oxygen were made half hourly over a four day period from the Monday prior to the incident; and
- Routine water samples for chemistry measurements were collected on the morning of Tuesday 23 March (one day prior to the incident). Commencing on Thursday 25 March 2004, SSD collected daily water samples from the Magela Creek monitoring sites for a week and also from Mudginberri Billabong. The total and filterable portions of those samples were analysed for the relevant inorganic components of the Drinking Water Suite of analytes and uranium (results for the filterable<sup>7</sup> fraction are given in Appendix 1C).

### **6.2.2 Chemical monitoring**

The half hourly measurements of electrical conductivity obtained using the dataloggers in the tanks at the creekside monitoring stations are shown in figure 12 together with the hydrograph obtained for the upstream site.

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<sup>7</sup> The filterable fraction is considered because (i) it can be compared to the routine monitoring and historic data, and (ii) it is generally considered to represent the bioavailable fraction



**Figure 12** Electrical conductivity measurements at the downstream and upstream creekside monitoring station header tanks and hydrograph from Magela Creek at the upstream site

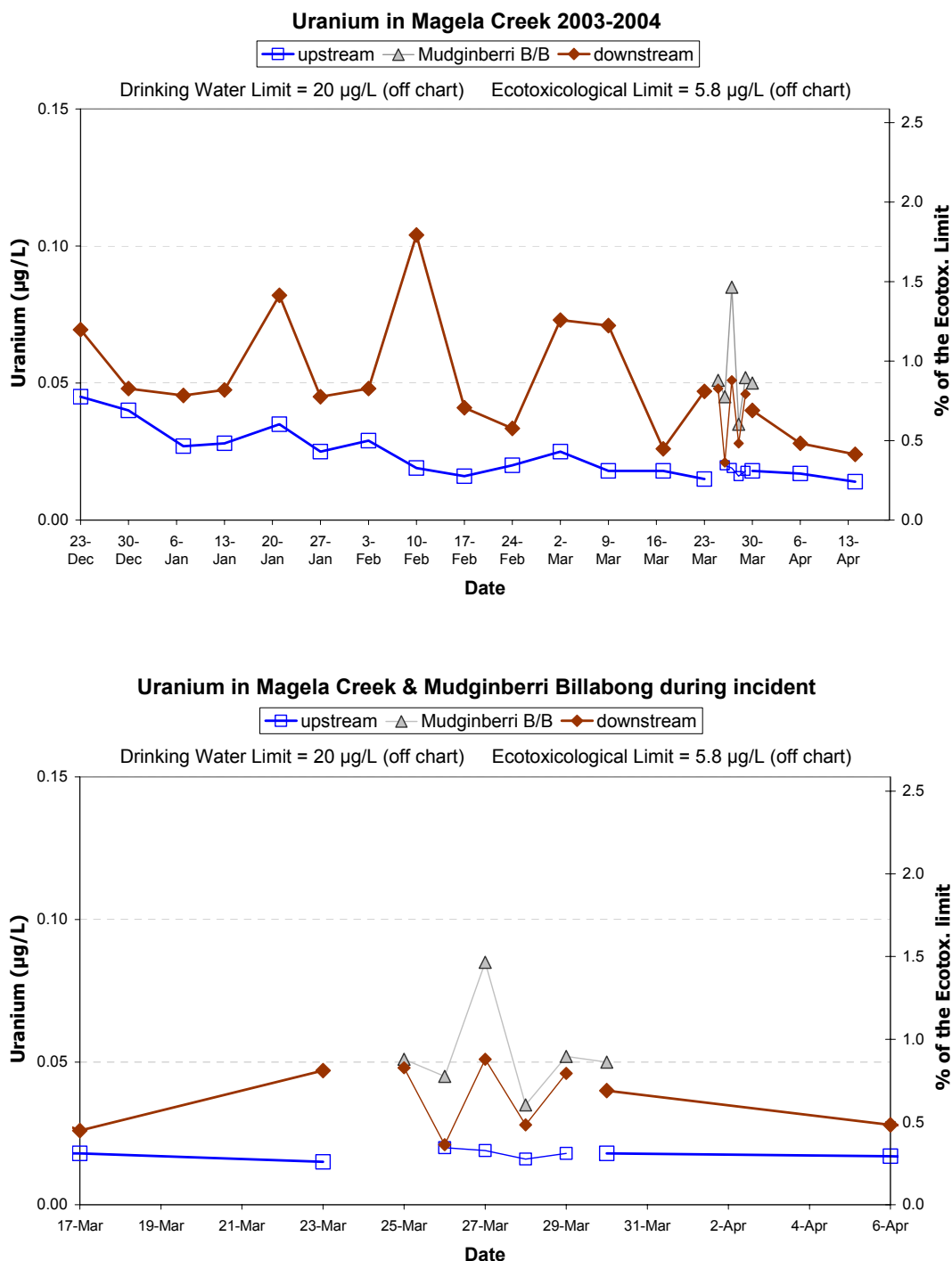
These measurements span the entire period from 22 March (before the incident) until 26 March (3 days after the incident). Since process water has electrical conductivity of about 20 000 µS/cm, these measurements should be a sensitive indicator of any contamination from the Jabiru East tank entering Magela Creek. The data show that the electrical conductivity remained constant at the downstream site throughout the period of the incident and that there is no evidence of contaminated water at the downstream site. The small difference in EC between the upstream and downstream sites is typical of historical behaviour at these sites.

The results obtained for uranium and manganese in daily water samples will be discussed below. There were, however, no samples collected from the creek on 24 March. The conductivity data shown in figure 12 for the downstream site can be used to estimate the maximum uranium and manganese concentrations that could have occurred in the creek during the period of overflow of the Jabiru East tank on 24 March.

It is clear from figure 12 that an increase in conductivity of about 2 µS/cm on 24 March could have been detected. Using the results obtained for conductivity, uranium and manganese in process water (20 000 µS/cm, 24 mg/L, and 1600 mg/L respectively) and assuming that uranium and manganese behave conservatively, the maximum undetected concentrations at the downstream site would have been 2.4 µg/L and 160 µg/L respectively for an increase in conductivity of 2 µS/cm. However, the data for uranium, manganese and sulfate in process water and the Jabiru East Tank overflow show that uranium and manganese were attenuated by factors of 0.4 and 0.6 respectively between the mine site and Jabiru East. In addition, the data in figure 9 show further attenuation factors for uranium and manganese of about 0.1–0.2 during overland flow. From these data it can be estimated that the maximum undetected increase in the concentrations of uranium and manganese in Magela creek downstream from the Ranger mine on 24 March would have been about 0.2 µg/L and 20 µg/L respectively.

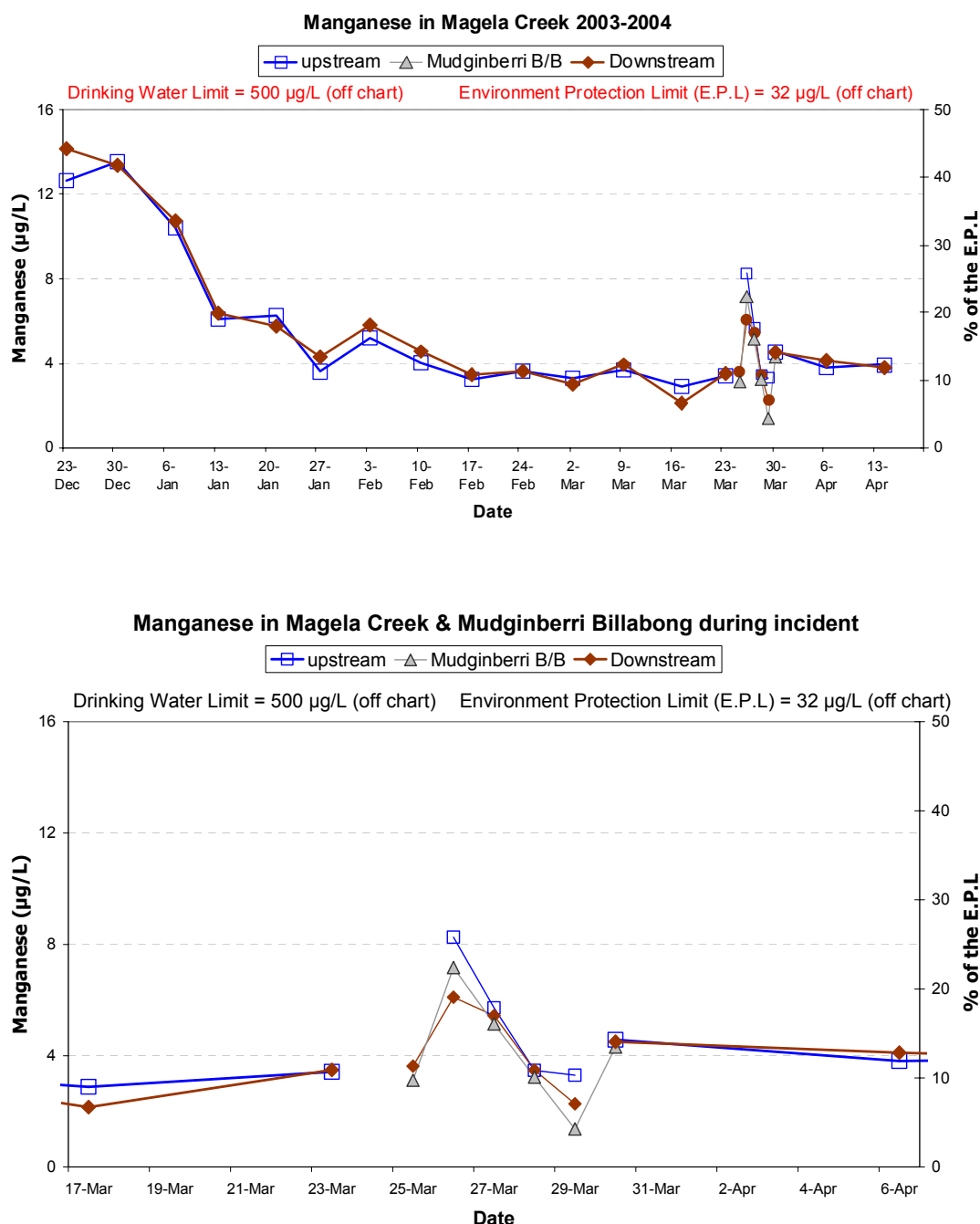
Uranium concentrations measured in both Magela Creek and Mudginberri Billabong during the incident are shown in figure 13 and these are compared with concentrations observed upstream, with the compliance limit and with values measured in Magela Creek in the Supervising Scientist's routine monitoring program. A pair of charts is shown. In the upper chart, data from the beginning of the 2003–04 wet season are shown while in the lower chart

only the daily data and that from two weeks either side of the incident are shown. The data show that uranium concentrations at the downstream sites during the period of the incident were typical of such concentrations throughout the wet season and that no detectable change occurred during the period of the incident. The maximum concentration of uranium at the downstream compliance point during the incident was lower than the uranium compliance limit by about a factor of one hundred.



**Figure 13** Time series charts of uranium concentrations at the routine monitoring sites on Magela Creek and at Mudginberri Billabong. The upper chart shows data for the 2003–04 wet season, the lower chart shows the period of the incident expanded.

The corresponding data for manganese, a major constituent of process water, are shown in figure 14. On first inspection, it seems that a small increase in manganese concentration occurred at both the downstream compliance point and at Mudginberri Billabong during the period of the incident. However, the same small increase (about 4  $\mu\text{g/L}$ ) was observed at the upstream site and the increase was probably a natural occurrence. In any case, these concentrations are significantly below the manganese compliance limit of 32  $\mu\text{g/L}$  and also lower than the concentrations observed typically each year in the early stages of the wet season (see upper chart in figure 14).



**Figure 14** Time series charts of manganese concentrations at the routine monitoring sites on Magela Creek and at Mudginberri Billabong. The upper chart shows data for the 2003–04 wet season, the lower chart shows the period of the incident expanded.

In addition to the above data for uranium and manganese, monitoring data for pH, conductivity, sulfate and copper are shown in Appendix 4 for the upstream and downstream monitoring points and for Mudginberri Billabong. For all of these parameters, the data for the downstream monitoring point are completely consistent with normal behaviour at this point.

The data for Mudginberri Billabong are consistent with the corresponding data at the downstream monitoring point with the exception of copper on 27 March 2004 where a result of about 0.8µg/L was obtained. This result occurred three days after the incident and one day after a major storm had produced a flow in the Magela Creek of about 220m<sup>3</sup>/s. Hence, it is considered highly unlikely that the elevated copper result on 27 March in Mudginberri Billabong was related to the contamination incident and the value recorded on that date is not far outside the normal range for Magela Creek.

In summary, all of the chemical analyses of water samples obtained during the period of the incident demonstrate that no significant change occurred in the chemistry of Magela Creek downstream from the Ranger mine as a result of the incident and, therefore, that it is highly unlikely that the incident gave rise to any harm to downstream ecosystems.

### 6.2.3 Biological monitoring

The routine biological monitoring program conducted by the Supervising Scientist in the vicinity of the Ranger mine has two principal components. Assessment of the conservation of biological diversity is carried out by measurements on the structure of communities of fish and macroinvertebrates. Early warning of potential adverse effects is obtained using Creekside monitoring techniques. The results of community structure measurements downstream from Ranger in the 2003–04 wet season are not yet available but the results for Creekside monitoring are rapidly available.

In Creekside monitoring, the effects of waters discharged from the mine are assessed using responses of aquatic animals held in tanks on the creek side. The responses of two test species are measured over a four-day period:

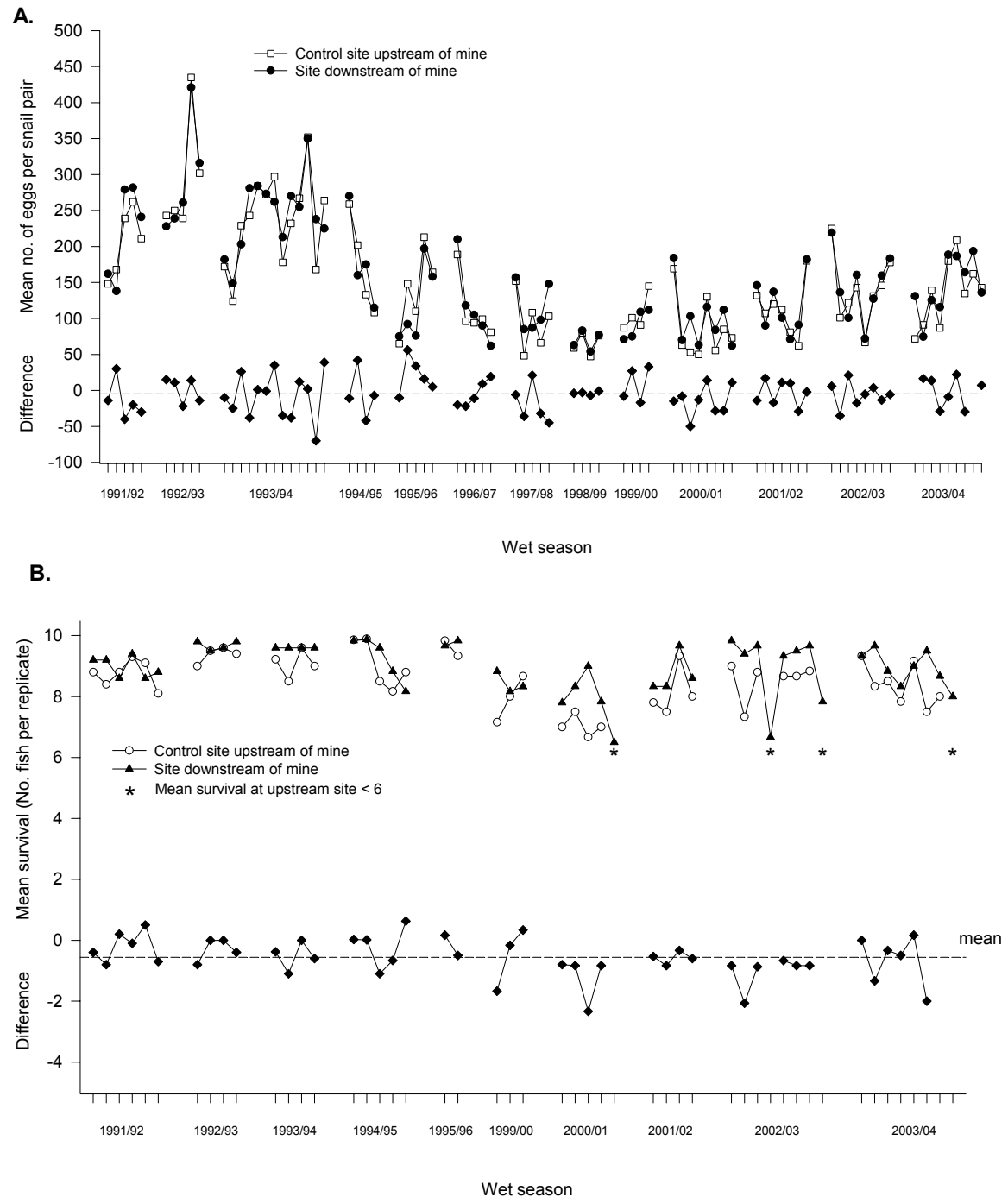
- Reproduction (egg production) in the freshwater snail, *Amerianna cumingi*, and
- Survival of black-banded rainbowfish, *Melanotaenia nigrans*, larvae.

Animals are exposed to a continuous flow of water pumped from upstream of the mine site (control site) and from the creek at gauging station GS8210009, some 5 km downstream of the mine. At the end of each four-day trial, the mean number of eggs per snail pair and mean number of fish surviving per replicate, are noted and compared for each of the upstream and downstream sites. Specifically, when data from the upstream site are subtracted from those at the downstream site, a set of ‘difference’ values can be derived. These difference values may be compared statistically for different parts of the time-series. For example, ‘difference’ data for the wet season of interest may be compared with those from previous years; if they differ significantly, using a Student’s *t* test, it may indicate a mine-related change. Since about 1996, creekside trials have been performed approximately every other week during the Wet season. Trials usually commence in December and cease in early April, the period of significant creek flow in Magela Creek.

The results of the creekside trials are plotted as part of a continuous time series of actual and ‘difference’ data in figure 15(A) for snail egg production, and in figure 15(B) for larval fish survival. Eight creekside tests were conducted in the 2003–04 wet season for snails, and seven for larval fish (there being too few fish larvae available to conduct a final, eighth test). The seventh test, using both test species, was conducted in the period 22–26 March 2004, coinciding with the drinking water incident. After results were acquired for this (seventh)



creekside test, it was extended for an additional 4-day period, 26–30 March, using the same test organisms (fish and snails). (This test is termed the ‘seventh-extended test’; the results of this test are depicted in figure 15 as the eighth set of actual data counts for the Wet season, while the results of the eighth snail test are depicted as the ninth set of such data points.) For the seventh-extended snail test, fresh egg-laying chambers were used (containing none of the previously-laid egg masses). Because the same test animals were employed in both tests, neither fish nor snail results for this extended period are strictly valid for a statistical comparison against other test results as there is lack of independence. Nevertheless, the results are certainly indicative of any potential water quality impacts.



**Figure 15** Creekside monitoring results for: A. freshwater snail egg production, and B. larval black-banded rainbowfish survival, for Wet seasons between 1992 and 2004

Snail egg production at upstream and downstream sites was very similar across all tests (figure 15A). Using the data shown in figure 15, 'difference' values for 2003–04 were compared with those from previous years. (The difference data shown and subsequently used in statistical analyses are those for valid tests only.) No significant difference was found ( $P>0.05$ ). The results for the seventh-extended test, while not included in the formal statistical analysis, lie well within the range of variability observed in other tests for the current and previous years (figure 15A).

There was a lack of fish larvae in the seventh creekside test with which to run a valid test so that only 3 replicate fish tanks, each holding 10 fish larvae, could be used at each of the two creekside stations instead of the normal 6 replicate tanks. While results for fish larvae arising from the seventh and 'seventh-extended' test are plotted, the 'difference' values for both tests, by convention, are not plotted to signify their invalid nature (figure 15B). Fish survival was found to be consistently high at the downstream site over the 8-day period of both consecutive tests. Poor larval fish survival at the upstream site is not uncommon (see results for seventh-extended test, figure 15B), an issue that has been addressed elsewhere (Supervising Scientist Annual Report, 2002–2003).

From these results, it is concluded that there were no adverse effects of mine waste waters on the snail test species over any period of the 2003–04 wet season, nor was there any evidence that fish larvae exposed to downstream waters were adversely affected during and immediately after the drinking water incident.

### 6.3 Assessment of environmental impact from amenities use at Ranger

Both grey water (such as hand basins and showers) and black water from the mine site is pumped to a macerator and then treated through filtration pits/beds located next to the coarse ore stockpile. These beds then discharge through groundwater in the general direction of Pit 1. Any contamination borne through the use of potable water in amenities through the minesite would have subsequently ending up in groundwater adjacent to Pit 1 or would have entered Pit 1 through seepage.

Based on information gained from employees on shift during the night of the incident and using the following conservative assumptions, modelling of worst case total contaminant load to the grey and black water systems were calculated:

- 144 employees washed their hands twice over the period of the incident;
- Each hand wash used 0.5 L/s and lasted 10 seconds;
- 144 employees went to the toilet twice over the period of the incident;
- Each use of the toilet resulted in 15 L moving into and out of the toilet cistern;
- A total of 24 showers were taken lasting 300 seconds each and using 0.5 L/s;
- A total of 131 L of water were consumed during the shift; and
- All water consumed was pure process water (a very conservative assumption) which has a uranium concentration of 24000 ppb.

These assumptions resulted in approximately 10 m<sup>3</sup> of potable water being used for amenities purposes. Using this estimate and assuming that all water used ended up in either the grey or black water systems, both of which report to the macerator and subsequently the filtration beds and potentially Pit 1 through seepage, approximately 0.22 kg of uranium was discharged from the amenities during the incident.

As the discharge is in the direction of Pit 1 and all assumptions were conservative, it is clear that there would have been no impact on the environment due to amenities use.

#### **6.4 Assessment of need for rehabilitation at Jabiru East**

Since the overflow of the tank at Jabiru East gave rise to increased concentrations of some constituents, for example uranium and manganese, in the soils in the vicinity of the tank, it is appropriate to consider whether or not remedial action is required at this site.

From the modelling in Section 6.2 it can be seen that under the worst case scenario approximately 0.07 kg of uranium spilled from the tank at Jabiru East of which 0.06 kg could have been attenuated overland using the assumption of 90% contaminant attenuation. If we assume that flow to Magela Creek overland was approximately 20 cm wide for approximately 600 m to the creek, and attenuation was in the first 5 cm of soil and was linear for the length of the discharge to the creek, a worst case additional load of 3.3 µg/kg of uranium in the soil could be expected over the period of the incident.

In reality the load applied overland on the path to Magela creek would be significantly less and as the attenuation would occur mainly within the vicinity of the tank, rather than linearly along the path to the creek, the only potential area that could be considered for rehabilitation would be the area in the immediate vicinity of the tank where wetland vegetation is evident

EWLS conducted a detailed soil survey on behalf of ERA between the tank and the Magela Creek along, and perpendicular to, the flowpath. The results are presented in Appendix 6 of the ERA Investigation Report (Appendix 5 to this report). The results obtained for uranium in this survey show that, with one exception, all concentrations were in the range 1 – 7 mg per kg dry weight which is typical of the natural range of uranium concentrations in similar soils of the region. One sample recorded a uranium concentration of about 30 mg per kg dry weight.

In these circumstances, it is not considered necessary to take any rehabilitation action at the site.

#### **6.5 Conclusions on environmental Impact**

Two approaches have been adopted in assessing the potential impact on the downstream environment of Kakadu National Park arising from the discharge of contaminated water from the water storage tank at Jabiru East on 24 March 2004.

The first approach was based upon modelling of the flow of contaminated water from the mine site to the Jabiru East tank, mixing in the tank, and overflow from the tank towards the Magela Creek. The model used very conservative assumptions and represented a worst case scenario. The results indicated that, of all the constituents present in process water, only manganese, uranium and possibly copper could have been present in Magela Creek at concentrations that would be measurable above background. Taking into account the measured attenuation of metals during overland flow towards Magela Creek, we have concluded that environmental impact downstream from the Ranger mine would not be expected.

The second approach was based upon assessment of a range of monitoring data. These included data from the Supervising Scientist's routine biological and chemical monitoring programs conducted in the vicinity of the Ranger mine, including continuous monitoring of electrical conductivity, as well as additional sampling conducted as part of this investigation. Assessment of all the chemical analyses of water samples obtained during the period of the incident demonstrate that no significant change occurred in the chemistry of Magela Creek downstream from the Ranger mine as a result of the incident. The creekside biological monitoring program using fish and freshwater snails was underway throughout the week in which the incident

occurred. No change was observed in fish larval survival or snail reproduction at the monitoring site downstream from the mine compared to results obtained upstream.

Based on all of these data, the overall conclusion has been drawn that the potable water contamination incident should not have given rise to any impact on the ecosystems of Kakadu National Park and that there should be no impact on the health of people who consume water or food from the creek or billabongs downstream from the mine.

We have also concluded that there is no immediate need for rehabilitation of soils in the vicinity of the tank at Jabitu East. The longer term requirement for soil rehabilitation should be addressed during the minesite rehabilitation stage through the site-wide assessment of contamination levels.

## **7 Conclusions and recommendations**

### **7.1 Causes of the potable water contamination incident**

This investigation has concluded that the primary cause of the contamination of the potable water system at the Ranger mine in March 2004 was that an operator, at about 9.40 pm on 23 March, opened a valve connecting the water manifold at the Fine Ore Bin Scrubber to a one inch hose. At the time of this connection, the manifold was also connected to the process water system. Unknown to this operator, the other end of the one inch hose was connected to the potable water system and the valve at that end of the hose was open. The higher pressure in the process water system caused water to flow from the process water system into the potable water supply system.

It has not been possible to determine when, or by whom, the valve at the potable water end of the hose was opened. Nor has it been possible to determine precisely when the hose was connected to the potable water system but it occurred some time between 11.45 am on 20 March 2004 and 6.30 pm on 23 March 2004.

We have concluded that supplementing the process water supply to the FOB scrubber with potable water (that is, simultaneous supply of process water and potable water to the scrubber) has probably not occurred in the past, is not a standard ERA procedure and is not a practice knowingly adopted by any ERA operators. However, it is likely that a hose has been connected between the FOB scrubber and the potable water hosepoint in the past and that, contrary to ERA stated policy, potable water may have been used by some staff to supply water to the FOB scrubber when process water was unavailable.

ERA has undertaken a Root Cause Analysis of the incident. This analysis concluded that the primary conditions that enabled the incident to occur were:

- The existence of the same type of connectors, albeit of different size, on the process and potable water systems;
- The lack of a system for early warning of contamination in the potable water system; and
- The absence of non-return valves in the potable water system.

The Supervising Scientist agrees with these conclusions.

In discussions and correspondence with the Supervising Scientist and DBIRD during the period leading up to recommencement of operations at Ranger, ERA made commitments to address these issues. These commitments have been incorporated in ERA's Investigation Report on the incident.

It is, however, possible that the loss of corporate knowledge or the failure of equipment in the future could lead to a situation where these commitments are not being adequately implemented unless they are made requirements of the company under legislation.

**Recommendation 1:**

*The Commonwealth Minister for Industry, Tourism and Resources should advise the Northern Territory Minister for Mines and Energy that ERA should be required, either through approval of an appropriately submitted Mining Management Plan for the Ranger mine or by required revisions to such a Plan, to:*

- a) Ensure that the fittings used throughout the Ranger potable water system should always remain incompatible with all other fittings used on the site to prevent the connection of the potable water system to any other system.*
- b) Install a water contamination probe within the Ranger potable water system. The probe should measure electrical conductivity and acidity continuously and should trigger an alarm alerting operators if the value of either of these variables changes significantly from pre-set values.*
- c) Install non-return valves at points in the potable water system where connections may be made to other water systems. A risk analysis of the potable, process and pond water systems should be used to determine where non-return valves are required.*

It is a conclusion of this investigation, however, that the causes of the incident go beyond the above root causes identified in the ERA Investigation Report. It is the Supervising Scientist's view that the underlying cause of the incident was the poor condition of the process water distribution system at Ranger.

During the conduct of this investigation, it was identified that the Control Room Log at Ranger contains about 30 entries related to the failure of, or repairs to, various parts of the process water distribution system at Ranger in the period 1 March to 24 March 2004. A general inspection of the mill noted that leaking pipes were common, valves were broken and corroded, temporary hose connections were present, and the colour coding of pipes was in many instances obscured by rust and grime. On this basis, it was obvious that a major refurbishment of the process water system was required to bring it up to a satisfactory standard.

Discussions with staff revealed that the condition of the process water system and the need for frequent repairs led to a situation where staff were forced to use alternative water supplies to keep the scrubber operational. While accepted practice, it is clear that such a switch did not require the formal change management procedure to be followed. Staff considered that these breaches of change management procedures were necessary to keep the plant operating.

ERA had previously identified the condition of the process water system as a significant risk, and had already commenced a program to replace the entire process water distribution system with new High Density Polyethylene (HDPE) and stainless steel pipes prior to the incident.

The main line between the process water head tank and the booster pumps had already been replaced and funding has been allocated in the 2004 calendar year ERA Maintenance Capital Budget to replace the remainder of the process water distribution system. The FOB scrubber has been refurbished in the annual maintenance shutdown of the plant in May 2004 and preparatory work for the replacement of the entire process water distribution system has been undertaken.

The replacement of the process water distribution system is planned to be completed by September 2004. Given the significance of the process water distribution system in this incident, it is the Supervising Scientist's view that an independent audit of the system should be carried out by the end of 2004 to determine whether the Process Water Pipe Replacement Project has been completed, and to identify any further work required to address any remaining deficiencies in the process water system.

**Recommendation 2:**

*The Commonwealth Minister for Industry, Tourism and Resources should advise the Northern Territory Minister for Mines and Energy that, by the end of 2004, an independent audit of the process water distribution system at Ranger should be carried out to determine whether the Process Water Pipe Replacement Project has been completed and to identify further work required to address any remaining deficiencies in the process water system.*

While the refurbishment of the process water system is considered essential, it is also the case that steps need to be taken at Ranger to tighten up procedures for the management of changes to the water systems on site and to address the culture of staff that has arisen as a result of the poor condition of the current system.

**Recommendation 3:**

*ERA should introduce a permit system requiring authorisation by a Superintendent for changes to water systems and should implement a program designed to improve the standard of housekeeping on site. ERA should determine the minimum competency standards required for operators, and implement a training system that ensures that operators meet those standards.*

In public discussion on this incident, it has been noted that the incident occurred only a few months after ERA received certification under the International Standard ISO 14001. Many have questioned the efficacy of this standard in the light of the occurrence of the incident. It should be noted that the ISO 14001 standard is designed to address environmental issues and, despite the secondary but important leak of contaminated water at Jabiru East, the primary risk associated with this incident was an Occupational Health and Safety (OHS) issue. OHS risks are not addressed in the systems implemented at Ranger under ISO 14001. It is the Supervising Scientist's view that this needs to be rectified.

**Recommendation 4:**

*The Commonwealth Minister for Industry, Tourism and Resources should advise the Northern Territory Minister for Mines and Energy that ERA be required to implement a Workplace Safety System consistent with, or equivalent to, Australian Standard 4801 and that the operation of this system be the subject of an annual independent audit.*

## **7.2 Environmental Requirements and the Ranger Authorisation**

It is the role of the Northern Territory Government to assess whether or not ERA has been in breach of the *Mining Management Act 2001* and the Ranger General Authorisation. In addition to the Ranger General Authorisation, there may be breaches of provisions of the *Mining Management Act 2001* related to ERA's duty of care to provide a safe work environment. This report has noted that the Northern Territory Minister for Mines and Energy announced on 19 May 2004 that the report of his Department on the incident had been referred to the Northern Territory Department of Justice to consider whether a case existed for prosecution of ERA.

ERA is required to comply with the Commonwealth Environmental Requirements (the ERs) for the Ranger mine as attached to the Authority issued under Section 41 of the Commonwealth *Atomic Energy Act 1953* and to the export permit for uranium granted under the *Customs (Prohibited Exports) Regulations 1958*.

ER 3.4 requires that process water must be totally contained within a 'closed system'.

For the purpose of ER 3.4, the Ranger Minesite Technical Committee has determined that the 'closed system' is comprised of the process water system (Pit 1, tailings dam, Retention Pond 3 and pipes and pumps connected to these storages) and the bunds and drains designed to collect spillages from the process water system. Retention Pond 2 is also included to the extent that it may collect infrequent spillage of small volumes outside the primary containment bunds. When process water entered the potable water system, it was not totally contained within the defined closed system and the losses from the closed system were not due to evaporation or seepage. It is the Supervising Scientist's view that this constitutes a breach of ER 3.4.

In addition, it has been established that the contaminated water moved through the potable water system to Jabiru East where it discharged to the general environment from the Jabiru East tank. It is the Supervising Scientist's view that this discharge constitutes a second breach of ER 3.4.

ER 5.1 requires, *inter alia*, that radiation doses to company employees and contractors must be kept as low as reasonably achievable and must always remain less than the dose limit for workers. While this report has concluded that radiation doses received by employees and contractors were below the dose limits for workers, it is the Supervising Scientist's view that ERA has not met the requirement to keep doses to employees and contractors as low as reasonably achievable and that this constitutes a breach of ER 5.1.

It could be argued that ERA has, as a result of this incident, also breached ERs 1.1 (c), 1.2 (c), 3.1, 6.1, 10.1(b), 12.1, 14.1 and 18.4. The Supervising Scientist has assessed the potable water contamination incident in the context of each of these ERs. He has concluded that it would probably be difficult to demonstrate that these ERs have been breached. In the light of his firm conclusions on the breach of ERs 3.4 and 5.1, this matter has not been pursued further.

#### **Recommendation 5:**

*The Commonwealth Minister for Industry, Tourism and Resources should consider whether action should be taken by the Commonwealth in response to the established breach of Environmental Requirements 3.4 and 5.1.*

### **7.3 Responsibilities of the Supervising Scientist and the Northern Territory Government**

The Commonwealth Government decided, in June 2000, that the inspectorial activities of the Supervising Scientist, which had ceased in 1995, should be reinstated. In making this decision, the Government made it clear that this inspectorial role should be limited, in a manner similar to that in place prior to 1995 and consistent with the Supervising Scientist's functions under the *Environment Protection (Alligator Rivers Region) Act 1978*, to assessing issues that could be relevant to off-site environmental protection.

The mechanism for implementing this decision was the commencement of Routine Periodic Inspections (RPI). These are carried out monthly and, while organised by the Supervising Scientist, are conducted jointly with the NT Department of Business, Industry and Resource Development and the Northern Land Council. These inspections focus on the environmental

protection mechanisms in place at Ranger including the condition and adequacy of containment structures and bunds. They do not involve inspections of plant inside the bunds nor do they address Occupational Health and Safety issues other than radiation safety. Those are issues that are the responsibility of the Northern Territory Government. This focus on off-site environmental protection issues is the reason why the RPI process did not identify the primary conditions that gave rise to this incident

The Supervising Scientist does not review in detail the Northern Territory Government's conduct of its responsibilities for the day-to-day regulation of mining of uranium at Ranger. However, in his report on the investigation of the leak of tailings water at Ranger in 2000, the Supervising Scientist recommended that the Northern Territory Department of Mines and Energy should undertake a comprehensive review of its site inspection regime in the light of deficiencies identified in the report, and design and implement a new proactive inspection regime within a risk management framework.

The Supervising Scientist is aware that the NT Department of Business, Industry and Resource Development (DBIRD) now carries out a much more comprehensive inspection and audit program at Ranger than applied in 2000. The results of these inspections and audits are not normally conveyed to the Supervising Scientist where they do not relate to environmental issues. The Commonwealth Government may wish to be satisfied that the occurrence of this incident can not be attributed to a lack of vigilance on the part of the Northern Territory Government in the discharge of its responsibilities in the day-to-day regulation of the mining of uranium at Ranger.

**Recommendation 6:**

*The Commonwealth Minister for Industry, Tourism and Resources should seek advice from the Northern Territory Minister for Mines and Energy on the nature and extent of the audit and inspection regime at the Ranger mine and, in particular, should seek details of any concerns expressed by the Department of Business, Industry and Resource Development on the condition of the process plant and on related OHS issues.*

## **7.4 Contamination of the Jabiru East potable water supply**

A faulty valve at the Jabiru East tank caused contaminated potable water to flow from the mine towards Jabiru East. Water quality data at Jabiru East businesses are limited but we have been able to conclude that water consumed at the Jabiru Field Station and the Gagudju Workshop on the morning of 24 March met all drinking water guidelines and that it is highly likely that this was also true at the Jabiru East Airport.

The consumption of water from the Jabiru Field Station of the Supervising Scientist by staff of the Supervising Scientist and Aboriginal Traditional Owners on 5 April 2004 arose from a misunderstanding by a member of staff and from the lack of tagging of potable water outlets within the Jabiru Field Station. We have concluded that the water from the Jabiru Field Station consumed by SSD staff and by Aboriginal Traditional Owners on 5 April met drinking water standards and did not represent any health risk. The Supervising Scientist will develop and implement an emergency response plan to ensure that the circumstances that led to this incident are not repeated.

The Jabiru East potable water supply was reinstated to a standard appropriate for industrial purposes on 22 April 2004.

Following repairs to various leaks in the Jabiru East water system, further flushing of the system and water quality analyses, ERA submitted a final proposal for reinstatement of the



potable water system in Jabiru East on 7 June 2004. This proposal was supported by the Supervising Scientist on 9 June 2004 and by the NT Department of Health and Community Services on 10 June 2004. Approval for reinstatement of the supply was given by the NT Department of Business, Industry and Resource Development on 11 June 2004.

## **7.5 Assessment of human health implications for ERA staff and contractors**

A detailed assessment has been carried out on the potential for adverse long-term health effects arising for workers at the Ranger mine who were exposed to contaminated water as a result of this incident. Such long-term effects could arise, in principle, as a result of chemical exposure and radiation exposure.

For radiation exposure, it has been concluded that, even under the worst-case scenario considered, the risks arising from radiation exposure of ERA staff and contractors who consumed contaminated water at the Ranger site on 23–24 March 2004 are very low and that long-term effects on their health would not be expected. It is considered that no follow-up radiation exposure monitoring is required.

The risks to workers from chemical exposure were assessed by two different approaches. The first approach used risk assessment methods that combine information on the exposure of workers to chemicals in the Ranger incident with data on effects of such chemicals on human health in the medical and scientific literature to draw conclusions on the likely effects on people who were exposed to contaminated water. The second approach involved the measurement of a range of chemical and biological response indicators in samples of blood and urine from workers who were exposed to contaminated water, and the expert medical assessment of the results to assess the likelihood of adverse long-term effects.

These two different approaches were adopted in two separate investigations. One investigation was carried out for ERA by the Rio Tinto occupational physician from the UK, assisted by a consultant toxicologist retained by ERA. The second investigation was carried out for the Supervising Scientist by a group of experts in the Australian Centre for Human Health Risk Assessment (ACHHRA) and the National Research Centre for Environmental Toxicology (EnTox). While the two investigations were independent and produced separate reports, they used common data sets (for example chemical data sets on the extent of water contamination and health testing analyses of blood and urine) provided by ERA and SSD as appropriate.

The principal conclusions of both investigations, supported by both the risk assessment and the medical assessment methods, were that:

- The short-term (or acute) skin irritation and/or gastrointestinal distress that were reported by some exposed workers were consistent with effects that would be expected from contact with water that was slightly acidic and that contained relatively high concentrations of the metals present in process water at Ranger; and
- It is most unlikely that there will be any longer-term or delayed health effects on target organs such as the brain, liver and kidney because of the brief period of exposure to the contaminated water.

Both the ERA and the SSD reports, however, adopted a precautionary approach to their conclusions.

Firstly, both reports noted that some clinical chemistry values were marginally above the normal range. In particular, kidney function tests for three individual workers showed slightly elevated results in the first set of tests and it was recommended that, on the basis of discussion between individual workers and their medical professionals, these tests could be repeated after 3–6 months.

Second, both reports noted that, even although longer-term or delayed effects are considered to be most unlikely, they cannot be completely ruled out. For this reason, both reports state that a more extensive longer-term monitoring program should be considered for the exposed workers.

The ERA report recommends a voluntary monitoring program consisting of:

- A specified blood and urine sampling and analysis program; and
- Subject to further assessment by a consultant neurotoxicologist, Magnetic Resonance Imaging (MRI) scans to be conducted for manganese and aluminium levels for workers with high potential or reported exposures.

The SSD report canvassed the use of some possible biomarkers relating to renal effects and neurotoxicity but it cautioned that the results of such tests might be difficult to interpret on an individual basis. In particular, MRI scans for manganese and aluminium were not recommended in the SSD report because such tests may only be useful in showing deposition of these metals at selected sites in the brain and the significance of such deposition may be difficult to interpret on an individual basis. For these reasons, the SSD report recommends that any decision to engage in a follow-up testing of individual workers should be made by their doctors and should be based upon their individual medical histories and factors such as their level of concern and the need for reassurance relating to the Ranger water contamination incident.

It is the Supervising Scientist's view that the precautionary approach recommended in both medical risk assessment reports should be adopted

#### **Recommendation 7:**

*ERA should provide copies of the two health risk assessments contained within the Supervising Scientist's report to affected workers, should counsel these workers to seek advice from their doctors on their possible participation in the proposed voluntary monitoring program and should facilitate the implementation of this program for those workers who choose to participate, including the provision of the advice of an independent consultant neurotoxicologist. When the results of the program become available, they should be assessed by both the Rio Tinto occupational physician and the Supervising Scientist's independent expert group and these assessments should be provided to the affected workers and their doctors.*

## **7.6 Assessment of environmental impact**

Two approaches have been adopted in this report in assessing the potential impact on the downstream environment of Kakadu National Park arising from the discharge of contaminated water from the water storage tank at Jabiru East on 24 March 2004.

The first approach was based upon modelling of the flow of contaminated water from the mine site to the Jabiru East tank, mixing in the tank, and overflow from the tank towards the Magela Creek. The model used very conservative assumptions and represented a worst case scenario. The results indicated that, of all the constituents present in process water, only

manganese, uranium and possibly copper could have been present in Magela Creek at concentrations that would be measurable above background. Taking into account the measured attenuation of metals during overland flow towards Magela Creek, we have concluded that environmental impact downstream from the Ranger mine would not be expected.

The second approach was based upon assessment of a range of monitoring data. These included data from the Supervising Scientist's routine biological and chemical monitoring programs conducted in the vicinity of the Ranger mine, including continuous monitoring of electrical conductivity, as well as additional sampling conducted as part of this investigation. Assessment of all the chemical analyses of water samples obtained during the period of the incident demonstrate that no change occurred in the chemistry of Magela Creek downstream from the Ranger mine as a result of the incident. The creekside biological monitoring program using fish and freshwater snails was underway throughout the week in which the incident occurred. No change was observed in fish larval survival or snail reproduction at the monitoring site downstream from the mine compared to results obtained upstream.

Based on all of these data, the overall conclusion has been drawn that the potable water contamination incident should not have given rise to any impact on the ecosystems of Kakadu National Park and that there should be no impact on the health of people who consume water or food from the creek or billabongs downstream from the mine.

We have also concluded that there is no immediate need for rehabilitation of soils in the vicinity of the tank at Jabitu East. The longer-term requirement for soil rehabilitation should be addressed during the minesite rehabilitation stage through the site-wide assessment of contamination levels.

## References

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- ERA 2004. Investigation Report into Potable Water Contamination at Ranger Mine on March 23 & 24, 2004. Energy Resources Australia Ltd, Commercial-in-Confidence, May 2004, 31 pp.
- International Commission for Radiation Protection 1996. *Age-dependant doses to members of the public from intake of radionuclides: Part 5. Compilation of ingestion and inhalation dose coefficients*. Pergamon, Oxford.
- NHMR & ARMCANZ 1996. *Australian Drinking Water Guidelines*. National Health and Medical Research Council & Agriculture and Resource Management Council of Australia and New Zealand, Canberra.

## **Appendix 1 Summaries of SSD data obtained in the investigation**

# Appendix 1A Physical and inorganic parameters (SSD data) for reticulation/consumer outlet samples

LOCATION_NAME	Time	SAMPLE_ID	Metal Fraction (except U)	EC µS/cm	pH pH unit	NO2_N mg/L	NO3_N mg/L	NH3_N mg/L	Al µg/L	As µg/L	B µg/L	Ba µg/L	Cd µg/L
<i>Australian Drinking Water Guideline - Aesthetic</i>													
<i>Australian Drinking Water Guideline - Health</i>													
					6.5 - 8.5	0.91	11.3	0.41	200	7	300	700	2
<b>JFS Potable Sources - 24/03/2004</b>													
JFS Header tank Outlet	930	A00307	Filterable					<0.005	0.9				
JFS Header Tank Top	930	A00308	Filterable	338				0.01	2.2				
JFS Mens Washroom	930	A00309	Filterable					<0.005	0.9				
JFS Tearoom	930	A00310	Filterable					<0.005	1				
Water Bottle filled approx 1700 13/03/04	930	A00311	Filterable					<0.005	0.9				
<b>Jabiru East Fire hydrant near tank 24/03/2004 "A"</b>	1330	A00315	Total	1045	6.9	<0.005	0.05	12.8	1160	0.7	37	7.1	3.86
<b>Ranger Buildings - potable system 24/03/2004</b>													
Urn in crib room d/s main building "B"	1505	A00316	Total			N.A.	N.A.	N.A.	2.3	<0.05	10	0.9	<0.02
Downstairs mill lab taps "C"	1520	A00317	Total	1516	7.5	<0.005	0.05	<0.005	3.4	0.25	14.5	2.2	0.38
Downstairs mill lab taps "D"	1520	A00318	Total			<0.005	0.045	0.615	6.2	0.15	15.5	1.8	0.1
Engineering shower block "E"	1540	A00319	Total	1505	6.7	<0.005	0.06	32.5	2140	1.7	61.5	13.2	2.12
Engineering, sink in toilets outside shower block "F"	1540	A00320	Total			N.A.	N.A.	N.A.	582	1.5	71.5	14	1.26
Engineering crib room "G"	1545	A00321	Total			N.A.	N.A.	N.A.	473	1.9	159	36	1.5
Grieng area grou floor toilet cistern "H"	1550	A00322	Total	8710	4.2	0.025	0.39	277	13200	32	442	22.8	10.6
<b>Jab. East Tank Overflow Area 25/03/2004</b>													
Jabiru east sump; flow from tank direction "A"	1005	A00323	Total	776	6.05	N.A.	N.A.	N.A.	5280	1.75	55	34.4	1.42
Jabiru east sump; flow from tank direction "B"	1010	A00324	Total	1476	6.54	N.A.	N.A.	N.A.	5700	1.8	61	37	1.26
Jabiru east sump; flow from airport direction "B"	1010	A00325	Total	1476	6.54	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.
Jabiru east sump 2 opening: from airport direction "E"	1030	A00328	Total	850	7.02	N.A.	N.A.	N.A.	7120	1.5	28.5	8.4	0.32
Jabiru east sump 2 opening: from airport direction "E"	1030	A00329	Total	850	7.02	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.
Jabiru east tank cemented drain at tank "F"	1100	A00330	Total	801	8.16	<0.005	<0.005	<0.005	548	0.6	22.5	4.5	0.16
<b>Jabiru Town Water supply 25/03/2004</b>	1300	A00314	Total	438	7.4	<0.005	0.025	<0.005	4.5	0.45	13.5	26.2	0.02
<b>JFS Potable Sources 6/04/2004</b>													
Mens Toilet JFS	pm	A00516	Total	390				<0.005	40.3	0.2	12.5	1.04	<0.02
Crib Room Tap JFS	pm	A00517	Total	388				<0.005	47	0.2	12.5	0.9	<0.02
Tap outside at rear of Bug Lab JFS	pm	A00518	Total					<0.005	40.2	0.15	13.5	1.1	<0.02
Hose outside Wetlab JFS	pm	A00519	Total	389				<0.005	21.5	0.25	13.5	0.94	<0.02
Wet Lab taps JFS	pm	A00520	Total					<0.005	25.5	0.25	14	1.02	<0.02

## Appendix 1A continued

SAMPLE_ID	Metal Fraction (except U)	Cr µg/L	Cu µg/L	Fe µg/L	Hg µg/L	I µg/L	Mg_F mg/L	Mn µg/L	Mo µg/L	Ni µg/L	Pb µg/L	SO4_F mg/L	Sb µg/L	Se µg/L	Sn µg/L	U_F µg/L	U_T µg/L	Zn µg/L
Guideline - Aesthetic		50*	1000	300	1	100		100	50	20	10	250	3	10		20	20	300
Guideline - Health																		
A00307	Filterable		3.57	<20			39.7	0.49			0.2	0.6				8.2		
A00308	Filterable		4.06	<20			39.5	1.3			0.11	1.2				8.24		
A00309	Filterable		22.3	<20			39.8	0.04			0.36	0.8				8.17		
A00310	Filterable		11.1	<20			39.6	0.03			0.24	0.8				8.04		
A00311	Filterable		99.1	<20			39.8	0.16			1.01	0.9				8.02		
A00315	Total	1.1	107	120	<0.02	<5	102	29700	0.2	69	9.67	410	<0.05	3.4	0.6	83.3	125	1730
A00316	Total	<0.1	5.3	<20	<0.02	<5	20.8	1.2	<0.05	0.2	0.12	1.1	<0.05	0.4	<0.1	0.2	0.6	7.1
A00317	Total	0.9	423	<20	<0.02	<5	40.1	0.4	0.1	0.5	5.19	0.8	<0.05	0.6	0.1	6.8	7.1	388
A00318	Total	0.3	525	<20	0.02	<5	44.3	709	0.1	1.4	1.86	30.8	<0.05	0.6	<0.1	9	9.6	338
A00319	Total	1.8	2170	268	0.02	<5	183	64200	2.3	128	35.3	913	3.2	8.8	0.3	189	366	5970
A00320	Total	0.7	1540	40	0.04	<5	204	75700	0.6	148	18.5	1080	2.55	4.8	<0.1	102	156	4380
A00321	Total	0.5	496	20	0.06	<5	587	197000	0.4	27.7	30.7	3420	1.6	8.6	0.1	250	527	1100
A00322	Total	69.8	11700	1842	<0.02	10	1130	607000	1.95	1690	1280	6940	12	147	0.1	5500 - 6500	7060	12600
A00323	Total	5.2	192	1200	<0.02	<5	188	70700	0.25	169	9.83	1060	0.1	7.4	5	400	414	4370
A00324	Total	5.5	186	1000	0.02	<5	203	75900	0.2	183	8.48	1180	0.05	7.6	3.7	441	460	4720
A00325	Total	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.
A00328	Total	6	210	560	<0.02	<5	90.5	20000	0.15	49.5	10.2	330	0.05	6.4	4.3	466	461	1000
A00329	Total	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.
A00330	Total	1.1	44.7	100	<0.02	<5	77	14100	0.15	26.6	2.86	257	0.1	2.2	<0.1	121	121	171
A00314	Total	2.9	2.15	20	<0.02	<5	32.8	0.11	<0.05	<0.01	0.13	0.1	<0.05	0.4	<0.1	0.465	0.514	7.8
A00516	Total	0.4	48.3	80	<0.02	<5		7.39	<0.05	0.21	2.58		<0.05	0.4	0.5		11.6	86.8
A00517	Total	0.4	25.9	60	<0.02	<5		3.46	<0.05	0.19	1.1		<0.05	0.4	0.2		11.5	53.3
A00518	Total	0.4	21.6	80	<0.02	<5		7.13	<0.05	0.26	3.37		<0.05	0.4	0.5		11.6	79.5
A00519	Total	0.4	57.4	40	<0.02	<5		3.48	<0.05	0.27	3.31		<0.05	0.4	0.1		11.4	73.8
A00520	Total	0.2	58.6	60	<0.02	<5		4.49	<0.05	0.4	1.3		<0.05	0.4	0.2		11.4	86.4

\* Cr guideline is for Cr (VI), results are for unspicated chromium; Only a range is reported for U\_F in sample A00322 due to an analytical problem; #\_F is the filterable fraction; #\_T is the total fraction

## Appendix 1B Full water quality data for SSD samples from Ranger buildings on 24 March 2004

Site		B	C	D	E	F	G	H
Sample ID		A00316	A00317	A00318	A00319	A00320	A00321	A00322
Time		1505	1520	1520	1540	1540	1545	1550
Parameter	Units							
EC	µS/cm		1516		1505			8710
pH	pH		7.5		6.7			4.2
NO2_N	mg/L		<0.005	<0.005	<0.005			0.025
NO3_N	mg/L		0.05	0.045	0.06			0.39
NH3_N	mg/L		<0.005	0.615	32.5			277
Ag_F	µg/L	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Ag_T	µg/L	<0.05	0.35	0.15	0.25	0.05	0.10	0.30
Al_F	µg/L	1.4	1.4	3.2	34.6	22.8	2.0	102000
Al_T	µg/L	2.3	3.4	6.2	2140	582	473	13200
As_F	µg/L	<0.05	0.25	0.15	1.05	1.05	0.85	27.5
As_T	µg/L	<0.05	0.25	0.15	1.7	1.5	1.9	32
B_F	µg/L	8.4	11.6	12.8	55.9	65.3	155	323
B_T	µg/L	10	14.5	15.5	61.5	71.5	159	442
Ba_F	µg/L	1	2	2	12	13	34	23
Ba_T	µg/L	0.9	2.2	1.8	13.2	14	36	22.8
Be_F	µg/L	<0.05	<0.05	<0.05	0.2	0.2	<0.05	19.5
Be_T	µg/L	<0.05	<0.05	<0.05	0.8	0.4	0.4	25.5
Br_F	µg/L	48	180	112	160	150	280	422
Br_T	µg/L	17	31	25	81	53	113	347
Ca_F	mg/L	1.7	23.1	24.5	56.6	60.1	250	182
Ca_T	µg/L	1600	22700	24000	63200	68200	294000	217000
Cd_F	µg/L	0.00	0.36	0.08	0.98	1.07	0.73	7.25
Cd_T	µg/L	<0.02	0.38	0.1	2.12	1.26	1.5	10.6
Cr_F	µg/L	<0.2	1	0.4	0.4	<0.2	0.2	68.4
Cr_T	µg/L	<0.1	0.9	0.3	1.8	0.7	0.5	69.8
Cu_F	µg/L	0.38	370	527	1630	1250	3.51	10700
Cu_T	µg/L	5.3	423	525	2170	1540	496	11700
Fe_F	µg/L	<20	<20	<20	<20	<20	<20	960
Fe_T	µg/L	<20	<20	<20	268	40	20	1842
Hg_F	µg/L	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02
Hg_T	µg/L	<0.02	<0.02	0.02	0.02	0.04	0.06	<0.02
I_F	µg/L	<5	<5	<5	5	<5	<5	10
I_T	µg/L	<5	<5	<5	<5	<5	<5	10
K_T	mg/L		0.22	0.23	3.33			51.13
Mg_F	mg/L	20.8	40.1	44.3	183	204	587	1130
Mg_T	mg/L		44	41	138			1260
Mn_F	µg/L	0.02	0.17	688	59500	66800	172000	528000
Mn_T	µg/L	1.2	0.4	709	64200	75700	197000	607000
Mo_F	µg/L	<0.05	0.1	0.1	0.25	0.4	0.3	1.25
Mo_T	µg/L	<0.05	0.1	0.1	2.3	0.6	0.4	1.95
Ni_F	µg/L	<0.01	<0.01	1.0	121	136	6.3	1490
Ni_T	µg/L	0.20	0.50	1.40	128	148	27.7	1690
Pb_F	µg/L	<0.01	3.50	1.60	11.3	10.4	0.20	913
Pb_T	µg/L	0.12	5.19	1.86	35.3	18.5	30.7	1280
SO4_F	mg/L	1.1	0.8	30.8	913	1080	3420	6940
SO4_T	mg/L				407			8370
Sb_F	µg/L	<0.05	<0.05	<0.05	0.40	0.50	0.05	0.45
Sb_T	µg/L	<0.05	<0.05	<0.05	3.2	2.55	1.6	12
Se_F	µg/L	0.2	0.6	0.6	3	2.4	3.8	113
Se_T	µg/L	0.4	0.6	0.6	8.8	4.8	8.6	147

## Appendix 1B continued

Site	B	C	D	E	F	G	H
Sample ID	A00316	A00317	A00318	A00319	A00320	A00321	A00322
Time	1505	1520	1520	1540	1540	1545	1550
Parameter	Units						
Sn_F	µg/L	0.1	<0.1	<0.1	<0.1	<0.1	0.1
Sn_T	µg/L	<0.1	0.1	<0.1	0.3	<0.1	0.1
Ti_T	µg/L	<2	4	4	4	4	14
U_F	µg/L	0.2	6.8	9	189	102	250
U_T	µg/L	0.6	7.1	9.6	366	156	527
V_T	µg/L	0.1	0.7	0.9	1.1	0.8	0.3
Zn_F	µg/L	0.8	291	305	5270	3760	6.9
Zn_T	µg/L	7.1	388	338	5970	4380	1100
Th_T	µg/L		0.008	0.006	0.95		64.2
Sc_T	µg/L		6.83	6.56	<10		356
Li	µg/L		9.53	9.17	63.7		784
Ti	µg/L		0.441	0.423	0.516		8.10
Co	µg/L		0.031	0.107	39.0		905
Ga	µg/L		0.000	0.000	0.201		0.000
Ge	µg/L		0.000	0.010	0.053		1.58
Rb	µg/L		0.600	0.663	14.5		202
Sr	µg/L		6.12	5.82	27.7		297
Y	µg/L		0.008	0.026	63.7		3930
Zr	µg/L		0.000	0.001	0.030		0.181
Nb	µg/L		0.000	0.000	0.001		0.020
Ru	µg/L		0.000	0.000	0.000		0.000
Rh	µg/L		0.000	0.000	0.005		0.149
Pd	µg/L		0.000	0.000	0.000		0.000
In	µg/L		0.000	0.000	0.000		0.000
Te	µg/L		0.000	0.000	0.026		0.000
I	µg/L		0.467	0.476	0.644		0.771
Cs	µg/L		0.072	0.086	1.50		18.0
La	µg/L		0.002	0.001	1.84		76.7
Ce	µg/L		0.003	0.008	5.254		301
Pr	µg/L		0.001	0.001	1.11		69.3
Nd	µg/L		0.000	0.006	7.21		421
Sm	µg/L		0.002	0.003	5.01		326
Eu	µg/L		0.001	0.001	1.64		123
Gd	µg/L		0.001	0.008	9.02		584
Tb	µg/L		0.001	0.002	2.25		153
Dy	µg/L		0.000	0.014	15.9		1170
Ho	µg/L		0.001	0.003	2.78		208
Er	µg/L		0.000	0.004	7.76		529
Tm	µg/L		0.000	0.001	0.810		60.1
Yb	µg/L		0.000	0.003	5.12		411
Lu	µg/L		0.000	0.000	0.580		46.2
Hf	µg/L		0.000	0.000	0.055		4.23
Ta	µg/L		0.000	0.000	0.012		0.863
W	µg/L		0.236	0.211	0.228		1.56
Re	µg/L		0.029	0.046	1.91		27.8
Os	µg/L		0.000	0.000	0.000		0.000
Ir	µg/L		0.000	0.000	0.000		0.000
Pt	µg/L		0.000	0.000	0.000		0.000
Au	µg/L		0.006	0.003	0.004		0.000
Tl	µg/L		0.001	0.000	0.306		4.95

\*: U\_F result for A00322 "H" only a range can be given due to an analytical problem

Fraction analysed: #\_F: filtrate fraction, #\_T: total fraction

Site names: B – Urn in crib room d/s main building, C – Downstairs mill lab taps, D – Downstairs mill lab taps, E – Engineering shower block, F – Engineering-sink in toilets outside shower block, G – Engineering crib room, H – Grinding area ground floor toilet cistern



## Appendix 1C SSD water quality data for environmental sites

SITE	DATE	SAMPLE_ID	Field EC µS/cm	Field pH pH unit	DO mg/L	Field Temp °C	Lab EC µS/cm	Lab pH pH unit	Lab. Turbidity NTU
009 central channel	25/03/2004	A00312	17	6.3	7.12	31.1	16.6	6.5	2.1
009 west channel	25/03/2004	A00313	19	6.33	7.84	31.0	18.5	6.4	2
Mudginberri Billabong In	25/03/2004	A00331	18	6.4	7.6	32.2	17	6.7	
009 central channel	26/03/2004	A00335	11	5.8	7.1	28.1	10	6.1	13
009 west channel	26/03/2004	A00336	11	5.8	7.2	28.2	10	6.0	11
009 west channel	26/03/2004	A00337	11	5.8	7.1	28.2	11	6.0	10
MCUS	26/03/2004	A00338	8	5.5	7.0	27.3	8	6.0	25
Creek side monitoring stations (upstream of mine)	26/03/2004	A00341					8	6.1	13
Creek side monitoring stations (downstream of mine)	26/03/2004	A00342					11	6.2	8.6
Creek side monitoring stations (downstream of mine)	26/03/2004	A00343					12	6.1	20
Mudginberri Billabong Inlet	26/03/2004	A00360	11	6.8	6.8	29.4	11	6.1	13
Jab. East Tank Overflow: Intersection of overflow and creek	26/03/2004	A00361	15	6.0	6.0	29.6	15	6.0	7.6
Jab. East Tank Overflow: puddle with max. EC	26/03/2004	A00362	225	7.6	4.2	34.4	250	7.6	2.5
009 central channel	27/03/2004	A00363	12	5.9	6.5	30.2	13	6.1	3.7
009 west channel	27/03/2004	A00364	16	6.0	6.4	30.3	17	6.1	3.5
MCUS	27/03/2004	A00366	10	5.9	6.5	30.2	10	6.1	3.7
Mudginberri Bbong	27/03/2004	A00367	14	6.0	6.1	30.5	14	6.1	3.8
009 West channel bank	27/03/2004	A00372	52	6.2	5.8	31.0	57	6.2	3.0
009 central channel	28/03/2004	A00373	10	5.9	6.8	31.0	10	6.4	3.0
009 central channel	28/03/2004	A00374							
009 west channel	28/03/2004	A00375	10	6.0	6.9	31.0	11	6.2	3.1
009 west channel bank	28/03/2004	A00376	22	6.2	6.3	31.2	23	6.3	2.3
MCUS	28/03/2004	A00377	10	6.0	7.6	31.4	10	6.3	3.0
Mudginberri Billabong Inlet	28/03/2004	A00380	10	6.1	6.8	31.2	10	6.3	2.8
MCUS	29/03/2004	A00381	11	6.0	6.7	31.9	12	6.3	2.5
009 central channel	29/03/2004	A00382	14	6.1	7.0	31.8	15	6.4	2.1
009 west channel	29/03/2004	A00383	17	6.1	6.9	31.8	18	6.4	3.5
009 west channel	29/03/2004	A00384	17	6.1	6.9	31.8	18	6.3	2.7
Mudginberri Billabong Inlet	29/03/2004	A00386	15	6.3	6.6	32.2	16	6.5	2.5
009 west channel bank	29/03/2004	A00389	20	6.2	7.3	32.8	21	6.4	2.5
MCUS	30/03/2004	A00390	11	6.0	7.1	28.8	12	6.3	
009 central channel	30/03/2004	A00391	14	6.2	6.6	29.5	15	6.4	2.3
009 west channel	30/03/2004	A00392	16	6.1	6.8	29.5	18	6.3	2.4
009 west channel	30/03/2004	A00393	17	6.1	6.7	29.5			
009 west channel bank	30/03/2004	A00394	17	6.3	7.3	29.8			
Mudginberri Billabong Inlet	30/03/2004	A00395	15	6.3	6.5	31.1	17	6.4	2.3
Connjimba Billabong	30/03/2004	A00404	170	6.7	6.8	34.8			

## Appendix 1C continued

SAMPLE_ID	NO2_N mg/L	NO3_N mg/L	NH3_N mg/L	Al_F µg/L	As_F µg/L	Ba_F µg/L	Be_F µg/L	Br_F µg/L	Ca_F mg/L	Cd_F µg/L	Cr_F µg/L	Cu_F µg/L
A00312	<0.005	<0.005	<0.005	29.1	0.1	3.16	<0.05	14	0.5	<0.02	0.2	0.22
A00313	<0.005	<0.005	0.21	29.3	<0.05	3.32	<0.05	14	0.5	<0.02	0.2	0.19
A00331	<0.005	<0.005	0.005	23	<0.05	4.34	<0.05	12	0.5	<0.02	0.2	0.23
A00335	<0.005	<0.005	0.005	40	0.05	1.62	<0.05	14	0.3	0	0.2	0.32
A00336	<0.005	<0.005	<0.005	111	0.05	3.87	<0.05	10	0.3	0	0.2	0.47
A00337	<0.005	<0.005	0.005	96.6	0.1	3.59	<0.05	8	0.3	0.0	0.2	0.46
A00338	<0.005	<0.005	0.01	48.9	<0.05	1.38	<0.05	6	0.3	0.0	<0.2	0.50
A00341	N.A.	N.A.	N.A.	144	<0.05	4.68	<0.05	2	0.4	0.01	<0.2	0.88
A00342	N.A.	N.A.	N.A.	68.2	<0.05	3.19	<0.05	6	0.4	0	<0.2	0.40
A00343	N.A.	N.A.	N.A.	56.3	0.05	2.84	<0.05	6	0.3	<0.0	<0.2	0.28
A00360	<0.005	<0.005	0.005	71.5	<0.05	4.01	<0.05	4	0.3	0.0	<0.2	0.44
A00361	<0.005	<0.005	0.005	71.5	<0.05	2.93	0.05	4	0.3	0.0	<0.2	0.40
A00362	<0.005	<0.005	0.095	304	0.4	26.8	0.1	60	13.3	0.03	3.4	1.50
A00363	<0.005	<0.005	<0.005	80	<0.05	2.41	<0.05	14	0.3	<0.02	0.2	0.26
A00364	<0.005	<0.005	<0.005	56.4	0.1	3.21	<0.05	12	0.3	<0.02	0.2	0.33
A00366	<0.005	<0.005	<0.005	78.4	<0.05	1.93	<0.05	12	0.3	<0.02	0.2	0.24
A00367	<0.005	<0.005	<0.005	52.6	0.05	2.98	<0.05	10	0.4	<0.02	0.2	0.81
A00372	<0.005	<0.005	<0.005	47.6	0.05	5.79	<0.05	18	0.6	<0.02	0.2	1.45
A00373	<0.005	<0.005	<0.005	66.7	0.1	1.72	<0.05	12	0.3	<0.02	0.4	0.15
A00374	<0.005	<0.005	<0.005	36.3	0.1	1.65	<0.05	12	0.3	<0.02	0.2	0.18
A00375	<0.005	<0.005	<0.005	65.8	0.1	2.14	<0.05	10	0.3	<0.02	0.2	0.19
A00376	<0.005	<0.005	<0.005	49.2	0.05	2.7	<0.05	14	0.4	<0.02	0.2	0.18
A00377	<0.005	<0.005	<0.005	81.8	0.1	1.71	<0.05	12	0.3	<0.02	0.4	0.15
A00380	<0.005	<0.005	<0.005	49.5	<0.05	2.21	<0.05	10	0.3	<0.02	0.2	0.20
A00381	<0.005	<0.005	<0.005	62.2	0.05	2.44	<0.05	16	0.4	<0.02	0.2	0.19
A00382	<0.005	<0.005	<0.005	56.9	0.1	3.19	<0.05	16	0.4	<0.02	0.2	0.21
A00383	<0.005	<0.005	<0.005	55.6	0.05	2.93	<0.05	18	0.4	<0.02	0.4	0.21
A00384	<0.005	<0.005	<0.005	54.3	0.1	2.9	<0.05	18	0.4	<0.02	0.4	0.19
A00386	<0.005	<0.005	<0.005	65.6	0.05	2.98	<0.05	20	0.4	<0.02	0.4	0.20
A00389	<0.005	<0.005	<0.005	50.8	0.1	2.92	<0.05	24	0.4	<0.02	0.2	0.45
A00390	<0.005	<0.005	<0.005	68.5	0.1	2.32	<0.05	24	0.4	<0.02	0.2	0.17
A00391	<0.005	<0.005	<0.005	66.9	0.05	2.59	<0.05	24	0.4	<0.02	0.2	0.25
A00392	<0.005	<0.005	<0.005	73.5	0.05	3.16	<0.05	24	0.4	<0.02	0.4	0.23
A00393	<0.005	<0.005	<0.005	63.1	0.1	3.15	<0.05	26	0.4	<0.02	0.2	0.22
A00394	<0.005	<0.005	<0.005	181	0.1	3.42	<0.05	20	0.3	<0.02	0.4	0.26
A00395	<0.005	<0.005	<0.005	107	0.05	3.92	<0.05	22	0.4	<0.02	0.4	0.33
A00404	<0.005	<0.005	<0.005	25.8	0.2	15.9	<0.05	78	2.2	<0.02	0.6	0.47

## Appendix 1C continued

SAMPLE_ID	Fe_F µg/L	Mg_F mg/L	Mn_F µg/L	Mo_F µg/L	Ni_F µg/L	Pb_F µg/L	SO4_F mg/L	Sb_F µg/L	Se_F µg/L	Sn_F µg/L	U_F µg/L	Zn_F µg/L
A00312	200	0.9	3.62	<0.05	0.1	0.03	1.4	<0.05	<0.2	0.2	0.048	0.6
A00313	240	1.1	4.3	<0.05	0.09	<0.01	2.4	<0.05	<0.2	0.2	0.061	0.3
A00331	160	0.9	3.12	<0.05	0.1	0.05	1.2	<0.05	<0.2	0.1	0.051	0.5
A00335	80	0.4	6.1	<0.05	0.22	0.03	0.6	0.05	<0.2	0.5	0.021	3.1
A00336	340	0.5	11.4	<0.05	0.11	0.07	0.8	<0.05	<0.2	<0.1	0.067	0.9
A00337	340	0.5	10.0	<0.05	0.11	0.07	0.9	<0.05	<0.2	<0.1	0.053	0.8
A00338	80	0.2	8.26	<0.05	0.18	0.07	0.2	<0.05	<0.2	0.3	0.020	3.1
A00341	320	0.3	7.70	<0.05	0.26	0.13	0.3	<0.05	<0.2	0.1	0.053	1.6
A00342	300	0.5	5.95	<0.05	0.13	0.06	0.6	<0.05	<0.2	<0.1	0.039	1.9
A00343	280	0.6	4.97	<0.05	0.09	0.06	0.7	<0.05	<0.2	<0.1	0.041	0.4
A00360	240	0.6	7.17	<0.05	0.08	0.06	0.6	<0.05	<0.2	<0.1	0.045	0.6
A00361	220	0.9	8.58	<0.05	0.08	0.07	2.7	<0.05	<0.2	<0.1	0.404	0.6
A00362	1780	24.3	439	0.15	0.54	1.3	8.8	<0.05	0.4	<0.1	2.40	19.4
A00363	100	0.6	5.44	<0.05	0.21	0.03	1.0	<0.05	<0.2	<0.1	0.051	0.6
A00364	180	1.0	6.15	<0.05	0.15	0.04	2.2	<0.05	<0.2	0.2	0.092	0.6
A00366	100	0.4	5.72	<0.05	0.16	0.01	0.2	<0.05	<0.2	<0.1	0.019	0.9
A00367	140	0.7	5.14	<0.05	0.10	0.03	1.7	<0.05	<0.2	0.2	0.085	0.6
A00372	220	4.4	6.80	<0.05	0.17	0.06	14.5	<0.05	<0.2	0.5	0.244	0.5
A00373	80	0.4	3.48	<0.05	0.2	<0.01	0.4	<0.05	<0.2	<0.1	0.028	0.5
A00374	80	0.4	3.39	<0.05	0.21	<0.01	0.3	<0.05	0.2	0.3	0.026	0.6
A00375	200	0.5	3.87	<0.05	0.17	0.02	0.5	<0.05	<0.2	0.3	0.047	0.4
A00376	200	1.6	3.87	<0.05	0.19	0.01	5.1	<0.05	<0.2	0.3	0.127	0.4
A00377	100	0.4	3.47	<0.05	0.20	<0.01	0.2	<0.05	0.2	0.1	0.016	0.4
A00380	180	0.4	3.23	<0.05	0.17	0.03	0.5	<0.05	<0.2	0.3	0.035	0.6
A00381	140	0.4	3.3	<0.05	0.11	0.02	0.3	<0.05	<0.2	0.1	0.018	0.2
A00382	140	0.7	2.27	<0.05	0.12	0.01	1.3	<0.05	<0.2	0.1	0.046	1.5
A00383	140	1.0	2.89	<0.05	0.10	0.01	2.5	<0.05	<0.2	0.1	0.059	0.2
A00384	140	1.0	2.80	<0.05	0.10	0.01	2.4	<0.05	<0.2	0.1	0.058	0.2
A00386	140	0.8	1.37	<0.05	0.10	0.01	1.4	<0.05	<0.2	0.1	0.052	0.2
A00389	160	1.3	2.02	<0.05	0.10	0.03	3.2	<0.05	<0.2	0.1	0.100	0.6
A00390	140	0.5	4.57	<0.05	0.18	0.01	0.3	0.15	<0.2	<0.1	0.018	1.8
A00391	160	0.7	4.50	<0.05	0.18	0.05	1.0	0.2	<0.2	<0.1	0.040	2.1
A00392	180	1.0	5.01	<0.05	0.28	0.02	1.9	0.2	<0.2	<0.1	0.057	1.5
A00393	160	1.0	4.83	<0.05	0.23	0.03	1.9	0.15	<0.2	<0.1	0.058	1.6
A00394	440	1.1	5.70	<0.05	0.19	0.04	2.4	<0.05	<0.2	<0.1	0.080	0.3
A00395	220	0.8	4.31	<0.05	0.27	0.09	1.0	0.2	<0.2	0.1	0.050	2.2
A00404	300	18.3	10.1	0.25	0.25	0.06	74	0.2	0.4	<0.1	0.967	2.1

## Appendix 2 Correspondence relating to the incident

### Appendix 2A Supervising Scientist of 30 March 2004 specifying conditions for return to site for maintenance purposes

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Australian Government  
Department of the Environment and Heritage  
Supervising Scientist

file ref: SG2002/0084

30 March 2004

Mr Tony McGill  
Department of Business, Industry and Resource Development  
GPO Box 3000  
DARWIN NT 0801

CC Mr Simon Prebble, Energy Resources of Australia  
Ms Elaine Glen, Northern Land Council

Dear Mr McGill

#### **Re: Potable Water System at the Ranger Mine**

My staff have been in discussion with the mining company in relation to the possible return to site of mine staff.

I was unable to confirm that all parts of the potable water system had been flushed, but my staff have examined water quality data for various other locations on the mine site, and it is our view that the risks to staff have been adequately managed and that, subject to those areas being flushed and meeting EC and pH targets, staff may return to the Ranger site for *maintenance purposes only*.

All drinking water points should remain tagged as "out of service" until the analysis of two consecutive samples indicates that it meets the drinking water guidelines. Clean potable water will need to be made available on site until the potable water supply is cleared for human consumption.

Where two clear consecutive water samples have not been returned, but that part of the system has been flushed and EC and pH readings test satisfactory, the water at that point may not be used for drinking but may be used for other purposes such as washing and emergency showers/eyewashes. Two clear samples should be returned prior to that point being used for drinking.

Subject to the above comments, it is my view that staff may return to the site for maintenance purposes only and that mining and milling operations *should not resume* until I am assured that adequate processes are in place to ensure that this type of incident does not recur.

Could you please advise me of your determination on whether ERA staff should return to the Ranger site, based on the assessments/work done by your staff?

Yours sincerely

A handwritten signature in black ink, appearing to read 'A Johnston', with a stylized, cursive script.

Dr Arthur Johnston  
Supervising Scientist  
Phone: 08 89201101  
Email: Arthur.Johnston@deh.gov.au

## Appendix 2B DBIRD of 30 March 2004 supporting Supervising Scientist's conditions

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rc b4 : 61 8 89996527

DBIRD MINES DIVISION

31/03/04 08:10 Pg: 2/4



**Northern Territory Government**  
Department of Business, Industry & Resource Development

Mines and Petroleum Management Division  
Centrepoint Building  
48 – 50 Smith Street Mail  
DARWIN NT 0800  
AUSTRALIA  
Telephone: +61 8 8999 6470  
Facsimile: +61 8 8999 6527

Our ref: M2004/0106

Mr Simon Prebble  
General Manager Operations  
Energy Resources of Australia Ltd  
Locked Bag 1  
JABIRU NT 0886

Cc Dr Arthur Johnston, OSS  
Mr Brendan Lewis, NLC

Dear Simon

I refer to the recent Ranger potable water contamination incident and your email dated 30 March requesting confirmation of agreement that employees could return to work at the commencement of this evening's shift at 7pm.

I note that the Supervising Scientist has provided you with a copy of his correspondence to me on this subject, in which he supports staff returning to site in accordance with certain conditions. A copy of the Supervising Scientist's letter confirming the conditions is attached.

In accordance with the agreement between ERA, the Supervising Scientist and this department in regard to this matter I confirm that, as regulator, the Northern Territory Department of Business, Industry and Resource Development concurs with the proposal for resumption of activities on site. This return to work is subject to the conditions stipulated in the attached letter from the Supervising Scientist.

Yours sincerely

A handwritten signature in black ink, appearing to read 'Tony McGill'.

Tony McGill

Director of Mines

30 March 2004

## **Appendix 2C Supervising Scientist of 31 March 2004 specifying conditions for re-commencement of mining and milling activities**

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**Australian Government**  
**Department of the Environment and Heritage**  
**Supervising Scientist**

31 March 2004

Mr Tony McGill  
Department of Business, Industry and Resource Development  
GPO Box 3000  
DARWIN NT 0801  
**cc:** Mr Simon Prebble, ERA, & Ms Elaine Glen, NLC

Dear Mr McGill

### Re-commencement of Mining and Milling Activities at Ranger

Following my letter to you dated 30 March 2004, in which I advised of the conditions under which I would support the return to the Ranger site of ERA employees for maintenance purposes, I have now completed a similar assessment related to the re-commencement of mining and milling activities at Ranger.

I would support the re-commencement of mining and milling activities at Ranger subject to the following conditions being met;

1. The requirements that I specified in my letter to you dated 30 March 2004 relating to the return to the Ranger site of ERA employees for maintenance purposes continue to be met.
2. ERA demonstrates that the potable water system at Ranger meets the Australian Drinking Water Guidelines based upon the following;
  - a. Chemical analysis of two consecutive daily samples taken from representative points throughout the potable water system indicates that the water meets the drinking water guidelines in respect of chemical/toxicological considerations, and
  - b. Microbiological analysis of at least one representative sample of water taken from the potable water system indicates that the water meets the drinking water guidelines in respect of microbiological considerations, and

ABN 34190894983

#### **Darwin Office**

GPO Box 461 Darwin NT 0801 Australia  
Tel (08) 8920 1100 Fax (08) 8920 1199  
E-mail: enquiries\_ssd@deh.gov.au  
Internet: www.deh.gov.au/ssd

#### **Jabiru Field Station**

Locked Bag 2 Jabiru NT 0886 Australia  
Tel (08) 8979 9711 Fax (08) 8979 2076  
E-mail: enquiries\_ssd@deh.gov.au  
Internet: www.deh.gov.au/ssd

- c. Radiological analysis of at least one representative sample of water taken from the potable water system indicates that the water meets drinking water guidelines in respect of radiological considerations
3. Noting our preliminary conclusion that a primary cause of the incident was the poor condition of the process water distribution system, ERA should demonstrate that it is taking appropriate steps to put in place systems and measures and make improvements to plant and infrastructure that will prevent a similar incident from occurring in the future.
4. ERA installs a probe in a strategic location within the potable water system at Ranger that continuously measures Electrical Conductivity, connected to an alarm system to immediately alert ERA of contamination of the potable water system.
5. Where the systems, measures or improvements to plant and infrastructure referred to in 3. and 4. above can not reasonably be completed immediately, ERA should demonstrate, based upon a risk assessment, that
  - a. ERA has taken steps to adequately manage any risk that continues to exist until the systems, measures or improvements to plant and infrastructure have been implemented, and
  - b. ERA is doing all that it can reasonably do to expedite the implementation of the systems, measures and improvements to plant and infrastructure.

Considering the specific issues raised by the potable water contamination incident, it is my view that the health and safety of workers and the protection of the environment can be ensured if the conditions described above are met prior to the re-commencement of mining and milling activities.

I would be grateful for your advice on any conditions that the Northern Territory Government, as the regulator of the Ranger Mine, will require of ERA prior to the re-commencement of mining and milling at Ranger.

Please note that I will write to ERA today requesting that it submit to the authorities a proposal for re-commencement of mining and milling operations that demonstrates that the above conditions have been met.

Yours sincerely



Dr Arthur Johnston  
Supervising Scientist



## Appendix 2D ERA of 31 March 2004 requesting re-commencement of mining (but not milling)

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**ERA**

**Energy Resources of Australia Ltd**

ABN 71 008 550 865

31 March 2004

**FAXED**

Dr Arthur Johnston  
Supervising Scientist  
Department of the Environment and Heritage  
GPO Box 461  
DARWIN NT 0801

Tony McGill  
Dept of Business, Industry and Resource Development  
GPO Box 3000  
DARWIN NT 0801

Dear Arthur and Tony,

**Re: Commencement of Mining Activities at Ranger**

I refer to your letters dated 30 and 31 March 2004.

In relation to mining activities, the potable water supply in the mining area has been returned to normal drinking water standards. Two consecutive chemical samples from potable water outlets in mining have met the Australian Drinking Water Guidelines.

Mining activities do not impact on the process or potable water circuits.

Given the above we believe that restart of mining operations is appropriate. The mine will feed stockpiles and not the processing plant in the short term.

I would appreciate if you could respond to this request in writing as soon as possible, as we have mining crews at work ready to start mining immediately.

Yours sincerely

Simon Prebble  
General Manager Operations

**Darwin Office** PO Box 36646, Winnellie NT, 0821 Australia Tel: (08) 8935 1900 Fax: (08) 8935 1910  
**Sydney Office** 120 Christie Street, St Leonards NSW 2065 Australia Tel: (02) 9467 9811 Fax: (02) 9467 9800  
**Ranger Mine** Locked Bag 1, Jabiru NT 0886 Australia Tel: (08) 8938 1211 Fax (Admin): (08) 8938 1203 Fax (Supply): (08) 8938 1202  
**Website** [www.energyres.com.au](http://www.energyres.com.au)

*A member of the Rio Tinto Group.*

## Appendix 2E Supervising Scientist of 31 March 2004 supporting re-commencement of mining

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**Australian Government**  
**Department of the Environment and Heritage**  
**Supervising Scientist**

31 March 2004

Mr Simon Prebble  
General Manager Operations  
Energy Resources of Australia Ltd  
Locked Bag No 1  
JABIRU NT 0886  
**cc:** Mr Tony McGill, DBIRD, & Ms Elaine Glen, NLC

Dear Mr Prebble

Re-commencement of Mining Activities at Ranger

I refer to your letter dated 31 March 2004 on the resumption of mining, as opposed to milling, operations at Ranger.

I agree that it is appropriate to consider mining activities separately from milling. I would support the resumption of mining activities on the same conditions as those which I recommended in my letter of 30 March for the return of staff to the site for maintenance purposes.

Yours sincerely,

A handwritten signature in black ink, appearing to read 'A Johnston'.

Dr Arthur Johnston  
Supervising Scientist

ABN 34190894983

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## Appendix 2F DBIRD of 31 March 2004 supporting resumption of mining

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**Northern Territory Government**  
Department of Business, Industry & Resource Development

Mines and Petroleum Management Division  
Centrepoint Building  
48 – 50 Smith Street Mail  
DARWIN NT 0800  
AUSTRALIA  
Telephone: +61 8 8999 6470  
Facsimile: +61 8 8999 6527

Our ref: M2004/0106

Mr Simon Prebble  
General Manager Operations  
Energy Resources of Australia Ltd  
Locked Bag 1  
JABIRU NT 0886

Cc Dr Arthur Johnston, OSS  
Mr Brendan Lewis, NLC

Dear Simon

I refer to the recent Ranger potable water contamination incident and subsequent resumption of mining activities.

I note that the Supervising Scientist has provided you with a copy of his correspondence to me on the resumption of mining and milling operations, in which he supports staff returning to site in accordance with certain conditions. A copy of the Supervising Scientist's letter confirming the conditions is attached.

In accordance with agreement between ERA, the Supervising Scientist and this department in regard to this matter I confirm that, as regulator, the Northern Territory Department of Business, Industry and Resource Development concurs with the proposal for resumption of mining activities on site. This return to work is subject to the same conditions given for the return of maintenance staff as given in my letter of 30 March 2004.

At this stage the department does not support recommencement of milling operations.

Yours sincerely

A handwritten signature in black ink, appearing to read 'Tony McGill'.

Tony McGill

Director of Mines

31 March 2004

## Appendix 2G Supervising Scientist of 2 April 2004 re Jabiru East water quality

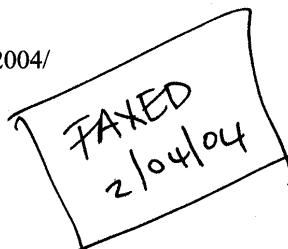
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*facsimile*



Australian Government  
Department of the Environment and Heritage  
Supervising Scientist

**To:** Simon Prebble, ERA  
cc Tony McGill, NTDBIRD  
**Date:** 2 April 2004  
**Fax no:** 89381203  
**doc name:**  
**From:** Arthur Johnston  
**file ref:** SG2004/  
**Fax no:** (08) 8920 1199  
Darwin Office  
**Subject:** Drinking Water Quality  
**No. pages (incl. this one):** 2



Dear Simon

We have reviewed the data you provided this morning in the spreadsheet (Water Quality Data MASTER) to determine whether it is sufficient to demonstrate that the potable water system at Ranger meets the Australian Drinking Water Guidelines. Our conclusion is that there are information gaps in the data that preclude the demonstration of compliance with drinking water guidelines. The information gaps and issues we have identified thus far are summarised below:

- Drinking water guidelines are applied to the total fraction – data in the spreadsheet are for filtrate only. Total fractions are required for comparison with drinking water guidelines rendering all comparisons made in the spreadsheet invalid.
- Microbiological results have not been received.
- The spreadsheet contains no data on organic compounds.
- No, or incomplete data for the following inorganic analytes appear to be included in the spreadsheet;
  - Nitrate, nitrite, ammonia, cyanide, fluoride, iodide
- Note that the drinking water guideline is expressed in terms of NO<sub>3</sub> whilst the results of analysis may be expressed in terms of NO<sub>3</sub>-N and an appropriate conversion will be required. A similar conversion may be required for NH<sub>3</sub> and NO<sub>2</sub>.
- The Guideline for Ag is 100ppm not 10ppm as quoted in the spreadsheet.
- The Guideline for As (7ppm) is not quoted in the spreadsheet. The guideline of 7 ppm is exceeded once at "Unknown location" – please clarify this location.
- It appears that many of the sites do not have two consecutive samples meeting the chemical criteria (note that the comparison is invalid in any case as filtered fraction rather than total fraction was analysed).

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**Jabiru Field Station**

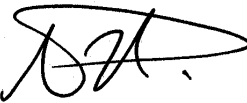
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- Gross alpha & gross beta analysis is not included. However, we note that such analysis is underway and that SSD is conducting specific radionuclide analysis.

To assist us in the interpretation of any further data when available, we would appreciate the results being tabulated against each of the following areas of the site:

- Administration
- Security/gatehouse/Jabiru East Line
- Engineering
- Mill Workshop
- Demin Plant
- Powerhouse
- Acid Plant
- Acid Storage
- Fine Crushing
- Area 42 (Pond Water Area)
- Primary Crushing
- Grinding
- Leaching
- CCD
- Neutralisation (Old)
- Lime Plant
- Clarifier
- Solvent Extraction
- Precipitation, Drying, Packing
- Ammonia Storage
- Water Management Yard
- Simon Carves Yard

Please do not hesitate to contact me if you require clarification.

  
for. Arthur Johnston  
Supervising Scientist

**Appendix 2H ERA of 6 April 2004 proposal to re-commencement of milling activities addressing the conditions stipulated by the Supervising Scientist on 31 March 2004**

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This 12 page document is contained in Appendix 2 of the ERA Investigation Report which is attached as Appendix 5 to this report.

## Appendix 2I Supervising Scientist of 6 April 2004 supporting re-commencement of milling activities

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**Australian Government**  
**Department of the Environment and Heritage**  
**Supervising Scientist**

6 April 2004

Mr Tony McGill  
Department of Business, Industry and Resource Development  
GPO Box 3000  
DARWIN NT 0801  
**cc:** Mr Simon Prebble, ERA, & Ms Elaine Glen, NLC

Dear Mr McGill

Re-commencement of Milling Activities at Ranger

I received today, 6 April 2004, a proposal from Energy Resources of Australia (ERA) to re-commence milling operations at the Ranger mine. We have now assessed that proposal and provide comment on it within the framework of my advice to you dated 31 March 2004.

1. The requirements that I specified in my letter to you dated 30 March 2004 relating to the return to the Ranger site of ERA employees for maintenance purposes continue to be met.
2. (a) ERA has now demonstrated, in my view, that the potable water system at Ranger meets the Australian Drinking Water Guidelines with respect to chemical/toxicological considerations.  
  
(b) ERA has now demonstrated that the drinking water on-site meets the drinking water guidelines with respect to microbiological considerations  
  
(c) ERISS has now analysed a sample from the drinking water system (collected on 31 March 2004) for Th-230, the radionuclide of the uranium series which gave rise to the highest dose estimate for water contaminated by process water on 24 March 2004. The measured concentration of Th-230 was 6 mBq/l. This result, together with the existing data for uranium in a number of samples, ensures that the water currently in the potable supply at Ranger meets the radiological guidelines in the Australian Drinking Water Guidelines.

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ERA will provide gross alpha and gross beta results in the next few days but, in the meantime, the above information can be used to demonstrate compliance with the guidelines.

3. Noting our preliminary conclusion that a primary cause of the incident was the poor condition of the process water distribution system, I requested that ERA should demonstrate that it is taking appropriate steps to put in place systems and measures and make improvements to plant and infrastructure that will prevent a similar incident from occurring in the future.

In the attachment to ERA's proposal to re-commence milling operations, entitled "Risk Review of Process Water System", ERA notes the work completed to date and the scope of works planned for the plant shutdown in May 2004. It has also identified the steps that it will take to minimise risks associated with the operation of the mill over the intervening period.

I am satisfied that, together with actions already implemented, these steps should ensure that a similar incident should not occur in the future.

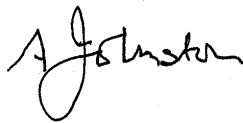
4. I note that ERA will install a probe within the potable water system at Ranger that continuously measures Electrical Conductivity and that it will be connected to an alarm system to immediately alert ERA of contamination of the potable water system. ERA proposes that, until this probe is installed and is operational, it will sample drinking water every 4 hours and check the pH and conductivity of the water. I consider this to be a satisfactory arrangement.

In addition, ERA has proposed that it would carry out hourly checks on the conductivity of samples from the potable supply during the first 24 hours following start-up of the mill. This procedure would be a useful check for the existence of any unknown connection between the process water system and the potable water system. I support this proposal as an appropriate additional check that should be carried out.

In summary, I am now satisfied that measures have now been implemented at Ranger that will ensure that the environment and health of workers and local people would not be put at risk as a result of an incident like this in the future.

I would be grateful for your advice on any conditions that the Northern Territory Government, as the regulator of the Ranger Mine, will require of ERA prior to the re-commencement of milling operations at Ranger.

Yours sincerely



Dr Arthur Johnston  
Supervising Scientist



## Appendix 2J DBIRD of 6 April 2004 supporting re-commencement of milling activities

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**Northern Territory Government**  
Department of Business, Industry & Resource Development

Mines and Petroleum Management Division  
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Telephone: +61 8 8999 6470  
Facsimile: +61 8 8999 6527

Our ref: M2004/0108

Mr Simon Prebble  
General Manager Operations  
Energy Resources of Australia Ltd  
Locked Bag 1  
JABIRU NT 0886

Cc Dr Arthur Johnston, OSS  
Mr Brendan Lewis, NLC

Dear Simon

I refer to the recent Ranger potable water contamination incident and your subsequent proposal dated 6 April, regarding resumption of milling activities.

The Supervising Scientist has indicated support for the resumption of milling operations at Ranger in accordance with certain conditions. A copy of the Supervising Scientist's letter confirming the conditions is attached.

In accordance with previous agreement between ERA, the Supervising Scientist and this department in regard to this matter I confirm that, as regulator, the Northern Territory Department of Business, Industry and Resource Development concurs with the proposal for resumption of milling activities on site. This return to work is subject to the conditions agreed between the parties and confirmed in the Supervising Scientist's letter.

Yours sincerely

Tony McGill

Director of Mines

6 April 2004

## Appendix 2K Supervising Scientist to ERA 20 April 2004 re Jabiru East supply

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*facsimile*



Australian Government  
Department of the Environment and Heritage  
Supervising Scientist

**To:** Tony Milnes, EWLS **Date:** 20 April 2004  
**Fax no:** 08-8922-5260  
**From:** Arthur Johnston **file ref:** SG2004/0039  
**Fax no:** (08) 8920 1199 **Darwin Office**  
**Subject:** Proposal to Re-Instate Jabiru East Potable Supply  
**No. pages (Incl. this one):**  
cc Mr Alan Hughes, DBIRD

Dear Tony

Following our discussion this morning, I would like to summarise our position on the re-instatement of the Jabiru East potable water supply.

We have a number of concerns about the data and information contained in the proposal dated 16 April. These include:

1. Total concentrations vs filtered

The drinking water guidelines require the use of total samples rather than filtered. While a number of total results have been presented, the final data set presented lacks balance in this respect. There are a number of samples for ERISS but very little data for the Airport, particularly for the Tourist Centre.

2. Organics

Analysis for organics is limited to one sample and this is for a sample collected from a tap at the Helicopter site.

3. Microbiological analyses

The only microbiological analysis presented is for a sample of water collected at the mine site itself on 30 March 2004. This is of particular concern because the Jabiru East system has been open on a number of occasions and the Australian Water Quality Guidelines state that microbiological analyses need to be carried out on systems after closure. The mine site sample is, therefore, not relevant to Jabiru East.

4. Nitrate, Nitrite and Ammonia

Few analyses are presented for Nitrate, Nitrite and Ammonia. Just how representative are these data of the Jabiru East system?

5. Sample preservation and storage

Details of sample preservation and storage were not provided. This is of concern because of the discrepancy between ERISS and ERA samples collected at the same time and place on 25 March 2004. The ERISS results are much higher for a number of analytes. After discussion, this has been explained because the ERA samples were filtered prior to acidification.

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Because of the above reservations, I believe that it would not be appropriate to re-instate the Jabiru East potable supply until additional samples are collected and analysed as follows:

- Samples: Samples should be collected from ERISS, the Tourist Centre at the Airport (two representative samples), the Gagadju Workshop and a suitable point on the line as it enters Jabiru East (for example, at the corner opposite the storage tanks at the end of the airport runway).
- Essential analyses: Before re-instatement of the supply, the samples should be collected and treated as specified in the Australian Drinking Water Standards and analysed for (a) the full suite of inorganic elements including Nitrates, Nitrites and Ammonia and (b) Micobiological analysis.
- Secondary analyses: In addition to the above analyses, arrangements should be put in place for (a) Gross alpha and Gross beta and (b) Total Petroleum Hydrocarbons. In a duty-of-care and risk assessment framework, given the known characteristics of water currently in the drinking water system at the mine, I do not believe that the results of these analyses need be available at the time of re-instatement of supply but should be reported as soon afterwards as possible.

I also reiterate my earlier advice that I believe that, since the supply to the Jabiru Airport, in particular, involves the supply of drinking water to members of the public, ERA would be well advised to ensure that all of the procedures that it has adopted would be supported by the responsible NT authorities.

Yours sincerely



Dr Arthur Johnston  
Supervising Scientist

## **Appendix 2L ERA to DBIRD and Supervising Scientist 22 April 2004 proposal to return water supply to Jabiru East for industrial purposes**

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Thursday April 22 2004

Mr Alan Hughes  
Department of Business, Industry and Resource Development  
GPO Box 3000  
DARWIN N T 0801

Dr Arthur Johnston  
Supervising Scientist  
Department of the Environment and Heritage  
GPO Box 461  
DARWIN N T 0801

### **Proposal to Return Water Supply to Jabiru East for Industrial Purposes**

Further to our discussions today, ERA proposes to reinstate water supply from the Brockman borefield at Ranger to Jabiru East for industrial purposes. This would include, but not be limited to, the following uses:

- Toilets.
- Garden sprinklers.
- Equipment washing facilities.

The water would not be for drinking purposes until we have clearance from the relevant authorities.

The reinstatement would be subject to the following conditions:

- Drinking water outlets will remain locked out of service.
- Outlets available for industrial use will be clearly marked "Not Drinking Water", together with a standard graphical symbol.
- An ERA representative will communicate with each Jabiru East business to explain the conditions before water supply is made available.
- Bottled water will continue to be available for drinking purposes.

In the unlikely event that these controls fail, and a person drinks water from a Jabiru East outlet, the extensive water quality data for Jabiru East gives confidence that there would be no risk to that person's health.

ERA requests that written approval be given to reinstate water supply to Jabiru East as outlined above.

Yours sincerely

**Simon Prebble**  
**General Manager Operations**

---

Head Office	GPO Box 2394, Darwin NT 0801 Australia Tel: (08) 8924 3500 Fax: (08) 8924 3555
Sydney Office	120 Christie Street, St Leonards NSW 2065 Australia Tel: (02) 9467 9811 Fax: (02) 9467 9800
Ranger Mine	Locked Bag 1, Jabiru NT 0886 Australia Tel: (08) 8938 1211 Fax: (08) 8938 1203
Web Site	<a href="http://www.energyres.com.au">www.energyres.com.au</a>

*A member of the Rio Tinto Group*

## **Appendix 2M Supervising Scientist to ERA 22 April 2004 supporting proposal to return water supply to Jabiru East for industrial purposes**

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**Australian Government**  
**Department of the Environment and Heritage**  
**Supervising Scientist**

22 April 2004

Mr Simon Prebble  
General Manager Operations  
Energy Resources of Australia Ltd  
Locked Bag No 1  
JABIRU NT 0886

**cc:** Mr Alan Hughes, DBIRD, & Ms Elaine Glen, NLC

Dear Mr Prebble

### **Return of Water Supply to Jabiru East for Industrial Purposes**

Thank you for your letter of today's date proposing the return of water supply to Jabiru East, from the Brockman borefield, for industrial purposes only.

I support your proposal to return supply of water to Jabiru East for industrial purposes under the conditions that you specify in your letter. Given the extensive testing of water in the Jabiru East region recently, it is clear that, even if the controls that you have specified fail, no harm would come to anyone who consumes a small quantity of the water in Jabiru East.

Yours sincerely

Dr Arthur Johnston  
Supervising Scientist

ABN 34190894983

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Internet: [www.deh.gov.au/ssd](http://www.deh.gov.au/ssd)

## **Appendix 2N ERA 7 June 2004 Final proposal for reinstatement of potable water system in Jabiru East**

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This 17 page document is contained in Appendix 9 of the ERA Investigation Report which is attached as Appendix 5 to this report.

## Appendix 2O Supervising Scientist 9 June 2004 supporting reinstatement of Jabiru East potable water supply

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**Australian Government**  
**Department of the Environment and Heritage**  
**Supervising Scientist**

9 June 2004

Mr Tony McGill  
Department of Business, Industry and Resource Development  
GPO Box 3000  
DARWIN NT 0801  
**cc:** Mr Simon Prebble, ERA; Ms Elaine Glen, NLC; Mr Xavier Schobben,  
DHCS

Dear Mr McGill

Proposal to Re-instate Potable Water Supply to Jabiru East

We have reviewed the proposal by ERA to re-instate the potable water supply to Jabiru East dated 7 June 2004. In relation to the proposal, we note the following:

- ERA has already demonstrated that the potable water system at the Ranger mine, which was the source of contamination at Jabiru east, again meets the Australian Drinking Water Guidelines.
- ERA has collected and analysed water samples from the Supervising Scientist Field Station, the Jabiru East Café, NA Helicopters facilities, the Jabiru East Tourist Centre and the Gagadju Workshop.
- With the exception of ammonium, nitrate and nitrite, all inorganic parameters meet drinking water guidelines in two consecutive samples for each of the 5 areas listed above. Ammonium, nitrate and nitrite data is limited to 7, 11 and 11 samples respectively and do not represent all 5 areas. However all ammonium, nitrate and nitrate data presented meet Australian Drinking Water Guidelines.
- Microbiological parameters meet Australian Drinking Water Guidelines in 3 consecutive samples for each of the 5 areas listed above.
- Analysis of organic parameters and gross alpha and gross beta activity are underway and will be reported when available.

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I am satisfied that the sampling strategy implemented by ERA has effectively characterised the quality of water in the Jabiru East potable water system.

