3 ENVIRONMENTAL RESEARCH AND MONITORING

The *Environment Protection (Alligator Rivers Region) Act 1978* established the Alligator Rivers Region Research Institute (ARRRI) to undertake research into the environmental effects of uranium mining in the Alligator Rivers Region. The scope of the research programme was widened in 1994 following amendments to the Act. ARRRI was subsequently renamed the Environmental Research Institute of the Supervising Scientist (***eriss***).

The work of ***eriss*** consists of two main areas:

- monitoring and research for the protection of people and the environment, focusing on the effects of uranium mining in the Alligator Rivers Region;
- research on the sustainable use and environmental protection of tropical rivers and their associated wetlands.

Six thematic areas (based primarily on geographic provenance) have been identified by the Alligator Rivers Region Technical Committee (ARRTC) as being the Key Knowledge Needs to ensure the current and future protection from uranium mining of the environment of the Alligator Rivers Region. The Key Knowledge Needs appear at Appendix 1.

For each of the thematic areas the key research needs relating to monitoring, closure and rehabilitation for current (Ranger and Jabiluka), rehabilitated (Nabarlek) and legacy (South Alligator River Valley) sites were identified and prioritised. These research topics provide the basis for defining the core ***eriss*** project activities to be carried out from year to year. The content and outcomes of the research programme are assessed annually by ARRTC, whose charter and activities are described in detail in Chapter 4 of this Annual Report.

eriss contributes to the addressing of each of the Key Knowledge Needs by applying a broad range of scientific expertise across the research fields of:

- Ecotoxicology;
- Environmental radioactivity;
- Hydrological and geomorphic processes;
- Monitoring and ecosystem protection;
- Biophysical pathways and ecological risk assessment.

A selection of highlights from each of these fields of endeavour is presented here.

In particular, the water quality monitoring programme has been considerably enhanced with the installation of continuous monitoring equipment for pH, electrical conductivity and turbidity in Magela Creek upstream and downstream of the mine site. Continuous, time-series water quality data will offer a more complete description of the fluctuations in quality that are missed by weekly grab sampling, such as effects caused by variation in flow.

An extended report has been provided of the outcomes of a benchmark landscape environmental risk assessment of threats and pressures to the Magela floodplain. This assessment is the final part of the 'Landscape-scale analysis of impacts' programme, established in 2002 following the report of the International Science Panel into the potential impacts of uranium mining at Jabiluka and Ranger on the World Heritage values of Kakadu National Park. The objective of this work was to help to clearly differentiate the relative risks posed by mining and non-mining impacts, whilst contributing to a broader assessment of the World Heritage values of the Park.

A major programme of research on characterisation of northern tropical rivers, and assessment of risk from actual and potential threats, is being carried out under the framework of the Tropical Rivers Inventory and Assessment Project (TRIAP). The work is funded by Land and Water Australia and the Natural Heritage Trust and is a collaborative effort between ***eriss***, James Cook University and the University of Western Australia, with additional involvement of the University of Wageningen in the Netherlands. The scope and current status of this project are described below.

Further details on research outcomes are published in journal and conference papers and in the Supervising Scientist and Internal Report series. Publications by Supervising Scientist Division staff in 2005–06 are listed in Appendix 2. More information on the Division's publications, including the full list of staff publications from 1978 to the end of June 2006, is available at www.deh.gov.au/ssd/publications.

3.1 Toxicity of treated pond water from Ranger uranium mine to five local freshwater species

Several factors, including a number of above average wet seasons, the need to keep the base of Pit 3 dry for mining and the removal of Djalkmara Billabong (a wetland previously used to hold and polish run-off from the minesite prior to controlled release into Magela Creek), prompted Energy Resources of Australia Ltd (ERA) to consider alternative methods for the reduction of onsite (pond) waters at the Ranger mine. Proposals for the treatment of pond water were discussed with stakeholders throughout 2004–05. Whilst a pilot plant and laboratory experiments demonstrated through water chemistry analysis that the quality of the treated pond water would likely be suitable for release, it was agreed that for additional assurance, SSD would undertake ecotoxicological testing on treated pond water (permeate) from the newly commissioned plant prior to release into the Corridor Creek wetlands.

ERA completed commissioning the pond water treatment plant in December 2005 and provided SSD with assurance that the permeate being produced at the time was representative of future outputs, and thus, ready for ecotoxicological testing. SSD staff from the Jabiru Field Station sampled the permeate on 12 December 2005 and ERA staff delivered the sealed sample bottles to the SSD Darwin laboratories for testing the same day.

Five local organisms, a unicellular alga (*Chlorella* sp.), macrophyte (duckweed; *Lemna aequinoctialis*), cnidarian (*Hydra viridissima*), crustacean (water flea; *Moinodaphnia macleayi*) and a fish species (*Mogurnda mogurnda*), were exposed to concentrations of

30%, 44%, 67% and 100% treated pond water permeate and a Magela Creek water control. All dilutions of the permeate were undertaken using freshly collected Magela Creek water.

Exposure to the treated pond water permeate had no effect on the growth of the two plant species and the hydra, nor on the survival of the fish. The water flea (*M. macleayi*), however, was shown to produce significantly less offspring when exposed to the two highest concentrations of permeate (67% and 100%) (Figure 3.1). Thus, the Lowest-Observed-Effect-Concentration (LOEC) and No-Observed-Effect-Concentration (NOEC) were 67% and 44% permeate, respectively.

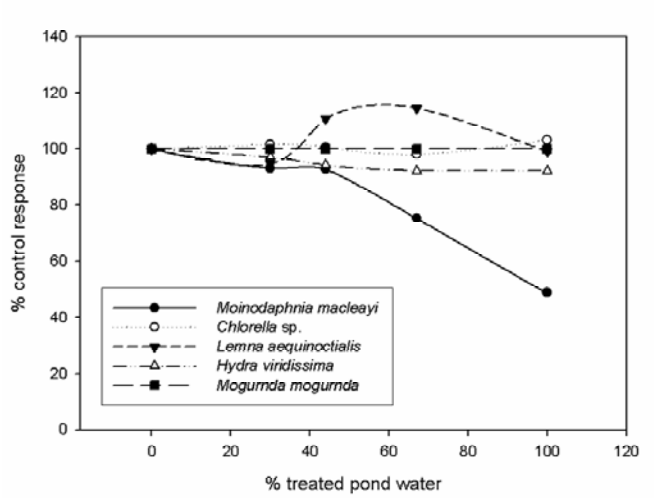

Figure 3.1 Response of five local species to treated pond water permeate. Note that the elevated response observed in the *L.aequinoctialis* test was found to be not significantly different from the control.

Chemical analysis of the treated pond water found that all metals, other than uranium, were below or around the limits of detection and hence unlikely to be contributing to the observed toxicity. The 4 µg/L of uranium in the treated pond water was less than what has been shown to cause toxicity to *M. macleayi* in Magela Creek water.

However, natural Magela Creek water typically contains 2–8 mg/L dissolved organic carbon, which has been shown to ameliorate uranium toxicity. A notable characteristic of the permeate was that dissolved organic carbon was below the detection limit (<1 mg/L). The absence of dissolved organic carbon in the permeate may therefore result in greater uranium toxicity to *M. macleayi*. An alternative hypothesis is that the absence of dissolved organic carbon and possibly other essential ions from the permeate may result in a reduction in reproduction and survival of *M. macleayi* as a result of nutrient/ion deficiencies.

It is planned to test the above hypotheses by measuring the toxicity of uranium in a 'synthetic' Magela Creek water that simulates the inorganic composition of the water but contains no dissolved organic carbon, and to compare the results to experiments conducted in natural Magela Creek water.