Even considering that there are limitations in the ammonium, nitrate and nitrite data, the data overwhelmingly indicates that the Jabiru East potable water supply meets Australian Drinking Water Guidelines. On this basis, I support the reinstatement of the potable water supply to Jabiru East, noting that the results of the analysis for organic parameters and gross alpha and gross beta activity will be reported in due course. I do not believe that there is a credible risk that the results of these analyses will fail to meet Australian Drinking Water Guidelines.

Yours sincerely

Dr Arthur Johnston  
Supervising Scientist



## Appendix 2P DBIRD 11 June 2004 approval of reinstatement of Jabiru East potable water supply

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**Northern Territory Government**  
Department of Business, Industry & Resource Development

Mines and Petroleum Management Div  
Centrepoint Bldg  
48 – 50 Smith Street  
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AUSTRALIA  
Telephone: +61 8 8999 6  
Facsimile: +61 8 8999 6

Our ref: M2004/0137

Mr Simon Prebble  
General Manager – Operations  
Energy Resources of Australia Ltd  
Locked Bag 1  
JABIRU NT 0886

Dear Simon

I refer to correspondence from Dr David Jones of EWL Sciences dated 7 June 2004, in regard to your proposal to reinstate the potable water supply at Jabiru East from the Ranger potable water supply.

Based on your proposal, I am satisfied that the Jabiru East water supply meets the Australian Drinking Water Quality Guidelines and that ERA has satisfied the conditions that it agreed with stakeholders would be prerequisite to reinstatement of the water supply for potable use. I therefore advise that I have no objection with ERA doing so in accordance with the conditions proposed in section 4 of your proposal.

Dr Arthur Johnston, Supervising Scientist, and Mr Xavier Schobben, Director of Environmental Health with Territory Health Services have also indicated that they support the proposed reinstatement of the potable water at Jabiru East. It is my understanding that you have received a copy of Dr Johnston's comments in this regard.

The Director of Environmental Health has indicated that Territory Health Services consider the water at Jabiru East to be a public water supply, and has made some further comments accordingly. A copy of these comments is attached for your information.

Yours sincerely

A handwritten signature in black ink, appearing to read 'Tony McGill'.

Tony McGill

Director of Mines and Petroleum Management

11 June 2004

## Appendix 3 SSD Human Health Risk Assessment

### Appendix 3A Details of expert group engaged by the Supervising Scientist

Organisation	Name, professional details and summary of experience
Australian Centre for Human Health Risk Assessment (ACHHRA)	<p><b>Professor Brian Priestly</b></p> <p><i>Director, ACHHRA; Professorial Fellow, Monash University Department of Epidemiology &amp; Preventive Medicine, Alfred Hospital</i></p> <p>PhD in Clinical Pharmacology.</p> <p>Extensive experience in drug toxicity and risk assessment and regulatory control of hazardous chemicals including: management of toxicological and public health assessments for agricultural, veterinary and industrial chemicals for relevant Australian regulatory authorities; responsibility for policy development for national and international chemicals regulatory activities; advice on regulation of OTC and complementary medicines; and community liaison on hazardous chemicals issues. Current role includes promoting Australian contributions to national and international chemicals risk assessment and risk management programs.</p>
National Research Centre for Environmental Toxicology (EnTox)	<p><b>Professor Michael Moore</b></p> <p><i>Director, EnTox; Director, Queensland Health Scientific Services (QHSS)</i></p> <p>PhD in Medicine, Doctorate in Science in the field of biochemistry in medicine and has trained in Clinical Pharmacology.</p> <p>Member of numerous advisory groups, working groups, task forces and expert committees including: NHMRC Group on Toxicity &amp; Risk Assessment and Chair, Drinking Water Treatment Chemicals Working Party; TGA, Australian Drug Evaluations Committee and National Drugs and Poisons Schedules Committee; Environment Australia, National Dioxins Consultative Group and Air Toxics forum; Department of Veterans Affairs, Korean Veterans Mortality and Health Studies, Depleted Uranium Exposure and the ADF and Study of Health Outcomes in Aircraft Maintenance Personnel.</p> <p><b>Associate Professor Barry Noller</b></p> <p><i>Deputy Director, EnTox</i></p> <p>PhD in Environmental Chemistry and spent 10 years working for the Office of the Supervising Scientist doing research in relation to Ranger mine.</p> <p>Current research themes include risk assessment of mined land and risk assessment of pesticide applications.</p> <p><b>Associate Professor Jack Ng</b></p> <p><i>Research Program Manager of Metals and Metalloids Research, EnTox</i></p> <p>PhD in Environmental Toxicology and Chemistry.</p> <p>An internationally recognised arsenic expert with research focus on toxicology of mixtures in the environment and food. He has extensive research experience in the fields of Environmental Toxicology and Chemistry, heavy metals, natural toxins and risk assessment of environmental toxicants.</p>

## **Appendix 3B Terms of Reference**

### **Assessment of health impacts following exposure of workers at Ranger mine to contaminated potable water**

#### *Terms of Reference*

**Based on the existing literature and state of expert knowledge, provide:**

1. An assessment of the short- and long-term health risks/impacts (arising due to chemical toxicity) to workers at Energy Resources of Australia's (ERA) Ranger mine, following exposure to potable water contaminated with mine process water containing elevated concentrations of numerous elements including, but not restricted to:
  - o□ Aluminium
  - o□ Cobalt
  - o□ Copper
  - o□ Manganese
  - o□ Nickel
  - o□ Lead
  - o□ Uranium
  - o□ Zinc
  - o□ Ammonia
  - o□ Major ions
2. Advice on the most appropriate procedures (eg. what types of samples – urine, blood, bile, hair, etc. – and what type of analytes/biomarkers) for testing for exposure to/presence of and effects of the key contaminants within the exposed workers; and
3. Advice on appropriate long-term procedures for monitoring effects on and health status of the exposed workers.

**The task should comprise two phases:**

1. A 'first-pass' assessment providing timely initial advice to the Supervising Scientist on points one and two, above, within two days of formal agreement for the task to commence; and
2. A detailed human health risk assessment of the incident, addressing points one to three, above (timeline to be advised).

#### **Additional information**

1. The consultant will need to liaise with and obtain information from relevant personnel within the Supervising Scientist Division (SSD) and ERA's human health expert, Richard Gaunt, which it has brought in from its parent company, Rio Tinto Australia.
2. SSD is separately undertaking an assessment of the risks of the radiological exposure to the workers.

## **Appendix 3C Final Report of the Health Risk Assessment**

# **HUMAN HEALTH RISK ASSESSMENT ON THE POTABLE WATER CONTAMINATION INCIDENT AT RANGER URANIUM MINE MARCH 2004**

The Australian Centre for Human Health Risk Assessment (ACHHRA) and the National Research  
Centre for Environmental Toxicology (EnTox)

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## Executive Summary

1. Workers at the Ranger uranium mine were potentially exposed to metals and other substances normally present in process water when an inappropriate connection allowed the process water to mix with potable water. The exposure was probably confined to a period of less than 12 hours, over the night shift of 23-24 March 2004, before the contamination was discovered, the system shut down, and the workers dismissed from the mill.
2. Analysis of potable water samples taken from various places in the reticulation system confirmed that contamination had occurred. However, the large variation in metal and other elemental concentration between different samples, and the probability that the process water penetrated the reticulation system at a rate dependent on water use and flow rates, meant that workers would not necessarily have been exposed to the most heavily contaminated water throughout the course of the incident.
3. While some workers reported strange taste and appearance of the water during the early hours of 24 March 2004, and few estimated they drank up to 5 litres during the course of their shift, it is likely that not all of this water was contaminated. Furthermore, the taste and gastrointestinal irritation associated with the rising metal concentrations may have limited intake, and therefore limited the potential for adverse health effects.
4. Acute health effects reported by 21 of the exposed workers (gastrointestinal distress; two cases of vomiting; skin itchiness on washing or showering) are consistent with the known irritant effects of some of the metals. The health risk assessment (HRA) in this report predicts that the levels of sulfate and some of the metals (e.g. magnesium, copper) could have been high enough to produce such acute symptoms based on a 'worst-case' estimated oral intake. The fact that most of the potentially exposed workers reported no adverse health effects, nor noticed any changes in the taste of the water, suggests that such 'worst-case' estimates of intake are probably overestimates of the actual exposures.
5. While the acute effects associated with short-term intake of contaminated water are reasonably clear cut and transient, this risk assessment also addresses possible longer-term or delayed adverse health effects. The estimates of intake for this longer-term risk assessment are based on the levels of metals and other substances in water samples drawn from a toilet cistern and a tap in the engineering shower block. They represent the potential range of potable water contamination during the course of the incident and while the levels were well below the levels of the same substances in undiluted process water, they have been used, suitably qualified, to estimate the 'worst-case' intakes. The worst case exposure scenarios were set out in instructions from the SSD and were based on estimates of the amount of water ingestion self-reported by the workers.
6. The extent to which the 'worst-case' levels in these two index samples exceed Health Guideline Values (HGVs) in the Australian Drinking Water Guidelines (ADWGs) was used as an initial screening tool, to prioritise the substances for the longer-term health risk assessment. Caution must be used in interpreting these 'exceedances', since HGVs are conservative estimates of a safe level of exposure over a lifetime, and the short-term exposure (<12 hours) in this incident would not necessarily affect the same target organs, or could require much longer term exposure to produce adverse health effects. Where possible, the 'worst-case' intake estimates in this incident have been compared with animal and/or human studies where exposures occurred acutely or over a short time span.

7. With the risk assessment conducted in this way, it is possible to conclude that it is most unlikely that the short-term exposures would result in any delayed (or longer-term) adverse health effects, beyond the acute skin and gastrointestinal irritation which were reported by some workers.
8. Preliminary health studies based on blood and urine samples taken from some workers about one week after the incident appear to show there were no adverse effects on the kidney, a significant target organ for uranium, lead and copper. However, some clinical chemistry values in individual workers were marginally above the normal range and this could be followed up with repeat testing of those workers, at the discretion of their attending physician(s).
9. This report makes some suggestions on possible health follow-up studies, to address the possibility that kidney or brain function may be affected at a later date as a result of the manganese, uranium or lead exposures. However, given the overall conclusion of this HRA, that such outcomes are unlikely, and the inherent difficulties in interpreting such tests in individual workers, the merits and design of such studies need to be carefully appraised. Any decision to conduct such tests at some future time should be left to medical professionals attending the workers, taking into consideration the level of reassurance needed in individual cases.

# 1 Introduction

This health risk assessment (HRA) has been prepared to assist the Supervising Scientist Division (SSD) of the Department of Environment & Heritage in its management of an incident at the Ranger uranium mine in March 2004. It was reported that some workers in the Ranger mill at the time of the incident were inadvertently exposed to unusual levels of metals and other substances when potable water became contaminated with process water. The workers were reported to have been potentially exposed to the contaminated water through drinking and showering during the night work shift on 23-24 March 2004 and the early day shift on 24 March 2004.

## 2 Supporting Information

### 2.1 Scope of this Report

This Health Risk assessment (HRA) addresses possible short term and longer term health risks of the exposed workers at the Ranger uranium mine arising from the toxicological characteristics of the metals and other substances identified in the contaminated water. It does not address potential human health risks or environmental effects arising from off-site exposure. The Terms of Reference for the HRA, as specified by the SSD, are provided in Appendix A. The SSD has advised that a separate assessment is being undertaken of the radiological risks to the workers.

The contamination incident is reported to have commenced around 8.00pm Tuesday 23 March 2004, when persistent triggering of a low water alarm in the Ranger mill resulted in certain actions to increase water supply to the scrubber. This report has not attempted to investigate the cause of an inappropriate connection which allowed process water from the circulation line from the mill to Pit 1 to enter the potable water supply to the mill area. This issue has been separately investigated by the SSD. It is likely that a pump seal failure elsewhere on the mine lease caused the process water to be drawn through various parts of the potable water system while the inappropriate connection was in place.

A table of general water quality characteristics is given in Table 1. The dominant feature of water quality is the high conductivity of the process water associated with the presence of major ions.

The contaminated samples (E and H) have significantly poorer water quality than the potable bore water from the Brockman borefield which usually supplies the Ranger mine, but neither of these samples is as concentrated as undiluted process water from Pit 1.

Exposure to the contaminated water during this incident was potentially via:

- Drinking directly from the potable water supply
- Using potable water for making tea or coffee. It is noted however that urns were available for supply of hot water, hence exposure to contaminated water would depend on whether the urn was filled during the time contamination was present in the pipe system.
- Using ice that may have been made from contaminated water.
- Showering or washing using contaminated water.

It was reported that workers first noted a changed taste in the potable water supply at around 2.30am on Wednesday 24 March 2004, and later the same morning, there were further reports of unusual taste, skin itchiness and poor lathering by workers using the showers. Two people vomited (see Table 5; Appendix C).



**Table 1: General water quality characteristics of drinking water process water and drinking water containing process water\***

Water quality variable	Potable water bore	Sample H	Sample E	Process Water in Pit 1
pH	7.79	4.2	6.7	3.68
Conductivity (µS/cm)	396	8710	1505	18700
Sulfate (mg/L)	1.1	8370	407	17240
Calcium (mg/L)	22	217	63	391 (f)
Magnesium (mg/L)	38.5	1260	138	2690
Ammonium (NH <sub>3</sub> -N) (mg/L)	-	277	32.5	-
Nitrite (as-N) (mg/L)	<0.005	0.025	<0.005	0.015
Nitrate (as-N) (mg/L)	0.045	0.39	0.06	1.0
Uranium (mg/L)	0.0083	7.1	0.37	18.9
Manganese	<0.001	607	64.2	1360

\* Samples E & H were selected for the risk assessment scenarios (see Section 2.2.1) and were taken to be representative of the 18 water samples taken from various parts of the reticulation system on 24 March 2004 (see Table 4, Appendix B). (f) indicates the sample was filtered.

Subsequent analysis of water samples from various parts of the potable water system confirmed the presence of high levels of substances consistent with contamination with process water, associated with high dissolved salts and metal concentrations.

This risk assessment does not attempt to quantitatively estimate the risk of any exposed individual suffering an adverse health effect, since the data do not permit an accurate assessment of individual exposures and there are significant data gaps in the databases describing short-term toxic effects of most of the metals concerned. The approach taken in this HRA is to compare representative exposures, including those based on ‘worst-case’ assumptions of exposure, with dose levels reported to cause adverse health effects in published reviews or studies with exposed humans or animals. The ‘margin of safety’ derived using this approach yields a semi-quantitative estimate of the likelihood that adverse health effects could arise as a consequence of the incident.

## 2.2 Construction of suitable ‘worst-case’ exposure scenarios

### 2.2.1 Water quality

The authors of this HRA have been provided with several sets of analytical data derived from samples taken by both the SSD and by the mine management from different parts of the potable water reticulation system on 24 March. The samples appear to have been analysed by two different laboratories.

The samples have been subject to re-analysis in some cases, to resolve issues around possible interferences. Table 4 (Appendix B) represents a final set of figures, provided to the authors of this report on 6 May 2004. Some of the figures are different to those provided on 29 March 2004, and on which a preliminary risk assessment was provided to the SSD. However, the magnitude of the differences is not sufficiently large to alter the basic conclusions of the HRA.

For many of the metals analysed, data are provided on filtered and total concentrations. On the information provided, it appears that samples designated as ‘filtered’, were filtered to remove particulate matter then acidified, with ICP-MS or other analytical techniques applied to the filtrates. The samples identified as ‘total’ underwent an 8 hour acid digestion prior to analysis.

In some cases, the differences between ‘total’ and ‘filtered’ are not large, indicating that most of the metals were already in solution in the slightly acidic water. Where there are differences between the ‘total’ and ‘filtered’ levels, this presumably reflects metals which are present as tightly bound particulate matter in the samples.

In this HRA, we have chosen to make comparisons with the values reported as ‘total’ for the various metals. In many cases, the differences are not large, in comparison with the much larger variation in levels between samples taken from different parts of the potable water system. As the metals may be further solubilised in the acid environment of the stomach after ingestion, the conservatism in the choice of ‘total’ samples is consistent with the adoption of a ‘worst-case’ approach to this HRA.

As requested by SSD (see Appendix A), the ‘worst case’ exposure estimates are derived from levels of analytes measured in two samples of potable water taken during the period of contamination. The samples are designated as:

- Sample E (also designated as sample A00319 in some reports), which was taken from the engineering shower block; and
- Sample H (also designated as sample A00322 in some reports), which was taken from a toilet cistern in the ground floor grinding area of the mill.

These two samples are shaded in the tabulated data shown in Table 4, Appendix B, which reports the levels of all analytes in all 18 water samples taken at the time of the incident.

Given that Sample H was drawn from a toilet cistern, and the contaminant levels were higher (in some cases up to one or two orders of magnitude higher) than many of the other 17 samples drawn during the time of the incident (see Table 4, Appendix B), a question arose as to whether this sample was truly reflective of the quality of the potable water supply that services the taps from which workers may have drawn water for drinking, washing and making ice or hot beverages. It is clear that the level of contaminants reported in samples taken from many other parts of the potable water reticulation system, including some taken off-site at downstream locations such as Jabiru East, the water quality was much closer to that of the bore water source for the potable water system.

However, it was confirmed to the authors of this HRA that the toilet block receives potable water from the same reticulation system. While it is possible that the higher levels of metals in Sample H are due in part to dissolution from accumulated sludge, in the absence of information on the sequence and precise timing of the sample collections, it is difficult to be sure that Sample H is not representative of the ultimate deterioration of the water quality to which the workers were exposed, at least for part of the time.

Irrespective of whether Sample H is truly reflective of the level of contamination to which most, or even some of the workers were exposed, the authors of this HRA concur with the instructions of the SSD and consider it suitably conservative to base the ‘worst-case’ exposure scenario on this water sample.

This report notes, but has not attempted to resolve, a number of apparent discrepancies between the data sets analysed by SSD and ERA, where they appear to have been sourced from similar points in the reticulation system (see Table 4, Appendix B). For example, it is noted that the ratios

between the concentrations of different metals are not consistent across all the samples. This is an observation which appears inconsistent with a simple process of dilution as the process water mixed with the potable water. It may have occurred as a result of some metals undergoing dissolution from sludge and/or particulates at different rates as the pH of the potable water slowly declined through mixing with the more acidic process water. It is further noted that mixing of acidic process water and sludge trapped within the system will bring adsorbed metal and other ions into solution, but will not dissolve the iron hydroxide which requires  $\text{pH} < 2.7$  to dissolve. The presence of any iron hydroxide should be evident from brown discoloration in the water unless masked by the presence of magnesium and aluminium hydroxides.

Speciation modeling was undertaken on various metals to identify soluble forms present in Samples E and H. In general metals are present in soluble forms in Sample H ( $\text{pH} 4.2$ ) being mildly acidic but may be removed from solution in Sample E ( $\text{pH} 6.7$ ). The following are details of the speciation of the key metals. Most manganese (85%) is in solution as free manganese cation in Sample H whereas only 25% is present in Sample E. Uranium is essentially present as the free uranyl cation or as uranyl sulfate in Sample H but in Sample E free uranyl cation is substantially reduced to  $<2\%$  and has converted to uranyl hydroxyl forms some of which can precipitate. Lead is mainly present (64%) as the free cation in Sample H but is reduced to 17% in Sample E. Nickel follows a similar pattern to lead. Aluminium is essentially all present as the free aluminium cation or aluminium sulfate form in Sample H but exists almost entirely in precipitated forms in Sample E. Thus samples containing predominantly process water (eg  $\text{pH} < 5$  as is the case with Sample H) will not be affected by taking a total or filtered sample. In the case of samples containing potable water with lesser quantities of process water there will be an effect from filtration of sample giving less than total concentration of the metal in question.

### 2.2.2 Water consumption estimates

Also as requested by SSD, the ‘worst case’ risk scenario considered in this report assumes that workers ingested either 500ml or 5 litres of Samples E or H. These figures are based on the range of water consumption reported by workers (see Figure 1 and Table 5; Appendix C).

On the advice given by ERA, no workers were exposed to the contaminated water for a period longer than 12 hours. The reported levels of ingestion of drinking water varied from zero to around 5 litres during the relevant period. The number of self-reported exposures, categorized by ERA into three groups were (see Table 5; Appendix C).

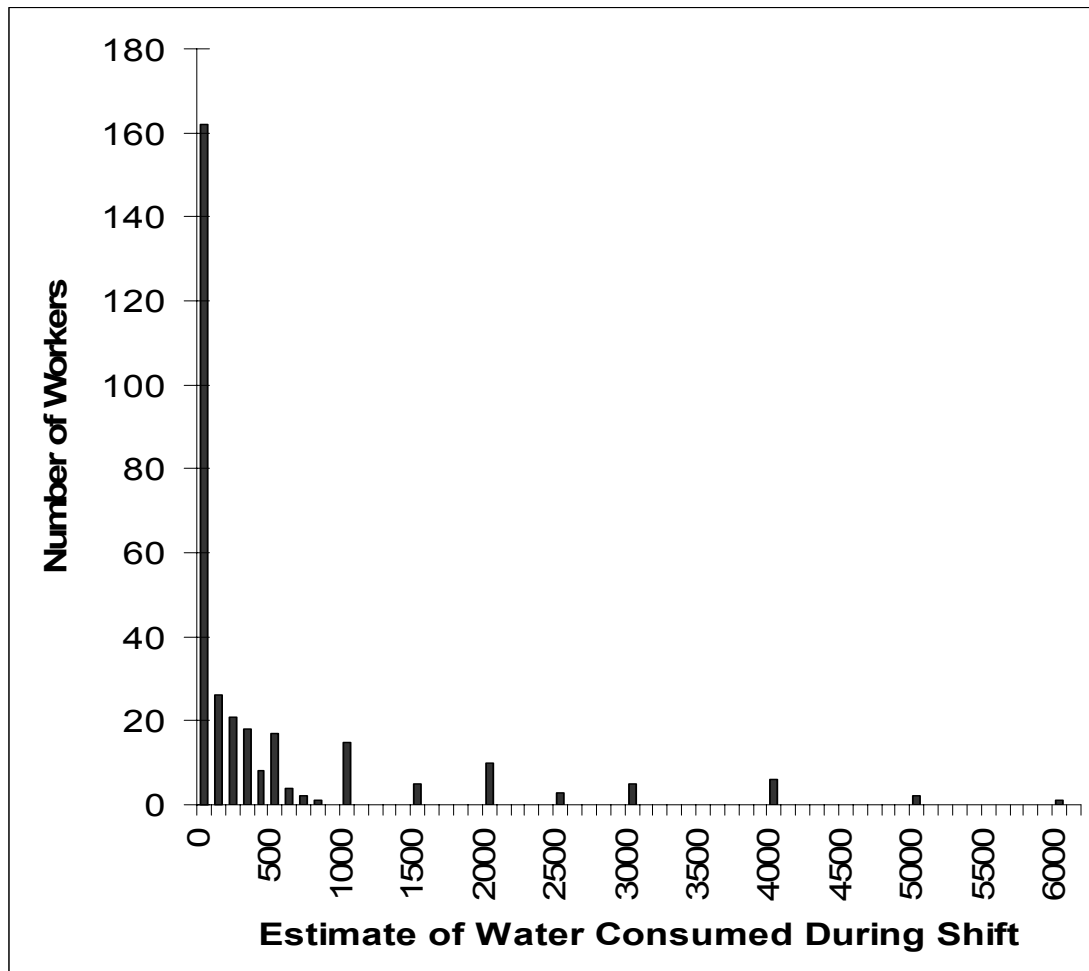
<500ml	71
500ml – 2 litres	45
>2 litres	27

Approximately half of the 306 workers interviewed did not report any water consumption, in many cases because they were absent or off-site during the course of the incident.

The intakes are also represented graphically in Figure 1.

The individual exposures to the analytes present in the contaminated water would actually vary quite substantially, since the contamination would spread to different parts of the potable water reticulation system at different rates, dependent on back pressure and flow. This is consistent with the variation in contaminant levels in samples drawn from different parts of the reticulation system. Workers using water from the system for drinking and washing would have been exposed to increasing levels of contaminants as mixing occurred within the reticulation system. While some individual workers reported ingesting up to 5 litres of water in total during the incident, it is likely

that as the levels of contaminants rose and changed the taste and appearance of the water, individuals would have limited their intake as this became apparent.



**Figure 1: Self-reported estimates of potable water consumption in mL during the incident (compiled from Table 5)**

It should be noted that some workers who reported drinking water during their shift did not report any unusual taste, and did not report any immediate change in their health.

To illustrate that the ‘worst-case’ scenario based on Sample H may overestimate the real exposures, it should be noted that Sample H contained 1357 mg/l magnesium and 11.7 mg/l copper. Both magnesium and copper sulfates are powerful gastrointestinal irritants. Oral administration of concentrated solutions causes gastrointestinal irritation, vomiting, abdominal pain and diarrhoea, usually of rapid onset (see Sections 4.1.1 and 4.2.6 of this report for more detail).

There were two reported cases of spontaneous vomiting from workers who may have ingested the water later in the morning and may therefore have been exposed to water containing the highest concentration of the contaminants (Table 5, Appendix C). If more workers had been exposed to water comparable to Sample H, more frequent reports of gastrointestinal distress might have been expected.

## 2.3 Exposures through showering and washing

This HRA focuses primarily on the amounts of analytes which may have been ingested through drinking. Since the workers also showered and washed using the contaminated water, it is possible that some systemic exposure occurred through skin absorption and inhalation. However, systemic exposure via these sources is likely to be much less than the ingested exposures and it is difficult to estimate. Such estimates require assumptions to be made around water flow rates, the duration of the showering or washing, the relative amounts of water which are retained on the skin or flow through to drains, the extent of dermal penetration and deposition of the analytes, the ability of the analytes to transfer through the skin (likely to be very low for most of the metals), and the extent to which the analytes could be incorporated into aerosol and inhaled (also expected to be very low for most of the metals).

To illustrate this point, a published paper by Kim, Little & Chiu (2004) estimated the comparative oral, dermal and inhalational exposures for three types of water contaminants where the exposures were associated with a combination of drinking, washing and showering. For lead, a non-volatile metal poorly absorbed through skin, the oral component was >99.9%, meaning that dermal exposures through washing and showering would account for less than 0.1% of total exposure. In comparison, more volatile and better absorbed substances such as dichlorobromomethane (62% inhalation, 27% ingestion) or the pesticide endosulfan (70% oral, 18% dermal transfer) were much more likely to have significant contributions from non-ingested pathways.

The above limiting factors make it reasonable to conclude that the dermal exposure route would have contributed little if anything to the systemic toxicity potential of the contaminated water, in comparison to the amounts ingested directly by drinking.

However, there is a much greater likelihood that adverse health effects could occur in the form of skin itching and irritation, which could be associated with the mildly acidic water and the presence of relatively high concentration of metals and other substances known to be irritant. These types of effects were in fact reported by a number of the workers (see Appendix C). Such localized effects on the skin are likely to be transient and reversible.

## 3 Health Effects

### 3.1 Assessment of potential adverse health effects

The approach taken in this HRA was to identify those substances which represent the greatest potential for toxicity, based on their levels in the ‘worst-case’ samples selected for analysis, and their known toxicological properties.

The chemical analysis of the drinking water samples from Ranger, including those considered to contain process water, has covered all possible elemental substances that could be present. In many cases the substances present are at very low concentration and unlikely to cause an effect. For substance considered to be a possible hazard, the toxic effect has been assessed. Where there is no further discussion of specific substances elsewhere in this report, it was considered that the levels of these substances in the contaminated water were of lesser toxicological concern.

### 3.2 Prioritisation of the systemic health risks in this report

It was noted that the levels of many of the contaminants exceeded Health Guideline Values (HGVs) of the Australian Drinking Water Guidelines (ADWG). While it may not be entirely appropriate to use Australian drinking water standards in this way (see Section 3.4 of this report),

it was decided that an initial screening of the risks may be informed by comparing measured levels in Samples E & H with HGVs, where such values are available.

The extent to which the most elevated samples (E and H) exceeded their respective HGVs is shown in Table 2.

**Table 2 - Reported Concentrations and comparison with Health Guideline Values**

Analyte	Sample E mg/l	Sample H mg/l	ADWG HGV mg/l	Exceedance ratio (compared to sample H)	Exceedance ratio (compared to sample E)
Manganese	64.2	607	0.5	1214	128
Uranium	0.37	7.1	0.02	355	18.5
Lead	0.035	1.28	0.01	128	3.5
Nickel	0.13	1.7	0.02	85	6.5
Sulfate	913 (filtered)	8370	500 (purgative)	16.7	1.8
Selenium	0.009	0.15	0.01	15	No exceedance
Copper	2.2	11.7	2.0	5.85	1.1
Cadmium	0.002	0.011	0.002	5.5	No exceedance
Arsenic	0.002	0.032	0.007	4.6	No exceedance
Chromium	0.002	0.07	0.05	1.4	No exceedance

### 3.3 HGVs in the ADWG

The ADWG contains two types of guidance values :

- **Health guideline values (HGVs):** These are values which, based on current knowledge, should not result in any significant health detriment to consumers over a lifetime of consumption. They are quite conservative in their derivation. Where based on animal studies, they include appropriate adjustment factors (also known as ‘safety factors’) to extrapolate from the intake level at which there is no observable adverse effect (NOAEL) in suitably designed studies, to a ‘safe’ level of human consumption. The NOAEL in long-term studies, usually determined over an entire lifetime of exposure, are most commonly used to derive HGVs, although if a shorter term exposure or special toxicity (e.g on reproductive function) results in the lowest NOAEL, this would have been used instead.

To convert the NOAEL to a potable water HGV, the following equation is used:

$$\text{HGV (mg/l)} = \frac{\text{NOAEL (mg intake/Kg body weight/day)} \times 70 \text{ kg}^* \times F^*}{2 \times \text{l/day} \times 100 \text{ (SF)}}$$

\* The inherent assumptions are that average adult body weight is 70 Kg; the average daily consumption of drinking water is 2 litres/day, and F represents the proportion of total intake which is generally attributable to drinking water intake (other sources being food, air, dusts etc).

The default value for F is 0.1 and the default SF is 100, although different values may have been used to calculate individual HGVs, where appropriate. The default value for average daily water consumption does not take into account the fact that water consumption in a tropical climate may be much higher (up to 5 litres/day).

The key point is that HGVs are conservative estimates of a 'safe' level of exposure, and based on an assumed lifetime exposure.

- **Other guideline values** (sometimes called 'aesthetic guideline values'): These are values where aesthetic considerations (taste, odour, corrosion, staining potential) may dictate a value lower than the HGV. In the case of some potential water contaminants (e.g pesticides) where it is desirable that no obvious contamination is consistent with good water quality and there is no need for the chemical to be present, the aesthetic guideline value may be set at the level of analytical determination (i.e the level at which it is practicable to measure the chemical).

### 3.4 Application of the HGVs in this report

It should be obvious that HGVs which are estimates of a safe level of consumption over a lifetime are not necessarily relevant to assessing risks of quite short exposures (in the case of the Ranger incident, <12 hours). For all of the substances under consideration in this HRA, the target health effects for chronic exposures are likely to be quite different to those associated with acute (short-term) exposures. Furthermore, the dose thresholds are generally much higher for acute exposures, even where the same target organ toxicity is suspected.

It is generally accepted that brief exceedances of an HGV would not necessarily result in the same adverse health outcomes associated with long-term exceedances and, as noted above, the HGVs are themselves derived using relatively conservative extrapolations from the available toxicity database. Furthermore, and depending on the magnitude of the exceedance, brief exceedances may not result in any adverse health effects. In this report, the HGVs are only used as a screening tool, to prioritise those contaminants which might warrant further health risk assessment or health follow-ups.

### 3.5 Evaluation of substances for which no HGVs have been established

HGVs have not been established in the ADWG for a number of the analytes which achieved relatively high concentrations (mg/l) in Sample H. These were magnesium (1260), aluminium (132), zinc (12.6), iron (1.8), cobalt (0.9), strontium (0.3), and ammonium (277 NH<sub>3</sub>-N). The levels in these metals were generally an order of magnitude lower in sample E (except for zinc, at 6 mg/l).

In some cases (e.g. aluminium, zinc, iron, and ammonium), an HGV has not been established because there are insufficient data to establish a guideline value based on health considerations, although guidelines have been set to manage water quality for aesthetic reasons (ADWG, 1996).

Where there has been no further discussion of these substances in Section 4, their short-term intake was considered to be of lower toxicological significance than those prioritized through the HGV approach.

## **4 Potential for adverse health effects arising from the Ranger incident**

### **4.1 Acute (short-term) effects**

The acute toxic effects of many metals, including those present in the contaminated water, include an ability to cause local toxic effects on exposed skin and mucous membranes. While the irritancy thresholds vary for different metals and inorganics, a number of the analytes were likely to have been present in sufficiently high concentrations to produce irritation of the skin, eyes and gastrointestinal mucosa. This is consistent with adverse health effects reported by some of the workers, which included skin itchiness, stomach discomfort, headaches, nausea, and vomiting. Such effects are generally reversible on cessation of exposure.

While there were no reports of skin rashes among the exposed workers, nickel was one of the metals present at an elevated level in the water samples, and nickel sensitization is relatively common in the community. The possible significance of this is discussed in Section 4.2.4 of this report.

#### **4.1.1 Sulfate**

Sulfates are relatively non-toxic, but high concentrations in water can have a purgative effect, possibly due to the sulfate anion itself, or more likely, because of the cations (e.g. magnesium) with which it is associated. Sulfate levels in Australian drinking water range from 1 – 240 mg/l and the ADWG guideline values for good quality drinking water are set at 250 mg/l (aesthetic; taste ) and 500 mg/l (purgative effects).

In the potable water samples from the Ranger incident, the highest level (Sample H) was 8370 mg/l (total) and 6940 mg/l (filtered), while in the other marker sample (Sample E), the levels were 407 mg/l (total) and 913 mg/l (filtered). It is not clear why the total level was lower than the filtered level in this sample. This may be an analytical error.

However, the sulfate levels in both samples appear to exceed the purgative threshold, and the gastrointestinal distress reported by some of the workers is consistent with them having drunk water which contains such high levels of sulfate and associated cations (e.g magnesium and copper) which could have contributed to this adverse effect.

### **4.2 Chronic (long-term) and/or delayed toxicity**

Systemic toxicity may be associated with damage to specific body organs following absorption of the compound in question. The potential for systemic toxicity arising from the Ranger incident is more difficult to predict since the availability of quantitative data on short-term systemic toxicity is quite limited for many of the analytes. However, in general terms, the dose of a heavy metal which results in organ damage or serious injury is often orders of magnitude higher than the dose required to produce the same effect when given over a long period of time. The fact that worst-



case estimates of intake exceed HGVs for many of the analytes does not necessarily indicate that systemic toxicity will result from such a short exposure.

#### 4.2.1 Manganese

Neurotoxicity is the most prominent toxic effect associated with chronic manganese exposure. The syndrome has some similarities to Parkinsons Disease, although the primary site of brain damage appears to be in the globus pallidus, rather than the substantia nigra (Pal et al., 1999). It is characterised by movement disorders, dementia, anxiety, and a 'mask-like' face. It is a progressive disease, with three distinct stages, the latter two of which are probably irreversible (Pal et al., 1999). It has been suggested that the earliest stage may be reversible upon removal of the source of exposure (Levy & Nassetta 2003), although the precise point at which removal of exposure stops the disease progression is unknown (Mergler & Baldwin, 1997). In a follow-up study of a cohort of workers from a dry-alkaline battery plant following cessation of manganese occupational (inhalational) exposure, Roels et al., (1999) reported a time-related improvement in one sensitive neurobehavioural test (eye-hand co-ordination), but not in others (hand steadiness; visual reaction time). The apparent recovery was mainly confined to the group categorized with the lowest manganese exposure history. A community-based study suggested that mild impairment in neurobehavioural tests could be related to blood manganese levels above 7.5 ug/l, although there was considerable variability associated with age, gender, and other possible metal exposures which needed to be factored into the analysis (Mergler et al., 1999).

Absorption of inorganic manganese from the gastrointestinal tract is in the range 2-5%, compared to nearly complete absorption following inhalational exposure (Andersen et al., 1999). It is rapidly and extensively excreted by the liver into bile, and its absorption and retention are regulated by homeostatic mechanisms. Accordingly, the occurrence of manganism has been most commonly reported in association with occupational inhalational exposure.

The relationship between oral exposure through long term consumption of contaminated drinking water and the occurrence of neurotoxicity is more controversial. Epidemiological studies have reached different conclusions and may have been confounded by imprecise exposure estimates or other factors.

One study found some neurological symptoms in a Greek population consuming around 2 mg/l manganese oxides in drinking water (Kondakis et al., 1989). Another study found no neurological effects in a German population using drinking water containing 0.3 – 2.16 mg/l (Vierregge et al., 1995). In a Japanese population (about 25 people in 6 families) exposed for around 3 months to contaminated water containing an estimated 14-29 mg/l manganese, along with some other heavy metals, there was clear evidence of neurological damage (Kawamura et al., 1941). Autopsy results from two who died as an outcome of the exposure showed lesions in the brain characteristic of manganese poisoning. However, because of the rapid onset and progression of the disease, it was considered likely that factors other than manganese contributed to the outbreak (ATSDR, 2000).

Cases of a severe neurological disorder with many of the characteristics of manganism have been reported among the aboriginal population of Groote Eylandt, a region which has relatively high environmental levels of manganese. However, the link with manganese exposure is controversial, because of the presence in the population of a hereditary neurological disease, called Machado-Joseph disease, which produces symptoms comparable with those of manganese neurotoxicity (Burt et al., 1993).

In the Ranger incident, ingested water concentrations of manganese may have been as high as 34-680 mg/l, which is well above the levels for which epidemiological studies have been done. However, the exposure periods in the epidemiological studies (3 months to several years) were

considerably longer than the 12 hours over which the Ranger workers were likely to have been exposed.

The manganese intakes for the ingestion scenarios under consideration for this incident would be 32.1 - 321 mg (equivalent to 0.46 - 4.6 mg/kg body wt for a 70 kg person) for Sample E and 304 - 3035 mg (equivalent to 4.33 - 43.3 mg/kg body wt for a 70 kg person) for Sample H at 500 ml and 5 litre intakes respectively.

To put these estimated doses into perspective, comparative doses in studies with rats show the following: acute oral lethal dose is of the order of 300-800 mg/kg; mild neurological effects have been observed after dosing with 22 mg/kg/day for 6 days; and ataxia after 150 mg/kg/day for 44 days (ATSDR, 2000).

#### 4.2.2 Uranium

Renal toxicity, specifically damage to the proximal tubules, has been described in humans and animals exposed to uranium (ATSDR, 1999). Systemic toxicity depends on the form of uranium administered and the route of administration. Soluble uranium salts appearing to be more toxic than insoluble forms of uranium (e.g uranium oxide) because they are better absorbed from the gastrointestinal tract or relatively well absorbed through the skin. The inhalation route appears to provide a much better opportunity for absorption and systemic toxicity than oral ingestion (ATSDR, 1999).

The relative oral toxicity in both rats and dogs of several uranium compounds has been ordered as follows (cited in ATSDR 1999):

- very toxic compounds –  
uranium tetrachloride, uranium peroxide, and uranyl fluoride;
- toxic compounds –  
uranium nitrate hexahydrate, uranyl acetate, ammonium diuranate, sodium diuranate, uranium trioxide, and high-grade uranium ore (carnotite);
- practically nontoxic compounds –  
uranium tetrafluoride, triuranium octaoxide, and uranium dioxide.

The difference in toxicity between different forms of uranium is demonstrated in Table 3.

Clearly the form of uranium to which exposure occurred will have a marked impact on judging the probability of harm arising from non-radiation aspects of short term exposure to uranium. Most uranium in the potable water and mixtures of potable water is expected to be in solution and present as uranyl sulfate or uranyl hydroxyl and carbonate species. Speciation modeling shows that the uranium is essentially present as the free uranyl cation or as uranyl sulfate form as described earlier. The toxic potency of this soluble form of uranium is likely to be close to that of uranyl nitrate. However there may be slight differences between the human toxicity response of uranium nitrate compared with uranyl sulfate and associated forms as found in the Ranger potable water contaminated with process water. Although there has been no specific HRA undertaken on ingesting uranyl sulfate solutions it is expected that the dominant effect of toxicity is derived from the uranyl cation itself.

**Table 3: Data illustrating differences in kidney toxicity of different forms of uranium (data cited in ATSDR 1999) <sup>a</sup>.**

Form of uranium	Study	NOAEL <sup>b</sup> (mg/kg/d)	LOAEL <sup>c</sup> (mg/kg/d)
Triuranium octaoxide [U <sub>3</sub> O <sub>8</sub> ]	Dietary dog 30 days (6d/wk)	2,827	5,653  (proteinuria, glucosuria, minimal histological changes in tubular epithelium)
Uranyl nitrate [UO <sub>2</sub> (CH <sub>3</sub> COO) <sub>2</sub> ·2H <sub>2</sub> O]	Dietary dog 138 days	47	95  (elevated NPN & BUN; proteinuria, glucosuria)

<sup>a</sup> This is a preliminary commentary and it has not been ascertained whether the doses quoted are for the form of uranium or whether they have been converted to uranium equivalent doses. It is assumed at this time they are for the former.

<sup>b</sup> NOAEL = dose which causes no observed adverse effect, i.e. the no observed adverse effect level.

<sup>c</sup> LOAEL = lowest dose causing an adverse effect, i.e. the low observed adverse effect level. For both uranium compounds the effects in the Table are not regarded as being serious. The extent of damage and hence the seriousness will increase as the dose increases.

According to ATSDR (1999) there is just one report of renal toxicity in humans after oral exposure to uranium. This was a case of deliberate ingestion of 15 g of uranyl nitrate (approx 131 mg/kg bw) but the authors suggested that pre-existing peptic ulcer disease in this patient may have exacerbated toxicity by increased absorption of uranium through the damaged stomach mucosal layer.

The concern for potential kidney toxicity arises primarily from studies in experimental animals. In the animal studies where kidney toxicity has been demonstrated to occur at relatively low exposures, the water soluble forms of uranium, such as uranyl nitrate, have been used. Their toxicity profile is likely to be similar to other soluble uranium salts, such as uranyl sulfate. The data from these studies suggest that oral doses in the range 10-100 mg/kg bw for up to 15 days are needed to produce renal toxicity (ATSDR, 1999). At low level exposures where renal toxicity is relatively mild, clinical experience with a variety of diseases and chemicals indicates such toxicity is readily reversible.

In the Ranger incident scenarios, the worst-case estimated uranium dose (probably as uranyl sulfate) was 0.185 -1.85 mg (equivalent to 0.0026 – 0.026 mg/kg body wt for a 70 kg person) for sample E and 3.55 – 35.5 mg (equivalent to 0.05 – 0.51 mg/kg body wt for a 70 kg person) for Sample H at 500 ml and 5 litre intakes respectively.

These figures suggest that there was a large margin between the short-term exposures of the Ranger workers and the doses needed to produce kidney damage. The low likelihood of kidney damage caused to workers exposed in the Ranger incident is supported by the results of clinical blood tests conducted for kidney function (see Section 7.1 and Appendix D), which have not detected any such damage.

While cancer risk is an unlikely outcome of a short-term exposure to uranium, such as the Ranger incident, the available long-term feeding studies in rats, mice, dogs, and rabbits are also

comforting, since they did not show any evidence of cancer induction upon histopathological examination of selected organs and tissues (ATSDR 1999).

#### 4.2.3 Lead

Lead is a toxic metal which, on prolonged intake, can have serious health effects on the kidney, brain and haematopoietic system. Like many metals, its acute toxicity depends on the solubility of the form presented. Estimates of the acute lethal dose in animals range from 190 – 1500 mg Pb/kg bw, with the more soluble acetate and nitrate salts being more acutely toxic than lead chloride, lead sulfate or lead oxide (ATSDR, 1999).

Haematological disturbances are probably the most sensitive indicator of lead toxicity, and a decrease in erythrocyte ALAD has been noted in humans exposed orally to as little as 0.02 – 0.03 mg/kg bw/day for 5 – 7 days (ATSDR, 1999). These doses reduce to 0.01 – 0.02 mg/kg bw /day for longer term exposures, which is not surprising since lead toxicity is cumulative, with absorbed lead being retained for long periods in bone and other tissues.

Although rats are thought to be less sensitive to lead than humans, studies in rats with short-term intakes in the range 17-145 mg/kg bw/day have produced haematological changes. Over 30 days, the haematological effects are seen at 5 mg/kg bw/day, with a NOAEL of 1.5 mg/kg bw/day. In the above 30 day rat study, there were also signs of renal tubular changes at 5 mg/kg bw/day, with the NOAEL also at 1.5 mg/kg bw/day.

It is difficult to determine a NOAEL for neurological effects of lead. Extensive studies in humans, and particularly in children, have detected subtle neurological changes at quite low blood lead levels (PBB), possibly in the range 10-40 µg/dl. There are extensive studies on lead neurotoxicity in experimental animals, but their interpretation is complicated and any of them have focused on lead effects on brain development in very young animals. As examples, monkeys receiving 0.05 – 0.1 mg Pb/kg bw/day for 200 days showed impairment of performance in a special discrimination task at 3 years of age, but the NOAEL was 0.05 mg/kg bw/day at 9-10 years of age. Rats showed clear histopathological changes in various brain regions at intakes producing blood lead levels (PBB) of 258 – 400 µg/dl, and some neurochemical changes at 10-19 µg/dl PBB. Young rats (21 days post partum) showed deficits in radial arm maze performance after 35 days treatment with lead in drinking water at 1.6 mg/kg bw/day, producing PBBs of 15 µg/dl.

In the Ranger incident scenarios, the worst-case lead would be 0.017 – 0.17 mg (equivalent to 0.00025 – 0.0025 mg/kg body wt for a 70 kg person) for sample E and 0.64 – 6.4 mg (equivalent to 0.009 – 0.09 mg/kg body wt for a 70 kg person) for Sample H at 500 ml and 5 litre intakes respectively.

The intakes associated with Sample E do not appear to represent a health risk. This conclusion is supported by measurements of blood lead levels in workers at the mine (Table 7; Appendix D). Blood lead levels are not elevated and not different from that expected in the general population.

The estimated lead intakes associated with Sample H are higher, and in the range of human exposures associated with subtle changes in porphyrin metabolism. Such changes were not assessed in the clinical chemistry tests done on the Ranger workers, and discussed in Section 7. However, even the worst-case estimated exposure based on Sample H is well below the level likely to result in renal or neurological effects for such a short period of exposure.

#### 4.2.4 Nickel

The systemic toxicity of nickel is markedly dependent on the solubility of the salt presented and the route of administration. Even the soluble nickel salts, such as nickel sulfate, are relatively non-

toxic when administered orally. Target organs include the gastrointestinal tract, lung, kidney, nervous system and haematopoietic systems (ATSDR, 1997).

The available data provides estimates for the acute lethal dose of nickel sulfate to range from 40 mg/kg in rats to 570 mg/kg in a young human child, and 7-10 mg/kg/day for up to 14 days for the various systemic effects.

Nickel-induced allergic dermatitis is one of the more sensitive indicators of toxicity in humans. There are reports in the literature (Burrows et al., 1981; Gawkrödger et al., 1986) that single oral exposures as low as 5.6 mg nickel (as soluble nickel sulfate) can produce signs of hand dermatitis in nickel-sensitive individuals. However, these same reports were unable to distinguish between the response to nickel (0.4 – 4 mg per day) and a placebo, suggesting that the oral dose threshold may be around 5 mg nickel in such sensitized individuals.

Nickel sensitization is generally tested by applying an ointment containing 5% nickel sulfate (50,000 mg/kg), which is a grossly higher level than the exposure scenario involving showering or washing with even the most heavily contaminated sample.

There is no specific information on oral or dermal doses which can lead to nickel sensitization in non-sensitized individuals, although such sensitization appears to require long periods of exposure, or repeated administration of quite high doses.

In the Ranger incident scenarios, the worst-case estimated dose of nickel was in the range 0.85 – 8.5 mg (approximately equivalent to 0.012 -0.12 mg/kg body wt for a 70 kg human), based on 500ml – 5 litres ingestion of sample H.

These data suggest a large margin of safety between the ingested doses of nickel in the Ranger incident and the doses likely to cause systemic toxicity over a short period of exposure.

#### **4.2.5 Aluminium**

Aluminium is the third most abundant element in the earth's crust. Food is therefore a common source of aluminium in the normal diet. Although aluminium has been used as a flocculant in the production of potable water, drinking water generally contributes only a small part of total dietary intake of aluminium (Soni et al., 2001). Estimates of normal aluminium intake are in the range 0.1 – 0.12 mg Al/kg bw/day (ATSDR, 1999) However, another significant source of aluminium is through oral medications and dermally applied personal care products. The intake can go as high as 12-71 mg Al/kg bw /day from antacids preparations and 2-10 mg Al/kg bw/day from buffered analgesics. These intakes are not associated with any adverse health effects, although the aluminium salts used in medicines tend to have low bioavailability because of their insolubility.

Aluminium is poorly absorbed from the gastrointestinal tract. Estimates of oral bioavailability are in the range 0.1 – 0.3%, with soluble citrate complexes going to as high as 1%. Aluminium which is systemically absorbed is rapidly excreted in the urine in those with normal renal function.

Concerns about the potential neurotoxicity of aluminium have come from animal studies, where it has been shown to cause neurobehavioural and decreased muscle strength changes at dose levels in the range 155 – 195 mg/kg bw/day. These studies have potentially been confounded by a lack of information of aluminium intake through the diet in control animals.

There have been conflicting findings in epidemiological studies of the association between aluminium intake and the incidence of Alzheimers disease (ATSDR, 1999; IPCS 1997), but a consensus view is emerging that the presently available data do not support such a linkage (Soni et al., 2001).

In an incident in the Camelford region of North Cornwall UK in 1988, some 12,000 - 20,000 local residents were exposed to drinking water to which 20 tons of aluminium sulfate had been added inadvertently (IPCS 1997; Owen & Miles, 1995; McMillan et al., 1993). The aluminium sulfate made the water quite acidic, and it also contained copper, lead and zinc, which had been leached from the water pipes. The aluminium content of the water consumed by people probably did not exceed 100 mg/l, above which it would have been unpalatable. Levels of 10-50 mg/l were present for 1-3 days, and for the next month were between 0.2 – 1 mg/l. Immediate symptoms included skin rashes and acute gastrointestinal distress with and without mouth ulceration. Longer-term follow up on some of the exposed people indicated retention of aluminium in bone for up to 6 months, but not after 12 months. There were persistent signs of mild cognitive impairment (memory and information processing) over 8 – 24 months following the incident, but since there were also some indications of anxiety and depression, it was difficult to attribute the findings to either brain damage or the effects of stress relating to the incident.

The aluminium intakes for the ingestion scenarios under consideration for the Ranger incident would be 1.1 – 10.7 mg (equivalent to 0.015 – 0.15 mg/kg body wt for a 70 kg person) for Sample E and 66 - 660 mg (equivalent to 0.94 – 9.4 mg/kg body wt for a 70 kg person) for Sample H at 500 ml and 5 litre intakes respectively.

At the lower end of this range, the intakes are not remarkably different from normal dietary intake levels. However, at the higher end (Sample H), the concentrations exceed the range of those associated with the Camelford incident, for which the official reports drew the conclusion that, after the immediate effects on the gastrointestinal system, there were no persistent health effects which could be attributable to the high metal exposures.

#### 4.2.6 Copper

The liver, kidney and cardiovascular system are the main sites for systemic copper toxicity (ATSDR, 2002). Deaths associated with shock and hepatorenal complications have been reported in humans after the oral ingestion of copper sulfate in doses 6-637 mg/kg bw and from solutions containing >100 mg/l copper sulfate. The dose thresholds for hepatorenal toxicity in short-term (14 day) studies in rats are of the order of 20-30 mg/kg bw/day, although a maximum tolerated dose for hepatic toxicity of 250 mg/kg bw/day has also been suggested (Barceloux, 1999).

Gastrointestinal distress is quite a sensitive indicator of copper toxicity in humans after oral administration. In more recent controlled studies, nausea, vomiting and abdominal pain have been reported with the consumption of copper sulfate solutions as low as 4 - 8 mg/l (0.01 - 0.07 mg Cu/kg bw), but NOELs have also been reported in these controlled studies in a similar range (3 - 4 mg/l; 0.01 - 0.03 mg Cu/kg bw) (ATSDR, 2002). These data are consistent with earlier reports of GI distress dose response relationships involving accidental exposures in humans. Barceloux (1999) reports the acute emetic dose of copper sulfate to be 250 – 500 mg (as copper) and gastroenteritis has been reported with food and beverage intakes above 25 mg Cu/l. Based on one of the controlled intake studies in women (Pizarro et al., 1999) the 2002 ATSDR report calculates a Minimal Risk Level (MRL) for copper at 0.02 mg/kg bw/day.

However, it should be noted that copper is an essential nutrient, and that estimates of the minimal daily intake are also in the range 0.02 – 0.08 mg/kg bw /day. It is clear that conservative estimates of a dose likely to produce gastrointestinal distress are within the dose range needed to maintain good health. This means that the copper concentration of the solutions ingested, and the time period over which the solutions are ingested are likely to be important determinants of whether gastrointestinal distress will occur.

The Australian Drinking Water Guidelines indicate that the taste threshold for solutions of copper is in the range 1 – 5 mg/l.

The copper intakes for the ingestion scenarios under consideration for this incident would be 1.1 – 11 mg (equivalent to 0.016 – 0.16 mg/kg body wt for a 70 kg person) for Sample E and 5.85 – 58.5 mg (equivalent to 0.083 – 0.83 mg/kg body wt for a 70 kg person) for Sample H at 500 ml and 5 litre intakes respectively.

On the basis of these calculations, the copper content of both Samples E and H could have been high enough to produce nausea, vomiting and abdominal pain, as reported by some of the exposed workers (see Table 5; Appendix C).

There is a hereditary disease (Wilson's disease) which predisposes individuals to copper-induced liver disease. A defect in copper transport allows unusual accumulation of copper in the liver, brain and other organs. Liver damage is the predominant effect but behavioural changes and renal complications can also occur (Barceloux, 1999; Gitlin, 2003). Wilson's disease is not difficult to diagnose and would be detectable at an early age. However it is not known whether any of the workers exposed at the Ranger mill suffer from this hyper-susceptibility to copper.

#### 4.2.7 Selenium

Selenium is present in the Ranger ore, but at relatively low concentration. The reported concentration in Sample H was 0.15 mg/l, which exceeds the HGV (0.01 mg/l), although the level reported in Sample E (0.007 mg/l) does not exceed the HGV. Selenium is likely to be present in process water in soluble form as selenate, the analogue of sulfate.

An acute toxic human dose for selenium has not been determined, but in animals, the lethal dose is of the order of 0.4 – 50 mg/kg bw, (depending on the solubility of the salt form); 75 – 3700 mg/kg bw for selenium sulfides, and 6700 mg/kg bw for elemental selenium (ATSDR, 2001). Female rats tolerated an intake of either sodium selenite or sodium selenate in drinking water at 280 µg/kg bw/day for up to 1 year, but male rats were more sensitive to sodium selenite (but not selenate), with half of them dying within 58 days at this intake level (ATSDR, 2001). After 13 weeks treatment, no effects were seen in the lungs (a sensitive site for selenium toxicity) in rats or mice receiving 1670 – 7170 µg/kg bw/day in drinking water as sodium selenate, or 1570 – 3830 µg/kg bw/day as sodium selenite.

The selenium intakes for the ingestion scenarios under consideration for this incident would be 4.5 – 45 µg (equivalent to 0.06– 0.6 µg /kg body wt for a 70 kg person) for Sample E and 75 – 750 µg (equivalent to 1– 10 µg /kg body wt for a 70 kg person) for Sample H at 500 ml and 5 litre intakes respectively.

While selenium is a relatively toxic metalloid, these short-term intake levels should not pose a health risk to the workers exposed at Ranger.

#### 4.2.8 Arsenic

Arsenic is a ubiquitous element in the environment ranked the 20<sup>th</sup> most abundant element on earth. Arsenic is classified as a metalloid and its chemistry is similar to that of other Group V elements, but is more labile in behaviour than phosphorus, which is essentially covalent. Both inorganic arsenite and arsenate are toxic to humans and animals. However, the so-called fish arsenic (arsenobetaine and arsenocholine) is generally regarded as non-toxic. For diagnostic purpose, it is important to speciate (measure various forms of arsenic) arsenic in the urine. This can be done using HPLC-ICP-MS. The absorption coefficient of soluble arsenic is ranging from 0.7 to 0.98. For risk assessment purposes, arsenic in drinking water is generally regarded as 100% bioavailable.

Inorganic arsenic is rapidly cleared from blood with a half-life of about 2 hours. It is for this reason that blood arsenic is considered to be a useful bioindicator only for recent relatively high level exposures (Ellenhorn, 1997).

Studies in adult human males, voluntarily ingesting a known amount of either trivalent or pentavalent arsenic, indicate that 45% to 75% of the dose is excreted in the urine within a few days to a week (Tam *et al.*, 1979; Yamauchi and Yamamura, 1979; Buchet *et al.*, 1981a; Buchet *et al.*, 1981b). Urine is generally used as a reliable bioindicator for the measurement of internal dose.

Wester *et al.*, (1993) studied the percutaneous absorption of arsenic acid ( $\text{H}_3\text{AsO}_4$ ) from water and soil both *in vivo* using rhesus monkeys and *in vitro* with human skin. The rhesus monkey percutaneous absorption of arsenic acid is low from either soil or water vehicle and does not differ appreciably at doses more than 10,000-fold apart. Wester also reported that using human skin, at the low dose, 1.9% was absorbed from water and 0.8% from soil. For a toxicological view point, the dermal exposure pathway is not generally regarded as important.

The acute and subacute exposure of arsenic may cause extensive gastrointestinal damage, resulting in severe vomiting and diarrhoea, often with blood-tinged stools. Other acute symptoms and signs include muscular cramps, facial oedema, and cardiac abnormalities (ATSDR, 2000; IPCS, 2001). The fatal dose of ingested arsenic trioxide for man has been reported to range from 70-180 mg (Vallee *et al.*, 1960). Pentavalent inorganic arsenic can act as a phosphate analog. At the molecular level this means that arsenate can compete with phosphate for active transport processes. This is why the addition of phosphate can decrease intestinal uptake of arsenate (Gonzalez *et al.*, 1995) and renal tubular reabsorption of arsenate (Ginsburg & Lotspeich, 1963).

Inorganic arsenic has been classified as Group I carcinogen based on primarily human epidemiological data. Chronic ingestion of inorganic arsenic can cause multi-site cancers in the human body. For people who are exposed to arsenic levels  $> 50 \mu\text{g L}^{-1}$  in drinking water, the cancer risk could be as high as 1 in 100 (Morales *et al.*, 2000), although their interpretation of the data has recently been challenged by Lamm *et al.*, (2003). The evidence for its carcinogenesis in animals is increasing (Wang *et al.*, 2002; Waalkes MP 2003). However, the mode of action for arsenic carcinogenicity is still unclear although its inhibitory effect on DNA repairs and its ability to induce oxidative stress have been implicated (Tran *et al.*, 2002; Wang *et al.*, 2002).

Arseniasis, arsenicosis and arsenicism are terms used to refer to diseases / syndromes caused by chronic exposure of arsenic in humans. Its clinical manifestations include conjunctivitis, hyperkeratosis, hyperpigmentation, hypopigmentation, gangrene, cardiovascular disease, peripheral vascular disease (including black foot disease) and disturbances in nervous system, cancers of the skin and various internal organs including the lung, bladder, liver and kidney (IPCS, 2001).

The current Australian HGV is set at 0.007 mg/l (7 $\mu\text{g/l}$ ). In 2001, the USEPA has set a new enforceable 'Maximum Concentration Level' of 10  $\mu\text{g/L}$  (reduced from 50  $\mu\text{g/L}$ ) in drinking water. In 2004, California set their HGV at 4  $\mu\text{g/l}$  whereas most countries around the world set their values between 10 and 50  $\mu\text{g/l}$  (0.01 to 0.05 mg/l). There is no published literature to indicate levels of below 50  $\mu\text{g/l}$  are not safe.

Only one of the eight Ranger water samples (sample H) returned an arsenic concentration (32  $\mu\text{g/l}$ ) which exceeds the Australian HGV. All the other samples met the current ADWG water quality standard for arsenic.

For the worst case scenario based on sample H, the arsenic consumption could have been 0.16 mg of arsenic from 5 litres of water (0.0023 mg/kg b.w. for an 70 kg adult). This is several orders of magnitude lower than the doses required to produce acute toxicity and it is unlikely that such



short-term exposure to arsenic, even from Sample H, would produce any adverse health effect. Although the epidemiological evidence is not yet conclusive, it appears that even for chronic exposures, arsenic levels in drinking water must exceed 50 µg/l for there to be a public health problem.

#### 4.2.9 Cadmium

Cadmium is a cumulative toxic metal (ATSDR, 1999). It is not well absorbed orally, but it is strongly sequestered in tissues, and accumulates on prolonged exposure. Renal tubular dysfunction and osteomalacia, with severe bone pain, are the main indicators of its chronic toxicity. The experience of Itai Itai disease in Japanese chronically exposed to high levels of cadmium pollution indicates that accumulation of more than 200 µg/g kidney represents a threshold for renal disease. A chronic exposure NOAEL of 2 µg/kg/day has been derived from studies of the Japanese experience.

The dose thresholds for acute exposures are less well defined. Human deaths, associated with deliberate oral dosing, have been reported with 25 mg/kg (cadmium iodide) or 1840 mg/kg (cadmium chloride). The acute LD<sub>50</sub> in rats and mice is in the range 100-300 mg/kg, and deaths have been reported among rats dosed orally with 40 mg/kg/day for 2 weeks. Renal and hepatic necrosis has been reported in rats dosed orally with 15-140 mg/kg/day over 10 days, with milder renal dysfunction at 6-12 mg/kg/day over 14 days.

Cadmium irritates the gastric mucosa, and gastrointestinal distress and vomiting has been reported in a child drinking water containing more than 16 mg/l (estimated emetic dose 0.07 mg/kg). Frank damage to the GI tract has been found in rats acutely dosed with >30 mg/kg, but there was no evidence of gastrointestinal lesions in rats receiving 8 mg/kg/day over 24 weeks in drinking water.

In the Ranger incident, the worst-case intakes associated with Sample H (10.6 µg/l) would have been 5.3 -53 µg (equivalent to 0.076 – 0.76 µg/kg body weight for a 70 kg person).

These intakes appear to provide a large margin of safety when compared to the doses producing renal toxicity or gastrointestinal damage over short-term exposures.

#### 4.2.10 Chromium

The toxicity of chromium depends markedly on its oxidation state. Cr(VI) is at least two orders of magnitude more toxic than Cr(III) (ATSDR, 2000).

Acutely lethal dosing incidents in humans suggest a lethal dose of Cr(VI), as potassium dichromate, in the region 4-30 mg, with deaths associated with gastrointestinal ulceration and corrosion. In rats, the gavage LD<sub>50</sub> for Cr(VI) is of the order of 13-30 mg/kg. Deaths have also been recorded in rats receiving 90-179 mg/kg Cr(VI)/day in drinking water, which delivers a dose more evenly over a day in comparison to gavage dosing.

In the Ranger incident, the worst-case intakes associated with Sample H (70 µg/l) would have been 35 -350 µg (equivalent to 0.5 – 5 µg/kg body weight for a 70 kg person).

The oxidation state of the chromium is predicted to be Cr (III) for the following reasons. Chromium exists as Cr (III) in the host ore at Ranger. During processing, the redox potential is maintained under acid conditions (pH 1.9) at around Eh +680mV which means that Fe is poised between equal portions of Fe (III) and Fe (II) in solution in order that Fe (III) can constantly supply electrons to oxidize U (IV) to U (VI). The redox potential required to allow oxidation of Cr (III) to Cr (VI) has to be far more positive (higher) than the potential which is maintained for U extraction. Redox potentials of +1100mV are required to produce Cr (VI) and so the dominant form of chromium present in process water will be Cr (III).

As chromium is predicted to be mainly Cr(III), there is a large margin of safety when compared to acutely toxic doses.

#### 4.2.11 Zinc

Zinc is an essential element in the diet, and like many other metals, its acute toxicity depends on the salt form and solubility. The LD<sub>50</sub> for soluble zinc salts in rats is in the range 90 – 600 mg/kg and deaths have been reported in rats receiving 191 mg Zn/kg/day in drinking water. An estimated lethal dose in humans is 27 g/day zinc oxide, which is equivalent to approximately 400 mg Zn/kg body weight (ATSDR, 1994) and the dose producing gastrointestinal distress in humans varies over a wide range (2 – 90 mg/kg). No renal effects were found in some patients treated with zinc sulfate at levels of 3.5 mg Zn/kg bw/day for 18 weeks.

In the Ranger incident, the worst-case intakes associated with Sample H (12.6 mg/l) would have been 6.3 - 63 mg (equivalent to 0.09 – 0.9 mg/kg body weight for a 70 kg person). These intakes appear to provide a large margin of safety.

#### 4.2.12 Cobalt

Cobalt is moderately toxic. The LD<sub>50</sub> in rats is of the order of 42 -317 mg/kg for soluble salts, with heart, liver, GI tract and kidneys the target organs. Deaths associated with cardiomyopathy were found in 20-25% of guinea pigs treated with cobalt sulfate at 20 mg Co/kg bw/day over 5 weeks. This is consistent with a well-known adverse effect in humans, where cobalt added to beer as a frothing agent caused several cases of cardiomyopathy. The cobalt intake was estimated to be in the range 0.04 – 0.14 mg/kg bw/day over several years, but the confounding effect of dietary inadequacies was difficult to dissociate (ATSDR, 2001). Cardiomyopathy was not seen in some patients receiving 0.6 – 1 mg Co/kg/day to treat anaemia (ATSDR, 2001).

In the Ranger incident, the worst-case intakes associated with Sample H (0.9 mg/l) would have been 0.45 – 4.5 mg (equivalent to 0.006 – 0.06 mg/kg body weight for a 70 kg person). These intakes appear to provide a large margin of safety.

#### 4.2.13 Strontium

Strontium is a relatively non-toxic metal (ATSDR, 2001). Its LD<sub>50</sub> in rats is of the order of 2000 – 3000 mg/kg, and even dosing at 3000 mg/kg/day for 2 weeks produced only minor effects in rats (changes in serum alkaline phosphatase).

In the Ranger incident, the worst-case intakes associated with Sample H (0.3 mg/l) would have been 0.15 – 1.5 mg (equivalent to 0.002 – 0.02 mg/kg body weight for a 70 kg person). These intakes appear to provide a large margin of safety.

#### 4.2.14 Ammonium ion

Most human poisonings with ammonia are associated with household ammonia products, which are strongly alkaline, and cause GI burns. The acidic NH<sub>4</sub><sup>+</sup> ion is less toxic (ATSDR, 2002). A lethal gavage dose of ammonium chloride in guinea pigs has been reported at 303 mg/kg. Rats tolerated an intake of 1000 mg/kg/day ammonium chloride for 6 days with only a mild loss of calcium and changes in bone structure. Decreased body weight gain was the only adverse effect noted in rats receiving ammonium acetate by daily gavage at a dose rate of 3000 mg/kg over 3-7 days.

In the Ranger incident, the worst-case intakes associated with Sample H (277 mg/l) would have been 138 – 1385 mg (equivalent to 2 – 19.8 mg/kg body weight for a 70 kg person). Even at such relatively high levels, these intakes appear to provide a large margin of safety.

## 5 Other potential contaminants

### 5.1 Organics

It is known that process water usually contains residues of kerosene and a tertiary amine (tri-n-octylamine) used in the mineral extraction process. The organic/amine phase is dispersed as microdroplets in the aqueous phase after back extraction. Some of this organic phase will become adsorbed onto sludge or be degraded by microbial action. Taking into account dilution factors from the raffinate, which contains up to 30-40 mg/l organics, the concentration of organics in Process pit 1 is generally less than 3 mg/l (ERA, 2004).

There is relatively little known of the systemic toxicity of tri-n-octylamine. It is an irritant to skin and mucous membranes in its undiluted form, so that if present in sufficiently high concentrations, it may have added to the skin irritancy reported by some workers who showered in the contaminated water.

However, analysis of process water, bore water and potable water from the Ranger mill water samples collected on 4 April showed no traces of total petroleum hydrocarbons or BTEX (benzene, toluene, ethylbenzene, xylene). Therefore, it appears unlikely that organic residues could have posed any appreciable risk in the Ranger incident.

### 5.2 Microbiological risks

The authors of this HRA have not been given any information on the microbiological content of the process water from Pit 1. However, information was given that samples taken from the potable water system on 30 March (a week after the event) showed nil counts for total coliforms and faecal streptococci.

These data suggest that there was no microbiological risk associated with the incident.

## 6 Interactions

The above HRA for individual metals is based on toxicological data which generally assume that exposures have only involved the one substance. In reality, human exposures often involve multiple substances, and the cited epidemiological studies on manganese and uranium suggest that, while they may have been the predominant exposure, other substances would have been part of the exposure scenarios that have led to observations of adverse health effects. While there is always a possibility that interaction between metals may modify the health impacts, interpretation and assessment of such interactions is always difficult and requires making a number of assumptions.

Homeostatic regulation of the absorption of metals from the gastrointestinal tract, their transport in the blood and storage in tissues often involves a complex interaction with other metals present at the time. For example, the importance of maintaining an adequate balance between zinc and copper intake was emphasized as an important factor in zinc homeostasis (IPCS, 1997).

The contaminated water at Ranger certainly contained a number of metals which may act on the same target organ if the absorbed dose was high enough and exposure was long enough. These targets are primarily the kidney (uranium, lead) and central nervous system (manganese, lead and aluminium). In the central nervous system, the toxicity profile of the three metals is sufficiently different to suggest they act on different cellular targets and by different mechanisms. However, the extent to which interactions may modify their toxicity in the brain, kidney or at other sites is largely unknown.

## 7 Discussion of health investigation results

### 7.1 Health investigations on workers and contractors from the Ranger mine

Blood and urine samples were taken from some of the workers and contractors who were exposed to the contaminated water. Samples were also taken from some workers who were off-site at the time of the incident, or who reported that they did not drink the contaminated water. This set of samples was taken by Dr Richard Gaunt, Rio Tinto's occupational health physician who had interviewed the workers to ascertain the extent of any immediate health problems. They were taken 10 days after the incident and subjected to a standard range of clinical chemistry tests designed to investigate possible kidney and/or liver damage, as well as some more specific tests for renal proximal tubular damage; serum  $\beta$ 2-microglobulinaemia (BMG) and the urinary enzyme N-acetyl-aminoglucosaminidase (NAG). The samples were also analysed for the presence of selected metals (manganese, uranium and lead).

A second set of urine samples were also taken from some workers 3-8 days after the incident for the analysis of certain metals. The complete sets of results are shown in Tables 7 and 8, Appendix D.

In interpreting these results, three factors need to be acknowledged.

- The blood and urine samples were drawn up to 10 days after the incident. For both uranium and manganese, excretion of the absorbed metals is expected to be quite rapid. Experience with monitoring occupational exposure monitoring to such suggests that it is often difficult to correlate blood or urinary levels with intake. While finding levels of the selected metals which exceed those normally present in such fluids may provide some indication of **exposure**, the source of that exposure may not be immediately apparent. No monitoring data have been provided which relate to worker exposure prior to the incident.
- In the case of uranium, the available data (ATSDR, 1999) suggests that most of the ingested metal is excreted in the faeces (>95%), with the remainder in the urine. In volunteers, most of the uranium in water drunk over a 6 hour period was excreted in faeces within 2 days. The residence half-time in human kidney for uranium reaching this organ has been estimated to be 1-6 days for 99% of the uranium, and 1,500 days for the remainder. Very little remains in any other organ.

For manganese, any systemically absorbed metal is likely to be rapidly excreted in bile, and thence through faeces. In various studies of workers occupationally exposed to inhaled manganese (a more bioavailable route of exposure than oral), it has often proved difficult to relate blood or urine levels to intakes (Greger, 1999).

- In order to determine whether any of the measured parameters represents an effect attributable to the Ranger incident, the results need to be compared to an appropriate set of reference values. In the case of standard clinical chemistry test results, a suitable reference range is generally reported in conjunction with the results and the comparison is relatively straightforward. Even so, a single result falling marginally outside the quoted 'normal' range does not necessarily indicate disease in that individual, particularly when it is not supported by the results of other tests measuring much the same disease. However, any such abnormal findings may merit further follow-up testing.

In the case of more specialized tests, such as NAG, there may be no generally accepted reference range, and it is necessary to compare the data to published information on test results in cohorts or groups comparable to the workers exposed in the Ranger incident.

- A third factor is that metal-induced effects on the liver and kidney are unlikely to be associated with a short-term oral exposure, even if the presence of elevated metals levels is found in the blood or urine. Target organ toxicity is more likely to be associated with a prolonged increase in metal levels the blood or in the target organs and manifested as a delayed, or slowly developing response. Therefore, in relation to the Ranger incident, the clinical chemistry tests undertaken so soon after the putative exposure may need to be repeated as part of an ongoing health monitoring program.

#### **7.1.1 Blood levels of manganese and lead**

All of the results for manganese and lead are within the normal range and there was no apparent trend towards increasing levels in those self-reporting a higher level of water intake during the Ranger incident. The findings are therefore consistent with there having been little actual absorption of ingested lead or manganese associated with the incident or minimal systemic retention. However, in the absence of information on the precise timing of the sample collection, it is impossible to rule out rapid clearance of any absorbed metal between the incident and the sample collection.

#### **7.1.2 Urinary levels of uranium**

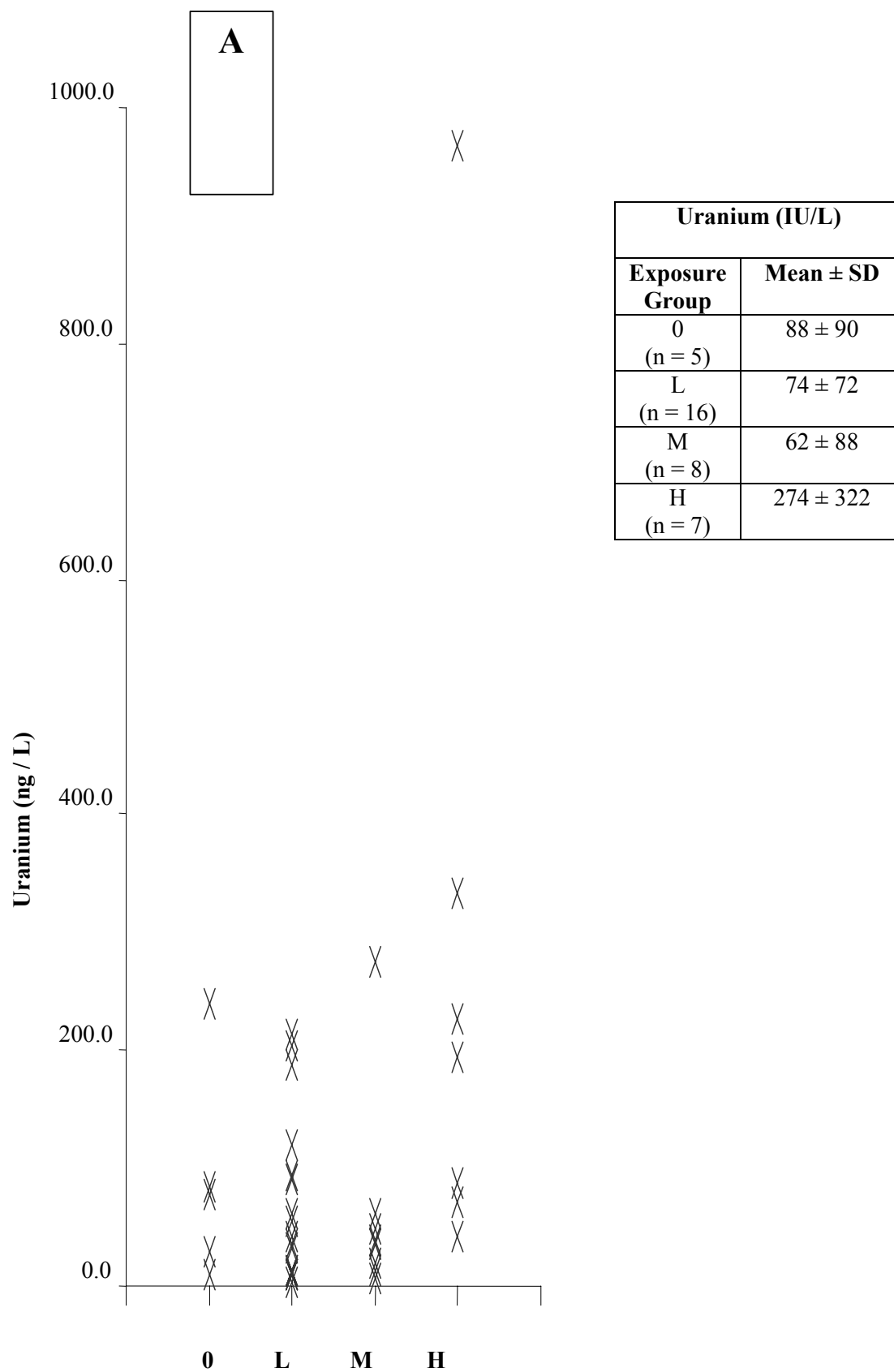
The urinary uranium levels found in 36 Ranger Mine workers ranged from 4 to 967 ng/L (0.004 to 0.967 µg/L). This is indicative of some individuals having had an exposure to uranium but whether it is the result of drinking contaminated water, and/or from normal consumption of potable bore water and/or from other exposures that usually occur within the mine precinct is difficult to determine. No data were available to the authors of this HRA on urinary uranium levels for any point of time other than the samples taken 3-10 days after the incident on 23-24 March 2004.

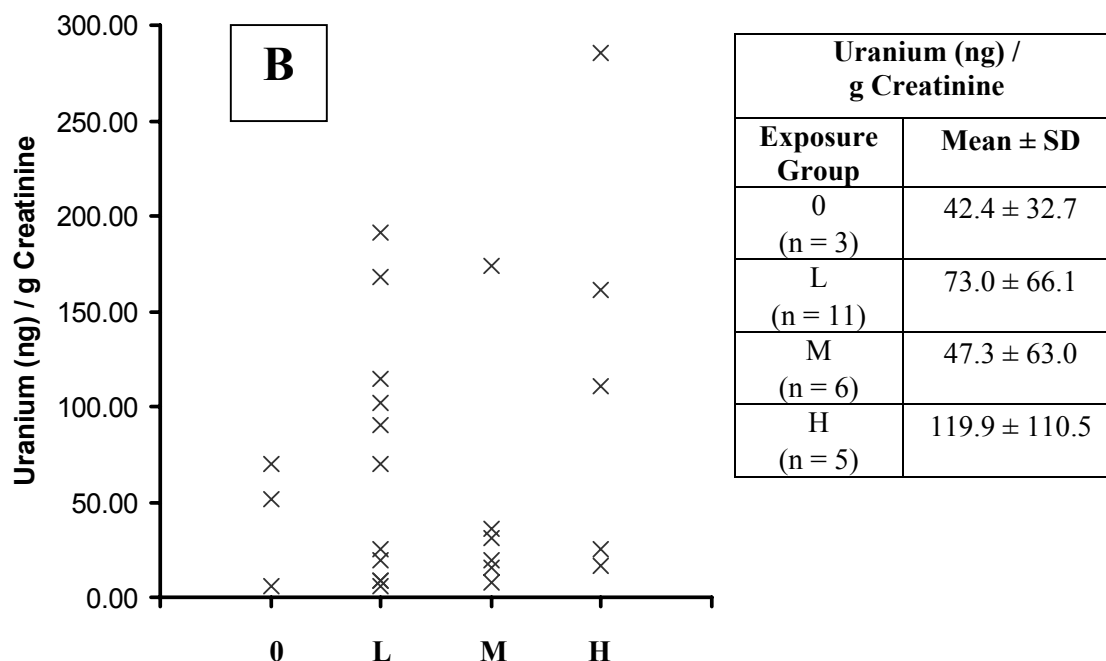
The levels in the Ranger workers are lower than the action level of 15 µg/L set by the U.S. Nuclear Regulatory Commission (NRC)) to protect occupationally exposed workers (NRC, 1978) and an action level of 10 µg/L set for Canadian mill workers (Napier and Smart, 1984).

In relation to the separate set of samples taken 3-8 days after the incident (see Table 8, Appendix D) the urinary uranium levels were analysed by a less sensitive method, with a Limit of Determination (LOD) of 0.1 µg/L (100 ng/L). These uranium levels in these samples ranged from <0.1 – 1.8 µg/L (<100 – 1800 ng/L). Five of the samples could be identified as having come from individuals also tested in Dr Gaunt's sampling program, and it is useful to compare them (Table 6).

While the data in Figure 2 suggest a trend towards higher urinary uranium levels in the group which self-reported the highest exposure to contaminated water during the Ranger incident, it is noted that at least one of the higher levels (239 ng/L) was found among a group which reported no consumption of potable water during the incident.

The urinary uranium levels taken 10 days after the incident appear to be lower in the same individuals than those taken 3 -8 days after the incident, although the comparison is made more difficult because of the different methodology used to generate the results.





**Figure 2: Urinary uranium results from the sampling programme undertaken 10 days after the Ranger water incident expressed as ng uranium/L urine in Panel A, or as ng uranium/ g creatinine in Panel B.**

The total number of subjects sampled was 36 but because urinary creatinine was not available for all there are 24 data points in panel B.

**Table 6 Comparison of Results for Urine Uranium Concentrations**

Subject code *	Urine uranium from Marshman Excel spread sheet 'RSRP-0403-02' (Table 8, Appendix D)		Urine uranium (ng/L) from Excel spread sheet 'Water Incidence Codes Version 25.05.04 - Water Incidence Health Results' (Table 7, Appendix D)	
	(ng/L) a	Days post event urine sample obtained	ng/L	Days post event urine sample obtained
* <i>Supervising Scientist's Note:</i> Subject Codes deleted to maintain anonymity.	200	4	11	10
	300	3	92	10
	100	3	71	10
	100	6	6	10
	200	8	87	10
Range <sup>b</sup>	<100 – 1800 <sup>d</sup> N = 28		4 - 967 N = 36	

<sup>a</sup> Results are recorded in the spread sheet only as  $\mu\text{g/L}$  urine. These cannot be corrected for creatinine excretion because data are not available, see Figure 2 where the Gaunt samples are expressed both as ng/L urine and ng/g creatinine.

<sup>b</sup> The range represents urine uranium concentration for all people sampled by Marshman and/or Gaunt. The subject sampling of Marshman was not targeted, however that of Gaunt was directed towards individuals who had expressed concern about potential exposure or had indicated they may have drunk the contaminated water.

<sup>d</sup> In the overall data set of Marshman there were two high values (1800 & 1300 ng/L) the next highest was 300 ng/L.

It is not known whether this apparent decline reflects the excretion of uranium ingested during the incident. In the absence of urinary uranium monitoring data from workers at the Ranger mine at times not connected with the incident, it is difficult to know whether these levels are reflective of their usual uranium intake through bore water (8.3 µg/L) or airborne dusts. The workers would not have had such ongoing exposure in the days following the incident, because the mine was closed.

It is important to consider the urinary concentration of uranium in the Ranger workers in the context of levels reported in various published studies.

In the National Health and Nutrition Examination Survey (1999-2000) conducted in the USA, the normal range of urinary uranium levels derived from 2460 non-occupational exposed individuals ranged from <6 to 66 ng/L. Mexican Americans reported a higher range of <6 - 298 ng/L in this survey.

In 27 individuals (20 males and 7 females) who were living and working in a normal background environment in Bombay India, Dang *et al.*, (1992) reported urinary uranium concentrations of  $12.8 \pm 10.4$  ng/L (arithmetic mean  $\pm$  SD) and  $9.4 \pm 2.2$  ng/L (geometric mean  $\pm$  SD). The range was 0 - 45 ng/L. In the same paper, the authors quoted urinary uranium from non-occupational subjects from Japan, the United States and Yugoslavia as being in the range of 3-310 ng/L.

Uranium was measured in 12 Israeli urine samples in the Depleted Uranium Program at Baltimore VA Medical Center (Ejnik *et al.*, 2000). Of these, six were from depleted-uranium-exposed (DU) subjects and six from non-DU-exposed subjects. The uranium concentrations in the DU-exposed group were all >1000 ng/L (exact concentrations not reported in this paper) which was two orders of magnitude above 6-30 ng/L in the non-DU-exposed group (Karpas *et al.*, 1996).

The median uranium concentration in urine was 78 µg/L (78,000 ng/L; range 1000 – 5,650,000 ng/L) in a cohort of 325 people living in a region of Southern Finland using water from more than 5,000 drilled wells where the median uranium content was 28 µg/L and the range 0.001 – 1920 µg/L (Kurttio *et al.*, 2002). When standardized against urinary creatinine, the median uranium level was 13 ng/mmol creatinine (range 0.1 – 955 ng/mmol creatinine). The exposure period was from 1 - 34 years and the estimated daily median uranium intake was 39 µg (range 0.006 – 4128 µg). This study also examined the relationship between uranium in drinking water and renal function, using various biochemical indicators of renal damage, including calcium, phosphate, glucose, albumin, creatinine, and  $\beta$ -2-microglobulin. No correlation was reported between uranium urinary concentration and creatinine clearance or urinary albumin (a reflection of glomerular function of the kidney). However, daily uranium intake was associated with increased fractional clearance of calcium, and urinary uranium concentration (but not estimated uranium intake) was significantly correlated with increased calcium and phosphate clearance and elevated urinary glucose excretion. However, unlike the results of a Canadian study (Zamora *et al.*, 1998), there was no effect on urinary  $\beta$ -2-microglobulin or urinary alkaline phosphatase, parameters thought to be more indicative of altered proximal tubular function. Although associations reported by Kurttio *et al.*, (2002) were not strong, they concluded that even low uranium concentration in drinking water could cause mild changes in renal function.

In a similar study, comparing two Canadian populations drinking water containing either low (<1 µg/L) or high (2 – 781 µg/L) levels of uranium, Zamora *et al.*, (1998) found significant positive correlations between uranium intake and elevated urinary glucose excretion, but also with urinary  $\beta$ -2-microglobulin and alkaline phosphatase excretion. The  $\beta$ -2-microglobulin values ranged from 11 – 340 µg/g creatinine. This study also measured NAG in urine, but found no association with uranium intake.



In summary, the urinary uranium levels in the Ranger workers tested were well below the 15 µg/L (15,000 ng/L) level of concern set for long-term exposure by NRC (1978) and could therefore be considered not to represent a health risk. The levels in the Ranger workers were comparable to, or slightly higher than, the ranges reported in some of the above studies in occupational and non-occupationally exposed environments.

### 7.1.3 Clinical chemistry results

The complete set of clinical chemistry data from the 36 Ranger workers tested are shown in Table 7, Appendix D.

Most of the clinical chemistry results were within the ‘normal’ range, although there were some which fell outside this range. There was no particular pattern to the abnormal results, with none apparently being more common among the higher exposure groups. Their interpretation would require knowledge of whether the individuals concerned had other possible risk factors. Overall, they do not suggest any significant toxic effects on the liver or kidney, two possible targets for some of the metals with the highest risk profiles in the Ranger incident.

#### 7.1.4 Urinary NAG and plasma β-2-microglobulin

Some tests (urinary NAG and serum β-2-microglobulin) are thought to be sensitive biomarkers of proximal tubular damage in the kidney, a potential site for uranium toxicity.

None of the serum β-2-microglobulin results were outside the ‘normal’ range.

In the Ranger workers, **serum** β-2-microglobulin fell as urinary uranium concentration rose, and the negative association was statistically significant ( $r^2=0.277$ ,  $p<0.05$ ). This is difficult to interpret, since elevated serum β-2-microglobulin is the more usual indicator of kidney damage. The finding also contrasts with the positive association Zamora *et al.*, (1998) found between uranium intake and **urinary** β-2-microglobulin. It would have been useful if the β-2-microglobulin in the Ranger workers had been measured in urine, to enable a direct comparison with the Zamora *et al.*, findings. However, it is understood that the instability of this protein in stored urine, and uncertainties around appropriate storage and handling of the samples during transit from the collection site to the laboratory resulted in the decision to measure this protein only in serum.

In relation to urinary NAG activity, while there is no standardized reference or ‘normal’ range for this parameter, there were some NAG results in individual Ranger workers which, on first inspection, merited further attention.

The two highest NAG results (20.2 and 18.4 IU/L) were reported in one worker in each of the ‘medium’ and ‘high’ exposures groups, as categorized on the basis of their self-reported water intake during the incident. However, in neither of these cases was there an indication of renal disease in any of the other clinical chemistry parameters. In one other case, urinary NAG appeared slightly high (15.2 IU/L), and there were some other clinical chemistry values outside the normal range. At least these three workers appear to warrant follow-up and further testing.

NAG activity is determined by reacting this enzyme with a selection of substrates resulting in the generation of a fluorescent or colour chromogenic product, which is then quantified by a fluorimetric or colorimetric method respectively (Yuen *et al.*, 1982). It is generally expressed in terms of Units (usually µmole of product formed per hour), and the activity may therefore depend on the substrate used. For this reason, comparison of published values may be difficult. It is also common for the NAG activity to be standardized against urinary creatinine, to overcome urine dilution effects.

A wide range of NAG values have been reported in the literature. For example, Yuen *et al.*, (1982) reported an average normal urinary NAG of  $14.6 \pm 8.2$  µmol product/mmol creatinine in 120

individuals using the same substrate as that used to obtain the Ranger Mine results. In the same paper, the authors used another two substrates to assay a subset of 30 and 33 urine samples (it is not clear whether they were from the original set of 120 samples) and the mean values were  $6.5 \pm 2.5$  and  $18.9 \pm 8.4$   $\mu\text{mol product}/\text{mmol creatinine}$ . It is not possible to assess the relative variation in the three assays, since all 120 samples were not assayed by all methods. Also, the results were not expressed in terms of a 'unit', defined as one  $\mu\text{mol chromophore}/\text{hour}$ , as was used in later publications (Yuen *et al.*, 1987).

In a subsequent paper published by the same research group (Yuen *et al.*, 1984), the authors compared NAG results from 54 urine samples determined by either the fluorimetric method or the colourimetric method (and hence different substrate) and found an excellent correlation between the two methods ( $r=0.998$ ). They also measured NAG activity in 100 normal individuals aged between 12 and 59 years and reported a mean of  $12.4 \pm 6.0$   $\mu\text{mol MNP}(\text{product})/\text{h}/\text{mmol creatinine}$  ( $110 \pm 53$  U/g creatinine). The NAG activity per litre of urine was between 25 and 387  $\mu\text{mol MNP}/\text{h}/\text{L}$  (25 -387 U/L).

Yuen *et al.*, (1987) measured NAG isoenzymes in normal and renal transplant patients. The total NAG activities in normal control, stable transplant, reversible rejection and irreversible rejection patients were  $15.4 \pm 1.2$  U/mmol creatinine (mean $\pm$ sem,  $n=34$  individuals),  $84.4 \pm 11.1$  ( $n=13$ ),  $72 \pm 10.7$  (13 episodes in 9 individuals) and  $585.0 \pm 180.0$  (3 episodes in 2 individuals) respectively.

In a more recent study (Oo *et al.*, 2000) included 875 inhabitants (346 males and 529 females) and 635 inhabitants (222 males and 413 females), 50-99 years of age, in two areas unpolluted by cadmium in the Noto Peninsula of Ishikawa Prefecture in Japan. The authors found a dose-response relationship between cadmium body burden and renal effects and that a significant correlation was observed between urinary cadmium and urinary NAG activity. The geometric mean NAG activity ranged from 2.7-5.4 U/L (geometric standard deviation 1.7-2.3) for all the males and 2.2-8.6 U/L (gsd 1.7-2.4) for all the females. Based on logistic-regression analysis, they proposed cut off values for NAG of 8.0 and 7.2 U/L for males and females respectively, where cut off values were based on the geometric mean  $\times$  1 geometric standard deviation.

Green *et al.*, (2004) reported mean values of 2.41 IU/g creatinine ( $n=54$ ) for control and 5.27 IU/g creatinine ( $n=70$ ) for exposed group in a report on kidney function among workers occupationally exposed to trichloroethylene in China.

When the NAG results from the Ranger workers are considered on the basis of their groupings into categories based on self-reported ingestion of potable water during the incident, the overall mean was  $8.5 \pm 5$  IU/L ( $n=36$ ) and the values ranged from 1.6 to 20.2 IU/L. When the NAG results were adjusted for creatinine concentrations (where creatinine results were available) and expressed as IU/g creatinine, the means  $\pm$  SD were:

non-exposed	$8.4 \pm 4.4$	( $n=3$ ),
low-exposed	$6.1 \pm 3.3$	( $n=11$ ),
medium-exposed	$7.2 \pm 2.2$	( $n=6$ )
high-exposed	$6.7 \pm 2.5$	( $n=5$ ).

Therefore, on a group basis, the urinary NAG levels in the Ranger workers do not appear to be different from the ranges reported for a variety of cohorts in the literature. Furthermore, there were no differences between any of the groups based on self-reported exposures (Student's unpaired t-tests;  $p>0.05$ ).

## 7.2 Possible follow-up actions

Health investigations done within the first week of the incident would be expected to detect damage to key target organs such as the kidney and liver, if the exposures had been high enough to produce an acutely toxic reaction. Such testing may not reveal more slowly developing health effects, although the main outcome of this HRA suggests that exposures were too short to produce any significant risk of such delayed adverse health effects.

Any decision to engage in follow-up testing of individual workers should be made by their attending medical professionals and should be based on their individual medical histories and factors such as their level of concern and need for reassurance relating to the Ranger incident. This is apart from the three workers identified in Section 7.1.4 as having clinical chemistry results marginally outside the normal range in the first round of testing.

Any follow-up program of health monitoring might be conducted 3–6 months after the incident. In such cases, consideration could be given to the inclusion of convenient biomarkers which may be indicative of slowly developing adverse health effects on the target organs for selected metals. A discussion of the possible merits, and drawbacks, of using various biomarkers specific for renal disease and neurotoxicity is outlined in the following sections of this report.

### 7.2.1 Renal disease

The kidney is an important target organ for uranium toxicity, as well as being a possible target for lead and copper. The tests discussed in Section 7.1.4 ( $\beta_2$ -microglobulinaemia and the urinary excretion of N-acetylglucosaminidase), are well established techniques used to monitor occupational kidney disease specific to the proximal renal tubules, a sensitive site for uranium toxicity. If required on the basis of discussion between individual workers and their medical professionals, these tests could be repeated after 3–6 months, especially in the three workers who showed slightly elevated levels in the first battery of tests.

### 7.2.2 Neurotoxicity

Manganese was the metal which featured most prominently in the HRA and the basal ganglia of the brain are a significant target for chronic manganese neurotoxicity.

Biomonitoring for developing neurotoxicity is difficult. Disturbances in the functioning of dopaminergic neurotransmission systems may reflect progressive changes associated with manganese neurotoxicity and a number of potential biomarkers have been studied (Manzo et al., 2001; Smargiassi & Mutti, 1999).

Prolactin secretion from the pituitary gland is regulated via a dopaminergic inhibitory pathway in the hypothalamus, and impairment of this regulatory system can result in elevated serum prolactin levels. Elevated serum prolactin has been demonstrated in groups occupationally exposed to neurotoxicants affecting the basal ganglia, including manganese (Mutti et al., 1996; Smargiassi & Mutti, 1999).

Urinary homovanillic and vanillylmandelic acids, which are the end products of dopamine metabolism, have also been shown to correlate to some extent with serum and urinary manganese levels in workers inhaling manganese dusts (Ai et al., 1998), although the value of such measurements where the correlation coefficients are so low (0.3–0.6) is questionable. Other approaches, including changes in type B monoamine oxidase (MAO-B) activity and dopamine beta-hydroxylase (DBH) activity have been examined, but tend to show poor correlations with other biomarkers of manganese exposure, such as blood and urine manganese levels.

A variety of neurobehavioural or functional tests have been used to investigate groups occupationally exposed to manganese (Beuter et al., 1999; Bowler et al., 1999; Mergler et al.,

1994). These have included questionnaires exploring mood disturbances and tests of neuromotor function (e.g. hand steadiness, hand-eye co-ordination,). In general, these types of tests have mainly been applied to groups occupationally exposed, although some studies involving Quebec communities have addressed non-occupational chronic exposures (Hudnell, 1999).

However, in relation to these possible biomarkers of neurotoxicity, the general consensus opinion at this time is that, while they may be capable of showing differences between exposed and non-exposed occupational groups, variability in the measured parameters and the assumption that changes in peripheral tissues are reflective of changes in the more complex neuronal system of the brain, significantly limits the applicability of these techniques to monitoring individuals (Manzo et al., 2001; Iregren, 1999).

Because of the relatively rapid clearance of manganese from the body, a similar conclusion has been drawn in respect of the interpretation of blood, urinary and hair manganese levels as exposure biomarkers, particularly where ongoing exposure complicates the differentiation of recent intake and accumulated body burden (Apostoli et al., 2000; Bader et al. 1999)

With these limitations in mind, careful consideration needs to be given to the merits of undertaking follow-up testing of possible neurotoxic outcomes from the Ranger incident.

## 8 Conclusions

1. Adverse effects reported by the workers at the Ranger mine who were exposed to potable water contaminated with process water included skin and gastrointestinal irritancy, and these effects are consistent with the known toxicity of low level exposure to the metals and other inorganic substances in the water and would be expected on the basis of the concentrations found.
2. The extent to which the contamination exceed the Health Guideline Values (HGVs) of the Australian Drinking Water Guidelines (ADWGs) was used as a screening tool, to prioritise those metals which warranted further attention in this HRA. Consequently, the HRA has focused mainly on eight metals or metalloids (manganese, uranium, lead, nickel, copper, aluminium, selenium and arsenic) which achieved relatively high concentrations in some samples of the contaminated water, and which have toxicological properties which merit attention to possible acute and delayed toxic effects.
3. The health risk assessment (HRA) in this report indicates that oral exposures to the metal contaminants should be too low and too short-term to cause systemic toxic effects on target organs. This is despite the exposure levels exceeding water quality guidelines, which are set on the basis of a lifetime of exposure.
4. The results of health studies undertaken on some of the workers, including blood and urine tests of various clinical chemistry parameters and measurements of blood and urinary levels of selected metals, are quite consistent with the predicted low risk of systemic toxicity.
5. While the HRA suggests that the potential for the exposures to result in systemic toxicity is very low, such a possibility cannot be completely ruled out. Some possibilities for follow-up blood/urine biomonitoring or organ function program focusing on the kidney and the brain have been considered.
6. However, it needs to be appreciated that biomarkers of renal disease or brain dysfunction may not be specific to metal-induced toxicity and may be difficult to interpret in the absence of baseline data for individual workers. A decision on the need for, and nature of

any follow-up medical assessment for individual workers should be made by their attending medical professionals and based on their individual medical histories. This decision should take into account other potential risk factors and their need for reassurance relating to the Ranger incident.

## 9 Other considerations

In the discussion of the toxicity of uranium in drinking water, it was noted that the toxicological database for soluble uranium salts relates to uranyl nitrate and uranyl acetate. It is suggested that consideration be given to undertaking studies to characterize the toxicity of uranyl sulfate and associated forms of uranium in drinking water, in comparison with these other soluble uranium salts.

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## Appendix A Letter of Commission From SSD with Exposure Scenarios Requested for the HRA

**file ref:** tba

30 March, 2004

**doc name:** cover letter\_hhra

Associate Professor Barry Noller  
Deputy Director  
National Research Centre for Environmental Toxicology (EnTox)  
39 Kessels Road  
Coopers Plains  
Brisbane QLD 4108

**cc.** Professor Michael Moore, Professor Brian Priestly

Dear Barry,

This letter is to confirm that the Supervising Scientist Division (SSD) wishes the National Research Centre for Environmental Toxicology (EnTox) and the Monash University Department of Epidemiology & Preventive Medicine (DEPM), under the banner of the Australian Centre for Human Health Risk Assessment (ACHHRA), to undertake an assessment of health impacts following exposure of workers at Ranger Uranium Mine to contaminated potable water, as specified in the attached Terms of Reference.

Based on relevant conversations and other correspondence to date, we understand that the project team will comprise the following individuals, each at a daily charge-out rate of \$1,500:

*Professor Brian Priestly:* Director, Australian Centre for Human Health Risk Assessment (ACHHRA); Professorial Fellow, Monash University Department of Epidemiology & Preventive Medicine;

*Professor Michael Moore:* Director, National Research Centre for Environmental Toxicology; Director, Queensland Health Scientific Services (QHSS );

*Associate Professor Barry Noller:* Deputy Director, National Research Centre for Environmental Toxicology; and

*Associate Professor Jack Ng:* Research Program Manager of Metals and Metalloids Research, National Research Centre for Environmental Toxicology.

We request that the first phase of the project (ie. the 'first pass' assessment) be undertaken over 1-2 April 2004, with the outcomes being reported to the Supervising Scientist, through the SSD project manager, Dr Rick van Dam, before close of business (cob; 5pm EST) 2 April. In addition to personnel time costs based on the above-specified daily rates, we agree to cover the cost (through reimbursement) of a Melbourne–Brisbane return airfare and accommodation for the night of 1 April for Professor Brian Priestly.

Following the provision of the outcomes of the 'first pass' assessment, SSD proposes that a detailed scope and budget for phase 2 of the project (ie. the comprehensive human health risk assessment) be developed for final approval prior to commencement.

If you are willing to undertake this project based on the conditions set out in this letter and its attachments, please notify Dr Rick van Dam in writing (by E-mail or fax) before cob 31 March.

In the meantime, and for the duration of the project, please direct all correspondence to Dr Rick van Dam.

Yours sincerely

Dr Rick van Dam

Tel (08) 8920 1175

Fax (08) 8920 1199

Email Rick.vanDam@deh.gov.au

## Appendix B (Table 4) Full Details of the Analytes in all the Water Samples

### Day 1 Potable water ERA and SSD results (Version 2, 06 May 2004)

#### Notes:

All filtrate results are for samples acidified and filtered on arrival to NTEL within 24 hrs of collection

All total results (except CDU pseudo totals) acid digested for 8 hrs

Unless otherwise highlighted all SSD results are from NTEL job EL03309

SSD samples E & H - some changes have been made to results following reanalyses:

E & H: replaced with result from 2nd NTEL analyses. Represents total fraction of same subsample as analysed at CDU.

Result from Charles Darwin University Environmental Chemistry Analytical Unit  
quantitative on total fraction OR TQ scan on pseudo totals

Sample Number	Site Description	Sample Code	Date	Temp °C	EC - lab µS/cm	pH - lab units	Turbidity NTU	Alkalinity mg/L	HCO <sub>3</sub> mg/L	CO <sub>3</sub> mg/L	OH mg/L
<b>SSD DATA from potable supply 24/3/04</b>											
A00315	Jabiru East Hydrant	A	24-Mar-04		1045	6.9					
A00316	Urn in crib room d/s main building	B	24-Mar-04	Insufficient sample for General parameters							
A00317	Downstairs mill lab taps	C	24-Mar-04		1516	7.5					
A00318	Downstairs mill lab taps	D	24-Mar-04	Insufficient sample for General parameters							
A00319	Engineering shower block	E	24-Mar-04		1505	6.7					
A00320	Eng toilet tap shower block	F	24-Mar-04	Insufficient sample for General parameters							
A00321	Engineering crib room	G	24-Mar-04	Insufficient sample for General parameters							
A00322	Grinding area ground floor toilet cistern	H	24-Mar-04		8710	4.2					
<b>ERA DATA from potable supply 24/3/04</b>											
100305	Potable Water from Ranger Admin Crib Rc	PW	24-Mar-04	23.2	2740	5.8	325	106	106	<1	<1
100324	Admin Potable Water Tank Discharge	PTPD	24-Mar-04								
100326	Potable Water - Underground pipe to Jabir	PTUP	24-Mar-04								
100323	Potable Water Header Tank (on the fine or	GPWT	24-Mar-04								
100309	Brockman Potable Water Bore 84/3 (fed b)	B84-3	24-Mar-04	22.6	389	7.7	<1	199	199	<1	<1
100306	ERISS Potable Water Storage Tanks (now	EPW	24-Mar-04	22.9	399	8.1	4	206	206	<1	<1
100308	Gagadiu Workshop (now known as JE036)	GPWT	24-Mar-04	23.7	399	8.2	2	205	205	<1	<1
100310	Jabiru East Potable Water Tank	JPWT	24-Mar-04	23.8	724	7.7	6	178	178	<1	<1
100307	Jabiru East Potable Water Tank Overflow	JPWTO	24-Mar-04	23.9	785	7.9	8	176	176	<1	<1
100311	Jabiru East Hydrant (Opposite Core Shed)	JH	24-Mar-04	23.8	1060	7.3	50	160	160	<1	<1

## Appendix B (Table 4) Page 2

## Day 1 Potable water ERA and SSD results (Version 2, 06 May 2004)

## Notes:

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All total results (except CDU pseudo totals) acid digested for 8 hrs

Unless otherwise highlighted all SSD results are from NTEL job EL03309

SSD samples E & H – some changes have been made to results following reanalyses:

E & H: replaced with result from 2nd NTEL analyses. Represents total fraction of same subsample as analysed at CDU.

Result from Charles Darwin University Environmental Chemistry Analytical Unit  
quantitative on total fraction OR TQ scan on pseudo totals

Sample Number	Site Description	Sample Code	Date	NO <sub>2</sub> _N mg/L FIA_4	NO <sub>3</sub> _N mg/L FIA_4	NH <sub>3</sub> _N mg/L FIA	Ag_F µg/L W105M	Ag_T µg/L W200M	Al_F µg/L W105M	Al_T µg/L W200M	As_F µg/L W105M
<b>SSD DATA from potable supply 24/3/04</b>											
A00315	Jabiru East Hydrant	A	24-Mar-04	<0.005	0.05	12.8	<0.05	<0.05	55.9	>LWR	0.4
A00316	Urn in crib room d/s main building	B	24-Mar-04	N.A.	N.A.	N.A.	<0.05	<0.05	1.4	2.3	<0.05
A00317	Downstairs mill lab taps	C	24-Mar-04	<0.005	0.05	<0.005	0.05	0.35	1.4	3.4	0.25
A00318	Downstairs mill lab taps	D	24-Mar-04	<0.005	0.045	0.615	<0.05	0.15	3.2	6.2	0.15
A00319	Engineering shower block	E	24-Mar-04	<0.005	0.06	32.5	0.05	0.25	34.6	2140	1.05
A00320	Eng toilet tap shower block	F	24-Mar-04	N.A.	N.A.	N.A.	<0.05	0.05	22.8	582	1.05
A00321	Engineering crib room	G	24-Mar-04	N.A.	N.A.	N.A.	<0.05	0.1	2	473	0.85
A00322	Grinding area ground floor toilet cistern	H	24-Mar-04	0.025	0.39	277	<0.05	0.3	102000	132000	27.5
<b>ERA DATA from potable supply 24/3/04</b>											
100305	Potable Water from Ranger Admin Crib Rc	PW	24-Mar-04				<0.05		27.4		0.2
100324	Admin Potable Water Tank Discharge	PTPD	24-Mar-04	N.A.	N.A.	N.A.	<0.05		114		0.2
100326	Potable Water - Underground pipe to Jabir	PTUP	24-Mar-04	N.A.	N.A.	N.A.	<0.05		94.2		0.25
100323	Potable Water Header Tank (on the fine or	GPWT	24-Mar-04	N.A.	N.A.	N.A.	<0.05		13300		7.95
100309	Brockman Potable Water Bore 84/3 (fed b)	B84-3	24-Mar-04				<0.05		0.5		0.1
100306	ERISS Potable Water Storage Tanks (now	EPW	24-Mar-04				<0.05		1.3		0.15
100308	Gagadiu Workshop (now known as JE036j)	GW/P	24-Mar-04				<0.05		30.3		0.2
100310	Jabiru East Potable Water Tank	JPWT	24-Mar-04				<0.05		128		0.25
100307	Jabiru East Potable Water Tank Overflow	JPWTO	24-Mar-04				<0.05		129		0.25
100311	Jabiru East Hydrant (Opposite Core Shed)	JH	24-Mar-04				<0.05		47.2		0.6

## Appendix B (Table 4) Page 3

### Day 1 Potable water ERA and SSD results (Version 2, 06 May 2004)

#### Notes:

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Unless otherwise highlighted all SSD results are from NTEL job EL03309

SSD samples E & H - some changes have been made to results following reanalyses:

E & H: replaced with result from 2nd NTEL analyses. Represents total fraction of same subsample as analysed at CDU.

Result from Charles Darwin University Environmental Chemistry Analytical Unit  
quantitative on total fraction OR TQ scan on pseudo totals

Sample Number	Site Description	Sample Code	Date	As_T µg/L W200M	B_F µg/L W105M	B_T µg/L W200M	Ba_F µg/L W105M	Ba_T µg/L W200M	Be_F µg/L W105M	Be_T µg/L W200M	Br_F µg/L W105M
<b>SSD DATA from potable supply 24/3/04</b>											
A00315	Jabiru East Hydrant	A	24-Mar-04	0.7	30	37	6.83	7.1	0.05	0.25	102
A00316	Urn in crib room d/s main building	B	24-Mar-04	<0.05	8.4	10	0.84	0.9	<0.05	<0.05	48
A00317	Downstairs mill lab taps	C	24-Mar-04	0.25	11.6	14.5	1.99	2.2	<0.05	<0.05	180
A00318	Downstairs mill lab taps	D	24-Mar-04	0.15	12.8	15.5	1.83	1.8	<0.05	<0.05	112
A00319	Engineering shower block	E	24-Mar-04	1.7	55.9	61.5	12.1	13.2	0.2	0.8	160
A00320	Eng toilet tap shower block	F	24-Mar-04	1.5	65.3	71.5	12.6	14	0.2	0.4	150
A00321	Engineering crib room	G	24-Mar-04	1.9	155	159	33.6	36	<0.05	0.4	280
A00322	Grinding area ground floor toilet cistern	H	24-Mar-04	32	323	442	23.1	22.8	19.5	25.5	422
<b>ERA DATA from potable supply 24/3/04</b>											
100305	Potable Water from Ranger Admin Crib Rc	PW	24-Mar-04		35		3.14		<0.05		39
100324	Admin Potable Water Tank Discharge	PTPD	24-Mar-04		22.5		1.38		<0.05		71
100326	Potable Water - Underground pipe to Jabir	PTUP	24-Mar-04		25.5		1.56		<0.05		70
100323	Potable Water Header Tank (on the fine or	GPWT	24-Mar-04		151		7.44		5.8		229
100309	Brockman Potable Water Bore 84/3 (fed b)	B84-3	24-Mar-04		13		1.06		<0.05		28
100306	ERISS Potable Water Storage Tanks (now	EPW	24-Mar-04		13		1.82		<0.05		65
100308	Gagadiu Workshop (now known as JE036,	GW/P	24-Mar-04		13.5		1.58		<0.05		51
100310	Jabiru East Potable Water Tank	JPWT	24-Mar-04		25		3.34		<0.05		35
100307	Jabiru East Potable Water Tank Overflow	JPWTO	24-Mar-04		28.5		3.42		<0.05		40
100311	Jabiru East Hydrant (Opposite Core Shed)	JH	24-Mar-04		63.5		6.7		0.1		50

## Appendix B (Table 4) Page 4

## Day 1 Potable water ERA and SSD results (Version 2, 06 May 2004)

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E & H: replaced with result from 2nd NTEL analyses. Represents total fraction of same subsample as analysed at CDU.

Result from Charles Darwin University Environmental Chemistry Analytical Unit  
quantitative on total fraction OR TQ scan on pseudo totals

Sample Number	Site Description	Sample Code	Date	Br_T µg/L W200M	Ca_F mg/L W105I	Ca_T mg/L	Cd_F µg/L W105M	Cd_T µg/L W200M	Cr_F µg/L W105M	Cr_T µg/L W200M	Cu_F µg/L W105M
<b>SSD DATA from potable supply 24/3/04</b>											
A00315	Jabiru East Hydrant	A	24-Mar-04	31	31	30.8	3.49	3.86	0.4	1.2	69.7
A00316	Urn in crib room d/s main building	B	24-Mar-04	17	1.7	1.6	0	<0.02	<0.2	<0.2	0.38
A00317	Downstairs mill lab taps	C	24-Mar-04	31	23.1	22.7	0.36	0.38	1	1	370
A00318	Downstairs mill lab taps	D	24-Mar-04	25	24.5	24	0.08	0.1	0.4	0.4	527
A00319	Engineering shower block	E	24-Mar-04	81	56.6	63.2	0.98	2.12	0.4	1.8	1630
A00320	Eng toilet tap shower block	F	24-Mar-04	53	60.1	68.2	1.07	1.26	<0.2	0.8	1250
A00321	Engineering crib room	G	24-Mar-04	113	250	294	0.73	1.5	0.2	0.6	3.51
A00322	Grinding area ground floor toilet cistern	H	24-Mar-04	347	182	217	7.25	10.6	68.4	69.8	10700
<b>ERA DATA from potable supply 24/3/04</b>											
100305	Potable Water from Ranger Admin Crib Rc	PW	24-Mar-04		27.9		0.3		1.2		546
100324	Admin Potable Water Tank Discharge	PTPD	24-Mar-04		25		0.12		1.4		22.5
100326	Potable Water - Underground pipe to Jabir	PTUP	24-Mar-04		26.5		0.18		1.3		47.5
100323	Potable Water Header Tank (on the fine or	GPWT	24-Mar-04		74.3		2.52		4.5		2270
100309	Brockman Potable Water Bore 84/3 (fed b)	B84-3	24-Mar-04		22.5		<0.02		1.7		4.02
100306	ERISS Potable Water Storage Tanks (now	EPW	24-Mar-04		23.3		<0.02		2		4.04
100308	Gagadiu Workshop (now known as JE036)	GWP	24-Mar-04		22.9		0.04		1.7		22.8
100310	Jabiru East Potable Water Tank	JPWT	24-Mar-04		27.4		0.22		1.5		48.8
100307	Jabiru East Potable Water Tank Overflow	JPWTO	24-Mar-04		28		0.22		1.3		44.1
100311	Jabiru East Hydrant (Opposite Core Shed)	JH	24-Mar-04		39.1		2.02		1.3		114

## Appendix B (Table 4) Page 5

## Day 1 Potable water ERA and SSD results (Version 2, 06 May 2004)

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Result from Charles Darwin University Environmental Chemistry Analytical Unit  
quantitative on total fraction OR TQ scan on pseudo totals

Sample Number	Site Description	Sample Code	Date	Cu_T µg/L W200M	Fe_F µg/L W105M	Fe_T µg/L W200M	Hg_F µg/L W105M	Hg_T µg/L W200M	I_F µg/L W105M	I_T µg/L W200M	Mg_F mg/L W105L
<b>SSD DATA from potable supply 24/3/04</b>											
A00315	Jabiru East Hydrant	A	24-Mar-04	107	<20	120	<0.02	<0.02	<5	<5	102
A00316	Urn in crib room d/s main building	B	24-Mar-04	5.3	<20	<20	<0.02	<0.02	<5	<5	20.8
A00317	Downstairs mill lab taps	C	24-Mar-04	423	<20	<20	<0.02	<0.02	<5	<5	40.1
A00318	Downstairs mill lab taps	D	24-Mar-04	525	<20	<20	<0.02	0.02	<5	<5	44.3
A00319	Engineering shower block	E	24-Mar-04	2170	<20	268	<0.02	0.02	5	<5	183
A00320	Eng toilet tap shower block	F	24-Mar-04	1540	<20	40	<0.02	0.04	<5	<5	204
A00321	Engineering crib room	G	24-Mar-04	496	<20	20	<0.02	0.06	<5	<5	587
A00322	Grinding area ground floor toilet cistern	H	24-Mar-04	11700	960	1842	<0.02	<0.02	10	10	1130
<b>ERA DATA from potable supply 24/3/04</b>											
100305	Potable Water from Ranger Admin Crib Rc	PW	24-Mar-04	<20	<0.02	<0.02	<0.02	<0.02	<5	<5	84
100324	Admin Potable Water Tank Discharge	PTPD	24-Mar-04	<20	<0.02	<0.02	<0.02	<0.02	<5	<5	55.7
100326	Potable Water - Underground pipe to Jabir	PTUP	24-Mar-04	<20	<0.02	<0.02	0.04	<0.02	<5	<5	65.7
100323	Potable Water Header Tank (on the fine or	GPWT	24-Mar-04	120	<0.02	<0.02	<0.02	<0.02	5	<5	422
100309	Brockman Potable Water Bore 84/3 (fed by	B84-3	24-Mar-04	<20	<0.02	<0.02	<0.02	<0.02	<5	<5	39.6
100306	ERISS Potable Water Storage Tanks (now	EPW	24-Mar-04	<20	<0.02	<0.02	<0.02	<0.02	<5	<5	39.7
100308	Gagadiu Workshop (now known as JE036,	GWPT	24-Mar-04	<20	<0.02	<0.02	<0.02	<0.02	<5	<5	40.1
100310	Jabiru East Potable Water Tank	JPWT	24-Mar-04	<20	<0.02	<0.02	<0.02	<0.02	<5	<5	70.2
100307	Jabiru East Potable Water Tank Overflow	JPWTO	24-Mar-04	<20	<0.02	<0.02	<0.02	<0.02	<5	<5	75
100311	Jabiru East Hydrant (Opposite Core Shed)	JH	24-Mar-04	<20	<0.02	<0.02	<0.02	<0.02	<5	<5	158

## Appendix B (Table 4) Page 6

## Day 1 Potable water ERA and SSD results (Version 2, 06 May 2004)

## Notes:

All filtrate results are for samples acidified and filtered on arrival to NTEL within 24 hrs of collection  
All total results (except CDU pseudo totals) acid digested for 8 hrs  
Unless otherwise highlighted all SSD results are from NTEL job EL03309

SSD samples E & H - some changes have been made to results following reanalyses:

E & H: replaced with result from 2nd NTEL analyses. Represents total fraction of same subsample as analysed at CDU.

Result from Charles Darwin University Environmental Chemistry Analytical Unit  
quantitative on total fraction OR TQ scan on pseudo totals

Sample Number	Site Description	Sample Code	Date	Mg_T mg/L	Mn_F µg/L W105M	Mn_T µg/L W200M	Mo_F µg/L W105M	Mo_T µg/L W200M	Ni_F µg/L W105M	Ni_T µg/L W200M	Pb_F µg/L W105M
<b>SSD DATA from potable supply 24/3/04</b>											
A00315	Jabiru East Hydrant	A	24-Mar-04	113	27900	27900	0.2	0.2	66.1	69	2.9
A00316	Urn in crib room d/s main building	B	24-Mar-04		0.02	1.2	<0.05	<0.05	<0.01	0.2	<0.01
A00317	Downstairs mill lab taps	C	24-Mar-04	44	0.17	0.4	0.1	0.1	<0.01	0.5	3.5
A00318	Downstairs mill lab taps	D	24-Mar-04	41	688	709	0.1	0.1	1	1.4	1.6
A00319	Engineering shower block	E	24-Mar-04	138	59500	64200	0.25	2.3	121	128	11.2
A00320	Eng toilet tap shower block	F	24-Mar-04		66800	75700	0.4	0.6	136	148	10.4
A00321	Engineering crib room	G	24-Mar-04		172000	19700	0.3	0.4	6.3	27.7	0.2
A00322	Grinding area ground floor toilet cistern	H	24-Mar-04	1260	528000	607000	1.25	1.95	1490	1690	913
<b>ERA DATA from potable supply 24/3/04</b>											
100305	Potable Water from Ranger Admin Crib Rc	PW	24-Mar-04		22500		0.2		67.9		7.87
100324	Admin Potable Water Tank Discharge	PTPD	24-Mar-04		8090		0.15		18.2		1.9
100326	Potable Water - Underground pipe to Jabir	PTUP	24-Mar-04		13400		0.2		29.8		3.27
100323	Potable Water Header Tank (on the fine or	GPWT	24-Mar-04		195000		0.4		425		415
100309	Brockman Potable Water Bore 84/3 (fed b)	B84-3	24-Mar-04		0.06		0.25		0.57		0.79
100306	ERISS Potable Water Storage Tanks (now	EPW	24-Mar-04		1.88		0.1		0.24		0.25
100308	Gagadiu Workshop (now known as JE036j)	GPW	24-Mar-04		0.27		0.1		0.23		0.33
100310	Jabiru East Potable Water Tank	JPWT	24-Mar-04		14800		0.1		35.9		2.01
100307	Jabiru East Potable Water Tank Overflow	JPWTO	24-Mar-04		17100		0.1		41		2.06
100311	Jabiru East Hydrant (Opposite Core Shed)	JH	24-Mar-04		55200		0.25		131		5.9



## Appendix B (Table 4) Page 7

## Day 1 Potable water ERA and SSD results (Version 2, 06 May 2004)

## Notes:

All filtrate results are for samples acidified and filtered on arrival to NTEL within 24 hrs of collection

All total results (except CDU pseudo totals) acid digested for 8 hrs

Unless otherwise highlighted all SSD results are from NTEL job EL03309

SSD samples E & H - some changes have been made to results following reanalyses:

E & H: replaced with result from 2nd NTEL analyses. Represents total fraction of same subsample as analysed at CDU.

Result from Charles Darwin University Environmental Chemistry Analytical Unit  
quantitative on total fraction OR TQ scan on pseudo totals

Sample Number	Site Description	Sample Code	Date	Pb_T µg/L W200M	Sb_F µg/L W105M	Sb_T µg/L W200M	Se_T µg/L W105M	Se_F µg/L W200M	Sn_F µg/L W105M	Sn_T µg/L W200M
<b>SSD DATA from potable supply 24/3/04</b>										
A00315	Jabiru East Hydrant	A	24-Mar-04	9.67	<0.05	<0.05	14.3	1.8	<0.1	0.6
A00316	Urn in crib room d/s main building	B	24-Mar-04	0.12	<0.05	<0.05		0.2	0.1	<0.1
A00317	Downstairs mill lab taps	C	24-Mar-04	5.19	<0.05	<0.05	6.83	0.6	<0.1	0.1
A00318	Downstairs mill lab taps	D	24-Mar-04	1.86	<0.05	<0.05	6.56	0.6	<0.1	<0.1
A00319	Engineering shower block	E	24-Mar-04	35.3	0.4	3.2	<10	3	<0.1	0.3
A00320	Eng toilet tap shower block	F	24-Mar-04	18.5	0.5	2.55		2.4	<0.1	<0.1
A00321	Engineering crib room	G	24-Mar-04	30.7	0.05	1.6		3.8	0.1	0.1
A00322	Grinding area ground floor toilet cistern	H	24-Mar-04	1280	0.45	12	356	113	0.1	0.1
<b>ERA DATA from potable supply 24/3/04</b>										
100305	Potable Water from Ranger Admin Crib Rc	PW	24-Mar-04		0.25			1	<0.1	
100324	Admin Potable Water Tank Discharge	PTPD	24-Mar-04		0.1			0.8	<0.1	
100326	Potable Water - Underground pipe to Jabir	PTUP	24-Mar-04		0.05			1	<0.1	
100323	Potable Water Header Tank (on the fine or	GPWT	24-Mar-04		0.3			38.6	<0.1	
100309	Brockman Potable Water Bore 84/3 (fed b)	B84-3	24-Mar-04		<0.05			0.4	<0.1	
100306	ERISS Potable Water Storage Tanks (now	EPW	24-Mar-04		<0.05			0.6	<0.1	
100308	Gagadiu Workshop (now known as JE036,	GW/P	24-Mar-04		<0.05			0.8	<0.1	
100310	Jabiru East Potable Water Tank	JPWT	24-Mar-04		<0.05			1.4	<0.1	
100307	Jabiru East Potable Water Tank Overflow	JPWTO	24-Mar-04		<0.05			1.2	<0.1	
100311	Jabiru East Hydrant (Opposite Core Shed)	JH	24-Mar-04		<0.05			2.6	<0.1	

## Appendix B (Table 4) Page 8

## Day 1 Potable water ERA and SSD results (Version 2, 06 May 2004)

## Notes:

All filtrate results are for samples acidified and filtered on arrival to NTEL within 24 hrs of collection

All total results (except CDU pseudo totals) acid digested for 8 hrs

Unless otherwise highlighted all SSD results are from NTEL job EL03309

SSD samples E & H – some changes have been made to results following reanalyses:

E & H: replaced with result from 2nd NTEL analyses. Represents total fraction of same subsample as analysed at CDU.

Result from Charles Darwin University Environmental Chemistry Analytical Unit  
quantitative on total fraction OR TQ scan on pseudo totals

Sample Number	Site Description	Sample Code	Date	SO4_F mg/L W105I	SO4_T mg/L	Th_T µg/L	U_F µg/L W105M	U_T µg/L W200M	V_T µg/L W200M	Zn_F µg/L W105M	Zn_T µg/L W200M
<b>SSD DATA from potable supply 24/3/04</b>											
A00315	Jabiru East Hydrant	A	24-Mar-04	410		0.493	83.3	125	0.6	>LWR	>LWR
A00316	Urn in crib room d/s main building	B	24-Mar-04	1.1			0.2	0.6	0.1	0.8	7.1
A00317	Downstairs mill lab taps	C	24-Mar-04	0.8		0.008	6.8	7.1	0.7	291	388
A00318	Downstairs mill lab taps	D	24-Mar-04	30.8		0.006	9	9.6	0.9	305	338
A00319	Engineering shower block	E	24-Mar-04	913	407	0.95	189	366	1.1	5270	>LWR
A00320	Eng toilet tap shower block	F	24-Mar-04	1080			102	156	0.8	>LWR	>LWR
A00321	Engineering crib room	G	24-Mar-04	3420			250	527	0.3	6.9	887
A00322	Grinding area ground floor toilet cistern	H	24-Mar-04	6940	8370	64.25500 - 6500		7060	<0.1	11000	>LWR
<b>ERA DATA from potable supply 24/3/04</b>											
100305	Potable Water from Ranger Admin Crib Rc	PW	24-Mar-04	345			2.21		2.5	1510	
100324	Admin Potable Water Tank Discharge	PTPD	24-Mar-04	110			62.4		--	197	
100326	Potable Water - Underground pipe to Jabir	PTUP	24-Mar-04	178			113		--	355	
100323	Potable Water Header Tank (on the fine or	GPWT	24-Mar-04	2570			1350		--	2560	
100309	Brockman Potable Water Bore 84/3 (fed b)	B84-3	24-Mar-04	0.9			8.38		3.4	6.7	
100306	ERISS Potable Water Storage Tanks (now	EPW	24-Mar-04	1.2			8.23		3.5	61.6	
100308	Gagadiu Workshop (now known as JE036,	GPWT	24-Mar-04	0.9			8.05		3.2	71.3	
100310	Jabiru East Potable Water Tank	JPWT	24-Mar-04	211			89.9		3.2	207	
100307	Jabiru East Potable Water Tank Overflow	JPWTO	24-Mar-04	239			103		2.8	178	
100311	Jabiru East Hydrant (Opposite Core Shed)	JH	24-Mar-04	736			116		2.8	1540	

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## Day 1 Potable water ERA and SSD results (Version 2, 06 May 2004)

## Notes:

All filtrate results are for samples acidified and filtered on arrival to NTEL within 24 hrs of collection

All total results (except CDU pseudo totals) acid digested for 8 hrs

Unless otherwise highlighted all SSD results are from NTEL job EL03309

SSD samples E & H – some changes have been made to results following reanalyses:

E & H: replaced with result from 2nd NTEL analyses. Represents total fraction of same subsample as analysed by ICPMS scans are semi-quantitative only - several analytes may be affected by uncorrected detection limits vary but are generally in the range 0.010ppb (e.g. Cd, Pb, U) to 50ppb

Charles Darwin Uni - additional analytes (TQ scan on pseudo total fraction OR TQ scan on pseudo totals)

Result from Charles Darwin University Environmental Chemistry Analytical Unit

quantitative on total fraction OR TQ scan on pseudo totals

Sample Number	Site Description	Sample Code	Date	Zn_T mg/L	Fully quantitative reanalysis on total portion					Ge µg/L
					Li µg/L	K µg/L	Ti µg/L	Co µg/L	Ga µg/L	
SSD DATA from potable supply 24/3/04										
A00315	Jabiru East Hydrant	A	24-Mar-04	1.73	51.151	2873.006	0.494	29.933	0.162	0.037
A00316	Urn in crib room d/s main building	B	24-Mar-04	--						
A00317	Downstairs mill lab taps	C	24-Mar-04	--	9.529	221.605	0.441	0.031	0.000	0.000
A00318	Downstairs mill lab taps	D	24-Mar-04	--	9.168	233.925	0.423	0.107	0.000	0.010
A00319	Engineering shower block	E	24-Mar-04	5.97	63.745	3327.863	0.516	38.970	0.201	0.053
A00320	Eng toilet tap shower block	F	24-Mar-04	4.38						
A00321	Engineering crib room	G	24-Mar-04	1.1						
A00322	Grinding area ground floor toilet cistern	H	24-Mar-04	12.6	783.963	51133.893	8.097	905.455	0.000	1.583
ERA DATA from potable supply 24/3/04										
100305	Potable Water from Ranger Admin Crib Rc	PW	24-Mar-04							
100324	Admin Potable Water Tank Discharge	PTPD	24-Mar-04							
100326	Potable Water - Underground pipe to Jabir	PTUP	24-Mar-04							
100323	Potable Water Header Tank (on the fire or	GPWT	24-Mar-04							
100309	Brockman Potable Water Bore 84/3 (fed by	B84-3	24-Mar-04							
100306	ERISS Potable Water Storage Tanks (now	EPW	24-Mar-04							
100308	Gagadiju Workshop (now known as JE036,	GWP	24-Mar-04							
100310	Jabiru East Potable Water Tank	JPWT	24-Mar-04							
100307	Jabiru East Potable Water Tank Overflow	JPWTO	24-Mar-04							
100311	Jabiru East Hydrant (Opposite Core Shed)	JH	24-Mar-04							

## Appendix B (Table 4) Page 10

## Day 1 Potable water ERA and SSD results (Version 2, 06 May 2004)

## Notes:

All filtrate results are for samples acidified and filtered on arrival to NTEL within 24 hrs of collection

All total results (except CDU pseudo totals) acid digested for 8 hrs

Unless otherwise highlighted all SSD results are from NTEL job EL03309

SSD samples E & H - some changes have been made to results following reanalyses:

E & H: replaced with result from 2nd NTEL analyses. Represents total fraction of same subsample as analysed at CDU.

Result from Charles Darwin University Environmental Chemistry Analytical Unit  
quantitative on total fraction OR TQ scan on pseudo totals

Sample Number	Site Description	Sample Code	Date	Rb µg/L	Sr µg/L	Y µg/L	Zr µg/L	Nb µg/L	Ru µg/L	Rh µg/L	Pd µg/L
<b>SSD DATA from potable supply 24/3/04</b>											
A00315	Jabiru East Hydrant	A	24-Mar-04	12.051	22.356	25.344	0.029	0.001	0.000	0.001	0.118
A00316	Urn in crib room d/s main building	B	24-Mar-04								
A00317	Downstairs mill lab taps	C	24-Mar-04	0.600	6.119	0.008	0.000	0.000	0.000	0.000	0.000
A00318	Downstairs mill lab taps	D	24-Mar-04	0.663	5.820	0.026	0.001	0.000	0.000	0.000	0.000
A00319	Engineering shower block	E	24-Mar-04	14.521	27.740	63.7	0.030	0.001	0.000	0.005	0.000
A00320	Eng toilet tap shower block	F	24-Mar-04								
A00321	Engineering crib room	G	24-Mar-04								
A00322	Grinding area ground floor toilet cistern	H	24-Mar-04	202.195	296.705	3930	0.181	0.020	0.000	0.149	0.000
<b>ERA DATA from potable supply 24/3/04</b>											
100305	Potable Water from Ranger Admin Crib Rc	PW	24-Mar-04								
100324	Admin Potable Water Tank Discharge	PTPD	24-Mar-04								
100326	Potable Water - Underground pipe to Jabir	PTUP	24-Mar-04								
100323	Potable Water Header Tank (on the fine or	GPWT	24-Mar-04								
100309	Brockman Potable Water Bore 84/3 (fed b)	B84-3	24-Mar-04								
100306	ERISS Potable Water Storage Tanks (now	EPW	24-Mar-04								
100308	Gagadiu Workshop (now known as JE036)	GPW	24-Mar-04								
100310	Jabiru East Potable Water Tank	JPWT	24-Mar-04								
100307	Jabiru East Potable Water Tank Overflow	JPWTO	24-Mar-04								
100311	Jabiru East Hydrant (Opposite Core Shed)	JH	24-Mar-04								

## Appendix B (Table 4) Page 11

## Day 1 Potable water ERA and SSD results (Version 2, 06 May 2004)

## Notes:

All filtrate results are for samples acidified and filtered on arrival to NTEL within 24 hrs of collection

All total results (except CDU pseudo totals) acid digested for 8 hrs

Unless otherwise highlighted all SSD results are from NTEL job EL03309

SSD samples E & H - some changes have been made to results following reanalyses:

E & H: replaced with result from 2nd NTEL analyses. Represents total fraction of same subsample as analysed at CDU.

Result from Charles Darwin University Environmental Chemistry Analytical Unit  
quantitative on total fraction OR TQ scan on pseudo totals

Sample Number	Site Description	Sample Code	Date	In	Te	I	Cs	La	Ce	Pr	Nd
				µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L
<b>SSD DATA from potable supply 24/3/04</b>											
A00315	Jabiru East Hydrant	A	24-Mar-04	0.000	0.014	0.569	1.278	1.246	4.999	0.703	3.878
A00316	Urn in crib room d/s main building	B	24-Mar-04								
A00317	Downstairs mill lab taps	C	24-Mar-04	0.000	0.000	0.467	0.072	0.002	0.003	0.001	0.000
A00318	Downstairs mill lab taps	D	24-Mar-04	0.000	0.000	0.476	0.086	0.001	0.008	0.001	0.006
A00319	Engineering shower block	E	24-Mar-04	0.000	0.026	0.644	1.505	1.839	5.254	1.11	7.21
A00320	Eng toilet tap shower block	F	24-Mar-04								
A00321	Engineering crib room	G	24-Mar-04								
A00322	Grinding area ground floor toilet cistern	H	24-Mar-04	0.000	0.000	0.771	17.960	76.707	301.40	69.29	420.79
<b>ERA DATA from potable supply 24/3/04</b>											
100305	Potable Water from Ranger Admin Crib Rc	PW	24-Mar-04								
100324	Admin Potable Water Tank Discharge	PTPD	24-Mar-04								
100326	Potable Water - Underground pipe to Jabir	PTUP	24-Mar-04								
100323	Potable Water Header Tank (on the fine or	GPWT	24-Mar-04								
100309	Brockman Potable Water Bore 84/3 (fed b)	B84-3	24-Mar-04								
100306	ERISS Potable Water Storage Tanks (now	EPW	24-Mar-04								
100308	Gagadiu Workshop (now known as JE036)	GPW	24-Mar-04								
100310	Jabiru East Potable Water Tank	JPWT	24-Mar-04								
100307	Jabiru East Potable Water Tank Overflow	JPWTO	24-Mar-04								
100311	Jabiru East Hydrant (Opposite Core Shed)	JH	24-Mar-04								

## Appendix B (Table 4) Page 12

## Day 1 Potable water ERA and SSD results (Version 2, 06 May 2004)

## Notes:

All filtrate results are for samples acidified and filtered on arrival to NTEL within 24 hrs of collection

All total results (except CDU pseudo totals) acid digested for 8 hrs

Unless otherwise highlighted all SSD results are from NTEL job EL03309

SSD samples E & H - some changes have been made to results following reanalyses:

E & H: replaced with result from 2nd NTEL analyses. Represents total fraction of same subsample as analysed at CDU.

Result from Charles Darwin University Environmental Chemistry Analytical Unit  
quantitative on total fraction OR TQ scan on pseudo totals

Sample Number	Site Description	Sample Code	Date	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm
				µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L
<b>SSD DATA from potable supply 24/3/04</b>											
A00315	Jabiru East Hydrant	A	24-Mar-04	2.653	1.107	5.899	1.407	9.987	1.900	4.513	0.543
A00316	Urn in crib room d/s main building	B	24-Mar-04								
A00317	Downstairs mill lab taps	C	24-Mar-04	0.002	0.001	0.001	0.001	0.000	0.001	0.000	0.000
A00318	Downstairs mill lab taps	D	24-Mar-04	0.003	0.001	0.008	0.002	0.014	0.003	0.004	0.001
A00319	Engineering shower block	E	24-Mar-04	5.01	1.64	9.02	2.25	15.87	2.78	7.763	0.810
A00320	Eng toilet tap shower block	F	24-Mar-04								
A00321	Engineering crib room	G	24-Mar-04								
A00322	Grinding area ground floor toilet cistern	H	24-Mar-04	326.43	122.98	584.09	152.90	1169.86	207.68	528.65	60.13
<b>ERA DATA from potable supply 24/3/04</b>											
100305	Potable Water from Ranger Admin Crib Rc	PW	24-Mar-04								
100324	Admin Potable Water Tank Discharge	PTPD	24-Mar-04								
100326	Potable Water - Underground pipe to Jabir	PTUP	24-Mar-04								
100323	Potable Water Header Tank (on the fine or	GPWT	24-Mar-04								
100309	Brockman Potable Water Bore 84/3 (fed b)	B84-3	24-Mar-04								
100306	ERISS Potable Water Storage Tanks (now	EPW	24-Mar-04								
100308	Gagadiu Workshop (now known as JE036)	GPW	24-Mar-04								
100310	Jabiru East Potable Water Tank	JPWT	24-Mar-04								
100307	Jabiru East Potable Water Tank Overflow	JPWTO	24-Mar-04								
100311	Jabiru East Hydrant (Opposite Core Shed)	JH	24-Mar-04								

## Appendix B (Table 4) Page 13

## Day 1 Potable water ERA and SSD results (Version 2, 06 May 2004)

## Notes:

All filtrate results are for samples acidified and filtered on arrival to NTEL within 24 hrs of collection

All total results (except CDU pseudo totals) acid digested for 8 hrs

Unless otherwise highlighted all SSD results are from NTEL job EL03309

SSD samples E & H - some changes have been made to results following reanalyses:

E & H: replaced with result from 2nd NTEL analyses. Represents total fraction of same subsample as analysed at CDU.

Result from Charles Darwin University Environmental Chemistry Analytical Unit  
quantitative on total fraction OR TQ scan on pseudo totals

Sample Number	Site Description	Sample Code	Date	Yb	Lu	Hf	Ta	W	Re	Os	Ir
				µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L
<b>SSD DATA from potable supply 24/3/04</b>											
A00315	Jabiru East Hydrant	A	24-Mar-04	3.276	0.343	0.049	0.012	0.205	1.606	0.000	0.000
A00316	Urn in crib room d/s main building	B	24-Mar-04								
A00317	Downstairs mill lab taps	C	24-Mar-04	0.000	0.000	0.000	0.000	0.236	0.029	0.000	0.000
A00318	Downstairs mill lab taps	D	24-Mar-04	0.003	0.000	0.000	0.000	0.211	0.046	0.000	0.000
A00319	Engineering shower block	E	24-Mar-04	5.117	0.580	0.055	0.012	0.228	1.908	0.000	0.000
A00320	Eng toilet tap shower block	F	24-Mar-04								
A00321	Engineering crib room	G	24-Mar-04								
A00322	Grinding area ground floor toilet cistern	H	24-Mar-04	410.56	46.2	4.233	0.863	1.560	27.832	0.000	0.000
<b>ERA DATA from potable supply 24/3/04</b>											
100305	Potable Water from Ranger Admin Crib Rc	PW	24-Mar-04								
100324	Admin Potable Water Tank Discharge	PTPD	24-Mar-04								
100326	Potable Water - Underground pipe to Jabir	PTUP	24-Mar-04								
100323	Potable Water Header Tank (on the fine or	GPWT	24-Mar-04								
100309	Brockman Potable Water Bore 84/3 (fed b)	B84-3	24-Mar-04								
100306	ERISS Potable Water Storage Tanks (now	EPW	24-Mar-04								
100308	Gagadiu Workshop (now known as JE036)	GWP	24-Mar-04								
100310	Jabiru East Potable Water Tank	JPWT	24-Mar-04								
100307	Jabiru East Potable Water Tank Overflow	JPWTO	24-Mar-04								
100311	Jabiru East Hydrant (Opposite Core Shed)	JH	24-Mar-04								



## Appendix B (Table 4) Page 14

## Day 1 Potable water ERA and SSD results (Version 2, 06 May 2004)

## Notes:

All filtrate results are for samples acidified and filtered on arrival to NTEL within 24 hrs of collection

All total results (except CDU pseudo totals) acid digested for 8 hrs

Unless otherwise highlighted all SSD results are from NTEL job EL03309

SSD samples E & H - some changes have been made to results following reanalyses:

E & H: replaced with result from 2nd NTEL analyses. Represents total fraction of same subsample as analysed at CDU.  
quantitative on total fraction OR TQ scan on pseudo totals

Sample Number	Site Description	Sample Code	Date	Pt µg/L	Au µg/L	Ti µg/L
<b>SSD DATA from potable supply 24/3/04</b>						
A00315	Jabiru East Hydrant	A	24-Mar-04	0.000	0.000	0.459
A00316	Urn in crib room d/s main building	B	24-Mar-04			
A00317	Downstairs mill lab taps	C	24-Mar-04	0.000	0.006	0.001
A00318	Downstairs mill lab taps	D	24-Mar-04	0.000	0.003	0.000
A00319	Engineering shower block	E	24-Mar-04	0.000	0.004	0.306
A00320	Eng toilet tap shower block	F	24-Mar-04			
A00321	Engineering crib room	G	24-Mar-04			
A00322	Grinding area ground floor toilet cistern	H	24-Mar-04	0.000	0.000	4.953
<b>ERA DATA from potable supply 24/3/04</b>						
100305	Potable Water from Ranger Admin Crib Rc	PW	24-Mar-04			
100324	Admin Potable Water Tank Discharge	PTPD	24-Mar-04			
100326	Potable Water - Underground pipe to Jabir	PTUP	24-Mar-04			
100323	Potable Water Header Tank (on the fine or	GPWT	24-Mar-04			
100309	Brockman Potable Water Bore 84/3 (fed b)	B84-3	24-Mar-04			
100306	ERISS Potable Water Storage Tanks (now	EPW	24-Mar-04			
100308	Gagadiu Workshop (now known as JE036,	GWP	24-Mar-04			
100310	Jabiru East Potable Water Tank	JPWT	24-Mar-04			
100307	Jabiru East Potable Water Tank Overflow	JPWTO	24-Mar-04			
100311	Jabiru East Hydrant (Opposite Core Shed)	JH	24-Mar-04			



## Appendix C (Table 5) Table of Workers Interviewed; Self-Reported Water Consumption and Reported Symptoms

*Supervising Scientist's Note:* Subject codes have been deleted to maintain anonymity.

### WATER INCIDENT

**Notes:**

1. Water in mining area appears not to have tested unusual. Therefore although exposure are rated as high, actual exposures probably low.
2. Further effort to be made to persuade Linetec Engineering and ESS NAAD staff to attend for testing.
3. Further effort to persuade Hu and Hu2 to be tested.

X = Off Site  
O = 0  
L = <500  
M = 500-2L  
H = 2L +

Code Number	Department or Contractor	Water consumed in ml	Location of consumption	Showered - and where	Symptoms Reported (Y)	Comments from Individual	Estimated Exposure
		0					O
		500	SX			No ill effects	M
		0				Off site	O
		0				On holidays	O
		0		No		Was on holidays	O
		20	Cribroom			Two mouthfuls coffee, no problems	L
		2000	Maintenance crib room cooler / Engineering Admin			No ill effects	H
		200	Met Lab cribroom			I have not felt sick at all	L
		300	Processing Crib Room	Yes		Had cup of coffee Wednesday mornig and showered Tuesday after day shift.	L
		2500	ERRIS Ice Machine	No		Drinking water from ERRIS ice machine - morning of 23/03/04 07.30am. Sample sent to NTEL of water actually consumed. Tested 15:15pm 23/03/04 46.9 USCM & 7.61pH.	H
		1000	Mine			Feeling OK	M
		0					O
		0					O
		300	HR cold water dispenser and taps			No problems noted	L
		100	Engineering Smoko Room	No		Tea tasted ok	L
		0				Off site	X
		0					O
		300	Grinding cooler			Water tasted strange	L
		0					O
		50	Mill Maintenance workshop				L
		0				Day off	X
		0					O
		500	Engineering crib room urn			Have felt OK since drinking	M
		100	Downstairs Projects Area			Did not taste bad	L
		500	Mill Maintenance workshop				M
		0					O
		0					O
		0					O
		300	Mill Maintenance workshop				L
		?	Hews	Yes		Don't know because when & how long was it going on? But it is all I drank and showered in	M
		0		No		Not on shift	X
		0					X
		0					O
		0				Off site	X

Code Number	Department or Contractor	Water consumed in ml	Location of consumption	Showered - and where	Symptoms Reported (Y)	Comments from Individual	Estimated Exposure
		200	Day services cribroom				L
		0					O
		1500	Mining Admin	No		Water tasted OK	M
		100	Mine cribroom			Wonderful - I'm feeling fine	L
		0				Was at fire extinguisher training. I drink about 5 litres of water each day before this date.	O
		500	Maintenance crib room urn		Y	For several days after I drank the water I hade a metallic taste/sensation on my tongue. I have also had a queasy felling in my digestive system, but I do not now whether this is related to drinking the contaminated water or not	M
		1000	Water bottle on ute			Water had been sourced the previous day - I feel OK	M
		0				Not on site Wednesday	X
		0				Washed hands at office	O
		0					O
		0				Off site	X
		200	Powerstation Oasis				L
		50	Grinding bubbler				L
		0				Leave	O
		2000	Mine crib room	Yes Mine showers			H
		0				Off site	O
		0					O
		300	Downstairs Projects Area		Y	I have had really bad headaches	L
		0		No		Not on shift	O
		0		No		Our shift was on days off at the time	X
		0					X
		0				Off site	O
		300	Mine crib room				L
		0					O
		0				Not on shift	X
		0		No		Days off, in Darwin	X
		0					O
		0					O
		600	Workshop Crib Room & bubbler	No	Y	Felt sick & had slight Diarohea for 3 days	M
		0		No		Off site	O
		1000	Mine crib room			Okay	M
		0					O
		0				Off site	X
		0		No		Did not drink. Warned in morning	O
		30	Engineering				L
		0				off site	X
		0		No			O
		0					O
		250	Env Ops bubbler	No		No taste - no effect. Water seem fine at the time.	L
		0					O
		2000	Inganarr Centre	No		Water was ok. Some pressure difference. Feel fine. Did not want to see Doctor	H
		0					O
		1000	Mine crib room	Yes Mine showers			M
		0					O
		700	HR kitchen				M
		250	Inganarr water cooler			No ill effect - tasted OK	L
		0		No		Was on site but do not recall drinking any water	O
		0					O
		0					O
		300	Engineering cribroom	No			L
		300	Engineering cribroom				L
		0					O
		0				Off 1900 23/03/04 - 27/03/04	X
		0		No		Not on site at time of incident	X
		0				Okay	O
		0					O
		0					O
		0					O

Code Number	Department or Contractor	Water consumed in ml	Location of consumption	Showered - and where	Symptoms Reported (Y)	Comments from Individual	Estimated Exposure
		0					O
		100	Powerstation urn				L
		?	Workshop cribroom		Y	Mouth was dry, constant spitting. Spitting out white fluid. Feels OK, had a headache on Wednesday. Wants a medical done in Townsville. Skilled to organise.	
		0					O
		300	Mine Crib room	Yes - Mining			L
		0		No			O
		30					L
		600	Maintenance Crib Room	Yes - Maintenance Change Rooms		My coffee tasted bad, but it usually does.	M
		500	Maintenance cribroom	No		Approx 1-2 cups. Washed hands and face. (This form sent on 1 Apr by email to Rob Rappa at 1548.) Not advised nature of contamination prior to leaving site. Unable to talk to ERA's doctor until 30 Mar, not on site, not available. Confirmation was sought re what tests should be done, no confirmation received. No advice provided on what tell-tale symptoms to look for. Signed Craig Forster 5 Apr 04.	M
		0		No		Rostered off during this incident	X
		1000	Electrical, Mill, Maintenance W/S	No		Washed hands and went home and showered.	M
		200	Mine crib			Okay	L
		0					O
		250	Mine crib room	Yes	Y	Sick about 6.30pm - okay Thursday	L
		0				Off site	X
		200	Engineering cribroom			Commented on how bad the taste (or my coffee making abilities)	L
		500	Admin cribroom fountain			No taste, no effect	M
		0					O
		10	Admin area water bubbler			No problems felt	L
		0					O
		30	Grinding crib			Does not feel ill, does not require counselling	L
		0					O
		4000	SX cooler Grinding	Sticky shower - shower block below admin	Y	Could not taste anything. Update from form 2: 'Was operating in two areas (CCD and SX). Was on duty n/s. I would have had 3-4 cups coffee and 1 cup tea throughout shift. I drink water in preference to soft drink and usually have a drink at the water bubbler when going past. Noticed at sometime before 4am that the water tasted funny, but thought that it must have been my tastebuds or else I'd heard that they'd done something with the bore pumps a couple of days prior so that may have caused change of taste. Then had cup of tea with 1 sugar, did not notice anything strange. Tried water again later - still tasted bad. Had 3 or 4 drinks from bubbler in SX throughout the night - didn't taste anything different. Last drink there was about 6am. Showered at 7am. Had another shower when I got home as the work one felt terrible - felt sticky.	H
		10	Engineering cribroom urn			No obvious effects	L

Code Number	Department or Contractor	Water consumed in ml	Location of consumption	Showered - and where	Symptoms Reported (Y)	Comments from Individual	Estimated Exposure
		1000	Mill	No		Water tasted off, feel ok. No problems	M
		0					O
		0				None	O
		1000	Urn and top/downstairs admin showers		Y	Rash on hands from using to drink	M
		200	Mine crib			Okay	L
		0				Does not require counselling	O
		0				Off site	X
		0					O
		0					O
		0				Off Site	X
		0				Off site	X
		10	Crusher	Yes		Water was disgusting, not normal - murky. No health problems, feel fine.	L
		0					O
		500	Warehouse bubbler		Y	Slight stomach upset	M
		0					O
		0		No		I was off site at time of contamination	X
		0		no		Was made aware of problem shortly after coming on site. Drank water from my water bottle which was filled on site on Tuesday. Left site approx. 1100.	O
		0					O
		1000	Mine crib room			Okay	M
		10	Supply			Cloudy and nasty, didn't swallow, does not feel ill	L
		400	Powerstation cribroom			at 8am	L
		0				Would like to make an appointment to get checked out. Spoke to Neil, he only wanted own unrelated medical. He will arrange this as a separate issue. - Bob Povey 08/04/04	O
		400	Cribroom			Okay	L
		0	Admin/HR water cooler				O
		0					O
		230	Engineering mouthwash Powerstation water fountain			Very bitter floury taste from water in engineering crib room. <b>NOTE: Bob Povey has spoken to this person</b> - person happy with outcome	L
		0				Not on site	X
		0				Not in Jabiru at that time	X
		2000	Acid Plant cribroom bubbler	Sticky shower		No noticeable taste - Noticed hot water cloudy at end of shift. Second form received: 'No reaction after drinking water. When showering, got covered in very thick solution, took about 20 mins to remove. Showered again when I got home'	H
		250	Engineering Crib room bubbler	No		Tasted salty. No physical effect	L
		4000	HEWS workshop & ice machine	No		No effects. Spoken to on 08/04/04	H
		400	Engineering hot water urn			To date I have had no ill effects	L
		1500	Cribroom urn/cooler			Had water with coffee and squincher - did not taste	M
		0		No			O
		1000	Engineering hallway bubbler		Y	Vomited at 11.30am Wed am, queasy stomach all day, very loose bowel motion at 4pm, still queasy up to Thurs am, loose bowel motions again at 3am. Since then OK.	M
		250	HR kitchen				L
		200	Production Admin Urn (filled previous day)				L

Code Number	Department or Contractor	Water consumed in ml	Location of consumption	Showered - and where	Symptoms Reported (Y)	Comments from Individual	Estimated Exposure
		3000	Gatehouse kitchen tap			I had made up the water with Squincher early in the night. Had coffee during the night. No ill effects. Likely to be low exposure although drank enough to be graded high.	H
		0				Not on site	X
		200	Workshop cribroom urn/cooler			I feel fine	L
		0				Off site in Darwin	X
		100	Maintenance cribroom hot water dispenser			Made cup coffee at 7.10 Wed not sure how much I drank. Tried to make another cup at around 9.30, but water made milk curdle, did not drink this. Also washed hands in toilet room.	L
		1000	ERRIS Ice Machine	No		Drinking water from ERRIS ice machine - morning of 23/03/04 07.30am. Sample sent to NTEL of water actually consumed. Tested 15:15pm 23/03/04 46.9 USCM & 7.61 pH.	M
		0					O
		200	HEWS, workshop bubbler and urn	No		No ill effects. Would like an appointment with Dr.	L
		100	Grinding crib room	No	Yes	Water had a very bad taste. Symptoms felt: Headaches, blurry/failing vision	L
		200	Powerstation crib room			Feel good	L
		200	Supply sink			Coffee did not taste very nice	L
		10	Admin management crib room			But did wash hands and rinsed coffee jug - had no symptoms, just had a 'salty' taste in mouth	L
		5000	Maintenance main water bubbler			None	H
		0					O
		2000	Mine	Yes Mine showers			H
		0					O
		2500	HWS bubbler	Yes - Mill		Did not taste funny, do not require counselling, feel OK	H
		0				Off site	X
		0				Off site	X
		0		No		Off site	X
		100	HR kitchen				L
		0				Off site	X
		0				Off site	X
		0					O
		0					O
		50	ESH cribroom cooler			No effect, just tasted bad	L
		1500	Electrical w/s & water outlet at back of w/s near ice machine	No	Y	A little bit of nausea feeling and flatulence.	M
		0		No		Finish nightshift on Monday morning	X
		0		No		Last nightshift was 22/03/04 & first day shift was 27/03/04	X
		0				Have been drinking the water over the past 4.5 years from HEWS Bubbblers. Was on days off on the day. But has this been going on over the years.?	X
		0		No		No problems, was not affected	O
		4000	Powerstation crib room and workshop water fountain				H
		0					O
		0		No			O
		0					O
		0				Off 1900 23/03/04 - 27/03/04	O
		0					X
		200	Mine cribroom			Does not feel ill, does not require counselling	L

Code Number	Department or Contractor	Water consumed in ml	Location of consumption	Showered - and where	Symptoms Reported (Y)	Comments from Individual	Estimated Exposure
		1000	Ice Machine Water Fountain	Mine			M
		0				Off site	X
		0				Brought a bottle at Mobil that morning	O
		50		Seemed normal		Noticed odd taste in last cup of tea	L
		1500	Mine crib room	Yes		Okay - have been feeling fine	M
		0				On Annual Leave	X
		?	Mine cribroom			Okay	
		0				Off site	X
		500	HR kitchen				M
		?	Cribroom			Okay	
		0					O
		1000	Mine crib room			Feels fine. Drank 3 cups of coffee.	M
		0				Holidays/Days off	X
		1500	Maintenance Workshop	No		Wahed hands and went home and showered	M
		0		No		Off site	X
		400	Day gang	No	Y	Headache	L
		0		No			O
		0		No			O
		2500	Mine crib room	Yes - Mining		Good Water was ok. Drinking water from water bottle. Likely to be low but drank enough to be graded High	H
		3000	Powerstation crib room and workshop water fountain				H
		?	Engineering Workshop, Crusher Control Room Bubblers	No		Unsure of quantity of water consumed.	
		500	Met Lab cribroom water dispenser		Y	Felt a little bit funny - felt a little different	M
		4000	HWS bubbler	HEWS Wed morning	Y	No effects, water tasted bad at end of shift, left a dry mouthed sensation. When I had shower, water seemed sticky, left me itchy. Did vomit after drinking in morning. Feeling fine now, no problems. First noticed bad tasting water at about 2am. Did not want to see Doctor	H
		0					O
		0				Off site	X
		0				I did wash a cup in mining crib room and had a drink of milk, feel fine, no counselling required	O
		1000	Powerstation				M
		0		No		On days off	O
		500	Drinking fountain in HEWS	No			M
		1000	Mine Maintenance cribroom fountain				M
		2000	Mine cribroom	Mining		Tasted OK, feel fine. Drank enough to be graded High but water tested ok. So probably a low actual exposure.	H
		200	Engineering water cooler		Y	Stomach upset for most of day	L
		2000	Water treatment cribroom cooler / Engineering Admin			No ill effects	H
		500	Engineering cribroom			Had two cups of coffee Wed am - felt OK	M
		0		No		Off site	X
		?	Workshop & Water bottle	No			
		500	ESH cribroom			Tea was OK at 0600 and 0630 - water tasted bad at 0730	M
		0				Not on site at time of incident	X
		10	?			Made cup coffee with contaminated water, had two sips, did not taste right, emptied cup	L
		700	Grinding bubbler	Sticky shower		First drink coffee 22.00; second at 4.30am; first drink from bubbler 23.00; second 3am; rinsed mouth out in shower.	M

Code Number	Department or Contractor	Water consumed in ml	Location of consumption	Showered - and where	Symptoms Reported (Y)	Comments from Individual	Estimated Exposure
		0				Drunk water in the past, so if any contamination is proven prior to 24 Mar I have certainly been exposed to it	O
		200	Engineering crib room urn		Y	Felt a little bit crook for a few days, but that might be due to too much sun on Wednesday after we got sent home	L
		500	Engineering Chiller	No	Y	Sick & nauseous for 12 hours. Metal taste in mouth. Now ok	M
		0					O
		0					O
		0					O
		0					O
		0					O
		3000	Various around site	Sticky shower - Maintenance	Y	Taste noticed at end of shift - Upset stomach next morning (bloating) - Did not know it was contaminated - noticed some taste difference during the night	H
						Sen by Dr Gaunt - no exposure	
		250	Engineering cribroom urn	No			L
		200	Engineering Crib room	No		No ill effects	L
		200	Admin upstairs cribroom urn				L
		200	Engineering maintenance cribroom				L
		0					O
		3000	HEWS Workshop & Boilermakers bubbler & ice room machine	No		Water shocking. Not effected as yet. Did not want to see Doctor	H
		0					O
		400	Mine cribroom	Mining		Brings own water - does not need counselling ... End of shift consumption	O
		0				off site	X
		0		No		Not on Shift	X
		4000	Maintenance	Maintenance	Y	Noticed about 2.30am having shower and felt stinging and slimy with soap - during day felt itchy	H
		250	Urn			Instant coffee which had been made from the urn filled up the previous day	L
						Consumption form to come	
		100	Grinding/mill			No ill feeling	L
		0				Not on shift	X
		0					O
		0					O
		0					O
		200	Grinding control cribroom				L
		100	Mining Crib Room	No			L
		0					O
		600	Mill Maintenance Crib room	No			M
		350	Downstairs Engineering Bubbler			Water tasted foul & felt like dry reaching	L
		0				Not on shift	X
		0		No		Not on site	X
		10	HEWS, Maintenance, Env Ops, Env Admin			No ill effects	L
		0				No on site	X
		10		Sticky shower			L
		0					O
		0				Told not to shower by Supervisor	O
		0					O
		750	?				M
		2000	Maintenance Workshop				H
		500				Before I knew of the problem I had seen Dr Rush	M
		500	M/workshop cribroom fountain				M
		0					O
		0					O
		400	Env Ops				L
		0				I was at home	O

Code Number	Department or Contractor	Water consumed in ml	Location of consumption	Showered - and where	Symptoms Reported (Y)	Comments from Individual	Estimated Exposure
		0					O
		0				Rostered day off	X
		1000	Warehouse fountain				M
		0					O
		500	Admin (projects) cribroom cooler				M
		0		No		Was rostered off from Tuesday 23rd to Friday 26th.	X
		0				Everything handled well	O
		200	HWS bubbler			Feel OK, did not notice anything wrong with water	L
		0				Off Sick prior to incident	X
		500	Mine Crib Room	Yes-Mining			M
		0		No		Was on days off - 22nd - 26th March	X
		0				Off Site	X
		0				Off Site	X
		0				Was on Annual Leave	X
		350	Engineering Ice Machine Outside	No		Did not notice any abnormal taste. Tested EC in Darwin - OK (<220ms)	L
		100	Admin, mill meeting room			The water drunk was from a bottle and kettle that had been filled the previous day	O
		200	Mine cribroom			Has the flu	L
		4000	Powerstation crib room and workshop water fountain				H
		0					O
		3000	Bubblers in Grinding Crib room, Engineering Crib, Downstairs Engineering, Acid Plant & Security	No		Split shift 23/3. Gone by 9.30 -10pm. Started at 6.30am 24/3.	H
		2000	Warehouse water cooler	No - but washed hands and arms at water station near receiving	Y	Had headache and itchiness/rash on arms - took headache tablets. Did not want to see doctor.	H
		600	Engineering Crib room	No			M
		0					O
		250	HR kitchen				L
		0					O
		0					O
		0				I am just a little concerned as I drank water the day before (23 March) the water tasted funny then as well. Has seen Dr Gaunt	O
		6000	Acid plant			Tasted OK. <b>NOTE: Bob Povey has spoken to this person</b> - no ill effects. Did not want to see Doctor	H
		2000	HWS bubbler, crib room			Tasted OK, feels OK, does not require counselling	H
		0					O
		0				Off site	X
		200	Mine cribroom			No problems with water, does not feel ill. Counselling - no.	L
		5000	HWS, workshop crib	Sticky shower - HEWS	Y	Water tasted bad, even tea. Showering caused itchiness to skin. No ill effects, does not want to see doctor. Will let us know.	H
		0				Not on shift	X



## Appendix D (Tables 7 & 8) Table of Urine and Blood Test Results

Supervising Scientist's Note: Subject codes have been deleted to maintain anonymity.

Table 7

### WATER INCIDENT HEALTH RESULTS

Code	Hb g/L	MCH Pg	Platelets x10 <sup>9</sup> /L	WCC x10 <sup>9</sup> /L	Neut Count x10 <sup>9</sup> /L	Lymph Count x10 <sup>9</sup> /L	Mono Count x10 <sup>9</sup> /L	Eos Count x10 <sup>9</sup> /L	Total Bilirubin u mol/L	AIK Phos U/L	Gamma GT U/L	ALT U/L	Alb U/L	Total Protein g/L	Urine Protein g/L	Urine Creatinine mmol/L	Prot/creat Ratio	Phosphate mmol/L	Creatinine mmol/L	Amino Acids mg/L	Serum B2m mg/L	PbB ug/dl	Blood Mn ug/L	Urine Uranium	Nickel
	143.0	29.7	266.0	9.2	6.9	2.0	0.1	0.2	25.0	107.0	23.0	22.0	52.0	77.0	<0.10	13.4	<3	23.0	13.4	5.8	2.1	3.0	0.17	78.0	
	144.0	31.2	226.0	5.5	3.5	1.8	0.1	0.1	12.0	64.0	23.0	13.0	47.0	81.0	<0.10	13.1	<3	26.0	13.1	14.2	1.5	3.0	<0.10	9.0	
	160.0	31.1	174.0	6.2	4.3	1.5	0.1	0.4	8.0	75.0	21.0	23.0	57.0	95.0	<0.10	10.8	<3	18.0	10.8	15.3	1.9	4.0	0.15	85.0	
																				2.7				239.0	
																				1.6				28.0	
	148.0	31.0	288.0	8.9	6.1	1.9	0.8	0.09	7.0	84.0	70.0	63.0	51.0	81.0	NT	16/24h	NT	NT	0.1	NT	1.2	<2.1	NT		
	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT		
	a	a	a	a	a	a	a	a	a	a	a	a	a	a	a	a	a	a	a	Normal	1.6	3.0	a	NT	4.0
	a	a	a	a	a	a	a	a	a	a	a	a	a	a	a	a	a	a	a	15.4	1.2	3.0	a	NT	967.0
	b	b	b	b	b	b	b	b	b	b	b	b	b	b	b	b	b	b	b	1.6	b	2.0	b	NT	12.0
	a	a	a	a	a	a	a	a	a	a	a	a	a	a	a	a	a	a	a	NT	1.2	3.0	a	NT	NT
	129.0	30.4	230.0	9.0	NT	NT	NT	NT	6.0	107.0	47.0	54.0	52.0	94.0	<0.10	12.7	<2	38.0	12.7	6.1	2.0	1.0	0.17	9.0	NT
	156.0	30.8	210.0	5.0	3.5	1.2	0.1	0.1	13.0	78.0	29.0	29.0	49.0	79.0	<0.10	14.2	<5	21.0	14.2	9.6	1.8	4.0	0.12	31.0	NT
	151.0	29.4	309.0	7.1	4.7	1.6	0.1	0.6	8.0	71.0	35.0	32.0	52.0	92.0	<0.10	10.9	<2	25.0	10.9	2.8	1.9	3.0	0.12	11.0	NT
	153.0	27.9	270.0	6.7	5.2	1.2	0.1	0.3	7.0	83.0	35.0	39.0	49.0	88.0	<0.10	11.7	<2	42.0	11.7	5.1	1.9	8.0	0.16	92.0	NT
	163.0	30.8	171.0	5.6	3.2	2.0	0.2	0.2	8.0	96.0	58.0	44.0	50.0	87.0	<0.10	4.9	<2	15.0	4.9	8.1	2.1	6.0	0.12	14.0	NT
	152.0	30.4	252.0	6.7	4.9	1.5	0.2	0.1	14.0	108.0	75.0	43.0	50.0	89.0	<0.10	4.3	<5	11.0	4.3	2.4	1.8	5.0	0.19	93.0	NT
	155.0	31.6	248.0	7.5	5.6	1.4	0.2	0.3	13.0	161.0	24.0	23.0	51.0	90.0	<0.10	12.7	<2	39.0	12.7	11.7	2.0	1.0	0.15	12.0	NT
	154.0	30.1	254.0	8.1	NT	NT	NT	NT	10.0	99.0	35.0	30.0	48.0	89.0	<0.10	11.8	<5	9.0	11.8	11.1	2.3	4.0	0.13	121.0	NT
	140.0	31.2	208.0	4.3	NT	NT	NT	NT	14.0	52.0	33.0	24.0	48.0	87.0	<0.10	9.9	<8	28.0	9.9	6.5	1.7	6.0	0.11	188.0	NT
	154.0	28.9	233.0	6.6	3.8	2.1	0.1	0.6	15.0	67.0	14.0	15.0	50.0	79.0	<0.10	17.8	<2	35.0	17.8	8.4	1.5	3.0	0.16	205.0	NT
	158.0	30.7	268.0	8.7	4.8	2.7	0.2	1.0	8.0	63.0	26.0	26.0	52.0	98.0	<0.10	16.4	<2	20.0	16.4	8.6	1.8	6.0	0.25	212.0	NT
																				3.0				54.0	
																				7.1				41.0	
																				5.2				63.0	
																				8.8				35.0	
	155.0	29.9	247.0	10.0	8.0	1.8	0.0	0.2	10.0	83.0	28.0	16.0	50.0	86.0	<0.10	18.6	<3	43.0	18.6	8.9	1.8	2.0	0.18	40.0	NT
	161.0	31.4	307.0	10.2	7.9	2.1	0.0	0.2	5.0	96.0	91.0	102.0	52.0	92.0	<0.10	10.2	<4	28.0	10.2	9.2	2.3	4.0	<0.10	36.0	NT
	150.0	27.2	254.0	10.8	NT	NT	NT	NT	7.0	107.0	65.0	58.0	44.0	84.0	<0.10	11.8	<3	31.0	11.8	13.8	2.3	3.0	0.12	48.0	NT
	152.0	30.3	197.0	6.5	4.4	1.8	0.1	0.3	8.0	67.0	20.0	39.0	49.0	79.0	<0.10	13.9	<4	29.0	13.9	8.0	1.7	3.0	0.11	274.0	NT
	144.0	31.2	333.0	7.7	5.2	1.9	0.2	0.3	5.0	NT	43.0	52.0	40.0	79.0	<0.10	21.4	<4	22.0	21.4	20.2	NT	3.0	0.10	19.0	NT
	159.0	30.0	205.0	4.9	2.9	1.7	0.1	0.2	15.0	92.0	31.0	55.0	48.0	84.0	<0.10	3.4	<3	8.0	3.4	2.9	1.7	4.0	<0.10	6.0	NT
	149.0	29.3	207.0	8.5	NT	NT	NT	NT	12.0	77.0	55.0	32.0	52.0	80.0	<0.10	37.1		68.0	37.1	15.2	2.3	2.0	0.24	60.0	NT
	144.0	30.1	313.0	8.6	NT	NT	NT	NT	5.0	87.0	29.0	17.0	46.0	78.0	<0.10	18.1	<2	39.0	18.1	18.4	1.8	4.0	0.13	226.0	NT
	161.0	31.1	214.0	8.9	6.6	1.7	0.1	0.5	8.0	80.0	77.0	42.0	51.0	86.0	<0.10	14.7	<3	22.0	14.7	14.9	1.8	2.0	<0.10	42.0	NT
	131.0	31.6	299.0	9.4	6.3	2.6	0.2	0.3	7.0	80.0	29.0	16.0	46.0	77.0	<0.10	10.6		40.0	10.6	5.5	2.0	3.0	0.11	193.0	NT
	147.0	32.5	178.0	7.2	NT	NT	NT	NT	5.0	81.0	142.0	84.0	49.0	88.0	<0.10	10.3	<6	36.0	10.3	8.3	2.1	4.0	<0.10	333.0	NT
	159.0	30.3	207.0	7.9	4.3	2.8	0.6	0.2	8.0	68.0	19.0	21.0	48.0	74.0	<0.10	18.6		25.0	18.6	3.2		3.0		87.0	NT
Reference Range	135-170	27.50-34.00	140-370	4.0-11.0	1.8-7.5	0.7-4.0	0.1-1.2	0.0-0.6	<21	35-115	<41	<36	36-48	60-85	<0.15	7.0-18.0	<23		7.0-18.0		0.0-2.4	<25	0.11-0.30		

Table 7

Comments	Reference Number Codes
a - These have been tested by a series of hospitals in Perth, no results available.	O - Individual on site 23rd/24th March 2004 who did not drink any water from the potable supply.
	O/S - Contractor who was on site 23rd/24th March 2004 but has been seen by other physicians.
	L - Individual on site 23rd/24th March 2004 who said they drank less than 500ml of water from the potable supply.
* <i>Supervising Scientist's Note: Comments have been deleted to maintain anonymity.</i>	M - Individual on site 23rd/24th March 2004 who said they drank between 500 and 2 Litres of water from the potable supply.
	H - Individual on site 23rd/24th March 2004 who said they drank over 2 Litres of water from the potable supply.
	NYA - Not Yet Available.
	NT - Not Tested.
	Result outside the laboratory reference range for this analyte.
	16/24h - Urine Creatinine in mmol in a 24hr urine collection.
	All the Ranger-taken bloods suffered from delay in transit to Perth, hence several red cell parameters and some white cell differentials are not available.
	The high albumin and proteins are also thought artefacts.
	Typical Reference Range which varies between Laboratories

**Table 8 – Urine Results (Marshman)**

Sample No.	Sample Date	Contam Date	Days since intake	Results					Dr Gaunt Blood & Urine Code	Drinking Water Consumed 24/03/2004	Worked in East Jabiru not at Ranger
				Cu µg/L P200M	Mn µg/L P200M	Pb µg/L P200M	U µg/L P200M	Zn µg/L P200M			
	28-Mar-04	24-Mar-04	4.00	25	<1	2	0.2	280	L3	300	N
	27/03/2004	24/03/2004	3	10	<1	<1	0.2	170		0	N
	28/03/2004	24/03/2004	4	15	<1	<1	0.2	280	O5	0	N
	28/03/2004	24/03/2004	4	28	<1	7	<0.1	80	O4	0	N
	28/03/2004	24/03/2004	4	19	<1	<1	0.2	280		500	N
	28/03/2004	24/03/2004	4	8	<1	1	<0.1	510		1000	N
	28/03/2004	24/03/2004	4	21	<1	2	<0.1	360	L2	250	N
	28/03/2004	24/03/2004	4	23	2	<1	0.2	670		0	N
	28/03/2004	24/03/2004	4	38	4	<1	<0.1	220		200	N
	27/03/2004	24/03/2004	3	28	<1	5	0.3	1060	L4	200	N
	27/03/2004	24/03/2004	3	23	1	2	0.1	870	H1	4000	N
	29/03/2004	24/03/2004	5	24	<1	<1	<0.1	470		0	N
	28/03/2004	24/03/2004	4	27	2	7	0.1	440		300	N
	28/03/2004	24/03/2004	4	42	2	6	1.8	1100		unknown	N
	28/03/2004	24/03/2004	4	9	2	<1	1.3	180		400	N
	28/03/2004	24/03/2004	4	10	<1	<1	<0.1	340	M2	1000	N
	30/03/2004	24/03/2004	6	2	1	4	0.1	360	M6	500	N
	31/03/2004	24/03/2004	7	7	1	7	0.3	1330		1500	N
	31/03/2004	24/03/2004	7	17	1	3	<0.1	90		400	Y
	31/03/2004	24/03/2004	7	5	<1	2	0.1	200		unknown	Y
	31/03/2004	24/03/2004	7	15	2	5	0.1	920		unknown	Y
	31/03/2004	24/03/2004	7	5	<1	4	<0.1	400		unknown	Y
	31/03/2004	24/03/2004	7	3	<1	1	<0.1	150	L7	200	N
	31/03/2004	24/03/2004	7	6	1	2	<0.1	230		10	N
	1/04/2004	24/03/2004	8	10	2	3	0.2	230	H6	3500	N
	1/04/2004	24/03/2004	8	9	<1	5	<0.1	130		500	N
	31/03/2004	24/03/2004	7	15	<1	2	<0.1	580		200	N
	31/03/2004	24/03/2004	7	12	<1	2	<0.1	640		unknown	Y

**NOTE:**

All results are from 24 hour collections.

The urines were analysed at Northern Territory Environmental Laboratory.

All results were expressed as µg/l of metal, the uranium results to 1 decimal place.

## **Appendix 3D ACCHRA/EnTox comments on the ERA health report**

MONASH University



**Department of Epidemiology & Preventive Medicine**  
Faculty of Medicine, Nursing and Health Sciences

Dr Arthur Johnston  
Supervising Scientist Division  
Department of Environment & Heritage  
GPO Box 461  
DARWIN NT 0801

### **Ranger mine potable water contamination incident 23-24 March 2004**

#### **Comment on the Report on the medical/health response prepared by Dr Richard Gaunt, Occupational Physician for Rio Tinto Report dated 14 July 2004**

Scientists from the Australian Centre for Human Health Risk Assessment (ACHHRA) and the National Centre for Environmental Toxicology (EnTox) were initially approached by the Supervising Scientist Division (SSD) late in March 2004 to assist with preparation of a Health Risk Assessment (HRA) of the potable water contamination incident at the Ranger uranium mine. A preliminary HRA was delivered on 2 April 2004, and a more detailed assessment report finalised on 12 July 2004.

Throughout the period the ACHHRA/EnTox report was in preparation, the authors were in contact with Dr Richard Gaunt, the Rio Tinto occupational physician who had been called to the Ranger mine to assess the possible health impacts on the workers who reported ingesting the contaminated potable water or who washed and/or showered using it. Included in these discussions was Dr Roger Drew, a consultant toxicologist retained by Rio Tinto in relation to the incident. These collaborations were useful, since they facilitated timely access to the results of investigations undertaken by Dr Gaunt in relation to the extent to which workers had been exposed to the contaminated water, the immediate symptoms of ill health they reported (mainly local skin irritation and gastrointestinal distress), and the results of blood and urine tests which were undertaken in the days following the incident.

Dr Gaunt has now submitted a report outlining his assessment of the workers' health risks associated with the incident, and the SSD has requested comment on his report from the ACHHRA/EnTox scientists who prepared the independent HRA commissioned by the SSD. Since the other authors of the ACHHRA/EnTox report are overseas at present, and in view of the timeframe requested for our comments, I am responding on behalf of the other authors of the ACHHRA/EnTox HRA.

The first point to be made is that, while Dr Gaunt used a slightly different approach to conducting a 1<sup>st</sup>, 2<sup>nd</sup> and 3<sup>rd</sup> level HRA on the incident, the overall conclusions of his report are consistent with those of the ACHHRA/EnTox report. In effect, both reports drew the conclusion that the few reported cases of skin irritation and/or gastrointestinal distress were to be expected from contact with low pH water which had relatively high levels of irritant metals. However, it was most unlikely that there would be longer-term, or delayed health effects on target organs such as the brain, liver and kidney, because of the brief period of exposure.

Since Dr Gaunt made his preliminary HRA before all the data on metal concentrations had become available, he based his HRA on assumptions about the worst-case levels of dilution of potable water with process water (1 part process water to 3 parts potable water). He refined these exposure estimates through a 2<sup>nd</sup> and 3<sup>rd</sup> stage as data on the levels of contaminants measured and the amounts consumed became available. On the other hand, the ACHHRA/EnTox report addressed worst case exposure estimates based on the total level of metals measured in two representative samples of the potable water, and reasonable upper and lower estimates of the amount of water ingested (500ml or 5 litres), as directed by the SSD.

While there are consequent differences between the actual exposure estimates in the Gaunt and ACHHRA/EnTox reports, these differences are not of much magnitude. The small differences do not detract from the fact that the two reports draw essentially the same conclusions about the very small likelihood of there being any delayed health effects.

Where the reports differ most is in respect of the recommendations for follow-up health testing. The ACHHRA/EnTox report provided an analysis of the health testing results which had been obtained from blood and urine samples taken up to 10 days after the incident, including samples taken under Dr Gaunt's direction. Both the Gaunt and ACHHRA/EnTox reports concluded that these results provided significant reassurance that no adverse health effects on the kidney or liver (two potential targets for some of the metals) could be reasonably attributed to the incident. Both reports noted that there were some isolated results outside the normal range, and suggested that these may be followed up. In the case of the ACHHRA/EnTox report, the point was made that, given the low risk predicted from the HRA, the decision for any follow-up testing should be made by the attending medical professional of individual workers, informed by the level of concern expressed by those workers, and by other possible risk factors from their individual medical histories.

The Gaunt report makes somewhat firmer recommendations about follow-up testing, although there is still a disclaimer that this is a precautionary approach, and it should be considered and supported by the workers' doctor(s).

The ACHHRA/EnTox report canvassed the use of some possible biomarkers relating to renal effects and neurotoxicity, but it cautioned that the results of such tests might be difficult to interpret on an individual basis. It is noted that Dr Gaunt proposes MRI testing for workers assessed to have the highest potential exposure to manganese and aluminium. However, the ACHHRA/EnTox report did not make such a recommendation because such tests may be only be useful in showing deposition of these metals at selected sites in the brain. The level of such deposition may be difficult to interpret on an individual basis. It is considered unlikely that such MRI testing could

provide evidence of brain dysfunction arising from the incident. Dr Gaunt also advised that the need for such MRI testing should be further assessed by a consultant neurotoxicologist.

In summary, both the ACHHRA/EnTox and Gaunt reports on the Ranger incident reach essentially the same conclusions about the reported short-term health effects, and the low likelihood of there being any longer-term effects associated with the incident. Both reports could be provided to relevant stakeholders with the expectation that the differences in approach and the differing emphasis on responsibility for follow-up testing, should not result in conflict between the findings.

A handwritten signature in black ink, appearing to read 'B. Priestly', with a stylized, flowing script.

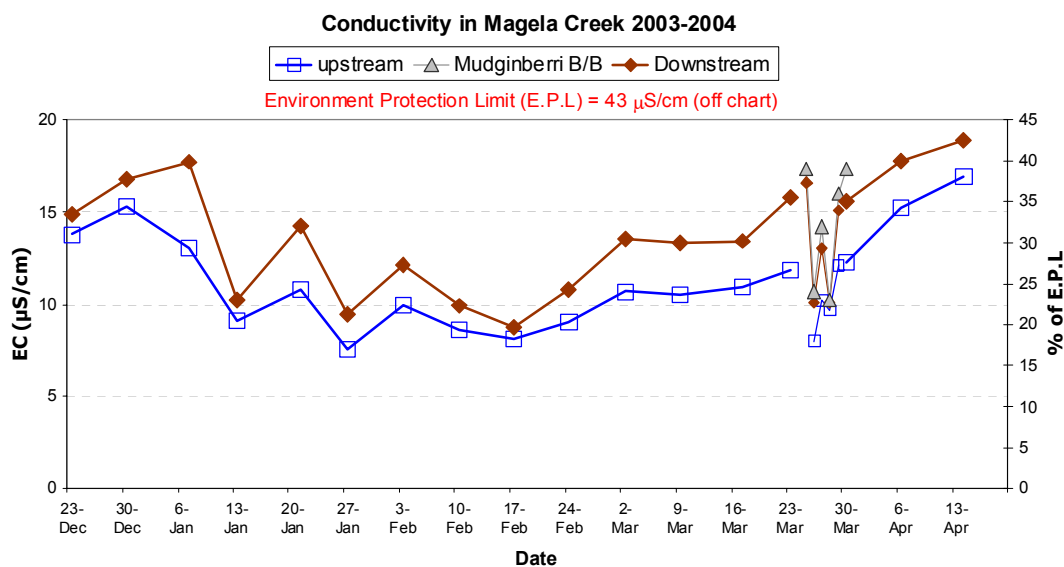
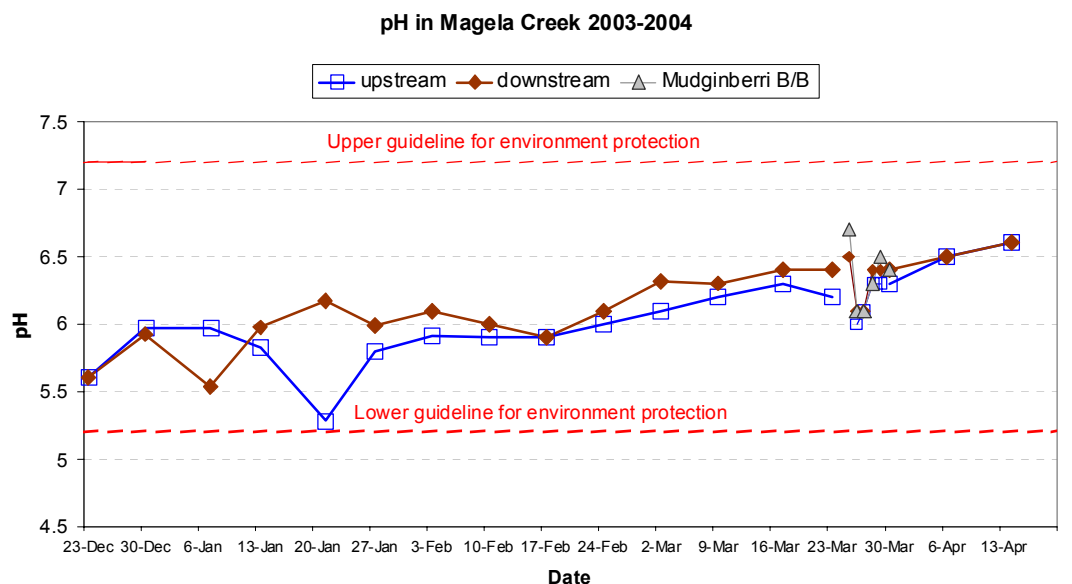
Professor Brian Priestly  
Director  
Australian Centre for Human Health Risk Assessment

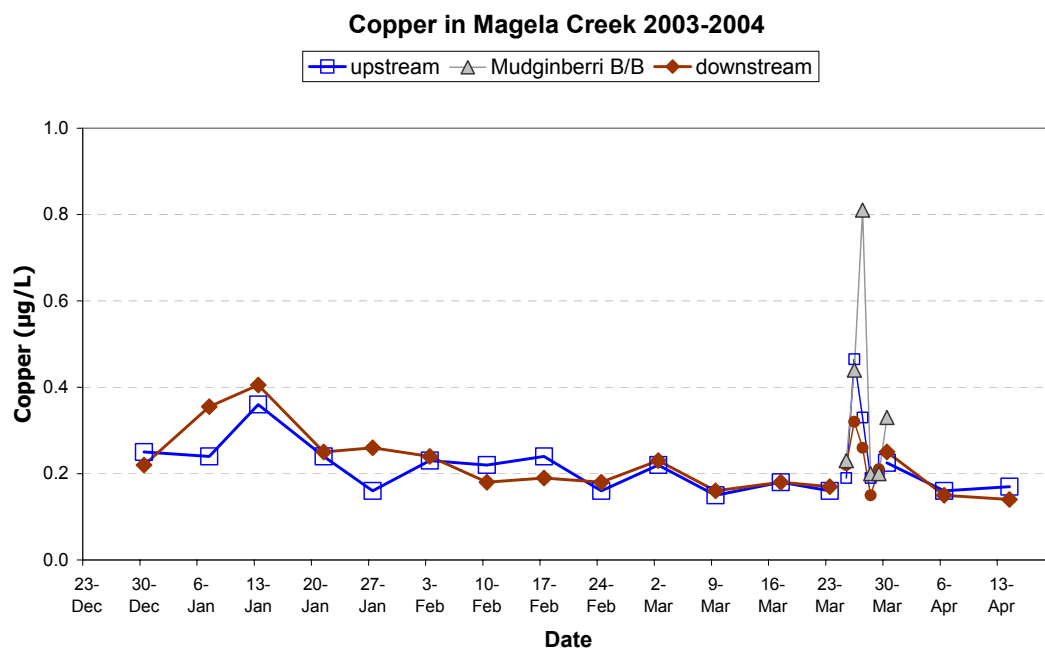
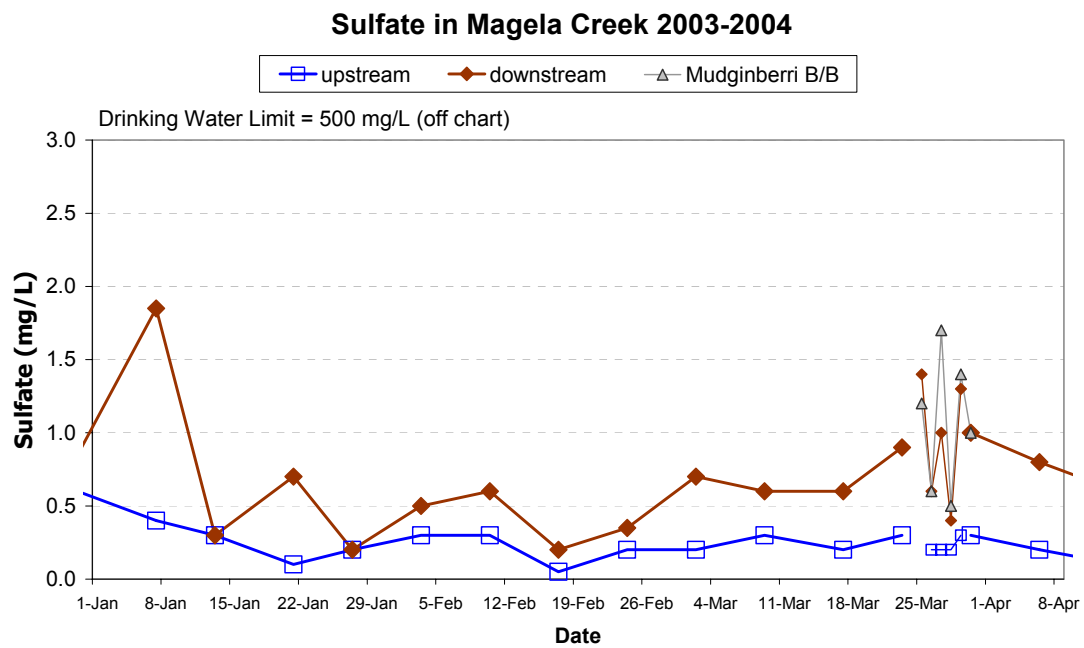
29 July 2004

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## Appendix 4 Time series data for Magela Creek and Mudginberri Billabong

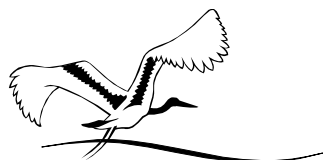
Time series charts of EC, pH, sulfate and copper measurements and concentrations at the routine monitoring sites on Magela Creek and at Mudginberri Billabong are shown below. The corresponding charts for uranium and manganese appear in the main report (Section 6.2).







## **Appendix 5 ERA Investigation Report into Potable Water Contamination Incident at Ranger mine 23 & 24 March 2004**



**ERA**

**Energy Resources of Australia Ltd**

ABN 71 008 550 865

## Investigation Report into Potable Water Contamination at Ranger Mine on March 23 & 24, 2004

July 2004

## 1 SUMMARY

### **Incident**

On the evening of March 23<sup>rd</sup> 2004, during night shift operations in the mill at Ranger Mine, a low flow alarm was indicated on the distributed control system from the fine ore bin scrubber #1. This scrubber ventilates the conveyor transfer points feeding the rod mill and removes dust particles from the air prior to discharge into the atmosphere. As required by regulations, the conveyors feeding the Mill are interlocked to the water flow. If flow drops below a particular set-point, then an alarm is activated on the distributed control system prompting action to be taken by the mill operators. If the flow of water drops further (below a second set-point) then the conveyors are tripped (switched off).

In an attempt to increase the flow of process water to the scrubber, an operator turned on a valve on the manifold for the scrubber water feed line which was connected to a flexible hose. The operator believed that the other end of the hose was connected to a process water outlet but it had been, in fact, connected to a potable water outlet. Owing to higher pressure in the process water system than in the potable water system, process water flowed through the potable water line and into the main potable water storage tank. This tank distributes water throughout the site for drinking, showering, washing, and toilets.

There were several reports on the morning of the March 24<sup>th</sup> by employees coming off night shift and employees coming on day shift that the water tasted 'off' and of feeling itchy after showering. Samples of water from the showers and drinking water taps collected in response to these complaints and, just prior to the time of shutdown of the potable water supply, were analysed to find elevated salt levels (Electrical Conductivity up to 5,900  $\mu\text{S}/\text{cm}$ ), low pH (4.5) and up to 8,000 parts per billion uranium compared with approximately 7 parts per billion in the potable water supply from Brockman Borefield. Announcements were made at 08.10h by Gai-phone and radio across the site that employees should not drink water from the potable water outlets. All employees, with the exception of those attending to the incident and an emergency crew, were sent home at 08.30h and the minesite closed for investigations to commence.

The Ranger potable water system also feeds water to the Jabiru East potable water storage tank, which is the northernmost of two tanks located at the eastern end of the airport, and the local businesses in the area including the airport and the OSS Jabiru East field station. This tank regularly overflowed into a constructed drain, which directs overflow water towards the north and east into Magela Creek, downstream from Coonjimba Billabong. Following the discovery of contamination on the minesite in the potable water system, the Jabiru East tank was inspected, found to be overflowing and isolated at 08.15h. Businesses were notified of the problem at 09.15h. Samples of input water to the tank were collected from a fire hydrant at the adjacent core shed and overflow water at the sump immediately adjacent to the tank. Analyses showed that the overflow contained up to 103 ppb uranium. However, water samples collected from potable water tanks at the OSS field station and the Gagadju workshop indicated that the 'front' of process water contamination had not reached these sites.

### **Significant actions and investigations**

A number of immediate significant corrective actions were taken by ERA as follows.

- All stakeholders and regulators were notified promptly beginning at 09.40h on Wednesday 24<sup>th</sup> March
- Non-critical employees were sent home and kept informed through daily communication updates in Jabiru by Ranger Management. Bottled water was made

available to employees remaining on site. Portable toilets and bottled water were organised for the Jabiru East community.

- A disaster was declared, the Disaster Management and Recovery plan was implemented and a Crisis Management Team was formed, headed by the General Manager-Operations, to direct investigations and manage outcomes from the incident.
- The milling and process plants were shut down pending the recovery of the potable water supply and clearance from the regulators.
- Detailed investigations into the incident were started.
- Immediate action was taken to identify any possible connection points and crossovers from the potable water system to any other system. Action was also taken to eliminate the possibility of any further inadvertent connection of the process water system to the potable water system.
- The potable water system on the minesite and at Jabiru East was flushed to remove contaminants. A systematic check involving the chemical analysis of potable water was followed to ensure that delivery systems were no longer contaminated and accorded with national guidelines (NHMRC & ARMCANZ 1996<sup>1</sup>) for water quality. Samples were drawn from 152 locations throughout the potable water system. All potable water outlets were tagged unfit for use until water quality was shown to meet the recommended guidelines.
- Water and soil sampling was undertaken downgradient of the Jabiru East potable water tank to evaluate whether environmental impacts had occurred.
- A review and risk assessment was undertaken on the process water system to determine whether specific actions were required.
- Regular communication with regulatory authorities and key stakeholders was instigated to ensure they were informed of developments in the recovery process.

### **Impacts on Health**

Samples taken from the potable water system on the morning of Wednesday 24<sup>th</sup> March contained metals and sulfates at concentrations that were potentially irritant to both the skin and gastro-intestinal tract of some individuals. A number of people in contact with the contaminated water experienced minor skin irritation after showering and a few developed minor gastric upsets. In total, 28 employees and contractors reported mild physical symptoms. It is believed that all settled within the first week.

ERA undertook a program of questionnaires and one-on-one confidential interviews with concerned individuals to determine the likely extent of exposure to contaminated potable water and initial physical symptoms.

The conclusions of initial health risk assessments, based on preliminary analysis of contamination levels and worst case exposures, were that long term effects were unlikely but some effects from uranium (on the kidneys) and from manganese (on the nervous system) could not be confidently excluded at that stage. This information was verbally conveyed to employees and contractors.

A series of voluntary blood and urine tests were arranged to assess body burden/impact of uranium and manganese for individuals (employees and contractors) with high levels of

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<sup>1</sup> NHMRC & ARMCANZ (1996) *Australian drinking water guidelines*. National Water Quality Management Strategy Paper No 6, National Health and Medical Research Council & Agricultural and Resource Management Council of Australia and New Zealand. (Australian Government Publishing Service, Canberra).

concern and/or reported exposures. In addition, advice on the tests was given to treating physicians.

The majority of the results of the routine clinical blood tests specifically designed to look for any effect of uranium and other metals on kidney function were within the acceptable range. One employee was referred to his family physician for further tests for a condition not thought to be related to drinking the contaminated water. The results of a specialist test of kidney function (NAG, a sensitive indicator of renal tubular damage) were not elevated and confirm the lack of an effect. All blood manganese levels were in the normal range, suggesting that there were no significant increases in the body levels of manganese in those tested.

In addition to these specific tests, full blood counts (looking for anaemia, and changes in white blood cells and platelets) and a full set of tests to check liver function were also performed. The full blood counts were normal. Analysis of samples for eight people indicated some minor changes in liver function, not consistent with a liver disease but probably reflective of delays in getting the samples to the laboratory for testing. All eight employees have been referred to their personal physician for repeat testing. The results of all blood tests undertaken to this stage have been provided to individuals with appropriate consultation.

The results of the medical testing program provided considerable reassurance that there will be no long term health effects from exposure to contaminated water at Ranger on March 23<sup>rd</sup> and 24<sup>th</sup>. However, given that the employees had only a brief exposure to relatively high concentrations of some metals, and that the literature reviewed for the risk assessment is generally focussed on longer term exposures, there is residual doubt about the direct extrapolation of the conclusions and findings from the literature to the Ranger incident. Hence, a further and comprehensive precautionary medical testing program for possible manganese, aluminium and uranium effects is warranted and will be implemented by ERA in order to provide additional confidence that there have been and will be no long term health effects.

### **Impacts on the Environment**

No impacts on the environment at the Ranger minesite, or on surrounding areas, were identified as a result of this incident.

### **Root cause analysis and corrective actions**

In addition to comprehensive field investigations, interviews with operators, and examination of manuals and procedures, a Root Cause Analysis was conducted by ERA and facilitated by an external consultant. The results indicate that the incident was caused by the following set of prime conditions and a prime action. Corrective actions that ERA has taken or committed to take are also stated.

<b>Cause</b>	<b>Corrective Actions to ensure the incident cannot recur</b>
<b><i>Prime conditions</i></b>	
1. The existence of common connections on process water and potable water systems	1. Change Potable Water connections so that they are not compatible with process water. Ensure that water pipes throughout the minesite are appropriately labelled and coloured.
2. The lack of a system for early warning of contamination in the potable water system;	2. Install pH & EC alarm in potable water system.
3. The absence of non-return valves in the potable water system	3. Install backflow protection in potable water system at key junctions where a risk of contamination exists.
<b><i>Prime action</i></b>	
4. Someone connected hoses and turned on valves	4. Counsel all operators. Raise awareness of Safety and Environmental Hazard associated with Potable Water.

In addition to the root causes listed in the table, a number of issues which may in some way have contributed to the incident or its consequences were also identified and ERA has committed to action on them to help prevent similar incidents from occurring. They include adequacy of formal operational procedures relating to the use of potable water, currency of site plans, training of operators, staffing levels and shift handover procedures.

ERA had commenced substantial works on upgrading the process water system after an incident in 2000 at which time maintenance issues relating to the condition of the process water system were identified. The initial work commenced in the tailings corridor areas. An additional focus on improvements in maintenance *per se* developed out of the review of all of Ranger operations in 2002 and 2003 as part of ERA's Performance Enhancement Program. A two year major capital works and maintenance program was implemented at this time and the final phase is scheduled for completion this year. It involves the progressive overhaul of the process water system including the replacement all mild steel process water lines in the processing plant with stainless steel and HDPE. A change management procedure is in place to control any changes to the water systems. A permit must now be completed and approved before any change to the water supply or piping can be made.

## **Conclusions**

Significant and prompt action was taken by ERA in response to contamination of the potable water system by process water at Ranger Mine during the night shift of March 23<sup>rd</sup> and 24<sup>th</sup> to protect the health of people and the environment. Extensive consultation with regulators, stakeholders, employees and contractors has occurred. The Root Cause of the incident has been identified, together with contributing factors, and actions have been taken to ensure that the incident cannot re-occur. Although the person or persons who connected the flexible hose to the process water and potable water systems have not been identified, the ERA has taken all necessary steps to ensure that an operator or operators will not be able to make such a connection in future.

There is no evidence to suggest that a connection between the process water and potable water systems such as that which occurred on March 23<sup>rd</sup> and 24<sup>th</sup> has ever been made before. An incident reported in 1983 caused contamination of potable water by ammonium diuranate but did not cause any significant exposure of employees through ingestion or contact. Other than the 1983 incident and the current incident, data from potable water tests over many years have not indicated a problem with water quality. Two operators have stated that they believed that they had seen a hose connecting the fine ore bin scrubber manifold to

a potable water line before March 23<sup>rd</sup> but there is no evidence that the relevant valves had been opened to supplement process water flow with potable water.

The health of employees and contractors who came into contact with, or ingested, contaminated water has been of primary concern to ERA. Comprehensive steps were taken to ensure that individuals were counselled by medical experts and tests were undertaken to ensure that potential health impacts were diagnosed. Expert medical and toxicological advice is that it is most unlikely that there will be any long term health effects. ERA has a responsibility to everyone who works at Ranger and will ensure that any relevant health needs of people affected by the incident will be adequately dealt with for as long as it is necessary.

No environmental impacts of the incident have been identified.

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## PLATES

## 2 INTRODUCTION

Potable water at the ERA Ranger Mine operations became contaminated during the evening of March 23<sup>rd</sup>, 2004 when a potable water supply was connected to the process water system. Process water, being at higher pressure than the potable supply, flowed throughout the potable system and out to Jabiru East. The incident was triggered some time in the evening of March 23<sup>rd</sup> and, immediately following reports of poor quality drinking and showering water and confirmatory testwork on water quality at around 08.00h on the morning of March 24<sup>th</sup>, actions were taken to:

- notify employees and advise them not to drink water;
- disconnect the hose connecting potable water to the scrubber circuit;
- progressively place 'out-of-service' tags on potable water outlets;
- send home all employees who were not essential to investigation and recovery;
- isolate water to Jabiru East; and
- shutdown the plant.

Flushing and cleaning of the potable water system then progressed.

This report is the outcome of a detailed investigation of the incident and follows a preliminary report to the NT Department of Business, Industry and Resource Development lodged on April 6<sup>th</sup>, 2004 in compliance with Clause 31 of the Mining Management Act 2001.

The investigation included:

- an assessment of the principal root causes and contributors to the incident on the basis of the sequence of events, operator interviews, drawings, manuals, procedures and training, and a formal root cause analysis process;
- a program of exposure profiling, medical testing and contamination analysis to establish if there was likely to be any long-term adverse health consequences for those exposed to the contaminated water;
- assessments of the possible environmental impacts of the incident; and
- establishment of remedial actions designed to ensure that a re-occurrence of the incident is not possible.

## 3 DESCRIPTION OF INCIDENT

### 3.1 Description of relevant plant

The components of the plant that are relevant to the incident are the potable water system (including the Jabiru East reticulation system), the process water system, and the fine ore bin scrubber.

#### 3.1.1 Potable Water System

Potable water for Ranger and Jabiru East is supplied from the Brockman borefield which is located approximately 1,000 m south of Pit #1 on the Ranger Project Area (Figure 1). Water is pumped from the borefield to a potable water day tank at the minesite and, from there, is pumped into a reticulation system which extends throughout the Ranger operations area and

Jabiru East (Figure 2). This system includes a potable water head tank located on top of the fine ore bins.

Potable water supply pipes are painted 'Auxiliary blue' in colour and offtake points are labelled 'Potable Water'. At the time of the incident there was a potable water outlet at ground level at the base of the fine ore bins. This outlet was designed as a "Truck Wash" and had a ball valve (Valve X; see Plates- photograph 1) and 25 mm Minsup coupling attached.

As required by the Ranger Authorisation (Schedule: Conditions of Authorisation number 0108-01; Annexe A- Environmental Monitoring Program; Table A.2), potable water is monitored regularly for quality (monthly for pH, EC, turbidity and dissolved sulfate; quarterly for microbiological attributes and radioactivity; and yearly for alkalinity and total metals and key anions). The composition of potable water is set out in Tables 3.1 and 3.2.