Regardless of the outcome of this planned testwork, the response of *M. macleayi* to the treated pond water was only mild to moderate, and any potential for an effect on downstream biota could be avoided by diluting the permeate as it is released off-site. An acceptable dilution factor of one part permeate to 23 parts Magela Creek water (that is, 4.4% permeate) was calculated using the 'safety factor' approach outlined in the ANZECC/ARMCANZ (2000) Water Quality Guidelines. The preferred distribution-fitting method for deriving acceptable concentrations/dilutions was inappropriate in this case because only one of the five species tested responded to the permeate.

The one in 23 dilution factor has been adopted by ERA as one of the primary criteria for the release of treated pond water to Magela Creek, and should be easily achievable through the wet season period.

An analogous approach to the testing of treated mine process water is expected to take place once the plant has been commissioned for this grade of water in late 2006.

3.2 Toxicity of uranium to two local freshwater species

Historically, uranium has been the primary toxicant of concern for the aquatic ecosystems downstream of the Ranger mine. Consequently, many ecotoxicological studies have been undertaken to assess the toxicity of uranium and the influence of various environmental variables (for example, pH, alkalinity, water hardness, and dissolved organic carbon) on the toxicity of uranium to local aquatic species. In total, nearly 20 local freshwater species have been assessed, comprising one plant, two cnidarian, one mussel, five crustacean and ten fish species.

The majority of data for these species, however, are derived from acute toxicity rather than chronic toxicity test endpoints. The latter are required for the derivation of *high reliability* water quality guidelines. Chronic data exist for only five of those species tested, namely the green alga, *Chlorella* sp. (72 hour growth inhibition), the cladoceran, *Moinodaphnia macleayi* (three brood reproductive inhibition), the green hydra, *Hydra viridissima* (96 hour population growth inhibition), the chequered rainbowfish, *Melanotaenia splendida inornata* (seven day survival and growth) and the purple-spotted gudgeon, *Mogurnda mogurnda* (seven day exposure/seven-day post-exposure survival and growth).

Based on a cumulative probability (loglogistic) distribution of no-observed-effect-concentration (NOEC) data for these five species, which range from 18 to 810 µg/L, a site-specific water quality trigger value for uranium of around 6 µg/L has previously been derived. This value represents the concentration that should be protective of 99% of species with 50% confidence. Notably, the trigger value has high uncertainty surrounding it, as demonstrated by the 95% confidence limits of 0.3–103 µg/L. Moreover, two of the five species represented are fish, which appear to be generally less sensitive to uranium than invertebrate and algal species. Thus, in order to increase confidence in the site-specific trigger value, chronic toxicity data for additional species, ideally, representing additional taxonomic groups and trophic levels, were required.

The tropical duckweed, *Lemna aequinoctialis*, is a small aquatic floating macrophyte that occurs in lentic and low-flow waterbodies throughout northern Australia, including the Alligator Rivers Region. The freshwater snail, *Amerianna cumingi*, is a hermaphroditic snail that occurs in lentic (pond) and lotic (flowing) waterbodies within a restricted range that encompasses the Alligator Rivers Region. Both species are of high ecological importance as food sources for other organisms and in their respective roles as a primary producer and detritivore. Toxicant effects on these species are assessed in the laboratory by observing the growth of exposed *L. aequinoctialis* and changes in the egg production of *A. cumingi* over 96 hours and comparing them with individuals of the same species maintained in clean water.

In order to accurately calculate exposure concentrations throughout the tests, it was essential that the fate of uranium in the test system was understood. Adsorption of uranium to the test container can reduce the uranium dissolved in the test waters and result in the organisms being exposed to a lower than expected concentration. Without quantifying this loss, the toxicity of uranium could be significantly underestimated. It is important to note that, in addition to adsorption of uranium to the test containers/tubes, losses of uranium from the test waters can also be due to uptake and accumulation by the test organisms, or by adsorption on to slimes or exudates produced by the organisms.