**Table 3-1:** Composition of potable water (January 1989–March 2004) prior to the incident - General parameters and major ions (filterable)

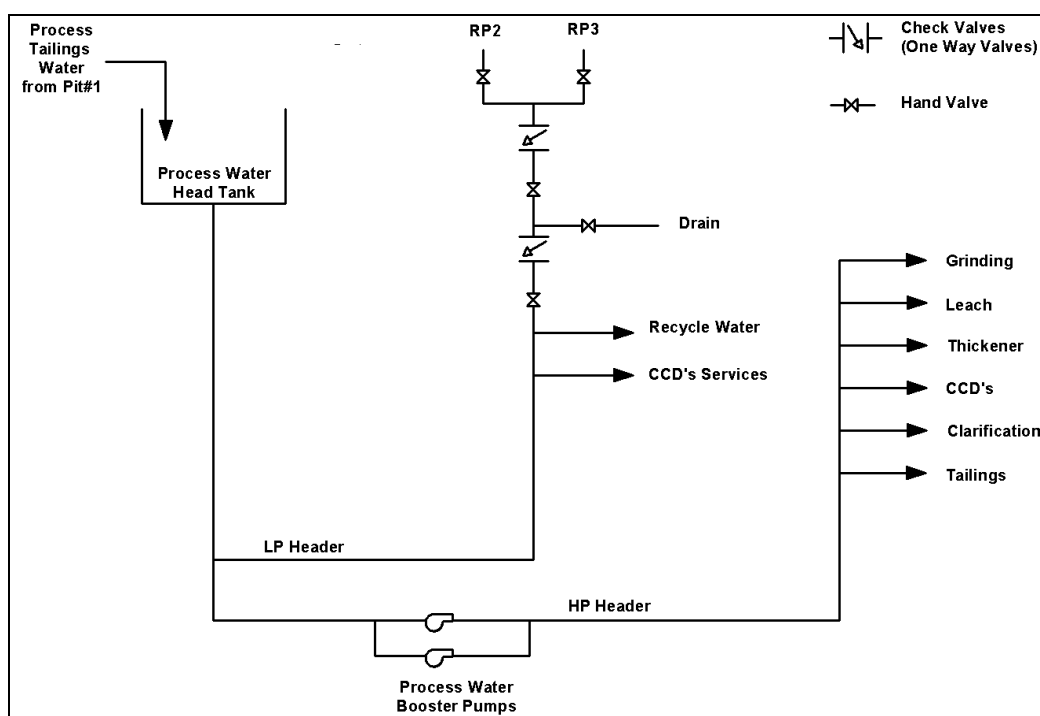
	pH (units)	EC ( $\mu\text{S}/\text{cm}$ )	Ca (mg/L)	Mg (mg/L)	K (mg/L)	Na (mg/L)	Cl (mg/L)	NO <sub>3</sub> (mg/L)	SO <sub>4</sub> (mg/L)
n	193	193	36	68	31	38	26	21	183
Mean	7.8	364	21.2	38.8	0.3	0.3	2.7	2.7	1.2
$\sigma$	0.2	43	2.1	4.9	0.1	0.1	2.6	2.6	0.9
Median	7.8	362	21.1	39.7	0.2	0.2	0.6	0.6	1.2
Min	7.0	233	15.4	7.7	0.1	0.1	2.0	2.0	<0.1
Max	8.4	689	26.0	44.5	1.3	1.3	4.4	4.4	9.4

**Table 3-2:** Composition of potable water (January 1989–March 2004) prior to the incident - Trace metals (filterable) and <sup>226</sup>Ra (filterable)

	Cu ( $\mu\text{g}/\text{L}$ )	Mn ( $\mu\text{g}/\text{L}$ )	Pb ( $\mu\text{g}/\text{L}$ )	U ( $\mu\text{g}/\text{L}$ )	Zn ( $\mu\text{g}/\text{L}$ )	<sup>226</sup> Ra (mBq/L)
n	35	44	25	187	37	156
Mean	22.8	2.7	0.8	5.9	106	10.1
$\sigma$	11.0	12.3	0.5	2.1	22	24.9
Median	20.9	0.5	0.7	6.3	103	5.2
Min	3.1	<0.1	0.3	0.9	51	1
Max	56.9	80.9	3.0	12.0	158	231

### 3.1.2 Process Water System

The basic functions of the process water storage and distribution system are to receive and store water from the process water collection system and to supply water to the process plant (Figure 3.1).

**Figure 3-1:** Schematic of process water collection and supply systems

Process water from Pit #1, the principal tailings storage facility, is pumped back to the process plant and stored in the process water head tank. While process water is the preferred source, pond water can also be used. Under specific standard operating procedures, either RP2 or RP3 water can be used as alternative (mutually exclusive) sources if required.

Process water is distributed to various areas of the plant, as required, except for solvent extraction (SX); precipitation, drying and Packing; the acid plant; and the power station. These parts of the plant cannot operate with process water because of high levels of salts and other contaminants present in the water.

Specific areas where process water is added to the process include:

- recycle water tank make-up (grinding area);
- CCD 7 and CCD 5 (as a substitute for raffinate when required);
- CCD thickener underflow pump gland seals; and
- fine crushing scrubbers 1 and 2, although either process water or pond water can be selectively supplied. Pond water is fed from the grinding recycle tank.

The process water booster pumps increase the water pressure into the distributed network throughout the plant to 650kPa. The increased pressure is required for pump gland water, scrubber operations, hosing up and such operations.

Process water supply pipes are painted green and offtake points are marked 'Process Water'.

The composition of process water is set out in Table 3.3.

**Table 3-3:** Composition of process water (August 15<sup>th</sup> 2003 to March 10<sup>th</sup> 2004)

Analysis	EC	pH	Al	Ca	Cu	Fe	Mg	Mn	Pb	SO <sub>4</sub>	U	Zn
Type	µS/cm		µg/L	mg/L	µg/L	µg/L	mg/L	µg/L	µg/L	mg/L	µg/L	µg/L
filtered	22800	3.8	368000	508	13560	72090	3660	1822000	3080	22350	14880	5200

### 3.1.3 Fine Ore Bin Scrubber

The fine ore bin scrubber is a venturi scrubber which draws dust laden gas from the discharge of the fine ore bins, removes the dust particulates by scrubbing with water, and discharges the cleaned gas through an adjacent stack. The water supply to the fine ore bin scrubber is normally provided from process water through a 50 mm stainless steel hard pipe connection (Figure 3). The flow of water to the scrubber is measured using a magnetic flow meter located close to the inlet of the scrubber spray. There is a local readout of flow at a meter near the pipe rack, but no flow reading in the plant control room.

The scrubber has a low flow alarm (FSL 101) which is set to activate when the water flow falls below a certain level (set point 2.5m<sup>3</sup>/hr). Normal flow is about 4m<sup>3</sup>/hr. When flow falls below a set point of ~2m<sup>3</sup>/hr the scrubber fan motor and feed to the rod mill will trip. As the plant is not permitted to operate without the scrubbers it is critical that the minimum flow to the fine ore bin scrubber is maintained. The alarms in the plant control room only signal when flow falls below the set point. Tests on the flows to the scrubber after the incident show that the alarm was activated at a flow rate of 2.5m<sup>3</sup>/hr and the plant tripped at ~2m<sup>3</sup>/hr.

## 3.2 Events Leading Up to March 23-24

A maintenance program has been progressively undertaken to replace the mild steel process water lines in the processing plant with stainless steel and HDPE pipes. During this maintenance program, and when there has been insufficient process water pressure or the system has been taken out of service for maintenance, the water source has been changed to pond water to maintain production. There is a specific standard operating procedure (SOP) for the water source to be changed over from process water to pond water and also for re-instatement of process water. The process water supply to the scrubbers was off-line between the March 8<sup>th</sup> and 20<sup>th</sup> while a spool was replaced. During this time the scrubber operated on pond water by running hoses from inside the grinding building. This was appropriate practice at the time.

## 3.3 Events of March 23-24 – Ranger Mine

Table 3.4 lists the events as they occurred as reconstructed from interviews, observations after the event, and data recorded by the plant distributed control system (see also photographs in Plates for locations of valves).

**Table 3-4:** Summary log of events

<b>Tuesday March 23<sup>rd</sup></b>	
5:30pm	Low flow alarm sounding (intermittent). Alarm was acknowledged by supervisor.
6:30pm	Day shift operator and day shift supervisor inspected 25 mm hose connected to the potable water valve (valve X) and leading up towards the FOB scrubbers manifold. The day shift supervisor reported that the day shift operator had been hitting the valve with a brick. The day shift operator reported that he was ensuring that Valve X was closed (the valve handle had been corroded off). Potable (X) and FOB scrubbers manifold (Y) valves believed by the operator to be closed because the hose was observed to be flat.
6:45pm	Potable (X) and FOB scrubbers manifold (Y) valves believed by operator to be closed because the hose was observed to be flat.
7:00pm	Shift changeover - only 3 staff on duty. Day shift supervisor advised night shift of alarm but no instruction given to fix the problem. Processing Superintendent was advised of short staffing – decided that no-one else would be usefully able to assist and instructed that the night shift should continue but always work within safe limits.
	FOB low flow scrubber alarm still sounding. Acting night shift supervisor carried out inspection and noticed 25 mm hose connected to the fine ore bin scrubber manifold. It appeared to have no flow on basis that hose was flat.
8:00pm	Acting night shift supervisor and night shift operator 2 checked filters on the fine ore bin scrubber manifold and stated that the hose into the manifold was not charged at the time.
8:30pm	Night shift operator 1 attempted to bring process water booster pump on - could not open discharge valve. One booster pump always operates. It is not usual for the second booster pump to be operating at the same time (it is basically a standby pump). The stuck valve indicated it had not recently been operated.
9:30 – 10:00pm	Night shift operator 2 asked to hook up 25 mm line by Acting night shift supervisor specifically into process water supply. Night shift operator 2 did not connect any hoses – he turned on valve (Y) for input of 25 mm line connected to the fine ore bin scrubber manifold adjacent to the filters – he did not check the source of the supply to this line.
9:48pm	Low flow alarm changed from intermittent to continuous (details in Section 3.3.2)
10:45pm	Processing Superintendent contacted Acting night shift operator to check on shift progress given low manning concerns.
<b>Wednesday March 24<sup>th</sup></b>	
4:30am	Change noticed in quality of drinking water (later reports).
6:40am	Administration Officer - Production noticed poor quality water and notified day shift supervisor.
7:00am	Administration Officer - Production reported apparent change to laboratory chemist. Initially possible contamination was suspected to be chlorine imbalance from treatment of borewater, as had happened the previous week.
7:30am	Shift supervisor collected a sample of water at the grinding building for analysis.
7:45am	Dayshift supervisor turned off valve (Y) at the manifold. Day shift operator shuts off potable water valve (X). Day shift operator later looks for 50 mm to 25 mm adaptor and connects hose to process supply valve (Z). During the day a fitter removed the potable water valve (X), replaced it with a new valve and tagged it to prevent use (photographs in Plates).
7:50am	Samples tested for U (XRF), conductivity and pH - results indicate process water contamination. Hose disconnected from valve (Y) on fine ore bin scrubber manifold.
8:00am	Laboratory chemist advises Maintenance Manager of the situation.
8:10am	Announcements on Gai-phone and radios across the site that employees should not drink potable water.
8:15am	Out of service “tagging” of potable water outlets commenced.
8:15am	As part of the potable water system shutdown the potable water supply to Jabiru East (which provides water to the mine, the airport, contractor and businesses) was disconnected at around 8.15am. Although flow to the distribution network was isolated, the potable water tank at Jabiru East was reported to be overflowing. Spillage of potable water from this tank had occurred on previous occasions. Difficulty was experienced in starting the diesel pumps to empty the tank and the overflow was not halted until 4pm.
8:22am	Email notifications sent to employees.
8:30am	Day shift mine operations employees and contractors sent home.
9:00am	Ranger processing plant shut down.

While the information in Table 3.4 was based mainly on interviews, it is important to note that no-one stated that they connected the hose to the potable water outlet or turned on Valve X, or knew who did it, or when it was done.

### 3.3.1 Hoses Connected and Valves Turned on

It has not been possible to establish the exact timing of the connection of the hose to the potable water valve, who was responsible for this, or who turned on the potable water valve. From discussions with operators, it appears most likely that the potable water was connected on the day shift on March 23<sup>rd</sup>. There is no evidence that it was turned on during that shift.

Valve Y was opened because the operator believed that the hose connected to Valve Y was connected to process water. It is not known why Valve X was opened. The operator may have believed (mistakenly) that this would result in the potable water actually supplementing the process water going into the scrubber, or the operator may have been intending to close the process water isolation valves on the scrubber inlet manifold (and thereby prevent process water from contaminating potable water), but forgot to do so.

Initial statements from the operators and supervisors indicated that the hose had been seen connected to the potable water supply, and that this hose may have been connected to the scrubber inlet valve for some time before this incident. Further interviews with the operators and supervisors indicate that only one operator and one supervisor maintain that the potable water has been connected to the scrubber system, but no dates or times could be provided. All other operators and supervisors (from 4 shift panels) deny ever having connected or having seen the potable water line so connected. The possibility that such an incident has occurred in the past therefore cannot be excluded but seems highly unlikely given the lack of impact on the flow to the scrubber this would have had.

### 3.3.2 Fine Ore Bin Scrubber Low Flow Alarm

On the night of March 23<sup>rd</sup>, from the commencement of night shift, the process alarm journal shows that alarm FSL23101A (fine ore bin scrubber low flow alarm) was indicating between 7 seconds and one minute. After initiating the alarm either returned to normal or was silenced (acknowledged) by the plant control room operator. It is understood that a similar alarm pattern occurred from around 5pm on the day shift. This suggests that the flow to the fine ore bin scrubber was fluctuating around a  $2.3\text{m}^3/\text{hr}$  flow level. This pattern continued until 21:48:27 when the alarm remained on (did not return to normal) until 22:58:16. The alarm indicated again at 22:58:22, was acknowledged at 22:58:31, and remained on again until 00:49:50. In fact it appears to have remained on until the plant was shut down at around 8am on March 24<sup>th</sup>. As the scrubber did not trip during this period, it suggests that the flow remained below  $2.3\text{m}^3/\text{hr}$  but was greater than  $\sim 2\text{m}^3/\text{hr}$ .

The time when the alarm stopped indicating every 7 to 60 seconds, and simply remained on (although acknowledged), generally coincides with the approximate time that night shift operator 2 turned on valve (Y) which connected the potable water supply with the process water supply. The apparent (slight) reduction in flow through the process water system from around  $2.5\text{m}^3/\text{hr}$  to between  $2.3\text{m}^3/\text{hr}$  and  $\sim 2\text{m}^3/\text{hr}$  is consistent with the connection of a potable water system at a lower pressures and the resulting draw of flow of process water away from the scrubber.

The activation and trip level has since been tested on the fine ore bin scrubber #1. The process water inflow was throttled until the low flow alarm signalled in the control room. This occurred at around  $2.3\text{m}^3/\text{hr}$ . Continued throttling activated the trip alarm at about  $1.9\text{m}^3/\text{hr}$ . Approximately  $64\text{m}^3$  of process water is estimated to have entered to the potable water system based on the analyses undertaken by Klessa (2004; Appendix 5).

### 3.3.3 Process Water Booster Pumps

On the night of March 23<sup>rd</sup> an operator attempted to bring into service the second of two process water booster pumps. The booster pumps, which are designed to operate



separately, provide additional pressure for supply wash points, gland sealing and the fine ore bin scrubber. Pressure is boosted by operating the booster pump to about 650kpa.

The low flow alarm had initiated towards the end of the day shift and continued into night shift. An operator hoped he could increase the flow by switching on the second pump but was unable to start the pump because the diaphragm valve on the supply side could not be opened. This valve had been difficult to open in the past and the pump had therefore not been used recently (photo 8). It is not clear why the operator felt that bringing the second pump into service would improve the flow to the scrubbers, as the pumps are not designed to operate in parallel and would have only had a small impact on flow. This was not normal practice and there are no procedures for this. None of the operators on other shifts had ever tried this as a solution to a low flow problem.

### **3.4 Events of March 23-24 – Jabiru East**

The contamination of the potable water at Ranger Mine was confirmed at 7:50am on Wednesday 24 March. The potable water system was immediately isolated and at 8:15 am the supply to Jabiru East was disconnected. This involved closing of valve V75 (Figure 2) which also isolated the branch of the potable water supply to the Mine Department offices. At the same time ERA's Manager Environment, Safety & Health and an Environmental Officer visited the Jabiru East facilities to ensure that occupants were aware of the problem and that there was no water available from the potable water reticulation system. These facilities included the airport café, Kakadu Air, Northwest Helicopters, Jayrow, Aero Club, Gagadju contractor's workshop, the core shed, nursery and the Office of the Supervising Scientist (OSS) field station.

ERA's Maintenance Superintendent - Processing went to the Jabiru East water tank (there are 2 tanks but one has been decommissioned) and nearby valves to further isolate the Jabiru East facilities and to prepare for emptying and flushing the system. At that time it was noticed that water was still running from the overflow pipe from the tank at about 7.5l/sec although subsequent calculations have suggested that the overflow may have been around 18 l/sec at its peak.

It was also confirmed that the Manager of the OSS field station turned off the main supply valve to that facility. The valve, however, was not tagged. At this time only two people, both from the Airport Café, had indicated that they had consumed water before the supply had been disconnected.

In order to empty the tank at Jabiru East, the main supply valve from the tank back to the potable water tanks at Ranger Mine was opened when the pumps located at Jabiru East were running and could be used to pump water back. However, in the first instance, neither the electric pump nor the diesel pump could be started. It was 4pm that afternoon before the diesel pump was repaired, emptying of the water tank at Jabiru East commenced, and the tank overflow stopped. A 25mm bypass pipe, which allows refilling of the tank to compensate for evaporation, was discharging water continuously into the tank because the high-level float valve inside the tank was broken and the supply could not be automatically closed. Also, though not confirmed, it is thought that one of the butterfly isolation valves linking the Jabiru East tank and pipeline to Ranger Mine was not closing properly and hence allowed additional water to flow into the tank. It had therefore been overflowing for some time before this incident (photograph 7 in Plates).

On March 25<sup>th</sup> the flowmeter near Jabiru East was removed to allow the line to drain. Water samples taken over a period of some hours indicated that the water in the line to the OSS field station and the airport contained an amount of contaminated water. An explanation for this is that the OSS field station and the airport run irrigation systems which were operating during the night of March 23<sup>rd</sup>. However, the amount of water used was not sufficient for the



contaminated water to reach the OSS field station or Gagadju workshop supply tanks. Samples collected and analysed confirmed this.

Flushing of the OSS field station was carried out on March 25<sup>th</sup>. However, the operator working on this project was not aware that the main valve on the water supply into the site was closed. Flushing, by pumping back from the field station tanks would not therefore have been successful. The operator did notice that the water level in the tanks hardly dropped (if at all) during the flushing process. OSS requested that the tanks be isolated and tagged but this was not done until March 30<sup>th</sup>. During this period the Jabiru East tank was partially filled with Magela borefield water which was pumped back down the line to Ranger Mine. The line from the Jabiru East tank to the OSS field station, the Airport and the Gagadju workshop was isolated throughout this period, except when backflushed from the Gagadju workshop and at the time of the attempted backflush from the OSS field station.

Flushing of all supply lines to Jabiru East sites, Ranger Mine and the Inganarr Training Centre continued until April 2<sup>nd</sup>.

On Thursday April 1<sup>st</sup> and Friday April 2<sup>nd</sup>, in order to collect samples of water from the main feed line at the OSS field station, the main valve near the site entrance was turned on. Personnel involved in the sampling recall not turning the valve off again on Friday April 2<sup>nd</sup> as it was understood the field station feeder line was isolated at the rear tanks. On Monday April 5<sup>th</sup> an **eriss** field team filled water bottles and departed on a 3-day trip. Also, on Monday, the field station site manager noticed that although the water tank valves were closed there was flow at the taps, indicating that there was another supply into the site. This occurred through a pressure activated valve designed to maintain water supply to the fire service. The site manager immediately turned off the main supply valve and notified ERA. On April 6<sup>th</sup> the main valve was isolated and tagged, and water was tested and flushed. No contamination of the facility was identified before or after flushing. The second line, via the pressure activated valve, which is believed to be for backup fire service, was unknown to field station staff.

#### 4 FIELD OBSERVATIONS

The location of the potable water supply valve (X) at ground level (photo 1 in Plates) is some 5 metres from an additional process water connection. Inspection of the site on March 26<sup>th</sup> showed a 25mm hose fixed to the supply side of the scrubbers about 5 metres directly overhead and hanging into the area near the potable water offtake valve (X) (photos 1, 5 in Plates; Figure 4). A 50mm hose also lay on the ground. The accepted practice at the time, when there was insufficient process water flow to the scrubber (two instances were logged during March 2004), was to change over to pond water by connecting the 50mm hose to a pond water line inside the nearby mill building, or a process water offtake about 20 metres away, then connect the smaller 25 mm hose to the larger 50mm hose. The process water connection located about 5 metres from the potable water valve (X) is not used often because it has not had a suitable coupling attached. Photograph 2 in Plates shows this connection with a 25mm coupling attached. This was attached after the incident. On the evening of March 23<sup>rd</sup>, in order to provide additional process water, the operator would have had to find such a coupling before being able to connect the 25mm or 50mm line to it.

The ball valve (X) on the potable water offtake, which had been removed after the incident, was severely corroded. The valve handle had broken off and the condition of the valve indicated some force had been used to try and open and close it (photo 6 in Plates). The spindle surface is corroded and it was difficult to see whether the valve was in the open or shut position. The valve is in the half closed position but the indicator position shows the valve to be fully open. A masonry brick was found on the ground near valve X and the operator admitted using it to close the valve. It appears that the valve stop had been hit with the brick causing it to bend. The stop was no longer in the correct position and therefore did

not properly indicate the valve closed position. The only way to tell the correct valve position is by the spindle direction. This is very difficult to see due to the covering corrosion.

Process water valves on the fine ore bin scrubber staging were in a similar condition with handles rusted off and corroded spindles, although it was still possible to see the position of the valve. To open and close these valves it was indicated during the interviews with operators that a shifting spanner had been used.

## 5 REVIEW OF PROCEDURES

A review of written procedures, training, instructions, induction, change management system, shift logs, drawings, labelling and identification and process system monitoring resulted in the following findings.

- There are procedures for scrubber filter cleaning (*SOP PPC09*) but no written procedures covering boosting water flow to the scrubber by replacing process water with potable water. The only way to do this is with hoses.
- There is no instruction in any documentation or training information indicating that connection of potable water to process or pond water supplies is forbidden.
- Required training is not up to date. ERA's training management system (TRACCESS) lists required training modules and records the completion of these modules for each employee. The timeframe for completion of the modules is dependent on each employee's development program and direction from management. At the time of the incident only 26% of all training modules allocated to employees had been completed since the introduction of the TRACCESS training system. Although not all training modules are expected to have been completed at this point in time, the numbers completed should be significantly higher than indicated. Of the modules related specifically to water (process, potable, water management) between 30 – 35% of modules had been completed by operators, although 49% had completed the *Water Management on Site* module.
- There are specifications for colour coding of pipes but they did not appear to be followed everywhere. Colour coding of stainless steel piping has to be addressed.
- Work undertaken to correct a low flow alarm by connecting to pond or process water should be covered by a change management request. This was not done for this incident as the occurrence (both initiation of alarm and connection of pond or additional process water) occurred so often that it was not considered to be a significant change.
- Drawings adequately represent the water system around the scrubbers. Potable water and process water systems are shown on separate drawings. The drawings relating to Jabiru East (*1253-42-P0034 Water and Fire Protection Temporary Township Laboratory Complex Water Supply System; 1253-42-P0037 Water and Fire Protection Temporary Township Single Men's Quarters Water Supply System*) no longer represent current arrangements.
- The procedure for addressing alarms does not include a step by step routine for addressing the cause for the alarm – such as checking filters (this is already a requirement), checking flow meter for blockages, checking pumping and piping systems and checking spray nozzles.

## 6 ROOT CAUSE ANALYSIS

ERA instructed ARMS Reliability Engineers, an independent organisation, to facilitate a root cause analysis of the incident with ERA using the Apollo Method. In its simplest form, this method is undertaken in four steps, namely:

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1. define the problem;
2. create a 'Cause and Effect' chart. For each primary effect ask "why?". Look for causes in actions and conditions. For each action and condition ask "why?". Provide evidence;
3. identify effective solutions. Challenge the cause and offer solutions. Identify the solutions that best prevent recurrence, can be controlled, and meet goals and objectives; and
4. implement the best solutions.

Any event requires both an action and condition cause in order for the event to occur. The benefit of the Apollo Method is that all possible causal paths are identified and considered. A simplified 'cause and effect' chart was developed and is presented in Figure 5 (attachment). All causes were tracked back to issues including behaviours, attitudes and circumstantial evidence.

Causes that have solutions that meet the criteria are termed the "Root Causes" and are shown in the chart below. The analysis indicates that the incident was caused by a set of *conditions*, namely:

- the existence of common connections on Process Water and potable water systems;
- the lack of a system for early warning of contamination in the potable water system; and
- the absence of non-return valves in the potable water system

and *actions*, namely:

- someone connected hoses and turned on valves.

The key outcomes of the Root Cause Analysis, together with proposed corrective actions, are summarised in Table 6.1.

**Table 6-1:** Summary outcomes of Root Cause Analysis & proposed corrective actions

<b>Cause</b>	<b>Corrective Actions</b>
<b>Conditions</b>	
Potable water system integrity compromised	1. Change potable water connections so that they are not compatible with process water
No on-line detection system for early warning of contamination	2. Install pH & EC alarm in potable water system.
No backflow protection	3. Install backflow protection and appropriate maintenance regimes in potable water system at key connections where a risk of contamination exists.
<b>Actions</b>	
Hoses installed between systems and valves opened.	4. Raise awareness of safety and environmental hazard associated with potable water.

In addition to the root causes, the exercise raised a number of other issues which it was thought may have in some way contributed to the incident, including:

- procedures for dealing with low process water flow;
- currency of plans;
- training;
- lower than normal numbers for the shift; and

- shift handover/exchange of information procedures.

All of these issues will be investigated and steps taken to improve performance.

## **7 RESPONSE TO THE INCIDENT**

This section documents and describes how Ranger responded to the incident and took action as part of disaster management recovery. Attention is given to the process which was followed in the lead-up to a return to work. This involved meetings and discussions with the workforce and stakeholders to ensure that concerns were met, risks were minimised, and that the requirements set internally by ERA and externally by the authorities for a resumption of mining, milling and processing, and the reinstatement of potable water supply to the mine and the Jabiru East community, were fully achieved.

### **7.1 Disaster management recovery**

Disaster management recovery was declared at 10:15h on March 24<sup>th</sup> immediately after DBIRD, OSS, and the Northern Land Council (NLC) were informed formally by telephone of the incident by the General Manager-Operations. In the lead up to the declaration, staff on site had been warned by Gai-phone and radio not to use the potable water system (08:10h) and mine operations staff who had arrived to start day shift were sent home (08:30h). By 09:00h the local Jabiru doctor had been contacted to advise him of the incident and preparations were made for employees who felt ill to be directed to the Health Centre in Jabiru. Local businesses and premises in Jabiru East were advised that their potable water supply had been disconnected (09:15h).

The primary objectives and the immediate response taken as part of disaster management recovery were to:

- achieve safe close down of the plant;
- prevent any further contamination of the potable water supply and access by mine personnel and the public to contaminated water;
- determine the personnel who may have either consumed, or had skin contact with, contaminated water drawn from the potable water system and provide support;
- safeguard the health of those staff remaining on site and the public at Jabiru East by organising the provision of bottled water and chemical toilets;
- establish the extent of contamination of the potable water system particularly in the supply to Jabiru East;
- set up effective communication and liaison with workers, the Jabiru community, Traditional Owners, stakeholders and the media to provide regular updates on developments related to the incident;
- ensure that the authorities investigating the incident were provided with the necessary support from site personnel; and
- identify the cause of the incident.

Secondary objectives were to:

- instigate an internal investigative process into the cause of the incident and establish how this incident could be prevented from recurring;
- determine a strategy, in consultation with the authorities, for the reinstatement of potable water supply to the Ranger minesite and to Jabiru East; and
- establish a plan, in consultation with the authorities, for the resumption of mining, milling and processing at Ranger.

Actions taken in response to the secondary objectives are described in the sections that follow. Internal investigations into the cause of the incident and recommendations arising out of it, including strategies to prevent a similar incident from reoccurring, forms the basis of this report.

## **8 ACTIONS**

### **8.1 Systems**

An upgrade of the process water system at Ranger has been in progress as follow-on to recommendations of the Supervising Scientist following the tailings water leak incident in 2000<sup>2</sup>. The initial upgrade work focussed on the tailings dam corridor components of the system (Recommendations 1, 2 & 10; Supervising Scientist 2000). Continuing upgrades were incorporated into ERA's Annual Plan in September 2003 and approved in concept in November 2003. This included replacing pipe work for all unserviceable process water piping in the mill area.

Works on process water systems in the tailings corridor, most recently the installation of a high-density polyethylene (HDPE) process water pipeline from tailings to the process water head tank, had been completed. Subsequently, an upgrade of the process water piping in the mill commenced in 2003. This included:

- replacement of the discharge nozzle and immediate spools from the process water head tank in stainless steel. The pipe work preceding this up until the booster pumps have been replaced in 355 mm poly pipe;
- replacement of several offshoots from the header pipe through the plant with HDPE pipe in critical areas such as grinding and CCD's; and
- preparation for replacement of the three carbon steel process water headers and associated distribution pipe work along the CCD corridor.

In addition, Simon Engineering and SKM have been working with ERA to survey the process water system, update process and instrumentation diagrams and plans, and order replacement materials.

The next stage of the process water upgrade, which is contained in the capital budget for 2004, was to complete a planned plant shutdown in May and replace the three carbon steel process water headers and associated distribution pipework along the CCD corridor. Owing to the lead-time on some materials, replacement of all the relevant pipework is estimated to take approximately 4 months. The project is planned for completion by the end of August 2004<sup>3</sup>.

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<sup>2</sup> Supervising Scientist (2000) Investigation of tailings water leak at the Ranger uranium mine. Supervising Scientist Report 153. (Supervising Scientist, Darwin)

<sup>3</sup> Details are set out in the ERA "Stage 2 PW and RW replacement schedule".

A number of additional commitments were made to regulators and stakeholders in relation to returning the workforce to the Ranger minesite and restarting mine operations, and re-instating the water supply to Jabiru East. These are contained in the proposals and reports attached as Appendices to this main document. Table 8.1 lists all commitments made by ERA and their current status.

**Table 8-1: Summary lists of commitments & current status**

<b>Commitments Prior to Re-start of Operations</b>			
<b>Commitment</b>	<b>Due Date</b>	<b>Status</b>	
1 Employees returned to the Ranger site for maintenance purposes on Wednesday March 30 <sup>th</sup> under the conditions stipulated in Dr Johnston's letter to Mr Tony McGill dated 30 March 2004, namely that: <ul style="list-style-type: none"> <li>all parts of the potable water system were flushed and water samples analysed to demonstrate that they met EC and pH targets;</li> <li>drinking water outlets remained tagged "out of service" and were only released for drinking water once two consecutive results indicated that the water met the drinking water guidelines.</li> </ul>	30/03/04	Completed	
2 ERA demonstrated that the potable water system at Ranger Mine met the Australian Drinking Water Guidelines. Figure 1 shows the location of all potable water outlets at Ranger Mine. Table 1 lists the water quality data ERA obtained for water samples from potable water outlets. <ol style="list-style-type: none"> <li><b>Chemical composition:</b> <ol style="list-style-type: none"> <li>At least two consecutive daily samples taken from representative points throughout the potable water system were analysed and the data summarised together with the Australian Drinking Water Guidelines data. Samples of water from outlets met the drinking water guidelines in respect of chemical/toxicological considerations.</li> </ol> </li> <li><b>Microbiological data:</b> <ol style="list-style-type: none"> <li>Two representative samples from the potable water system were submitted for microbiological analysis (total coliform, <i>E. coli</i> and faecal <i>Streptococci</i>) on Tuesday 30<sup>th</sup> April and returned results that met the drinking water guidelines.</li> </ol> </li> <li><b>Radiological Analysis</b> <p>A radiological analysis of a representative sample of potable water was analysed for Thorium activity by <i>eriss</i> and the results were consistent with drinking water guidelines. Additional analyses of gross-<math>\alpha</math> and gross-<math>\beta</math> were undertaken as required by the Ranger Authorisation.</p> </li> </ol>	30/04/04	Completed	
3 ERA initially implemented manual sampling and analysis of potable water for pH and conductivity on a four-hourly basis. The frequency was increased to hourly for the first 24 hours of operations. <p>A temporary continuous monitor for EC and pH has been installed. The monitor triggers an alarm if EC or pH move outside the normal ranges.</p> <p>Permanent EC and pH probes have been installed at the outlet from the potable water day tank and the return line from the processing safety showers. The probes will be wired through the processing control "DCS" system to allow alarms via the processing control panel.</p>	6/04/04  16/04/04  12/6/04	Completed  Completed  Completed	
4 A new permit system has been implemented requiring Superintendent authorisation for any changes, temporary or permanent, to water pipework.	05/04/04	Completed	



<b>Systems Commitments</b>			
<b>Commitment</b>		<b>Due Date</b>	<b>Status</b>
5	Undertake a risk analysis of the potable water system.	30/04/04	Completed
6	Undertake a risk analysis of the process water and pond water systems.	30/04/04	Completed
7	Engage an external consulting company to conduct a process integrity review on the quality of the management operating systems, and the operational standards, to assess compliance levels. The review will benchmark the Company against best practice in the chemical industry.	21/07/07	Completed
8	A review of the present maintenance standards and systems will be conducted by Rio Tinto Asset Utilisation. The review will consider present strategies and their execution and make recommendations as to how the preventative maintenance regime can be improved at Ranger	30/06/04	Completed
9	Engineering specifications will be reassessed to ensure that it becomes a standard requirement to install non-return valves on any connection to the potable water system where a risk of contamination exists.	30/09/04	
10	Continue annual review of environmental risks as committed to in the Environmental Management System.	31/03/05	
11	Complete planned risk review workshops to fully populate safety & health risk register.	By end 2004	
	Build annual risk review into safety management system.	By end 2004	

<b>Equipment Commitments</b>			
<b>Commitment</b>		<b>Due Date</b>	<b>Status</b>
12	Remove all quick-connect fittings such as Minsup connections from potable water lines unless absolutely necessary. If there is a demonstrable necessity to retain such connections, a different type of fitting will be used.	02/05/04	Completed
13	Review the potable water system with a view to reducing the number of branches. Back flow valves with appropriate maintenance regimes will be installed at key junctions to further protect the potable water system	30/04/04	Initial review completed. Installation of back flow valves complicated by recirculating nature of system. Further review will be completed by end August
14	Implement the proposed program of works listed as Stage 2 Process Water Pipe Replacement.	31/10/04	In progress
15	Identify any connection points and crossovers from the potable water system to any other system. Ensure that actions are taken to eliminate the possibility of inadvertent connection to the potable water system.	02/05/04	Completed
16	Process water pipe work outside of bunded areas will be inspected and upgraded to HDPE or stainless steel, or removed if redundant.	31/10/04	Inspection of pipe work completed. Identified work to be undertaken as part of commitment 14
17	Review the colour code for process and pond water.	12/04/04	Completed
18	Inspect water pipes throughout the Ranger minesite site to ensure they are appropriately labelled and coloured.	31/10/04	Scope & plan of work completed.
19	Refurbish the fine ore bin scrubber during the planned May shutdown	20/05/04	Completed

People Commitments			
Commitment		Due Date	Status
20	Review the site water management training modules following the incident.	12/04/04	Completed
21	Retrain all relevant personnel on updated site water management systems.	30/04/04	Completed
22	Establish clear criteria for the minimum training that is required to be completed before an operator is allowed to work without direct supervision by another operator. Build clear training objectives and targets into leaders' role accountabilities. Establish a formal management reporting framework for progress on training.	31/07/04	
23	Complete ' <i>Employees Driving Improvement</i> ' initiative to establish clear requirements for a quality shift handover.	31/05/04	Completed
24	Review staffing levels in Processing and develop a procedure for situations where limited labour is available.	30/06/04	Completed
25	Review the scope and breadth of senior operational management roles to ensure that the areas of responsibility are appropriate.	31/07/04	Completed

Jabiru East			
Commitment		Due Date	Status
26	Water for industrial purposes was reinstated to Jabiru East subject to the following conditions: <ul style="list-style-type: none"> <li>drinking water outlets will remain locked out of service;</li> <li>outlets available for industrial use will be clearly marked "Not Drinking Water", together with a standard graphical symbol;</li> <li>an ERA representative will communicate with each Jabiru East business to explain the conditions before water supply is made available; and</li> <li>bottled water will continue to be available for drinking purposes.</li> </ul>	23/04/04	Completed
27	A testing regime has been agreed with NT Health, DBIRD, and OSS for the return of drinking water to Jabiru East. A submission for the reinstatement of drinking water will be made as soon as all testing is complete.	11/06/04	Completed
28	Install independent water supply to Jabiru East.	By end 2004	

## 8.2 Behavioural Aspects

The incident has drawn attention to concerns with working culture and operating practices, in particular the use of unauthorised 'work-arounds' to operational problems, failure to identify and respond appropriately to known hazards, and shortfalls in and departures from accepted shift handover procedures.

ERA will address these concerns by reminding all personnel of the standards, procedures and principles which they are expected to follow, the reasons for those standards, procedures and principles, and the consequences of failing to accept and implement these standards, procedures and principles.



## 9 IMPACTS OF THE INCIDENT

### 9.1 Ranger Minesite

Details of the investigations to determine the level of contamination in the potable water system at the Ranger minesite are described in the report by Klessa (2004) attached as Appendix 5.

#### 9.1.1 Factors determining the level of contamination in the potable water supply at the mine site

Contaminated water was first discovered by assay on site, before plant shutdown at 09.00h on March 24<sup>th</sup>, in outlets servicing the Mill Laboratory and Grinding Crib Room amenities (Table 8.1). Later sampling by OSS on the same day verified that the highest contaminant levels measured on site were located in this area (the OSS sample was obtained from a toilet cistern).

**Table 9-1:** pH, EC and U content of contaminated potable water compared with process water and uncontaminated potable water (*eriss* sample is shown in italics)

Sampling Point	Time	pH	EC (µS/cm)	Total U (mg/L)
Grinding Crib Room	07.45	4.5	5900	8†
Mill Laboratory Tap	08.10	4.5	5900	3†
<i>Grinding area ground floor toilet cistern</i>	<i>15.50</i>	<i>4.2</i>	<i>8710</i>	<i>6.82‡</i>
Process water	–	3.7	19000	18
Potable water	–	7.9	390	0.007

Note: †Converted to U for consistency; ‡Note – this sample was not acidified on collection.

The ERA data were derived from analyses that were conducted on site immediately after sampling and show a high degree of contamination of the potable water supply. However, these data may not be reliable for providing an estimate of the proportional contamination of potable water by process water because the technique used to analyse total uranium (X-ray fluorescence) was not optimised for the aqueous matrix and has a low accuracy (estimated 50% error margin).

Arguably, the most reliable data is from the OSS sample, although a possible complicating issue arises from the fact that the sample was taken almost 7 h after plant shutdown, allowing time for the settlement of suspended material in the cistern and perhaps difficulties with obtaining a representative sample.

The analysis of the OSS sample allows for other key indicators of process water contamination to be used to calculate and verify the proportion of process water that mixed with potable water (Table 9.2). This is important for establishing a worst case scenario in toxicological assessment of contaminant intake.

Hence, the limited data indicates a conservative worst case of about 1 part process water in 2 parts potable water<sup>4</sup>, a dilution factor of approximately 3.

**Table 9-2:** Inferred dilution of process water in the cistern sample (mg/L)

Source	Al	Cu	Mg	Mn	Ni	Pb	SO <sub>4</sub>
Cistern	124	11.7	1130	594	1.69	1.28	6940
Process water	352	17.8	2690	1360	3.44	3.05	17240
Potable water	<0.001	<0.05	40	0.0001	0.001	0.001	1.5
Implied dilution factor	2.8	1.5	2.4	2.3	2.0	2.4	2.5

The high degree of contamination found in the potable supply to the Mill Laboratory/Grinding Crib Room was caused by the proximity of the potable water take-off from the point of entry of process water to the main. Other outlets within the administration building which houses the Mill Laboratory and associated amenities, were potentially likely to have been similarly affected. In the absence of corroborating data, we cannot preclude the possibility that other potable water supply points elsewhere on the minesite were similarly contaminated. However, it is unlikely (Klessa 2004; Appendix 5).

There are a number of factors that would have influenced the actual concentration of contaminants drawn into potable water during the time process water entered the potable water system. For example, at the grinding crib room facilities, where the potable supply was being used, the opportunity was provided for contaminated water to flow from the main to the outlet. Initially, residual clean potable water in the feeder line would have made up this expression. Once contaminated water entered this line, the issue of predicting concentration variation at the tap becomes one of reconciling concentration variation in the 100 mm main line to the time at which water was drawn and its delivery rate at the tap. In the absence of a model to describe concentration variation in the main pipe with respect to offtake points around the minesite, as well as a lack of information on actual potable water discharge rate at these points, the prediction of contaminant concentration at each supply point in real time is not possible. However, some generalisations can be made as to the likely pattern in the concentration of contaminants over time passing offtake points from the main, taking account of the principle drivers of flow within the potable water system.

The flow of water in the potable water system feeding Ranger (and Jabiru East as a continuation of the Ranger potable water main) is controlled by the maintenance of a minimum pressure head in the header tank (which sits on top of the fine ore bin). As the header tank empties in response to potable water use, a height level sensor triggers a large capacity pump<sup>5</sup> which transfers water from the day tank through two-way valves to the header tank, and, at the same time meets on-going demand for potable water supply drawn elsewhere from the main (Klessa 2004; Appendix 5). As the day tank empties to meet ongoing demand, a height level is reached when feed from the Brockman borefield is triggered by a sensor and the tank is refilled. Filling stops when another sensor is triggered as water in the tank reaches its maximum height. A self-contained and constantly recirculating system supplies cool water from the day tank to safety showers.

The implications of the directional flow of potable water for the dispersion of contaminants from the influx of process water (detailed in Klessa 2004; Appendix 5) are as follows.

<sup>4</sup> Corresponding dilutions using U and EC data (Table 3.1) indicate dilutions respectively of 1 in 2.6 and 1 in 2.2. Note that Cu and Ni concentrations in the cistern are probably unreliable because of possible contamination from metal fittings.

<sup>5</sup> Potable water supply pump (PWSP)

- a) Inflow of the most highly contaminated water (emanating from process water entry into the potable water main) entered the header tank on refill where it was subsequently diluted by water remaining in the header tank and by the water transferred from the day tank.
- b) Water in the main between the day tank and header tank was temporarily replaced with water from the day tank via the potable water supply pump.
- c) When the potable water supply pump was not operating, continuous outflow took place from the header tank along the main in response to steady demand by the demineralisation plant and leakage to the Jabiru East water storage tank. Process water was picked up by this stream where it entered the main.
- d) When the potable water supply pump was not operating and the volume of the water contained in the day tank was within operating limits (Klessa 2004), a similar composition of water described in (c) was fed into the day tank.
- e) Pick-up of water for the shower circuit from the day tank meant that it reflected progressive changes in the bulk composition of the day tank.
- f) Dilution of contaminated water in the day tank occurred each time the bore pump replenished the tank.

In turn, the following inferences can be made.

- Contaminant concentration in the main potable water pipe was at its worst when potable water demand was met from the header tank. This was simply because of its small volume and the relatively larger effect of process water ingress on the composition of the bulk solution compared to the day tank.
- It is likely that the quality of potable water feed to the Grinding Room and Mill Lab facilities became worse after the second demineralised train was shut down around 03.00–03.30 on March 24<sup>rd</sup> because less flushing of the main took place after this time.
- The variation in the concentration of contaminants in water delivered to the demineralisation plant and the Jabiru East potable water tank is complex but best described in terms of contaminant plugs. In other words, within the pipes delivering water to these points there were 'plugs' of poorer quality water interspersed with better quality water. Hence the quality of water extracted from a potable source during the incident (and assuming that all residual, unaffected water had already been evacuated) depended on the temporal juxtaposition of these plugs at the time within the delivery system.
- The concentration of contaminants in the header tank probably reached near steady state over the duration of the incident as a consequence of the regular emptying and filling of around 25% of the capacity of the tank. Hence the worst case for drinking water which may have been consumed on site, other than the grinding and mill Lab areas, would have been the composition of header tank water just prior to the warning issued at 08.10h (March 24<sup>th</sup>) to all staff that they should not use the potable water supply.

### **9.1.2 Estimating process water influx to the potable water system during the incident**

The connection of process water to potable water resulted in a pressure differential of 300 kPa in favour of the flow of process water into the potable supply line. Additionally, the rate of process water influx was probably also influenced by Venturi effects brought about by time variation in potable water usage and hence flow rate. However, evidence suggests the use of potable water during the period of contamination by process water over operational and non-operational periods for the demineralisation plant was relatively constant. Hence,

variation in the rate of process water import caused by a change in Venturi effects was probably minor compared to the maintenance of gross pressure differences between the process water and potable water systems.

An estimate of the volume of process water that entered the potable water system can be made by accounting for the fact that process water flow to the fine ore bin scrubber must have been maintained at  $\geq 2 \text{ m}^3/\text{h}$  because had it fallen below this threshold, the conveyor would have tripped. Since the low flow alarm is set by flows into the scrubber of  $\leq 2.5 \text{ m}^3/\text{h}$ , the process water flow into the potable water system must have been in the range  $0.5\text{--}2.0 \text{ m}^3/\text{h}$ , given a maximum feed rate to the scrubber of  $4.0 \text{ m}^3/\text{h}$ . This in turn implies that between 5 and  $21 \text{ m}^3$  of process water entered the potable water system over the duration of the connection. However, this estimate seems low.

The levels of contamination in the Jabiru East potable water tank, the day tank and the header tank alone accounts for about 16, 3 and  $1 \text{ m}^3$  respectively. Potable water feed to the demineralisation plant and entrained process water within the supply pipes would also add to the process water inventory.

Over 12h (from approximately 19.30h on March 23<sup>rd</sup> to 07.30h the following day) at least  $1,100 \text{ m}^3$  of water was exported from the day tank.  $120 \text{ m}^3$  can be accounted for by the production of demineralised water. A small quantity of potable water was also consumed by vacuum pumps at the Power Station (36 L/min) but, with the exception of minor draw (ie normal usage) of water from the potable water system by employees, about  $1,000 \text{ m}^3$  was used elsewhere. Apart from overflow at the Jabiru East potable water tank, and excluding the possibility of other leaks, no other major consumer of potable water has been identified during this period.

An estimate of process water influx made using pressure differential suggested a flow rate of 1.72 L/s (Klessa 2004).

A test conducted to determine the overflow rate at the East Jabiru potable water Tank on April 8<sup>th</sup> 2004 showed a maximum flow rate into the tank of approximately  $18 \text{ L/s}$ <sup>6</sup>. Since the cut-off valve was not working, it is believed that the tank continued to overflow during the whole period process water entered the potable system. The figure of  $18 \text{ L/s}$  ( $18 \text{ L/s}$  containing  $1.7 \text{ L/s}$  process water) appears to be reasonable suggesting that process water was diluted in approximately a 1 in 10 ratio with potable water in the 100 mm main.

### **9.1.3 Estimating the level of contamination of the potable water system during the incident**

Details are provided in Klessa (2004).

#### **Safety showers**

The recirculating safety shower system was significantly less contaminated than the non-recirculating section of the potable water system because any contamination associated with the day tank was constantly being diluted by bore water used to replenish the tank. Using the composition of the day tank measured pre-flush<sup>7</sup>, the sulfate and manganese data imply a 1 in 230 dilution.

A sample from the day tank taken at 09.30h on March 24<sup>th</sup>, 1.5 h after the line carrying the process water was disconnected, registered an EC of  $650 \mu\text{S/cm}$ . A similar EC would have been present at 08.00h because the supply of  $17.2 \text{ L/s}$  to meet the overflow demand at

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<sup>6</sup> Personal communication (David Borries)

<sup>7</sup> ERA sample 100322 (March 24<sup>th</sup>, 12.00h)

Jabiru East would have resulted in a delivery of 93 m<sup>3</sup> of water primarily from the day tank which is equivalent to less than a 30% drop in volume (before refilling is triggered). However, taking a worst case of 30% dilution just prior to sampling implies an EC of about 800 µS/cm which, in turn, suggests around a 1 in 100 dilution of process water in potable water<sup>8</sup>.

#### Potable water serving the Grinding Building Amenities

The worst affected area of the minesite by contamination of the water supply was the line serving the grinding building amenities. Direct evidence suggests a worst case dilution of 1 in 2.

#### Potable water serving areas other than Grinding Building Amenities

Klessa's estimate of process water influx suggests a rate of 1.7 L/s. Consumption by the demineralisation plant was approximately 3 L/s and overflow at the Jabiru East potable water tank was made up of around 17 L/s of potable water. Thus, the worst case dilution during operations of the demineralisation plant was 1 in 13 and the worst case when the demineralisation plant was not operating (ie after 03.00 h on March 24<sup>th</sup>) was 1 in 11.

#### **9.1.4 Laboratory assessments – mixing of potable water with process water**

To quantify the chemical effects of contaminating potable water with process water, laboratory mixing experiments were conducted. The experiments were not intended to quantify or qualify the quality of potable water that employees may have contacted or ingested at the time of the incident. The experiments were undertaken by adding potable water to process water in various ratios as detailed by Klessa (2004) in Appendix 5. The behaviours of Mn and U were compared to Cd, Cu, Ni, Pb, Zn and Fe. The concentrations of all other metals, metalloids and non-metals that comprise the suite of elements determining water quality in accordance with the Australian Drinking Water Guidelines, were also determined.

The behaviour of metals in solution was verified using the program MINTEQA2 to predict the speciation of ions at chemical equilibrium, allowing for precipitation of permitted solids. As detailed by Klessa (2004) modelling confirmed the precipitation of Al(OH)<sub>am</sub> between pH 4.9–5.0 with a further increase in pH substantially influencing the proportion of Al remaining in solution. Of the Al remaining in solution, the dominant forms are non-hydrolysed Al<sup>3+</sup> and cation and anion sulphate complexes (ie AlSO<sub>4</sub><sup>+</sup> and Al(SO<sub>4</sub>)<sub>2</sub><sup>-</sup>). Similarly, the main forms of U in solution are non-hydrolysed UO<sub>2</sub><sup>2+</sup>, neutral and anionic sulphate species (ie UO<sub>2</sub>SO<sub>4</sub><sup>0</sup> and UO<sub>2</sub>(SO<sub>4</sub>)<sub>2</sub><sup>2-</sup>), and the product of first hydrolysis, UO<sub>2</sub>OH<sup>+</sup>. Over the pH 4.8–5.3 pH range, Mn speciation is invariant with approximately one third as MnSO<sub>4</sub><sup>0</sup> and the remainder as aqueous Mn<sup>2+</sup>. Copper, Ni and Pb in solution show a similar distribution although in the case of the latter a small proportion is present as Pb(SO<sub>4</sub>)<sub>2</sub><sup>2-</sup>. Iron is controlled by ferrihydrite precipitation which together with amorphous Al(OH)<sub>3</sub> acts a sorbing surface for heavy metals, principally Cu, Pb and U. Process water is saturated in gypsum and contains colloids of the salt. In a 1 in 10 mix, gypsum approaches saturation (saturation index = -0.6) but does not precipitate.

Additional experiments were carried out to identify the behaviour of metals in tea and coffee prepared with potable water contaminated with process water (Klessa 2004). The complexity of the chemistry of tea and coffee and the absence of quantitative analyses of their components excludes any attempt to conduct speciation modelling. However, the presence of organic complexing agents such as polyphenols and organic acids would have selectively complexed and chelated heavy metals.

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<sup>8</sup> Derived from a mixing experiment.



### 9.1.5 Health Impacts

A detailed report on the medical and health response to the incident, and assessments of health risks, has been provided by Gaunt (2004; see Appendix 8).

The potential impact to workers during the March 23<sup>rd</sup>-24<sup>th</sup> night shift was determined by exposure to contaminated water in the potable water system through three main pathways, namely:

- skin exposure through showering, leading to skin absorption as well as residual salts remaining on the skin;
- inhalation of vapour as well as eye and ear exposure; and
- oral ingestion by drinking.

Levels of metals and sulfates in samples taken from the potable water system on the morning of Wednesday 24<sup>th</sup> March were potentially irritant to both the skin and gastro-intestinal tract of some individuals. A number of people experienced minor skin irritation after showering and a few developed minor gastric upsets. In total, 28 employees and contractors reported mild physical symptoms. It is believed that all settled within the first week.

In terms of an initial health risk assessment, ERA undertook a programme of questionnaires and one-on-one confidential interviews with concerned individuals to determine the likely extent of exposure to contaminated potable water and initial physical symptoms. Details are provided in Gaunt (2004). The conclusions of initial level health risk assessments, based on preliminary analysis of contamination levels and worst case exposures, were that long term effects were unlikely but some effects from uranium (on the kidneys) and from manganese (on the nervous system) could not be confidently excluded. This information was verbally conveyed to employees and contractors.

Following on from the initial health risk assessments, a series of voluntary blood and urine tests were arranged to assess body burden/impact of uranium and manganese, for individuals with high levels of concern and/or reported exposures. In addition, advice on the appropriate tests required was given to treating physicians.

As detailed by Gaunt (2004), the majority of the results of routine clinical blood tests specifically designed to look for any effect of uranium and other metals on kidney function were within the acceptable range. One employee was referred to his family physician for further tests for a condition not thought to be related to drinking the contaminated water. The results of a specialist test of kidney function (NAG, a sensitive indicator of renal tubular damage) were not elevated and confirm the lack of an effect. All blood manganese levels were in the normal range, suggesting that there were no significant increases in the body levels of manganese in those tested.

In addition to these specific tests, full blood counts (looking for anaemia, and changes in white blood cells and platelets) and a full set of tests to check liver function were also performed (Gaunt 2004). The full blood counts were normal. Analysis of samples for eight people indicated some minor changes in liver function, not consistent with a liver disease but probably reflective of delays in getting the samples to Perth for testing. All eight were referred to their personal physician for repeat testing. The results of all blood tests undertaken to this stage have been provided to individual employees and consultants with appropriate consultation.

Given that some employees and contractors had only a brief exposure to relatively high concentrations of some metals, and that the literature reviewed for the risk assessment is generally focussed on longer term exposures, there is some residual doubt about the direct extrapolation of the conclusions and findings from the literature to the Ranger incident.

Hence, a further precautionary medical testing program for possible manganese, aluminium and uranium effects is suggested by Gaunt (2004) in order to provide additional confidence that there have been and will be no long term health effects.

Although Gaunt (2004) does not consider that any metals present in the Ranger potable water system, apart from manganese, aluminium and uranium, are of genuine concern to health, based on the observed and calculated concentrations and chemical properties within the potable water system and on a review of the available literature and relevant health standards, he notes that the chemistry of the water drunk at Ranger was complex. Thus, he considers it sensible to conduct a further detailed review of the properties of the contaminants present in the Ranger potable water system during the period of the incident and a further precautionary program of voluntary testing in respect of the possible effects of manganese, aluminium and uranium, for all those who declared any exposure to potentially contaminated water. This could involve further blood and urine analysis for kidney function and manganese levels. Additional blood and urine tests (ie repeat tests for liver function) could be conducted at the same time. In addition, an MRI scan could be conducted for those workers with higher levels of exposure for manganese and aluminium levels. However, the need for, and parameters of, such a further testing program would benefit from a review by the OSS and its independent panel of experts, and discussion with treating physicians, before being implemented.

Gaunt (2004) concludes that the investigations, research and tests conducted to date indicate that it is most unlikely there will be any long term health effects as a result of the incident. The results of a further precautionary voluntary testing program could provide even greater certainty of no risk to the long term health of employees and contractors exposed to contaminated water during March 23<sup>rd</sup>-24<sup>th</sup>.

### **9.1.6 Environmental impacts**

No impacts on the environment at the Ranger minesite, or on surrounding areas, have been identified as a result of this incident.

## **9.2 Jabiru East**

### **9.2.1 Environmental issues**

Jones *et al.* (2004; see Appendix 6) investigated the environmental impacts of contamination of the potable water supply at Jabiru East by process water. The specific context of the study related to the overflow of the Jabiru East potable water tank located at the southeastern edge of the airport caused by a low set-point on the pressure valve and the potential for contamination of the local environment and adjacent Coonjimba Creek and Magela Creek. Water discharged from an overflow pipe flowed along a formed earthen drain for a distance of about 200m. After leaving the drain the water fanned out into a broad swampy area several hundred metres on length before entering Magela Creek downstream of Coonjimba Billabong.

The three key issues addressed in the investigation were:

- estimating the equivalent volume of process water that may have escaped from the storage tank during the time window when the connection was made between process water and potable water in the plant, and when overflow from the storage tank at Jabiru East ceased;
- determining the extent of influence on downstream surface water as a result of the overflow of diluted process water from the storage tank; and

- determining the extent of impact on soils and sediments downstream of the storage tank in the context of background soil levels of uranium and whether there is a need to undertake remediation of effected areas.

Field surveys of water and soil quality in the drainage line between the discharge point at the storage tank and Magela Creek were complemented by a mixing model developed to provide an initial estimate of the volume of process water that may have discharged. A water quality survey carried out along the flow line between the tank and Magela Creek indicates at least a 10-fold attenuation of uranium along the flow path, consistent with the known adsorptive properties of surface soils in the area and the effectiveness of uranium removal in wetland filters. Water quality measurements made in Magela Creek by OSS at the downstream compliance site on March 24<sup>th</sup> and on several days thereafter indicated no detectable impact, with EC, Mn and U remaining below their respective focus levels.

Apart from a slightly elevated level of uranium in the surface soil immediately downstream of the tank, all other soil concentrations between the source and the creek line (at a spatial separation of 50m between each sampling point) were within the background range for soils in the local area.

Jones *et al.* (2004) concluded that whilst there was a small release of diluted process water, there was sufficient attenuation capacity in the soils between the tank and the creek line to adsorb the uranium before it reached the creek. The low measured concentrations of uranium in the soil, including locations immediately downstream of the tank, indicate that no remediation of soil is required.

### **9.2.2 Potable water contamination**

The pipeline to Jabiru East passes adjacent to a storage tank located at the south east edge of the airport. There is a valve assembly at this location that isolates the pipeline from the tank (which was used as one of the original water supply tanks for the town of Jabiru East). However, the valve assembly was leaking at the time of the incident, allowing a proportion of water from the line to flow under pressure into the tank. Consequently the tank was able to be filled from the pipeline.

The first water samples were taken on Wednesday March 24<sup>th</sup> between 10.00h and 11.30h from sites associated with the Jabiru East potable water tank, the OSS field station potable water tank, and the Gagadju workshop (Table 1 in Jones 2004, see Appendix 7). The pipeline to Jabiru East was isolated at 08.00h that morning as part of the system shutdown on the Ranger site.

The composition of the samples from the OSS field station potable water tank and the Gagadju potable water tank were, except for Al, Cu and Zn, essentially identical to that of the Brockman borefield water, indicating no contamination with process water. Zn and Cu are ubiquitous contaminants in reticulation systems and the levels of Cu and Zn in the two tanks are directly comparable with the values reported for the Ranger reticulated system (which show a higher concentration than the water as extracted from the Brockman borefield, B84\_3: Jones 2004, Table 1: see Appendix 7). The slightly higher level of Mn in the OSS field station tank relative to Brockman borefield water could be the result of dissolution from materials of construction. The slightly greater concentration of Al in the Gagadju workshop tank is a likely consequence of the zincalume construction of this tank.

Thus the initial sampling indicates that the front of process water contamination had not reached the Gagadju or OSS field station header tanks on the morning of March 24<sup>th</sup>.

In contrast, the water data from the sites in the vicinity of the Jabiru East potable tank (JPWT) clearly indicates that the front of diluted process water had reached this location. The Jabiru East hydrant represents the composition of the incoming water. At 10.15h on March 24<sup>th</sup>, when the first suite of water samples was collected for chemical analysis, the EC was



1,256  $\mu\text{S}/\text{cm}$ . The contents of the tank and the overflow stream were also sampled at this time, and the compositions show a clear indication of low-level contamination by process water (Jones 2004, Table 1).

Based on the above data it can be concluded that Jabiru East storage tank was contaminated with process water as a result of the leaking valve providing a pressure relief in the pipeline. It was likely that the front of contaminated water had also progressed further along the pipeline towards the airport and OSS offices. The extent of this movement was likely to be limited by the lack of draw on the system during the night. In order to limit the further progress of water down the line, and to remove the head of contaminated water in the emergency potable water storage tank, a recovery program was initiated at 1400h on March 24<sup>th</sup>.

The recovery program (detailed in Jones 2004) involved the following steps.

- 1) The Jabiru East storage tank was emptied by pumping back to site and then partly filled with clean water from the Magela potable water bore field.
- 2) The supply pipelines at Jabiru East were drained back to the sump near the Jabiru East storage tank, with the water being recovered and transported back to site.
- 3) The Ranger fire truck was used to backflush the lines from the Gagadju workshop and the OSS field station header tank, with the backflush water being collected in the storage tank at Jabiru East.
- 4) The Jabiru East storage tank was emptied again by pumping back to site.
- 5) The Jabiru East storage tank was flushed once more with clean water from Magela borefield, with the contents of the tank being pumped back to site.
- 6) All potable water outlets tagged out of service pending clearance.

The potable water line to Jabiru east was re-pressurised on March 31<sup>st</sup> with two hydrants at the extremities of the lines and all accessible taps flushed and tested for pH and EC, and sampled for full water quality analysis.

The flushing, field testing and sampling for water quality analysis were repeated on April 1<sup>st</sup> and 2<sup>nd</sup>. Full details of the flushing and water sampling protocols are provided by Jones (2004). All samples were screened for 37 chemical attributes including anions and metals to demonstrate that the potable water system complied with Australian standards.

Based on the length and dimensions of the pipelines it is estimated that 5-10 pipe volumes of clean water were flushed through known contaminated lines; and 2-4 pipeline volumes were flushed through potentially contaminated lines. The objective of the flushing and testing program was to restore water quality to all outlets in Jabiru East.

## 10 RE-STATEMENT OF WATER SUPPLY

ERA demonstrated that the potable water system at Ranger Mine meets the Australian Drinking Water Guidelines for inorganic, microbiological and radiological components and accordingly received approval on April 6<sup>th</sup> to re-commence milling activities at the mine.

The results from consecutive daily samples taken from points throughout the Jabiru East potable water system indicate that it also clearly met the applicable guideline values for relevant analytes. However, additional testwork was undertaken following consultation with the NT Department of Health. In the meantime, although water for industrial purposes had been approved for supply to Jabiru East, bottled water was provided for drinking. The data resulting from the additional testwork (summarised in Appendix 9) show that three consecutive measurements (obtained during May) of microbiological and key inorganic parameters (including uranium) indicative of process water at five key locations at Jabiru East (Tourist Centre, Café, NA Helicopters, Gagadju workshop, OSS field station building) meet the Australian drinking water guidelines. The data for free chlorine residuals measured

on June 3 (Appendix 9; Table 4) are consistent with the guideline recommendations for small water supplies ("a free chlorine residual of between 0.2 and 0.5 mg/L is adequate"). Accordingly, approval was given for re-instatement of the potable water supply at Jabiru East on June 11<sup>th</sup>.

ERA has undertaken to make improvements to its water systems to prevent a similar incident in the future, as detailed elsewhere in this report. However, if a new potable water source is commissioned for Jabiru East, a separate monitoring program will be implemented with the range of inorganic, microbiological and radiological parameters included as per the current requirements for potable water testing under the Ranger Authorisation.

## 11 CONCLUSIONS

Significant and prompt action was taken by ERA in response to contamination of the potable water system by process water at Ranger Mine during the night shift of March 23<sup>rd</sup> and 24<sup>th</sup>. Extensive consultation with regulators, stakeholders, employees and contractors was undertaken and a number of detailed investigations carried out in relation to the particular components of the plant that were involved and the events leading up to and during the incident.

The root causes of the incident were identified as part of a workshop facilitated by an external consultant. Contributing factors were also delineated. Although the person or persons who made the connection between the process water and potable water lines has not been identified, ERA believes that it has taken all necessary steps to ensure that an operator or operators will not be able to make such a connection in future. There is no evidence to suggest that an incident such as that of March 23<sup>rd</sup> has ever occurred previously.

The health of employees and contractors who came into contact with, or ingested, contaminated water has been of primary concern to ERA. Comprehensive steps were taken to ensure that individuals were counselled by medical experts and tests were undertaken to ensure that potential health impacts were diagnosed. Expert medical and toxicological advice at this time is that it is most unlikely that there will be any long term health effects. ERA will consider a program of further medical testing to increase the certainty of no risk to the long term health of employees and contractors exposed to the contaminated water during March 23<sup>rd</sup> and 24<sup>th</sup>.

No environmental impacts of the incident were identified.

ERA has detailed a number of commitments to regulators and stakeholders to ensure that such an incident cannot happen again.

# FIGURES & PLATES

**Figure 1:** Site location satellite image (April 3<sup>rd</sup>, 2004)

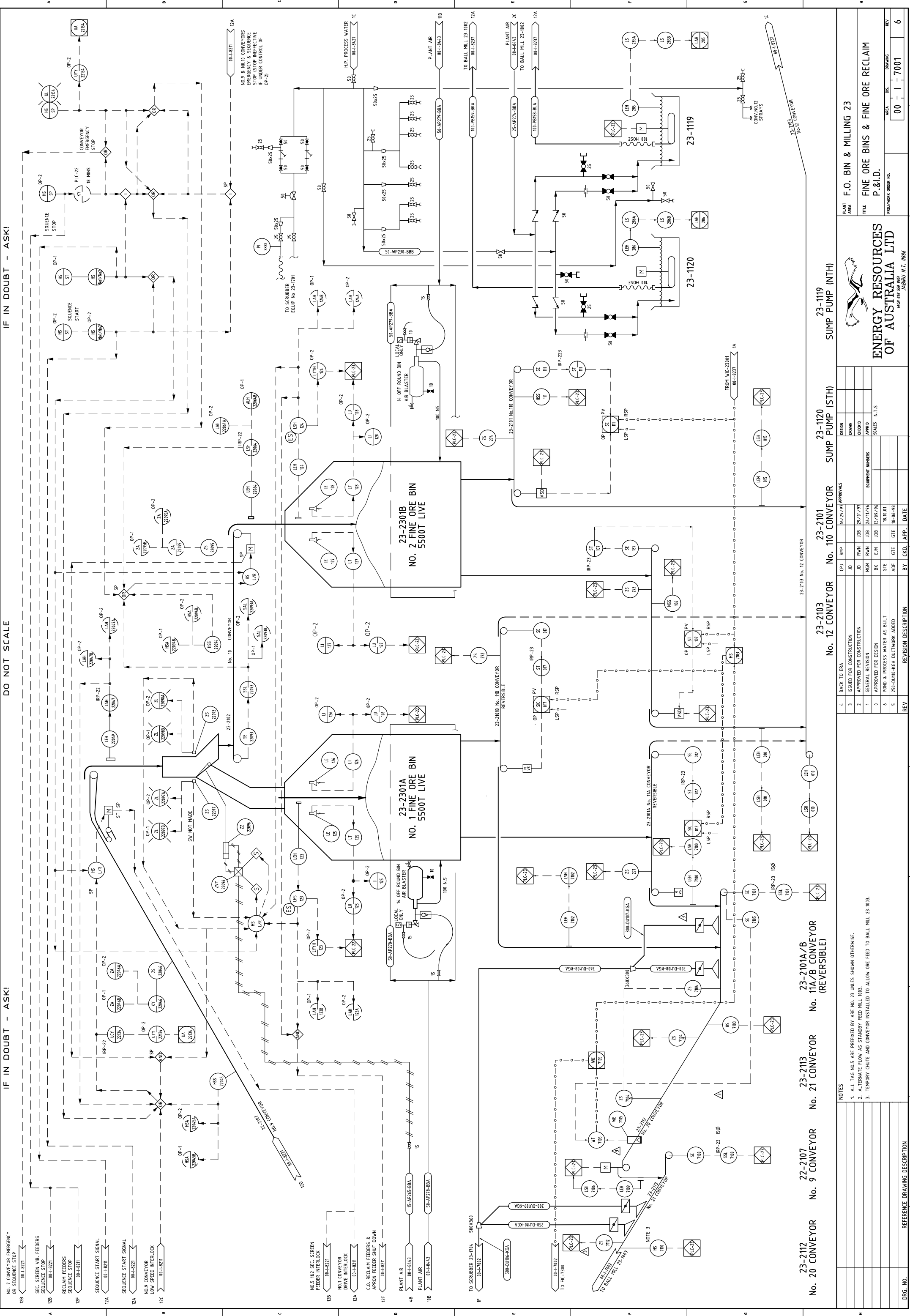




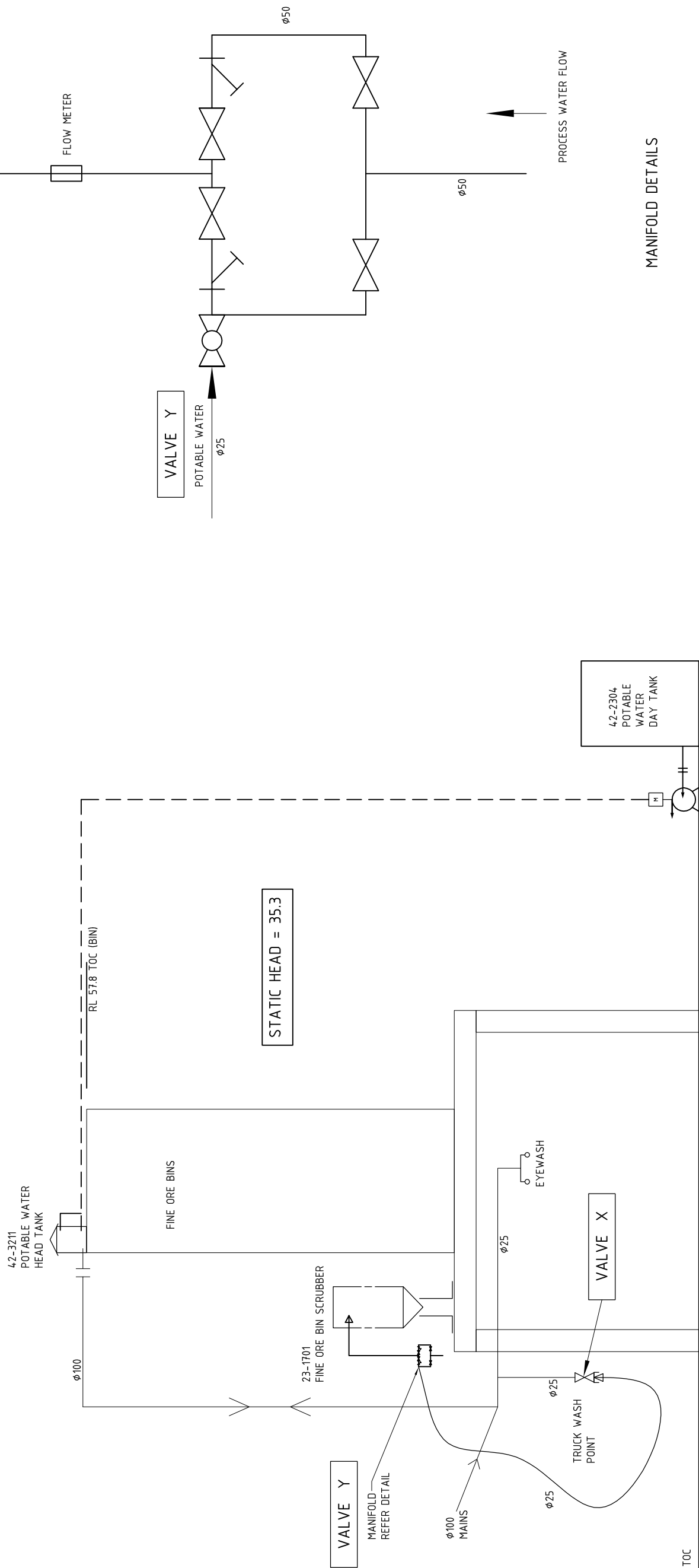
IF IN DOUBT - ASK!

DO NOT SCALE

IF IN DOUBT - ASK!



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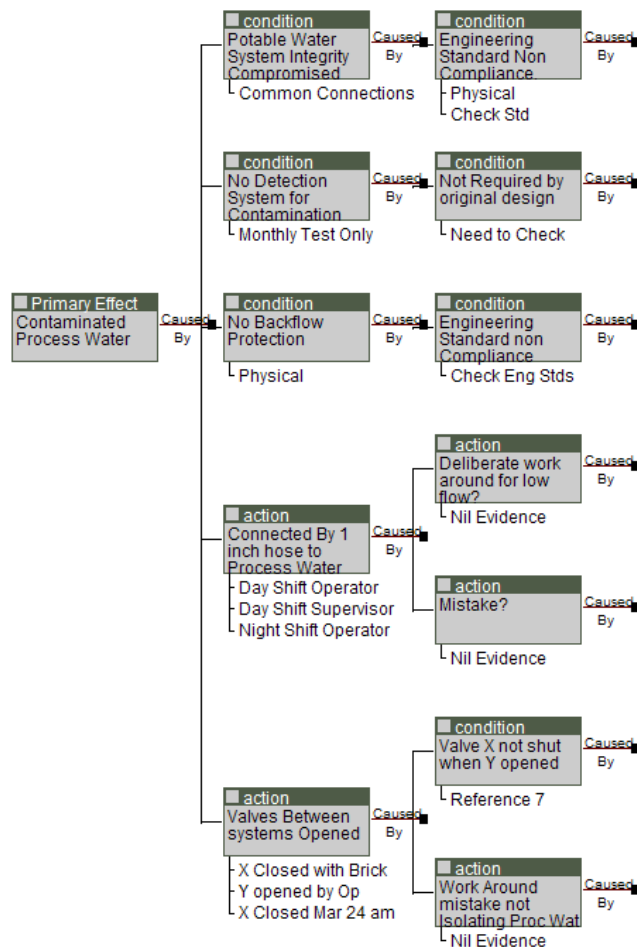
NOT TO BE USED FOR CONSTRUCTION PURPOSES

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**Figure 5: Root Cause Analysis – simplified chart**

Page 1 of 1



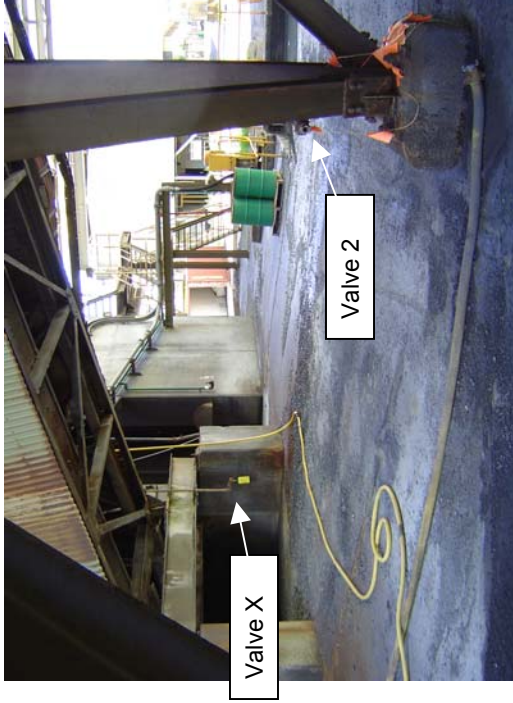
#### References:

1. Hose was reported by Day shift Operator and Day shift Supervisor to be connected between Valve X and Y on afternoon of March 23.
2. Night Shift Operator (Mar 23) stated hose was in place ever since he started 5 weeks ago.
3. Day shift operator was seen by Supervisor hitting Valve with Brick and said he was trying to close it (implies it was open) on afternoon of Mar 23.
4. Day shift operator straight to valve and closed it on morning of March 24.
5. Night Shift Operator said he opened Valve X evening March 23.
6. Hose connections compatible with Process Water.
7. Handle missing and hard to tell what position it is in i.e. open or closed position.



# PLATES

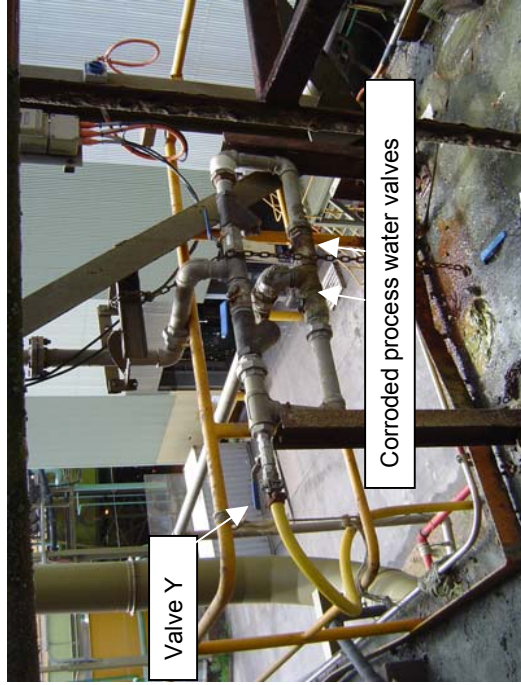
Potable water Valve (x) Connection area  
**Photograph 1**



Nearby Process Water Connection  
**Photograph 2**



Water Supply manifold to Scrubbers  
**Photograph 3**



Potable water valve  
**Photograph 4**



## PLATES (continued)

1" hose hanging from scrubber manifold  
**Photograph 5**



Removed potable water valve  
**Photograph 6**





## PLATES (continued)

Overflow Jabiru East Water Tank  
**Photograph 7**



Booster Pumps – Faulty Valve shown on right  
**Photograph 8**



## PLATES (continued)

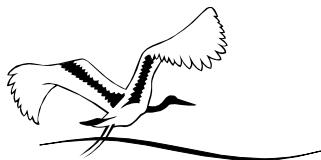
1" flattened hose when discharging  
**Photograph 10**



# APPENDICES

## **APPENDIX 1:**

### **Return to Work Strategy for Ranger Mine, 30 March 2004.**

**ERA****Energy Resources of Australia Ltd**

ABN 71 008 550 865

## **Return to Work Strategy for Ranger Mine, 30 March 2004**

Following the contamination of potable water supply at Ranger on 23 March 2004, all potable water outlets were isolated and non-essential staff sent home. This document details the process through which staff will be returned to work. The broader question of the start-up of uranium production activities will be addressed separately.

In order to return to work, ERA has taken steps to ensure that:

- 1 The source of the contamination has been found
- 2 The source of the contamination has been removed
- 3 Facilities and services (in particular potable water supply) are restored
- 4 Further safeguards have been built into the system

### **1 CONTAMINATION SOURCE**

The source of the contamination has been traced back to a potable water line being connected to the process water system via a hose between 8:00 and 9:00 pm on 23 March 2004.

### **2 REMOVAL OF SOURCE OF CONTAMINATION**

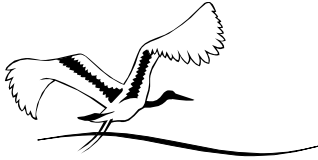
The potable water hose, which was connected to the process water system, was disconnected around 8:00 am on 24 March 2004 and the connector removed from the potable water line. All commonly used drinking outlets were immediately tagged "out of service", and all non-essential personnel were requested to leave the site.

### **3 RESTORATION OF FACILITIES AND SERVICES**

The potable water system has been drained, flushed, partially refilled, drained again, and then continuously flushed for several days. An opportunity has also been taken to remove a build-up of sediment from the bottom of the main potable water storage tank.

All tagged potable water outlets were initially tested for electrical conductivity and pH as an indicator of the presence of process water. An electrical conductivity of less than 450 uScm and pH >7.3 were used as the criteria. Following flushing, every outlet tested has been able to meet these criteria.

A systematic process of chemical analysis of potable water has followed. A full suite of analyses against the drinking water standard have been tested, including uranium, manganese, magnesium, sulphate and ammonia. Samples were drawn from 152 locations throughout the potable water system.



The chemical analyses indicate that potable water has returned to drinking water standards in all areas of the site that have been tested. The chemical analysis demonstrates that clean water is entering the system, and clean water is being dispensed at outlets from the system.

During the extensive testing programme, a number of hot water urns and cold water bubblers were not able to meet the standard and were disposed of. All of these outlets have now been physically disconnected and removed.

Drinking water outlets will remain tagged "out of service" and will only be released for drinking water use once two consecutive results at drinking water standard have been received for that outlet, or group of outlets. All drinking water outlets have returned at least one result to drinking water standard and ERA will be able to release outlets for use as results are returned from the lab over the next week. Even if an employee were to ignore an "out of service" tag and drink from a tagged outlet, we can be confident that there is no risk to the health of the employee, based on the extensive flushing and testing conducted.

It is proposed that employees return to work on their normal rosters from 7pm Tuesday 30<sup>th</sup> March.

The mining area potable water circuit is on a separate branch to the main system. This circuit has been fully flushed, though to date no chemical analyses have been received. No employees will be allowed to use the mining offices until a similar level of confidence has been achieved in the drinking water quality in that area.

#### **4 FURTHER ACTION**

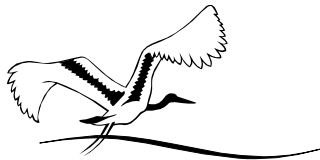
A full incident investigation has commenced and will result in medium and long-term actions to prevent recurrence.

Immediate action has been taken to identify any possible connection points and crossovers from the potable water system to any other system. Action has been taken to eliminate the possibility of any inadvertent connection to the potable water system.



## **APPENDIX 2:**

### **Proposal to Re-commence Milling Activities at Ranger on Tuesday April 6<sup>th</sup>.**



ERA

## Energy Resources of Australia Ltd - Ranger Mine

ABN 71 008 550 865

Tuesday April 6, 2004.

Mr Tony McGill  
Department of Business, Industry and Resource Development  
GPO Box 3000  
DARWIN N T 0801

Dr Arthur Johnston  
Supervising Scientist  
Department of the Environment and Heritage  
GPO Box 461  
DARWIN N T 0801

### **Proposal to Re-commence Milling Activities at Ranger on Tuesday April 6<sup>th</sup>**

#### ***Context***

On the morning of Wednesday March 24<sup>th</sup> ERA staff at Ranger Mine discovered contamination of the potable water supply as a result of an erroneous connection made between process water and potable water. The potable water system was immediately closed down, an orderly shutdown of the mine was completed and non-essential staff were sent home. Once regulators and stakeholders were notified, a number of investigations were commenced immediately by ERA.

The Supervising Authority (NTDBIRD) and the Office of the Supervising Scientist also fielded teams to conduct independent investigations.

Our employees returned to the Ranger site for maintenance purposes on Wednesday March 30<sup>th</sup> under the conditions stipulated in Dr Johnston's letter to you dated 30<sup>th</sup> March 2004, namely that:

- all parts of the potable water system were flushed and water samples analysed to demonstrate that they met EC and pH targets;
- drinking water outlets remained tagged "out of service" and will only be released for drinking water use (although the water may be used for other purposes such as washing and emergency showers) once two consecutive results indicate that the water meets the drinking water guidelines; and
- clean potable water (commercial bottled drinking water) was made available on site until the potable water supply was cleared for human consumption.

#### ***Maintenance Works and Reclaim of Potable Water System***

Maintenance works were focussed on the continued checking and analysis of all outlets in the potable water system to demonstrate the effectiveness of the flushing process and the re-attainment of drinking water quality.

Figure 1 shows the location of all potable water outlets (numbered) at Ranger. Table 1 lists the water quality data ERA has obtained for water samples from potable water outlets.

Chemical analyses of large numbers of water samples were conducted on filtered samples to provide relative rapid screening of water quality in samples taken over time after draining and flushing of the potable water system at the Ranger minesite and Jabiru East. Comparative analyses were made of Brockman borefield water and Magela Creek water. Almost 300 samples were screened for 37 chemical attributes including anions and metals to demonstrate that the potable water system complied with Australian Drinking water standards.

Figures 2 –9 are time series plots of key attribute and analyte concentrations (see first sheet in attached Excel workbook for the source data) and show the progressive attainment of potable water quality. Those outlets that exceed required analyte concentrations remain tagged until two successive samples return appropriate data. Sampling and analysis of key outlets is continuing.

Figure 10 shows U concentration data for potable water outlets in the Administration area and shows progressive attainment of potable water (Brockman borefield) quality with one specific outlet ('Geology men's sink 2' highlighted).

The rapid analysis technique (analysis of filtered samples) used to screen water samples from all outlets provides a good indication of the composition of reclaimed Ranger potable water in terms of both source water (Brockman borefield) and Australian drinking water guideline values. This strategy has been used to provide rapid guidance to ERA in the management of the cleanup operation to ensure that there are no impacts on the health of employees.

### ***Re-commencement of Mining***

Mining operations were able to re-commence at Ranger at night-shift on March 31<sup>st</sup> under the conditions set out for the resumption of maintenance operations on the approval of the Supervising Authority and the Office of the Supervising Scientist.

### ***Proposal to Re-commence Milling Operations***

Arthur Johnston's letter to me dated 31<sup>st</sup> March 2004, with an attached copy of his letter to you of the same date, set out the conditions under which he would support the re-commencement of milling activities at Ranger. These specific aspects are addressed below.

1. ERA has demonstrated that the potable water system at Ranger Mine meets the Australian Drinking Water Guidelines.

- a. ***Trend to compliance with Australian Drinking Water Quality Guidelines:***

At least two consecutive daily samples taken from representative points throughout the potable water system indicated on Figures 1 and 2 have been analysed and the data are summarised in the attached Excel workbook together with the applicable Australian Drinking Water Guidelines values. Totals concentration data have now been obtained for a range of samples for which filterable values were previously available (see sheet 2 in attached Excel workbook). The totals data show no significant difference to the filtered values, thus addressing a key concern in Dr Johnston's letter.

The screening level criterion for potable water outlets has been set at 15 µg/L U (which is conservatively less than the 20 µg/L value in the drinking water quality guidelines). Those outlets that return a value a greater than or equal to 15 µg/L will remain tagged out of service until two consecutive reading of less than 15 µg/L are returned.

**b. *Specific Inorganic Analytes***

Specific questions were asked about a range of inorganic analytes that appear in the Australian Drinking Water Guidelines. These are addressed below in the context of relevance to the Ranger site.

Cyanide is not used on site so cyanide in water is not a risk factor in this instance. Fluoride has recently been measured in process water (see attached analysis report by AMDEL) and found to be less than 0.1 mg/L which is the instrument detection limit. Iodine has now been reported as part of the ICPMS suite. Nitrite is not of relevance for the current situation since nitrite can only be formed, and persist in significant concentrations, under anoxic conditions – and the potable water system at Ranger is not anoxic.

Nitrate will be produced by the nitrification of ammonia in pit water. Owing to the acidic pH in process water, nitrification would be greatly suppressed (the optimum pH for nitrification is around pH 7-8). The concentration of NO<sub>3</sub> was measured in process water on 24/10/2001 and found to be 6.4 mg/L NO<sub>3</sub>. Current levels would be expected to be of a similar, if not lower value, under the prevailing pH regime.

**c. *Organic Compounds***

A restricted range of organic compounds is used as part of the U extraction process. It is these compounds that are of potential relevance in the current context rather than the full range of organic chemicals listed in the Australian Water Quality Guidelines. The compounds comprise flocculating agents (Magnaflow 5000 - used at low dose rates in the thickeners), Shellsol (the bulk kerosene-like carrier phase used in solvent extraction), and tertiary amine (the ion-pairing reagent used in solvent extraction of the uranyl ion).

The role of the flocculating reagent is to agglomerate particles of ground ore by adhering to their surfaces and modifying the surface properties. Hence the solution phase concentration of these high molecular molecules will be very low, and they will report with the tailings particles to the pit, being permanently incorporated into the tailings mass. Given that the product is of very low toxicity (ChemAlert Database) with an oral LD<sub>50</sub> in rats of greater than 2000 mg/kg, the risk of significant human exposure through ingestion under the current circumstances is negligible.

The most significant source of organics to Ranger Process water comes from the solvent extraction (SX) circuit in the form of entrained organic in raffinate. Raffinate is the barren liquor left after the U is stripped from the clarified pregnant leach liquor. Excess raffinate is bled from the SX circuit into the tailings neutralisation tank. Raffinate contains microdroplets of organic phase entrained from the bulk organic phase in the solvent extraction tanks.

The organic medium in the SX circuit comprises the bulk organic solvent phase (Shellsol 2046 – a type of kerosene) in which is dissolved approximately 3% by weight of long chain (C8-C10) tertiary amines. The protonated tertiary amine forms a neutral ion triplet with the uranyl ion and sulfate. It is this neutral complex that is extracted into the organic phase on the initial acidic adsorption part of the solvent extraction circuit.

A very small amount of the organic/amine phase becomes entrained as microdroplets in the aqueous phase, which is bled from the system. Periodic measurements of entrained organic are made to track solvent and amine loss from the system. This loss is monitored since the solvent and amine inventory comprise a considerable proportion of the cost for consumables used in the U process circuit.

The maximum concentration of entrained organic that has been measured is around 35-40 mg/L in the raffinate. In 2003 approximately 100,000 m<sup>3</sup> of raffinate was bled from the SX circuit into the tailings neutralisation tank. This volume was mixed with a total of approximately 1,400,000 m<sup>3</sup> of tailings slurry from the leach circuit,

representing a direct dilution of approximately 14 times. Thus organic (primarily hydrocarbon) concentration in the tailings supernatant reporting to the pit is estimated to be around 3 mg/L (on average). This figure does not take into account further attenuation by adsorption of the organics on to the tailings particles. Once in the pit further degradation of trace organics would occur by microbial action..

The indicative very low concentration of organics in undiluted process water implies an extremely low risk pathway for human ingestion under the current condition where the known contaminated potable water lines have been flushed with 5-10 volumes of clean water.

Samples of process water, Brockman borefield water, and samples of water from potable water outlets were collected on Sunday April 4 for analysis at the AGAL laboratories in Sydney. These samples have now been analysed for Total Petroleum Hydrocarbons and BTEX. All samples returned non-detectable values (see attached photocopy of AGAL report), indicating that there is negligible risk to human health from the perspective of organics in the flushed potable water supply. Indeed the results for process water itself confirm very low concentrations of relevant organics and indicate negligible risk from this source (ie organic component of process water) on the Wednesday morning when the contamination was detected.

d. **Microbiological data:**

Two representative samples from the potable water system (sample location PW and MC058, Figure 1) were submitted for microbiological analysis (total coliform, *E. coli* and faecal *Streptococci*) on Tuesday 30<sup>th</sup> April and have returned nil count results (sheet 3 in the attached Excel workbook) that are consistent with drinking water guidelines.

e. **Radiological Analysis**

A radiological analysis of a representative sample of potable water from location ECW (Figure 1) has been analysed for Thorium activity by *eriss* and the results are consistent with drinking water guidelines. Additional analyses of gross- $\alpha$  and gross- $\beta$  are in progress, as required by the Ranger Authorisation.

2. Prior to the potable water contamination incident, ERA had in place an on-going program of review of the condition of the process water system and a comprehensive upgrade plan. Since the incident, ERA has re-examined the review and upgrade plan and taken specific steps to make improvements that will prevent a similar incident in the future. ERA's commitments are detailed in the attached document "*Risk Review of Process Water System*".
3. ERA will install a conductivity meter in a strategic location within the potable water system to continuously measure electrical conductivity and provide warning of any potential contamination. The conductivity meter will be connected to an alarm system. Efforts are being made to expedite the implementation of the meter, including the airfreight of parts from Melbourne and Adelaide. The unit is expected to be installed and operational by April 16<sup>th</sup>. In the interim, ERA proposes to manually analyse pH and conductivity on a representative sample of potable water on a four hourly basis until the conductivity meter is installed.

Based on the additional information supplied above, ERA requests written permission to re-commence milling operations.

Yours sincerely

Simon Prebble  
General Manager Operations  
Ranger Mine

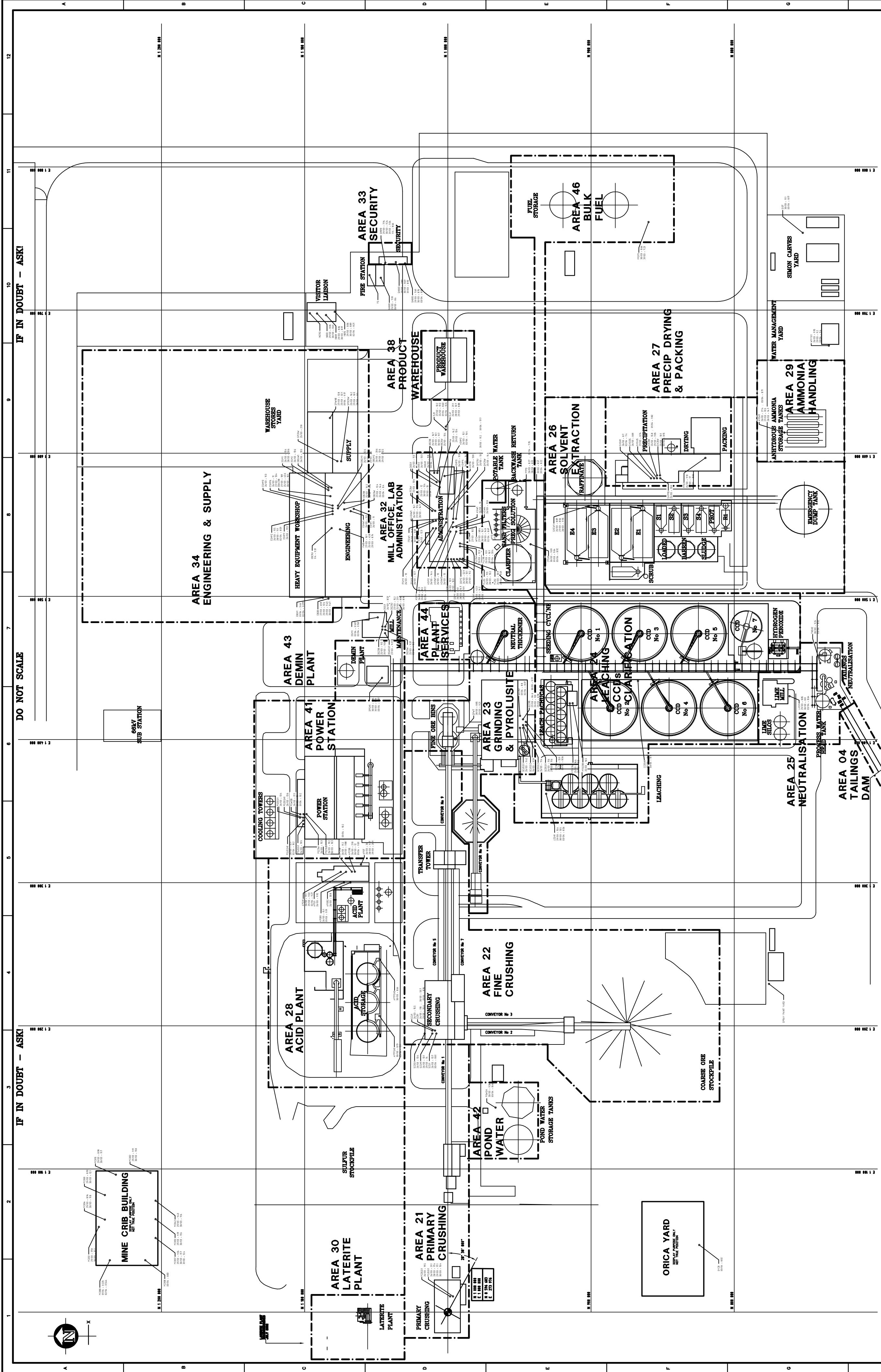
*Attachments to this document:*

- *Figures showing location of all potable water system outlets at Ranger Mine*
- *Graphs of potable water chemistry showing progressive cleanup by draining and flushing*
- *Copy of Amdel analysis report for process water (collected 10/03/04) showing data for fluoride*
- *Copy of relevant sheets from AGAL report on organics in water samples collected on 4/04/04*
- *Risk Review of Process Water System*

*Electronic Files:*

- *Excel workbook containing water quality data, comparison of filtered and total values, and microbiological screening results.*

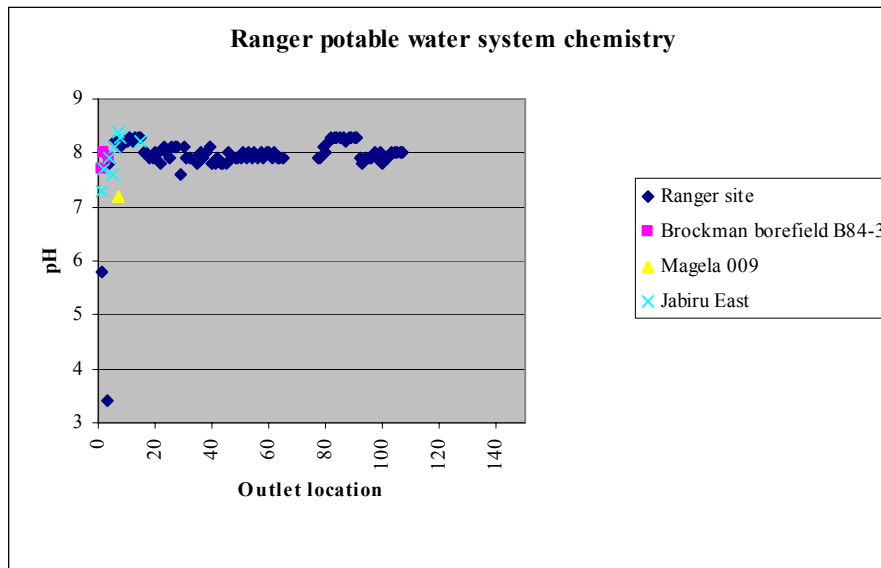
**Figure 1:** Maps showing potable water outlet locations at Ranger Mine and Jabiru East



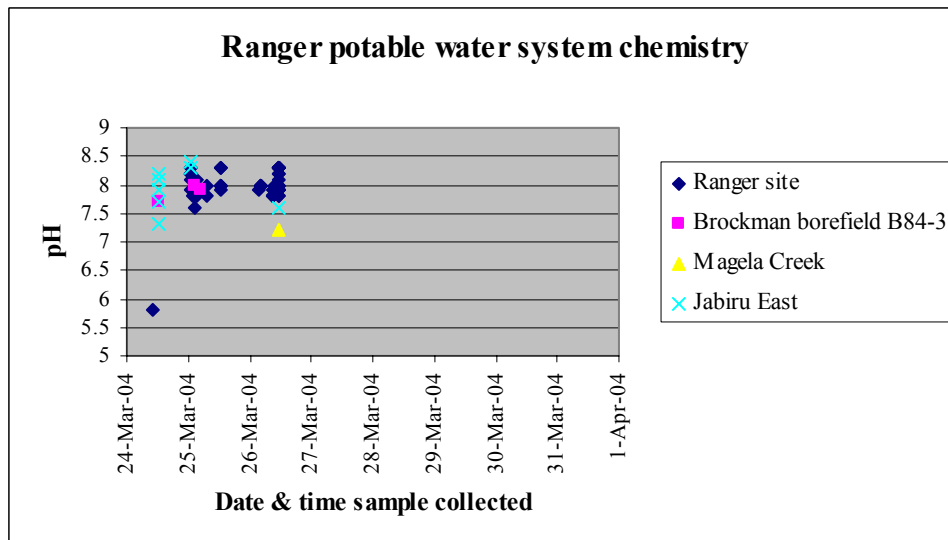
NOTES										1. GRID SHOWN IS ERA RANGER PLANT GRID										PLANT AREA										AREA 20 OTP GENERAL									



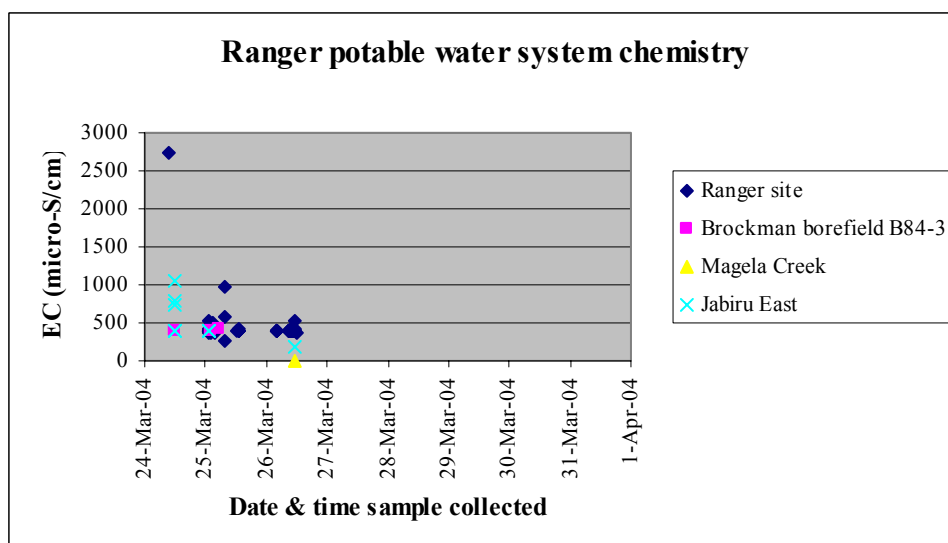




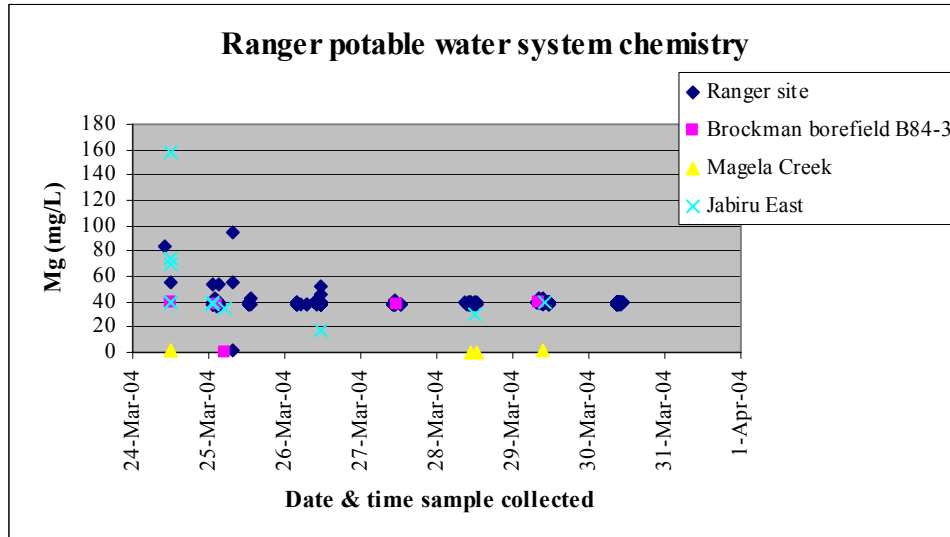
**Figure 2:** Range of pH values for samples collected from various locations. Low values reflect samples collected during immediately after flushing.



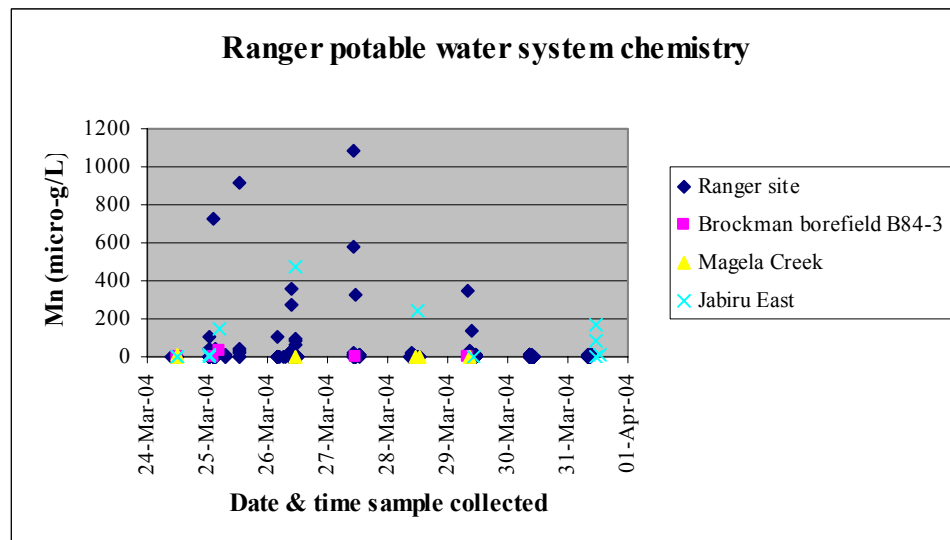
**Figure 3:** pH values for samples collected from various locations in time.



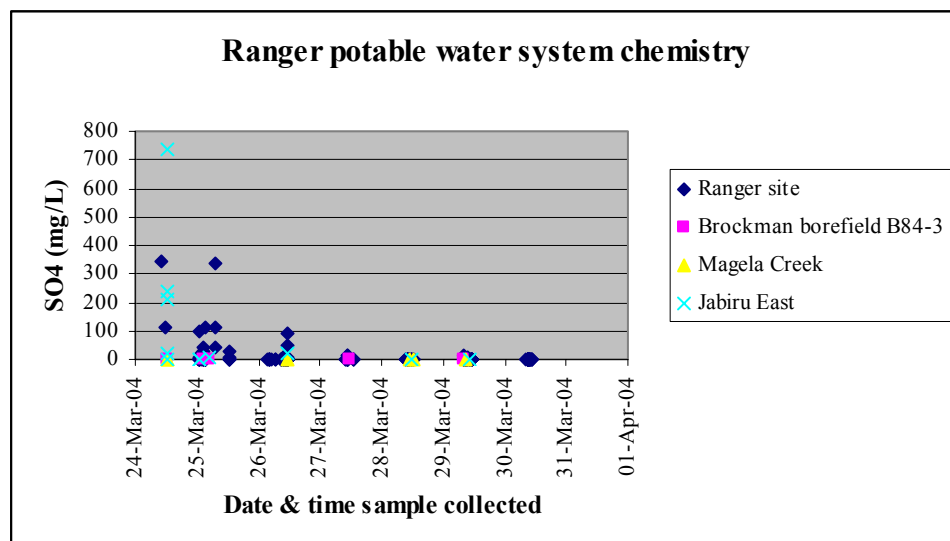
**Figure 4:** EC values for samples collected from various locations in time.



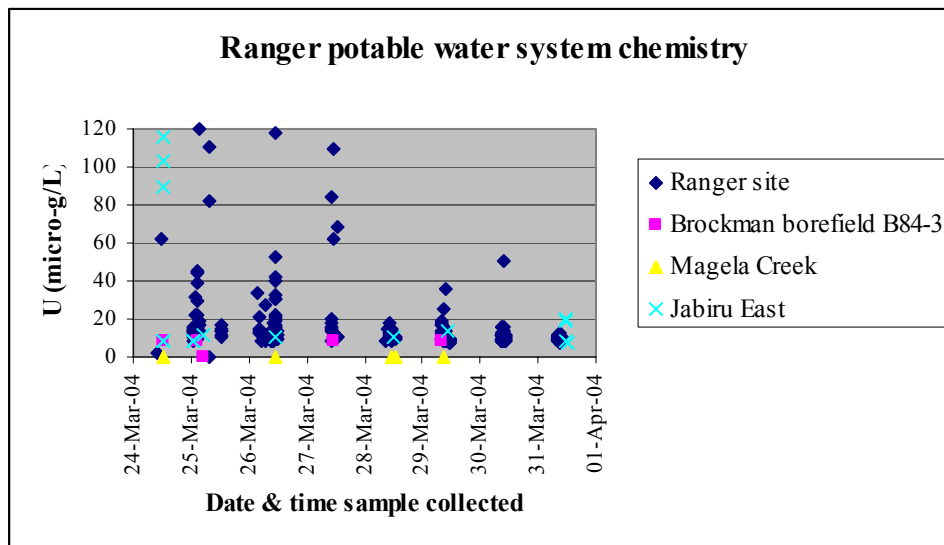
**Figure 5:** Mg concentrations for samples collected from various locations in time.



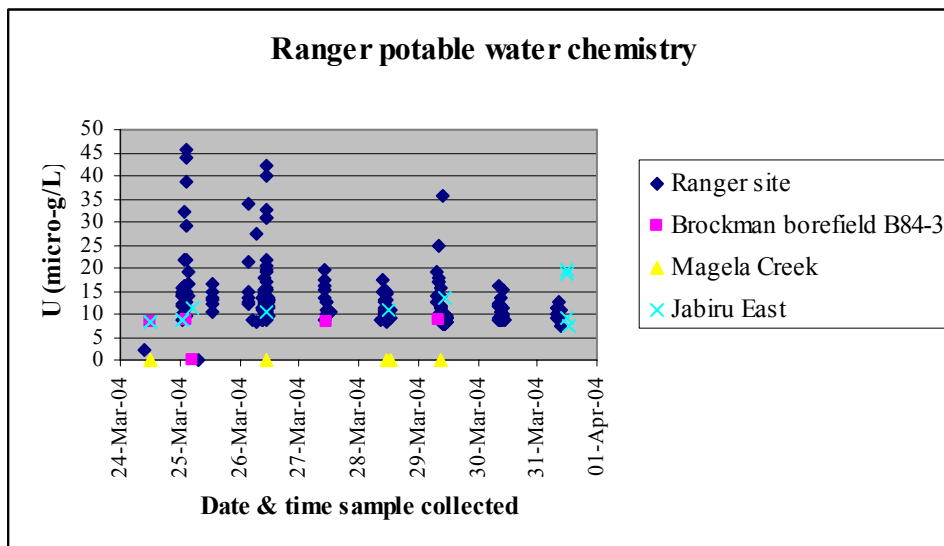
**Figure 6:** Mn concentrations for samples collected from various locations in time. Note that Drinking Water Guideline value for Mn is 500µgm/L



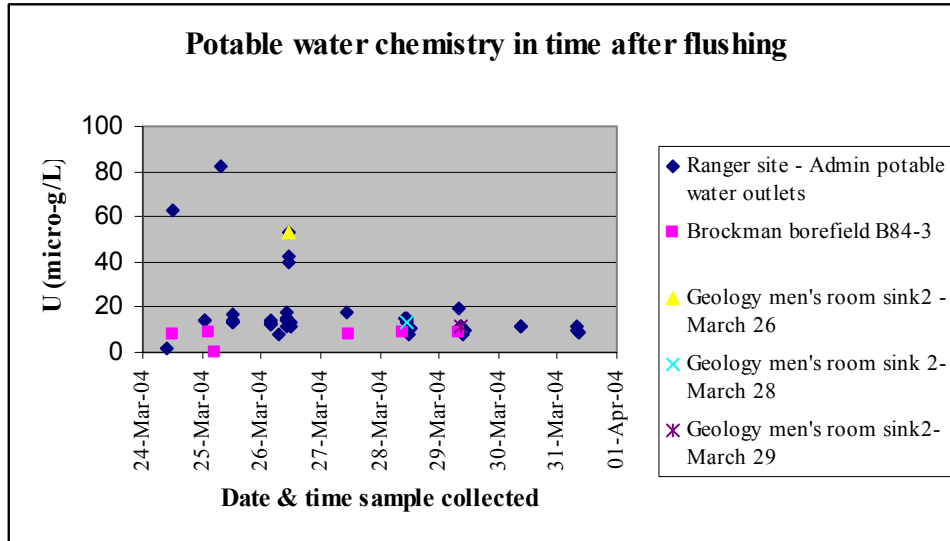
**Figure 7:** SO<sub>4</sub> concentrations for samples collected from various locations in time. Note that Drinking Water Guideline value for SO<sub>4</sub> is 500mg/L



**Figure 8:**  $U_4$  concentrations for samples collected from various locations in time. Note that Drinking Water Guideline value for U is  $20\mu\text{g/L}$



**Figure 9:** U concentrations for samples collected from various locations in time with expanded concentration scale. Note Drinking Water Guideline value of  $20\mu\text{g/L}$ . Locations with U concentrations above  $15\mu\text{g/L}$  remain tagged out until repeated analyses indicate appropriate levels have been attained.



**Figure 10:** U concentrations for samples collected from various locations in time from the Administration area at the Ranger minesite showing progressive return to potable water (Brockman borefield) composition. (Drinking Water Guideline value of 20µg/L U.) Note decline in U concentration of 'Geology men's room sink 2' as a specific example.

**ANALYTICAL SERVICES DIVISION**

ABN 30 008 127 802

Correspondence to:

PO Box 331

HUNTER REGIONAL MAIL

CENTRE NSW 2310

99 Mitchell Rd

CARDIFF NSW 2285

Telephone: (02) 4902 4800

Facsimile: (02) 4902 4899

**CERTIFICATE OF ANALYSIS**

**Contents :**

1. Cover Pages (2)
2. Analysis Report Pages
3. QA/QC Appendix
4. Additional Reports - External  
(if applicable)
5. Chain of Custody (if applicable)

**Report No.** : 4E0513

**Attention** : Ms Nicole Jacobsen

**Client** : EWL Sciences Pty Ltd  
: PO Box 39443  
: WINNELLIE NT 0821

**Samples** : 1

**Reference/Order** : E040359.AR

**Project** : ERA RANGER MINE

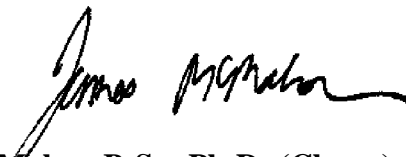
**Received Samples** : 19/03/04 **Instructions** : 19/03/04

**Date Reported** : 01/04/04

PLEASE SEE FOLLOWING PAGES FOR METHOD LISTING AND RESULTS

**RESULTS**

All samples were analysed as received. This report relates specifically to the samples as received. Results relate to the source material only to the extent that the samples as supplied are truly representative of the sample source. This report replaces any preliminary results issued. Note that for methods indicated with "\*", NATA accreditation does not cover the performance of this service. Three significant figures (or 2 for < 10PQL) are reported for statistical purposes only. Where "Total" concentrations are reported for organic suites of compounds this is the summation of the individual compounds and the PQL is noted for reporting purposes only. This report has been authorized by NATA signatories for PDF format. Refer to the method descriptions for further information.



**James McMahon B.Sc.,Ph.D. (Chem.)**  
**Manager - Environmental**



**Report No.** : 4E0513

**Please note:** Where samples are collected/submitted over several days, the date on which the last samples were analysed or extracted is reported.

Unless Ferrous Iron is determined on site, the possibility of a ferrous-ferric ratio change may occur.

<u>Method</u>	<u>Description</u>	<u>Extracted</u>	<u>Analysed</u>	<u>Authorised</u>
E2330	Ammonia as N	30/03/04	30/03/04	MCM 101
E4810	Dissolved Metals by ICP-AES	25/03/04	25/03/04	DLU 093
E4870	Dissolved Metals by ICP-MS	25/03/04	25/03/04	DLU 093
E2720	Sulphate	26/03/04	26/03/04	MCM 101
E2380	Chloride	24/03/04	24/03/04	MCM 101
E2500	Fluoride	23/03/04	23/03/04	MCM 101

**NATA Signatory**

<u>Initials</u>	<u>Name</u>	<u>Sections/Methods</u>
MCM	James McMahon	093, 094, 095, 101
MNG	Minh Nguyen	094, 095
MFA	Mark Fahmy	094
LHA	Ly Kim Ha	095
DJA	Dilanthi Jayamanne	094
GTO	Greg Towers	094
DLU	Darrel Luck	093



Job Number : 4E0513

Client : EWL Sciences Pty Ltd

Reference : E040359.AR

Project : ERA RANGER MINE

Page 1 of 1  
plus Cover Page

Analyte	Lab No	E71234				
		PROCESS				
	Sample Id	WATER				
	PQL					
E2330 Ammonia as N in Water						
Ammonia as N	0.01	889				
E4810 Dissolved Metals in Waters						
Aluminium	0.05	224				
Calcium	0.1	520				
Potassium	0.1	130				
Magnesium	0.1	3700				
Manganese	0.05	1980				
Sodium	0.2	50				
Silicon	1.0	nd				
E4870 Dissolved Metals in Waters						
Cobalt	0.001	1.89				
Copper	0.001	3.15				
Nickel	0.001	3.75				
Lead	0.001	0.458				
Uranium	0.001	4.78				
Zinc	0.002	4.66				
LITHIUM	0.002	1.85				
E2720 Sulphate in Water						
Sulphate	1	24000				
E2380 Chloride in Water						
Chloride	1	45				
E2500 Fluoride in Water						
Fluoride	0.1	nd				

PQL = Practical Quantitation Limit

LNR = Samples Listed not Received

nd = < PQL

-- = Not Applicable

Refer to Amdel standard laboratory qualifier codes for comments.

Soils : mg/kg (ppm) dry weight unless otherwise specified

Waters : mg/L (ppm) unless otherwise specified in Method Header

Leachates : mg/L (ppm) in leachate unless otherwise specified in Method Header





**Australian Government**

**Department of Industry, Tourism and Resources**

# REPORT OF ANALYSIS

Page: 1 of 2

Report No. RN419837

<b>Client</b> : ERA RANGER MINE ENVIRONMENTAL OPERATIONS LOCKED BAG 1 JABIRU NT 0886	<b>Job No.</b> : ERAE01/040405 <b>Quote No.</b> : QT-00782 <b>Order No.</b> : 79572 <b>Date Sampled</b> : <b>Date Received</b> : 5-APR-2004 <b>Sampled By</b> : CLIENT
<b>Attention</b> : JOHN MILSOM <b>Project Name</b> : <b>Your Client Services Manager</b> : BRIAN WOODWARD	<b>Phone</b> : (02) 94490151

Lab Reg No.	Sample Ref	Sample Description
N04/011655	100849	WATER PRW
N04/011628	100850	WATER JEO35
N04/011629	100851	WATER MLCRW
N04/011630	100852	WATER MLCRW

Lab Reg No.		N04/011655	N04/011628	N04/011629	N04/011630	
Sample Reference	Units	100849	100850	100851	100852	Method
<b>BTEX</b>						
Benzene	ug/L	<1.0	<1.0	<1.0	<1.0	NGCMS_1121
Toluene	ug/L	<1.0	<1.0	<1.0	<1.0	NGCMS_1121
Ethyl Benzene	ug/L	<1.0	<1.0	<1.0	<1.0	NGCMS_1121
m,p-Xylene	ug/L	<2.0	<2.0	<2.0	<2.0	NGCMS_1121
o-Xylene	ug/L	<1.0	<1.0	<1.0	<1.0	NGCMS_1121
<b>Total Petroleum Hydrocarbons</b>						
TPH C6 - C9	ug/L	<25	<25	<25	<25	NGCMS_1121
TPH C10 - C14	ug/L	<25	<25	<25	<25	NGCMS_1112
TPH C15 - C28	ug/L	<100	<100	<100	<100	NGCMS_1112
TPH C29 - C36	ug/L	<100	<100	<100	<100	NGCMS_1112
<b>Surrogate</b>						
Surrogate volatile Rec	%	99	101	100	105	
<b>Dates</b>						
Date extracted		5-APR-2004	5-APR-2004	5-APR-2004	5-APR-2004	
Date analysed		5-APR-2004	5-APR-2004	5-APR-2004	5-APR-2004	

  
 Danny Slee, Section Manager  
 Organics - NSW, (Accreditation No: 198)

6-APR-2004



**Australian Government**

**Department of Industry, Tourism and Resources**

# REPORT OF ANALYSIS

Page: 1 of 1

Report No. RN4 9838

<b>Client</b>	ERA RANGER MINE ENVIRONMENTAL OPERATIONS LOCKED BAG 1 JABIRU NT 0886	<b>Job No.</b>	ERAE01/040405
<b>Attention</b>	JOHN MILSOM	<b>Quote No.</b>	QT-00782
<b>Project Name</b>		<b>Order No.</b>	79572
<b>Your Client Services Manager</b>	BRIAN WOODWARD	<b>Date Sampled</b>	
		<b>Date Received</b>	5-APR-2004
		<b>Sampled By</b>	CLIENT
		<b>Phone</b>	(02) 94490151

Lab Reg No.	Sample Ref	Sample Description
N04/011631	100853	WATER BS4_3
N04/011632	100854	WATER EBCRW
N04/011633		WATER TRIP BLANK

Lab Reg No.		N04/011631	N04/011632	N04/011633	
Sample Reference	Units	100853	100854		Method
<b>Total Petroleum Hydrocarbons</b>					
TPH C8 - C9	ug/L	<25	<15	<25	NGCMS 1121
TPH C10 - C14	ug/L	<25	<15	<25	NGCMS 1112
TPH C15 - C28	ug/L	<100	<100	<100	NGCMS 1112
TPH C29 - C36	ug/L	<100	<100	<100	NGCMS 1112
<b>Surrogate</b>					
Surrogate volatile Rec	%	111	107	112	
<b>Dates</b>					
Date extracted		5-APR-2004	5-APR-2004	5-APR-2004	
Date analyzed		5-APR-2004	5-APR-2004	5-APR-2004	

*[Signature]*  
 Danny Slee, Section Manager  
 Organics - NSW, (Accreditation No: 198)

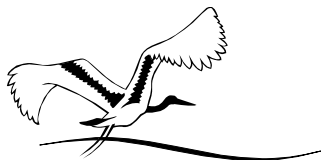
6-APR-2004



This Laboratory is accredited by the National Association of Testing Authorities, Australia.  
 The tests reported herein have been performed in accordance with its scope of accreditation.  
 This Report shall not be reproduced except in full.

NATA Accredited Laboratory  
 Number: 198

Sample/s analysed as received.

**ERA****Energy Resources of Australia Ltd**

ACN 008 550 865

## Risk Review of Process Water System

An upgrade of the Process Water System at Ranger has been in progress as follow-on to recommendations of the Supervising Scientist following the tailings water leak incident in 2000<sup>1</sup>. The initial upgrade work focussed on the tailings dam corridor components of the system (Recommendations 1, 2 & 10). Continuing upgrades were incorporated into ERA's Annual Plan in September 2003 and approved in concept in November 2003. This included installing replacement pipe work for all unserviceable process water piping in the Mill area.

### Work done to date

Following completion of works on process water systems in the tailings corridor, including most recently the installation of a high-density polyethylene (HDPE) process water pipeline from tailings to the process water head tank, an upgrade of the process water piping in the Mill commenced in 2003 namely:

- (a) Replacement of the discharge nozzle and immediate spools from the process water head tank in stainless steel. The pipe work preceding this up until the booster pumps have been replaced in 355 mm poly pipe;
- (b) Replacement of several offshoots from the header pipe through the plant with HDPE pipe in critical areas such as Grinding and CCD's; and
- (c) Preparation for replacement of the three carbon steel process water headers and associated distribution pipe work along the CCD corridor. In addition, Simon Engineering and SKM have been working with ERA to:
  - Survey the process water system;
  - Update the P & ID's, plans, elevations and isometrics;
  - Scope the project; and
  - Order materials (ongoing).

### Planned Process Water Work

The next stage of the process water update program, which is contained in the capital budget for 2004, is planned to commence on 6<sup>th</sup> May during a planned plant shutdown of approximately twelve days. This involves replacing the three carbon steel process water headers and associated distribution pipework along the CCD corridor.

The three headers (DN200, DN150 and DN100) are the main feed line for the plant distributing water for the process, gland flushing, and washing systems. The current mild steel pipes will be replaced with HDPE pipe PE-80 type "B" PN-10 rating, which has a high

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<sup>1</sup> Supervising Scientist (2000) Investigation of tailings water leak at the Ranger uranium mine.  
Supervising Scientist Report 153. (Supervising Scientist, Darwin)

chemical resistance. The branch connections for DN80 and less will be replaced with seamless 316L stainless steel pipe to minimise corrosion issues. .

The headers need to be tied into the existing infrastructure during the planned complete plant shutdown. Owing to the lead-time on some material, replacement of all the planned pipework is estimated to take approximately 4 months. The project is planned for completion by the end of August 2004. Details are set out in the ERA "*Stage 2 PW and RW replacement schedule*".

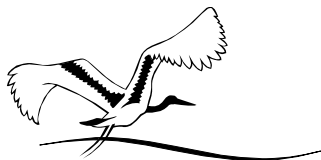
### **Risk Assessment and Mitigating Strategies**

A risk review was carried out on the process water system within the plant. Until the planned upgrade is completed, the following actions will put in place

1. The site water management training modules will be reviewed and updated in reference to the water incident by 12<sup>th</sup> April 2004
2. Further training/updates for all relevant personnel on site water management systems will be completed by the end of April 2004. Priority will be given to the mill and maintenance personnel.
3. Procedures for authorising water type changes, bypassing or making changes to water pipe work will be implemented by 5<sup>th</sup> April 2004. Until this system is implemented, all water type changes will be prohibited without the permission of the General Manager Operations.
4. Process water pipe work outside of bunded areas will be inspected and upgraded to HDPE or stainless steel, or removed if redundant, by the end of July 2004.
5. Water pipes throughout the Ranger minesite site will be inspected to ensure they are appropriately labelled and coloured by the end of July 2004.
6. The colour code for process and pond water will be reviewed by 12<sup>th</sup> April 2004.
7. The segregation of the process and potable water systems will be reviewed to ensure that unauthorised inter-connection cannot be made by 2<sup>nd</sup> April 2004.
8. The fine ore bin scrubber will be refurbished during the planned May shutdown.

## **APPENDIX 3:**

### **Preliminary Report – Process Water Incident Investigation.**

**ERA****Energy Resources of Australia Ltd**

ABN 71 008 550 865

## Preliminary Report – Potable Water Incident Investigation

This report represents the status of investigations as at 6<sup>th</sup> April 2004. The investigation is continuing.

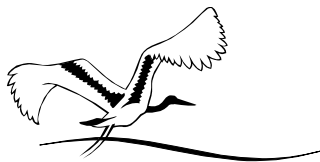
### 1 INCIDENT SUMMARY

On the evening of March 23<sup>rd</sup> 2004, a low flow alarm was indicated on the Distributed Control System (DCS) from the Fine Ore Bin (FOB) Scrubber #1. This scrubber ventilates the conveyor transfer points feeding the Rod Mill and removes particulates from the air prior to discharging into the atmosphere. The scrubbers utilise water in a venturi to drop particulates out. As per regulations, the conveyors feeding the mill are interlocked to the water flow. If flow drops below a set level, then an alarm is activated on the DCS. If water flow reduces further, then the conveyors are tripped.

In an apparent attempt to increase water flow, an operator opened a valve on a flexible hose connected to the process water feed line to the scrubber on the second floor level. The operator was unaware that the other end of the hose was connected to a potable water outlet on the ground level of the facility. It is thought that owing to higher pressure in the process water line relative to the potable water line, process water back flowed through the potable line and into the main potable water storage tank. This tank then distributes water throughout the site for drinking, showering, washing, and toilets.

There were several reports on the morning of the 24<sup>th</sup> March by employees coming off night shift and employees coming on day shift that the water tasted 'off' and of feeling itchy after showering. Samples of water from the showers and drinking water taps were immediately collected in response to these complaints, and just prior to the time of shutdown of the potable water supplies, were analysed to find elevated EC (up to 5,900  $\mu\text{S}/\text{cm}$ ), low pH (4.5) and up to 8,000 parts per billion Uranium compared with approximately 7 parts per billion in the potable water supply from Brockman borefield. Employees were progressively sent home from 8.30am and shutdown of processing commenced at 9am.

The Ranger potable water system feeds water to the Jabiru East potable water storage tank, which is the northernmost of two tanks located at the eastern end of the airport (this storage tank feeds the local businesses in the area including the airport and eriss). This tank regularly overflowed into a constructed drain, which directs overflow water towards the north and east into Coonjimba Creek near its confluence with Magela Creek, downstream from Coonjimba Billabong. Following discovery of contamination on the mine site in the potable water system, the Jabiru East tank was inspected, found to be overflowing and isolated at 8.45am. Businesses were notified of the problem at 9.15am. Samples of input water to the tank were collected from a fire hydrant at the adjacent core shed and overflow water at the sump immediately adjacent to the tank.



## 2 TIMING OF EVENTS AND ACTIONS TAKEN

Below is a summary of the timing of significant events and remedial action that took place immediately following the incident:

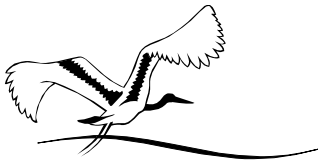
### 23<sup>rd</sup> March

Evening Connection made between potable water line and FOB Scrubber

### 24<sup>th</sup> March

7.00am First report of poor water from employee commencing day shift.  
7.20am Water samples collected from laboratory and tested for chlorine by laboratory staff  
7.50am Results of analysis of water samples by (Mill Laboratory staff) showing pH 4.5, EC 5,900  $\mu\text{S}/\text{cm}$  and U 8ppm.  
8.00am Investigation by Shift Supervisor found hose from potable water connected to scrubber system – inlet valve to scrubber was turned off. Hose disconnected from potable line into scrubber circuit by Process Operator.  
Immediate action followed to identify any possible connection points and crossovers from the potable water system to any other system.  
8.10am Notification over Gai phone sent out by Engineering Superintendent advising personnel not to drink water  
8.15am Placement of 'Out of Service' tags on all potable water outlets commenced by Maintenance personnel  
8.22am E-mail sent to all employees by Processing Assistant notifying them not to drink water  
8.30am Mine employees and non-critical employees were sent home and kept informed through daily communication updates in Jabiru by the Ranger Management team. Bottled water was made available to employees on site. Portable toilets and bottled water were organised for the Jabiru East Community.  
8.45am Water to Jabiru East isolated by the technical officer turning off the valve at the distribution manifold near RP2  
9.00am Plant shutdown commenced pending the return of suitable potable water and clearance from the regulators.  
9.15am Jabiru East notified by Manager Environment Health Safety of problems with potable water and that the East Jabiru storage tank and supply has been shutdown.  
9.30am Isolation Valves at Jabiru East storage tank turned off by Technical Officer  
9.41am OSS (Alex Zapantis) rang Manager Environment Health Safety enquiring about the incident. A brief overview was given.  
9.45am DBIRD (T McGill) notified of incident by General Manager Operations  
9.55am A Johnson (OSS) updated about incident by General Manager Operations  
10.05am NLC (B Lewis) notified of incident by General Manager Operations  
10.15am Disaster Management Recovery declared by General Manager Operations indicating the situation was substantial and could affect the integrity of the operation. Crisis Management Team formed headed by General Manager Operations.  
11.05am Samples taken from eriss water tank, MG009 and MCUS.  
11.36am ITR (A Laird) in Canberra notified by Manager Environment, OH&S  
Afternoon Flushing of the potable water system on minesite and at Jabiru East commenced to remove unacceptable level of contaminants.

### 25<sup>th</sup> March and following



A systematic process of chemical analysis of potable water has followed. A full suite of analyses against the Australian Drinking Water Guidelines have been conducted, including uranium, manganese, magnesium, sulphate and ammonia. Samples have been drawn from 188 locations throughout the potable water system. All potable water outlets have been tagged 'out of service' until water quality is suitably proven. Representative samples of potable water have also been taken and analysed for microbiological, organic and radiological content.

On the 25<sup>th</sup> March it was recognised that the overflow from the Jabiru East potable water supply tank had contained a component of process water and DBIRD, OSS and NLC were notified.

Water and soil sampling were undertaken downstream from the Jabiru East potable water tank to evaluate the fate of contaminants and potential environmental impacts.

A review and risk assessment was undertaken on the process water system with mitigating strategies recommended as included below.

### **3 IMPACTS ON HEALTH AND ENVIRONMENT**

#### **3.1 Health**

There have been twenty-four cases in which personnel have reported some symptoms. Attached is a schedule entitled Effects Analysis, summarising reported symptoms and exposures as at Monday 5<sup>th</sup> April.

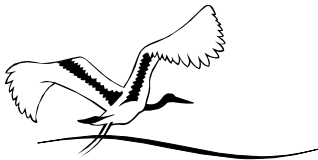
Calculations of the radiological dose based on ingesting two litres of the poorest quality contaminated water measured on the morning of March 24 immediately prior to disconnection of the water supply has given a conservative estimate of approximately 100 micro sieverts. The toxicology effects from the contaminants in the water are being investigated in detail but as yet are uncertain. The advice ERA has received to date indicates the exposure is not expected to cause long term adverse consequences.

ERA employees, contractors and members of the public working at Jabiru East have been offered the opportunity to undertake urine and blood sampling to indicate any excess trace metals that may be in people's systems as a result of digesting process water. To date some 29 people have given samples and these samples are currently being processed. ERA has also obtained the services of Dr Richard Gaunt, Chief Occupational Health Physician with Rio Tinto, to assist with the evaluation and to provide information to employees, stakeholders and members of the public.

#### **3.2 Environment**

Field investigations including sampling of waters and soils downstream of the Jabiru East overflow was undertaken by ERA and OSS. An evaluation of the results shows that there has not been any detrimental environmental effect on the downstream environments. Monitoring of water quality at the principal compliance site at 009 has demonstrated that there has not been any departure from expected water quality and that the waterways of Kakadu remain protected.

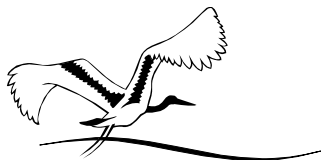




## 4 COMMITMENTS

A full investigation is being conducted from which further actions may be recommended. This is being done against the background of progressive implementation of process water upgrade work commissioned in December 2003, the next stage of which is due to be implemented during and following a planned plant shutdown on 6 May 2004. In the short term, the following actions are being implemented.

- (a) Identify any connection points and crossovers from the potable water system to any other system. Ensure that actions are taken to eliminate the possibility of inadvertent connection to the potable water system. Complete.
- (b) Remove all quick-connect fittings such as minsup connections from potable water lines unless absolutely necessary. If there is a demonstrable necessity to retain such connections, a different type of fitting will be used. Complete.
- (c) Review procedures for authorising water type changes, bypassing or changes to the water pipe work. Complete - new 'water work permit' installed.
- (d) Install a potable water monitoring system including online conductivity and pH to provide early warning of contamination – 16<sup>th</sup> April 2004.
- (e) Until item (d) is addressed, a manual monitoring program has been implemented in which a representative sample of potable water is tested for pH and conductivity on a four hourly basis.
- (f) A risk analysis of the potable water system will be undertaken – End of April 2004
- (g) Risk analyses of the process water and pond water systems will be undertaken – End of April 2004
- (h) The site water training modules will be reviewed and updated in reference to the water incident. – 16<sup>th</sup> April 2004
- (i) Further training / updates for all relevant personnel on site water management systems – End of April
- (j) A review of the potable water system will be carried out with a view to reducing the number of branches. Back flow valves with appropriate maintenance regimes will be considered at key junctions to further protect the potable water system – End of April 2004
- (k) The proposed program of works listed as Stage 2 Process Water Pipe Replacement will be implemented – complete by end of August 2004
- (l) Process water pipework outside of bunded areas will be inspected and upgraded to HDPE or stainless steel, or removed if redundant. – End of July
- (m) Water pipes throughout the site will be inspected to ensure they are appropriately labelled and coloured - End of July



## SCHEDULE - EFFECTS ANALYSIS

### Codes used

Consumption of potable water on night shift of 23<sup>rd</sup> and dayshift of 24<sup>th</sup> March up to turning water off.

High	More than 2.0 litres
Medium	Between 500 ml and 1.99litres
Low	Less than 499 ml and/or showering
O	No water consumed, brought water onto site or not on site.
?	Uncertain about exposure

### Symptoms

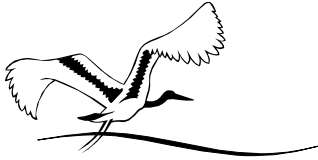
SA	Symptoms Acute: typical of acute irritation from drinking water – now settled.
SC	Symptoms Chronic: typical (initially) of acute irritation from drinking water that are continuing – even if changing character.
SU	Symptoms Uncertain: that are not typical in type or time relationship to drinking the water.

All these results are based on the information available to Richard Gaunt at 16h00 on Monday 5<sup>th</sup> April.

	Number of people <u>not</u> reporting symptoms	Number of people reporting symptoms	SA	SC	SU
<b>High</b>	9	10	7	3	0
<b>Medium</b>	27	9	8	0	1
<b>Low</b>	55	4	4	0	0
<b>O</b>	93	1	0	0	1
<b>?</b>	10	0	0	0	0
<b>TOTAL</b>	194	<b>24</b>	19	3	2

## **APPENDIX 4:**

### **Proposal to Return Water Supply to Jabiru East for Industrial Purposes.**

**ERA****Energy Resources of Australia Ltd - Ranger Mine**

ABN 71 008 550 865

Thursday April 22 2004

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### **Proposal to Return Water Supply to Jabiru East for Industrial Purposes**

Further to our discussions today, ERA proposes to reinstate water supply from the Brockman borefield at Ranger to Jabiru East for industrial purposes. This would include, but not be limited to, the following uses:

- Toilets.
- Garden sprinklers.
- Equipment washing facilities.

The water would not be for drinking purposes until we have clearance from the relevant authorities.

The reinstatement would be subject to the following conditions:

- Drinking water outlets will remain locked out of service.
- Outlets available for industrial use will be clearly marked "Not Drinking Water", together with a standard graphical symbol.
- An ERA representative will communicate with each Jabiru East business to explain the conditions before water supply is made available.
- Bottled water will continue to be available for drinking purposes.

In the unlikely event that these controls fail, and a person drinks water from a Jabiru East outlet, the extensive water quality data for Jabiru East gives confidence that there would be no risk to that person's health.

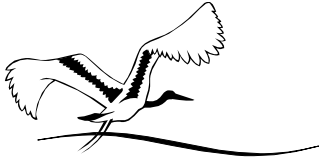
ERA requests that written approval be given to reinstate water supply to Jabiru East as outlined above.

Yours sincerely

**Simon Prebble**  
**General Manager Operations**

## **APPENDIX 5:**

**Klessa (2004) Investigation Report - Contamination of the Potable Water Supply by Process Water at Ranger Mine, March 2004.**



**ERA**

**Energy Resources of Australia Ltd**

ABN 71 008 550 865

## **Investigation Report**

# **Contamination of the potable water supply by process water at Ranger Mine, March 2004**

**Author: D A Klessa**

May 2004

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*A member of the Rio Tinto Group*

## 1 EXECUTIVE SUMMARY

This report deals with three aspects of the incident that occurred overnight on 23 March 2004 when process water entered the potable water system which supplies Ranger mine and Jabiru East. First, an analytical account is provided of the manner in which process water mixed and dispersed with potable water within the tanks and pipelines which constitute the potable water system. This is especially important for understanding how contaminants were distributed within the system over time and, as such, is a prerequisite to risk assessment. Second, consideration is given to the chemistry of the mixing of process and potable waters since this could have affected the bioavailabilities of contaminants and also determine aspects of risk assessment. Third, the remediation measures which were taken to reinstate the potable water supply to Ranger and Jabiru East are documented together with the analytical results of a sampling program to verify that water quality objectives had been achieved.

### Distribution of process water in the potable water system at Ranger

Predicting the dynamics of the mixing of process water with potable water during the incident was extremely difficult because the potable water system is complex; there are limited data on the composition of water in the potable water system once contamination by process water occurred; there is an incomplete record of the volume drawn on delivery lines to tap, shower and toilet outlets; and there is a problem of validating a predicted concentration in time and space even if a model could be formulated. Hence, only generalisations can be drawn on how process water became distributed within the potable water system.

The influx of process water into the potable water system was estimated to be 1.7 L/s. Over 10.5 h, volume flow amounted to a maximum of 64 m<sup>3</sup> and a minimum of about 32 m<sup>3</sup>. The maximum is conservative because the distribution of process water into the potable system was probably restricted largely to the times when discharge from the Header Tank occurred.

It was important to examine the main drivers of water flow in the potable water system because flow would have determined the pattern to contaminant dispersion. During the incident, there was evidence from the record of water level in the Day Tank that potable water was constantly drawn. The major consumers of potable water that have been identified were the demineralisation plant (120 m<sup>3</sup>) and overflow at the Jabiru East Potable Water Tank (640 m<sup>3</sup>). Whilst use by the demineralisation plant is known, the overflow at Jabiru East tank is an estimate based on field measurements made after the incident. Reconciliation of the known and estimated use of potable water against recorded use from the Day Tank trace suggests, on the basis of constant draw, that perhaps as much as 30% of total use (approximately 340 m<sup>3</sup> over 12 h) was unaccounted for.

Contamination of potable water was influenced by the proximity of the drawing off point from the main to where process water entered the potable supply. Process water entered the main near the Header Tank and hence the most badly affected areas of the mine site were the Grinding Building Amenities, including the Administration Block. Water samples taken from the Grinding Crib Room (07.45 h) and the Mill Laboratory tap (08.10 h) on 24 March and analysed immediately on site showed elevated salt and uranium contents, and low pH, and were decisive in confirming that the potable water system had become contaminated. A worst case of 1 part process water to 2 parts potable water (ie 1 in 3) for the Grinding Building Amenities area was identified from the results of sampling by **eriss** and ERA.

The distribution of contaminants elsewhere on site was influenced by general flow into and out of the Header Tank. In the Header Tank, a 1 in 10 mix was formed relatively quickly and was maintained throughout the incident. Consequently, when the Header Tank discharged, pick up of process water at its point of entry would have concentrated the mix, in a worst case, to an estimated 1 in 6. A portion of the Header Tank discharge which is unknown would have been delivered to the Day Tank. Hence the degree of contamination of flow emanating from the Header Tank to meet demand cannot be predicted but would have ranged between 1 in 6 and 1 in 10.

Flow from the Header Tank was interspersed with flow from the Day Tank. A worst case level of contamination in the Day Tank was estimated to be 1 in 100. Hence the pattern of contaminant distribution to potable water outlets involved a high frequency pattern of a recurring step function composed of a relatively high concentration immediately followed by a relatively low concentration of probably longer duration. As an average in the worst case of delivery to areas of the Ranger site other than the Grinding Building Amenities, this was considered to be 1 in 13 when the demineralisation plant operated and 1 in 11 when it did not. A worst case for the safety shower circuit was 1 in 100.

### **Chemistry of mixing process water with potable water**

The chemistry of mixing process and potable waters together was investigated by laboratory experiment and speciation modelling. The laboratory mixing experiment was undertaken using a range of mixing ratios from 1 to 1 to 1 to 100. Speciation modelling was used to describe the distribution of metals between solution and solid phases in a 1 in 10 mix which represented a ratio at or near to which significant changes took place in chemistry. In addition, attention was given to whether the preparation of beverages using potable water contaminated with process water affected change in the bioavailability of contaminants. This was conducted using a worst case 1 to 1 mix

When process water was added to potable water, irrespective of mixing ratio, manganese, magnesium, sulphate, nickel, cadmium and zinc behaved conservatively. In contrast, iron, aluminium, lead, copper and uranium behaved conservatively at ratios less than 1 in 5 but non-conservatively at ratios greater than between 1 in 5 and 1 in 10 as shown by marked reductions in their dissolved concentrations. The behaviour of these metals was determined by pH which itself was dictated by the degree of dilution of process water. In particular the behaviour of Al was indicative of a precipitation reaction whilst that of lead, copper and uranium was suggestive of sorption.

Speciation modelling confirmed the precipitation of an amorphous aluminium hydroxide phase and ferrihydrite (ie iron (III) hydroxide). These solid phases provided a surface on to which the sorption of lead, copper and uranium was favoured. The speciation of metals in solution including uranium was dominated by cationic, anionic and zero-charged complexes with sulphate, which was the dominant anion in solution.

Tea, coffee and milk exerted marked changes in the distribution of metals between precipitates and solution. With the exception of magnesium, sulphate, manganese and zinc, major changes occurred in the composition of the solution phase as a consequence of the formation of a precipitate in coffee and tea. The extent of the removal of metals from solution, corrected for the diluting effect of milk, was greatest when milk was added in the order lead (60-70%) >aluminium (50-60%) >copper (40-50%)>uranium (30-40%) >nickel (<10%). About 30% of total iron was lost from solution when milk was added to tea but no loss of iron was shown when milk was



added to coffee. In the absence of milk, minor losses (commonly <20%) of metals from solution occurred in tea and coffee but this effect was most apparent for aluminium in coffee (about 30%). The likely mechanisms for metal loss from solution and its implications to bioavailability are discussed.

### **Remediation of the potable water supply**

An account is provided of the methodology used to reinstate the potable water systems at Ranger and Jabiru East as part of Disaster Management Recovery. Monitoring of the potable water supply is described. This was undertaken, following flushing to remove contamination, to ensure that NH&MRC Australian national guidelines for water potability standards were met. The results of the chemical assays to ensure water quality objectives were met are provided.

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## 2 INTRODUCTION

For 10.5 hours from approximately 21.30 Tuesday 23 March 2004 until 08.00 Wednesday 24 March 2004, process water entered the potable water system at Ranger Mine. As a result, potable water became contaminated and the Australian drinking water guidelines for a number of key water quality parameters were exceeded. Some personnel on site at the time consumed water and had skin contact during washing and showering with water from the potable water supply. In addition, the potable water supply to Jabiru East from the mine also became contaminated and overflow from the Jabiru East Potable Water Tank resulted in the discharge of some of this water to the environment. As a consequence of the incident, the mine was closed, employees sent home and an extensive program of remedial work begun as a prerequisite to allowing mining, milling and processing at Ranger to restart.

The purpose here is to augment the findings of a report by ERA (ERA 2004<sup>1</sup>) into the cause of the incident and the actions taken to prevent a similar incident from re-occurring. In particular, a number of specific investigations which were instigated by ERA to better understand the impact of the incident are compiled. The terms of reference of this report are as follows.

1. To provide an analytical account of the incident which gave rise to the entry of process water into the potable water system.
2. To assist in quantifying the impact of the incident, especially in relation to worker health and the environment.
3. To document how ERA responded to the incident and the measures, plans and strategies that were taken in the lead-up to the resumption of mining and milling.

## 3 FACTUAL ACCOUNT OF THE INCIDENT

A full account of the incident is provided elsewhere (ERA, 2004) with information having been sourced from interviews, plant records and the *log of events* established in accordance with *Disaster Management Recovery* procedures. Importantly, however, the ERA report is concerned primarily with the events which took place between 17.30 on Wednesday 23 March, when the low flowrate alarm to Scrubber 1 first sounded, until 09.00 the following day during which time process water had entered the potable water system and plant shutdown had occurred.

## 4 ANALYTICAL ACCOUNT OF THE INCIDENT

The scope of any study to quantify or model temporally the volume of process water which entered the potable water system and the dynamics of the mixing process is made extremely difficult by several factors. The most important are:

- the complexity of the potable water system in terms of its distributional network, varying pipe sizes, recirculating system and pressure controls;
- limited data on the composition of water in the potable water system once contamination by process water occurred;
- an incomplete record of the volume drawn on delivery lines to tap, shower and toilet outlets; and

<sup>1</sup> ERA (2004) Investigation into potable water contamination at Ranger Mine on March 23 & 24, 2004. Main report. May 2004. 31pp plus figures & appendices.

- the difficulty of validating a predicted concentration in time and space even if a model could be formulated.

Nevertheless, a number of approaches can be adopted to help understand the gross effects of how the mixing of process water and potable water took place and the volume of process water involved. These approaches involve taking account of:

- the principle drivers for the entry of process water into the potable water system and for the flow of potable water during the incident;
- the low flowrate warning system at the scrubber;
- the height record of potable water in the Day Tank;
- the composition and rate of overflow from the Jabiru East Potable Water Tank (JEPWT); and
- differences in the concentration of contaminants in the potable water supply when samples were first taken (ie when the problem was first realised and when the process water line into the potable water was disconnected).

#### 4.1 Factors determining level of contamination in potable water supply at mine site

At Ranger, contaminated water was first discovered by assay on site, before plant shutdown at 09.00 on 24 March 2004, in outlets servicing the Mill Laboratory and the Grinding Crib Room amenities (Table 4.1). Later sampling by *eriss* that same day verified that the highest contaminant levels from a potable water outlet on site occurred within the same area at a toilet cistern.

**Table 4-1:** pH, EC and U<sub>3</sub>O<sub>8</sub> content of contaminated potable water compared with process water and uncontaminated potable water (*eriss* sample is shown in italics)

Sampling Point	Time	pH	EC (µS/cm)	Total U (mg/L)
Grinding Crib Room	07.45	4.5	5900	8†
Mill Laboratory Tap	08.10	4.5	5900	3†
<i>Grinding area ground floor toilet cistern</i>	<i>15.50</i>	<i>4.2</i>	<i>8710</i>	<i>6.82‡</i>
Process water	–	3.7	19000	18
Potable water	–	7.9	390	0.007

Note: †Expressed as U<sub>3</sub>O<sub>8</sub>; ‡analysed as a psuedo-total following acidification to pH 2 on collection.

The ERA data were derived from analyses that were conducted on site immediately after sampling and clearly show a high degree of contamination of the potable water supply. However, these data are unreliable for providing an estimate of the proportional contamination of potable water by process water for the following reasons.

- The mixing of process and potable water would have resulted in the precipitation of aluminium and iron oxy-hydroxides which buffered pH change and reduced the free salt concentration (as measured by EC)<sup>2</sup>. For example, there is evidence of precipitates from the comments of staff to the effect that contaminated water had a milky appearance; that significant differences were found in the composition of

<sup>2</sup> This has important implications for assessing the toxicological implications of contaminated water intake given that metal concentrations in solution would have been reduced by sorption to newly formed oxy-hydroxides (refer to Section 5).

samples from the same location and time which were treated and analysed separately for pseudo-total metals<sup>3</sup> and dissolved (<0.45 µm) metals implying the presence of a colloidal fraction (Section 5); and that speciation modelling and a laboratory mixing experiment (Section 5) indicate that precipitation would have occurred.

- The technique used to analyse total uranium was XRF which was not optimised for the aqueous matrix, has a very low accuracy of  $\pm 50\%$  near the lowest limit of detection (ie 1 mg/L) and was undertaken with an instrument that had not recently been calibrated for aqueous samples.

Arguably, the most reliable data is from the **eriss** sample. A possible complicating issue arises from the fact that the sample was taken almost 7 h after plant shutdown allowing time for the settlement of suspended material in the cistern and perhaps difficulties with obtaining a non-representative sample.

The **eriss** sample allows for other key indicators of process water contamination to be used to calculate and verify the proportion of process water that mixed with potable water (Table 4.2). This is important for establishing a worst case scenario in toxicological modelling of contaminant intake (Section 5).

Hence, the limited data indicates a conservative worst case of about 1 part process water in 2 parts potable water<sup>4</sup>.

**Table 4-2:** Inferred dilution of process water in the cistern sample (mg/L)

Source	Al	Cu	Mg	Mn	Ni	Pb	SO <sub>4</sub>
Cistern	124	11.7	1130	594	1.69	1.28	6940
Process water (X=1)	352	17.8	2690	1360	3.44	3.05	17240
Potable water (Y)	<0.001	<0.05	40	0.0001	0.001	0.001	1.5
Implied dilution (X in Y)	2.8	1.5	2.4	2.3	2.0	2.4	2.5

Note: All concentration units are mg/L

The high degree of contamination found in the potable supply to the Mill Laboratory/Crib Room was caused by the proximity of the potable water take-off from the point of entry of process water to the main. Other outlets within the Administration building which houses the Mill Laboratory and associated amenities were potentially likely to have been similarly affected. Whilst this does not preclude the possibility, in the absence of corroborating data, that other potable water supply points elsewhere on the mine site were not similarly contaminated, it is unlikely and this is discussed more fully below.

There are a number of factors which would have influenced the actual concentration of contaminants drawn in potable water during the time process water entered the potable water system. For example, at the grinding room facilities, where the potable supply was being used, the opportunity was provided for contaminated water to flow from the main to the outlet. Initially, residual potable water in the feeder line would have made up this expression. Once contaminated water entered this line, however, the issue of predicting concentration variation at the tap becomes one of reconciling concentration variation in the 100 mm main line to the time at which water was drawn

<sup>3</sup> By adjustment of unfiltered samples by the addition of 1% *aqua regia* (nominally to pH2).

<sup>4</sup> Corresponding dilutions using U and EC data (Table 3.1) indicate dilutions respectively of 1 in 2.6 and 1 in 2.2. Note that Cu and Ni concentrations in the cistern are probably unreliable because of possible contamination from metal fittings.

and its delivery rate at the tap. In the absence of a model to describe concentration variation in the main pipe with respect to offtake points around the minesite, as well as a lack of information on actual potable water discharge rate at these points, the prediction of contaminant concentration at each supply point in real time is difficult. However, some generalisations can be made as to the likely pattern in the concentration of contaminants over time passing offtake points from the main taking account of the principle drivers of flow within the potable water system.

The flow of water in the potable water system feeding Ranger (and Jabiru East as a continuation of the Ranger potable water main) is managed by the maintenance of a minimum pressure head in the Header Tank (which sits on top of the Fine Ore Bin). When the Header Tank is full (10.5 m<sup>3</sup> capacity) a maximum pressure head of 35–36 m applies to the potable water supply. As the Header Tank empties in response to potable water use, a preset minimum head of 75% capacity is reached at which point a height level sensor in the tank triggers a large capacity pump<sup>5</sup> which transfers water from the Day Tank through two-way valves to the Header Tank, and, at the same time meets on-going demand for potable water supply drawn elsewhere from the main. A rating curve of the delivery rate against pressure head by the PWSP is shown in Figure 4.1. For a pressure head of about 35 m and the fitted pump impeller (189 mm diameter), delivery rate is around 35 L/s.

As the Day Tank (320 m<sup>3</sup> capacity) empties to meet ongoing demand, a height level is reached at 65 % capacity when feed from the Brockman borefield is triggered by a sensor and the Day Tank fills. Filling stops at the triggering of another sensor when water in the tank reaches its maximum height of 95% capacity ie around 300 m<sup>3</sup>. Also, a self-contained and constantly recirculating system (2 L/s) supplies cool water from the Day Tank to showers.

The implications of the directional flow of potable water to the dispersion of contaminants from the influx of process water are thus as follows.

- (a) Inflow of the most highly contaminated water (emanating from process water entry into the potable water main) to the Header Tank on refill where it was subsequently diluted by water remaining in the Header Tank (7.9 m<sup>3</sup>) and by the volume transferred from the Day Tank (2.6 m<sup>3</sup>).
- (b) Temporary replacement of water in the main between the Day Tank and Header Tank with water from the Day Tank.
- (c) When the PSWP was not operating, continuous outflow took place from the Header Tank along the main in response to steady demand by the Demineralisation Plant and Jabiru East Water Tank. Process water was picked up by this stream where it entered the main.
- (d) When the PSWP was not operating and the volume of the water contained in the Day Tank was greater than 65% but less than 95%, a similar composition of water described in (c) was fed into the Day Tank.
- (e) Pick-up of water for the shower circuit meant that it reflected progressive changes in the bulk composition of the Day Tank.
- (f) Dilution of contaminated water in the Day Tank occurred each time the bore pump replenished the tank.

In turn, the following inferences can be made.

- Contaminant concentration in the 100 mm main potable water pipe was at its worst when potable water demand was met from the Header Tank. This was

<sup>5</sup> Potable water supply pump (PWSP)



simply because of its small volume and the relatively larger effect of process water ingress on the composition of the bulk solution compared to the Day Tank.

- It is likely that the quality of potable water feed to the Grinding Room and Mill Lab facilities became worse after the second train of demineralised water was produced around 03.00–03.30 because less flushing of the main took place (on PSWP response to refill the Header Tank) after this time (Figure 4.2).
- The variation in the concentration of contaminants and its load pattern in water delivered to the Demineralisation Plant and Jabiru East Potable Water Tank is complex but best described in terms of contaminant ‘plugs’. In other words, within a reach of the pipe delivering water to these points, there were ‘plugs’ of poorer quality water interspersed with better quality water. Hence the quality of water from a potable source during the incident (and assuming that all residual, unaffected water had already been evacuated) depended on the temporal juxtaposition of these plugs at the time within the delivery system.
- The concentration of contaminants in the Header Tank probably reached near steady state over the time of the incident as a consequence of the regular emptying and filling of 25% of the capacity of the tank. Hence the worst case for drinking water which may have been consumed elsewhere<sup>6</sup> on site would have been the composition of Header Tank water just prior to the warning issued at 08.10 (25/3/04) to all staff not to use the potable water supply.
- The worst case for the composition of water in the shower circuit was the composition of the water in the Day Tank just prior to the warning issued at 08.10 (25/3/04) to all staff not to use the potable water supply.

#### 4.2 Estimating process water influx to potable water system during incident

The connection of the potable supply valve to the process water system resulted in a pressure differential of 300 kPa in favour of the flow of process water into the potable supply line (ERA 2004). Additionally, the rate of process water influx was probably influenced potentially by Venturi effects brought about by time variation in potable water usage and hence flowrate. However, evidence suggests that the use of potable water during the period of process water contamination and over two characterising phases (ie of operation and non-operation of the demineralisation plant) was relatively constant (Fig 4.2). Hence, variation in the rate of process water import caused by a change in Venturi effects was probably minor to that of the maintenance of gross pressure differences between the process water and potable water systems.

An estimate of the volume of process water that entered the potable water system can be made by accounting for the fact that process water flow to the Fine Ore Bin Scrubber must have been maintained at  $\geq 2 \text{ m}^3/\text{h}$  because had it fallen below this threshold, the conveyor would have tripped. Since the low flow alarm is set by flows into the scrubber of  $\leq 2.5 \text{ m}^3/\text{h}$ , process water flow into the potable water system must have been in the range  $0.5\text{--}2.0 \text{ m}^3/\text{h}$ , given a maximum feed rate to the scrubber of  $4.0 \text{ m}^3/\text{h}$ . In turn, this implies that between 5 and  $21 \text{ m}^3$  of process water entered the potable water system. However, this estimate seems to be low. For example contamination in the Jabiru East Potable Water Tank, Day Tank and Header Tank alone accounts for about 16, 1 and  $1 \text{ m}^3$  respectively. Potable water feed to the demineralisation plant and entrained process water within the supply pipes would also add to the process water inventory.

From 15.44 (23 March 2004) until 03.00 the next day, two trains of demineralised water were produced amounting to 120 t. The rate of consumption of potable water

<sup>6</sup> Other than from the Grinding Crib Room and Mill Laboratory area.



for make-up of the first train<sup>7</sup> averaged 2.65 L/s and for the second train<sup>8</sup> it was 3.28 L/s<sup>9</sup>. While the demineralisation plant was operating, there was a noticeable lag in the time it took to fill the Day Tank (Fig 4.2). However, when demineralisation of potable water ended, the fill and depletion rates of the Day Tank were approximately the same with no lag in the fill time and implying the following.

- There was a constant feed of water from the potable supply to a consuming source which was not the demineralisation plant.
- The outflow<sup>10</sup> was in the order of 30 L/s (Figure 4.4).
- The rate of replenishment of the tank (assuming constant draw and accounting for the symmetrical nature of inflow/outflow) was about double the consumption rate.

Over 12 h (from approximately 19.30 on 23 March to 07.30 the following day), at least 1100 m<sup>3</sup> of water was exported from the Day Tank of which 120 m<sup>3</sup> can be accounted for by the production of demineralised water. A small quantity of potable water was also consumed by vacuum pumps at the power station (36 L/min) but with the exception of minor draw (ie normal usage) of water from the potable system by staff, about 1,000 m<sup>3</sup> was used elsewhere. Apart from overflow at the Jabiru East Potable Water Tank and excluding the possibility of other leaks, no other major consumer of potable water has been identified during this period.

An estimate of process water influx was made using 'Pipe Flow'<sup>11</sup> software by assuming a constant differential pressure head of 300 kPa over the pipe that connected the potable water system to the process water system but in favour of reverse flow. The geometry of the pipe system was made up of a continuous horizontal 10 m section and vertical 10 m section of reinforced hose (1" ID) which was coupled to a 16 m length of steel pipe (1" ID) and which then connected into the potable water supply. Default frictional factors for the hose and steel pipe were 0.065 and 0.025 respectively and frictional loss at the coupling between the hose and the steel pipe was ignored. Under 'Pipe Flow', flowrate was adjusted until such point that the cumulated loss of pressure head over the whole length of the pipe was 300 kPa. This was attained at a flowrate of 1.72 L/s (ie fluid velocity = 3.4 m/s and Reynolds number = 86219 with turbulent flow). Pressure drop over the three sections of pipe in the order described above was 152.4, 48.6 and 99.4 kPa

In an experiment to determine the overflow rate at the Jabiru East Potable Water Tank (JPWT) on 8 April 2004, a maximum flowrate into the tank of approximately 17 L/s was measured<sup>12</sup>. Since the cut-off valve was not working, it is believed that the tank continued to overflow during the whole period that process water entered the potable system. The figure of 17 L/s appears therefore to be reasonable suggesting that process water was diluted in approximately a 1 in 10 ratio with potable water in the 100 mm main.

The relatively quick establishment of a 1 in 10 mix of process water in potable water in the Header Tank can be reasonably assumed. With a delivery rate of around 30-35 L/s, the PWSP would have made up the fall in the Header Tank in about 2.5 mins while continuing to meet demand elsewhere (ie principally the overflow at the JPWT). Pick-up of 1.7 L/s flow of process water would have given rise to an exponential increase in contamination within the tank (Fig 4.3) with around 95% of the maximum

<sup>7</sup> The first train was made up of 55 t from 15.44 until 21.30.

<sup>8</sup> The second train was made up of 65 t from 21.30 until 03.00.

<sup>9</sup> The rounded up production rate for the demineralisation plant was 10 000 L/h.

<sup>10</sup> It is important to note that the outflow from the tank is not strictly a consumption rate because a portion of the flow (which would have been small) would have been directed to the Header Tank.

<sup>11</sup> <http://www.pipeflow.co.uk/>.

<sup>12</sup> Personal communication (David Borries)

concentration attained within 50 minutes. Hence discharge from the Header Tank would have given rise to a mix downgradient of the point of process water influx which was more concentrated than that contained in the tank. If it is assumed that Header Tank discharge occurred at a rate in response to meeting only a 17 L/s overflow at the JEPWT then a worse case suggests a slug of water containing a 1 in 6 mix of 2.5 minute duration (Fig 4.4). However, this is a highly conservative estimate because we know that process water entered the Day Tank<sup>13</sup> and hence the slug of water which did not go there would have been less contaminated (ie between 1 in 6 and 1 in 10) and of shorter duration than 2.5 minutes.

Unfortunately, an estimate of how much Header Tank water entered the Day Tank is impossible to make. Like the Header Tank, contamination of the Day Tank was likely to have been progressive but the attainment of an equilibrium took longer because of its larger volume. A best estimate (Section 4.3) suggests that at the time the potable water was isolated there was about a 1 in 100 mix in the Day Tank. Hence a picture emerges of variable ratio of process water mixed with potable water in which streams from the Header Tank and Day Tank entered the potable water system providing for at least an order of magnitude difference between streams in their relative level of contamination. This took place over discreet but recurring cycles in which there was a slow but gradual increase in the concentration of contaminants over time.

### 4.3 Estimating level of contamination of potable water system during incident

Assuming the process water flow rate to be 1.7 L/s suggests that around 64 m<sup>3</sup> of process water entered the potable water system over 10.5 h. However, this is conservative because when the Day Tank was operating there was no opportunity for the process water to directly enter the main. Consequently, assuming that the Day Tank was operating half the time, a minimum input of 32 m<sup>3</sup> process water is suggested. A mass balance of the Header Tank, Day Tank, JEPWT (Jones *et al* 2004) and Jabiru East line (ie 120 m<sup>3</sup>) accounts for 21 m<sup>3</sup>, implying that at least a third of process water influx over 10.5 h (discounting residual contamination in the pipe network) entered the demineralisation plant.

#### 4.3.1 Safety showers

The recirculating safety shower system was significantly less contaminated than the non-recirculating section of the potable water system because any contamination associated with the Day Tank was constantly being diluted by bore water replenishing the tank. Using the composition of the Day Tank measured pre-flush<sup>14</sup> as a rough guide, the sulphate and manganese data imply a 1 in 230 dilution. However as a worst case, this estimate is unreliable because, between the time process water contamination was halted and the time of sampling, the contents of the Day Tank were diluted by its refilling to meet the overflow at the Jabiru East Potable Water Tank.

A sample from the Day Tank taken at 09.30 h, 1.5 h after the line carrying the process water was disconnected, registered an EC of 650 µS/cm. A similar EC would have been present at 08.00 because the supply of 17.2 L/s to meet the overflow demand at Jabiru East would have resulted in a delivery of 93 m<sup>3</sup> of water, primarily from the Day Tank, which is equivalent to less than a 30% drop in volume (before refilling is triggered). However, taking a worst case of 30% dilution just prior to sampling implies

<sup>13</sup> ie discharge from the Header Tank was composed of two streams – one meeting demand and the other partially filling the Day Tank in response to pressure head loss.

<sup>14</sup> ERA sample 100322 (24 March 12.00 pm)

an EC of about 800  $\mu\text{S}/\text{cm}$  which, in , suggests around a 1 in 100 dilution of process water in potable water<sup>15</sup> (Fig 4.5).

**The worst case for safety showers was 1 in 100.**

#### **4.3.2 Potable water serving Grinding Building amenities**

The area of the mine most affected by contamination of the water supply was the line serving the grinding building amenities (Section 4.1). Evidence suggests a worst case of 1 in 2.

**The worst case for Grinding Building Amenities was 1 in 2.**

#### **4.3.3 Potable water serving areas other than Grinding Building amenities**

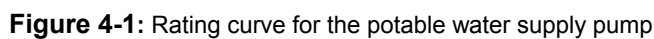
From Section 4.2, an estimate has been made of the level of contamination of water fed from the Header Tank which ultimately ranged between 1 in 6 and 1 in 10. This flow was interspersed with better water quality from the Day Tank, the worse case contamination of which was 1 in 100 and for which the duration of flow was longer. Whilst a 1 in 10 mix for 17% of the time and 1 in 100 for 83% of the time can account for the mixing chemistry of the JEPWT, there is no way of validating this for the Ranger site where uncertainties in the distribution of contaminated water to the demineralisation plant in particular is unknown. In the absence of this information, an average, conservative worst case is estimated to be:

**1 in 13 when the demineralisation plant was operating; and**

**1 in 11 when the demineralisation plant was not operating (after 03.00 h).**

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<sup>15</sup> Derived from a mixing experiment described in Section 5.1.





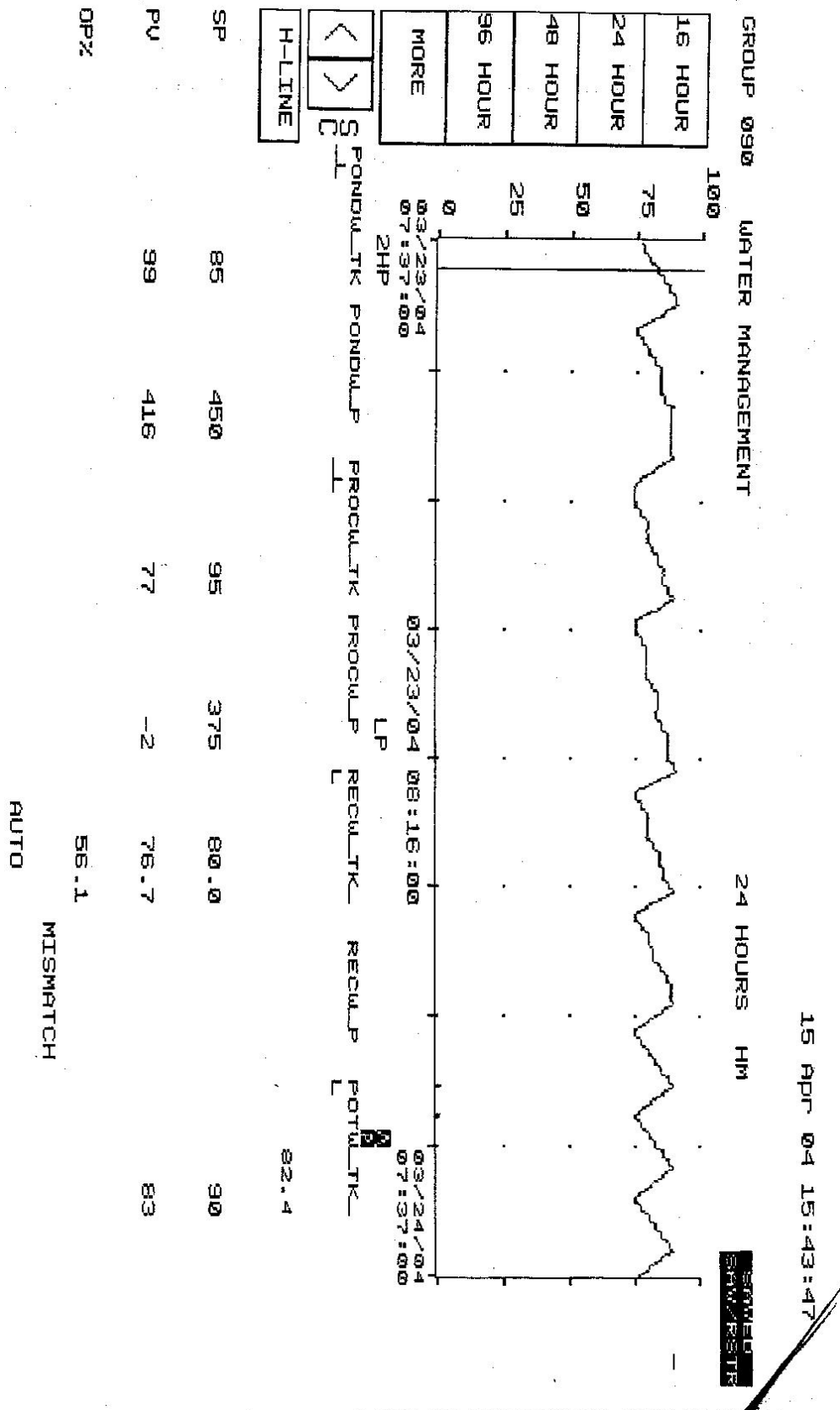
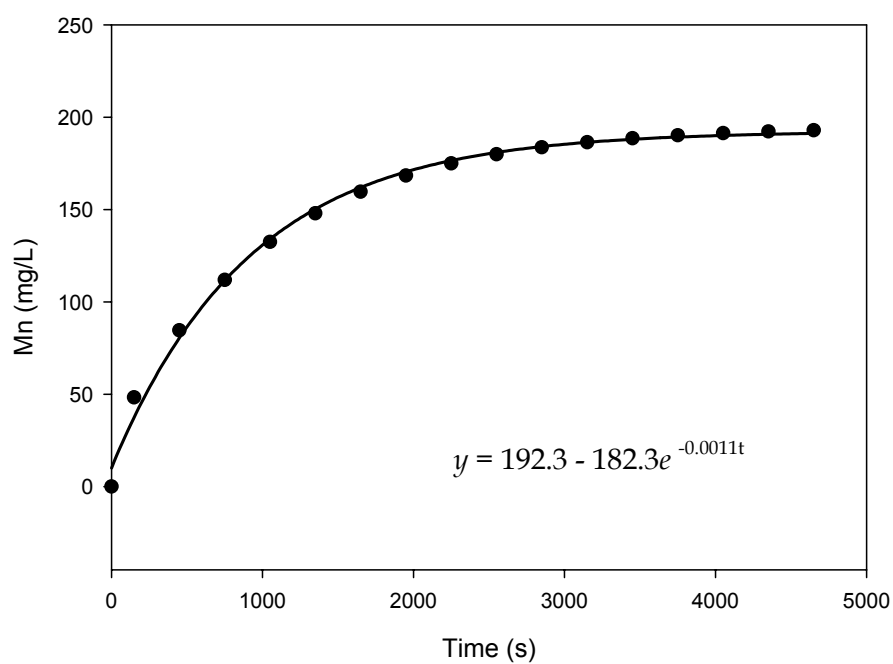
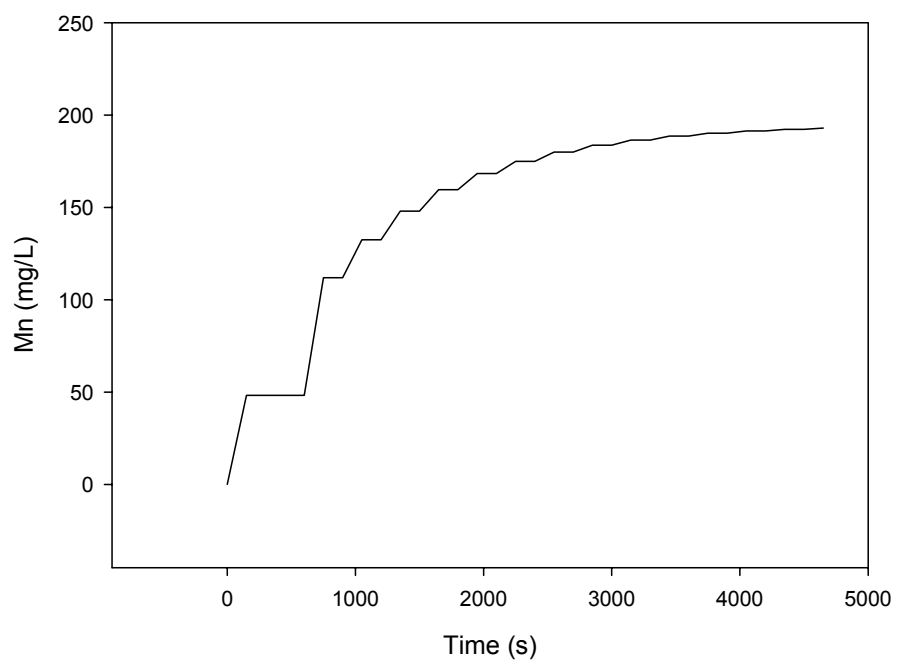
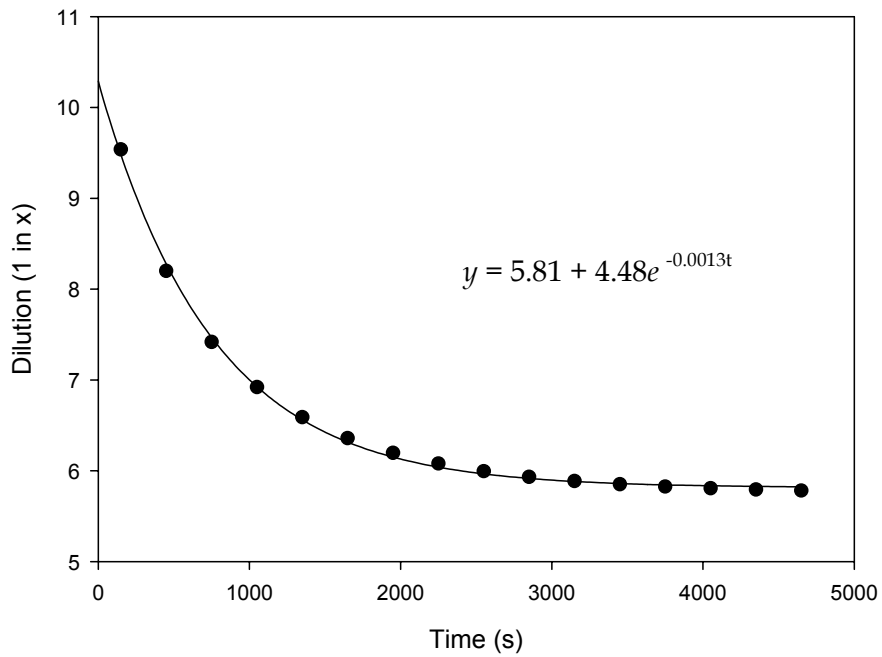


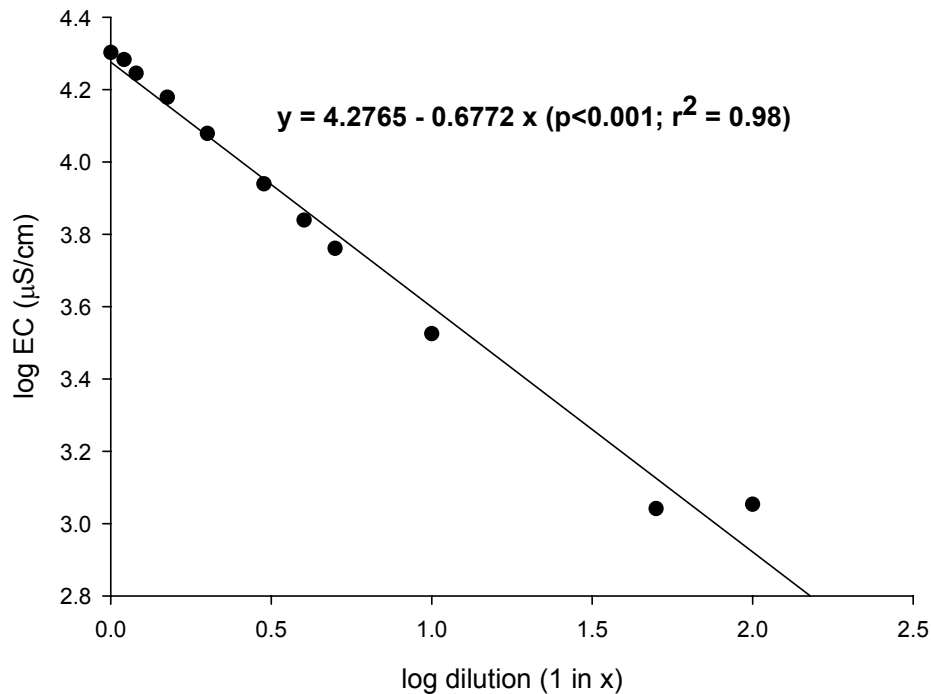
Figure 4-2: Event log of volume change in the Day Tank



**Figure 4-3:** Predicted change in the Mn concentration of the contents of the Header Tank (top) with fitted curve (bottom)



**Figure 4-4:** The effect of the discharge of Header Tank water on the level of contamination for that slug of water entering the potable water system as a result of process water pick-up



**Figure 4-5:** The effect on EC of diluting process water with potable water

## 5 IMPACTS OF THE INCIDENT

### 5.1 Worker Health

Potential impact to workers during the Night Shift of 23<sup>rd</sup>-24<sup>th</sup> March was determined by exposure to contaminated water in the potable water system and dose either by volume intake or contact with contaminated shower water. However, it is not the purpose of this report to quantify or qualify the dose or its effects but to provide information on the chemical nature of water which had become contaminated.

#### 5.1.1 Laboratory mixing experiment

To quantify the chemical effects of diluting process water with potable water on the composition of the solution phase, a laboratory mixing experiment was conducted in which potable water was added in varying ratios to process water, shaken (for 16 h), filtered (<0.45 µm), and analyses conducted on the filtrate by ICMP-MS or OES. The mixing experiment and analyses were conducted on behalf of EWL Sciences by NTEL, Berrimah. Treatments were not replicated and were composed of the following:

Control A (Process Water); Control B (Potable Water); 1 in 1.1 (ie A in B); 1 in 1.2; 1 in 1.5; 1 in 2; 1 in 3; 1 in 4; 1 in 5; 1 in 10; 1 in 50; and 1 in 100.

The results are summarised in Figure 5.1 and Table 5.1 for pH, EC, Al, Mn, Mg, SO<sub>4</sub>, U and Al. In Figure 5.3, the behaviours of Mn and U are compared to Cd, Cu, Ni, Pb, Zn and Fe. The results for all other metals, metalloids and non-metals which comprise the suite of elements determining water quality in accordance with the Australian Drinking Water Guidelines can be made available separately in electronic files.

The following conclusions are drawn.

- Manganese, magnesium and sulphate behaved identically (Fig 5.1) and conservatively (Fig 5.2).
- There was a dilution error with the 1 in 100 treatment.
- Aluminium and uranium behaved non-conservatively (Fig 5.1).
- Cadmium, nickel and zinc behaved conservatively (Fig 5.3).
- Lead and copper behaved non-conservatively with the degree of deviation from conservativeness in the order Pb>Cu>U.
- The behaviour of iron was non-conservative and markedly different from other heavy metals.
- The solubility of aluminium decreased markedly at some point within the open range between 1 in 5 and 1 in 10 dilution corresponding to a pH of between 4.3 and 4.8.
- The decrease in the mass of aluminium in solution was indicative of a precipitation reaction.
- The precipitation of aluminium was not accompanied by a change in sulphate concentration thus ruling out aluminates commonly of the form AlOHSO<sub>4</sub> (ie khademite or variant) or Al<sub>4</sub>SO<sub>4</sub>(OH)<sub>10</sub> (ie basaluminate, metabasaluminate or variant) which form in the pH 4.3 –5.0 range.
- The similarity in the behaviour of Pb, Cu and U and the relatively small decrease in their solubilities was indicative of sorption.



- The most likely solid phases that formed were amorphous aluminium hydroxide and iron hydroxide (as ferrihydrite).
- The implied sorption of Cu, Pb and U conforms with their preferential adsorption<sup>16</sup> under acid conditions (around pH 5), compared to other divalent metal ions, on freshly precipitated aluminium and iron oxy-hydroxides<sup>17</sup>.

### 5.1.2 Speciation of metals in a 1 in 10 mixture of process water in potable water

The behaviour of metals in solution was verified by running MINTEQA2 (Version 3.11) to predict the speciation of ions at chemical equilibrium allowing for precipitation of permitted solids. The output of the model consists of the calculation of saturation indices from ion activity products and known solubility product constants, and ion types in solution as speciated complexes from known stability constants. No attempt was made to model sorption reactions on to precipitates. A 1 in 10 dilution mixture of process water by potable water was modelled for the following reasons.

- The mixing experiment indicated that it was only at dilutions of approximately 1 in 10 or greater that significant loss of aluminium took place from solution.
- A 1 in 10 dilution of process water by potable water represents a worst case of contamination of the potable water system on the mine site apart from spurs from the line serving the grinding area and amenities (Section 4.3).

Speciation was modelled using a 1 in 10 dilution at pH 4.8 and by conducting a sweep at +0.1 pH increments to a maximum of pH 5.3. The sweep was undertaken because predictions by MINTEQA2 are based on idealised conditions set by the constraints of the thermodynamic database. For example, the presence of high sulphate concentrations can reduce the pH edge at which  $\text{Al}(\text{OH})_3$  precipitates. Also, the actual mixing process when process water entered the potable water system was most likely non-ideal giving rise to a heterogeneous mix whose composition varied over time and with distance from the point of influx.

The composition of the 1:10 mix used for modelling is given in Table 5.2. The model was run at a nominal 25°C without redox coupling but allowed ferrihydrite precipitation by assuming total Fe to be all in the ferric form. The following solids were not allowed to precipitate:  $\text{AlOH}\text{SO}_4$ ,  $\text{Al}_4(\text{OH})_{10}\text{SO}_4$ , hematite, goethite, diaspore, gibbsite, boehmite and anhydrite. For the minerals listed, there was no evidence of aluminate formation (Section 5.1.1) and hematite and goethite require the formation of ferrihydrite as a precursor. Whether gibbsite or its polymorphs diaspore and boehmite form is highly dependent on the chemical conditions of neutralisation including the anions present and the manner in which the neutralisation reaction is controlled (eg the alkali to Al mole ratio). Hence, to simplify the model, only amorphous  $\text{Al}(\text{OH})_3$  was allowed which requires the attainment of a slightly higher pH than the aforementioned mineral forms before precipitation is triggered. A check of cation to anion charge balance for the input data indicated excellent agreement (ie 2% difference).

Modelling confirmed the precipitation of  $\text{Al}(\text{OH})_{\text{am}}$  between pH 4.9–5.0 with a further increase in pH substantially influencing the proportion of Al remaining in solution (Fig 5.4). Of the Al remaining in solution, the dominant forms are non-hydrolysed  $\text{Al}^{3+}$  and cation and anion sulphate complexes (ie  $\text{AlSO}_4^+$  and  $\text{Al}(\text{SO}_4)_2^-$ ) (Fig. 5.5). Similarly, the main forms of U in solution are non-hydrolysed  $\text{UO}_2^{2+}$ , neutral and anionic sulphate species (ie  $\text{UO}_2\text{SO}_4^0$  and  $\text{UO}_2(\text{SO}_4)_2^{2-}$ ), and the product of first

<sup>16</sup>  $\text{Pb}^{2+}$ ,  $\text{Cu}^{2+}$  and  $\text{UO}_2^{2+}$  all have first hydrolysis constants which favour the formation of the  $\text{M}(\text{OH})^+$  surface complex.

<sup>17</sup> Hsu PH 1989. Aluminium hydroxides and oxyhydroxides. In JB Dixon & SB Weed *Minerals in Soil Environments*. 2<sup>nd</sup> Edition, Soil science Society of America, Madison. pp 331-378.

hydrolysis,  $\text{UO}_2\text{OH}^+$  (Fig 5.6). Over the pH range 4.8–5.3, Mn speciation is invariant with approximately one third as  $\text{MnSO}_4^0$  and the remainder as aqueous  $\text{Mn}^{2+}$ . Copper, Ni and Pb in solution show a similar distribution although in the case of the latter a small proportion is present as  $\text{Pb}(\text{SO}_4)_2^{2-}$ . Iron is controlled by ferrihydrite precipitation which, together with amorphous  $\text{Al}(\text{OH})_3$ , acts a sorbing surface for heavy metals, principally Cu, Pb and U (see Section 5.1.1). Process water is saturated in gypsum and contains colloids of the salt. In a 1 in 10 mix of process water in potable water, gypsum approaches saturation (saturation index = -0.6) but does not precipitate.

### 5.1.3 Behaviour of metals in beverages prepared with process water

In a laboratory experiment conducted by NTEL, Berrimah on behalf of EWL Sciences, tea and coffee were prepared in a 1 in 1 mix of process water and potable water by simulating the steps which normally would be taken. These included the use of near boiling water, the addition of coffee or tea bag, brewing (of tea), and the addition of milk. All samples were filtered ( $<0.45 \mu\text{m}$ ) before assays were conducted on the filtrate. The procedure and treatments (in duplicate) after boiling a 1 to 1 mix were as follows

1. Subsample, allow to cool (15 minutes) and filter – Control.
2. Add 1 teaspoon of instant coffee to 250 ml of boiled mix, stir, cool (15 minutes) and filter – C1.
3. As in 2, but with the addition of milk (40 ml) after coffee followed by stirring – C2.
4. Brew tea with a teabag (1 jiggle<sup>18</sup>/second for 1 minute) in 250 ml of boiled mix, withdraw the teabag, cool (15 minutes) and filter – T1.
5. As in 4, but with the addition of milk (40 ml) after tea bag use (ie jiggling) – T2.

A summary of findings is contained in Figures 5.7–5.9 and photographs of the beverages are given in Appendix A. The following conclusions are reached.

- With the exception of Mg,  $\text{SO}_4$ , Mn and Zn, major changes occurred in the composition of the solution phase as a consequence of the formation of a precipitate in coffee and tea (Appendix A).
- The extent of the removal of metals from solution, corrected for the diluting effect of milk<sup>19</sup>, was greatest when milk was added in the order  $\text{Pb} > \text{Al} > \text{Cu} > \text{U} > \text{Ni}$ .
- The loss of metals from solution when milk was added accounted for about 60–70% Pb, 50–60% Al, 40–50% Cu, 30–40% U and  $<10\%$  Ni compared to the control.
- About 30% of Fe was lost from solution when milk was added to tea but no loss of Fe was shown when milk was added to coffee.
- Coffee was a minor source term for Cd and tea was a major source term for Ba.
- In the absence of milk, minor losses (commonly  $<20\%$ ) of metals from solution occurred in tea and coffee. This was most apparent for Al in coffee (about 30%).

<sup>18</sup> A jiggle is defined as one complete cycle of teabag movement, as part of the brewing process, involving the continuous motion of teabag withdrawal from, and entry into, the brew undertaken in a near vertical direction without splashing.

<sup>19</sup> Dilution alone would have accounted for a 14% lower concentration in C2 and T2 compared to the control.

The complexity of the chemistry of tea and coffee and the absence of quantitative analyses of their components excludes any attempt here to conduct speciation modelling. However, the presence of organic complexing agents such as polyphenols and organic acids will selectively complex and chelate heavy metals.

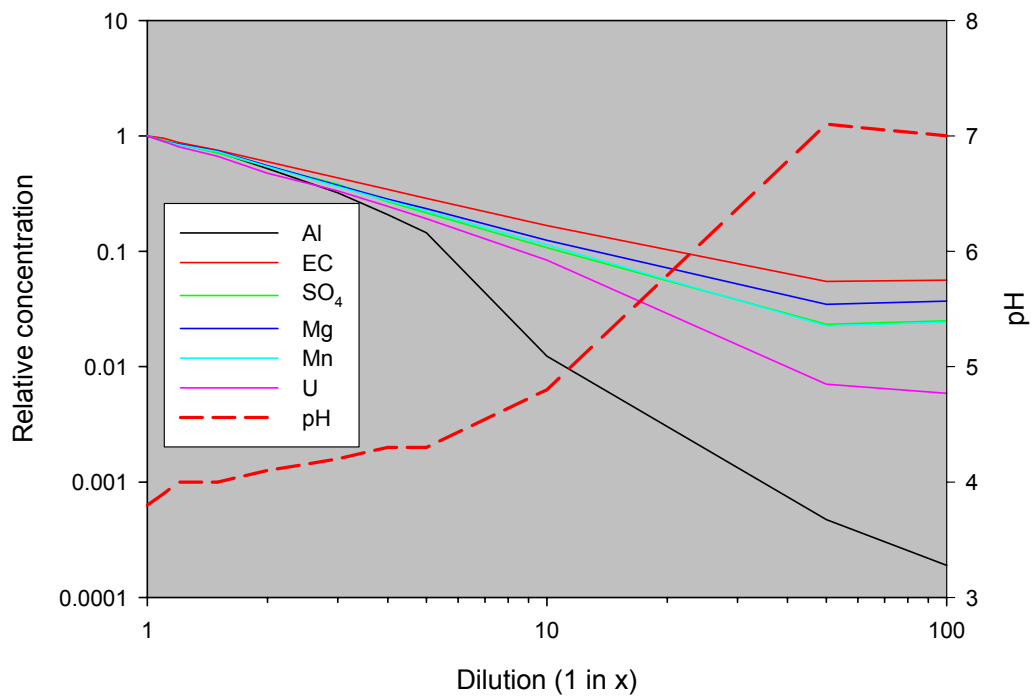
There are probably a number of factors that dictate the behaviour of metals in tea and coffee prepared with process water. Under acid conditions, certain high molecular weight polyphenolics may precipitate in a manner similar to that humic acid in the preparation of soil extracts. The colloids which form would then coprecipitate chelated metals and might act as a surface for further sorption of metals from solution. This was likely to have been the predominant mechanism for metal removal in the absence of milk. However, in the presence of milk, additional organics such as proteins may further modify metal speciation (particularly the soft Lewis Acids such as  $\text{Cu}^{2+}$  and  $\text{Pb}^{2+}$ ) and may become peptised under the relatively acid conditions. Further, milk itself will partially neutralise active acidity which may account for the additional loss of Al and Fe from solution as oxyhydroxides. The latter will also scavenge metals from solution, particularly Pb, Cu and U (see Section 5.1.1).

The significance of the findings described here are two-fold. Firstly, while tea and coffee could mask the taste imparted by the presence of a high salt concentration from process water and perhaps improved palatability, there were obvious indications during the preparation of the beverages that process water affected their appearance adversely to the extent that the chemist undertaking the work stated that he would not have drunk the tea or coffee based on appearance. Secondly, it has been demonstrated that the preparation of tea and coffee affects the proportion of heavy metals remaining in solution by reducing their bioavailability. Settlement of precipitates (Appendix A) would have probably resulted in a lower intake of metals by ingestion particularly if a reaction by the subject to an adverse taste had limited that intake. Whilst other mixing ratios were not tested, it is likely that in more dilute solutions of process water the presence of milk would have mitigated soluble metal intake.

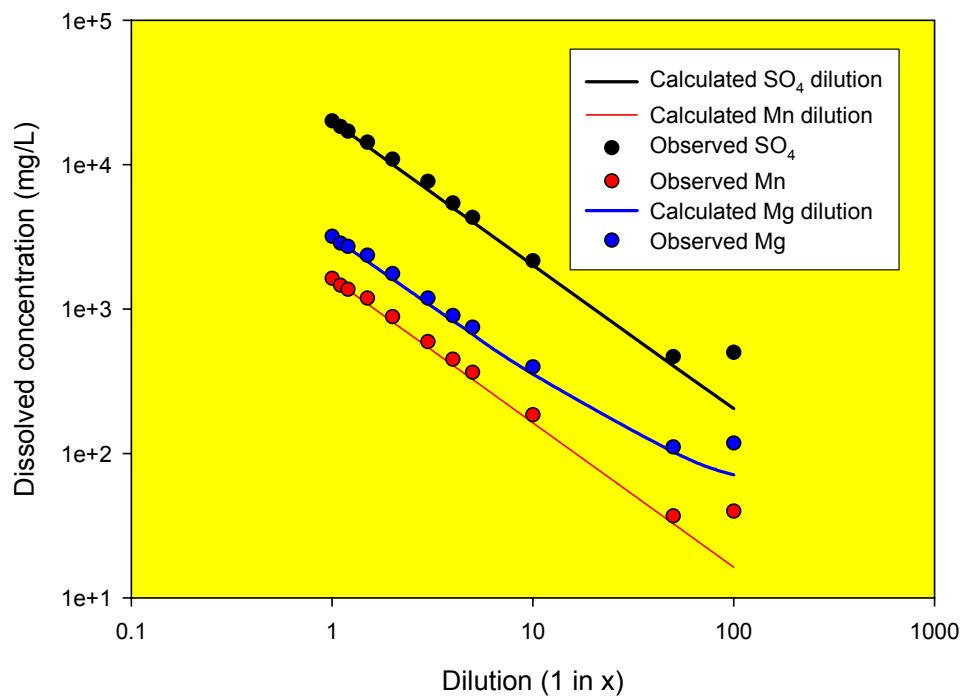
## 5.2 Environmental

A full account of the environmental impact of the incident is contained elsewhere (Jones *et al.* 2004<sup>20</sup>).

<sup>20</sup> Jones, D R, Klessa, D A & Hollingsworth, I D (2004) Investigation Report – Jabiru East potable water contamination: environmental aspects. Report to ERA Ltd, May 2004. 27pp.



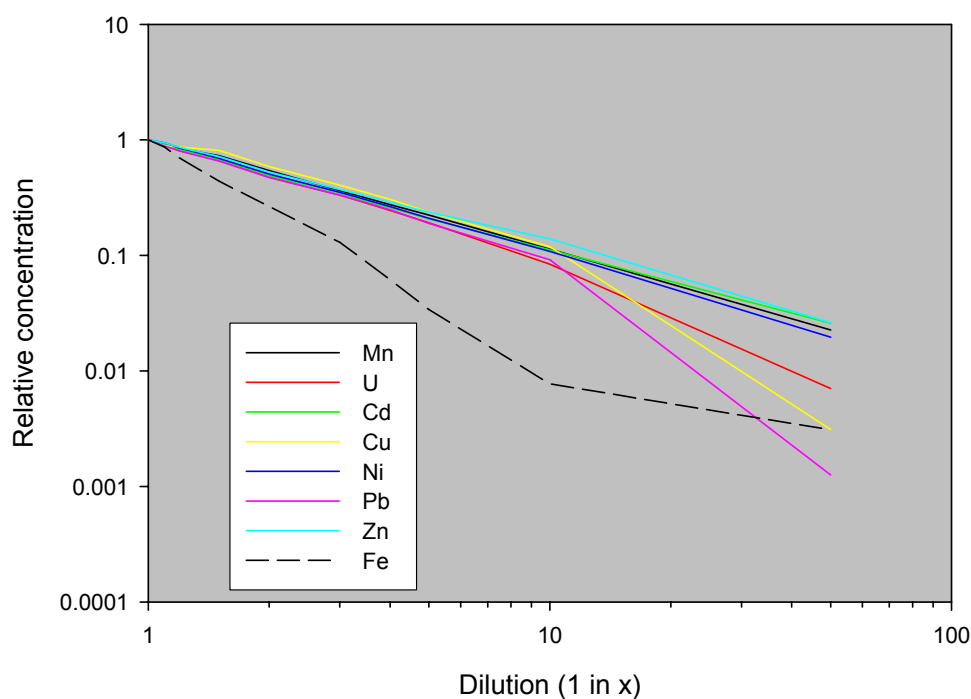
**Figure 5-1:** The effects of diluting process water with Brockman Bore water on the relative change in pH and EC, and Mg, SO<sub>4</sub>, Al, Mn and U in solution



**Figure 5-2:** Calculated dilution for Mg, SO<sub>4</sub> and Mn assuming conservative behaviour following mixing compared to observed concentrations

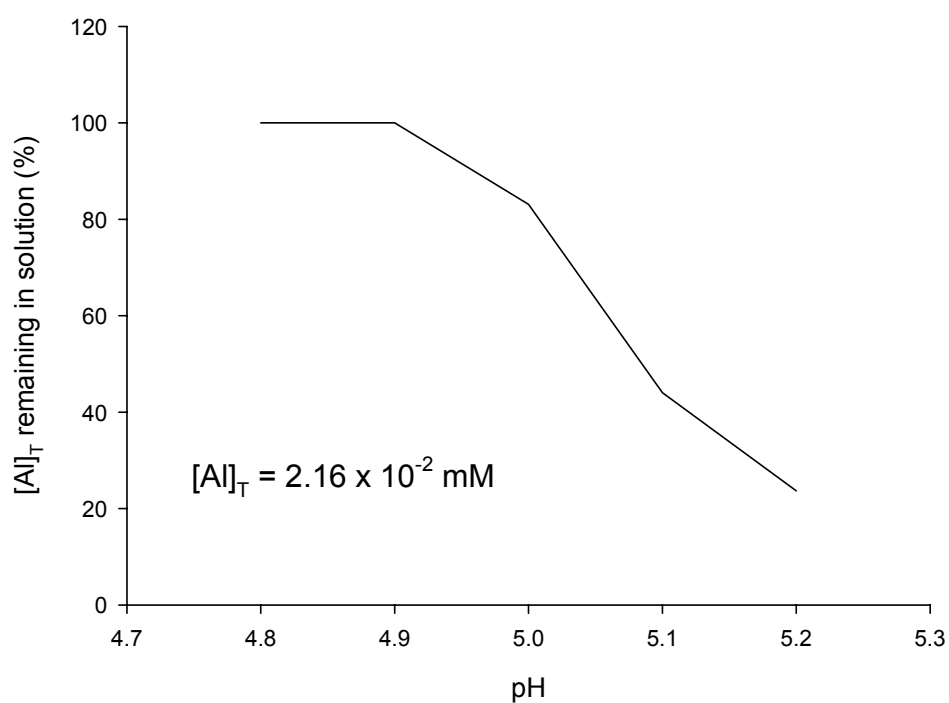
**Table 5-1:** Composition of the treatments used in the mixing experiment

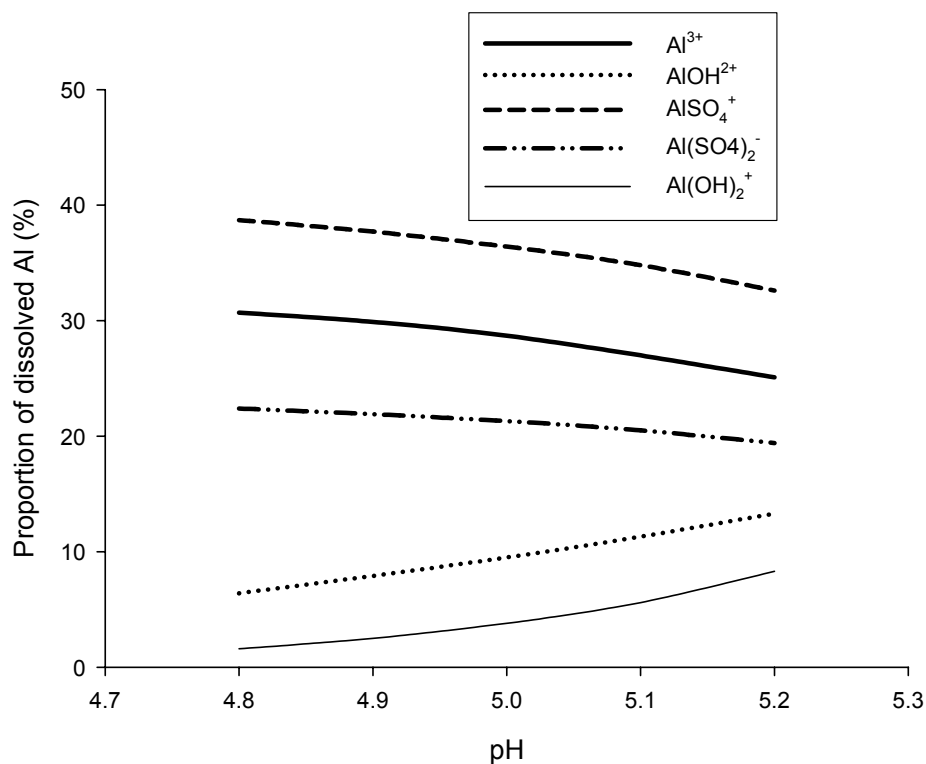
Treatment	pH	EC	Mg	SO <sub>4</sub>	Mn	Al	U
	units	( $\mu$ S/cm)	mg/L				
Process water	3.8	20100	382	20070	1630	423	24.0
1 in 1.1	3.9	19200	382	18350	1460	382	21.5
1 in 1.2	4	17600	382	17040	1370	357	19.3
1 in 1.5	4	15100	382	14280	1190	307	16.0
1 in 2	4.1	12000	382	10910	884	220	11.4
1 in 3	4.2	8700	382	7650	594	136	8.04
1 in 4	4.3	6910	382	5420	449	87.8	5.88
1 in 5	4.3	5770	382	4310	365	61.2	4.60
1 in 10	4.8	3350	382	2160	185	5.22	2.01
1 in 50	7.1	1100	382	468	36.9	0.2	0.17
Bore water	8.0	382	39.5	3.5	0.045	0.02	0.01

**Figure 5-3:** The effects of diluting process water with Brockman Bore water on the relative change in Mn, U, Cd, Cu, Ni, Pb, Zn and Fe in solution

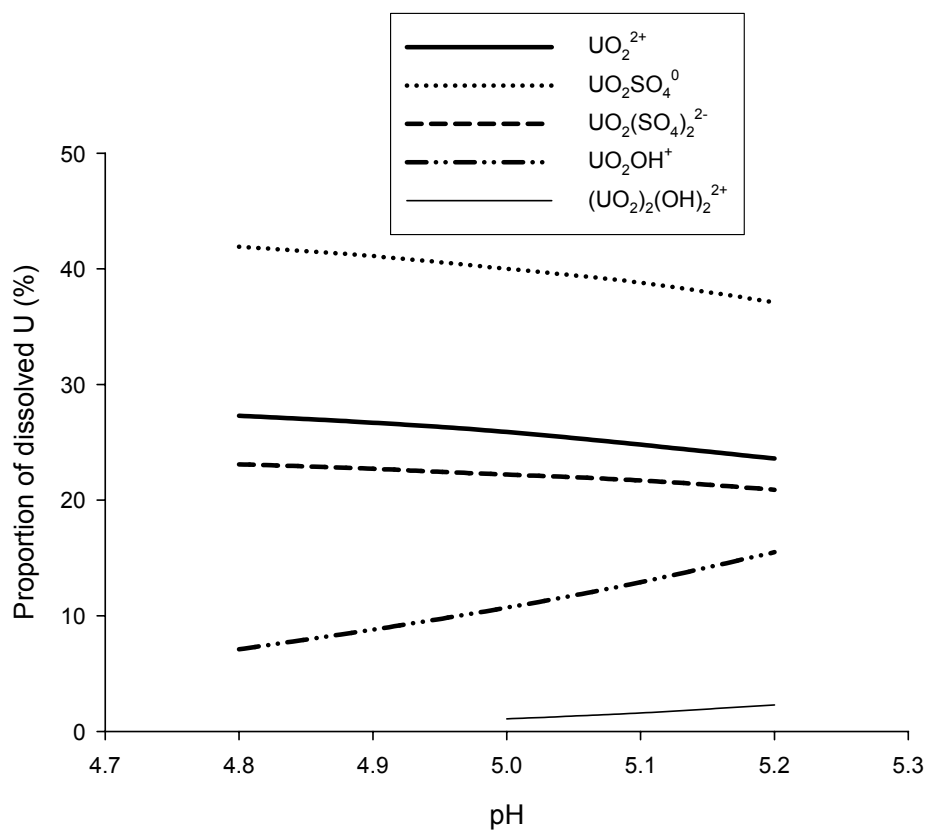
**Table 5-2:** Composition of 1 in 10 mix given as totals

Input	mg/L	Input	mg/L
Al	20.6	NH <sub>4</sub>	6.0
Ca	74.3	Pb	0.4
Cu	2.51	SO <sub>4</sub>	2570
Mg	422	UO <sub>2</sub>	2.36
Mn	195	Zn	3.13
Ni	0.42	Fe	0.19

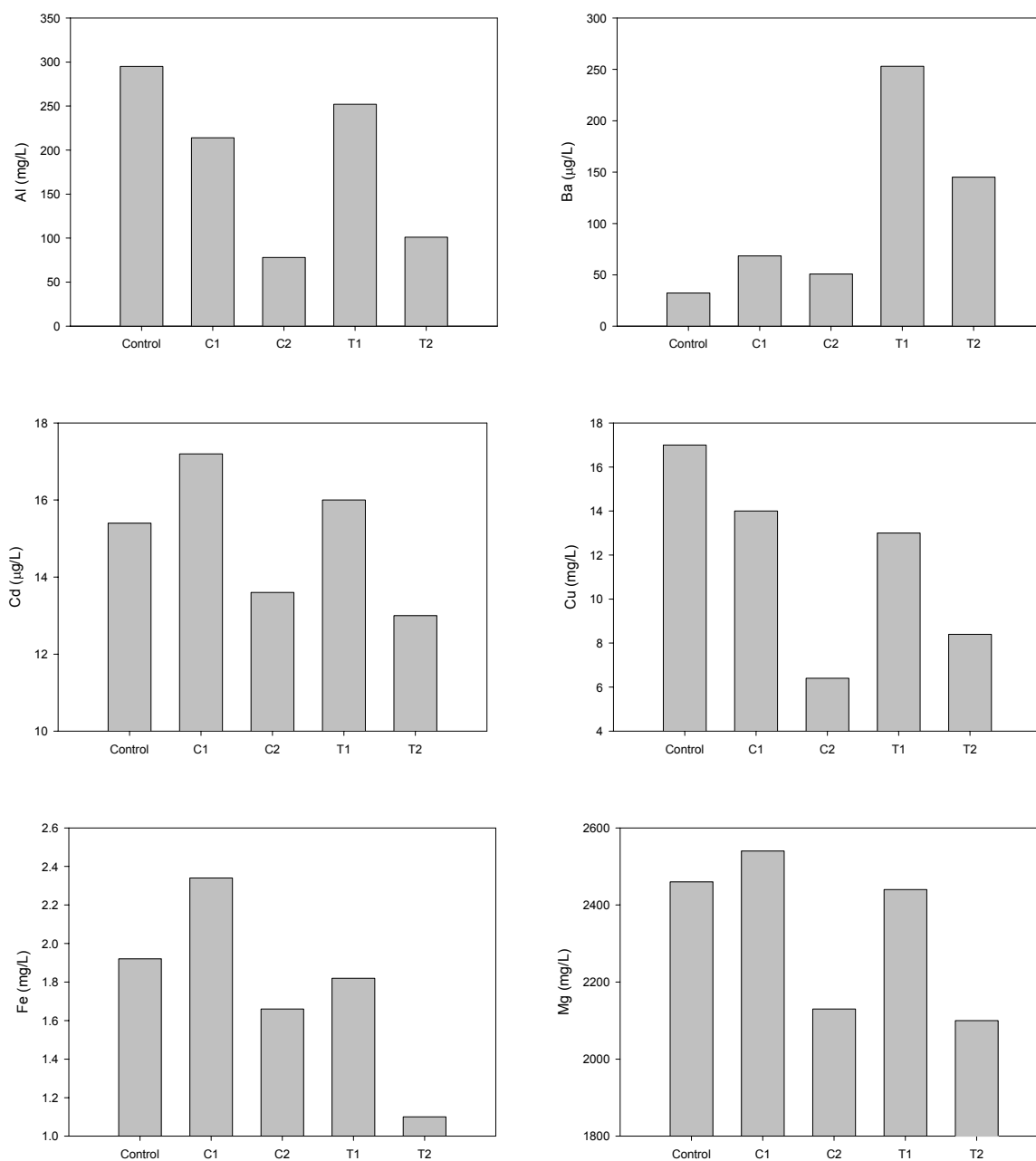
**Figure 5-4:** The precipitation of Al(OH)<sub>am</sub> as a function of pH



**Figure 5-5:** The distribution of the principal aluminium species in solution as a function of pH

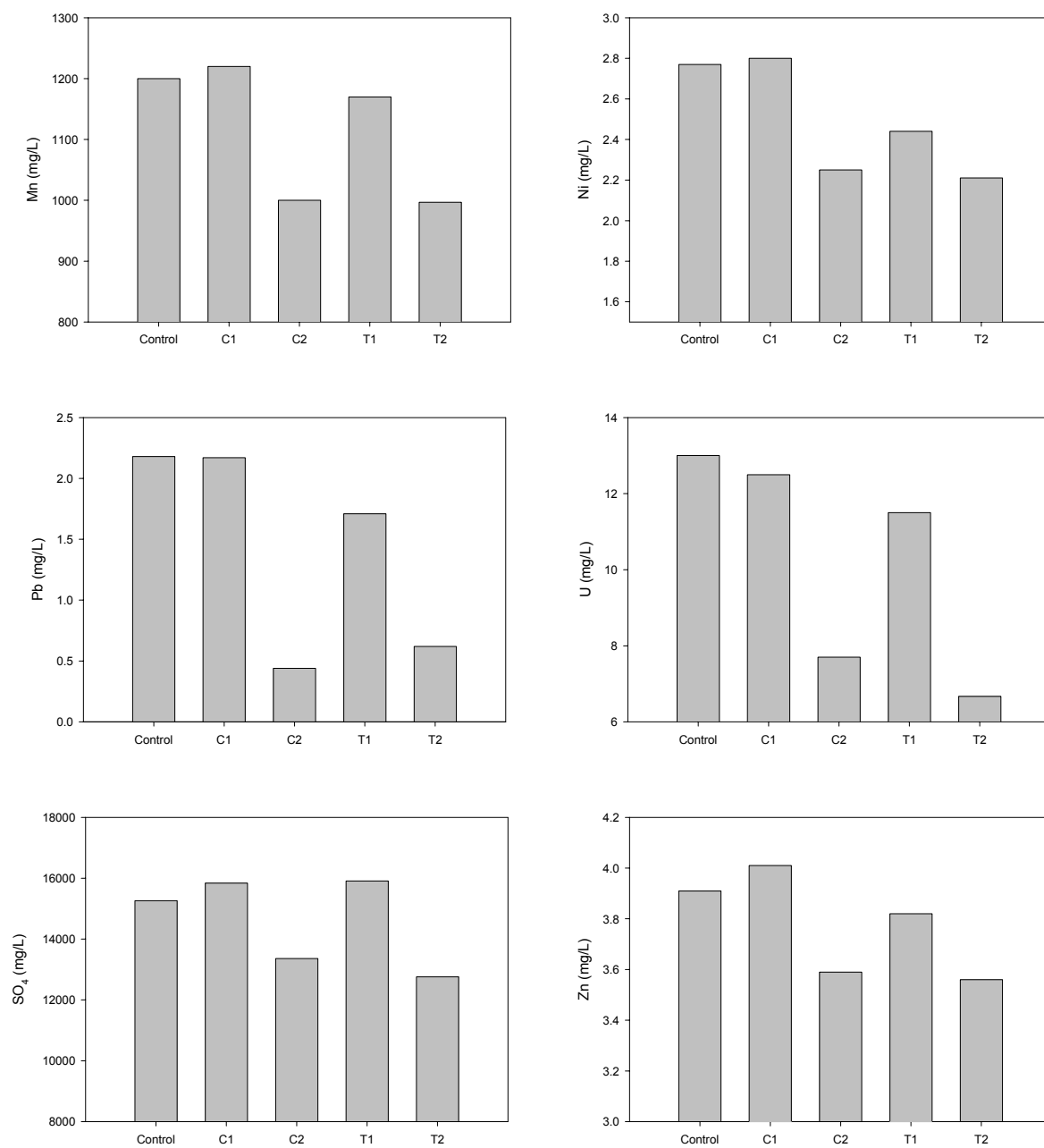


**Figure 5-6:** The distribution of the principal uranyl species in solution as a function of pH

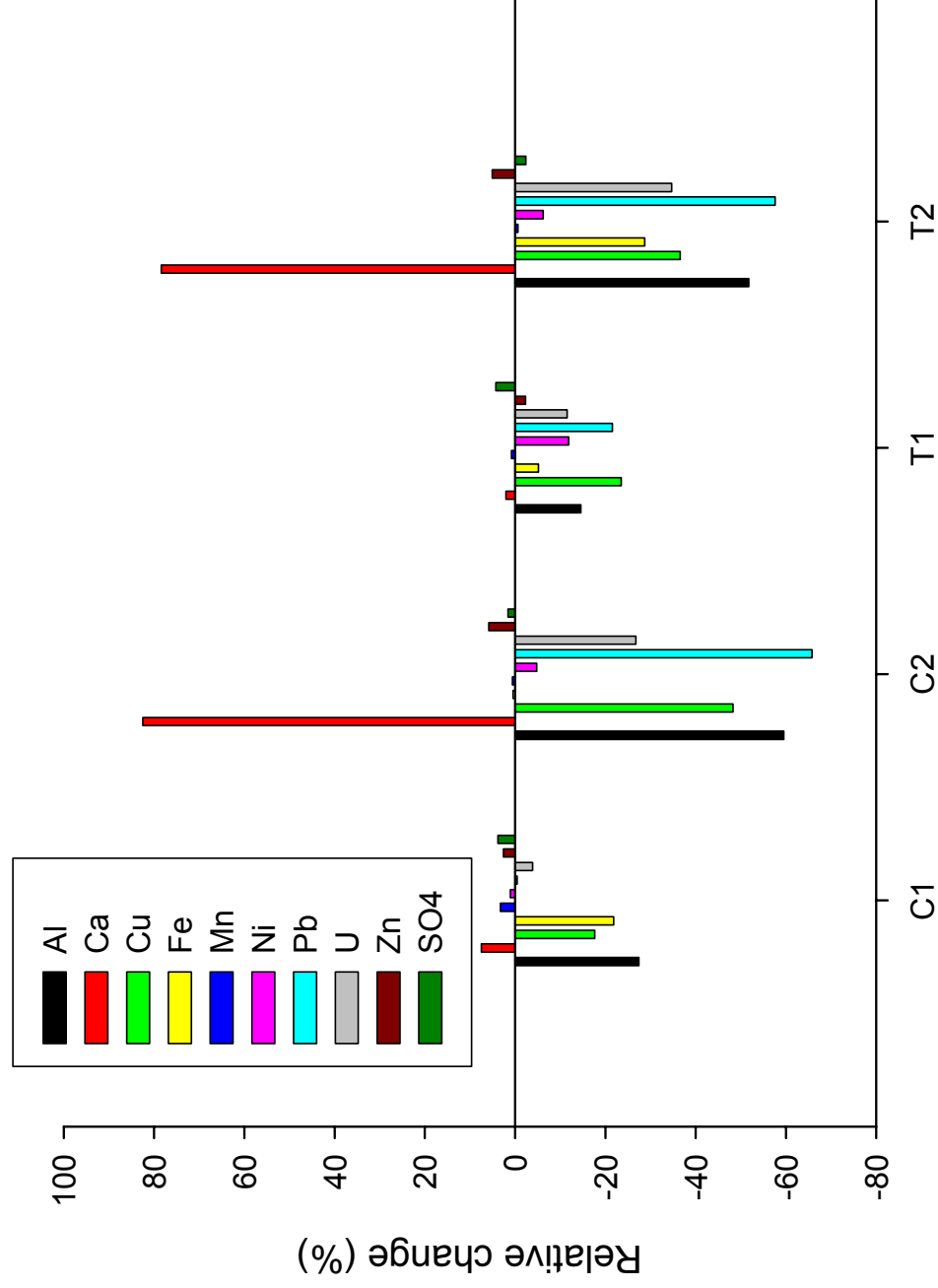


**Figure 5-7:** The effect of beverage on the concentration of soluble Al, Ba, Cd, Cu, Fe and Mg





**Figure 5-8:** The effect of beverage on the concentration of soluble Mn, Ni, Pb, U, SO<sub>4</sub> and Zn



**Figure 5-9:** Summary of treatment effects corrected for the diluting effect of milk on the concentration of metals and non-metals in solution

## 6 ACTIONS TAKEN BY ERA RANGER MINE

This section documents and describes how ERA responded to the incident including the actions which were taken as part of Disaster Management Recovery. Attention is given to the process that was followed in the lead-up to a return to work involving meetings and discussions with the workforce and stakeholders to ensure that concerns were met, risks were minimised and that the requirements set internally by ERA and externally by the authorities were fully achieved.

### 6.1 Disaster management recovery

Disaster management recovery was declared at 10:15 h on 24 March 2004 immediately after DBIRD, OSS and the NLC were informed formally by telephone of the incident by the General Manager Operations at Ranger Mine and, at which time, shutdown procedures for the acid and processing plants were started. In the lead-up to the declaration, staff on site had been warned by Gai-phone and radio not to use the potable water system (08:10 h) and mine operation staff who had arrived to start day shift were sent home (08:30 h). By 09:00 h, the local Jabiru doctor had been contacted to advise him of the incident and preparations made for employees who felt ill to be directed to the Health Centre in Jabiru. Local businesses and premises in Jabiru East were advised that their potable water supply had been disconnected (09:15 h).

The primary objectives and the immediate response taken as part of disaster management recovery were to:

- achieve safe closedown of the plant;
- prevent any further contamination of the potable water supply and access by mine personnel and the public to contaminated water;
- determine the personnel who may have either consumed, or had skin contact with, contaminated water drawn from the potable water system and provide support;
- safeguard the health of those staff remaining on site and the public at Jabiru East by organising the provision of bottled water and chemical toilets;
- establish the extent of contamination of the potable water system particularly in the supply to Jabiru East;
- set up effective communication and liaison with workers, the Jabiru community, Traditional Owners, stakeholders and the media to provide regular updates on developments related to the incident;
- ensure that the authorities investigating the incident were provided with the necessary support from site personnel; and
- verify the cause of the incident.

The secondary objectives were to:

- instigate an internal investigative process into the cause of the incident and future prevention;
- determine a strategy, in consultation with the authorities, for the re-instatement of potable water supply to the Ranger site and Jabiru East; and
- establish a plan, in consultation with the authorities, for a return to work and the resumption of mining, milling and processing at Ranger.

### 6.1.1 Reinstatement of the potable water supply

Reinstatement of the potable water system at Ranger and Jabiru East required a staged approach which involved locating all potable water outlets, verifying their locations against records of the potable water supply system, and the decontamination and remediation of the supply system at these outlets to a standard which met public health requirements.

There does not appear to be a recognised set of either Territory, State or National guidelines or procedures which determine how a potable water system might be remediated following its contamination. Perhaps this is not surprising given that the form remediation might take in any particular circumstance will depend ultimately on the contaminants themselves and their interaction with the delivery system. In the case of Ranger process water, the dominant contaminants are inorganic comprising metals, metalloids and non-metals, with trace levels of organics made up of flocculating agents, kerosene and tertiary amine derived from processing<sup>21</sup>. However, recent analysis of process water has shown that organics are present at undetectable levels<sup>12</sup> and hence any residual absorption by plastics which are components of the potable water delivery system would have been negligible.

With a few exceptions, the majority of contaminants in process water, once mixed with potable water, remained in solution (refer to Section 5.1 for a more complete discussion of the mixing chemistry). However, precipitation of amorphous aluminium hydroxide most likely occurred with the extent of this and associated heavy metal coprecipitation dictated by the relative dilution of process water by potable water which, in turn, determined pH and whether the saturation index for amorphous  $\text{Al}(\text{OH})_3$  remained high enough to still allow it to precipitate. In addition, some heavy metals such as U which have a high charge density are commonly adsorbed on to surfaces which, in the case of pipes and hot water systems particularly, may also include oxyhydroxides and lime deposits present as scale.

There were a number of factors that had to be considered in relation to removing contaminants from the potable water system. To evacuate contaminated water held within the system, flushing of the mains and feeders had to take place at an accessible and convenient point downgradient of contamination dispersion to avoid remnant slugs of contaminated water remaining in the system. It was also important that flushing was effective in removing residual, sorbed metals and precipitates, and that any tank sludge that may have become contaminated or contained precipitates was removed. Contaminated water could not be released to the environment and had to be evacuated to an appropriate storage pond on site. Lastly, there had to be an acceptable and agreed water quality standard by which it would be demonstrated that remediation had been successfully achieved, public and worker health was assured, and that a monitoring program to provide such safeguards was in place.

At an early stage in planning the remediation of the potable water system it was determined that, if it all possible, it was preferable to use potable water alone as the flushing agent rather than a chemical agent. Potentially, the use of a relatively weak bicarbonate solution might have some advantage by aiding the desorption of U as negatively charged carbonate complexes from surfaces making up the delivery system under slight to moderately alkaline conditions. In this regard, a  $\text{NaHCO}_3$  solution itself carries a very low risk of impact to people and the environment. Evidence of U sorption on surfaces of the potable water delivery system comes from the higher dilution ratios of observed U concentrations to the U content of process

<sup>21</sup> Refer to Appendix (*Proposal to Recommence Milling Activities at Ranger on Tuesday April 6<sup>th</sup>*)

water (eg refer to Tables 4.1 & 4.2 and Jabiru East Potable Water Tank overflow composition- Section 4.1). The disadvantages of using a flushing agent were partly conceptual (ie the risk of misperception by the workforce and public that contaminants were being replaced by other contaminants), operational (ie preparing large volumes of flushing solution), efficacious (ie the uncertainty of whether a flushing agent was required) and economic (ie even if bicarbonate was more efficient in removing sorbed U, the system would still need to be flushed with potable water to remove the sodium bicarbonate). Consequently, it was decided that the disadvantages outweighed the advantage and potable water alone would be used as the flushing agent.

The principle contained in Environmental Requirement (ER) 3.4 determined how flushed water would be managed. ER 3.4 states:

*Process water must be totally contained within a closed system except for:*

*(b) .....process water which has been treated to achieve a quality which:*

*(ii) is not less than that of the water to which it is discharged.*

Hence it was determined that flushed water which was highly diluted process water should be directed to RP2.

The principle used to decide whether flushing was successful and the endpoint for meeting water quality objectives at which flushing could cease was the current Australian Drinking Water Guidelines (1996)<sup>22</sup>. These form the basis upon which the water utility in the Top End of the Northern Territory (ie Power & Water Authority - PAWA) and the Department of Health & Community Services (DHCS), Northern Territory under public health legislation interpret whether potable water standards are met. Advice was obtained from PAWA and DHCS. Hence, as an integral part of the exercise to flush the potable water system at Ranger and Jabiru East, it was important that representative samples of water were taken from potable supply points and that these were analysed frequently during remediation to determine whether water quality objectives were attained. To this end, during flushing, interpretation was augmented by *in situ* measurements of electrical conductivity (EC) as a guide to verifying that entrained contaminated water was being flushed. In addition, after lines were flushed, individual outlets were sampled and analysed repeatedly with time for the suite of elements that comprise the Australian Drinking Water Guidelines but initially in filterable<sup>23</sup> (ie soluble) form. Concentration data are summarised graphically in Appendix B. Verification that the potable water supply at Ranger and Jabiru East complied with the minimum standards listed in the Australian Drinking Water Guidelines was determined by total assays of inorganic chemicals<sup>24</sup>, and on a limited number of samples for gross  $\alpha$  and  $\beta$  counts, bacterial counts, and Total Petroleum Hydrocarbons (TPH) and BTEX<sup>25</sup>. In addition, pH, EC and total calcium were determined on the majority of samples. All analyses apart from *in situ* EC gross  $\alpha$  and  $\beta$  and bacterial counts, were conducted independently by NTEL, Berrimah which is a NATA accredited laboratory. Gross  $\alpha$  and  $\beta$  counts were undertaken by Western Radiation, Perth (NATA accredited), bacterial counts by NT Dept of Industry & Resource Development (Water Microbiology Laboratory, Berrimah), and TPH and BTEX by AGAL, Sydney (NATA accredited).

<sup>22</sup> National Health & Medical Research Council and Agriculture & Resource Management Council of Australia & New Zealand 1996. Australian Drinking Water Guidelines.

<sup>23</sup> <0.45  $\mu$ m fraction

<sup>24</sup> Listed under 'Summary of Inorganic Chemicals' (GL-8) in the Guidelines and comprising aluminium, ammonium, antimony, arsenic, barium, beryllium, boron, cadmium, chloride, chromium, copper, iodine, iron, lead, manganese, mercury, molybdenum, nickel, nitrate, nitrite, selenium, silver, sodium, sulphate, tin and zinc.

<sup>25</sup> BTEX is a standard analytical suite of mono-aromatic hydrocarbons represented by (b)enzene, (t)oluene, (e)thylbenzene and (x)ylene.

Background data on the composition of uncontaminated potable water is given in Tables 6.1 & 6.2. The water is characterised by a circumneutral/slightly alkaline pH, is slightly hard and has a low free salt and trace metals content. The current water supply from Brockman Borefield was first connected in mid 1988. Prior to this time, potable water had been obtained from the Magela Borefield which had also served the former township at Jabiru East. Since 1988, there has been a gradual and similar relative increase (ie around 4 fold) in the concentration of free salt (as measured by sulphate) and of dissolved U which now appears to have reached a plateau (Figure 6.1). The reason for this increase is unclear but is thought to be hydrogeologically influenced as a consequence of the dewatering of the local groundwater table. Evidence of a previous incident when potable water had become contaminated with process water in 1983 is clearly shown in Figure 6.1. However, the other sulphate spikes that are shown are aberrant and probably indicative of sample contamination resulting from poor quality control either during sampling or analysis.

### Ranger minesite

The entry of process water into the potable water system gave rise to extensive contamination of the supply within the minesite including tanks and supply pipes as shown by sampling undertaken on 24 March and discussed previously in relation to contaminant dispersion (Section 4) and toxicological considerations (Section 5.1). A complete record of water sample analyses can be provided separately in electronic form.

A summary of the sequence of events which constituted the remediation of the potable water system at Ranger is given in Table 6.4. Sampling of the potable water system to determine water quality during the remediation began on 26 March and continued to be undertaken frequently until it could be verified that the system had recovered. The conditions attached to declaring that potability standards had been attained is given in *Proposal To Recommence Milling Activities at Ranger on Tuesday April 6<sup>th</sup>*.

The results of analyses are summarised graphically in Appendix B using EC, manganese and uranium as indicators of water quality. Results are collated for areas of the mine site and the sampling points making up each area are listed.

### Jabiru East

A summary of results is contained in Appendix B. There was no evidence from samples taken before or after flushing that any resident contamination was present.

The resumption of Brockman borewater supply as industrial water took place on 16 April after consultation and agreement with DBIRD, DHCS and OSS. To date<sup>26</sup>, the reinstatement of the public potable water supply awaits the approval of the DHCS following analyses of three successive samples from several key locations meeting microbiological and chemical standards in accordance with NH&MRC national water quality guidelines.

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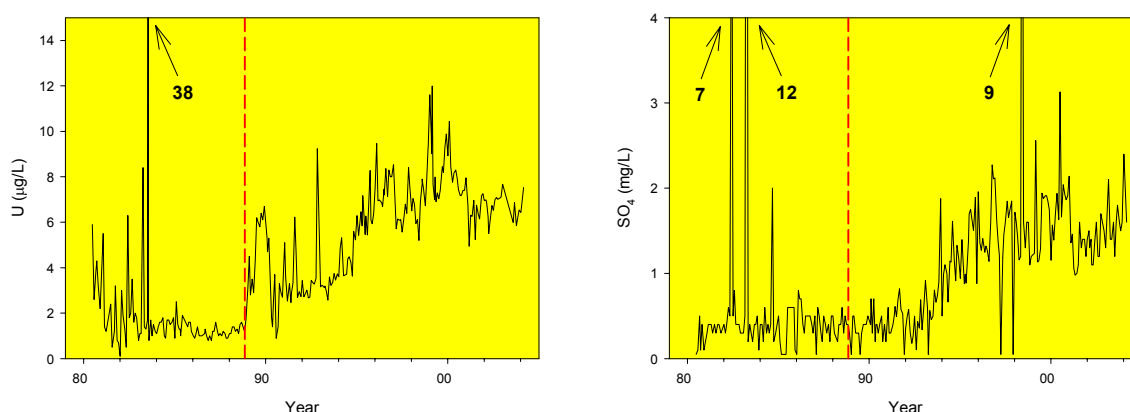
<sup>26</sup> 19 May 2004

**Table 6-1:** Composition of potable water from the Brockman Borefield (January 1989–March 2004) prior to the incident - General parameters and major ions (filterable)

	pH (units)	EC ( $\mu\text{S}/\text{cm}$ )	Ca (mg/L)	Mg (mg/L)	K (mg/L)	Na (mg/L)	Cl (mg/L)	NO <sub>3</sub> (mg/L)	SO <sub>4</sub> (mg/L)
n	193	193	36	68	31	38	26	21	183
Mean	7.8	364	21.2	38.8	0.3	0.3	2.7	2.7	1.2
$\sigma$	0.2	43	2.1	4.9	0.1	0.1	2.6	2.6	0.9
Median	7.8	362	21.1	39.7	0.2	0.2	0.6	0.6	1.2
Min	7.0	233	15.4	7.7	0.1	0.1	2.0	2.0	<0.1
Max	8.4	689	26.0	44.5	1.3	1.3	4.4	4.4	9.4

**Table 6-2:** Composition of potable water from the Brockman Borefield (January 1989–March 2004) prior to the incident - Trace metals (filterable) and <sup>226</sup>Ra (filterable)

	Cu ( $\mu\text{g}/\text{L}$ )	Mn ( $\mu\text{g}/\text{L}$ )	Pb ( $\mu\text{g}/\text{L}$ )	U ( $\mu\text{g}/\text{L}$ )	Zn ( $\mu\text{g}/\text{L}$ )	<sup>226</sup> Ra (mBq/L)
n	35	44	25	187	37	156
Mean	22.8	2.7	0.8	5.9	106	10.1
$\sigma$	11.0	12.3	0.5	2.1	22	24.9
Median	20.9	0.5	0.7	6.3	103	5.2
Min	3.1	<0.1	0.3	0.9	51	1
Max	56.9	80.9	3.0	12.0	158	231

**Figure 6-1:** Historical change in dissolved U and sulphate in potable water at Ranger (Note the dashed line shows the switchover date from Magela to Brockman borewater)

**Table 6-3: Ranger Mine– Drain and Flush Sequence of Events – Potable Water System**

Date	Approximate time	Action
28/3/04	2 pm	Flushing of main line to mine facilities commenced
29/3/04	9 am	Main line flushing ceased; all taps turned on and flushing of all outlets commenced.
	10 am	All outlets at Inganarr training centre and security were flushed
	4 pm	All outlets at Inganarr training centre, security and mine facilities turned off
30/3/04		Outlets at the mine were flushed again; pH and EC tested OK at all points

**Table 6-4: Jabiru East– Drain and Flush Sequence of Events – Potable Water System**

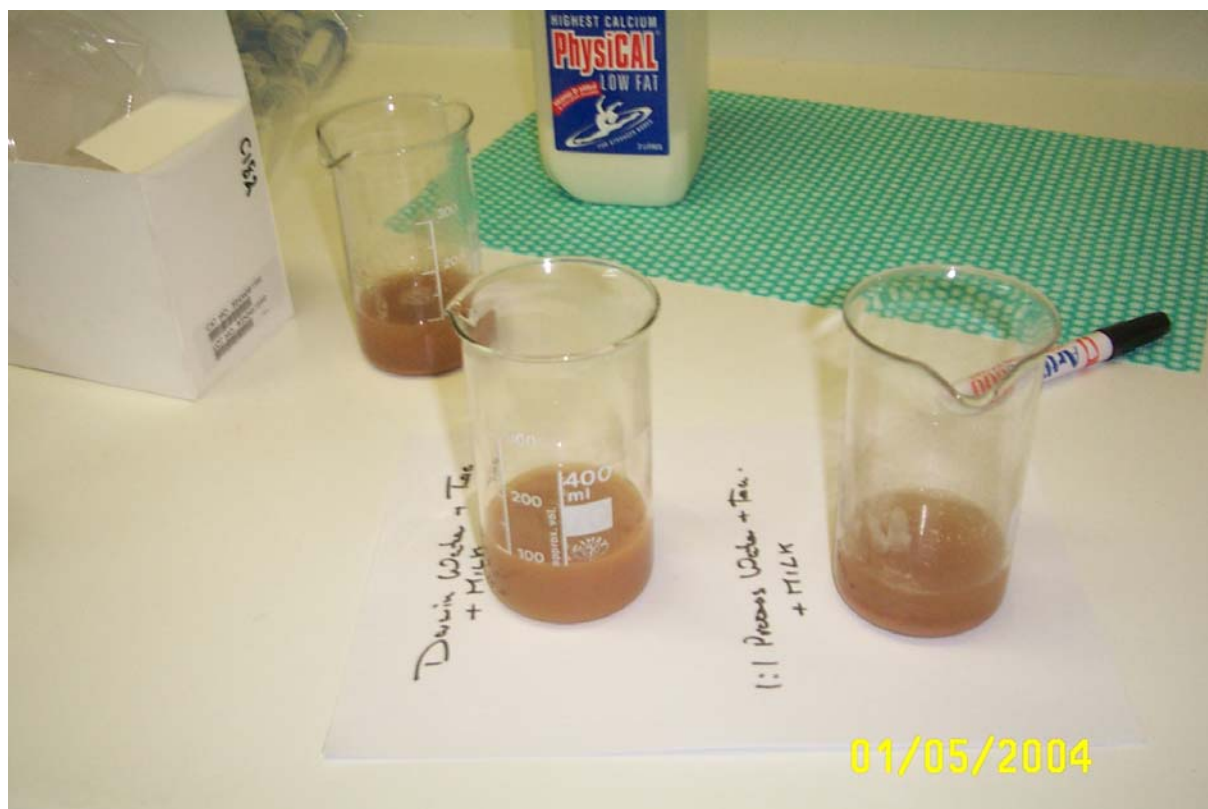
Date	Approximate time	Action
24/3/04	8 am	Jabiru East line isolated
	2 pm	Commenced pumping water from Jabiru East Tank back to site
25/3/04	4 am	Tank emptied; pumping stops
	9 am	Commenced pumping Magella Borefield water into Jabiru East Tank
	10 am	Drained Jabiru East line at the sump near tanks until empty; approximately 20,000 L removed and taken back to site.
	1 pm	Flushed line from Gagadju back to tank using fire truck; approximately 12,000 L flushed down the line
	2 pm	Flushed back from <i>eriss</i> tanks to Jabiru East Tanks and tested pH and EC at the tank while flushing; approximately 20,000 L used
	4 pm	Commenced pumping water from Jabiru East tank back to site
	7 pm	Pumping back to site stopped; tank now empty
26/3/04	7 am	Pumping at Magella Bore stops
	9 am	Pumping out of Jabiru East Tanks back to site resumes
	10 am	Residual water removed from bottom of Jabiru East tank and brought back to site in Collex truck.
27/3/04	11 am	Jabiru East Tank completely emptied
	1 pm	Magella bore restarted and filling of Jabiru East tank commences
28/3/04	8 am	Commenced flushing back from Jabiru East Tank to site with Magella water
	11am	Flushing completed; no evidence of contamination from pH and EC values; approximately 300,000L L flushed
30/3/04	All day	All Jabiru East potable water points identified and locked out using 'out of service' procedures
31/3/04		Jabiru East line re-pressurised
		2 hydrants at extremities were flushed for approx 10 min; water tested for pH & EC; all OK.
		All accessible taps were flushed for between 10 – 20 min; water tested for pH & EC; all OK
1/4/04		Samples taken for analyses and EC & pH testing of remaining outlets completed
2/4/04		All accessible outlets flushed for 10 – 20 min and pH & EC tested.; all OK



## **Appendix A: Photographs: Tea and coffee experiment**











## **Appendix B: Water quality analyses of samples from selected individual potable water outlets with time following flushing, Ranger Mine & Jabiru East.**

Note: Closed and open symbols in the graphs depict filterable and total respectively.  
Dashed lines on the graphs depict Australian Water Quality Guideline concentrations.

Figure B1: Quality of the potable water supply in the acid plant (Area 28) and power station (Area 41)

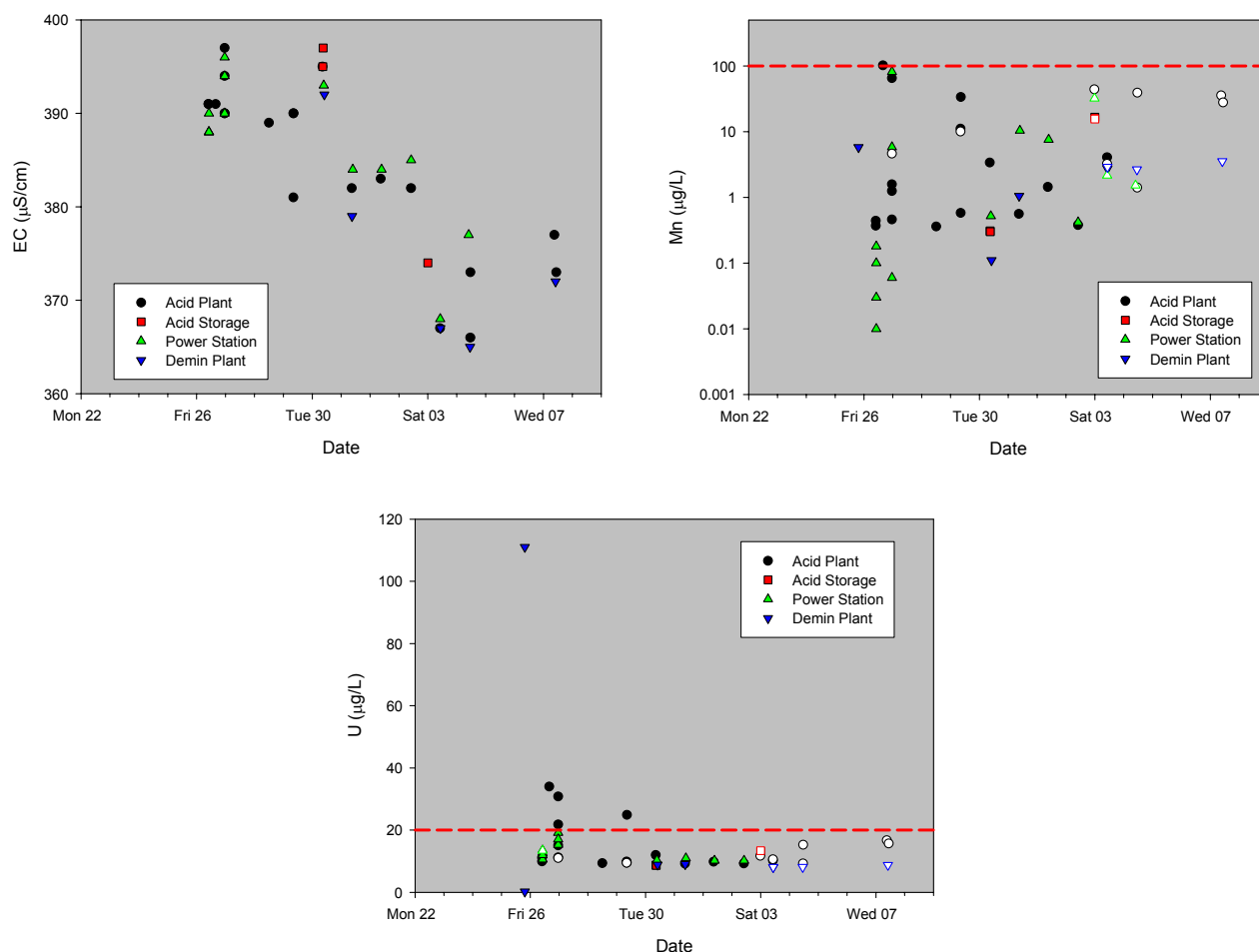


Table B1: Sampling points making up the acid plant and power station

Acid Plant		Power Station	
Code	Location	Code	Location
APSH1	Shower 1	PSUSSH1	Upstairs Shower 1
APSI1	Sink 1	PSUSSI1	Upstairs Sink 1
APCRW	Crib Room Washbasin	PSDSSH1	Downstairs Shower 1
APCRB	Crib Room Bubbler	PSDSSI1	Downstairs Sink
APOB1	Outside Bubbler 1	PSCRW	Crib Room Washbasin
APOB2	Outside Bubbler 2	PSCRUB	Crib Room Upstairs Bubbler
APOT	Outside Tap	PSWDB	Workshop Downstairs Bubbler
APOT	Acid Plant Outside Tap		
APTFSH1	Tank Farm Safety Shower		

Figure B2: Quality of the potable water supply in engineering (Area 34) and administration (Area 32)

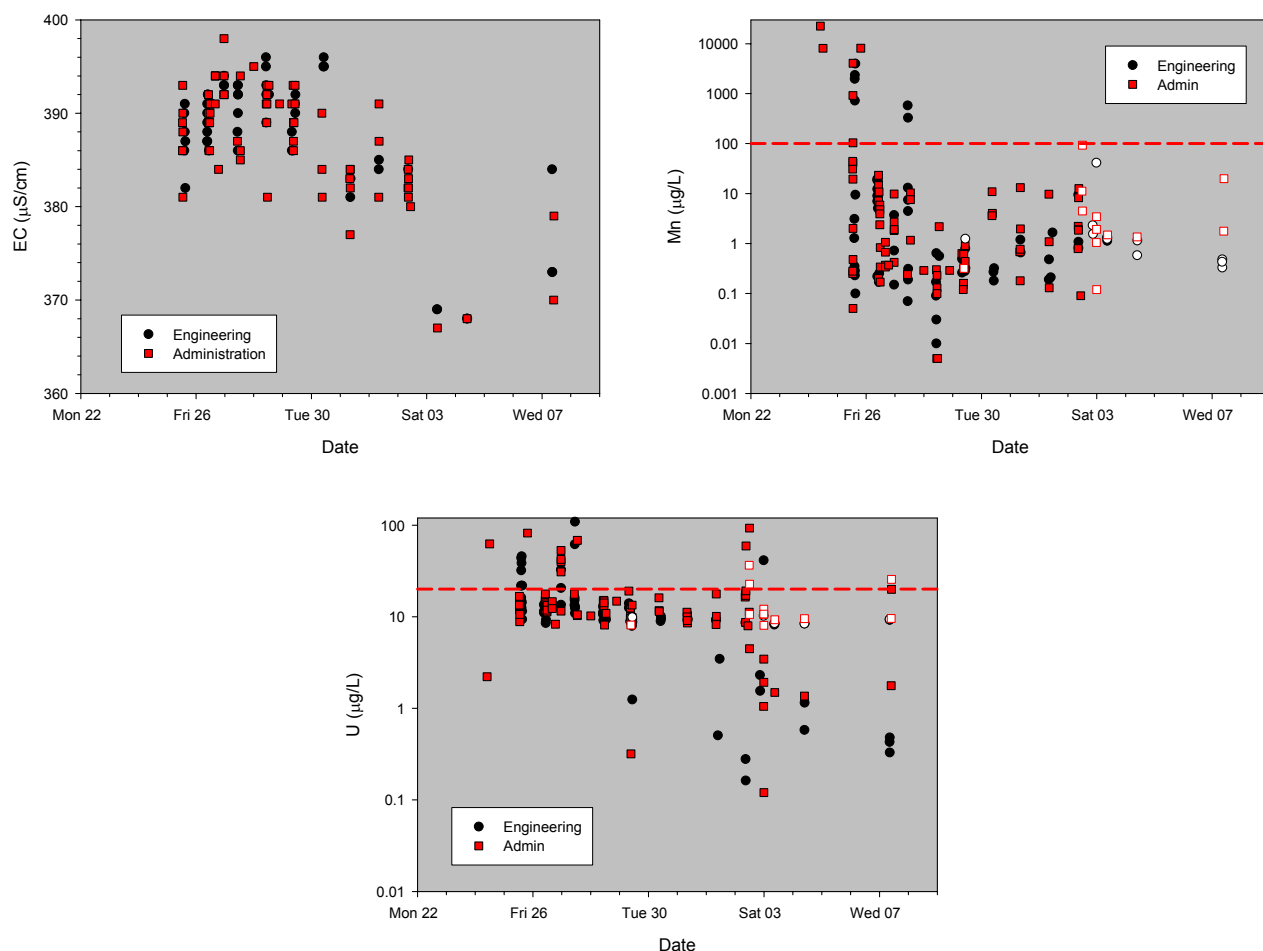


Table B2: Sampling points making up the acid plant and power station

Engineering		Administration	
Code	Location	Code	Location
DSCRB	Day Services Crib Room Bubbler	AHWF	Admin Hot Water Plant Feed
DSCRU	Day Services Crib Room Urn (Hot Water Dispenser)	ASHM1	Admin Mens Shower 1
DSCRW	Day Services Crib Room Wash Basin	ASHM2	Admin Mens Shower 2
DSIM1	Day Services Ice Machine #1	ASHM3	Admin Mens Shower 3
DSSI1	Day Services Sink 1	ASHM4	Admin Mens Shower 4
DSWSSI1	Day Services Workshop Sink 1	ASHW1	Admin Womens Shower 1
EBACRB	Engineering Building Admin Corridor Bubbler	ASHW3	Admin Womens Shower 3
EBCRB	Engineering Building Crib Room Bubbler	ASIM1	Admin Mens Sink 1
EBCRU	Engineering Building Crib Room Urn (Hot Water Dispenser)	ASIM2	Admin Mens Sink 2
EBCRW	Engineering Building Crib Room Wash Basin	ASIM8	Admin Mens Sink 8
EBOB	Engineering Building Outside Bubbler	ASIW1	Admin Womens Sink 1
EBOIM	Engineering Building Outside Ice Machine	ASIW4	Admin Womens Sink 4

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Engineering		Administration	
Code	Location	Code	Location
EBSIM1	Engineering Building Mens Sink 1	DOSH1	Doctors Office Shower 1
EBSIM2	Engineering Building Mens Sink 2	DOSI1	Doctors Office Sink 1
EBSIW1	Engineering Building Sink Womens 1	DOSI2	Doctors Office Sink 2
EHWF	Engineering Building Hot Water Plant Feed	GEOB	Geology Bubbler
ESHM1	Engineering Building Mens Shower 1	GMCRU	General Managers Crib Room Urn (Hot water dispenser)
ESHM2	Engineering Building Mens Shower 2	GMCRW	GM Crib Room Wash Basin
ESHM3	Engineering Building Mens Shower 3	GSIM1	Geology Sink Mens Room 1
ESHM6	Engineering Building Mens Shower 6	GSIM2	Geology Sink Mens Room 2
ESHW1	Engineering Building Womens Shower 1	GSIW1	Geology Sink Womens 1
ESIW1	Engineering Building Womens Sink 1	HRCRB	HR Crib Room Bubbler
MWB	Mechanical Engineering Washhouse Bubbler	HRCRW	HR Crib Room Wash Basin
SPOCRW	Supply Office Crib Room Wash Basin	ITCRU	IT Crib Room Urn (Hot water dispenser)
SPWHB	Supply Warehouse Washbasin	ITCRW	IT Crib Room Wash Basin
<b>Admin (continued)</b>		ITSIM1	IT Sink Mens Room 1
		ITSIM3	IT Sink Mens Room 3
		ITSIW2	IT Sink Womens Room 2
ITSIW1	IT Sink Womens Room 1	MLCRW	Mill Laboratory Crib Room Washbasin
MLCRB	Mill Laboratory Crib Room Bubbler	MLUSI	Mill Lab Upstairs Sink
MLDSI	Mill Lab Downstairs Sink	PW	Potable Water from Admin Crib Room
PTPD	Admin Potable Water Tank Discharge	PWU	Potable Water urn
PWB	Potable water basin	WM2	Washing Machine Feed Tap 2
WM1	Washing Machine Feed Tap 1		
WM3	Washing Machine Feed Tap 3		

Figure B3: Quality of the potable water supply in primary crushing (Area 21), pond water (Area 42) and fine crushing (Area 22)

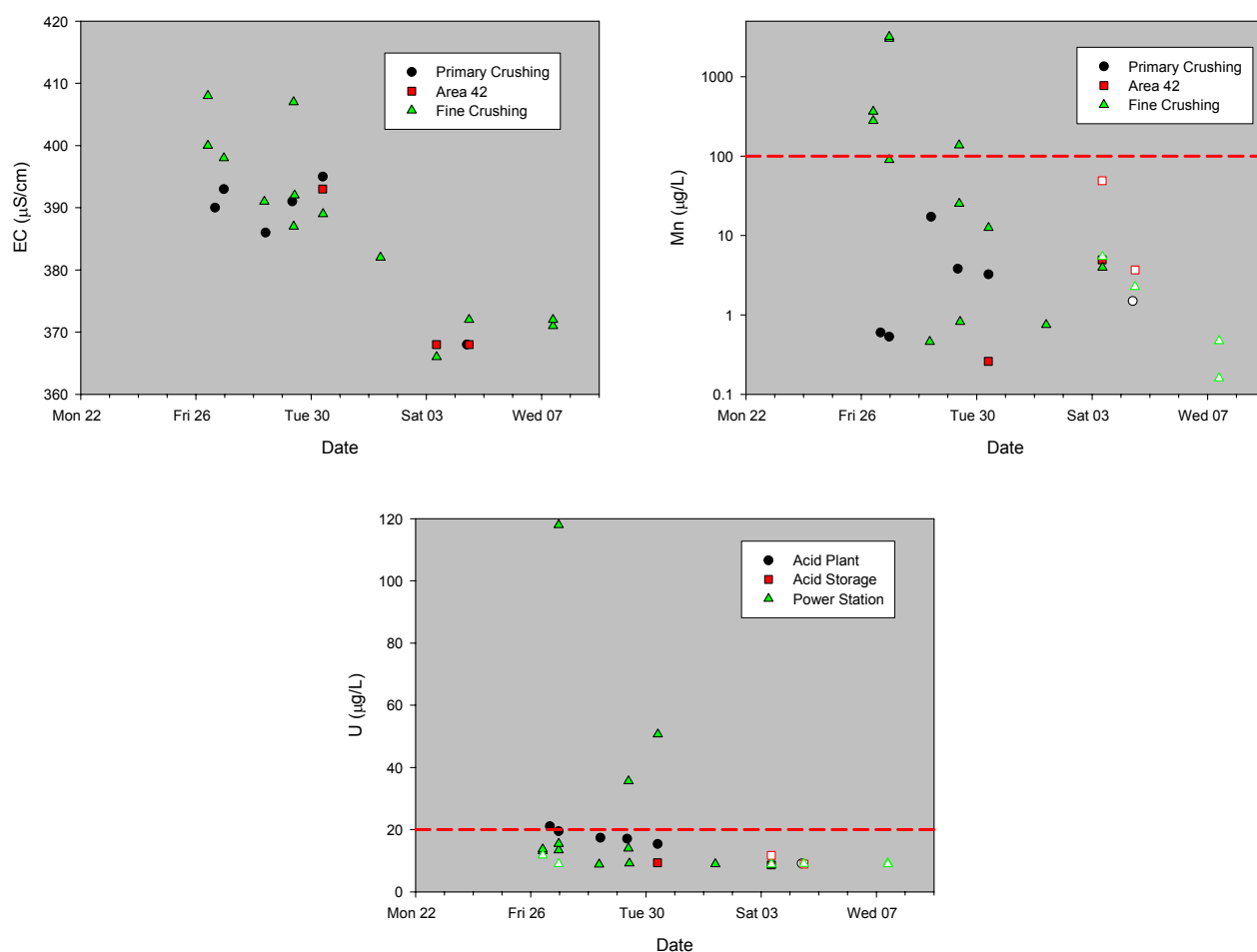


Table B3: Sampling points making up the crushing and pond water areas

Crushing		Pond Water	
Code	Location	Code	Location
PCDSSI1	Primary Crusher Downstairs Sink 1	POWSH	Pond Water Storage Tanks Safety Shower
PCUSSI1	Primary Crusher Upstairs Sink 1		
GPWT	Potable Water Header Tank (on the fine ore bins)		
SCB1	Secondary Crushing Bubbler 1		
SCOSI1	Secondary Crushing Outside Sink 1		
SCSH1	Secondary Crushing Shower 1		
SCSI1	Secondary Crushing Sink 1		
SCU1	Secondary Crushing Urn 1		

Figure B4: Quality of the potable water supply in grinding & pyrolusite (Area 23), leaching, CCDs and clarifier (Area 24) and neutralisation (Area 25)

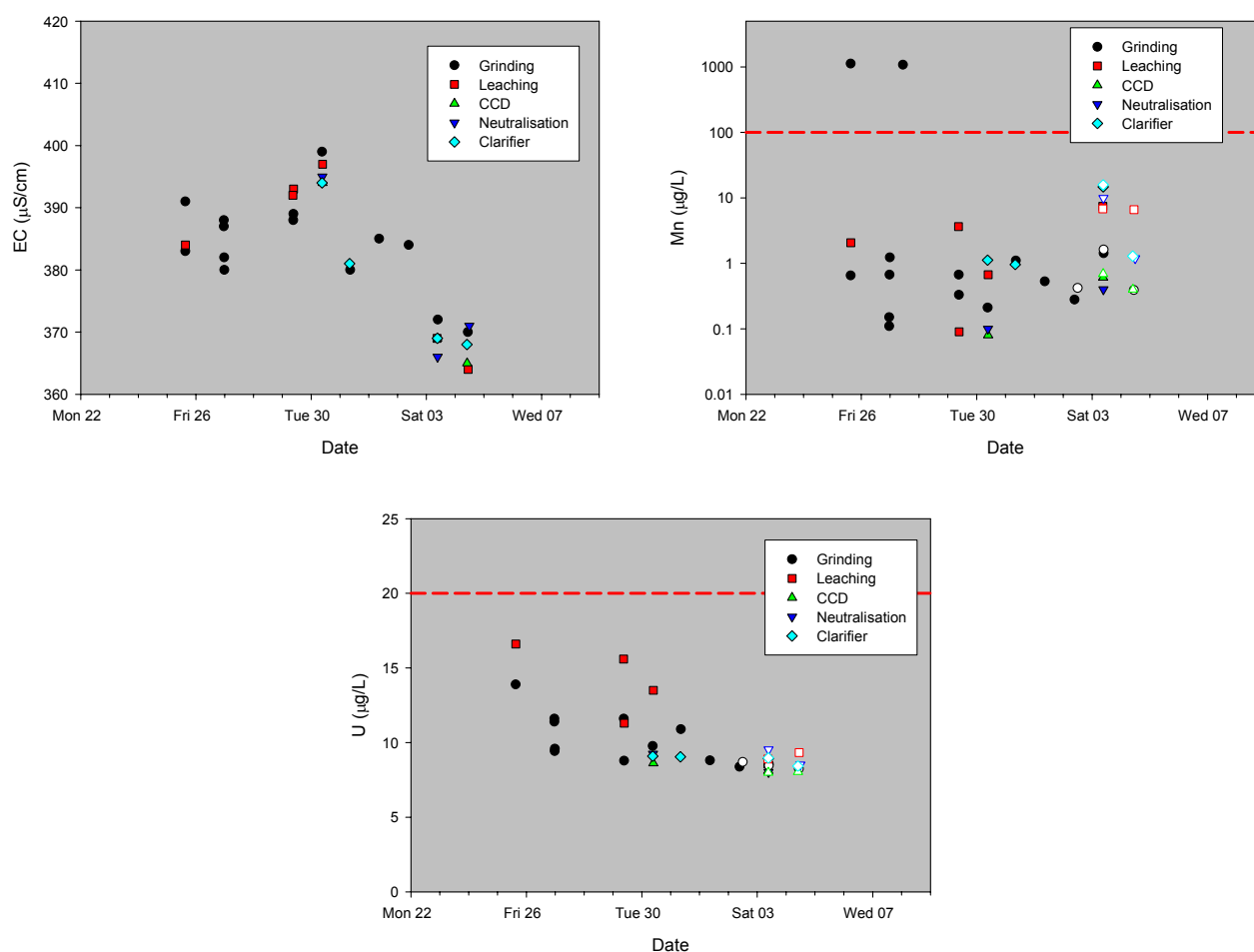


Table B4: Sampling points making up Areas 23, 24 and 25

Code	Location	Code	Location
GCCRB	Grinding Control Crib Room Bubbler	MTOCRW	Mill Training Office Crib Room Wash Basin
GCCRU	Grinding Control Crib Room Urn (Hot water dispenser)	CCDSH1	CCD Safety Shower #1
GCCRW	Grinding Control crib Room Wash Basin	CFSH1	Clarification/filtration Safety Shower #1
GCDSSI1	Grinding Control Downstairs Sink 1	TNSH2	Tailings Neutralisation Safety Shower #2
GCDSSI2	Grinding Control Downstairs Sink 2		
GCUSI1	Grinding Control Upstairs Sink 1		
GCUSI2	Grinding Control Upstairs Sink 2		
LESH	Leaching Tanks Safety Shower		

Figure B5: Quality of the potable water supply in environmental operations, fuel storage (Area 46), lime plant, mine crib and Orica yard

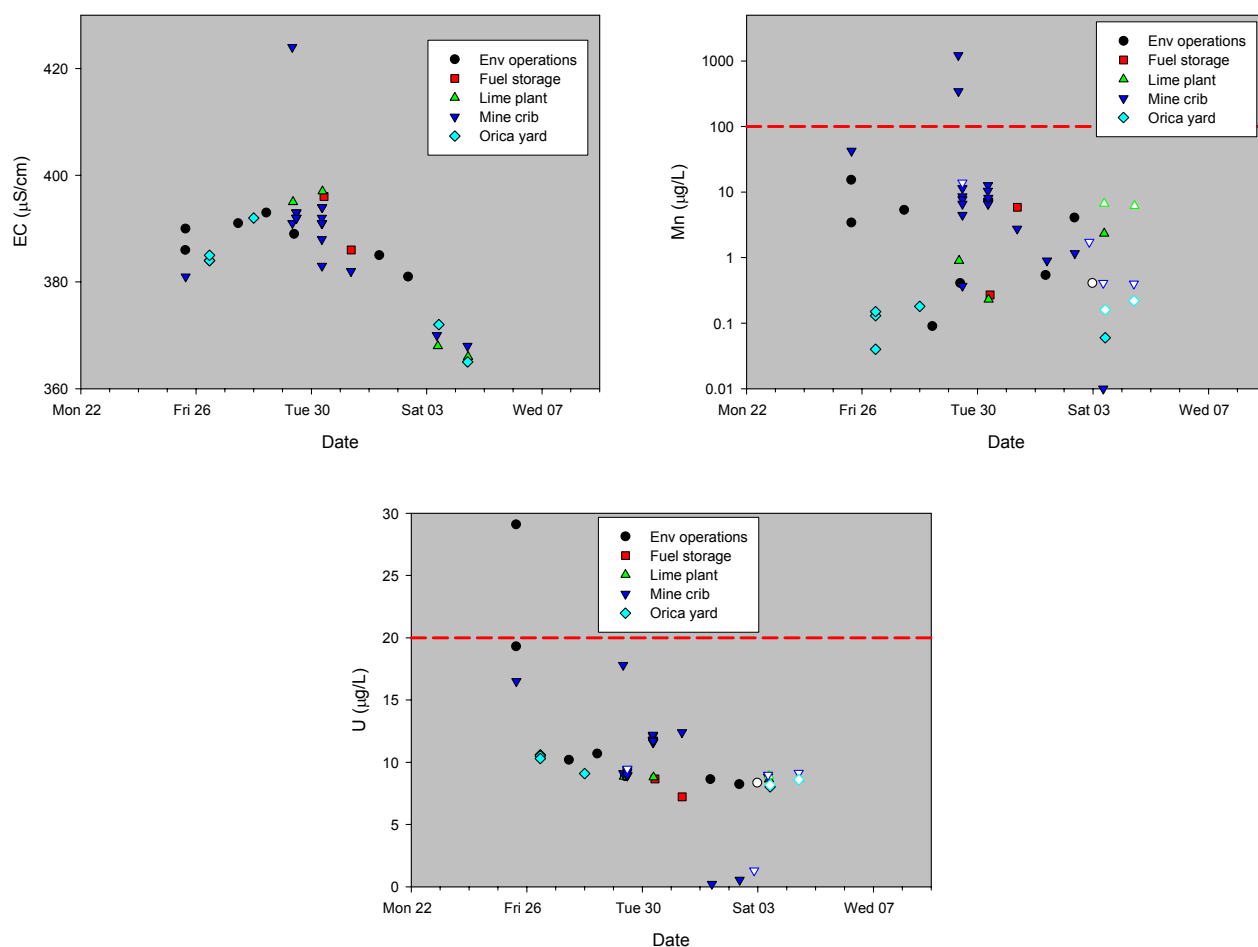


Table B5: Sampling points making up env ops, fuel storage lime plant, mine crib and Orica yard

Code	Location	Code	Location
ELW	Env Ops Laboratory Washbasin	MC050	Mine Crib Building Female Shower
ELB	Environmental Ops Lab Bubbler	MC051	Mine Crib Room Building Womens Shower #2
FFOT1	Fuel Farm Outside Tap #1	MC054	Mine Crib Building Female Hand Wash Basin
LASH	Lime Area Safety Shower	MC057	Mine Crib Building Bubbler Feed Tap
MC002	Mine Crib Building Ice Machine Feed Tap	MC058	Mine Crib Room Tap
MC013	Mine Crib Outside Hand Wash Basin	MC080	Mine Crib Building Ice Machine #1
MC032	Mine Crib Building Male Shower Pole South	MTOCRB	Mine Training Office Crib Room Bubbler
MC042	Mine Crib Building Male Hand Wash Basin	OYSI1	Orica Yard Sink 1
OYSI2	Orica Yard Sink 2	OYCB	Orica yard crib room sink.

Figure B6: Quality of the potable water supply in precipitation, drying and packing (Area 27), and solvent extraction (Area 26)

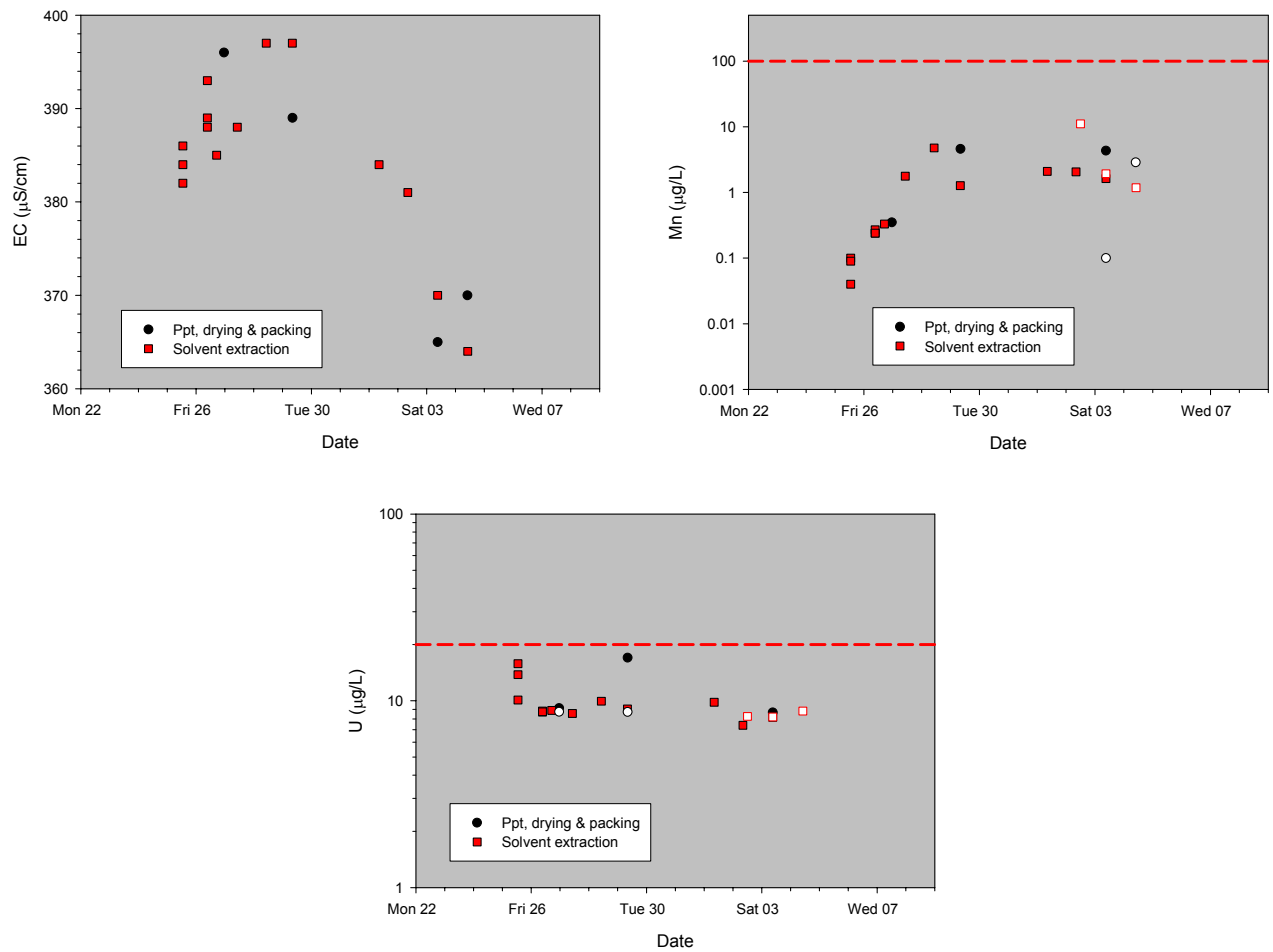


Table B6: Sampling points making up Areas 26 and 27

Code	Location	Code	Location
PPSI1	Process Packing Sink	SXCBB	SX crib room bubbler
SXCBW	SX Crib Room Washbasin	SXEW1	SX Eye Wash 1
SXPPB	SX Potable P Basin	SXSH1	SX Shower
SXSIDS	SX Downstairs Sink	SXSIUS	SX Upstairs Sink

Figure B7: Quality of the potable water supply in the security gatehouse (Area 33), and Simon Carves and water management yards

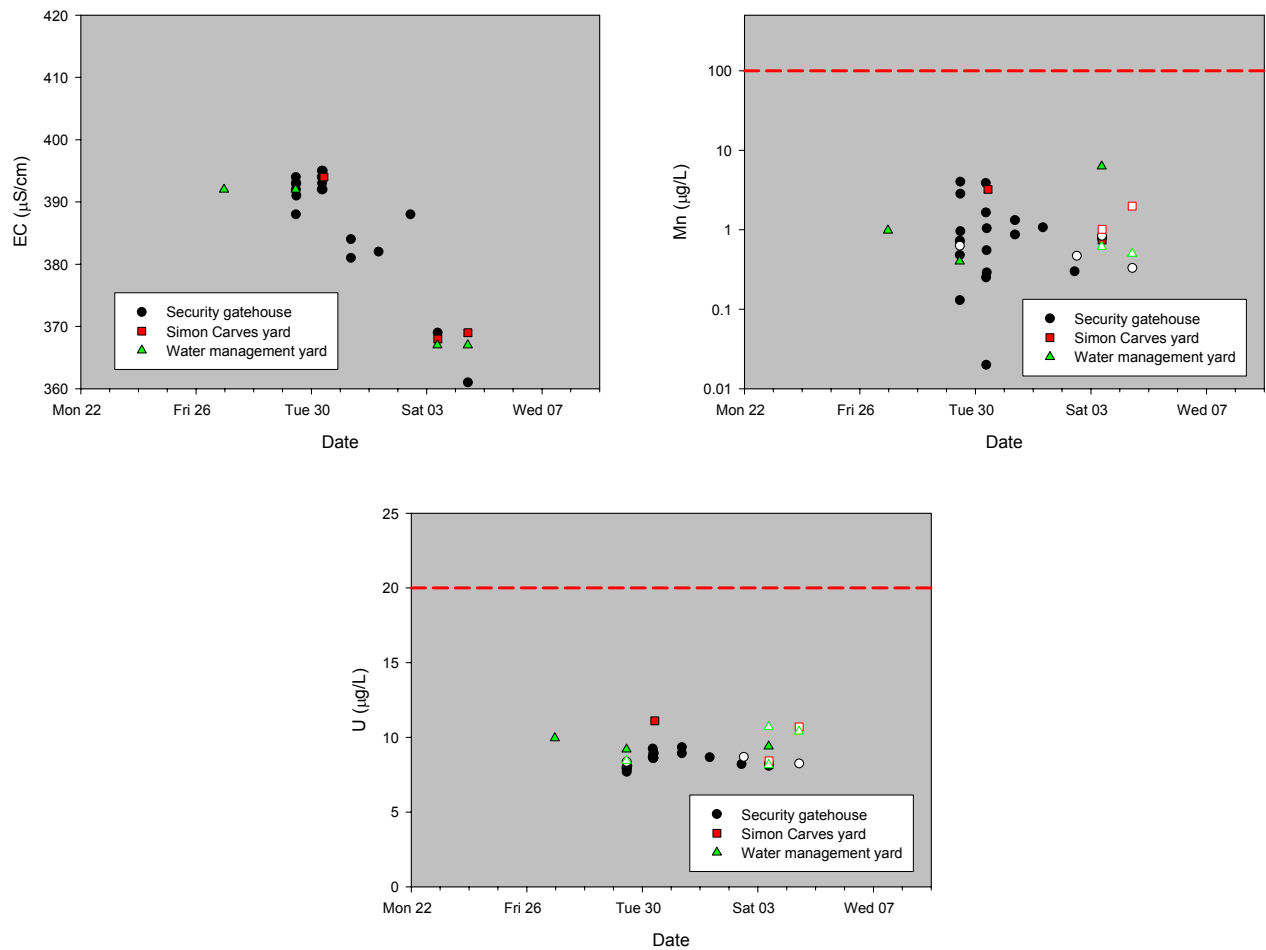


Table B7: Sampling points making up the security gatehouse, and Simon Carves and water management yards

Code	Location	Code	Location
GH003	Gatehouse bubbler feed tap	GH005	Gatehouse toilet wash basin tap
GH009	ESC office tap	GH010	Gatehouse Urn Feed Line
IN003	Inganarr Male Toilets Sink	IN009	Inganarr Female Toilets Sink
IN015	Inganarr Water Cooler Outside Crib Room	SIOT	Simon Carves Yard Outside Tap
WMYSI1	Water Management Yard Sink 1		

Figure B8: Quality of the potable water supply in Jabiru East

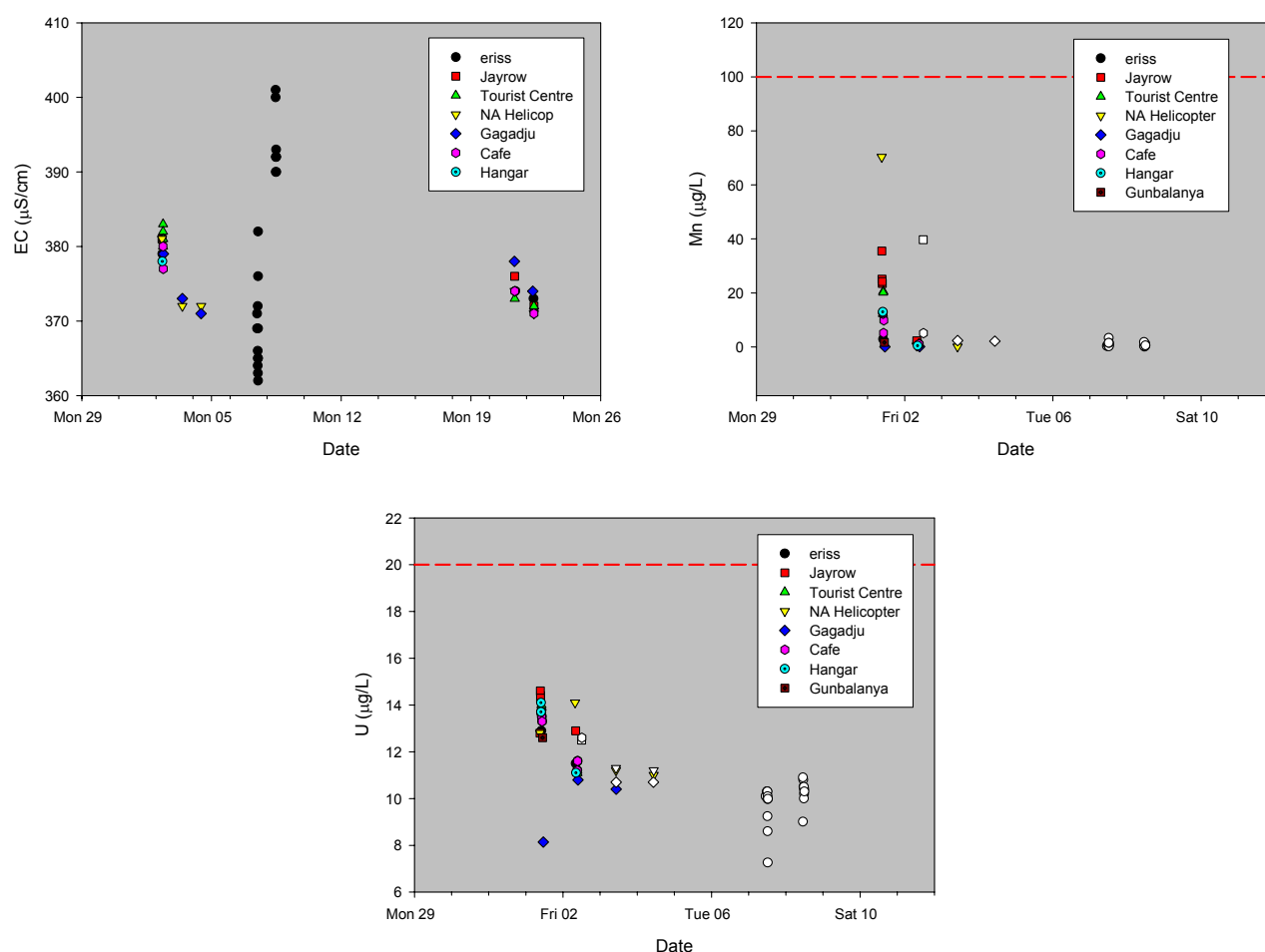


Table B8: Sampling points making up Jabiru East

Code	Location	Code	Location
JE100	ERISS- Admin bubbler	JE155	ERISS - hose reel at covered wetlab
JE101	ERISS - Crib Room urn	JE156	ERISS - Storage Tank Drain Pipe
JE103	ERISS - Ladies Toilet Sink	JE157	ERISS - Wetland Suite Safety Shower
JE104	ERISS - Mens Toilet Sink	JE049	ERISS storage tank feed.
JE105	ERISS - Conference Room Sink	JE011	Tourist Centre mens toilet sink (x2).
JE108	ERISS - Crib Room Hand basin	JE013	Tourist Centre ladies toilet sink (x2).
JE151	ERISS - Ecosystem Protection	JE019	Tourist Centre outside wash sink tap set.
JE152	ERISS - Aquaculture wash hose sink	JE020	Tourist Centre outside wash sink tap set.
JE153	ERISS - SPL outside bubbler	JE033	Tourist Centre office bathroom sink.
Code	Location	Code	Location
JE154	ERISS - Ice Machine	JE005	Jayrow outside tap.
JE036	Gagadju Workshop Tank Tap	JE006	Jayrow laundry tap.
JE028	Cafe washing tub tap.	JE040	Jayrow bathroom sink (hot/cold).
JE029	Cafe hand basin tap (hot/cold).	JE042	Jayrow shower (hot/cold).
JE033	Tourist Centre office bathroom sink.	JE050	Jayrow office crib room sink tap.

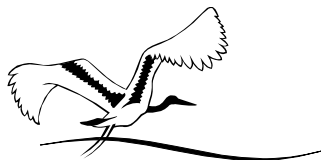
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Code	Location	Code	Location
JE024	Hangar (fuel yard) outside tap (in car port).	JE057	Gunbalanya Air Charters outside garden tap.
JE051	Hangar (fuel yard) safety shower/eye wash.		



## **APPENDIX 6:**

**Jones, Klessa & Hollingsworth (2004) Investigation Report – Jabiru East Potable Water Contamination: Environmental Aspects.**



**ERA**

**Energy Resources of Australia Ltd**

ABN 71 008 550 865

## **Investigation Report**

# **Jabiru East Potable Water Contamination Environmental Aspects**

**Authors: D Jones; D Klessa; I Hollingsworth**

May 2004

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### APPENDIX

Replicate U analyses for Jabiru East Soil Samples

Electronic data – full water quality analyses in Excel workbook supplied on CD on request

## 1 SUMMARY

This report documents the investigations undertaken following discharge through the early morning of 24/03/04 of a small volume of diluted process water from the potable water storage tank at Jabiru East.

Field surveys of water and soil quality in the drainage line between the discharge point and Magela Creek were complemented by a mixing model developed to estimate the volume of water that might have discharged.

The mixing model indicates that a maximum of 16m<sup>3</sup> of process water entered the Jabiru East Potable Water Tank prior to 9.00 am on 24/03/2004 when the inlet to the pipeline to Jabiru East was closed. The large majority of this contaminated water was contained in the tank with the equivalent of about 2.5m<sup>3</sup> of process water discharged to the environment over 8.5 hours. The maximum dissolved concentration of U in the water discharged from the storage tank was around 100 µg/L as shown by chemical analysis of the overflow water.

A water quality survey carried out along the flow line between the tank and Magela Creek indicates at least a ten-fold attenuation of U along the flow path. This result is consistent with the known adsorptive properties of surface soils in the area, and the effectiveness of U removal in wetland filters.

Water quality measurements made in Magela Creek at the downstream compliance point MG009 on the day after the event (24/03) and on several days thereafter indicated no detectable impact, with EC, Mn and U remaining below their respective focus values.

Apart from a slightly elevated level of U in the surface soil immediately downstream of the tank, all other soil concentrations between the source and the creek line (at a spatial separation of 50 m between each sampling point) were within the background range for soils in the local area.

The conclusion is that whilst there was a small release of diluted process water, there was sufficient attenuation capacity in the soils between the tank and the creek line to absorb the U in the water before it reached the creek. The low measured concentrations of U in the soil, including locations immediately downstream of the tank, indicate that no remediation of soil is required.

## 2 CONTEXT

At approximately 9 pm on the evening of Tuesday 23/04/2004 connection was made between the Process and Potable water circuits at the Ranger Mine. The consequence was that over a period of hours process water entered the potable water system including the Header Tank on top of the fine ore bin. This Header Tank provides the gravity head for distribution to the site as well as to a feeder line to Jabiru East.

The pipeline to Jabiru East passes adjacent to a storage tank (JPWT) located at the south east edge of the airport (See location schematic in Figure 2.1). This tank was one of two that were used as the original water supply tanks for the town of Jabiru East. It no longer feeds into the potable water reticulation system and is maintained as an emergency reservoir for fire fighting.

There is a valve assembly that isolates the pipeline from the tank. However, the valve assembly was leaking at the time of the process water incident, allowing a proportion of water from the line to flow under pressure into the tank. Consequently the tank was filled to overflowing from the pipeline.

The surplus water discharged from an overflow pipe and flowed along a formed earthen drain for a distance of about 200m (Figure 2.1). After leaving the drain the water fanned out into a broad swampy area of several hundred metres in length before entering the downstream section of Coonjimba Creek.

At this time of the year the groundwater table is very close to the ground surface, with the majority of the area downstream of the tank being a groundwater discharge area for higher ground. This situation has two important implications, firstly, for dilution of surface flow originating from the tank, and secondly, for limiting the depth of infiltration of water through the soil profile.

It is understood that the potable water storage tank had been overflowing for some time as a consequence of the leaking valve in the delivery pipeline. This has in turn provided conditions conducive to the development of a wetland system along the flow line. The capacity of soils and wetlands on the Ranger site to strip metals and nutrients from site water has been well established and documented.

The composition of potable water (from the Brockman borefield) is provided for reference in Table 2.1. The most important points to note are that this water has an EC around 400  $\mu\text{S}/\text{cm}$  and a uranium content around 7  $\mu\text{g}/\text{L}$ . Whilst this U concentration is very low, the long history of exposure of a soil and wetland environment to water of this composition needs to be considered in the context of levels of U in the soil near the discharge point from the tank. The EC of this water also needs to be considered in relation to measurements of EC made between the tank and the creek line as part of the surface water quality measurements for the current incident investigation.

There are three key issues to be addressed in this report.

- (1) Estimating the equivalent volume of process water that may have escaped from the storage tank during the time window between when the connection was made between process and potable water in the plant, and when overflow from the storage tank ceased at Jabiru East.
- (2) The extent of influence on downstream surface water as a result of the overflow of diluted process water from the storage tank.

- (3) The extent of impact on soils and sediments downstream of the storage tank in the context of background soils levels of U, and whether there is a need to undertake remediation of affected areas.

**Table 2-1:** Filtered compositions of Brockman borefield potable water, process water, and water samples collected at Jabiru East

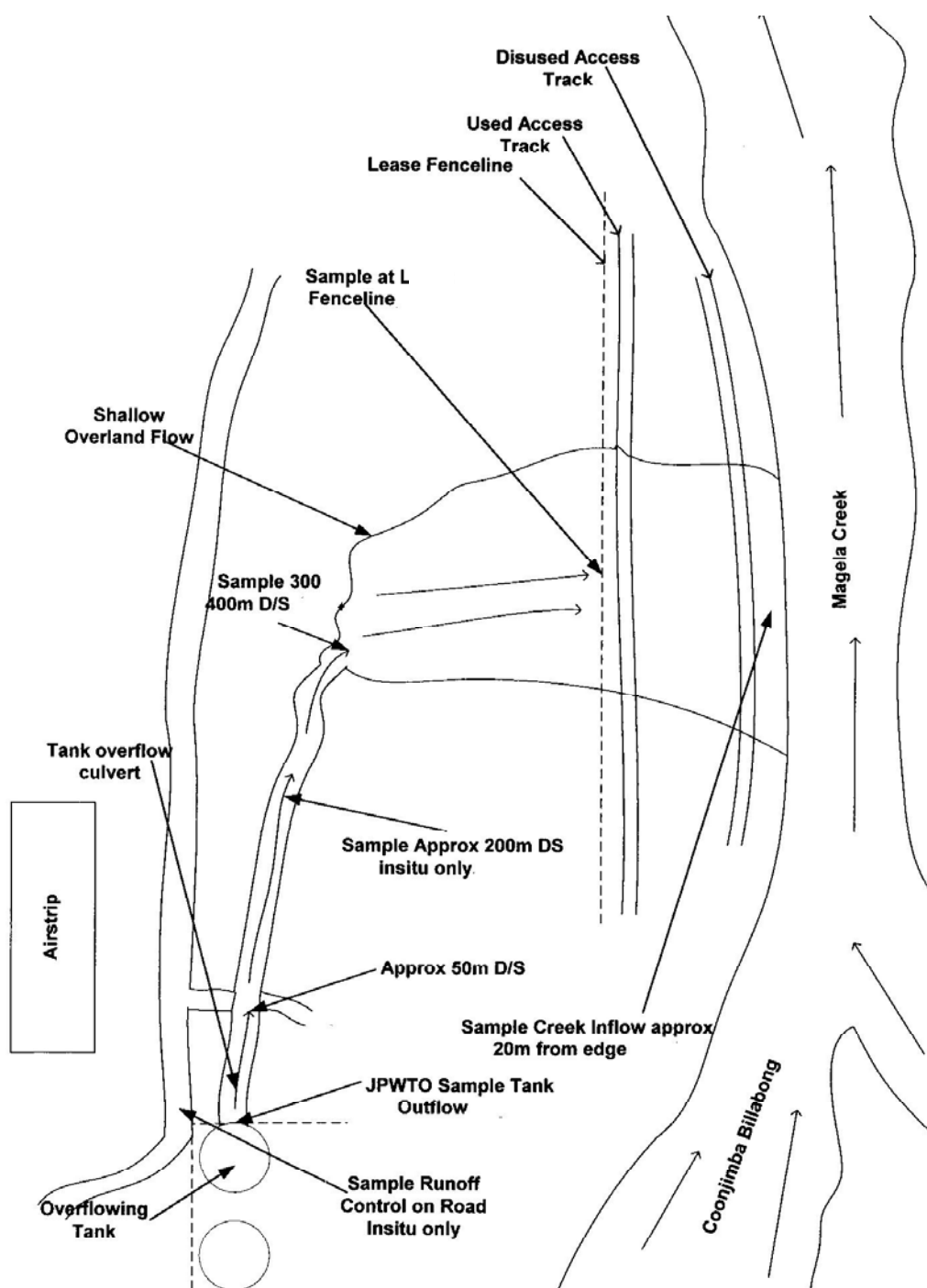
Sampling Code	Sample Description	Sample Number	Date Sampled	Sample Time	Type	EC	pH	Al	Ca	Cu	Fe	Mg	Mn	Ni	Pb	SO4	U	Zn
	Brockman Bore Field (Mean, April2000-Mar 2004)				filtered	393	7.87		21.3	23		39.9	0.2			1.55	6.88	111
B84_3	Brockman Bore Supply	100309	24/03/2004	9:13	filtered	400	-	0.5	22.5	4.02	<20	39.6	0.06	0.57	0.79	0.9	8.38	6.7
PRW	Process Return Water (Mean 15/703 to 10/3/04)				filtered	22800	3.8	368000	508	13560	72090	3660	1822000			22350	14880	5200
EPW	eriss Potable Water Tank	100306	24/03/2004	11:30	filtered	338	-	1.3	23.3	4.04	<20	39.7	1.88	0.24	0.25	1.2	8.23	61.6
GWP	Gagadju Workshop	100308	24/03/2004	10:00	filtered	411	6.88	30.3	22.9	22.8	<20	40.1	0.27	0.23	0.33	0.9	8.05	71.3
JH	Jabiru East Hydrant (opposite core sheds)	100311	24/03/2004	10:15	filtered	1256	6.82	47.2	39.1	114	<20	158	55200	131	5.9	736	116	1540
JPWT	Jabiru East Potable Water Tank	100310	24/03/2004	10:06	filtered	775	7.13	128	27.4	48.8	<20	70.2	14800	35.9	2.01	211	89.9	207
JPWTO	Jabiru East Potable Water Tank Overflow	100307	24/03/2004	9:57	filtered	784	7.2	129	28	44.1	<20	75	17100	41	2.06	239	103	178
					Total			2720	31.1	162	80	82.1	18100	46	14.1	203	184	359
					filtered			26.5	39.1	47.2	<20	154	51700	124	0.37	740	121	2800
					Total			8560	41.5	240	940	162	53700	141	9.44	808	558	3250
	Jabiru East –draining of pipeline to sump	100338	25/03/2004	10:07	filtered			41.3	29.8	25.1	<20	88.7	18900	46.9	0.41	333	119	604
					Total			13200	31.9	459		94.8	20000	58.5	20	344	769	1370
	Jabiru East –draining of pipeline to sump	100339	25/03/2004	10:31	filtered			46.2	29.6	23	<20	83.4	12100	31.3	0.41	284	102	497
					Total			1200	31.7	51.8	180	89.2	12700	32.7	2.72	330	144	589

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**Table 2-2:** Water samples between overflow of tank and Magela creekline

Sampling Code	Sample Description	Sample Number	Date Sampled	Sample Time	Type	EC µS/cm	pH	Al µg/L	Ca mg/L	Cu µg/L	Fe µg/L	Mg mg/L	Mn µg/L	Ni µg/L	Pb µg/L	SO4 mg/L	U µg/L	Zn µg/L
JPWTO	Jabiru East Potable Water Tank Overflow	100422	26/03/2004	10:19	filtered	195	7.14	59	11.2	9.55	20	16.7	472	2.09	0.05	24.3	10.6	34.6
JPWTO50	50 meters downstream	100423	26/03/2004	10:39	filtered	121	6.69	40	7.4	6.12	180	10.8	225	1.44	0.16	5.7	2.96	40.7
JPWTO200	200 meters downstream	100424	26/03/2004	10:46	filtered	44.5	6.66	25.2	1.7	1.3	60	3	62.6	0.34	0.05	1.8	0.386	5.1
JPWTO400	400 meters downstream			10:55	filtered	50	6.63											
EJBFL	Jabiru East Fenceline	100425	26/03/2004	11:11	filtered	146	7.13	15.7	7.9	0.62	40	15	12.8	0.17	0.03	6.6	0.559	2.6
EJBMGCI	Jabiru East Magela Creek Inflow	100427	26/03/2004	11:30	filtered	183	6.19	3.3	3.3	0.19	180	15.1	14	0.1	0.02	2.2	0.128	5
	Runoff from Airstrip			10:24	filtered	28.2	6.9											



**Figure 2-1:** Schematic (not to scale) indicating locations of sampling sites for ERA water quality survey on 26/03/2004.

### 3 WATER QUALITY MEASUREMENTS

#### 3.1 Overview

The first samples from the potable water system were taken on Wednesday 24/03/2004 between 10 am and 11:30am, from sites associated with the Jabiru East potable water tank, the **eriss** potable water tank, and the Gagadju workshop (Table 2.1). The pipeline to Jabiru East was isolated at 8:45am that morning as part of the system shutdown on the Ranger site. The compositions of Brockman borefield (potable water supply) and process water are provided for reference in Table 2.1.

The composition of the samples from the **eriss** potable water tank and the Gagadju potable water tank were essentially identical to that of the Brockman borefield water, indicating no contamination with process water. Zn and Cu are ubiquitous contaminants in reticulation systems and the levels of Cu and Zn in the two tanks are directly comparable with the values reported for the Ranger reticulated system (which show a higher concentration than the water sampled from the Brockman borefield B84\_3; Table 2.1). The slightly higher level of Mn in the **eriss** tank relative to Brockman borefield water could be the result of dissolution from materials of construction. The slightly greater concentration of Al in the Gagadju tank is a likely consequence of the zincalume construction of this tank.

In contrast, the water data from the sites in the vicinity of the Jabiru East Potable Water Tank (JPWT) clearly indicates that the front of diluted process water had reached this location. The Jabiru East hydrant represents the composition of the incoming water. At 10:15 am, when the first suite of water samples was collected for chemical analysis, the EC was 1260  $\mu\text{S}/\text{cm}$ . The contents of the tank and the overflow stream were also sampled at this time, and the compositions show a clear indication of low-level contamination by process water.

There is a substantial difference between the total and dissolved concentrations for several of the metals (especially Al, Cu, Pb, and U). This difference is to be expected given the effect of increased pH on reducing the solubility of these metals.

The essentially identical composition of the water in the tank and in the overflow is an important finding since it indicates that the tank is well mixed. This is an assumption that is made below in the derivation of the mixing model used to estimate the volume of process water (and associated loads of metals) that entered the tank and discharged via the overflow.

The EC values of the tank and overflow sample samples were around 780  $\mu\text{S}/\text{cm}$  compared with the average around 400  $\mu\text{S}/\text{cm}$  for potable water from the Brockman bore field, and an average of 22,800  $\mu\text{S}/\text{cm}$  for process water. The total U concentration of around 200  $\mu\text{g}/\text{L}$  (filtered – 100  $\mu\text{g}/\text{L}$ ) compares with an average of 7  $\mu\text{g}/\text{L}$  in potable water, and an average of around 15,000  $\mu\text{g}/\text{L}$  for process water.

Shortly after the elevated EC was detected in the overflow from the storage tank recovery was initiated by pumping out the tank back to RP2 at the Ranger site, and overflow ceased.

An indication of the extent of dilution of the process water is provided by comparing the ratios of concentrations of solutes in the JPWT and JPWTO (Jabiru East potable water tank overflow) samples (on 24/03/04) with the average PRW (Process return water) composition in Table 2.1. Manganese provides the best indicator for this purpose since it is:

- 1) present at high concentrations in process water,
- 2) present in very low concentrations in potable water; and
- 3) is essentially chemically conservative at the pH prevailing in the tank.

The dilution ratio derived using the Mn data is 114, whilst that using filterable U is 157. Of these the Mn ratio is the most reliable. Some U is likely to have been lost from the input water by adsorption on surfaces, or by precipitation within the pipeline delivery system including the tank, thus yielding a higher ratio for this element. When the total U concentration is used to calculate the ratio, the derived value is much more similar to that for Mn.

On the morning of 25/03 the pipeline to Jabiru East was opened adjacent to the storage tank and the line allowed to backflow into a collection sump. This water was sampled three times (between 10am and 12 noon) and the data are reported in Table 2.1. The majority of the Al, Cu, Pb and U were present in the pipeline water in particulate form.

The numbers show that higher concentrations of metals were present in the pipeline than in the tank. This is to be expected given the dilution that would have occurred following the mixing of the contaminated water in the pipeline with the large volume of initially clean water present in the tank.

Of note is the much lower concentrations of metals in the third sample, indicating that the worst quality water had not reached the end of the distribution system before the supply was shut off on the morning of 24/03.

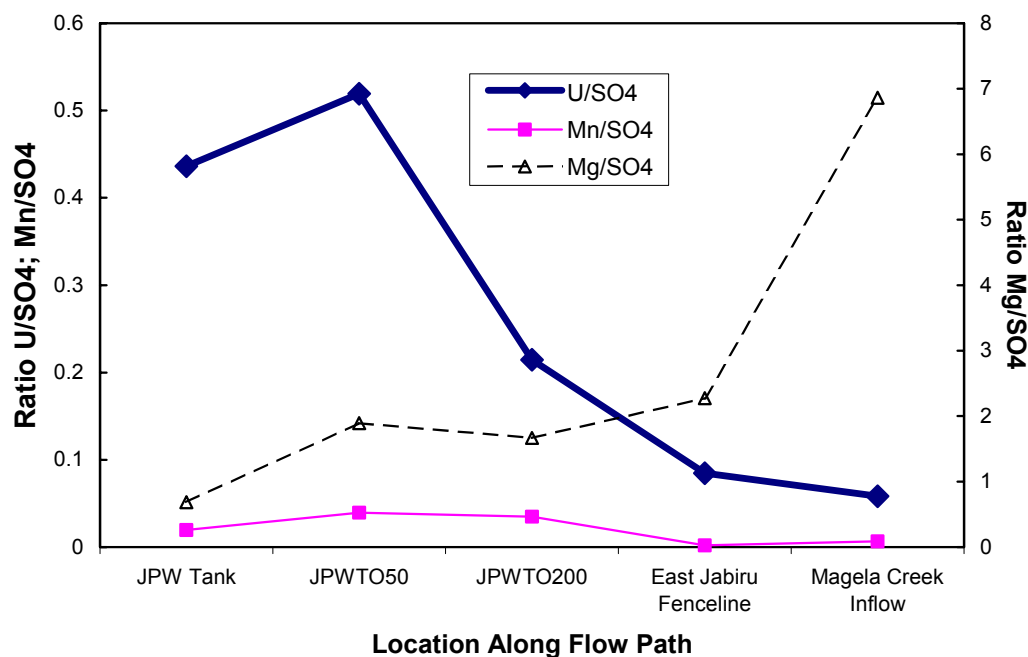
### 3.2 Between Tank and Creekline

A longitudinal transect (see schematic in Figure 2.1) of surface water quality between the tank overflow (JPWTO) and the creek line was sampled by ERA staff on the morning of 26/03/2004 (Table 2.2). In this context it should be noted that 35 mm of rain was recorded at the Jabiru airport on the preceding night.

The pH of all samples along the transect was around neutral, with the EC varying between 44 and 182  $\mu\text{S}/\text{cm}$ . For comparison, the surface water runoff from the airstrip area had an EC of 28  $\mu\text{S}/\text{cm}$ .

Interpretation of the dataset is complicated by the fact that there is considerable dilution, by surface and groundwater runoff, along the flow path as well as the likely attenuation of metals by the soil. An indication of the effect of these processes can be obtained by normalising the concentrations of metals to sulfate at each location along the flow path (Figure 3.2). It is clear that U was substantially attenuated by a factor of approximately 10 along the flow path. There was also significant attenuation of Mn.

The plot for Mg is especially significant since the sustained rise in the Mg/SO<sub>4</sub> ratio along the flow path implies water with a substantially different composition to process water (ratio of 0.28). In fact the ratio for potable water from the Brockman borefield is close to 26 (see Table 2.1). The increase in the Mg/SO<sub>4</sub> ratio is therefore probably more indicative of the washout (following the 35mm of rain on the previous evening) of a potable water dominated signature through the system. It is not consistent with significant influence by process water.



**Figure 3-1:** Ratios of indicator cations to sulfate showing attenuation for U and Mn, and inputs of Mg-rich water.

### 3.3 Water Quality in Magela Creek

Water quality measurements were made at the upstream reference (MCSUS) and downstream compliance (MG009) points in Magela Creek on 24/03/2004 and on succeeding days thereafter. In addition, special measurements of water quality were made in the western channel of Magela Creek, which would have been the most responsive to any significant inputs of solutes.

The results from these measurements are compiled below in Table 3.1. The data clearly show that the focus values for EC, Mn and U were not exceeded at MG009, the downstream compliance point in Magela Creek for the Ranger Mine. This was the case even for the western channel. These findings are in accord with the plots in Figure 3.1 that show substantial attenuation of U and Mn along the overland flow path between the tank and creek line.

**Table 3-1:** Key water quality parameters in Magela Creek

Sample Location	Sample ID	Sample Date/Time	EC $\mu\text{S}/\text{cm}$	Mn(f) $\mu\text{g}/\text{L}$	U(f) $\mu\text{g}/\text{L}$
Magela Creek Gauging Station 009	100312	24/03/2004 12:06:00 PM	na	3.67	0.046
Magela Creek Gauging Station 009	100441	26/03/2004 11:15:00 PM	12	4.35	0.018
Magela Creek Gauging Station 009	100511	28/03/2004 10:55:00 AM	12	3.84	0.025
Magela Creek-009 West channel	100521	28/03/2004 12:45:00 PM	13	3.99	0.037
Magela Creek-009 West Channel	100571	29/03/2004 09:10:00 AM	22	4.11	0.087
Magela Ck upstream reference (MCUS)	100510	28/03/2004 11:40:00 AM	11	3.45	0.018
		Focus	21	10	0.2

## 4 MODELLING OF DISCHARGE VOLUME

### 4.1 Introduction

The purpose of the modelling exercise was to establish the loads of contaminants which entered the Jabiru East Potable Water Tank (JPWT). This was important primarily to assess environmental impact as a consequence of the tank overflowing but also to seek validation of the volume of process water which entered the potable water system. Validation is possible because the concentrations of contaminants in overflow and in the tank are known soon after the supply of potable water at Ranger (and hence to Jabiru East) was isolated.

An analysis of how process water entered the potable water system at Ranger and thence to the East Jabiru line is provided elsewhere (Klessa 2004). In brief, there was temporal variation in water quality depending on whether water emanated from the Ranger Header Tank or the Ranger Day Tank in response to demand. Feed from the Header Tank, which would have subsequently become more contaminated by contacting the influx of process water, was of a much poorer quality than water derived from the Day Tank.

There are, however, a number of difficulties with deriving a model. These difficulties stem largely from the complexity of the flow dynamics of contaminated water and mixing chemistry, and include:

- the apportionment of volume flow from the Header and Day tanks and the timing of these flows;
- the splitting of flow from the Header Tank once it entered the main to meet demand (eg overflow at Jabiru East) and in response to a head drop at the Day Tank;
- defining an initial period during which contaminants concentrated in both tanks before reaching equilibrium or quasi-equilibrium (ie assumed steady-state);
- the influence of demineralisation plant operation on the distribution of contaminated water between there and East Jabiru; and
- precipitation of aluminium hydroxide and ferrihydrite, and metal sorption by these phases (Klessa 2004).

A worst case for the contamination of feed from the Header Tank suggests around 1 in 6 dilution based on 17 L/s flow of an initial 1 in 10 dilution of process water picking up a further 1.7 L/s process water (Klessa 2004). However, the dilution of process water by Header Tank water was most probably greater than 1 in 6 because the supply rate from the Header Tank would have also met a pressure drop at the Day Tank. In the absence of flowrate data from the Header Tank, it is difficult to formulate a model which accounts for a dual flow regime and chemistries from the tanks in alternating sequence. However the modelling can be simplified to account for an average single source flow and source term to simulate what in reality would be a recurring step function describing the influx of contaminants to the JPWT.

### 4.2 Model Description and Assumptions

The derivation of a mass balance mixing model to describe the temporal change in concentrations of key parameters within the JPWT and its outflow was formulated based upon the following assumptions.

- Steady state flow within the feed pipe to the tank and from the tank as overflow of 17 L/s (Klessa 2004).
- A process water composition of 4220 mg/L Mg, 25700 mg/L SO<sub>4</sub>, 13.5 mg/L U and 1950 mg/L Mn.

- A mass balance model involving complete mixing of input stream with residual water within the JPWT.
- After 2 h had elapsed, the input of a 1 in 20 mix of process water in potable water every 2.5 minutes for half the total time and potable water only for half the total time. A time of 2.5 minutes recurrence was taken because this is the estimated time it would have taken to refill the Header Tank (Klessa 2004).

#### 4.3 Key parameters and Flow Regime

To establish the mixing model for the JPWT and to account for temporal change in the composition of the influent, tank contents and outflow, the following data were used.

- Volume of JPWT = 1200 m<sup>3</sup>.
- Volume of delivery pipe system to JPWT = 120 m<sup>3</sup>.
- Composition of overflow from JPWT at t = 10 h is 75 mg/L Mg, 239 mg/L SO<sub>4</sub>, 103 µg/L U and 17.1 mg/L Mn.
- Composition of potable water is 40.1 mg/L Mg, 1.5 mg/L SO<sub>4</sub>, 7.0 µg/L U and 0.1 µg/L Mn.

Since the capacity of the potable water pipe between the Ranger circuit and the JPWT is 120 m<sup>3</sup>, this means that it takes about 2 h for residual water to be displaced at the rate of 17 L/s.

Hence, modelling took account of flow into the JPWT involving the input of residual potable water (2 h) followed by contaminated water of a given dilution derived from process water mixing with potable water.

#### 4.4 Model Validation

The key requirement in terms of the validation of the model is that 10.5 h after process water first entered the potable water system at Ranger it should predict overflow concentrations that were measured at the JPWT.

#### 4.5 Results and Conclusions

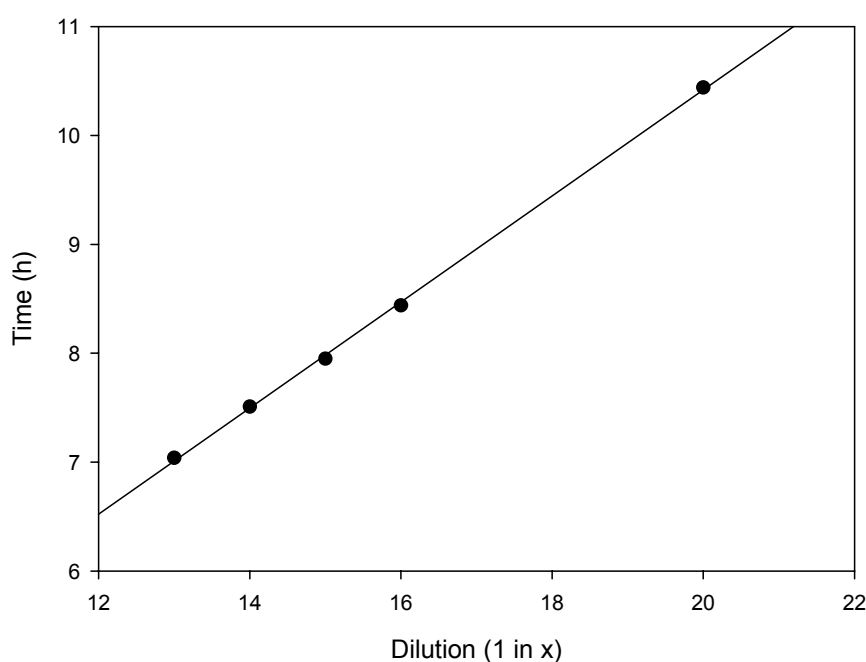
Mn was used as the indicator to determine the mixing ratio of process water in potable water because of its conservative behaviour in solution (Klessa 2004). Modelling runs indicated that a mixing ratio of 1 in 20 provided a breakthrough concentration after 10.5 h of 17.1 mg/L similar to that measured at the tank (Fig 4.1). Using 1 in 20 as the mixing ratio, Figures 4.2–4.5 show the predicted concentrations of Mg, SO<sub>4</sub>, Mn and U in the JPWT. While predicted Mg and SO<sub>4</sub> concentrations in the tank and overflow at 10.5 h show reasonable agreement with that observed, the fit for U was not as good because U behaved non-conservatively and was sorbed by precipitates of oxyhydroxides formed during the mixing of process water with potable water (Klessa 2004).

Under a steady flow rate of 17 L/s during which time contaminated water (1 in 20) entered the JPWT over 5.25 h, the equivalent of 16 m<sup>3</sup> raw process water was transferred. However, only around 15% of the influx of Mn derived from process water overflowed from the tank which amounted to 4.7 kg. Equivalent losses of SO<sub>4</sub> and Mg over 10.5 h were 64 and 19 kg respectively. The load of U in overflow was very small at <30 g assuming that the overflow concentration of 103 µg/L was maintained over a further 2 h to that predicted by the model (Figure 4.4). The volume of water which overflowed from the tank from the time the tank first became contaminated with process water (ie 2 h after the process water first entered the potable system at Ranger) until the potable water system was isolated was about 520 m<sup>3</sup>.



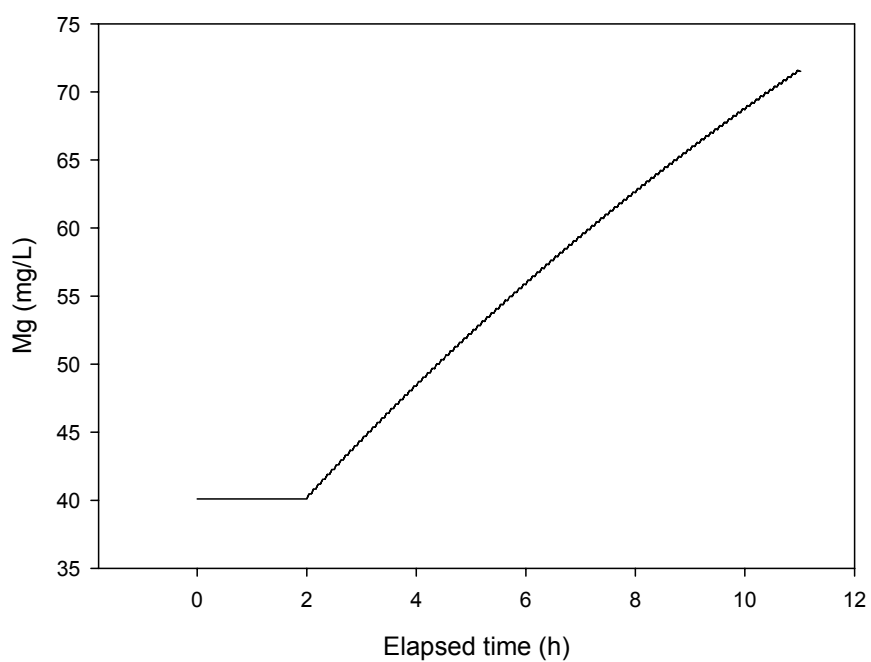
containing an average concentration in solution of about 9 mg/L Mn and 58 µg/L U derived from process water.

Uncertainties about the flow dynamics of contaminated water contained in the potable water system at Ranger makes the modelling of concentration variation in any part of the system including Jabiru East very difficult. For example, what cannot be verified is whether the operation of the demineralisation plant had a major effect on reducing the delivery of contaminated water to Jabiru East. Also the fit which was obtained of an average of 1 in 20 for 50% of the time is the same as saying 1 in 40 for 100% of the time or, to place the scenario closer to what is thought to have occurred on site, 1 in 10 for 17% of the time and 1 in 100 for 83% of the time. In the absence of data to validate the flow dynamics, model construction is highly constrained.

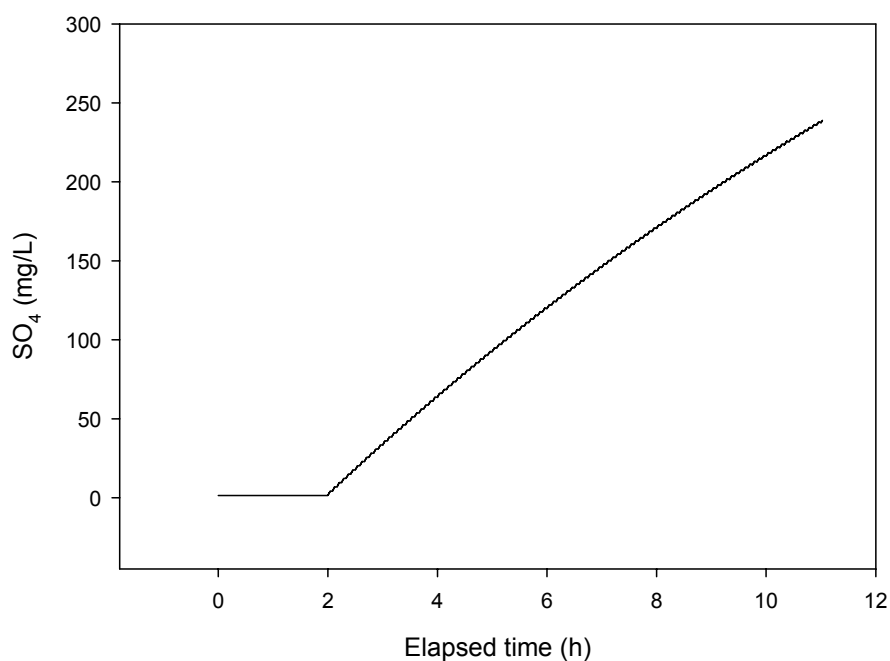


**Figure 4-1:** The effect of varying the mixing ratio on the breakthrough concentration of Mn in overflow from the JPWT

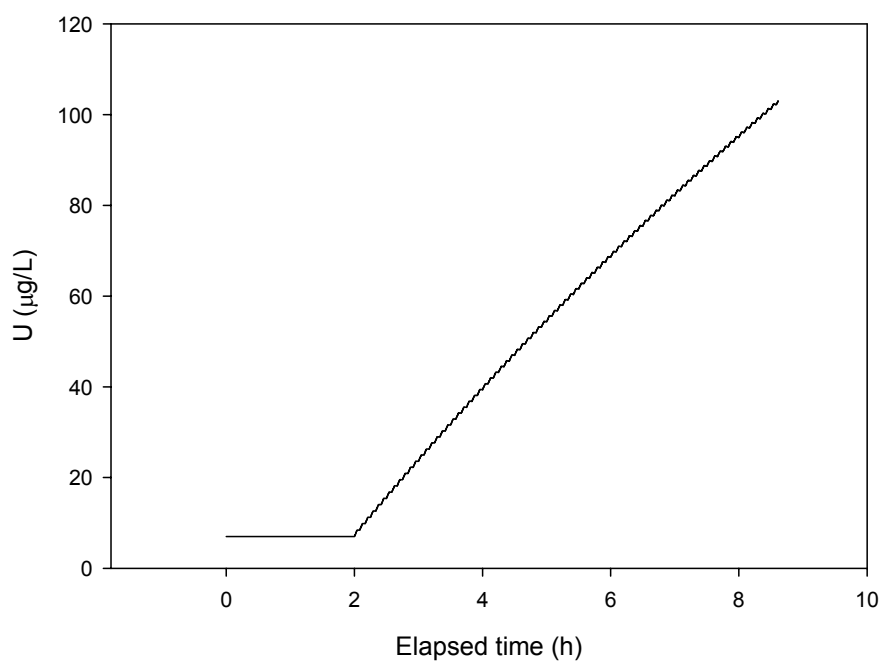




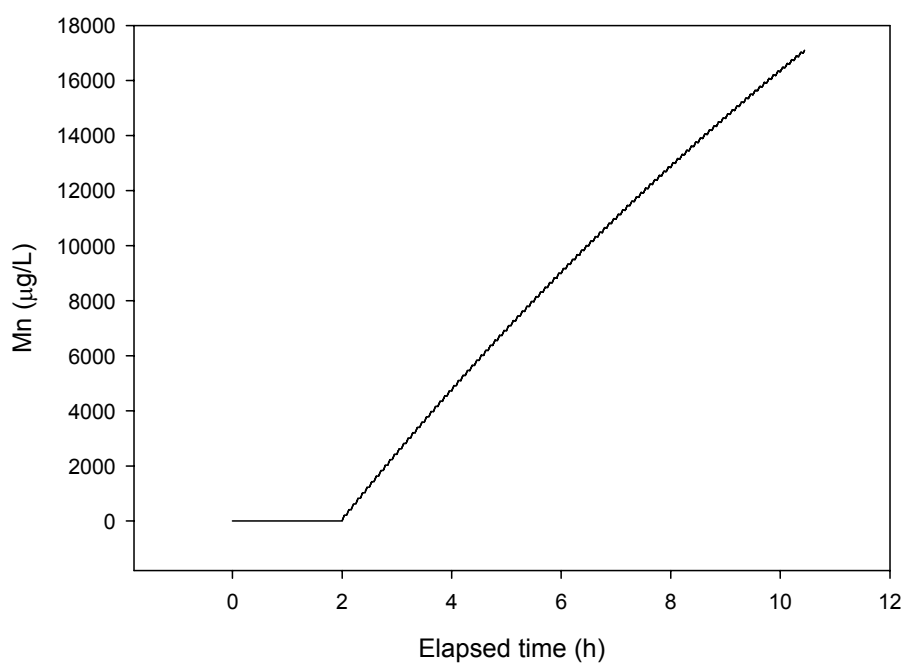
**Figure 4-2:** Predicted change in the Mg concentration of water contained in the JPWT



**Figure 4-3:** Predicted change in the SO<sub>4</sub> concentration of water contained in the JPWT



**Figure 4-4:** Predicted change in the U concentration of water contained in the JPWT



**Figure 4-5:** Predicted change in the Mn concentration of water contained in the JPWT

## 5 SOIL SURVEY RESULTS

### 5.1 Background

The mixing model developed in Section 4 predicts that only a small volume ( $2.5\text{m}^3$ ) of process water equivalent overflowed from the potable water storage tank. A soil survey was carried out on 27/03/2004 to quantify U levels in soil along the axis of the flow path, and to obtain an indication of local background levels of U by running lateral transects perpendicular to the flow path. The results from the soil survey were used to place the measured U values in the context of both expected background values and the amount of U that could have come from the discharge of diluted process water.

### 5.2 Methods

#### 5.2.1 Sampling

Soils were sampled along the flow path from the constructed overflow drain at the Jabiru East water storage tank to the receiving water body (Magela Ck close to its intersection with Coonjimba Ck). The field survey began at 12:00 hours on Saturday 27 March 2004 and was completed at 14:00.

Twenty seven samples of the surface 1 to 2 cm of soil (over an approximate 30cm x 30cm area for each sample) were collected using a shovel. The GPS co-ordinates of the sampling locations are given in Table 5.1, and the locations are marked on Figure 5.1.

Samples were numbered consecutively, from 1 to 27, in the order in which they were collected. The first sample (1) was collected in the drain invert directly below the spigot outlet from the water holding tanks (Plate 5.1).



Plate 5-1: Sample site 1, overflow pipe outlet at base of storage tank

The second sample site (2) was located at the end of the flow path to the receiving water body, ie, in the overflow channel adjacent to Coonjimba Creek (Plate 5.2).





Figure 5-1: Locations of soil sampling sites (refer Table 5.1)

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**Plate 5-2:** Sample site 2, overflow channel

Sampling sites were located along the flow path between the spigot outlet at the tank (site 1) and the creek (site 2) approximately 50 m apart. In addition, two lateral transects were surveyed at right angles to the flow path. The first lateral transect was located at the creek side (sites 3 to 10). The second lateral transect (sites 14 to site 22) was located at the point where electrical conductivity of the surface water was measured to be relatively high by **eriss** on the afternoon (16:30) of the previous day.

Wetland vegetation has established along the formed invert of the drain (Plate 5.3). This indicates that it carries prolonged flow through the dry season. The drain receives flow from the water storage tank overflow (wet and dry seasons) and runoff (wet season) from the airstrip.



**Plate 5-3:** Wetland vegetation along the drain invert

The invert of the drain ended and overland flow began at site 23 (Plate 5.4). Samples collected in the flow line above site 23 corresponded with 50 m mark above the end of the drain invert (site 24), the bottom corner of the airstrip (site 25), a track crossing the drain which carries airstrip runoff (site 26) and a gauging structure in the drain invert (site 27).



**Plate 5-4:** End of drain channel and start of overland flow

### 5.2.2 Chemical Analysis

The soil samples were submitted to the NATA accredited Northern Territory Environmental Laboratories (NTEL) for subsampling and analysis.

A 10g subsample of wet soil was weighed into a polypropylene vial. A 10 ml volume of 3:1 reverse aqua regia was then added and the suspension mixed. Digestion was carried out at 80°C for 8 hours. The digest solution was diluted to 50 ml and a further 1 in 20 dilution made prior to ICPMS analysis.

Half of the total numbers of samples were analysed in triplicate to provide a quantitative assessment of the effects of subsampling and method of analysis on the precision of the analysis.

Soil water contents were measured so that the wet weight results could be converted to dry weight equivalents.

### 5.3 Results

The results from the analyses are compiled in Table 5.1 and plotted on a site aerial photograph in Figure 5.2. It is clear that there is substantial attenuation in soil U away from the immediate vicinity of the tank discharge. This is consistent with the attenuation of U noted from the water quality results reported in Section 3.





Figure 5-2: Concentrations of U in surface 0-2 cm of soil (mg/kg dry weight)

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ERA investigation report, Jabiru East potable water contamination - environmental aspects

Date Printed: 20/05/2004

**Table 5-1:** U concentration values in soil samples

Location	Latitude	Longitude	U mg/Kg wet	Fraction H2O	U mg/kg dry wt
1	-12.65973159	132.9026413	8.67	0.70	29.26
2	-12.6574839	132.9061443	2.17	0.40	3.58
3	-12.65734979	132.9061174	1.77	0.30	2.52
4	-12.65730687	132.9061389	1.28	0.20	1.61
5	-12.65714058	132.9061604	2.79	0.36	4.36
6	-12.65703329	132.906155	1.59	0.32	2.33
7	-12.65755364	132.9061496	1.95	0.25	2.59
8	-12.6576502	132.9061443	2.53	0.33	3.76
9	-12.65784332	132.9061872	1.10	0.25	1.47
10	-12.65788623	132.9061872	2.83	0.32	4.14
11	-12.65740343	132.9056883	0.91	0.19	1.12
12	-12.657559	132.9052109	0.65	0.09	0.71
13	-12.65785405	132.904712	0.77	0.27	1.05
14	-12.65793451	132.9043525	1.53	0.22	1.97
15	-12.65781113	132.9044008	0.78	0.31	1.14
16	-12.65773603	132.9043901	0.58	0.26	0.78
17	-12.6576341	132.9044062	0.47	0.16	0.56
18	-12.65756437	132.9044169	0.45	0.20	0.56
19	-12.65800961	132.9043472	2.32	0.29	3.28
20	-12.65812227	132.9043257	1.96	0.28	2.71
21	-12.65824565	132.9043043	1.36	0.23	1.78
22	-12.65835294	132.9043096	1.98	0.50	3.93
23	-12.65824028	132.903505	1.53	0.17	1.85
24	-12.65865871	132.9032528	2.48	0.27	3.41
25	-12.65913614	132.9032689	5.53	0.43	9.63
26	-12.65958139	132.9030973	3.36	0.21	4.27
27	-12.6597155	132.902931	3.20	0.33	4.75

The results of analyses of triplicate subsamples of the soils are provided in Appendix 1 to assess the effect of subsampling on the precision of the reported data. These data indicate that the results in Table 5.1 above accurately represent the concentrations of U in the bulk samples.

#### 5.4 Comparison With Regional Background

The ARR heavy metals monitoring program (White & Mcleod 1985) contains two sites which are considered representative of background concentration values in the drainage line of Coonjimba Creek. These sites were surveyed along Coonjimba Creek in 1982, namely site number 1 (LCU No R76, grid reference 272000, 8595000) and site number 10 (LCU No R10, grid reference 272400, 8599230). The total uranium concentrations in the 0-5 cm horizon of surface soil were 2.80 and 1.72 mg/kg dry weight, respectively, as measured on nitric/perchloric acid digests.

A recent survey of the Magela Land Application Area (Hollingsworth *et al.* 2004) included measurements of background uranium concentrations in a similar physiographic location to



Jabiru East. These background values ranged from 1.00 to 7.00 mg/kg dry weight, as measured on reverse aqua regia digest of the surface 5 cm of soil material.

Thus, a U concentration between 3 and 7 mg/kg for the surface (1-2 cm deep) material would not be considered to be atypical for the soils around Jabiru East.

## 5.5 Conclusions

On the basis of the soils data presented above it can be concluded that there was sufficient attenuation capacity in the soils between the tank and the creek line to absorb the U in the water before it reached the creek – given that the U concentrations downstream of the end of the formed drain are within the expected background range. The low measured concentrations of U in the soil closer to the tank are well below the screening guideline value of 200 mg/kg for U and indicate that no remediation is required.

## 6 REFERENCES

- Hollingsworth, ID, Overall, R, Puhlovich, A., Klessa, D, Jones, D, and Stockton, D (2004) Status of the Ranger Irrigation Areas - Interim Report on the Magela Land Application Area. Report to ERA Ranger Mine, -March 2004. 51pp plus appendices.
- Klessa, DA (2004) Investigation Report – The contamination of the potable water supply by process water at Ranger Mine, March 2004. ERA Limited. 52pp.
- White, LA & McLeod, PJ (1985) Heavy Metal Monitoring Alligator Rivers Region Uranium Province, 1982 A compendium of results. *Technical Report Number 18*, Conservation Commission of the Northern Territory, Darwin.

## Appendix 1

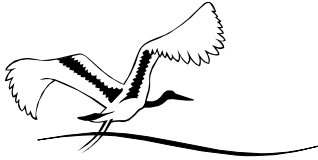
Replicate U analyses for Jabiru East Soil Samples

Table A2: Replicate analysis of selected soil samples

Sample No & Replicate	NTEL Job number	U mg/kg dry wt G200M
0001 #1	EL03331	29.3
0001 #2	EL03331	27.5
0001 #3	EL03331	17.5
0003 #1	EL03331	2.52
0003 #2	EL03331	2.49
0003 #3	EL03331	2.43
0005 #1	EL03331	4.36
0005 #2	EL03331	4.39
0005 #3	EL03331	3.25
0007 #1	EL03331	2.59
0007 #2	EL03331	2.33
0007 #3	EL03331	2.21
0009 #1	EL03331	1.47
0009 #2	EL03331	4.08
0009 #3	EL03331	3.29
0011 #1	EL03331	1.12
0011 #2	EL03331	1.04
0011 #3	EL03331	0.94
0013 #1	EL03331	1.05
0013 #2	EL03331	1.33
0013 #3	EL03331	1.69
0015 #1	EL03331	1.14
0015 #2	EL03331	1.67
0015 #3	EL03331	1.87
0017 #1	EL03331	0.56
0017 #2	EL03331	0.62
0017 #3	EL03331	0.56
0019 #1	EL03331	3.29
0019 #2	EL03331	2.64
0019 #3	EL03331	2.96

## **APPENDIX 7:**

### **Discussion Paper – Re-instatement of Water Supply at Jabiru East.**



**ERA**

**Energy Resources of Australia Ltd - Ranger Mine**

ABN 71 008 550 865

# **Discussion Paper**

## **Re-Instatement of Water Supply to Jabiru East**

Authors: D R Jones

April 2004

## 1 CONTEXT

On the morning of Wednesday March 24<sup>th</sup> ERA staff at Ranger Mine discovered contamination of the potable water supply as a result of a connection made between process water and potable water. The consequence was that over a period of several hours process water entered the potable water header tank on top of the fine ore bin. This header tank provides the gravity head for distribution to the site as well as to the potable water feeder line to East Jabiru.

The potable water system (including the supply line to Jabiru East) was closed down at 0800h. An orderly shutdown of the mine was completed, and non-essential staff were sent home. Once regulators and stakeholders were notified, a number of investigations were commenced immediately by ERA.

The specific issues concerned with reinstating the potable water supply on the Ranger site have been addressed separately. The focus of this Discussion Paper is the reinstatement of the potable water supply from the minesite to East Jabiru. The sequences of actions taken to identify the extent of contamination, the flushing of the system, and the sampling and analysis undertaken to document recovery of water quality to potable standard in the Jabiru East reticulation system are documented here.

## 2 IDENTIFYING THE EXTENT OF CONTAMINATION AND RECLAIM OF THE POTABLE WATER SYSTEM

Figure 1 shows the Jabiru East reticulation system and the location of all known potable water outlets (numbered).

The pipeline to Jabiru East passes adjacent to a storage tank located at the south east edge of the airport (See location schematic in Figure 3.1). There is a valve assembly at this location that isolates the pipeline from the tank (which was used as one of the original water supply tanks for the town of Jabiru East). However, the valve assembly was leaking at the time of the incident, allowing a proportion of water from the line to flow under pressure into the tank. Consequently the tank was able to be filled from the pipeline.

The first water samples were taken on Wednesday 24/03/2004 between 10 am and 11:30am from sites associated with the Jabiru East potable water tank, the **eriss** potable water tank, and the Gagadju workshop (Table 1 summarises the key analytes of relevance to assessing the extent of contamination by process water; the full data set is provided in the accompanying Excel spreadsheet). The pipeline to Jabiru East was isolated at 8 am that morning as part of the system shutdown on the Ranger site.

The composition of the samples from the **eriss** potable water tank and the Gagadju potable water tank were, except for Al, Cu and Zn, essentially identical to that of the Brockman borefield water, indicating no contamination with process water. Zn and Cu are ubiquitous contaminants in reticulation systems and the levels of Cu and Zn in the two tanks are directly comparable with the values reported for the Ranger reticulated system (which show a higher concentration than the water as extracted from the Brockman borefield, B84\_3 in Table 1). The slightly higher level of Mn in the **eriss** tank relative to Brockman borefield water could be the result of dissolution from materials of construction. The slightly greater concentration of Al in the Gagadju tank is a likely consequence of the zincalume construction of this tank.

Thus the initial sampling indicates that the front of process water contamination had not reached the Gagadju or **eriss** header tanks on the morning of 24/03/04.

In contrast, the water data from the sites in the vicinity of the Jabiru East potable tank (JPWT) clearly indicates that the front of diluted process water had reached this location. The Jabiru East hydrant represents the composition of the incoming water. At 10:15 am on 24/03/2004, when the first suite of water samples was collected for chemical analysis, the EC was 1256 µS/cm. The contents of the tank and the overflow stream were also sampled at this

time, and the compositions show a clear indication of low-level contamination by process water (Table 1).

Based on the above data it can be concluded that Jabiru East storage tank was contaminated with process water as a result of the leaking valve providing a pressure relief in the pipeline. It was likely that the front of contaminated water had also progressed further along the pipeline towards the airport and **eriss** offices. The extent of this movement was likely to be limited by the lack of draw on the system during the night. In order to limit the further progress of water down the line, and to remove the head of contaminated water in the emergency potable water storage tank, a recovery program was initiated at 2pm on 24/03/04.

The details of the recovery program are provided in Appendix 1. In summary this involved the following steps.

- 1) The Jabiru East storage tank was emptied by pumping back to site and then partly filled with clean water from the Magela potable water bore field.
- 2) The supply pipelines at Jabiru East were drained back to the sump near the Jabiru East storage tank, with the water being recovered and transported back to site.
- 3) The Ranger fire truck was used to backflush the lines from the Gagadju workshop and the **eriss** header tank, with the backflush water being collected in the storage tank at Jabiru East.
- 4) The Jabiru East storage tank was emptied again by pumping back to site.
- 5) The Jabiru East storage tank was flushed once more with clean water from Magela borefield, with the contents of the tank being pumped back to site.
- 6) All potable water outlets tagged out of service pending clearance.

The potable water line to Jabiru east was re-pressurised on 31/03/04 with two hydrants at the extremities of the lines and all accessible taps flushed and tested for pH and EC, and sampled for full water quality analysis.

The flushing, field testing and sampling for water quality analysis was repeated on 1/04/04 and 2/4/04. Full details of the flushing and water sampling protocols are provided in Appendix 2, with complete chemistry data provided in the accompanying Excel spreadsheet. All samples were screened for 37 chemical attributes including anions and metals to demonstrate that the potable water system complied with Australian Drinking water standards.

Based on the length and dimensions of the pipelines it is estimated that 5-10 pipe volumes of clean water were flushed through known contaminated lines; and 2-4 pipeline volumes were flushed through potentially contaminated lines. The objective of the flushing and testing program was to restore water quality to all outlets in Jabiru East. The highest level field screening criteria were provided by pH and EC values ( $>7.3$  and  $<450$   $\mu\text{S}/\text{cm}$ , respectively).

Final clearance for those outlets that met the screening criteria was provided by the results of ICPMS analysis for total U. The screening level criterion for U for was set at 15  $\mu\text{g}/\text{L}$  (which is conservatively less than the 20  $\mu\text{g}/\text{L}$  value in the drinking water quality guidelines). In this context it should be noted that the initial analyses were done on filtered samples to provide rapid turnaround to facilitate management action. Subsequent check analysis showed no significant difference between filtered and total results.

The U concentration data for all water samples collected during the initial investigation and subsequent recovery program are summarised in Table 2. The results of repeated sampling through time at the potable water outlets show the recovery of the system to levels of U that are consistently less than 15  $\mu\text{g}/\text{L}$  for two successive measurements, thus meeting the performance criterion established for reinstatement of the potable water system at Ranger. These same data are shown graphically in Figure 2.

All other relevant parameters measured in the sampled waters, including possible process water-related organics (below detection limit), meet drinking water quality guideline values.



The results of microbiological assays on the reticulated potable water supply at the Ranger mine (the source of the water for Jabiru East) were well below (nil count returned) applicable guideline values for potable water supplies. A radiological analysis of a representative sample of the source potable water from the Ranger mine has been analysed for Thorium activity by *eriss* and the results are consistent with drinking water guidelines.

### 3 RE-CONNECTION OF THE JABIRU EAST WATER SUPPLY

ERA demonstrated that the potable water system at Ranger Mine meets the Australian Drinking Water Guidelines. The results from at least two consecutive daily samples taken from points throughout the Jabiru East potable water system (indicated on Figure 1), it also clearly meets the applicable guideline values for relevant analytes. However, further testing of microbiological and radiological properties is warranted because the system has been open for flushing. Moreover, the NT Department of Health, who have been consulted on this issue, recommend checking three consecutive samples from key locations in Jabiru East for compliance with guideline values. This work has commenced and the results will be reported to the Department of Health. In the meantime, although water for industrial purposes can be supplied at once to Jabiru East, bottled water will be provided for drinking.

ERA has undertaken to make improvements to its water systems to prevent a similar incident in the future. These improvements include:

1. upgrades to the process water pipework system and enhancements to the site training program as detailed in the attached document "*Risk Review of Process Water System*" (Appendix 3).
2. ERA will install a conductivity meter in a strategic location within the potable water system at Ranger to continuously measure electrical conductivity and provide warning of any potential contamination. The conductivity meter will be connected to an alarm system. The unit is expected to be installed and operational by April 16<sup>th</sup>. In the interim, ERA proposes to manually analyse pH and conductivity on a representative sample of potable water on a four hourly basis until the conductivity meter is installed.
3. Investigations and assessments are currently in progress to determine if the existing mine supply system of potable water to Jabiru East can be replaced by a local source (for example, reinstatement of the existing Magela borefield, or equivalent). In the event that this option proves to be feasible then the supply line from Ranger will be isolated, thus completely removing any future link to the mine.

If a new potable water source is commissioned for Jabiru East, a separate monitoring program will be implemented with the range of inorganic, microbiological and radiological parameters included as per the current requirements for potable water testing under the Ranger Authorisation.

#### *Attachments to this document:*

- *Figure showing location of all potable water system outlets at Ranger Mine*
- *Figure showing U concentrations through time*
- *Tables of water chemistry*
- *Jabiru East and Mine – Drain and Flush Sequence of Events- Potable Water System*
- *Jabiru East – Flushing and Sampling Protocol*
- *Risk Review of Process Water System*

*Electronic Files available separately on request: Excel workbook containing water quality data.*

**Figure 1:** Schematic showing potable water system and outlet locations at Jabiru East



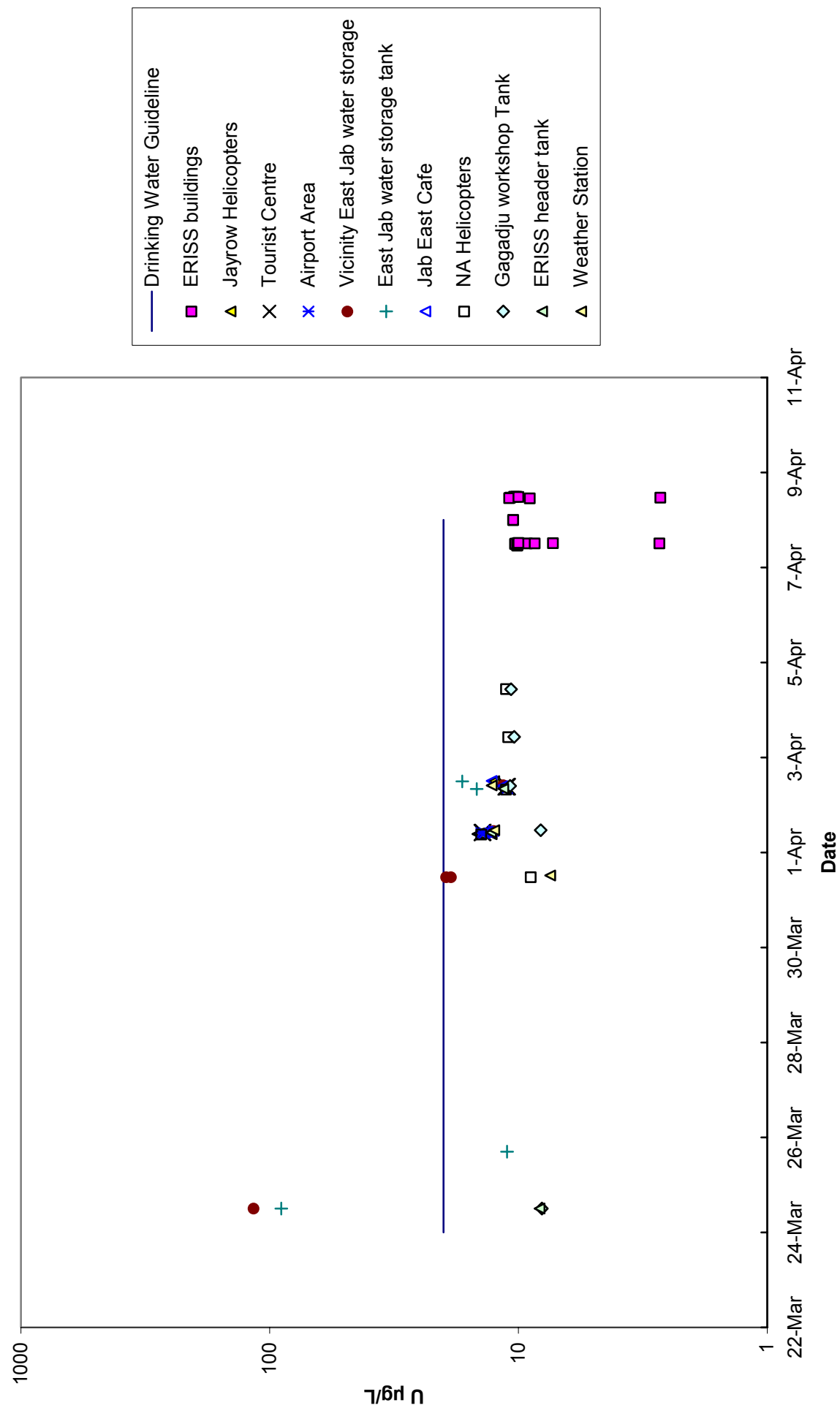


Figure 2: Time series data for Jabiru East showing recovery of reticulation system

**Table 1:** Comparison of Brockman borefield (potable) supply with process water and with waters sampled at Jabiru East on 24-26/03/2004

Sampling Code	Sample Description	Sample Number	Date Sampled	Sampled Time	EC µS/cm	pH	Al µg/L	Ca mg/L	Cu µg/L	Fe µg/L	Mg mg/L	Mn µg/L	Ni µg/L	Pb µg/L	SO4 mg/L	U µg/L	Zn µg/L
	Brockman Bore Field (Av April 2000-Mar 2004)-reticulated				393	7.87		21.3	23		39.9	0.2			1.55	6.88	111
B84_3	Brockman Bore Supply - source	100309	24/03/2004	9:13	400	-	0.5	22.5	4.02	<20	39.6	0.06	0.57	0.79	0.9	8.38	6.7
	Process Return Water (Av 15/703 to 10/3/04)				22800	3.8	368000	508	13560	72090	3660	1822000					
EPW	eriss Potable Water Tank	100306	24/03/2004	11:30	338	-	1.3	23.3	4.04	<20	39.7	1.88	0.24	0.25	1.2	8.23	61.6
GWP	Gagadiju Workshop	100308	24/03/2004	10:00	411	6.88	30.3	22.9	22.8	<20	40.1	0.27	0.23	0.33	0.9	8.05	71.3
JH	Jabiru East Hydrant (opposite core sheds)	100311	24/03/2004	10:15	1256	6.82	47.2	39.1	114	<20	158	55200	131	5.9	736	116	1540
JPWT	Jabiru East Potable Water Tank	100310	24/03/2004	10:06	775	7.13	128	27.4	48.8	<20	70.2	14800	35.9	2.01	211	89.9	207
JPWTO	Jabiru East Potable Water Tank Overflow	100307	24/03/2004	9:57	784	7.2	129	28	44.1	<20	75	17100	41	2.06	239	103	178
JPWTO	Jabiru East Potable Water Tank Overflow	100338	25/03/2004	10:07			26.5	39.1	47.2	<20	154	51700	124	0.37	740	121	2800
JPWTO	Jabiru East Potable Water Tank Overflow	100339	25/03/2004	10:31			41.3	29.8	25.1	<20	88.7	18900	46.9	0.41	333	119	604
JPWTO	Jabiru East Potable Water Tank Overflow	100337	25/03/2004	11:52			46.2	29.6	23	<20	83.4	12100	31.3	0.41	284	102	497
JPWTO	Jabiru East Potable Water Tank Overflow	100422	26/03/2004	10:19	195	7.14	59	11.2	9.55	20	16.7	472	2.09	0.05	24.3	10.6	34.6

**Table 2:** U concentration data for sites at Jabiru East (see Figure 1 for locations)

Sample Location	ID	Sample No	Sample Date Time	U_F µg/L	U_T µg/L
Jabiru East Potable Water Tank	JPWT	100310	24/3/04 12:06 PM	89.9	
Jabiru East Potable Water Tank	JPWT	100593	25/3/04 4:50 PM	11.1	
Jabiru East Potable Water Tank	JPWT	100746	02/4/04 8:05 AM	14.7	
Jabiru East Potable Water Tank	JPWT	100769	02/4/04 11:53 AM		16.8
Potable Water - Under ground pipe to Jabiru East	PTUP	100505	28/3/04 12:00 AM	10.9	
Jabiru East Hydrant (Opposite Core Shed)	JH	100311	24/3/04 12:06 PM	116	
Jabiru East EOL Hydrant Pre-Flush.	JE004-1	100674	31/3/04 11:35 AM	19.5	
Jabiru East EOL Hydrant Post-Flush.	JE004-2	100673	31/3/04 11:35 AM	18.7	
Jabiru East - Former Environmental Lab Hydrant	JE004	100713	01/4/04 10:55 AM	12.6	
Jabiru East - Nursery Standpipe	JE001	100740	02/4/04 9:58 AM	11.5	
Jabiru East - Jayrow Outside Tap	JE005	100710	01/4/04 9:32 AM	14.4	
Jabiru East - Jayrow Laundry Tap	JE006	100700	01/4/04 9:22 AM	14.6	
Jabiru East - Jayrow Bathroom Sink	JE040	100699	01/4/04 9:15 AM	12.8	
Jabiru East - Jayrow Bathroom Sink	JE040	100768	02/4/04 12:05 PM		12.5
Jabiru East - Jayrow Shower	JE042	100701	01/4/04 9:30 AM	14.3	
Jabiru East - Jayrow Office Crib Room Sink Tap	JE050	100745	02/4/04 7:55 AM	11.3	
Jabiru East - Tourist Centre Mens Toilet Sink	JE011	100734	02/4/04 9:10 AM	11.2	
Jabiru East - Tourist Centre Ladies Toilet Sink	JE013	100735	02/4/04 9:12 AM	11.1	
Jabiru East - Tourist Centre Outside Wash Sink Tap Set	JE019	100705	01/4/04 10:10 AM	13.9	
Jabiru East - Tourist Centre Outside Wash Sink Tap Set	JE019	100736	02/4/04 9:24 AM	11.1	
Jabiru East - Tourist Centre Outside Wash Sink Tap Set	JE020	100706	01/4/04 10:06 AM	14	
Jabiru East - Hangar/Fuel Yard Outside Tap (in Car Port)	JE024	100709	01/4/04 9:51 AM	13.7	
Jabiru East - Hangar/Fuel Yard Outside Tap (in car port)	JE024	100737	02/4/04 8:25 AM	11.1	
Jabiru East - Hangar (Fuel Yard) Safety Shower / Eye Wash	JE051	100698	01/4/04 9:48 AM	14.1	
Jabiru East - Gunbalanya Air Charters Outside Garden Tap	JE057	100711	01/4/04 10:50 AM	12.6	
Jabiru East - Café Washing Tub Tap	JE028	100704	01/4/04 10:20 AM	13.5	
Jabiru East - Café Washing Tub Tap	JE028	100738	02/4/04 9:28 AM	11.6	
Jabiru East - Café Washing Tub Tap	JE028	100767	02/4/04 12:10 PM		12.6
Jabiru East - Café Hand Basin Tap	JE029	100703	01/4/04 10:30 AM	13.3	
Jabiru East - Tourist Centre Office Bathroom Sink	JE033	100702	01/4/04 10:00 AM	13.7	
Jabiru East - Tourist Centre Office Bathroom Sink	JE033	100739	02/4/04 9:16 AM	11.2	
Jabiru East EOL Weather Station.	JE034	100676	31/3/04 12:25 PM	7.45	
Jabiru East - Weather Station Evaporation Pan Tap	JE034	100712	01/4/04 11:15 AM	12.5	
Jabiru East - Weather Station Evaporation Pan Tap	JE034	100741	02/4/04 9:55 AM	12.8	
Jabiru East Mens Toilet A (right hand side)	JETA	100335	25/3/04 1:00 PM	8.74	
Jabiru East Mens Toilet B (left hand side)	JETB	100336	25/3/04 1:00 PM	8.56	
Jabiru East - EOL NA Helicopters Outside Garden Tap	JE035	100675	31/3/04 11:35 AM	8.93	
Jabiru East - NA Helicopters Outside Garden Tap	JE035	100707	01/4/04 9:08 AM	14.1	
Jabiru East - NA Helicopters Outside Garden Tap	JE035	100742	02/4/04 7:50 AM	11.2	
Jabiru East - NA Helicopters Outside Tap	JE035	100800	03/4/04 10:15 AM	11	11.3
Jabiru East - NA Helicopters Outside Garden Tap	JE035	100820	04/4/04 10:35 AM		11.2
Jabiru East - NA Helicopters Outside Garden Tap	JE035	100850	04/4/04 1:10 PM		

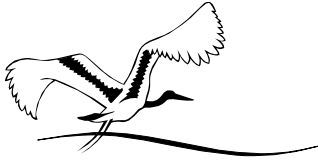
**Table 2 Contd:** U concentration data for sites at Jabiru East (see Figure 1 for locations)

Sample Location	ID	Sample No	Sample Date Time	U_F µg/L	U_T µg/L
Jabiru East - Gagadju Workshop Tank Pump Outlet	JE036	100308	24/3/04 12:06 PM	8.05	
Jabiru East - Gagadju Workshop Tank Pump Outlet	JE036	100714	01/4/04 11:15 AM	8.14	
Jabiru East - Gagadju Workshop Tank Pump Outlet	JE036	100743	02/4/04 9:40 AM	10.8	
Jabiru East - Gagadju Workshop Tank Pump Outlet	JE036	100801	03/4/04 10:22 AM	10.4	10.7
Jabiru East - Gagadju Workshop Tank Pump Outlet	JE036	100821	04/4/04 10:30 AM		10.7
Jabiru East - ERISS Storage Tank Feed	JE049	100306	24/3/04 12:06 PM	8.23	
Jabiru East - ERISS Storage Tank Feed	JE049	100708	01/4/04 10:02 AM	12.9	
Jabiru East - ERISS Storage Tank Feed	JE049	100744	02/4/04 8:15 AM	11.5	
Jabiru East ERISS Building - Admin Labs Bubbler	JE100	100939	07/4/04 11:53 AM	N.A.	10.3
Jabiru East ERISS Building - Admin Labs Bubbler	JE100	100956	08/4/04 11:50 AM		10.4
Jabiru East ERISS Building - Crib Room Urn	JE101	100940	07/4/04 11:56 AM	N.A.	10.2
Jabiru East ERISS Building - Ladies Toilets Sink	JE103	100933	07/4/04 11:07 AM	N.A.	10.1
Jabiru East ERISS Building - Ladies Toilets Sink	JE103	100957	08/4/04 11:19 AM		10.8
Jabiru East ERISS Building - Mens Toilets Sink	JE104	100936	07/4/04 11:05 AM	N.A.	10.1
Jabiru East ERISS Building - Conference Room Sink	JE105	100937	07/4/04 12:16 PM	N.A.	9.97
Jabiru East ERISS Building - Conference Room Urn	JE106	100938	07/4/04 12:12 PM	N.A.	2.71
Jabiru East ERISS Building - Conference Room Urn	JE106	100958	08/4/04 11:21 AM		2.69
Jabiru East ERISS Building - Crib Room Hand Basin	JE108	100941	07/4/04 11:58 AM	N.A.	10.3
Jabiru East ERISS Building - Admin Lab Ecosystem Protection	JE151	100942	07/4/04 12:07 PM	N.A.	10.3
Jabiru East ERISS Building - Admin Lab Ecosystem Protection	JE151	100959	08/4/04 12:00 AM		10.5
Jabiru East ERISS Building - Aquaculter Wash Hose Sink	JE152	100943	07/4/04 12:10 PM	N.A.	9.24
Jabiru East ERISS Building - Aquaculter Wash Hose Sink	JE152	100960	08/4/04 11:45 AM		10.2
Jabiru East ERISS Building - SPL's Outside Bubbler	JE153	100944	07/4/04 12:12 PM	N.A.	10.1
Jabiru East ERISS Building - SPL's Outside Bubbler	JE153	100961	08/4/04 12:00 AM		10.5
Jabiru East ERISS Building - Ice Machine	JE154	100947	07/4/04 12:18 PM	N.A.	7.26
Jabiru East ERISS Building - Ice Machine	JE154	100962	08/4/04 11:04 AM		10.9
Jabiru East ERISS Building - Covered Area Outside Wetlabs Hose Reel	JE155	100946	07/4/04 12:26 PM	N.A.	9.99
Jabiru East ERISS Building - Covered Area Outside Wetlabs Hose Reel	JE155	100963	08/4/04 11:40 AM		10
Jabiru East ERISS Building - Storage Tank Drain Pipe	JE156	100945	07/4/04 12:14 PM	N.A.	8.6
Jabiru East ERISS Building - Storage Tank Drain Pipe	JE156	100964	08/4/04 11:00 AM		9.01

## **Appendix 1**

### **Jabiru East and Mine – Drain and Flush Sequence of Events- Potable Water System**





**ERA**

**Energy Resources of Australia Ltd - Ranger Mine**

ABN 71 008 550 865

## **Jabiru East and Mine – Drain and Flush Sequence of Events – Potable Water System**

24/3/04 – Approx 8am – Jabiru East Line Isolated  
24/3/04 – Approx 2pm – Commenced pumping Water from Jabiru East Tank back to site  
25/3/04 – Approx 4am – Tank Emptied Pumping Ceased  
25/3/04 – Approx 9am – Magella Borefield commenced pumping into Jabiru East Tanks  
25/3/04 – Approx 10am – Drained Jabiru East Lines at the sump near tanks until empty. Approximately 20,000 ltrs removed and taken back to site.  
25/3/04 – Approx 1pm – Flushed line from Gagadju back to tanks using fire truck. Approx 12,000ltrs flushed down the line  
25/3/04 – Approx 2pm – Flushed back from Eriss Tanks to Jabiru East Tanks and tested pH and EC at the tanks while flushing. Approx 20,000 ltrs.  
25/3/04 – Approx 4pm - Commenced pumping Water from Jabiru East tanks back to site  
25/3/04 – Approx 7pm – Pumping back to site stopped as tank was empty  
26/3/04 – Approx 7am – Magella Bore Stopped  
26/3/04 – Approx 9am – Pumped Water from Jabiru East tanks back to site until tank empty  
26/3/04 – Approx 10am – Water Sucked out of bottom of Jabiru East tank and brought back to site in Collex truck.  
27/3/04 – Approx 11am – Jabiru East Tank was completely emptied  
27/3/04 – Approx 1pm – Magella bore started and filling of tank commenced  
28/3/04 – Approx 8am – Commenced flushing back from Jabiru East Tank to site with Magella water  
28/3/04 – Approx 11am – Flushing completed – pH & EC tested good – Approx 300,000ltrs flushed  
28/3/04 – Approx 2pm – Flushing of main line to mine facilities commenced  
29/3/04 – Approx 9am – Main line flushing ceased. All taps turned on and flushing of all outlets commenced.  
29/3/04 – Approx 10am – All outlets at Inganarr training centre and security were flushed  
29/3/04 – Approx 4pm – All outlets at Inganarr training centre, security and mine facilities were turned off.  
30/3/04 – Approx. 10am – Outlets at the mine were flushed again – pH and EC tested good at all points.  
30/3/04 – All Day – All Jabiru East potable water points were identified and lock out using out of service procedures.  
31/3/04 – Jabiru East line was re-pressurised.  
31/3/04 – 2 Hydrants at extremities were flushed for approx 10 mins. Tested for pH & EC all OK.  
31/3/04 – All accessible taps were flushed for between 10 – 20 mins. Tested for pH & EC. All OK  
1/4/04 – Samples taken and completion of EC & pH testing of remaining outlets.  
2/4/04 – All accessible outlets reflushed for 10 – 20mins and pH & EC tested. All OK.

### **Estimated Flush Quantities:**

Known Contaminated Lines – from 5 - 10 times pipe volume  
Potentially Contaminated Lines – from 2 – 4 times pipe volume

## **Appendix 2**

### **Jabiru East – Outlet Flushing and Sampling Protocols**

## **Jabiru East – Flushing and Sampling Protocol**

### Flushing (Stage 1):

- Ensure all taps at Jabiru East are tagged out and isolated.
- Mark the location of all taps on map to determine the sampling program.
- Sample at Jab East Storage Tank following flush-back of water line from ERISS tanks.
- Select Line extremities for flushing and sampling (Gagadju W/shop, ERISS Hydrant, NAA Helicopters and Weather Station)
- Pressurise potable line to Jabiru East using clean Brockman Borefield water.
- Estimate time to flush water from clean section of line to outlet (pipe volume)
- Flush pipe volume of line extremities and until EC is less than 400 uS/cm pH greater than 7.3.
- For small taps direct drainage water into 500 ml container underlain by 20L bucket, constantly monitoring with TPS meter for pH and EC and letting clean water overflow. Write down results.
- Monitor flushing from hydrants and extremities with a TPS meter for pH and EC. If EC exceeds 450 uS/cm collect drainage in the fire truck and return it to mine site. Allow clean water to flush to ground.

### Sampling (Stage 1)

- Test first water to flush out of line extremities
- Sample if EC increases whilst flushing
- Sample at end of flush.

### Flushing (Stage 2)

- Flush Env Lab hydrant and Gagadju Workshop for at least 12 hours
- Drainage to ground

### Sampling (Stage 2)

- Sample line extremities following major flush
- Select most likely drinking points for sampling
- Flush pipe volume of all outlets - drainage to ground or sewer
- Record EC and pH of first water to flush out of all outlets
- Sample first water to flush out all selected outlets
- Sample all selected outlets after flush

### Flushing (Stage 3):

- Flush all selected outlets for at least 1 hour

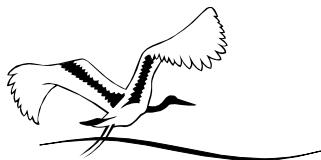
### Sampling (Stage 3):

- Sample all selected outlets after flushing

A further round of flushing and sampling may be necessary if positive results are returned from any stage sampling.

## **Appendix 3**

### **Risk Review of Process Water System**

**ERA****Energy Resources of Australia Ltd**

ACN 008 550 865

## Risk Review of Process Water System

An upgrade of the Process Water System at Ranger has been in progress as follow-on to recommendations of the Supervising Scientist following the tailings water leak incident in 2000<sup>1</sup>. The initial upgrade work focussed on the tailings dam corridor components of the system (Recommendations 1, 2 & 10). Continuing upgrades were incorporated into ERA's Annual Plan in September 2003 and approved in concept in November 2003. This included installing replacement pipe work for all unserviceable process water piping in the Mill area.

### Work done to date

Following completion of works on process water systems in the tailings corridor, including most recently the installation of a high-density polyethylene (HDPE) process water pipeline from tailings to the process water head tank, an upgrade of the process water piping in the Mill commenced in 2003 namely:

- (a) Replacement of the discharge nozzle and immediate spools from the process water head tank in stainless steel. The pipe work preceding this up until the booster pumps have been replaced in 355 mm poly pipe;
- (b) Replacement of several offshoots from the header pipe through the plant with HDPE pipe in critical areas such as Grinding and CCD's; and
- (c) Preparation for replacement of the three carbon steel process water headers and associated distribution pipe work along the CCD corridor. In addition, Simon Engineering and SKM have been working with ERA to:
  - Survey the process water system;
  - Update the P & ID's, plans, elevations and isometrics;
  - Scope the project; and
  - Order materials (ongoing).

### Planned Process Water Work

The next stage of the process water update program, which is contained in the capital budget for 2004, is planned to commence on 6<sup>th</sup> May during a planned plant shutdown of approximately twelve days. This involves replacing the three carbon steel process water headers and associated distribution pipework along the CCD corridor.

The three headers (DN200, DN150 and DN100) are the main feed line for the plant distributing water for the process, gland flushing, and washing systems. The current mild steel pipes will be replaced with HDPE pipe PE-80 type "B" PN-10 rating, which has a high

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<sup>1</sup> Supervising Scientist (2000) Investigation of tailings water leak at the Ranger uranium mine.  
Supervising Scientist Report 153. (Supervising Scientist, Darwin)

chemical resistance. The branch connections for DN80 and less will be replaced with seamless 316L stainless steel pipe to minimise corrosion issues. .

The headers need to be tied into the existing infrastructure during the planned complete plant shutdown. Owing to the lead-time on some material, replacement of all the planned pipework is estimated to take approximately 4 months. The project is planned for completion by the end of August 2004. Details are set out in the ERA "*Stage 2 PW and RW replacement schedule*".

### **Risk Assessment and Mitigating Strategies**

A risk review was carried out on the process water system within the plant. Until the planned upgrade is completed, the following actions will put in place

1. The site water management training modules will be reviewed and updated in reference to the water incident by 12<sup>th</sup> April 2004
2. Further training/updates for all relevant personnel on site water management systems will be completed by the end of April 2004. Priority will be given to the mill and maintenance personnel.
3. Procedures for authorising water type changes, bypassing or making changes to water pipe work will be implemented by 5<sup>th</sup> April 2004. Until this system is implemented, all water type changes will be prohibited without the permission of the General Manager Operations.
4. Process water pipe work outside of bunded areas will be inspected and upgraded to HDPE or stainless steel, or removed if redundant, by the end of July 2004.
5. Water pipes throughout the Ranger minesite site will be inspected to ensure they are appropriately labelled and coloured by the end of July 2004.
6. The colour code for process and pond water will be reviewed by 12<sup>th</sup> April 2004.
7. The segregation of the process and potable water systems will be reviewed to ensure that unauthorised inter-connection cannot be made by 2<sup>nd</sup> April 2004.
8. The fine ore bin scrubber will be refurbished during the planned May shutdown.

## **APPENDIX 8:**

**Gaunt (2004) ERA Ranger Mine. Contamination of drinking water 23/24 March 2004. Report on medical/health response & preliminary assessment of health risks. 14<sup>th</sup> July, 2004.**

# ERA RANGER MINE

## CONTAMINATION OF DRINKING WATER 23/24 MARCH 2004 REPORT ON MEDICAL / HEALTH RESPONSE & PRELIMINARY ASSESSMENT OF HEALTH RISKS

14<sup>th</sup> JULY 2004

*Dr Richard Gaunt  
Occupational Physician  
Rio Tinto HSE Department  
Bristol*

### Executive Summary

#### Incident & Immediate Impact

On the morning of Wednesday 24<sup>th</sup> March, samples taken from the potable water system contained metals and sulphates at concentrations that were potentially irritant to both the skin and gastro-intestinal tract of some individuals. A number of people on site experienced minor skin irritation after showering and a few developed minor gastric upsets. In total, 28 employees and contractors reported mild physical symptoms. It is believed that all settled within the first week.

#### 1<sup>st</sup> & 2<sup>nd</sup> Level Health Risk Assessment

ERA undertook a programme of questionnaires and one-on-one confidential interviews with concerned individuals to determine the likely extent of exposure to contaminated potable water and initial physical symptoms. Attached at **Appendix D** is a spreadsheet of exposure profiles and at **Appendix E** a spreadsheet of individuals reporting symptoms, recording the results of this programme (the identity of individual participants is not disclosed).

The conclusions of the 1<sup>st</sup> & 2<sup>nd</sup> level health risk assessments, based on preliminary analysis of contamination levels and worst case exposures, were that long term effects were unlikely but some effects from uranium (on the kidneys) and from manganese (on the nervous system) could not be confidently excluded at that stage. This information was verbally conveyed to workers.

#### Initial Testing Programme

Following on from the initial health risk assessments, a series of voluntary blood and urine tests were arranged to assess body burden / impact of uranium and manganese, for individuals with high levels of concern and/or reported exposures, both on site (employees and contractors) and in Perth (contractors). In addition, advice on the appropriate tests required was given to treating physicians in Perth and in Queensland.

The majority of the routine clinical blood tests specifically designed to look for any effect of uranium and other metals on kidney function came back within the acceptable range. One employee has been referred to his family physician for further



tests for a condition not thought to be related to drinking the contaminated water. The results of a specialist test of kidney function, NAG, were returned to site on the 20<sup>th</sup> May: they are not elevated. As NAG levels are a sensitive indicator of renal tubular damage they confirm the lack of an effect on renal function. All blood manganese levels were in the normal range, suggesting that there were no significant increases in the body levels of manganese in those tested.

In addition to these specific tests, full blood counts (looking for anaemia, and changes in white blood cells and platelets) and a full set of tests to check liver function were also performed. The full blood counts were normal. Analysis of samples for eight people indicated some minor changes in liver function, not consistent with a liver disease but probably reflective of delays in getting the samples to Perth for testing. All eight have been referred to their personal physician for repeat testing. The results of all blood tests undertaken to this stage have been provided to individual workers with appropriate consultation.

Attached at **Appendix F** is a spreadsheet showing the medical test results returned to date (again, the identity of individual participants is not disclosed). A small number of results remain outstanding.

### 3<sup>rd</sup> Level Health Risks Assessment

The results of the blood and urine testing programme, and the further work performed by Earth-Water-Life Sciences (EWLS) for ERA on the level and chemical properties and behaviour of the contaminants found in the Ranger potable water system, have enabled a review of the initial health risk assessments. This review is based on my knowledge of the data to the 9<sup>th</sup> June 2004.

The results of the initial medical testing programme provide considerable reassurance that there will be no long term health effects from exposure to contaminated water at Ranger on the 23rd and 24th of March. However, given that the workers had only a brief exposure to relatively high concentrations of some metals and that the literature reviewed for the risk assessment is generally focussed on longer term exposures, there must be some residual doubt about the direct extrapolation of the conclusions and findings from the literature to the Ranger incident. Hence, a further and comprehensive precautionary medical testing programme for possible manganese, aluminium and uranium effects is warranted, in order to provide additional confidence that there have been and will be no long term health effects. These conclusions are endorsed by Dr. Roger Drew, a consultant toxicologist retained by ERA.

I do not presently consider that any metals present in the Ranger potable water system, apart from manganese, aluminium and uranium, are of genuine concern to health. This conclusion is based on the observed and calculated concentrations and chemical properties within the potable water system and on my review of the available literature and relevant health standards. However, as the chemistry of the water drunk at Ranger was complex, I consider that it would be sensible to conduct a further detailed review of the properties of the contaminants in the Ranger potable water system over the same period as the additional testing programme.

## Recommendations - Precautionary Medical Testing Programme

Details of a 2<sup>nd</sup> level medical testing programme that I recommend be implemented by ERA are set out in the body of this report. These recommendations have not yet been agreed with the Office of the Supervising Scientist or the health experts retained by the OSS, or discussed with treating physicians.

In summary, I recommend that ERA conduct a voluntary programme over the next three months, extended to all workers who advised exposure, involving further blood and urine analysis for kidney function and manganese levels. Additional blood and urine tests (ie repeat tests for liver function) can be conducted at the same time. I also recommend that an MRI scan be conducted for those workers with higher levels of exposure for manganese and aluminium levels, but I suggest that it would be appropriate for ERA to obtain further specialist advice on this recommendation from independent toxicologists. The results of the testing programme will be provided to subjects and their treating physicians and the collated results (in anonymised form) will be provided to and discussed with the health experts retained by the OSS.

At the conclusion of the precautionary medical testing programme, and the further detailed review of the properties of the contaminants in the Ranger potable water system, ERA and the OSS will be in a position to again consider my conclusion that long term health effects are most unlikely. At that point ERA can also consider with the OSS whether, if any, further testing, research or monitoring may be appropriate.

## Office of the Supervising Scientist – Health Risks Assessment

ERA has cooperated with the OSS in its own investigations into the likely health effects of the incident. This has included providing the relevant empirical data collected by ERA after the incident to the OSS, who has passed the information to a team of independent toxicologists commissioned by the OSS to undertake an independent Health Risk Assessment. Information provided to the OSS has included: the EWLS work on contaminant levels and chemical properties; exposure profile; spreadsheet of symptoms reported; and medical test data. ERA has also kept the OSS informed of the various stages of ERA's testing and health risk assessment process, and has liaised with the OSS and their experts as required with further information, clarification and assistance.

## Conclusions

It is very pleasing that the investigations, research and tests conducted to date indicate that it is most unlikely there will be any long term health effects as a result of the incident. However, for the sake of increased certainty, it is recommended that ERA conduct a comprehensive precautionary programme of (voluntary) further testing in respect of the possible effects of manganese, aluminium and uranium, for all those who declared any exposure to potentially contaminated water. The need for and parameters of such a further testing programme will be reviewed with the OSS and its independent panel of experts, and discussed with treating physicians, before being implemented. Upon completion of the further testing programme, ERA and the OSS will be in a position to assess with even greater certainty the risk of long term health

effects and consider whether any further testing, research or monitoring may be appropriate.

# ERA RANGER MINE

## CONTAMINATION OF DRINKING WATER 23/24 MARCH 2004 REPORT ON MEDICAL / HEALTH RESPONSE & PRELIMINARY ASSESSMENT OF HEALTH RISKS

14<sup>th</sup> JULY 2004

*Dr Richard Gaunt  
Occupational Physician  
Rio Tinto HSE Department  
Bristol*

### 1. Introduction

I am the Occupational Physician of Rio Tinto plc, a position I have held since 1988. My CV is attached at **Appendix A**.

On Thursday the 25<sup>th</sup> of March I was contacted by Chris Leiner of ERA and informed that the potable water system at Ranger had been contaminated by process water. I arrived on site on 27<sup>th</sup> March and remained in Australia until 9<sup>th</sup> April. I returned for further attendance on site on April 18<sup>th</sup>, departing on April 23<sup>rd</sup>.

I have prepared this Report to set out my involvement on behalf of ERA in coordinating a response to the medical and health implications of the incident and the information gathering and medical testing programmes I have initiated.

I also provide preliminary conclusions on likely long term health effects. My preliminary conclusions are that long term health effects are most unlikely. However, I consider that a further testing programme is warranted to increase confidence that there will be no long term health effects, and I set out my recommendations for such a programme. The details of this recommended further testing programme have not yet been finalised, pending the completion of the medical testing regime that I implemented on behalf of ERA and further discussions with the OSS and consultation with treating physicians.

I was requested to provide assistance and advice in relation to health aspects of the incident. My involvement has included:

- Provision of specialist information to individuals and/or their medical practitioners
- Provision of information to local communities and stakeholders
- Liaison with regulators
- Establishment and implementation of exposure profiling and medical testing programmes
- Analysis of exposure and medical test results information
- Dissemination of medical test results and general conclusions reached on general medical test results and exposure data, to individuals, their medical practitioners and regulators

- Provision of advice to ERA on health risk issues

I should state that I have made clear to individuals who I have met that I was not assuming the role of a treating medical practitioner, that they should seek their own medical advice, and that they should consult their medical practitioner for medical advice on the general information and specific test results I provided.

## **2. 1<sup>st</sup> Level Health Risk Assessment**

There was, obviously, some immediate concern in those who had been exposed to the water about long-term health risks. I therefore conducted an immediate “worst case” risk assessment prior to my arrival at Ranger, concentrating on the chemical effects of the contaminated water and using an iterative risk assessment process to assess the health risks, so maximising the benefit from the limited data immediately available and giving the maximum reassurance to people affected as early as possible.

Ian Marshman of ERA had already conducted an initial risk assessment for ionising radiation, concluding that at worst exposures were equivalent to a chest x-ray. Mr. Marshman has considerable expertise in this area, and I had no reason to doubt his conclusions. I understand that the OSS has agreed with the conclusions of Mr. Marshman.

I was informed that in the immediate aftermath of the incident ERA management staff had taken the following steps:

- A sample collected by Processing personnel at 7.45am from the Grinding Crib Room was analysed in the Ranger Mill Laboratory. The sample reported 8ppm U; 5,900 uS/cm; pH 4.5. On the basis of the sampling conducted, this was identified as the “worst-case” water quality that may have been consumed at or about the time that a problem with drinking water quality was first identified.
- Based on the sample results (8ppm U; 5,900 uS/cm; pH 4.5) and known water quality for process and potable waters, the ratio 1 part process water to 3 parts potable water was applied. That ratio was based on known “normal” process water quality of 25-30 ppm U and 22,000 uS/cm.
- The 1 part process water to 3 parts potable water ratio was applied to a range of analytes present in process water and therefore theoretically present in the potable water/process water mix. To ensure the most conservative approach, the ratio was applied to the highest individual analyte concentrations taken from process water routinely collected at Ranger since September 2002. Some rounding off was applied. The determinations were as follows:
  - Aluminium 100mg/L (process water 432ppm)
  - Copper 6mg/L (process water 23.6mg/L)
  - Iron 100mg/L (process water 392mg/L)
  - Manganese 500mg/L (process water 2,031mg/L)
  - Lead 2mg/L (process water 4.96mg/L)
  - Uranium 7mg/L (process water 27.8mg/L)
  - Zinc 1.5mg/L (process water 6.06mg/L)
  - Magnesium 1mg/L (process water 4.22mg/L)
  - Potassium 35mg/L (process water 137mg/L)
  - Sulphate 7,000mg/L (process water 27,940mg/L)

An initial literature search was done to begin to provide background information for my immediate assessment. The result of this literature review is attached as **Appendix B**, “Initial summary of toxicological information”, and the screening assessment based on the literature is set out below. Calculated exposures are based on an assumed consumption of 2 litres of water at the above calculated concentration levels. In the absence of data on chemical speciation, all the metals assumed to be bioavailable.

### ***Aluminium***

Internationally, drinking water standards for aluminium are between 100 and 200 µg/l. Daily dietary intakes of aluminium are up to 14 mg. Aluminium is used medically in antacids, the dose is 500 to 1000mg aluminium hydroxide up to 4 times daily. There is doubt if aluminium in drinking water is more readily absorbed than from food. At the calculated concentrations, a single acute exposure of 200mg aluminium is less than medical dosage levels and not assessed as a major long-term health risk.

### ***Copper***

For the majority of people tested in a programme to provide data for the EU risk assessment of copper, (Araya et al, 2003) 6 mg/litre copper imparts a metallic taste and is associated with nausea. The guidelines for long-term daily exposure suggest safe dietary levels as being in the range 9 to 10 mg per day. The only relevant human chronic study (long term, ongoing exposure) shows severe liver effects at 60 mg/day. At the calculated concentrations, a single acute exposure of 12 mg copper is not assessed as a long-term health risk.

### ***Iron***

The medical dose of iron to treat anaemia is 250 mg/day. At the calculated concentrations, a single acute exposure of 200mg iron is not assessed as a long-term health risk.

### ***Zinc***

Zinc is essential to life. The daily requirement is around 15 mg. At the calculated concentrations, a single acute exposure of 3mg zinc is less than the daily dietary requirement and not assessed as a long-term health risk.

### ***Magnesium***

At the calculated concentrations, a single acute exposure of 2mg magnesium is lower than the dose taken medically in antacids and not assessed as a long-term health risk.

### ***Potassium***

2 grams of potassium is taken in lo sodium salt on a meal. At the calculated concentrations, a single acute exposure of 70mg potassium is not assessed as a long-term health risk.

### ***Sulphate***

At the calculated concentrations, a single acute exposure of 14,000mg sulphate is expected to cause gastric irritation, nausea, vomiting and diarrhoea in some people. However, it is not assessed as a long-term health risk.

### ***Lead***

Lead has low acute toxicity but with long term chronic exposure significant toxicity to the neurological system. The occupational exposure limit assumes that a long term daily intake of 150 micrograms is safe for repeated exposures. In addition, lead is teratogenic, affecting the unborn child, particularly if exposure is in the first 3 months of pregnancy. However, at the calculated concentrations, a single acute exposure of 4mg lead is not assessed as a long-term health risk.

### ***Manganese***

The WHO state that long term exposures of up to 20 mg per day are unlikely to be associated with adverse health effects. The calculated exposures were well above this level but as a one off dose. At the calculated concentrations, long-term health effects of a single acute exposure of 1000mg manganese were considered unlikely, but could not be excluded.

### ***Uranium***

The WHO drinking water review identified populations in British Columbia with long-term exposures to up to 700 micrograms per litre in their everyday drinking water. They had a tendency to higher B2 microglobulins than controls but no evidence of clinical renal disease. At the calculated concentrations, long-term health effects of a single acute exposure of 14mg uranium were considered unlikely but could not be excluded.

### **Conclusions of 1<sup>st</sup> Level Health Risk Assessment**

Exposures to sulphates, copper and probably manganese were sufficiently high to produce acute skin or gastric symptoms in some individuals after bathing or drinking respectively. These symptoms should be immediate for showering and within 24 hours for nausea and gastric irritation. The symptoms should resolve in a few days – perhaps up to a week for anyone with pre-existing irritable bowel disorder.

These very short-term exposures were probably not high enough to cause long-term health effects but these could not be excluded for uranium (renal effects) and for manganese (manganism which produces symptoms similar to Parkinson's disease). The lead exposure could be significant for any woman who was in the first three months of pregnancy.

Further work was required to refine the exposure scenario. The analytical results were a worst-case scenario and actual exposures were believed to be less than those presented. The level of uranium was measured in a process laboratory not set up for measuring uranium at this level; accuracy of result assessed by site as +/- 50%.

The conclusions of this 1<sup>st</sup> Level Health Risk Assessment were presented to a public meeting held in Jabiru on the 28<sup>th</sup> March.

### **3. Attendance At Ranger - Contamination / Exposure / Effects Information & Consultation**

#### **Contamination Levels**

When I arrived on site at Ranger further testing of contaminated water samples had been done by an independent laboratory specialising in drinking water analyses. Not every potable water source had been tested. A copy of all potable water analyses obtained by ERA (including analyses subsequently provided to ERA by the OSS) is attached at **Appendix C**.

## Consultation with Individuals

I met with about 30 workers and contractors who expressed concerns regarding the effects of drinking or exposure to contaminated water, in confidential one-on-one interviews. This included travelling to Perth to meet with three contractors who were no longer on site. During this process I was able to listen to the individual concerns of those effected, including their reported symptoms, and I provided them with background information regarding health issues and the results of my immediate health risk assessment. I also met with Dr. Rush, the Jabiru town doctor, to consider with him my preliminary views on likely health risks.

## Exposure Profile

A questionnaire was circulated to all site personnel (contractors and employees), requesting details of possible exposure and symptoms experienced. A spreadsheet setting out the results of this exposure profiling process is attached as **Appendix D**.

## Acute Effects Information

Based on the initial results of the exposure profiling process and these meetings with concerned individuals, an assessment of the scale of acute exposures and effects was made. The volume of water each person said they had drunk was accepted and only a limited attempt was made to identify which water source an individual had used.

The scales used for the acute effects assessment were:

### ***Exposure***

High	More than 2 litres of water consumed;
Medium	Between 0.5 and 2 litres of water consumed;
Low	Less than 0.5 litre consumed or showered on Wednesday morning
None	No water consumed or off site.

### ***Symptom Scale***

Sa	Nausea, headaches, gastric irritation or skin rash beginning within 2 days of consumption but now resolved;
Sc	Symptoms beginning within 2 days and continuing – even if changed in character. These may be stress type reactions;
Su	Classical symptoms but outside the above time frame.

I set out below a table with the results of this process to Monday 5<sup>th</sup> April, by which time 25 individuals had returned questionnaires complaining of immediate physical symptoms. Since that time, a further three individuals have returned questionnaires complaining of immediate physical symptoms, for a total of 28 individuals complaining of immediate physical symptoms to date. Attached at **Appendix E** is the most up to date version of the Acute Effects Assessment. The information obtained from the Acute Effects Assessment confirmed for me at the time that the most highly exposed were more likely to suffer from acute symptoms.



	Number reporting no symptoms	Number reporting symptoms	Sa	Sc	Su
<b>High</b>	11	10	7	3	0
<b>Medium</b>	33	9	8	0	1
<b>Low</b>	58	4	4	0	0
<b>None</b>	116	2	0	0	2
<b>Uncertain</b>	10	0	0	0	0
<b>TOTAL</b>	194	25	19	3	3

#### **4. 2<sup>nd</sup> Level Health Risk Assessment**

Following collation of further information on contamination levels, exposures and acute effects, I was able to make a more focussed but still preliminary health risk assessment.

A worst-case assumption of contamination levels was again used. It was also assumed that all through the Tuesday night and on Wednesday morning until the potable water system was shut down, the water had the same composition as the worst case from Wednesday morning. Again it was assumed that all the metals were bioavailable and that there would be no interaction between metals at the intestinal wall to reduce absorption.

The site management had concluded that it was not possible to produce an accurate model of the flow of contamination throughout the Tuesday night and Wednesday morning due to the complexity of the system and uncertainty at that stage over when and how much water had been drawn off. Hence at that stage it was not possible to be certain of the chemical composition of the water drunk by each person (the issue has since been considered further by D.A. Klessa in his Investigation Report – Contamination of the Potable Water Supply by Process Water at Ranger Mine, March 2004).

It was assumed for the 2<sup>nd</sup> Level Health Risk Assessment that the specialist laboratory results of ERA's samples from potable water outlets would be more accurate than the plant screening results. The OSS analysis results of additional samples taken by the OSS were not available at that point. The ERA sample results from the filtered water were used, and these are given below with the original, calculated, results in brackets

- Aluminium 13.3 mg/L(100mg/L)
- Copper 2.27 mg/L (6mg/L )
- Iron <0.02 mg/L (100mg/L )
- Manganese 195mg/l (500mg/L )
- Lead 0.4 mg/L (2mg/L )
- Uranium 1.3 mg/L (7mg/L)
- Zinc 2.56 mg/L (1.5mg/L)
- Magnesium 0.42 mg/L (1mg/L)
- Potassium 35mg/L
- Sulphate 257 mg/L (7,000mg/L )
- Arsenic 7.95 microgm/L
- Nickel 0.425 mg/L

## Conclusions of 2<sup>nd</sup> Level Health Risk Assessment

The dramatic lowering of the sulphate levels and the lowering of the copper levels made these substances much less important as a likely source of short-term symptoms. Nevertheless the acidic nature of the water, the manganese content plus the sulphate and copper levels were considered together to be a likely cause of acute symptoms in some people.

In addition to the analytes of significant health risk assessed in the initial assessment (uranium and manganese), the concentration of arsenic was established. Arsenic levels at approximately 8µ/L (drinking water standards typically 10 to 25 µg/L) were not considered to pose a significant health risk. Arsenic is a known carcinogen for which it is assumed by regulators that any dose will cause an increase in cancer. However, given that the levels measured were lower than the drinking water standard, this risk is not considered significant.

Aluminium levels at 13.3 mg/l were higher than the drinking water standard in many countries (100 to 200 µg/L) and at maximal exposure levels approximately four times the daily intake from food. However, they were well below the medical intake in antacids. CSIRO in Australia have stated (Media Release Ref 98/258) that “the way the human body copes with aluminium from food and water is similar. That means that aluminium from alum-treated drinking water is not uniquely bioavailable...”. Aluminium was not considered a significant health risk.

Although the exposures to uranium and manganese were still considered too low to cause long-term systemic effects, there were reasons for uncertainty in that conclusion. The reasons were:

- There is no literature on the effect of a single dose when compared to the effect of exposures over longer terms. This is particularly relevant in the case of manganese;
- There are uncertainties in the concentration of metals in the water;
- Interactions between the contaminants in the intestine could decrease absorption in the body;
- Two or more contaminants acting on the same target organ (for instance uranium, cadmium and lead all have renal toxicity) could theoretically increase toxicity; and
- Any pre-existing renal, brain or bowel disorder could make an individual more sensitive.

The effects considered possible were:

### *Renal proximal tubule damage from the uranium.*

Based on human experience from British Columbia and from animal studies these effects would be expected to be chemical, such as increased enzyme leakage from proximal tubule cells. Based on this, the animal data and the very short-term exposure, any such chemical changes are anticipated to be reversible.

To assess this and give reassurance, I considered that further testing was required for urine uranium as a marker of exposure, and serum  $\beta$ 2-microglobulin (B2M) and urine proteins, amino acids and phosphates as markers of proximal tubular function.

*Long-term neurological damage from manganese.*

To date the research has identified no markers to predict the effect of manganese. Blood manganese is said in some studies to be a possible indicator of body burden. I concluded that blood manganese was therefore required.

I also considered that a blood lead, full blood count and liver function tests could be performed at the same time.

## **5. 1<sup>st</sup> Level Medical Testing Programme**

I devised a (voluntary) testing programme of:

Urine Testing:           urine uranium, urine proteins, enzymes, amino acids and phosphates

Blood Testing:           blood manganese, blood lead, full blood count, serum B2M and liver function.

This programme was communicated verbally to the site management. I also briefed Dr Rush about the samples I had taken and tests I had requested be done and the reasons for them. Dr Rush agreed to recommend the same tests to any other workers or contractors who came to see him with concerns regarding exposure to contamination.

On Friday 4<sup>th</sup> of April a testing programme began on site to measure these parameters in all those people who had expressed concern. All samples taken on site were sent to Western Diagnostics in Perth, and from there to other independent medical laboratory services. In addition, some individuals no longer at the site were tested according to this programme.

I discussed my conclusions on 1<sup>st</sup> and 2<sup>nd</sup> level health risk assessments and my proposed testing programme with Dr Brian Galton-Fenzi, the medical advisor to the Mining Inspectorate in Western Australia (who was advising certain individuals). Dr. Galton-Fenzi agreed with the proposed testing programme. I also subsequently discussed my conclusions and testing programme with health experts (consultant toxicologists) retained by the OSS to conduct an independent Long Term Health Risks Assessment. The OSS health experts agreed with my conclusions on likely long term health risks for uranium and manganese and also supported the testing programme agreed. The OSS health experts also raised the issue of sensitisation from exposure to nickel, which in my view was not likely.

I departed from the Ranger mine site on Wednesday 7<sup>th</sup> April, having implemented the above testing programme and conducted my 2<sup>nd</sup> level health risk assessment. ERA requested me to return to site when medical test results became available, to consider these and to provide the test results and my considered general views to individual employees and contractors during further one-to-one confidential

interviews, as well as to provide the results and my considered opinion on the results overall to treating physicians, as necessary.

## **6. Medical Testing Programme Results**

The medical test results received to the date of this report are attached at **Appendix F**.

Results received initially were for serum B2M, urine proteins, amino acids and phosphates, blood manganese, blood lead, full blood count and liver function. The results of these blood and urine tests have been provided to workers with appropriate consultation. Results of urine uranium, and also urine NAGs, on certain of these samples were not received by ERA until 20<sup>th</sup> May, after I had left site. A programme will be devised to give these later results to the sampled workers and contractors. Some results remain outstanding.

The majority of the routine clinical blood tests, including all serum B2M testing specifically designed to look for any effect of uranium on kidney function, came back within the acceptable range. One employee has been referred to his family physician for further tests for a condition that I do not consider to be related to drinking the contaminated water.

All blood manganese levels were in the normal range, suggesting that there were no significant increases in the body levels of manganese in those tested.

Full blood counts (looking for anaemia, and changes in white blood cells and platelets) were all normal. Analysis of the full set of tests showed normal liver function, save for eight people showing some minor changes which were not consistent with a liver disease but is likely an artefact reflective of delays in the process of getting the samples to Perth for testing. All eight have been referred to their personal physician for repeat testing.

The urine NAG results are not elevated. As NAG levels are a sensitive indicator of renal tubular damage they confirm the lack of an effect on renal function. A detailed review of the NAG analyses by Dr Roger Drew of Toxikos, an independent consultant toxicologist retained by ERA to advise on health issues, is attached at **Appendix G**.

## **7. Review of Contamination Concentration Data**

Further work has been performed by EWLS for ERA on the levels and chemical properties and likely behaviours of the contaminants found in the Ranger potable water system. D.A. Klessa's conclusions are that the analysis of samples taken from various points across the Ranger mine site provide little guidance as to what workers may have actually been exposed to when they drank contaminated water. The worst case scenarios for contamination levels proposed by Klessa, based on an understanding of the actual operation of the potable and process water systems during the 23<sup>rd</sup> and 24<sup>th</sup> March 2004, are:

- For safety showers, 1 part process water in 100 parts potable water
- For Grinding Building Amenities, 1 in 2
- For other potable water serving areas, up to 1 in 11

Accordingly, the revised worst case scenario of contamination levels for health risk assessment purposes should be based on 1 part process water in 2 parts potable water. I have revisited the scenario used for the 2nd level health risk assessment (Section 4 above), based on Klessa's views. The revised maximum "worst case" concentrations for the contaminated water were therefore:

- Aluminium 144mg/L (process water 432 mg/L)
- Copper 8mg/L (process water 23.6mg/L)
- Iron 130mg/L (process water 392mg/L)
- Manganese 660mg/L (process water 2,031mg/L)
- Lead 1.65mg/L (process water 4.96mg/L)
- Uranium 9.3mg/L (process water 27.8mg/L)
- Zinc 2mg/L (process water 6.06mg/L)
- Magnesium 1.4mg/L (process water 4.22mg/L)
- Potassium 46mg/L (process water 137mg/L)
- Sulphate 9,300mg/L (process water 27,940mg/L)

These concentrations are similar to those considered in the 1<sup>st</sup> level health risk assessment but somewhat higher than those considered in the 2<sup>nd</sup> level health risk assessment. The revised concentrations do not change my present assessment of the likely long term health effects of the one-off exposures to these metals during the incident.

## **8. 3<sup>rd</sup> Level Health Risk Assessment**

The results of the blood and urine testing programme, and the further work performed by EWLS for ERA on the level and chemical properties and behaviour of the contaminants found in the Ranger potable water system, have enabled a review of the initial health risk assessments. The following review of issues and my conclusions is based on my knowledge of the data to the 9<sup>th</sup> June 2004.

Klessa's calculations of "worst case" concentrations of contaminants are consistent with the acute temporary symptoms reported by some workers, which I believe have all resolved.

Concern was expressed through the OSS about the isotopic ratio of lead on site differing greatly from natural lead, and whether the blood lead results might not be reliable. This concern was discussed with the laboratory, who concluded that any margin of error that might result would be small and not material given the very low blood lead results.

I understand that the OSS experts may have a concern that blood manganese levels would rise and fall rapidly given the short exposure period, and therefore a sample taken about a week after the event may not reflect the actual exposure (or intake). I consider that the weight of the literature supports the view that blood manganese is a reliable reflection of body burden. The blood manganese results received were within the normal range.

In 1988, people in the town of Camelford in the UK were exposed to a very acidic drinking water containing up to 620 mg aluminium per litre for up to 3 days. An initial public enquiry found that there was no greater prevalence of ill-health as a result. However this has been challenged, see for example Altman et al 1999. A further enquiry is underway and is likely to report in 2004. Some comments on this incident are attached at **Appendix H**. The aluminium concentrations consumed at Ranger are about 144 mg/l worst case with maximum possible consumption less than 12 hours, compared to up to 625 mg/l consumed for 3 days at Camelford, and the medical dosage found in antacids.

## Conclusions

The results of the initial medical testing programme provide considerable reassurance that there will be no long term health effects from exposure to contaminated water at Ranger on the 23rd and 24th of March.

I conclude that clinically significant renal damage from the uranium intake has not occurred. A small number of further medical testing results (for subjects who had samples taken off-site) have still not been received and reviewed. However, based on the exposure profiling and acute effects analyses performed, I do not expect these results to differ markedly from the medical test results already received.

I do not consider, based on my present view of the literature, that there are likely to be any sub-clinical effects of uranium ingestion on the kidneys that might increase the susceptibility of exposed workers to future renal disease. However, as a first step towards addressing any such concerns, I consider that a detailed review of the scientific literature on the kidney changes caused by uranium exposure should be conducted with particular attention being given to the clinical significance of any changes. This would require the participation of an experienced nephrologist.

I also conclude that adverse long term effects from manganese and aluminium are unlikely, but cannot be excluded entirely at this stage. The interaction of aluminium and manganese is a potential theoretical concern as both are neurotoxins.

Given that the workers had only a brief exposure to relatively high concentrations of metals whereas the literature reviewed for the risk assessment is generally focussed on longer term exposures, there must be some residual doubt about the direct extrapolation of the conclusions and findings from the literature to the Ranger incident. Hence, a further and comprehensive precautionary medical testing programme for possible manganese, aluminium and uranium effects is warranted, in order to provide additional confidence that there have been and will be no long term health effects.

I do not presently consider that any metals present in the Ranger potable water system, apart from manganese, aluminium and uranium, are of genuine concern to health. This conclusion is based on the observed and calculated concentrations and chemical properties within the potable water system and on my review of the available literature and relevant health standards. However, as the chemistry of the water drunk at Ranger was complex, I consider that it would be sensible to conduct a further detailed review of the properties of the contaminants in the Ranger potable

water system. Such a review could be performed over the same period as the precautionary testing programme was implemented.

I have discussed my above conclusions with Dr. Roger Drew, who has endorsed my views and agrees with my recommendations on further testing set out below.

## **9. Recommendations**

I recommend that ERA conduct a further testing programme over the next three months to increase confidence in the conclusions of the 3<sup>rd</sup> Level Health Risks Assessment. The contents and details of any recommended further testing programme have not been finalised, pending discussion with the OSS and their health experts, and consultation with medical practitioners treating individual employees and contractors. Upon completion of the further testing programme, ERA and the OSS will be in a position to assess with even greater certainty the risk of long term health effects and consider whether any further testing, research or monitoring may be appropriate.

In the meantime, I also recommend that ERA commission a further detailed review of the properties of the contaminants in the Ranger potable water system.

My recommendations for a further testing programme are at this stage:

- ERA establish a voluntary programme extended to all workers and contractors who advised exposure to contaminated water on site on 23/24 March 2004
- Blood and urine samples are taken from subjects during a single period of time (one to two days)
- Blood samples are analysed for:
  - Serum B2M (medical diagnostic marker for kidney damage)
  - Manganese
  - Glucose (to cross check with urinary glucose)
  - Liver Function
  - Lead (by graphite furnace)
- Urine samples are analysed for:
  - Levels of uranium and ratio of U / creatinine
  - NAG content relative to creatinine excretion (research laboratory marker for possible kidney effects)
  - Protein, calcium, phosphate & glucose (possible kidney effects)
- MRI scan conducted for manganese and aluminium levels for workers with high potential or reported exposures
- Individual results of the testing programme provided to subjects and/or their treating physicians. Collated results (anonymised) provided to the OSS
- Further conclusions of ERA and the experts retained by OSS regarding long term health effects are exchanged for comment and discussion, and made available to subjects and/or their treating physicians.

I further recommend that ERA instruct an experienced neurotoxicologist to provide specialist advice on the proposed testing programme in respect of the potential long term effects of manganese and aluminium, and in particular the recommendation relating to an MRI scan. My preferred choice is Dr. Carl Keen of the University of California, Davis, who has confirmed that he is prepared to assist.

## **10. Wider consultation**

During the course of providing assistance to ERA in relation to the incident, I have provided information and data to workers and their treating practitioners, to members of the local community, and to government regulators including DBIRD and OSS and the OSS health experts. I summarise this consultation process below:

- Presentation of conclusions from my 1<sup>st</sup> level health risk assessment to a town meeting at Jabiru
- Meetings with individual workers with concerns regarding exposure
- Met with Brian Galton-Fenzi of Delta Health, medical advisor to the Factory and Mining Inspectorates in WA, and consulted by some of the contractors and sub-contractors, to provide background information, discuss worst case assumptions and preliminary health risk assessments, and consider proposed health testing programme
- Met with Contracting Companies as required to explain health aspects and proposed testing programme.
- Office of the Supervising Scientist – Mr. Rick van Dam – Discussed specialist health advisory group, background information regarding events, and my initial health risks assessments.
- Dr Emma Kennedy from the Bogot community – Discussed my initial conclusions regarding health risks and testing programme.
- Locum for Dr Kerry Gillespie – Discussed my initial conclusions regarding health risks and proposed testing programme.
- OSS Experts – spoke with Mike Moore regarding a draft risk assessment, and passed information on contamination, exposure and acute effects.

## **11. Conclusions**

A considerable number of workers at ERA's Ranger mine site were exposed during 23<sup>rd</sup> and/or 24<sup>th</sup> March to potable water contaminated with varying concentrations of process water. 28 workers complained of immediate physical symptoms, consistent with the likely health effects of the chemical composition of the contaminated water. I believe that these immediate physical symptoms have resolved.

My initial health risk assessments concluded that long term health effects were unlikely, but that the possible effects from uranium (kidney function) and manganese (neurological effect) should be considered further through a programme of medical testing. Having received and considered the results of initial medical testing, I consider that long term health effects as a result of the incident are most unlikely.

To increase the level of confidence in this conclusion, I recommend that ERA implement a limited further testing programme to trace the possible effects of uranium, manganese and aluminium. Upon completion of the further testing programme, I expect that ERA and the OSS will be in a position to assess with even greater certainty the risk of any long term health effects and consider whether any further testing, research or monitoring may be appropriate.



**Dr. Richard Gaunt**  
**Bristol, UK**  
**14<sup>th</sup> July 2004**

# **APPENDICES**

<b>APPENDIX A</b>	<b>Curriculum Vitae, Dr. Richard Gaunt</b>
<b>APPENDIX B</b>	<b>Initial summary of toxicological information</b>
<b>APPENDIX C</b>	<b>Contamination Test Results</b>
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<b>APPENDIX F</b>	<b>Medical Test Results</b>
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<b>APPENDIX H</b>	<b>Camelford Incident - consideration of aluminium levels</b>

# **APPENDIX A**

## **Curriculum Vitae Dr. Richard Gaunt**

**RICHARD GAUNT (DR)**  
**Occupational Health Physician**  
**Health Safety & Environment**

Manager: Elaine Dorward-King  
Current Role From: 1 June 1988  
Date Joined Group: 2 November 1981  
Role: Health & Safety

**Qualifications and Professional Memberships**

<b>MB ChB</b>	<b>Clinical Medicine</b>	<b>Sheffield University 1974</b>
<b>MA</b>	<b>Medical Sciences</b>	<b>Sidney Sussex College, Cambridge 1974</b>
<b>BA</b>	<b>Medical Sciences</b>	<b>Sidney Sussex college, Cambridge 1971</b>
<b>Member</b>		<b>Faculty of Occupational Medicine</b>

**Employment History (Group)**

Occupational Health Physician to date	Health, Safety & Environment	June 1988
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Currently the occupational physician within the corporate HSE group responsible for health aspects of the review programme and with interests in the health aspects of product safety issues.

Industrial Medical Adviser AM&S Europe / CSLNov	1981	May 1988
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**Employment History (External)**

Area Medical Officer	NCB	1978 - 1981
Deputy Medical Officer	NCB	1977 - 1978

**Work Experience Summary**

Registered as a medical practitioner in 1974. Post graduate training as a family physician and then as an occupational physician; certified in the United Kingdom as an occupational physician. Responsible for the medical aspects of the British Coal Selby coalfield development. Moved to the Rio Tinto Group as company physician at the Avonmouth lead zinc smelter and provided medical cover to the local chemicals industry. Currently the occupational physician within the corporate HSE group. Member of the Environment Program Review Committee of the International Copper Association and chairs the Health technical sub-committee that develops and monitors

progress on all the ICA's health research. Member of the technical sub-committee of the World Alliance for Community Health – the World Alliance promotes co-operation between its mining company members and the World Health Organisation to promote improvements in community health.

# **APPENDIX B**

## **Initial summary of toxicological information**

## Summary Toxicological Information

### **Manganese**

Manganese in drinking water imparts an undesirable taste to water at concentrations greater than 100 µg/L, yet the natural range for manganese in lakes and rivers is from 1 to 600 µg/L. Manganese is also found in food (meats, fish and eggs) in the range of 100 to 4,000 µg/kg, vegetables 400 to 6,600 µg/kg and grains and cereals 400 to 41,000 µg/kg. A cup of tea can contain 400 to 1,300 µg of manganese. Therefore usually our greatest daily exposure to manganese is in food, as adults usually consume 2,000 to 20,000 µg/day in their diets. Typically around 3-8% of an ingested dose of manganese is absorbed through the gut but absorption is greater for the young. The WHO notes that intake of manganese can be as high as 20,000 µg/day without apparent ill effects, but absorption from the gut can be variable. If 20% of the intake is from water a guideline value of 500 µg/L in drinking water is considered protective of human health. Also see IPCS (1981): Manganese. Environmental Health Criteria 17. International Programme on Chemical Safety, Geneva  
<http://www.inchem.org/documents/ehc/ehc/ehc017.htm>.

Manganese is one of the more abundant elements in the earth's crust and is widely distributed in soils, sediments, rocks, water, and biological materials. Manganese is an essential element to human health and is a cofactor in a number of enzyme systems and so plays a role in the production of a number of essential body substances (e.g. haemoglobin). Manganese is present in all foodstuffs, usually at concentrations below 5,000 µg/kg. However, concentrations in certain cereals, nuts, and shellfish can be much higher, exceeding 30,000 µg/kg in some cases. Levels in finished tea leaves may amount to several hundred mg/kg. Manganese is an essential trace element for both animals and man. It is necessary for the formation of connective tissue and bone, and for growth, carbohydrate and lipid metabolism, the embryonic development of the inner ear, and reproductive functions.

Estimates from intake and balance studies in man show that the daily requirement for adults is 2,000-3,000 µg/day and that of pre-adolescent children, at least 1,250 µg/day. Food is the major source of manganese for man. Daily intake ranges from 2,000 to 9,000 µg, depending on the relative consumption of foods with high manganese content, especially cereals and tea. Daily intake with drinking water may range from a few micrograms to 200 µg, the average intake being about 10-50 µg/day.

#### ***Manganese in water:***

- Surface waters of various American lakes - 0.02 to 87.5 µg Mn/L, mean of 3.8 µg/L;
- Large rivers in the USA - below the detection limit to 185 µg/L;
- Welsh rivers - 0.8 to 28.0 µg/L;
- River sampling sites in the United Kingdom and in the Rhine and the Maas and their tributaries - 1 to 530 µg/L;
- USSR groundwater not associated with manganese-bearing rock - 1 to 250 µg/L;
- Deep well water in the Takamatsu City area (Japan) - 220 to 2,760 µg/L;
- Drinking-water in the Federal Republic of Germany - 1 to 63 µg/L;

- Treated drinking-water supplies in 100 large cities in the USA - undetectable to 1,100 µg/L, with a median level of 5 µg/L;
- US Public Health Service survey of tap water from 148 municipal supplies - 2 to 1,000 µg/L, with a median level of 10 µg/L.

Thus, surface waters may have a manganese content of 1-500 µg/L, but in areas where high concentrations of manganese occur naturally, levels may be considerably higher. Average manganese levels in drinking water range from 5 to 25 µg/L.

### ***Manganese Metabolism:***

The total manganese body burden for a man of 70 kg is about 10,000 to 20,000 µg. It is transported in the plasma and is widely distributed throughout the body. Manganese concentrates mainly in the liver, pancreas, kidney and the intestines. It can also penetrate both the blood-brain barrier and the placenta. The disappearance half time for manganese from the whole body is about 37 days and the half-life in the brain appears to be longer than that for the whole body. Inorganic manganese is mainly eliminated in the faeces.

### ***Manganese Toxic Effects:***

In humans, manganese toxicity has occurred mainly as a result of inhalation of manganese dust over long periods of time. By the oral route, manganese is regarded as one of the least toxic elements. Only one epidemiological report is available on adverse effects from drinking water contaminated with manganese. Kawamura *et al.* (1941) studied 16 cases of manganese poisoning, 3 of which were fatal (including one suicide), in a small Japanese community. All 16 intoxicated subjects regularly drank water from contaminated wells used as a water supply. The manganese content of the water was about 14,000 µg/L and concentrations of 8,000 and 11,000 µg/L were found in 2 other wells. The subjects exhibited lethargy, increased muscle tone, tremor and mental disturbances however concentrations of other metals were also high and the reported effects may not be due solely to manganese. When excessive manganese is absorbed, effects over the short term are usually manifested in the nervous system in the form of muscular in-coordination and weakness and a hyperactive response, but the dose required to produce effects has varied widely in animal studies (1,000 – 150,000 µg/kg of body weight).

The levels of manganese in water at ERA were:

- Jabiru E Potable Water Tank – 14,800 µg/L;
- Admin Crib Room Tap – 22,500 µg/L;
- Jabiru E Potable Water Tank Overflow – 17,100 µg/L; and
- Jabiru E Hydrant (10:15 am) – 55,200 µg/L.

These are all above the 500 µg/L limit and an order of magnitude above 'natural' high levels in water. Drinking 2L of this water would provide an oral intake of between 29,600 and 110,400 µg Mn, but assuming 8% absorption across the gut, then the effective dose would be a maximum of 8,830 µg, which is 8 times the daily intake range.

### **Opinion:**

Although the manganese dose is not likely to have a toxic effect if only about 2L was

consumed, one cannot completely guarantee no health effects. However, toxicity following acute ingestion of inorganic manganese is rare due to poor gastrointestinal absorption. Most of the health effects of manganese seem to be from chronic exposures rather than acute exposures.

Recommendation:

There is no useful biological measure for manganese exposure, although a baseline serum manganese level may be done for those individuals who request it. People who consumed the contaminated water should be followed up for a year for neuropsychiatric symptoms.

## **Nickel**

In major Australian reticulated supplies, concentrations of nickel range up to 30 µg/L, with typical concentrations less than 10 µg/L. A limit of 20 µg/L is suggested, derived by applying a 1000 fold safety factor to the no effect level from results of animal studies (10 for interspecies variations, 10 for intraspecies variations, and 10 to compensate for the lack of adequate studies on chronic effects and for increased intestinal absorption when taken on an empty stomach), and assuming 2L/day consumption. Also see: IPCS (1991). Nickel. Environmental Health Criteria 108. International Programme on Chemical Safety, Geneva  
<http://www.inchem.org/documents/ehc/ehc/ehc108.htm>.

Nickel is a ubiquitous trace metal and occurs in soil, water, air, and in the biosphere. Nickel concentrations in food are usually below 500 µg/kg fresh weight. Cocoa, soybeans, some dried legumes, various nuts, and oatmeal contain high concentrations of nickel. Daily intake of nickel from food will vary widely, because of different dietary habits, and can range from 100 to 800 µg/day; the mean dietary nickel intake in most countries is 100-300 µg/day. Release of nickel from kitchen utensils may contribute significantly to oral intake. Pulmonary intake of 2-23 µg nickel/day can result from smoking 40 cigarettes a day (1 – 3 µg Ni per cigarette).

### ***Nickel in water:***

Levels in natural fresh waters have been found to range from 2 to 10 µg/L. Drinking water generally contains less than 10 µg Ni/L, but occasionally nickel may be released from plumbing fittings, resulting in concentrations of up to 500 µg/L. In Denmark, levels of up to 490 µg/L were observed, when water was left standing overnight in nickel-containing plumbing fittings. Between 18,000 and 900,000 µg of nickel were leached from 10 used water taps, which had been filled, in an inverted position, with 15 ml deionised water, and left overnight for 16 h. In areas where nickel is mined, as much as 200 µg Ni/L has been recorded in drinking water.

Assuming a daily intake of 1.5 litres water and a level of 5-10 µg Ni/L, the mean daily intake of nickel from water for adults would be between 7.5 and 15 µg.

### ***Nickel Metabolism:***

Gastrointestinal absorption of nickel is variable and depends on the composition of the diet. In a study on human volunteers, absorption of nickel was 27% from water



compared with less than 1% from food, at a dose between 12 and 50 µg/kg body weight. All body secretions are potential routes of excretion including urine, bile, sweat, tears, milk, and mucociliary fluid. Non-absorbed nickel is eliminated in the faeces. Transplacental transfer has been demonstrated in rodents. Following parenteral administration of nickel salts, the highest nickel accumulation occurs in the kidney, endocrine glands, lung and liver. Data on nickel excretion suggest a two-compartment model. Nickel concentrations in the serum and urine of healthy non-occupationally exposed adults are 0.2 µg/L (range: 0.05-1.1 µg/L) and 1.5 µg/g creatinine (range: 0.5-4.0 mg/g creatinine), respectively. Increased concentrations of nickel are seen in both of these fluids following occupational exposure. The body burden of nickel in a non-exposed, 70-kg adult is 0.5 µg.

### ***Nickel Toxic Effects:***

Metallic nickel is relatively non-toxic on oral ingestion. It should be noted that nickel compounds differ significantly in their toxicity with the insoluble compounds being the least toxic. Cases of nickel poisoning have been reported in patients dialysed with nickel-contaminated dialysate and in electroplaters who accidentally ingested water contaminated with nickel sulphate and nickel chloride. Oral nickel intake may trigger nickel sensitivity (allergy) and may aggravate vesicular hand eczema and, possibly, also eczema arising on other parts of the body where there has not been any skin contact with nickel. Transient nephrotoxic effects have been recorded after accidental ingestion of nickel salts. Animal studies have reported altered body weights, some evidence of liver toxicity and mild kidney toxicity with high nickel doses (over 100 mg/kg body weight per day). Nickel has also affected the immune system in laboratory mice.

Some forms of nickel are considered carcinogenic, although this is related to occupational inhalation exposure; no carcinogenic effects have been observed on ingestion.

The levels of nickel in water at ERA were:

- Jabiru E Potable Water Tank – 35.9 µg/L;
- Admin Crib Room Tap – 67.9 µg/L;
- Jabiru E Potable Water Tank Overflow – 41 µg/L; and
- Jabiru E Hydrant (10:15 am) – 131 µg/L.

These are all above the 20 µg/L limit and up to an order of magnitude above 'natural' levels in normal drinking water, but lower than levels in water left standing overnight in nickel-containing plumbing fittings or other contaminated drinking water.

Drinking 2L of this water would provide an intake of between 72 and 262 µg Ni.

### **Opinion:**

The nickel dose is not likely to have a toxic effect if only about 2L was consumed, although one cannot completely guarantee no health effects.

### **Recommendation:**

Baseline levels of nickel in urine should be done for all affected individuals, however it should be impressed that the biological monitoring of Nickel is an index of exposure only and cannot be related to any health effects. Affected people should probably be followed up for

## **Lead**

Lead can be present in drinking water as a result of dissolution from natural sources, or from household plumbing systems containing lead. These may include lead in pipes, or in solder used to seal joints. The amount of lead dissolved will depend on a number of factors including pH, water hardness, and the standing time of the water. A limit of 10 µg/L is suggested, based on protecting children, who are most sensitive to lead effects.

### ***Lead in water:***

Drinking water concentrations of lead reported overseas are usually less than 2 µg/L, but concentrations of 100 µg/L have been reported in Scotland where lead pipes and soft, acidic water are contributing factors. In major Australian reticulated supplies, total lead concentrations range up to 10 µg/L, with typical concentrations less than 5 µg/L.

### ***Lead Metabolism:***

Approximately 80% of the daily intake of lead is from the ingestion of food, dirt and dust. Food contains small but significant quantities of lead, which can increase when acidic food is stored in lead-glazed ceramic pottery or lead-soldered cans. The use of lead-free solders is becoming more widespread in the food processing industry. The average Australian adult dietary intake of lead is approximately 100 µg per day.

The body through inhalation, ingestion or placental transfer can absorb lead. In adults, approximately 10% of ingested lead is absorbed but in children this figure can be 4 to 5 times higher. After absorption, the lead is distributed in soft tissue such as the kidney, liver and bone marrow where it has a biological half-life in adults of less than 40 days, and in skeletal bone where it can persist for 20 to 30 years.

### ***Lead Toxic Effects:***

In humans, lead is a cumulative poison that can severely affect the central nervous system. Infants, foetuses and pregnant women are most susceptible. Placental transfer of lead occurs in humans as early as the 12th week of gestation and continues throughout development. Many epidemiological studies have been carried out on the effects of lead exposure on the intellectual development of children. Although there are some conflicting results, on balance the studies demonstrate that exposure to lead can adversely affect intelligence.

Other adverse effects associated with exposure to high amounts of lead include kidney damage, interference with the production of red blood cells, and interference with the metabolism of calcium needed for bone formation. The International Agency for Research on Cancer has concluded that lead is possibly carcinogenic to humans.

The levels of lead in water at ERA were:

- Jabiru E Potable Water Tank – 2.01 µg/L;
- Admin Crib Room Tap – 7.87 µg/L;
- Jabiru E Potable Water Tank Overflow – 2.06 µg/L; and
- Jabiru E Hydrant (10:15 am) – 5.9 µg/L.

These are all below the 10 µg/L limit and of the same order of magnitude as found in normal drinking water. Drinking 2L of this water would provide an intake of between 4.0 and 15.7 µg Pb, but assuming 10% absorption across the gut, then the effective dose would be a maximum of 1.6 µg, which is well within the average daily intake. It should be noted that lead in plumbing systems may contaminate drinking water and monitoring should always be performed after the pipes have been flushed by letting the water run for several minutes.

Opinion and Recommendation:

The lead dose is not likely to have a toxic effect if only about 2L was consumed. No monitoring of affected workers should be required.

## **Uranium**

Although ubiquitous in the environment, uranium has no metabolic function in animals or humans and is currently regarded as non-essential. Natural uranium consists almost entirely of the <sup>238</sup>U isotope, with the <sup>235</sup>U and <sup>234</sup>U isotopes constituting about 0.71% and 0.0057%, respectively; 1 µg of natural uranium has an activity of 0.025 Bq.

Food is the major source of uranium intake and highest concentrations are found in shellfish. Dietary intake of uranium is estimated at 1.4 µg/day. Drinking water contributes less than one tenth of this. It has been estimated that the total body burden of uranium in humans is 40 µg.

### ***Uranium in water:***

Studies overseas have reported uranium concentrations in drinking water of generally less than 1 µg/L; however concentrations as high as 700 µg/L have been reported in some private water supplies in Canada. In a British Columbian survey in 1980-1981 the mean concentration of water supplies was 4.06 µg/L (range < 0.05 – 2020 µg/L). A limit of 20 µg/L is suggested, derived by applying a 10 fold safety factor to the no effect level from results of animal studies, and assuming 2L/day consumption.

### ***Uranium Metabolism:***

Absorption of dietary uranium by the gastro-intestinal tract has been estimated on average to be between 1 and 2% (0.1 – 6%). Clearance from the bloodstream is rapid, however, uranium accumulates in the kidney and bone, with little in the liver. The overall biological half-life has been estimated at 6-12 months.

### ***Uranium Toxic Effects:***

In humans, the main toxic effect to high concentrations of uranium is inflammation of the kidney (renal tubular defects). Little information is available on the effects of long-term environmental exposure in humans. In a number of studies carried out in rats, rabbits and dogs, most report that uranium has an effect on the kidney and the effect seems to be reversible, although it needs to be noted that there may be significant differences between species. The human health impact of chronic exposures to uranium in water is not precisely known. One study, where 324 people drank contaminated water from wells with uranium concentrations up to 700 µg/L, reported no increase in the incidence of kidney disease or any other symptomatic complaint. However, a trend towards increasing excretion of urinary  $\beta_2$  – microglobulin was found with increasing well-water uranium levels. Urinary  $\beta_2$  – microglobulin is a sensitive marker of renal tubule damage along with urinary levels of glucose, aminoacids and phosphate. However, the authors concluded that the suspected tubular effect might well be rapidly reversible. In a recent Finnish report, alterations in the renal proximal tubule were found in people drinking from uranium contaminated wells with mean concentrations of 131 µg/L. No data is available on chemically-induced mutagenic effects in relation to uranium.

The levels of uranium in water at ERA were:

- Jabiru E Potable Water Tank – 89.9 µg/L;
- Jabiru E Potable Water Tank Overflow – 103 µg/L; and
- Jabiru E Hydrant (10:15 am) – 116 µg/L.

These are all above the 20 µg/L limit but are within recorded high levels in drinking water in many water supplies across the world where the contamination is from natural sources. Drinking 2L of this water would provide an intake of between 180 and 232 µg U.

#### Opinion:

The uranium dose is not likely to have a toxic effect if only about 2L was consumed.

#### Recommendation:

Urinary uranium levels should be measured as a baseline and may be followed up three monthly until levels return to normal if elevated, although this will itself may not predict health effects. Individuals should be followed up for 5 years due to the long half-life of uranium in the body.

### **Radiological quality of water:**

Potential effects due to radiological quality of the drinking water should be determined according to the National Health and Medical Research Council (1996) Drinking Water Guidelines at

[http://www.nhmrc.gov.au/publications/pdf/eh19\\_2001.pdf](http://www.nhmrc.gov.au/publications/pdf/eh19_2001.pdf).

There is evidence from both human and animal studies that radiation exposure at low to moderate doses may increase the long-term incidence of cancer. There is also evidence from animal studies that the rate of genetic disorders may be increased by radiation exposure. Acute health effects of radiation, ranging from skin burns to nausea, vomiting, diarrhoea, reduced blood cell counts and death, occur at much higher doses and therefore are not a concern for water supplies except in extreme accident situations.

It is recommended that a guideline dose of 1 mSv per year should be applied for radioactivity in drinking water.

# APPENDIX C

## Contamination Test Results



Contamination  
results SSD ERA ...

Initial potable water samples tested by ERA 24th March 2004

ERA site number	LIMS Sample No	LIMS sampling point	Sampling Point	Time (am)	U <sub>3</sub> O <sub>8</sub> (ppm)*	Lab EC (microS/cm)	Lab pH
1	-	GCR	Grinding crib room	7.45	8	5900	4.50
2	-	MLT	Mill Laboratory Tap	8.1	3	5900	4.50
3	-	PTPD	Potable Tank Pump Discharge	9.3	undetectable	650	7.45
4	-	PTUP	Potable Tank Underground Pipe (to Jabiru East)	9.3	undetectable	770	7.44
5	-	GPWT	Gravity Potable Water Tank (on FOB)	9.45	3	5380	-

\* analyses by XRF

ERA water samples (pre-flush) collected 24th March 2004.

All samples collected on site, transported to NTEL, then filtered through 0.45um membrane. Filtrate preserved by acidification to 1% HNO3 prior to analysis.

Laboratory Method Code - W100M - ICP/MS analysis; W106I - ICPOES

Area	Sample Number	Sample Time	Laboratory Method		Potable Water from Ranger Admin Crib Room		Potable Water Header Tank (on the fine ore bins)		Admin Potable Water Tank Discharge		Potable Water - Underground pipe to Jabiru East	
			Units	Method	PW	Administration	GPWT	PTPD	Administration	PTUP	PTUP	PTUP
EC			µS/cm	ALK1	100305	24/03/2004 09:50:00 AM	100323	100323 (total)	100324	100324 (total)	100326	100326 (total)
Temp			°C	ALK1		2740	24/03/2004 12:00:00 PM				24/03/2004 12:00:00 PM	
pH			units	ALK1		23.2						
Turbidity			NTU	TURB		5.8						
Alkalinity			mg/L	ALK1		325						
HCO3			mg/L	ALK1		106						
CO3			mg/L	ALK1		<1						
OH			mg/L	ALK1		<1						
NO2_N			mg/L	FIA_4		N.A.	N.A.		N.A.		N.A.	
NO3_N			mg/L	FIA_4		N.A.	N.A.		N.A.		N.A.	
Cl			mg/L	FIA_4		N.A.	N.A.		N.A.		N.A.	
NH3_N			mg/L	FIA		N.A.	N.A.		N.A.		N.A.	
Ag_F			µg/L	W100M		<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Al_F			µg/L	W100M		27.4	>LWR	114	94.2	136.9		
Al_F			µg/L	W106I		ND	13300	20634	ND	ND		
As_F			µg/L	W100M		0.2	7.95	13.51	0.2	0.1	0.25	0.12
B_F			µg/L	W100M		35	151	233	22.5	24.5	25.5	49.2
Ba_F			µg/L	W100M		3.14	7.44	6.88	1.38	1.52	1.56	1.46
Be_F			µg/L	W100M		<0.05	5.8	8.27	<0.05	<0.05	<0.05	0.06
Br_F			µg/L	W100M		39	229	104	71	8	70	10
Ca			mg/L	W106I		27.9	74.3		25	27.4	26.5	
Cd_F			µg/L	W100M		0.3	2.52	2.67	0.12	0.12	0.18	0.19
Cr_F			µg/L	W100M		1.2	4.5	5.4	1.4	1	1.3	1.3
Cu_F			µg/L	W100M		546	>LWR	2511	22.5	24.1	47.5	53.3
Cu_F			µg/L	W106I		ND	2270	192	ND	ND	ND	
Fe_F			µg/L	W100M		<20	120	192	<20	40	<20	35
Hg_F			µg/L	W100M		<0.02	<0.02	0.03	<0.02	<0.02	0.04	0.14
Li_F			µg/L	W100M		5	5	11	<5	<5	<5	6
Mg			mg/L	W106I		84	422		55.7	58.8	65.7	
Mn_F			µg/L	W100M		ND	>LWR		>LWR	>LWR	>LWR	
Mn_F			µg/L	W106I		22500	195000	N/A	8090	8330	13400	17310
Mo_F			µg/L	W100M		0.2	0.4	0.35	0.15	0.1	0.2	0.21
Ni_F			µg/L	W100M		67.9	425	537	18.2	20.7	29.8	33.5
Pb_F			µg/L	W100M		7.87	415	402	1.9	1.45	3.27	3.49
Sb_F			µg/L	W100M		0.25	0.3	0.17	0.1	<0.05	0.05	<0.05
Se_F			µg/L	W100M		1	38.6	86.9	0.8	0.8	1	1.1
Su_F			µg/L	W100M		<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
SO4			mg/L	W106I		345	2570		110	110	178	
U_F			µg/L	W100M		2.21	>LWR	2355	62.4	69.2	113	115
U_F			µg/L	W106I		ND	1350		ND	ND	ND	
Zn_F			µg/L	W100M		ND	>LWR	3128	197	221	355	397
Zn_F			µg/L	W106I		1510	2560		ND	ND	ND	
V_F			µg/L	W100M		2.5	ND	0.4	ND	ND	ND	0.6

N.A. - not available  
>LWR - outside calibration of technique  
ND - no data



IDENT UNITS SCHEME	Job number	Project code	pH units ALK1	EC µS/cm ALK1	Ca, F mg/L W105I	Mg, F mg/L W105I	SO4, F mg/L W105I	Aq, F µg/L W105M	Al, F µg/L W105M	As, F µg/L W105M	B, F µg/L W105M	Ba, F µg/L W105M	Be, F µg/L W105M	Br, F µg/L W105M	Cd, F µg/L W105M	Cr, F µg/L W105M	Cu, F mg/L W105M	Fe, F µg/L W105M	Hq, F µg/L W105M	I, F µg/L W105M	Mn, F µg/L W105M	Mn, F mg/L W105I	Mo, F mg/L W105I	Mo, F µg/L W105M	Ni, F µg/L W105M	Pb, F µg/L W105M	Sb, F µg/L W105M	Se, F µg/L W105M	Sn, F µg/L W105M	U, F mg/L W105M	Zn, F µg/L W105M
PROCESS WATER	EL03471	BROCKMAN BOREFIELD&PROCESS WATER	3.8	20100	460	3190	20070 <1	>LWR	>LWR	423	100	1760 <50	99	564	23.2	320 >LWR	22.5	6480 <0.4	70 >LWR	1630 <5	4690	3970 <1	398 <2	>LWR	24	5750					
	EL03471	BROCKMAN BOREFIELD&PROCESS WATER	3.9	19200	412	2860	18350 <1	>LWR	>LWR	382	89	1600 <50	89	584	21	295 >LWR	20	5580 <0.4	80 >LWR	1460 <5	4430	3510 <1	382 <2	>LWR	21.5	5430					
	EL03471	BROCKMAN BOREFIELD&PROCESS WATER	4	17600	391	2710	17040 <1	>LWR	>LWR	357	83.5	1380 <50	78	638	19	265 >LWR	19.5	4480 <0.4	50 >LWR	1370 <5	3980	3180 <1	336 <2	19300 -	4830						
	EL03471	BROCKMAN BOREFIELD&PROCESS WATER	4	15100	342	2360	14280 <1	>LWR	>LWR	307	68	1120 <50	61	684	15.6	210	18200 -	2840 <0.4	30 >LWR	1190 <1	3240	2600 <1	273 <2	16000 -	4130						
1 IN 2	EL03471	BROCKMAN BOREFIELD&PROCESS WATER	4.1	12000	259	1760	10910 <1	>LWR	>LWR	220	51.5	860 <50	42	634	11.4	145	13200 -	1720 <0.4	30 >LWR	884 <1	2370	1880 <1	203 <2	11400 -	3030						
1 IN 3	EL03471	BROCKMAN BOREFIELD&PROCESS WATER	4.2	8700	182	1190	7650 <0.5	>LWR	>LWR	136	35	560 <50	33	686	7.8	95	9110 -	840 <0.2	20 >LWR	594 <0.5	1650	1320 <0.5	142 <1	8040 -	2140						
1 IN 4	EL03471	BROCKMAN BOREFIELD&PROCESS WATER	4.3	6910	141	901	5420 <0.5	>LWR	>LWR	87.8	28	420 <50	21	622	6	50	6870 -	400 <0.2	20 >LWR	449 <0.5	1240	985 <0.5	114 <1	5890 -	1680						
1 IN 5	EL03471	BROCKMAN BOREFIELD&PROCESS WATER	4.3	5770	120	747	4310 <0.5	>LWR	>LWR	61.2	22	320 <50	16	578	4.8	30	5330 -	220 <0.2	20 >LWR	365 <0.5	984	753 <0.5	90 <1	4600 -	1360						
1 IN 10	EL03471	BROCKMAN BOREFIELD&PROCESS WATER	4.8	3350	72.3	397	2160 <0.25	>LWR	>LWR	5.22	10.5	160 <50	4	388	2.6 <5	2670 -	<100	<0.1	10 >LWR	185 <0.25	508	365 <0.25	44 <0.5	2010 -	800						
1 IN 50	EL03471	BROCKMAN BOREFIELD&PROCESS WATER	7.1	1100	32.1	111	468 <10	200 -	<0.5	40 <50	<1	74	0.6 <5	70 -	20 <0.1	<10	>LWR	36.9 <5	92	5 <0.2	1 <10	169 -	150								
1 IN 100	EL03471	BROCKMAN BOREFIELD&PROCESS WATER	7	1130	33.1	118	501 <10	80 -	<0.5	40 <50	<1	76	0.6 <5	80 -	<20	<0.1	<10	>LWR	38.8 <5	104	5 <0.2	1 <10	141 -	180							
POTABLE WATER	EL03471	BROCKMAN BOREFIELD&PROCESS WATER	8	382	22.4	39.5	3.5 <10	20 -	<0.5	<20	<50	<1	34	0.2 <5	10 -	<20	<0.1	<10	>LWR	45 -	<5	<0.2	<1	10.3 -	140						

# APPENDIX D

## Water Incident Exposure Profile



Exposure profile  
270504.xls

Code Identifiers for individual persons have been replaced to protect confidentiality

## WATER INCIDENT

### Notes:

1. Water in mining area appears not to have tested unusual. Therefore although exposure are rated as high, actual exposures probably low.
2. Further effort to be made to persuade Linetec Engineering and ESS NAAD staff to attend for testing.
3. Further effort to persuade Hu and Hu2 to be tested.

X = Off Site  
O = 0  
L = <500  
M = 500-2L  
H = 2L +

Code Number	Department or Contractor	Water consumed in ml	Location of consumption	Showered - and where	Symptoms Reported (Y)	Comments from Individual	Estimated Exposure
		0					O
		500	SX			No ill effects	M
		0				Off site	O
		0				On holidays	O
		0		No		Was on holidays	O
		20	Cribroom			Two mouthfuls coffee, no problems	L
AAA		2000	Maintenance crib room cooler / Engineering Admin			No ill effects	H
		200	Met Lab cribroom			I have not felt sick at all	L
		300	Processing Crib Room	Yes		Had cup of coffee Wednesday mornig and showered Tuesday after day shift.	L
AAA		2500	ERRIS Ice Machine	No		Drinking water from ERRIS ice machine - morning of 23/03/04 07.30am. Sample sent to NTEL of water actually consumed. Tested 15:15pm 23/03/04 46.9 USCM & 7.61pH.	H
		1000	Mine			Feeling OK	M
		0					O
		0					O
		300	HR cold water dispenser and taps			No problems noted	L
		100	Engineering Smoko Room	No		Tea tasted ok	L
		0				Off site	X
		0					O
		300	Grinding cooler			Water tasted strange	L
		0					O
		50	Mill Maintenance workshop				L
		0				Day off	X
AA		0					O
		500	Engineering crib room urn			Have felt OK since drinking	M
		100	Downstairs Projects Area			Did not taste bad	L
		500	Mill Maintenance workshop				M
		0					O
		0					O
		0					O
		0					O
		300	Mill Maintenance workshop				L
		?	Hews	Yes		Don't know because when & how long was it going on? But it is all I drank and showered in	M
		0		No		Not on shift	X
		0					X
		0					O
		0				Off site	X
		200	Day services cribroom				L
		0					O
		1500	Mining Admin	No		Water tasted OK	M
		100	Mine cribroom			Wonderful - I'm feeling fine	L
		0				Was at fire extinguisher training. I drink about 5 litres of water each day before this date.	O
AA		500	Maintenance crib room urn		Y	For several days after I drank the water I had a metallic taste/sensation on my tongue. I have also had a queasy felling in my digestive system, but I do not now whether this is related to drinking the contaminated water or not	M
		1000	Water bottle on ute			Water had been sourced the previous day - I feel OK	M
AA		0				Not on site Wednesday	X
		0				Washed hands at office	O
		0					O
		0				Off site	X
		200	Powerstation Oasis				L
		50	Grinding bubbler				L
		0				Leave	O
AAA		2000	Mine crib room	Yes Mine showers			H
		0				Off site	O
		0					O
AAA		300	Downstairs Projects Area		Y	I have had really bad headaches	L
		0		No		Not on shift	O
		0		No		Our shift was on days off at the time	X
		0					X
		0				Off site	O

## WATER INCIDENT

**Notes:**

1. Water in mining area appears not to have tested unusual. Therefore although exposure are rated as high, actual exposures probably low.
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3. Further effort to persuade Hu and Hu2 to be tested.

X = Off Site  
O = 0  
L = <500  
M = 500-2L  
H = 2L +

Code Number	Department or Contractor	Water consumed in ml	Location of consumption	Showered - and where	Symptoms Reported (Y)	Comments from Individual	Estimated Exposure
		300	Mine crib room				L
		0					O
		0				Not on shift	X
		0		No		Days off, in Darwin	X
		0					O
		0					O
		600	Workshop Crib Room & bubbler	No	Y	Felt sick & had slight Diarohea for 3 days	M
		0		No		Off site	O
		1000	Mine crib room			Okay	M
		0					O
		0				Off site	X
		0		No		Did not drink. Warned in morning	O
		30	Engineering				L
		0				off site	X
		0		No			O
		0					O
		250	Env Ops bubbler	No		No taste - no effect. Water seem fine at the time.	L
		0					O
AAA		2000	Inganarr Centre	No		Water was ok. Some pressure difference. Feel fine. Did not want to see Doctor	H
AA		0					O
		1000	Mine crib room	Yes Mine showers			M
		0					O
		700	HR kitchen				M
AA		250	Inganarr water cooler			No ill effect - tasted OK	L
		0		No		Was on site but do not recall drinking any water	O
		0					O
		0					O
		300	Engineering cribroom	No			L
AA		300	Engineering cribroom				L
		0					O
		0				Off 1900 23/03/04 - 27/03/04	X
		0		No		Not on site at time of incident	X
		0				Okay	O
		0					O
		0					O
		0					O
		0					O
		0					O
		100	Powerstation urn				L
AAA		?	Workshop cribroom		Y	Mouth was dry, constant spitting. Spitting out white fluid. Feels OK, had a headache on Wednesday. Wants a medical done in Townsville. Skilled to organise.	
		0					O
		300	Mine Crib room	Yes - Mining			L
		0		No			O
		30					L
		600	Maintenance Crib Room	Yes - Maintenance Change Rooms		My coffee tasted bad, but it usually does.	M
		500	Maintenance cribroom	No		Approx 1-2 cups. Washed hands and face. (This form sent on 1 Apr by email to Rob Rappa at 1548.) Not advised nature of contamination prior to leaving site. Unable to talk to ERA's doctor until 30 Mar, not on site, not available. Confirmation was sought re what tests should be done, no confirmation received. No advice provided on what tell-tale symptoms to look for. Signed Craig Forster 5 Apr 04.	M
		0		No		Rostered off during this incident	X
		1000	Electrical, Mill, Maintenance W/S	No		Washed hands and went home and showered.	M
		200	Mine crib			Okay	L
		0					O
		250	Mine crib room	Yes	Y	Sick about 6.30pm - okay Thursday	L
		0				Off site	X

## WATER INCIDENT

### Notes:

1. Water in mining area appears not to have tested unusual. Therefore although exposure are rated as high, actual exposures probably low.
2. Further effort to be made to persuade Linetec Engineering and ESS NAAD staff to attend for testing.
3. Further effort to persuade Hu and Hu2 to be tested.

X = Off Site  
O = 0  
L = <500  
M = 500-2L  
H = 2L +

Code Number	Department or Contractor	Water consumed in ml	Location of consumption	Showered - and where	Symptoms Reported (Y)	Comments from Individual	Estimated Exposure
AA		200	Engineering cribroom			Commented on how bad the taste (or my coffee making abilities)	L
		500	Admin cribroom fountain			No taste, no effect	M
		0					O
		10	Admin area water bubbler			No problems felt	L
		0					O
		30	Grinding crib			Does not feel ill, does not require counselling	L
		0					O
AA		4000	SX cooler Grinding	Sticky shower - shower block below admin	Y	Could not taste anything. Update from form 2: 'Was operating in two areas (CCD and SX). Was on duty n/s. I would have had 3-4 cups coffee and 1 cup tea throughout shift. I drink water in preference to soft drink and usually have a drink at the water bubbler when going past. Noticed at sometime before 4am that the water tasted funny, but thought that it must have been my tastebuds or else I'd heard that they'd done something with the bore pumps a couple of days prior so that may have caused change of taste. Then had cup of tea with 1 sugar, did not notice anything strange. Tried water again later - still tasted bad. Had 3 or 4 drinks from bubbler in SX throughout the night - didn't taste anything different. Last drink there was about 6am. Showered at 7am. Had another shower when I got home as the work one felt terrible - felt sticky.	H
		10	Engineering cribroom urn			No obvious effects	L
		1000	Mill	No		Water tasted off, feel ok. No problems	M
		0					O
		0				None	O
AA		1000	Urn and top/downstairs admin showers		Y	Rash on hands from using to drink	M
		200	Mine crib			Okay	L
		0				Does not require counselling	O
		0				Off site	X
		0					O
		0					O
		0				Off Site	X
		0				Off site	X
		10	Crusher	Yes		Water was disgusting, not normal - murky. No health problems, feel fine.	L
		0					O
		500	Warehouse bubbler		Y	Slight stomach upset	M
		0					O
		0		No		I was off site at time of contamination	X
		0		no		Was made aware of problem shortly after coming on site. Drank water from my water bottle which was filled on site on Tuesday. Left site approx. 1100.	O
		0					O
		1000	Mine crib room			Okay	M
		10	Supply			Cloudy and nasty, didn't swallow, does not feel ill	L
		400	Powerstation cribroom			at 8am	L
		0				Would like to make an appointment to get checked out. Spoke to Neil, he only wanted own unrelated medical. He will arrange this as a separate issue. - Bob Povey 08/04/04	O
		400	Cribroom			Okay	L
		0	Admin/HR water cooler				O
		0					O

## WATER INCIDENT

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1. Water in mining area appears not to have tested unusual. Therefore although exposure are rated as high, actual exposures probably low.
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3. Further effort to persuade Hu and Hu2 to be tested.

X = Off Site  
O = 0  
L = <500  
M = 500-2L  
H = 2L +

Code Number	Department or Contractor	Water consumed in ml	Location of consumption	Showered - and where	Symptoms Reported (Y)	Comments from Individual	Estimated Exposure
AA		230	Engineering mouthwash Powerstation water fountain			Very bitter floury taste from water in engineering crib room. <b>NOTE: Bob Povey has spoken to this person</b> - person happy with outcome	L
		0				Not on site	X
		0				Not in Jabiru at that time	X
AA		2000	Acid Plant cribroom bubbler	Sticky shower		No noticeable taste - Noticed hot water cloudy at end of shift. Second form received: 'No reaction after drinking water. When showering, got covered in very thick solution, took about 20 mins to remove. Showered again when I got home'	H
		250	Engineering Crib room bubbler	No		Tasted salty. No physical effect	L
AAA		4000	HEWS workshop & ice machine	No		No effects. Spoken to on 08/04/04	H
		400	Engineering hot water urn			To date I have had no ill effects	L
AA		1500	Cribroom urn/cooler			Had water with coffee and squincher - did not taste	M
		0		No			O
		1000	Engineering hallway bubbler		Y	Vomited at 11.30am Wed am, queasy stomach all day, very loose bowel motion at 4pm, still queasy up to Thurs am, loose bowel motions again at 3am. Since then OK.	M
		250	HR kitchen				L
		200	Production Admin Urn (filled previous day)				L
AAA		3000	Gatehouse kitchen tap			I had made up the water with Squincher early in the night. Had coffee during the night. No ill effects. Likely to be low exposure although drank enough to be graded high.	H
		0				Not on site	X
		200	Workshop cribroom urn/cooler			I feel fine	L
		0				Off site in Darwin	X
AAA		100	Maintenance cribroom hot water dispenser			Made cup coffee at 7.10 Wed not sure how much I drank. Tried to make another cup at around 9.30, but water made milk curdle, did not drink this. Also washed hands in toilet room.	L
		1000	ERRIS Ice Machine	No		Drinking water from ERRIS ice machine - morning of 23/03/04 07.30am. Sample sent to NTEL of water actually consumed. Tested 15:15pm 23/03/04 46.9 USCM & 7.61 pH.	M
		0					O
		200	HEWS, workshop bubbler and urn	No		No ill effects. Would like an appointment with Dr.	L
		100	Grinding crib room	No	Yes	Water had a very bad taste. Symptoms felt: Headaches, blurry/failing vision	L
		200	Powerstation crib room			Feel good	L
		200	Supply sink			Coffee did not taste very nice	L
		10	Admin management crib room			But did wash hands and rinsed coffee jug - had no symptoms, just had a 'salty' taste in mouth	L
AAA		5000	Maintenance main water bubbler			None	H
		0					O
AAA		2000	Mine	Yes Mine showers			H
		0					O
AAA		2500	HWS bubbler	Yes - Mill		Did not taste funny, do not require counselling, feel OK	H
		0				Off site	X
		0				Off site	X
		0		No		Off site	X
		100	HR kitchen				L
		0				Off site	X
		0				Off site	X
		0					O
		0					O
		50	ESH cribroom cooler			No effect, just tasted bad	L

## WATER INCIDENT

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3. Further effort to persuade Hu and Hu2 to be tested.

X = Off Site  
O = 0  
L = <500  
M = 500-2L  
H = 2L +

Code Number	Department or Contractor	Water consumed in ml	Location of consumption	Showered - and where	Symptoms Reported (Y)	Comments from Individual	Estimated Exposure
		1500	Electrical w/s & water outlet at back of w/s near ice machine	No	Y	A little bit of nausea feeling and flatulence.	M
		0		No		Finish nightshift on Monday morning	X
		0		No		Last nightshift was 22/03/04 & first day shift was 27/03/04	X
		0				Have been drinking the water over the past 4.5 years from HEWS Bubblers. Was on days off on the day. But has this been going on over the years.?	X
		0		No		No problems, was not affected	O
AAA		4000	Powerstation crib room and workshop water fountain				H
		0					O
		0		No			O
		0					O
		0				Off 1900 23/03/04 - 27/03/04	O
		0					X
		200	Mine cribroom			Does not feel ill, does not require counselling	L
		1000	Ice Machine Water Fountain	Mine			M
		0				Off site	X
		0				Brought a bottle at Mobil that morning	O
AA		50		Seemed normal		Noticed odd taste in last cup of tea	L
		1500	Mine crib room	Yes		Okay - have been feeling fine	M
		0				On Annual Leave	X
		?	Mine cribroom			Okay	
		0				Off site	X
		500	HR kitchen				M
		?	Cribroom			Okay	
		0					O
		1000	Mine crib room			Feels fine. Drank 3 cups of coffee.	M
		0				Holidays/Days off	X
		1500	Maintenance Workshop	No		Washed hands and went home and showered	M
		0		No		Off site	X
		400	Day gang	No	Y	Headache	L
		0		No			O
		0		No			O
AAA		2500	Mine crib room	Yes - Mining		Good Water was ok. Drinking water from water bottle. Likely to be low but drank enough to be graded High	H
AA		3000	Powerstation crib room and workshop water fountain				H
		?	Engineering Workshop, Crusher Control Room Bubblers	No		Unsure of quantity of water consumed.	
AA		500	Met Lab cribroom water dispenser		Y	Felt a little bit funny - felt a little different	M
		4000	HWS bubbler	HEWS Wed m	Y	No effects, water tasted bad at end of shift, left a dry mouthed sensation. When I had shower, water seemed sticky, left me itchy. Did vomit after drinking in morning. Feeling fine now, no problems. First noticed bad tasting water at about 2am. Did not want to see Doctor	H
		0					O
		0				Off site	X
		0				I did wash a cup in mining crib room and had a drink of milk, feel fine, no counselling required	O
		1000	Powerstation				M
		0		No		On days off	O
		500	Drinking fountain in HEWS	No			M
		1000	Mine Maintenance cribroom fountain				M
AAA		2000	Mine cribroom	Mining		Tasted OK, feel fine. Drank enough to be graded High but water tested ok. So probably a low actual exposure.	H
		200	Engineering water cooler		Y	Stomach upset for most of day	L

## WATER INCIDENT

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3. Further effort to persuade Hu and Hu2 to be tested.

X = Off Site  
O = 0  
L = <500  
M = 500-2L  
H = 2L +

Code Number	Department or Contractor	Water consumed in ml	Location of consumption	Showered - and where	Symptoms Reported (Y)	Comments from Individual	Estimated Exposure
AAA		2000	Water treatment cribroom cooler / Engineering Admin			No ill effects	H
		500	Engineering cribroom			Had two cups of coffee Wed am - felt OK	M
		0		No		Off site	X
		?	Workshop & Water bottle	No			
		500	ESH cribroom			Tea was OK at 0600 and 0630 - water tasted bad at 0730	M
		0				Not on site at time of incident	X
		10	?			Made cup coffee with contaminated water, had two sips, did not taste right, emptied cup	L
AA		700	Grinding bubbler	Sticky shower		First drink coffee 22.00; second at 4.30am; first drink from bubbler 23.00; second 3am; rinsed mouth out in shower.	M
		0				Drunk water in the past, so if any contamination is proven prior to 24 Mar I have certainly been exposed to it	O
AA		200	Engineering crib room urn		Y	Felt a little bit crook for a few days, but that might be due to too much sun on Wednesday after we got sent home	L
		500	Engineering Chiller	No	Y	Sick & nauseous for 12 hours. Metal taste in mouth. Now ok	M
		0					O
		0					O
		0					O
		0					O
		0					O
AAA		3000	Various around site	Sticky shower - Maintenance	Y	Taste noticed at end of shift - Upset stomach next morning (bloated) - Did not know it was contaminated - noticed some taste difference during the night	H
						Sen by Dr Gaunt - no exposure	
		250	Engineering cribroom urn	No			L
		200	Engineering Crib room	No		No ill effects	L
		200	Admin upstairs cribroom urn				L
		200	Engineering maintenance cribroom				L
		0					O
AAA		3000	HEWS Workshop & Boilermakers bubbler & ice room machine	No		Water shocking. Not effected as yet. Did not want to see Doctor	H
		0					O
		400	Mine cribroom	Mining		Brings own water - does not need counselling ... End of shift consumption	O
		0				off site	X
		0		No		Not on Shift	X
AAA		4000	Maintenance	Maintenance	Y	Noticed about 2.30am having shower and felt stinging and slimy with soap - during day felt itchy	H
		250	Urn			Instant coffee which had been made from the urn filled up the previous day	L
						Consumption form to come	
AA		100	Grinding/mill			No ill feeling	L
		0				Not on shift	X
		0					O
		0					O
		0					O
AA		200	Grinding control cribroom				L
		100	Mining Crib Room	No			L
		0					O
		600	Mill Maintenance Crib room	No			M
AAA		350	Downstairs Engineering Bubbler			Water tasted foul & felt like dry reaching	L
		0				Not on shift	X
		0		No		Not on site	X
		10	HEWS, Maintenance, Env Ops, Env Admin			No ill effects	L
		0				No on site	X
AAA		10		Sticky shower			L
		0					O
		0				Told not to shower by Supervisor	O



## WATER INCIDENT

### Notes:

1. Water in mining area appears not to have tested unusual. Therefore although exposure are rated as high, actual exposures probably low.
2. Further effort to be made to persuade Linetec Engineering and ESS NAAD staff to attend for testing.
3. Further effort to persuade Hu and Hu2 to be tested.

X = Off Site  
O = 0  
L = <500  
M = 500-2L  
H = 2L +

Code Number	Department or Contractor	Water consumed in ml	Location of consumption	Showered - and where	Symptoms Reported (Y)	Comments from Individual	Estimated Exposure
		0					O
		750	?				M
AAA		2000	Maintenance Workshop				H
AA		500				Before I knew of the problem I had seen Dr Rush	M
AA		500	M/workshop cribroom fountain				M
		0					O
		0					O
		400	Env Ops				L
		0				I was at home	O
		0					O
		0				Rostered day off	X
		1000	Warehouse fountain				M
		0					O
		500	Admin (projects) cribroom cooler				M
		0		No		Was rostered off from Tuesday 23rd to Friday 26th.	X
		0				Everything handled well	O
		200	HWS bubbler			Feel OK, did not notice anything wrong with water	L
		0				Off Sick prior to incident	X
		500	Mine Crib Room	Yes- Mining			M
		0		No		Was on days off - 22nd - 26th March	X
		0				Off Site	X
		0				Off Site	X
		0				Was on Annual Leave	X
		350	Engineering Ice Machine Outside	No		Did not notice any abnormal taste. Tested EC in Darwin - OK (<220ms)	L
		100	Admin, mill meeting room			The water drunk was from a bottle and kettle that had been filled the previous day	O
		200	Mine cribroom			Has the flu	L
AAA		4000	Powerstation crib room and workshop water fountain				H
		0					O
AA		3000	Bubblers in Grinding Crib room, Engineering Crib, Downstairs Engineering, Acid Plant & Security	No		Split shift 23/3. Gone by 9.30 - 10pm. Started at 6.30am 24/3.	H
AAA		2000	Warehouse water cooler	No - but washed hands and arms at water station near receiving	Y	Had headache and itchiness/rash on arms - took headache tablets. Did not want to see doctor.	H
		600	Engineering Crib room	No			M
		0					O
		250	HR kitchen				L
		0					O
		0					O
		0				I am just a little concerned as I drank water the day before (23 March) the water tasted funny then as well. Has seen Dr Gaunt	O
AAA		6000	Acid plant			Tasted OK. <b>NOTE: Bob Povey has spoken to this person - no ill effects. Did not want to see Doctor</b>	H
AAA		2000	HWS bubbler, crib room			Tasted OK, feels OK, does not require counselling	H
		0					O
		0				Off site	X
		200	Mine cribroom			No problems with water, does not feel ill. Counselling - no.	L
AA		5000	HWS, workshop crib	Sticky shower - HEWS	Y	Water tasted bad, even tea. Showering caused itchiness to skin. No ill effects, does not want to see doctor. Will let us know.	H
		0				Not on shift	X

# **APPENDIX E**

## **Acute Effects Assessment**

## ACUTE EFFECTS ASSESSMENT 22 April 2004

### Codes used

Consumption of potable water on night shift of 23<sup>rd</sup> and dayshift of 24<sup>th</sup> March up to turning water off.

High	More than 2.0 litres
Medium	Between 500 ml and 1.99litres
Low	Less than 499 ml and/or showering
O	No water consumed, brought water onto site or not on site.
?	Uncertain about exposure

### Symptoms

SA	Symptoms Acute (Short Term): typical of acute irritation from drinking water – now settled. Mild expected symptoms at the time of exposure including rash, slight diarrhoea, headache, and nausea.
SC	Symptoms Chronic: typical (initially) of acute irritation from drinking water that are continuing – even if changing character.
SU	Symptoms Uncertain: that are not typical in type or time relationship to drinking the water.

All these results are based on the information available to Bob Povey of ERA at 11:00 on Thursday 22 April.

	Number of people not reporting symptoms	Number of people reporting symptoms	SA	SC	SU
<b>High</b>	18	10	7	3	0
<b>Medium</b>	40	10	9	0	1
<b>Low</b>	65	6	4	0	2
<b>0</b>	151	2	0	0	2
<b>?</b>	10	0	0	0	0
<b>TOTAL</b>	284	28	20	3	5

# **APPENDIX F**

## **Medical Test Results**



Water Incident  
Codes.xls

Code Identifiers for individual persons have been removed to protect confidentiality





# APPENDIX G

## Interpretation of Urine NAG results from Ranger uranium mine workers

**Roger Drew, PhD, DABT  
Toxikos Pty Ltd.**



NAG info & results  
analysis (TC010604-F

# ***DRAFT***

## **Interpretation of urine NAG results from Ranger uranium mine workers.**

**Prepared by: Roger Drew, PhD, DABT,  
Toxikos Pty Ltd.**

**Toxikos Document TC010604-R2**

This brief report provides contextual information on the measurement of NAG activity in urine and on the levels of NAG activity in 'normal' populations. This information is used to facilitate interpretation of results of NAG measurements in urine of workers at the Ranger mine that may have been exposed to contaminated water during the March 2004 incident.

### **Summary of Conclusions:**

#### **1. NAG assay and reference range.**

- Urinary NAG activity assays are not standardised.
- Urinary NAG activity results are best normalised to the amount of creatinine excreted as this decreases variation due to excretion of different urine volumes.
- There are many common factors within a normal population that influence urinary NAG activity; these include age, blood pressure, diabetes and smoking.
- Even when normalised to creatinine excretion there is within a given 'normal' population a 10 – 20 fold variation between individuals in urinary NAG activity. The variation may be up to approximately 100 fold if data are from the general population with no account taken of age, smoking or other factors that affect appearance of NAG in urine.
- For any given person there is day to day variation in urinary NAG activity.
- Taking into account all of the above, it is not possible to identify a reference range for urinary NAG activity with which to compare the results from Ranger uranium mine workers.

#### **2. Interpretation of urinary NAG results from Ranger workers.**

- Urine NAG activity is a sensitive indicator of renal tubular damage. The urine NAG results from workers at the Ranger mine have a variation in activity consistent with that of many 'normal' populations around the world. There is no difference in the average or range of NAG activity between workers who did not drink contaminated water, or drank low, medium or high amounts. It is concluded urinary NAG activity in workers potentially exposed to contaminated water at the mine are not elevated, the results do not provide evidence for impairment of renal function.



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## **1. The NAG Assay:**

A number of parameters are routinely measured in urine and blood to provide a diagnostic evaluation of kidney function. There are also a range of tests that are performed in clinical research which are adjuncts to the routine clinical tests. One of these is measurement of N-Acetyl-b-D-glucosaminidase (NAG) in urine.

N-Acetyl- $\beta$ -D-glucosaminidase, also known as hexosaminidase, is an enzyme that occurs in different forms (isoenzymes) in a variety of body tissues; the liver, kidney, spleen and serum (Dance et al. 1968). It is present in high concentration in lysosomes of cells in the glomerulus and proximal tubules of the kidney. The enzyme can leak out of kidney cells and be found in urine.

Although NAG is normally present in urine the levels are increased:

- in kidney disease (Price 1992, D'Amico and Bazzi 2003 ),
- in diabetes (Oba et al. 2000),
- by a variety of drug therapies, e.g. antibiotic, antiarthritic, antiepileptic drugs (Wiland & Szechinski 2003, Wiland et al. 1997, Otsuka et al. 1994),
- by hypertension (Oba et al. 1999, Alderman et al. 1983, Agirbasli et al. 1996),
- in urinary tract infections (Diazyme 2004, PPR Diagnostics 2004),
- exposure to some workplace or environmental pollutants
  - Trichloroethylene (Green et al. 2004),
  - Long term occupational lead exposure (Endo et al. 1990, Chia et al. 1994, EL-Safty et al. 2004, Sonmez et al. 2002),
  - Environmental cadmium (Uchida et al. 2004, Satarung et al. 2004),
  - Occupational silica (EL-Safty et al. 2003).
- with increasing age (Berg et al. 1998, Oba et al. 1999, Moriguchi et al. 2003, Agirbasli et al. 1996) and
- by smoking (EL-Safty et al. 2004, 2003a).

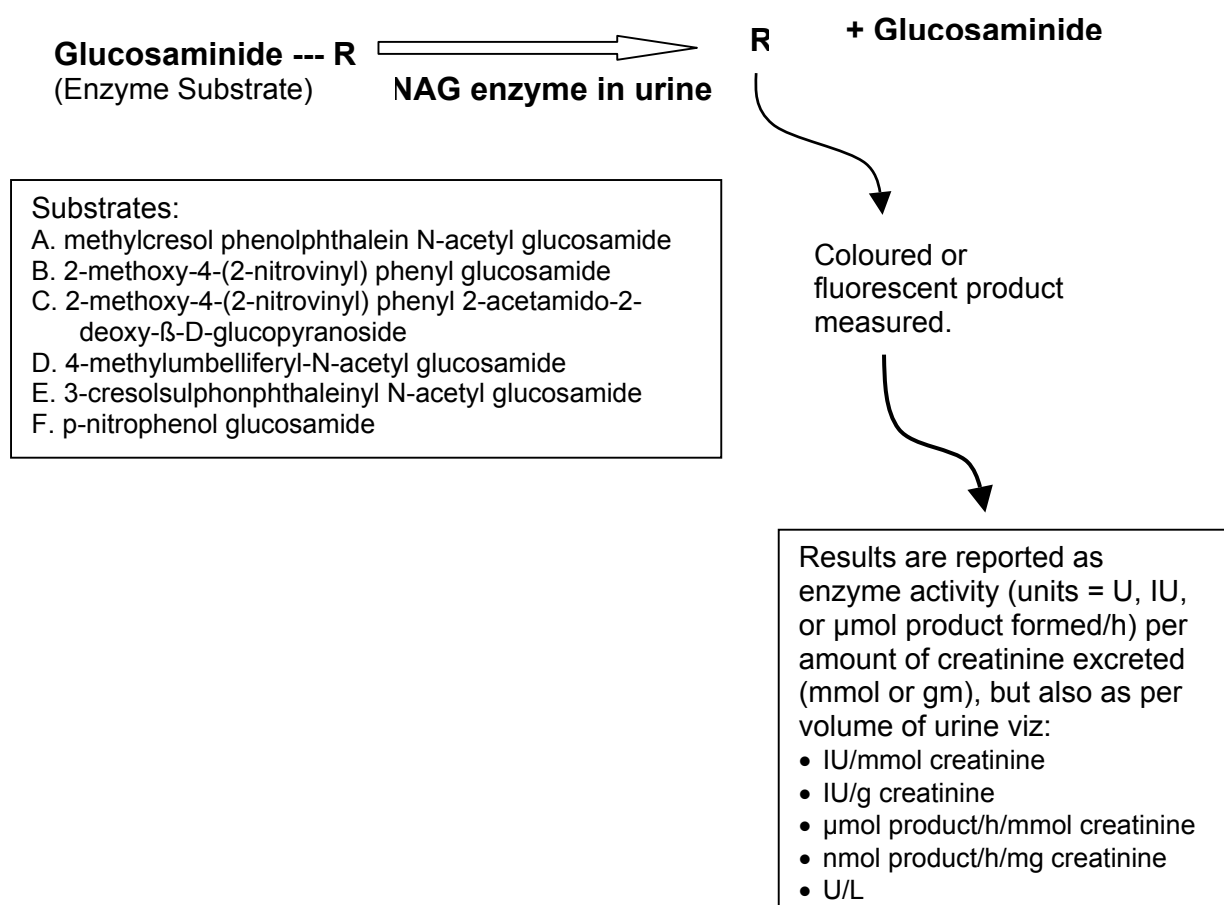
Although increased urinary enzyme activity is generally regarded as an indicator of renal tubular dysfunction there are many circumstances which do not involve exposure to environmental pollutants that cause elevation of urinary NAG activity. Indeed in experimental situations it has been observed that when increased protein is presented to renal tubular cells there is an increase in lysosomal activity that increases urine NAG levels. Urine NAG activity is thus a

# DRAFT

measure of altered function in the renal tubules and not simply an indicator of toxic damage (Bosomworth et al 1999).

The analysis of NAG activity in urine relies on the enzyme cleaving a glucosaminide substrate molecule to yield a coloured product that can be measured (see Figure 1 for general scheme). A range of chromogenic substrates have been developed for the urinary NAG assay, (see Figure 1). However because the efficiency of the NAG enzyme to metabolise the substrates differs and the optimum conditions for each substrate is different the numerical results that are obtained with each substrate are not directly comparable, this is illustrated in Tables 1 and 2. Nevertheless, investigational studies which contain 'control data' do provide useful information on the degree of spread and variation that may be expected in urinary NAG activity within a normal population, even though different assay methods may have been used.

**Figure 1: Schematic representation of urinary NAG activity measurement.**



# DRAFT

**Table 1: Influence of substrate on NAG activity in urine from normal individuals. Data from Yuen et al (1982) <sup>a</sup>.**

Substrate as designated in Figure 1	NAG activity ( $\mu\text{mol product/mmol creatinine}$ ) mean $\pm$ SD	Number of urines
D	6.5 $\pm$ 2.5	30
F	18.9 $\pm$ 8.4	33
B or C <sup>b</sup>	14.6 $\pm$ 8.2	120

<sup>a</sup> Other than the age range of 12 to 87 years a description of the 'normal' individuals us not provided.

<sup>b</sup> This is the substrate [2-methoxy-4-(2-nitrovinyl) phenyl 2-acetamido-2-deoxy- $\beta$ -D-glucopyranoside] used in the NAG assay kits used to evaluate NAG activity in workers from the ERA mine after the water incident.

## 2. 'Normal' Urinary NAG activity.

Table 2 shows that the range of urinary NAG activity in 'normal' people varies quite widely, this is probably a reflection of the ease with which the enzyme is released into urine and the large number of situations which can influence the release. Because of these factors, and because the method of measuring urinary NAG activity has not been standardised, it is difficult to identify a 'normal' reference range that is appropriate for evaluating the results obtained for workers from the Ranger mine.

Table 2 contains 24 studies from around the world in which control groups were evaluated for urinary NAG activity. In studies (n = 22) that reported control group variation as the standard deviation (SD) of the mean, the average SD was 48% of the mean. For those (n = 17) that reported a range of values the range varied 2.4 – 96 fold, the average being approximately 20 fold. Thus a number of studies indicate that urinary NAG activity within specified control populations is variable between subjects with inter-subject variation of 10 – 20 times being common. For the general population with no account taken of common factors that influence NAG activity the variation may be 100 fold or more.

Besides there being a high inter-subject variability in urinary NAG activity there is also significant daily variability in the amount of NAG excreted in urine by an individual. Dance et al. (1969) measured daily urinary NAG activity in five volunteers for up to 207 days. The individual

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daily variation for NAG activity uncorrected for creatinine concentration was 1.4 to 4.4 times. More recently Stengel et al. (1999) examined a healthy population of male workers and concluded that within that homogeneous population, day-to-day differences in biomarker values appeared to be nearly as great as differences between subjects. The authors concluded that while the within-subject variance is not high enough to warrant systematic repeated measurements in epidemiological surveys, when the number of subjects is limited, measuring twice may improve study power by reducing total variance by about 25% and may improve the accuracy of NAG estimates.

The urinary NAG activity range of 0.3 – 12 IU/L for healthy individuals quoted by the makers (Diazyme 2004) of the test kit used for measuring NAG in urine from Ranger workers is not appropriate because in the publication cited by Diazyme to support the range (Yuen et al. 1982):

1. No information other than the age range (12 to 87 years) of the “healthy individuals” is provided.
2. It is stated urine “samples were stored at 4<sup>0</sup>C and normally assayed within 48 hours or stored at -20<sup>0</sup>C until required”. Information is not provided on how many were frozen. However the work of Berg et al. (1998) shows that after two weeks storage at -20<sup>0</sup>C there was an average decrease in NAG activity of 13%, and for the 150 samples evaluated for the effects of storage the range of change in NAG activity was a decrease of 88% to an increase of 16.9%. Thus there is significant uncertainty about the range quoted by kit manufacturers.
3. The authors do not report the range of 0.3 -12 IU/L as cited by the manufacturer. The values reported by Yeun et al. (1982) are  $14.6 \pm 8.2$   $\mu\text{mol product/mmol creatinine}$ . Thus neither the range nor the units that are quoted in the assay kit correspond to those of the publication cited to support that range.

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**Table 2: Comparison of NAG activity in various control ('normal') populations <sup>a</sup>**

Reference	Description of control group			Substrate	Urinary NAG		
	Comments	Age (yrs)	Race		X ± SD <sup>b</sup>	Range	Units
Oba et al 2000	Hospitalised patients; No kid disease, No nephrotoxic drugs (n = 30)	30 - 71	Japanese	D	26.8 ± 17.7	3.4 – 71.3	nmol/h/ g Cr
Green et al 2004	Administrative hospital staff. No exposure to solvents or metals (n = 54)	30.3 ± 9.1	Chinese	E	2.41 ± 1.91	-	U/g Cr
Machiguchi et al 1999	?	?	Japanese	?	6.7 ± 6.2	-	U/g Cr
Berg et al 1998	Healthy volunteers. No drug or alcohol intake (n = 150)	20 – 34 35 – 49 50 - 69 All ages	Norwegian	E	0.117 0.137 0.184 0.142	0.077 – 0.228 0.086 – 0.224 0.103 – 0.346 0.077 – 0.311	U/mmol Cr
Mason et al 2002	Patients attending local GP. No renal disease, 5/15 diabetic, 3/15 hypertensive, 4/15 on NSAIDs.	41 - 80	British	B	23.44 ± 2.9	-	µmol/h/ mmol Cr
Yeun et al 1982				C	14 .6 ± 8.2	-	µmol/ mmol Cr
Xu et al 1999	Healthy individuals (n = 100)	15 - 60	Chinese	F	-	0.22 – 2.48	U/mmol Cr
Dance et al 1969	Normal individuals (30 samples from 5 individuals)	19 - 40	British	D	57.2 ± 22 [1.4 – 4.4 fold range within an individual]	-	nmol/h/ mg Cr
Alderman et al 1983	Normal controls (n = 30)	<34 - >65	Mixed	D	29 ± 16	-	nmol/h/ mg Cr
Tassi et al 2004	Healthy adults. No UTI, diabetes, hypertension, kidney disease, liver/pancrease disorders, infections over previous mth, no nephrotoxic drugs, no smokers (n = 30)	Aged matched to 43.5 ± 8.5	Italian	D		26.1 – 256.4	U/mmol Cr
Uchida et al 2004	Normal male volunteers (n = 21)	78.3 ± 3.6	Japanese	?	5.0 ± 1.9 <sup>b</sup>	-	U/g Cr
Satarung et al. 2004	Students, factory workers, teachers & labourers from suburban Bangkok. Middle class (n = 200)	16 - 60	Thais	?	4.6 ± 4.0	0.5 - 48	U/g Cr
El-Safty et al 2004	Healthy adults. No UTI, diabetes, hypertension, kidney disease, liver/pancrease disorders. No antihypertensives, steroids, antibiotics or analgesics. No exposure to solvents or heavy metals.	Non-smokers (n = 36) 39 ± 6.65  Smokers (n = 39) 43.9 ± 9.9	Egyptian	?	4.96 ± 1.88  15.6 ± 3.7	1.52 – 9.15  8.73 – 21.2	nmol/h/ mg Cr
El-Safty et al 2003	As for El-Safty et al 2004 above. Smokers & non-smokers. (n = 28)	30 - 59	Egyptian	?	20.32	2.11 – 42.53	nmol/ mg Cr
Moriguchi et al. 2003	Healthy adults (n = 817)	20 – 74	Japanese	?	3.74 ± 1.85	0.6 – 44.8	U/L

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Reference	Description of control group			Substrate	Urinary NAG		
	Comments	Age (yrs)	Race		X $\pm$ SD <sup>b</sup>	Range	Units
Nakadaira et al. 2003	Healthy adults	Female 22 – 77 (n = 21) Male 20 – 83 (n = 29)	Japanese	?	4.6 $\pm$ 1.8 5.1 $\pm$ 2.01	1.9 – 19.2 1.6 – 15.0	U/g Cr
El-Safty et al 2003a	Healthy adults. No kidney disease, hypertension, diabetes, UTI. No heavy metal or solvent exposure. No nephrotoxic drugs. (n = 36)	35 $\pm$ 9.5	Egyptian	?	6.87 $\pm$ 2.05	-	nm/mg Cr
Sonnez et al. 2002	Healthy adults from rural area. No medication 30 d prior to sampling. No smokers	12 - 18	Turks	E	3.07 $\pm$ 1.2	-	U/g Cr
Suwazon et al. 2000	General population from non-polluted area	50 – 59 (n = 98) 60 – 69 (n = 167) 70 – 79 (n = 138) 80 – 99 (n = 26)	Japanese	?	3.9 $\pm$ 2.2 4.0 $\pm$ 1.8 4.8 $\pm$ 1.7 5.4 $\pm$ 2.0	- - - -	U/g Cr
Tassi et al. 2000	Healthy adults. No kidney disease, hypertension, diabetes, UTI. No heavy metal or solvent exposure. No nephrotoxic drugs. No smokers or alcoholics. (n = 50)	Age matched to 30 – 63	Peruvian	D	0.77 <sup>m</sup>	0.17 – 2.02	U/g Cr
Jin et al. 1999	General population from non-polluted area. (n = 253)	35 – 45 (n = 86) 45 – 54 (n = 77) >55 (n = 90)	Chinese	?	For total cohort 29.99 <sup>b</sup>	5.81 – 154.76	$\mu$ mol/g Cr
Stengel et al. 1999	Healthy workers examined longitudinally. n = 50 – 130 for each examination time).  Significant within subject variation in NAG results.	39.9 $\pm$ 10.9 (21- 55)	French	E	@ T = 0 0.21 <sup>b</sup> @ T = 2-5 mths 0.23 <sup>b</sup> @ T = 2 yrs 0.21 <sup>b</sup>	0.09 – 1.14 0.11 – 0.73 0.09 – 0.67	IU/mmol Cr
Lorini et al. 1995	Healthy subjects. (n= 69)	14.7 $\pm$ 2.5	Italian	E	1.49 $\pm$ 0.63	0.6 – 3.8	U/g Cr
Otsuka et al 1994	Normal volunteers. (n = 132)	11.4 $\pm$ 2.7	Japanese	E	2.12 $\pm$ 1.26	-	U/g Cr

<sup>a</sup> To compile the information in Table 2 studies that have investigated the impact of disease and/or toxic chemicals on the kidney were sought and the information pertaining to control groups extracted. The literature search has not been exhaustive. The letter in the substrate column refers to the substrate code in Figure 1.

<sup>b</sup> Data is presented as arithmetic mean  $\pm$  SD except were marked <sup>b</sup>, it is then geometric mean  $\pm$  geometric SD.

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## **Conclusions:**

- Urinary NAG activity assays are not standardised.
- Urinary NAG activity is best normalised to the amount of creatinine excreted as this decreases variation.
- There are many common factors within a normal population that influence urinary NAG activity; these include age, blood pressure, diabetes and smoking.
- Even when normalised to creatinine excretion there is within a given 'normal' population a 10 – 20 fold variation between individuals in urinary NAG activity. The difference may up to approximately 100 fold if the control population is loosely defined as in Satarung et al (2004).
- For any given person there is there is day to day variation in urinary NAG activity.
- It is not possible to identify a reference range for urinary NAG activity with which to compare the results for the Ranger uranium mine workers.

It is noted that the laboratory results report for the urine samples obtained from Ranger workers quotes an “expected range” of  $11.5 \pm 2$  IU/L but does not provide an explanation or basis for the range. From the above considerations it is concluded there is no justification for the use of this “expected range” in interpreting the NAG results from Ranger mine workers, and it is inappropriate to do so.

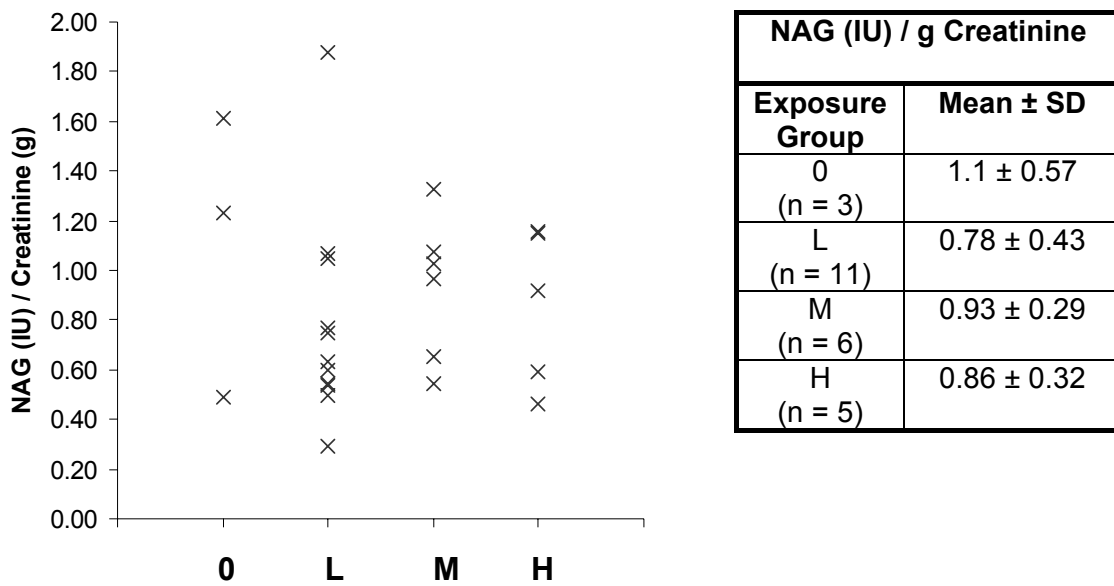
## **3. Interpretation of NAG results from Ranger workers.**

In the urine obtained from Ranger workers NAG activity varied from 1.6 to 20.2 IU/L of urine ; although the absolute levels cannot be compared with any of the studies summarised in this brief report (i.e. data in Table 2), the variation in activity (12.6 times) between workers is consistent with that observed in control populations around the world. When NAG activity is expressed as IU/g creatinine the variation decreases to being only 6.5 fold between individuals (0.29 – 1.88 IU/g creatinine). These small variations in activity are consistent with there being no elevation of urinary NAG amongst members of the work force.

This interpretation is supported by comparison of NAG activity between exposure groups (Figure 2). On visual inspection of Figure 2 it can be seen there is no difference between the average NAG activity for groups of workers not exposed to the contaminated water, and those estimated to have ingested low (<500 mL), medium (500 – 2,000 mL) or high (>2,000 mL) amounts of contaminated water. In addition the variation in the urine NAG results is comparable

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between the four groups of workers. Taken together the data shows urinary NAG activity is not elevated in workers assumed to have been exposed to contaminated water. Since urine NAG activity is a sensitive indicator of renal tubular damage the NAG results do not provide evidence for impairment of renal function or of toxicity.



**Figure 2: Urinary NAG activity (IU/g creatinine) for workers from the Ranger mine according to estimated exposure to contaminated water.**

Exposures: 0 = None, L = low, M = Medium, H = High



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## **APPENDIX H**

### **Camelford Incident - consideration of aluminium levels**

## Camelford Incident Reviewed

The working group set up by the UK Government to re-examine the health effects of the alum overdosing incident that occurred in Camelford, North Cornwall in 1988 has commenced its investigation. The new investigation was announced by the Department for Environment, Food and Rural Affairs in August last year, but the membership of the group was not finalised until January.

The group comprises five members of the Committee of Toxicity of Chemicals in Food, Consumer Products and the Environment (CoT) with expertise in toxicology, epidemiology and child health, plus two local representatives nominated by the local Member of Parliament. The chair is Professor Frank Woods of the University of Sheffield, who also chairs the CoT.

The terms of reference for the investigation are:

- to advise on whether the exposure to chemicals resulting from the 1988 Lowermoor water pollution incident has caused, or is expected to cause, delayed or persistent harm to human health; and
- to advise whether the existing programme of monitoring or research into the human health effects of the incident should be augmented and, if so, to make recommendations.

Camelford is a small town of about 2,500 people situated in Cornwall. The contamination incident occurred in July 1988 when a contractor dumped 20 tons of aluminium sulphate into the wrong tank at the Lowermoor treatment plant operated by South West Water. The plant was an unmanned installation and the contractor was a relief driver unfamiliar with the plant layout and delivery procedures. The resultant acidic water entered the water supply directly, causing public complaints about the taste, skin irritation and corrosive effects on plumbing and fixtures, however the cause of the problem was not

determined for two days. The public were assured by a spokesman for the water authority that the water, while tasting slightly acidic, was safe to drink.

It was estimated that consumers were exposed for up to three days to water with pH as low as 3.9 to 5.0. An aluminium content of up to 620 milligram per litre and a sulphate concentration of up to 4,500 milligram per litre were recorded in the water supply. Once the cause of the problem was determined, a program of flushing reduced levels rapidly to 1 milligram per litre.

Over the following months more than 400 of the town's residents complained of a range of symptoms including skin rashes, arthritic pains, sore throats, loss of memory and general exhaustion. These complaints were investigated by health authorities and the government appointed the Lowermoor Incident Health Advisory Group to report on the health effects of the incident. In two reports delivered in 1989 and 1991, the Advisory Group concluded that there was no convincing evidence that harmful accumulation of aluminium had occurred, nor that there was a greater prevalence of ill health due to the toxic effects of the contaminated water. The report also stated that the Advisory Group recognised that the incident and subsequent events had led to real suffering in the community, but attributed this to anxiety rather than direct health effects; a conclusion which angered many residents.

Since the incident, over 700 claims for damages have been paid with individual amounts ranging as high as 10,000 pounds. The South West Water Authority was prosecuted for causing a public nuisance, fined 10,000 pounds and ordered to pay 25,000 pounds in costs. The concerns of residents over the health effects have not declined in the intervening 13 years, and there has been an ongoing campaign for a full public inquiry. The new inquiry is believed to have been prompted in part by research conducted in 1991, but not published until 1999 for legal reasons, reporting disturbances in cerebral function associated with the incident (1).

The new investigation is more limited in nature than a public inquiry, however its Chair has commented that the lack of formal legal proceedings and cross-

examination may allow individuals to be more freely forthcoming in their evidence. The working group will hear personal testimony from individuals who believe their health has been affected, as well as reassessing the evidence evaluated by previous inquiries, assessing more recently published studies and analysing local area health statistics. While the investigation will focus on the toxic effects of aluminium, possible exposure to other substances that may have occurred as a consequence of the incident including copper, zinc, lead, sulphate and hydrogen ion will also be assessed. The group is expected to complete its work in March 2002.

(1) Reviewed in Health Stream Issue 16 - From the Literature section.

Disturbance of cerebral function in people exposed to drinking water contaminated with aluminium sulphate: retrospective study of the Camelford water incident. Altmann P, et al. British Medical Journal (1999) 319 (7213) p807-11.

# **Disturbance of cerebral function in people exposed to drinking water contaminated with aluminium sulphate: retrospective study of the Camelford water incident**

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Accepted June 9, 1999.

## **Lowermoor Water Contamination Incident (Camelford)**

One of the most serious incidents of drinking water contamination in recent years was at South West Water's Lowermoor water treatment works at Camelford in 1988. A lorry driver accidentally put 20 tonnes of aluminium sulphate in the wrong tank, which led to the pollution of water supplies to the surrounding area.

Public Health questions were addressed by the Lowermoor Incident Health Advisory Group, who found there to be no convincing evidence that harmful accumulation of aluminium had occurred, nor was there a greater prevalence of ill health as a result of the toxic effects of the contaminated water (DEFRA news release, 14/8/01).



## **APPENDIX 9:**

**Proposal to re-instate potable water supply to Jabiru East. June 7, 2004.**



**ERA**

## **Energy Resources of Australia Ltd - Ranger Mine**

ABN 71 008 550 865

Monday June 7, 2004

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### **Proposal to Re-Instate Potable Water Supply to Jabiru East**

#### **1 CONTEXT**

On the morning of Wednesday March 24<sup>th</sup> ERA staff at Ranger Mine discovered contamination of the potable water supply as a result of a connection made between process water and potable water. The consequence was that over a period of several hours process water entered the potable water header tank on top of the fine ore bin. This header tank provides the gravity head for distribution to the site as well as to the potable water feeder line to East Jabiru.

The potable water system (including the supply line to Jabiru East) was closed down at 0800h. An orderly shutdown of the mine was completed, and non-essential staff were sent home. Once regulators and stakeholders were notified, a number of investigations were commenced immediately by ERA.

The specific issues concerned with reinstating the potable water supply on the Ranger site have been addressed separately. The focus of this proposal is the reinstatement of the potable water supply from the minesite to East Jabiru. The sequences of actions taken to identify the extent of contamination, the flushing of the system, and the sampling and analysis undertaken to document recovery of water quality to potable standard in the Jabiru East reticulation system are documented here.

#### **2 IDENTIFYING THE EXTENT OF CONTAMINATION**

Figure 1 shows the Jabiru East reticulation system and the location of all known potable water outlets (numbered).

The pipeline to Jabiru East passes adjacent to a storage tank located at the south east edge of the airport (See location schematic in Figure 1). There is a valve assembly at this location that isolates the pipeline from the tank (which was used as one of the original water supply tanks for the town of Jabiru East). However, the valve assembly was leaking at the time of the incident, allowing a proportion of water from the line to flow under pressure into the tank. Consequently the tank was able to be filled from the pipeline.

The first water samples were taken on Wednesday 24/03/2004 between 10 am and 11:30am from sites associated with the Jabiru East potable water tank, the **eriss** potable water tank, and the Gagadju workshop (Table 1 summarises the key analytes of relevance to assessing the extent of contamination by process water; the full data set is provided in the accompanying Excel spreadsheet). The pipeline to Jabiru East was isolated at 8 am that morning as part of the system shutdown on the Ranger site.

The composition of the samples from the **eriss** potable water tank and the Gagadju potable water tank were, except for Al, Cu and Zn, essentially identical to that of the Brockman borefield water, indicating no contamination with process water. Zn and Cu are ubiquitous contaminants in reticulation systems and the levels of Cu and Zn in the two tanks are directly comparable with the values reported for the Ranger reticulated system (which show a higher concentration than the water as extracted from the Brockman borefield, B84\_3 in Table 1). The slightly higher level of Mn in the **eriss** tank relative to Brockman borefield water could be the result of dissolution from materials of construction. The slightly greater concentration of Al in the Gagadju tank is a likely consequence of the zincalume construction of this tank.

Thus the initial sampling indicates that the front of process water contamination had not reached the Gagadju or **eriss** header tanks on the morning of 24/03/04.

In contrast, the water data from the sites in the vicinity of the Jabiru East potable tank (JPWT) clearly indicates that the front of diluted process water had reached this location. The Jabiru East hydrant represents the composition of the incoming water. At 10:15 am on 24/03/2004, when the first suite of water samples was collected for chemical analysis, the EC was 1256  $\mu\text{S}/\text{cm}$ . The contents of the tank and the overflow stream were also sampled at this time, and the compositions show a clear indication of low-level contamination by process water (Table 1).

Based on the above data it can be concluded that Jabiru East storage tank was contaminated with process water as a result of the leaking valve providing a pressure relief in the pipeline. It was likely that the front of contaminated water had also progressed further along the pipeline towards the airport and **eriss** offices. The extent of this movement was likely to be limited by the lack of draw on the system during the night. In order to limit the further progress of water down the line, and to remove the head of contaminated water in the emergency potable water storage tank, a recovery program was initiated at 2pm on 24/03/04.

### 3 RECLAIM OF THE POTABLE WATER SYSTEM

#### 3.1 Physical Flushing of the Reticulation System

The details of the recovery program for the potable water system at Jabiru east are provided in Appendix 1. In summary this involved the following steps.

- 1) The Jabiru East storage tank was emptied by pumping back to site and then partly filled with clean water from the Magela potable water bore field.
- 2) The supply pipelines at Jabiru East were drained back to the sump near the Jabiru East storage tank, where the water was recovered and transported back to site.
- 3) The Ranger fire truck was used to backflush the lines from the Gagadju workshop and the **eriss** header tank, with the backflush water being collected in the storage tank at Jabiru East.
- 4) The Jabiru East storage tank was emptied again by pumping back to site.

- 5) The Jabiru East storage tank was flushed once more with clean water from the Magela borefield, and the contents of the tank were pumped back to site.
- 6) All potable water outlets were tagged out of service pending clearance.

The potable water line to Jabiru east was re-pressurised on 31/03/04 using two hydrants at the extremities of the lines. All accessible taps were flushed and field tested for pH and EC, and sampled for full water quality analysis. In the first instance a pH value  $>7.3$  and EC  $<450$   $\mu\text{S}/\text{cm}$  was used to screen for absence of significant contamination by process water.

Based on the length and dimensions of the pipelines it is estimated that 5-10 pipe volumes of clean water were flushed through known contaminated lines; and 2-4 pipeline volumes were flushed through potentially contaminated lines.

The flushing, field testing and sampling for water quality analysis was repeated on 1/04/04 and 2/4/04.

### 3.2 Screening of Water Quality

Full details of the flushing and water sampling protocols are provided in Appendix 2, with complete chemistry data provided in the accompanying Excel spreadsheet. All samples were screened for 37 chemical parameters including anions and metals to demonstrate that the inorganic solutes in the potable water system complied with Australian Drinking water standards. The initial focus was, understandably, on the inorganic solutes as markers of any residual contamination by process water. In this context the results from at least two consecutive daily samples taken from points throughout the Jabiru East potable water system (indicated on Figure 1), was used to quantitatively screen the outlets for proof of absence of contamination.

Initial clearance for those outlets that met the field pH and EC screening criteria was provided by the results of ICPMS analysis for total U. The screening level criterion for U for was set at 15  $\mu\text{g}/\text{L}$  (which is conservatively less than the 20  $\mu\text{g}/\text{L}$  value in the drinking water quality guidelines). In this context it should be noted that the initial analyses were done on filtered samples to provide rapid turnaround to facilitate management action. Subsequent check analysis showed no significant difference between filtered and total results.

The U concentration data for all water samples collected during the initial investigation and subsequent recovery program are summarised in Table 2. The results of repeated sampling at the potable water outlets show the recovery of the system to levels of U that were less than 15  $\mu\text{g}/\text{L}$  for two successive measurements, thus meeting the performance criterion established for reinstatement of the potable water system at Ranger. These same data are shown graphically in Figure 2.

Although the data in Figure 2 indicate that the U content of the water complied with the required guideline value, other indicators of potability, especially microbiological indicators, needed to be met. Both the OSS and NT Public Health flagged microbiological assessment as being a vital part of the screening program, given that the pipelines had been opened as part of the flushing process. The NT Department of Health was consulted on this issue and recommended assaying three consecutive samples from key locations in Jabiru East for compliance with guideline values.

Other parameters of actual or potential relevance include possible process water-related organics and gross alpha and beta radiological counts. Given the below-detection-limit concentrations of organics measured in the restored potable water supply at Ranger, and the fact that radiological measurements of the Ranger supply were below guideline values it was unlikely that anything of significance would be found in the Jabiru East supply. Consequently organics and radionuclide activity were not considered by the OSS and NT Public Health to preclude restoration of potable supply, provided that the inorganics and microbiological parameters met drinking water quality guideline values.

Nevertheless it was requested that a one-off analysis of organics and gross alpha and beta counts be done to provide final confirmation that the whole suite of WQ parameters met guideline values. These analyses are currently in progress and will be reported separately when they become available.

#### **4 RE-CONNECTION OF THE JABIRU EAST POTABLE WATER SUPPLY**

ERA has demonstrated that the potable water system at Ranger Mine meets the Australian Drinking Water Guidelines for inorganic, microbiological and radiological components.

In particular, reference to Table 3 (U and microbiological results) and the supplied electronic data spreadsheet shows that three consecutive measurements (obtained during May) of microbiological and key inorganic parameters indicative of process water at five key locations at Jabiru East (Tourist Centre, Café, NA Helicopters, Gagadju workshop, eriss building) meet the Australian drinking water guidelines. The most recent U and microbiological data for these sites are summarised in Table 3. Free chlorine residuals were measured on June 3 (Table 4) and the results are consistent with the guideline recommendations for small water supplies ("a free chlorine residual of between 0.2 and 0.5 mg/L is adequate").

It is intended to reduce the frequency and numbers of sites being monitored, following demonstration of compliance at the five key locations, to a steady baseline level that will demonstrate continuing compliance with drinking water quality guidelines. The initial program will comprise collection of a water sample from one site across the Jabiru East network each week and analysis of this sample for chemical constituents (ICP-MS scan for total inorganics) and microbial counts. The location of this sample site will be moved around the network from week to week, across the five key sites listed in Table 3. This monitoring schedule will continue until the end of July. From August onwards the weekly chemical analysis schedule will be continued, with microbiology being run monthly.

In addition to the above, ERA has undertaken to make improvements to its water systems to prevent a similar incident in the future. These improvements include the key elements listed below.

1. Upgrades to the process water pipework system and enhancements to the site training program – pipework modifications initiated as part of the recent plant shutdown, training system updated.
2. A conductivity meter has been installed within the potable water system at Ranger to continuously measure electrical conductivity and to provide warning of any potential contamination. The conductivity meter is connected to an alarm system.
3. Investigations and assessments are currently in progress to determine if the existing mine supply system of potable water to Jabiru East can be replaced by a local source (for example, reinstatement of the existing Magela borefield, or equivalent). In the event that this option proves to be feasible then the supply line from Ranger will be isolated, thus completely removing any future link to the mine.

If a new potable water source is commissioned for Jabiru East, a separate monitoring program will be implemented with the range of inorganic, microbiological and radiological parameters included as per the current requirements for potable water testing under the Ranger Authorisation.

In view of the monitoring results obtained and commitments given above, written approval is now requested to resume supply of potable water to premises at Jabiru East.

Simon Prebble  
General Manager Operations  
Ranger Mine

*Attachments to this document:*

- *Figure showing location of all potable water system outlets at Ranger Mine*
- *Figure showing U concentrations through time*
- *Tables of water chemistry*
- *Jabiru East and Mine – Drain and Flush Sequence of Events- Potable Water System*
- *Jabiru East – Flushing and Sampling Protocol*

*Electronic File:*

- *Excel workbook containing complete ERA water quality dataset for Jabiru East.*

**Figure 1:** Schematic showing potable water system and outlet locations at Jabiru East





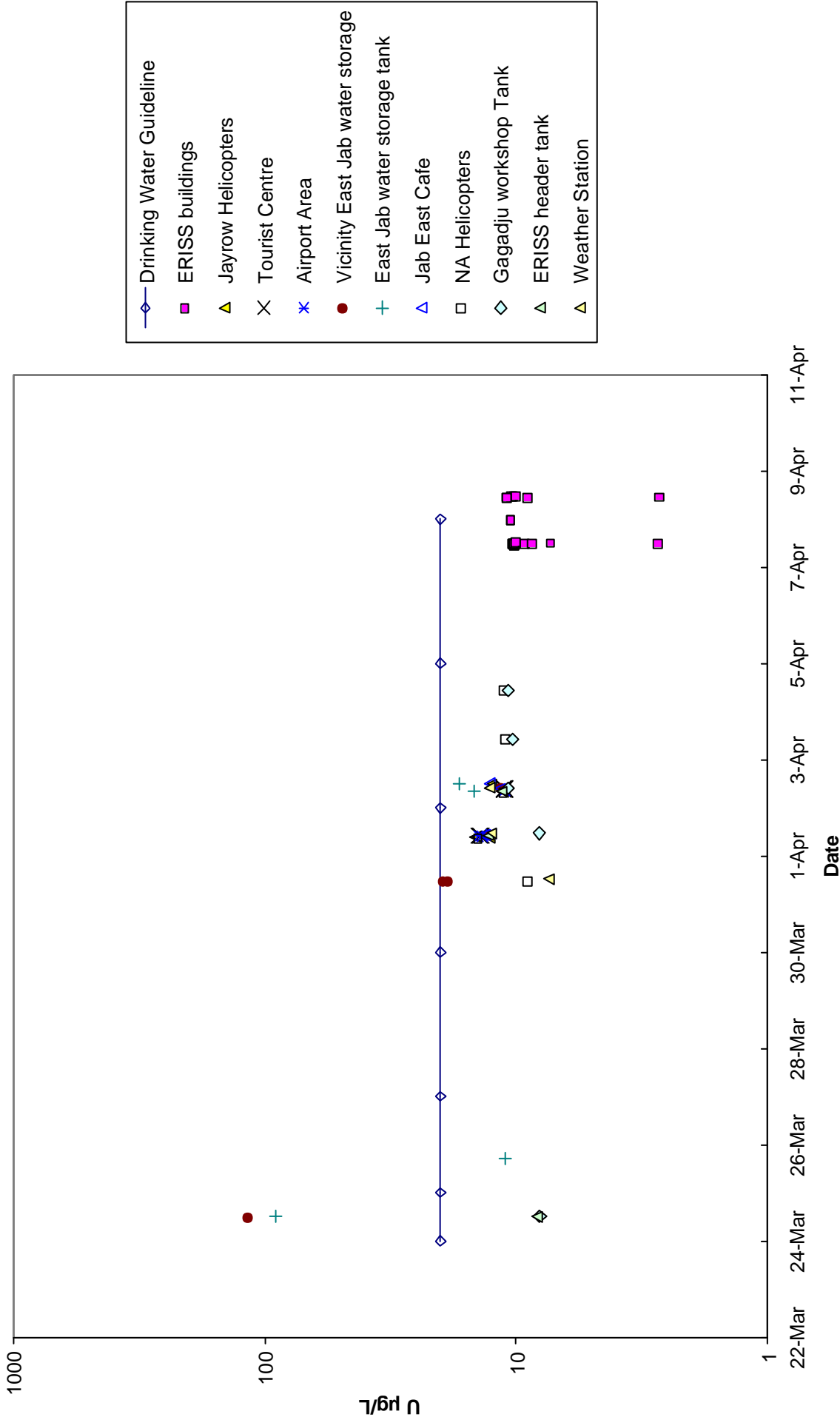


Figure 2: Time series data for Jabiru East showing recovery of reticulation system

Table 1: Comparison of Brockman borefield (potable) supply with process water and with waters sampled at Jabiru East on 24-26/03/2004

Sampling Code	Sample Description	Sample Number	Date Sampled	Sampled Time	EC µS/cm	pH	Al µg/L	Ca mg/L	Cu µg/L	Fe µg/L	Mg mg/L	Mn µg/L	Ni µg/L	Pb µg/L	SO4 mg/L	U µg/L	Zn µg/L
	Brockman Bore Field (Av April2000-Mar 2004)-reticulated				393	7.87		21.3	23		39.9	0.2			1.55	6.88	111
B84_3	Brockman Bore Supply - source	100309	24/03/2004	9:13	400	-	0.5	22.5	4.02	<20	39.6	0.06	0.57	0.79	0.9	8.38	6.7
	Process Return Water (Av 15/703 to 10/3/04)				22800	3.8	368000	508	13560	72090	3660	182200		3080	22350	14880	5200
EPW	eriss Potable Water Tank	100306	24/03/2004	11:30	338	-	1.3	23.3	4.04	<20	39.7	1.88	0.24	0.25	1.2	8.23	61.6
GWP	Gagadju Workshop	100308	24/03/2004	10:00	411	6.88	30.3	22.9	22.8	<20	40.1	0.27	0.23	0.33	0.9	8.05	71.3
JH	Jabiru East Hydrant (opposite core sheds)	100311	24/03/2004	10:15	1256	6.82	47.2	39.1	114	<20	158	55200	131	5.9	736	116	1540
JPWT	Jabiru East Potable Water Tank	100310	24/03/2004	10:06	775	7.13	128	27.4	48.8	<20	70.2	14800	35.9	2.01	211	89.9	207
JPWTO	Jabiru East Potable Water Tank Overflow	100307	24/03/2004	9:57	784	7.2	129	28	44.1	<20	75	17100	41	2.06	239	103	178
	Jabiru East Potable Water Tank Overflow	100338	25/03/2004	10:07			26.5	39.1	47.2	<20	154	51700	124	0.37	740	121	2800
JPWTO	Jabiru East Potable Water Tank Overflow	100339	25/03/2004	10:31			41.3	29.8	25.1	<20	88.7	18900	46.9	0.41	333	119	604
JPWTO	Jabiru East Potable Water Tank Overflow	100337	25/03/2004	11:52			46.2	29.6	23	<20	83.4	12100	31.3	0.41	284	102	497
	Jabiru East Potable Water Tank Overflow	100422	26/03/2004	10:19	195	7.14	59	11.2	9.55	20	16.7	472	2.09	0.05	24.3	10.6	34.6

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**Table 2: U concentration data for sites at Jabiru East (see Figure 1 for locations)**

Sample Location	ID	Sample No	Sample Date Time	U_F µg/L	U_T µg/L
Jabiru East Potable Water Tank	JPWT	100310	24/3/04 12:06 PM	<b>89.9</b>	
Jabiru East Potable Water Tank	JPWT	100593	25/3/04 4:50 PM	11.1	
Jabiru East Potable Water Tank	JPWT	100746	02/4/04 8:05 AM	14.7	
Jabiru East Potable Water Tank	JPWT	100769	02/4/04 11:53 AM		16.8
Potable Water - Under ground pipe to Jabiru East	PTUP	100505	28/3/04 12:00 AM	10.9	
Jabiru East Hydrant (Opposite Core Shed)	JH	100311	24/3/04 12:06 PM	<b>116</b>	
Jabiru East EOL Hydrant Pre-Flush.	JE004-1	100674	31/3/04 11:35 AM	19.5	
Jabiru East EOL Hydrant Post-Flush.	JE004-2	100673	31/3/04 11:35 AM	18.7	
Jabiru East - Former Environmental Lab Hydrant	JE004	100713	01/4/04 10:55 AM	12.6	
Jabiru East - Nursery Standpipe	JE001	100740	02/4/04 9:58 AM	11.5	
Jabiru East - Jayrow Outside Tap	JE005	100710	01/4/04 9:32 AM	14.4	
Jabiru East - Jayrow Laundry Tap	JE006	100700	01/4/04 9:22 AM	14.6	
Jabiru East - Jayrow Bathroom Sink	JE040	100699	01/4/04 9:15 AM	12.8	
Jabiru East - Jayrow Bathroom Sink	JE040	100768	02/4/04 12:05 PM		12.5
Jabiru East - Jayrow Shower	JE042	100701	01/4/04 9:30 AM	14.3	
Jabiru East - Jayrow Office Crib Room Sink Tap	JE050	100745	02/4/04 7:55 AM	11.3	
Jabiru East - Tourist Centre Mens Toilet Sink	JE011	100734	02/4/04 9:10 AM	11.2	
Jabiru East - Tourist Centre Ladies Toilet Sink	JE013	100735	02/4/04 9:12 AM	11.1	
Jabiru East - Tourist Centre Outside Wash Sink Tap Set	JE019	100705	01/4/04 10:10 AM	13.9	
Jabiru East - Tourist Centre Outside Wash Sink Tap Set	JE019	100736	02/4/04 9:24 AM	11.1	
Jabiru East - Tourist Centre Outside Wash Sink Tap Set	JE020	100706	01/4/04 10:06 AM	14	
Jabiru East - Hangar/Fuel Yard Outside Tap (in Car Port)	JE024	100709	01/4/04 9:51 AM	13.7	
Jabiru East - Hangar/Fuel Yard Outside Tp (in car port)	JE024	100737	02/4/04 8:25 AM	11.1	
Jabiru East - Hangar (Fuel Yard) Safety Shower / Eye Wash	JE051	100698	01/4/04 9:48 AM	14.1	
Jabiru East - Gunbalanya Air Charters Outside Garden Tap	JE057	100711	01/4/04 10:50 AM	12.6	
Jabiru East - Café Washing Tub Tap	JE028	100704	01/4/04 10:20 AM	13.5	
Jabiru East - Café Washing Tub Tap	JE028	100738	02/4/04 9:28 AM	11.6	
Jabiru East - Café Washing Tub Tap	JE028	100767	02/4/04 12:10 PM		12.6
Jabiru East - Café Hand Basin Tap	JE029	100703	01/4/04 10:30 AM	13.3	
Jabiru East - Tourist Centre Office Bathroom Sink	JE033	100702	01/4/04 10:00 AM	13.7	
Jabiru East - Tourist Centre Office Bathroom Sink	JE033	100739	02/4/04 9:16 AM	11.2	
Jabiru East EOL Weather Station.	JE034	100676	31/3/04 12:25 PM	7.45	
Jabiru East - Weather Station Evaporation Pan Tap	JE034	100712	01/4/04 11:15 AM	12.5	
Jabiru East - Weather Station Evaporation Pan Tap	JE034	100741	02/4/04 9:55 AM	12.8	
Jabiru East Mens Toilet A (right hand side)	JETA	100335	25/3/04 1:00 PM	8.74	
Jabiru East Mens Toilet B (left hand side)	JETB	100336	25/3/04 1:00 PM	8.56	
Jabiru East - EOL NA Helicopters Outside Garden Tap	JE035	100675	31/3/04 11:35 AM	8.93	
Jabiru East - NA Helicopters Outside Garden Tap	JE035	100707	01/4/04 9:08 AM	14.1	
Jabiru East - NA Helicopters Outside Garden Tap	JE035	100742	02/4/04 7:50 AM	11.2	
Jabiru East - NA Helicopters Outside Tap	JE035	100800	03/4/04 10:15 AM	11	11.3
Jabiru East - NA Helicopters Outside Garden Tap	JE035	100820	04/4/04 10:35 AM		11.2
Jabiru East - NA Helicopters Outside Garden Tap	JE035	100850	04/4/04 1:10 PM		

**Table 2 Contd: U concentration data for sites at Jabiru East (see Figure 1 for locations)**

Sample Location	ID	Sample No	Sample Date Time	U_F µg/L	U_T µg/L
Jabiru East - Gagadju Workshop Tank Pump Outlet	JE036	100308	24/3/04 12:06 PM	8.05	
Jabiru East - Gagadju Workshop Tank Pump Outlet	JE036	100714	01/4/04 11:15 AM	8.14	
Jabiru East - Gagadju Workshop Tank Pump Outlet	JE036	100743	02/4/04 9:40 AM	10.8	
Jabiru East - Gagadju Workshop Tank Pump Outlet	JE036	100801	03/4/04 10:22 AM	10.4	10.7
Jabiru East - Gagadju Workshop Tank Pump Outlet	JE036	100821	04/4/04 10:30 AM		10.7
Jabiru East - ERISS Storage Tank Feed	JE049	100306	24/3/04 12:06 PM	8.23	
Jabiru East - ERISS Storage Tank Feed	JE049	100708	01/4/04 10:02 AM	12.9	
Jabiru East - ERISS Storage Tank Feed	JE049	100744	02/4/04 8:15 AM	11.5	
Jabiru East ERISS Building - Admin Labs Bubbler	JE100	100939	07/4/04 11:53 AM	N.A.	10.3
Jabiru East ERISS Building - Admin Labs Bubbler	JE100	100956	08/4/04 11:50 AM		10.4
Jabiru East ERISS Building - Crib Room Urn	JE101	100940	07/4/04 11:56 AM	N.A.	10.2
Jabiru East ERISS Building - Ladies Toilets Sink	JE103	100933	07/4/04 11:07 AM	N.A.	10.1
Jabiru East ERISS Building - Ladies Toilets Sink	JE103	100957	08/4/04 11:19 AM		10.8
Jabiru East ERISS Building - Mens Toilets Sink	JE104	100936	07/4/04 11:05 AM	N.A.	10.1
Jabiru East ERISS Building - Conference Room Sink	JE105	100937	07/4/04 12:16 PM	N.A.	9.97
Jabiru East ERISS Building - Conference Room Urn	JE106	100938	07/4/04 12:12 PM	N.A.	2.71
Jabiru East ERISS Building - Conference Room Urn	JE106	100958	08/4/04 11:21 AM		2.69
Jabiru East ERISS Building - Crib Room Hand Basin	JE108	100941	07/4/04 11:58 AM	N.A.	10.3
Jabiru East ERISS Building - Admin Lab Ecosystem Protection	JE151	100942	07/4/04 12:07 PM	N.A.	10.3
Jabiru East ERISS Building - Admin Lab Ecosystem Protection	JE151	100959	08/4/04 12:00 AM		10.5
Jabiru East ERISS Building - Aquaculter Wash Hose Sink	JE152	100943	07/4/04 12:10 PM	N.A.	9.24
Jabiru East ERISS Building - Aquaculter Wash Hose Sink	JE152	100960	08/4/04 11:45 AM		10.2
Jabiru East ERISS Building - SPL's Outside Bubbler	JE153	100944	07/4/04 12:12 PM	N.A.	10.1
Jabiru East ERISS Building - SPL's Outside Bubbler	JE153	100961	08/4/04 12:00 AM		10.5
Jabiru East ERISS Building - Ice Machine	JE154	100947	07/4/04 12:18 PM	N.A.	7.26
Jabiru East ERISS Building - Ice Machine	JE154	100962	08/4/04 11:04 AM		10.9
Jabiru East ERISS Building - Covered Area Outside Wetlabs Hose Reel	JE155	100946	07/4/04 12:26 PM	N.A.	9.99
Jabiru East ERISS Building - Covered Area Outside Wetlabs Hose Reel	JE155	100963	08/4/04 11:40 AM		10
Jabiru East ERISS Building - Storage Tank Drain Pipe	JE156	100945	07/4/04 12:14 PM	N.A.	8.6
Jabiru East ERISS Building - Storage Tank Drain Pipe	JE156	100964	08/4/04 11:00 AM		9.01

**Table 3: Recent screening data for five key sites that show three consecutive results for U (total) and microbiology meeting the drinking water quality standards.**

SAMPLE POINT DESCRIPTION	Location Code	Sampled Date	Sample Number	U (f) µg/L	U (total) µg/L	BACTO Counts
Jabiru East Tourist Centre outside wash sink tap set.	JE019	1/04/2004	100705	13.9		
		2/04/2004	100736	11.1		
		21/04/2004	101159		9.47	
		21/04/2004	101166			0
		22/04/2004	101170		10.8	
		13/05/2004	101663			0
		17/05/2004	101718			
		27/05/2004	101830			0
		28/05/2004	101836		9.41	
Jabiru East Cafe washing tub tap.	JE028	1/04/2004	100704	13.5		
		2/04/2004	100738	11.6		
		2/04/2004	100767		12.6	
		21/04/2004	101160		9.46	
		21/04/2004	101167			0
		22/04/2004	101171		10.6	
		13/05/2004	101664			0
		17/05/2004	101719			
		27/05/2004	101831			0
Jabiru East NA Helicopters Garden Tap.	JE035	1/04/2004	100707	14.1		
		2/04/2004	100742	11.2		
		3/04/2004	100800	11	11.3	
		4/04/2004	100820		11.2	
		4/04/2004	100850			
		21/04/2004	101161		9.93	
		22/04/2004	101172		10.2	
		28/04/2004	101265			0
		13/05/2004	101662			0
		17/05/2004	101715			
		27/05/2004	101829			0
		28/05/2004	101837		9.46	0
Jabiru East Gagadju Workshop Tank Tap	JE036	1/04/2004	100714	8.14		
		2/04/2004	100743	10.8		
		3/04/2004	100801	10.4	10.7	
		4/04/2004	100821		10.7	
		21/04/2004	101162		10.6	
		22/04/2004	101173		11.4	
		12/05/2004	101656			0
		17/05/2004	101716			
		27/05/2004	101833			0
		28/05/2004	101838			0
Jabiru East eriss building - Admin labs bubbler	JE100	7/04/2004	100939		10.3	
		8/04/2004	100956		10.4	
		21/04/2004	101164		8.96	
		22/04/2004	101175		9.44	
		13/05/2004	101665			0
		17/05/2004	101717			
		27/05/2004	101832			0
		28/05/2004	101839			0

**Table 4: Chlorine residuals for Ranger and Jabiru East potable supply (June 03, 2004)**

Site Code	Description	Chlorine Residual mg/L
PW	Ranger Potable Water	1.5
JE035	(North Australia Helicopters)	0.3
JE019	Tourist Centre	0.2
JE028	Airport Cafe	0.8
JE100	Eriss Admin	0.8
JE036	Gagadu Workshop	0.2

## **Appendix 1**

### **Jabiru East and Mine – Drain and Flush Sequence of Events- Potable Water System**



**ERA**

**Energy Resources of Australia Ltd - Ranger Mine**

ABN 71 008 550 865

## **Jabiru East and Mine – Drain and Flush Sequence of Events – Potable Water System**

24/3/04 – Approx 8am – Jabiru East Line Isolated  
24/3/04 – Approx 2pm – Commenced pumping Water from Jabiru East Tank back to site  
25/3/04 – Approx 4am – Tank Emptied Pumping Ceased  
25/3/04 – Approx 9am – Magella Borefield commenced pumping into Jabiru East Tanks  
25/3/04 – Approx 10am – Drained Jabiru East Lines at the sump near tanks until empty.  
Approximately 20,000 ltrs removed and taken back to site.  
25/3/04 – Approx 1pm – Flushed line from Gagadju back to tanks using fire truck. Approx  
12,000ltrs flushed down the line  
25/3/04 – Approx 2pm – Flushed back from Eriss Tanks to Jabiru East Tanks and tested pH  
and EC at the tanks while flushing. Approx 20,000 ltrs.  
25/3/04 – Approx 4pm - Commenced pumping Water from Jabiru East tanks back to site  
25/3/04 – Approx 7pm – Pumping back to site stopped as tank was empty  
26/3/04 – Approx 7am – Magella Bore Stopped  
26/3/04 – Approx 9am – Pumped Water from Jabiru East tanks back to site until tank empty  
26/3/04 – Approx 10am – Water Sucked out of bottom of Jabiru East tank and brought back to  
site in Collex truck.  
27/3/04 – Approx 11am – Jabiru East Tank was completely emptied  
27/3/04 – Approx 1pm – Magella bore started and filling of tank commenced  
28/3/04 – Approx 8am – Commenced flushing back from Jabiru East Tank to site with Magella  
water  
28/3/04 – Approx 11am – Flushing completed – pH & EC tested good – Approx 300,000ltrs  
flushed  
28/3/04 – Approx 2pm – Flushing of main line to mine facilities commenced  
29/3/04 – Approx 9am – Main line flushing ceased. All taps turned on and flushing of all outlets  
commenced.  
29/3/04 – Approx 10am – All outlets at Inganarr training centre and security were flushed  
29/3/04 – Approx 4pm – All outlets at Inganarr training centre, security and mine facilities were  
turned off.  
30/3/04 – Approx. 10am – Outlets at the mine were flushed again – pH and EC tested good at  
all points.  
30/3/04 – All Day – All Jabiru East potable water points were identified and lock out using out  
of service procedures.  
31/3/04 – Jabiru East line was re-pressurised.  
31/3/04 – 2 Hydrants at extremities were flushed for approx 10 mins. Tested for pH & EC all  
OK.  
31/3/04 – All accessible taps were flushed for between 10 – 20 mins. Tested for pH & EC. All  
OK  
1/4/04 – Samples taken and completion of EC & pH testing of remaining outlets.  
2/4/04 – All accessible outlets reflushed for 10 – 20mins and pH & EC tested. All OK.

### **Estimated Flush Quantities:**

Known Contaminated Lines – from 5 - 10 times pipe volume

Potentially Contaminated Lines – from 2 – 4 times pipe volume



## **Appendix 2**

### **Jabiru East – Outlet Flushing and Sampling Protocols**

## **Jabiru East – Flushing and Sampling Protocol**

### Flushing (Stage 1):

- Ensure all taps at Jabiru East are tagged out and isolated.
- Mark the location of all taps on map to determine the sampling program.
- Sample at Jab East Storage Tank following flush-back of water line from ERISS tanks.
- Select Line extremities for flushing and sampling (Gagadju W/shop, ERISS Hydrant, NA Helicopters and Weather Station)
- Pressurise potable line to Jabiru East using clean Brockman Borefield water.
- Estimate time to flush water from clean section of line to outlet (pipe volume)
- Flush pipe volume of line extremities and until EC is less than 400 uS/cm pH greater than 7.3.
- For small taps direct drainage water into 500 ml container underlain by 20L bucket, constantly monitoring with TPS meter for pH and EC and letting clean water overflow. Write down results.
- Monitor flushing from hydrants and extremities with a TPS meter for pH and EC. If EC exceeds 450 uS/cm collect drainage in the fire truck and return it to mine site. Allow clean water to flush to ground.

### Sampling (Stage 1)

- Test first water to flush out of line extremities
- Sample if EC increases whilst flushing
- Sample at end of flush.

### Flushing (Stage 2)

- Flush Env Lab hydrant and Gagadju Workshop for at least 12 hours
- Drainage to ground

### Sampling (Stage 2)

- Sample line extremities following major flush
- Select most likely drinking points for sampling
- Flush pipe volume of all outlets - drainage to ground or sewer
- Record EC and pH of first water to flush out of all outlets
- Sample first water to flush out all selected outlets
- Sample all selected outlets after flush

### Flushing (Stage 3):

- Flush all selected outlets for at least 1 hour

### Sampling (Stage 3):

- Sample all selected outlets after flushing

A further round of flushing and sampling may be necessary if positive results are returned from any stage sampling.