As the uptake of uranium by the organisms represents the exposure to uranium, the relative proportions of uranium 'lost' from the test waters due to (i) adsorption to test containers/tubes and (ii) accumulation by the test organisms need to be determined before exposure concentrations can be appropriately adjusted. To address this, uranium concentrations were measured in test waters periodically throughout each test and in the duckweed/snail tissues at the conclusion of a test.

A small but significant loss of uranium (8–18%, $P < 0.05$) was detected in the *L. aequinoctialis* test system over the four day duration. Samples taken at 48 hours indicated that the majority of the uranium was being lost within the first half of the test, after which uranium concentrations remained relatively stable. When integrated over a four day period (by calculating the area under the curve) these losses ranged from 6–13%, with the proportion being positively related to the initial uranium concentration of the water. Plant tissue measurements indicated that uranium uptake by the plants accounted for approximately 50% of the uranium 'lost' from the test waters. As the overall 'loss' was quite small and a significant proportion of this was shown to be taken up by the plants, it was decided that no adjustment of the exposure concentrations would be required.

A more substantial loss of uranium was observed from the test waters in the snail (*A. cumingi*) tests, with samples taken 24 hours after each water change containing 30–70% less uranium than at the start of the test. Figure 3.2 shows an example of uranium loss for one of the uranium treatments over the 96 hour test duration. Because waters are changed daily during *A. cumingi* tests, and the loss of uranium over each 24 hour period was found to be gradual and to decrease in magnitude over the duration of the test, it was essential that the final losses were integrated over each 24 hour period, and then over the entire 96 hours before calculating the exposure concentrations. Using data from three different experiments, and regardless of whether total or dissolved uranium concentrations were used, it was found that uranium loss over the entire test duration was approximately 25% of the uranium concentration at the start of the test.

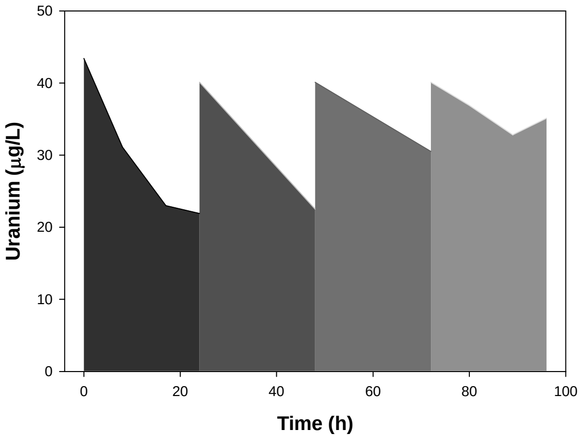

Figure 3.2 Loss of uranium in an *A. cumingi* test solution initially containing 43 µg/L uranium (measured). Each shaded bar represents a 24 hour period between water renewals.

An experiment designed to address the uptake of uranium by the snails was being conducted at the time of preparation of this summary, and hence the results could not be reported at this time. Therefore, the toxicity results reported below are based on uranium concentrations adjusted according to the total losses measured (that is, corrected concentration is 75% of the initial uranium concentration). Should a significant proportion of the 'lost' uranium be found to have been taken up by the snails, then the exposure concentrations will be adjusted accordingly.

The effect of uranium exposure on the growth of *L. aequinoctialis* is shown in Figure 3.3. An IC_{10} (concentration resulting in a 10% inhibition of egg production) of 250 (lower/upper 95% confidence limits: 207/288) µg/L U was calculated from these data. The IC_{10} is generally considered to be a measure of an 'acceptable' concentration (ie, one that will not result in unacceptable ecological effects at the population level). The IC_{50} could not be calculated, but was >2850 µg/L U. When compared to the other local freshwater species that have been assessed for their sensitivity to U, *L. aequinoctialis* was found to be less sensitive than most. Only the two fish species, the northern trout gudgeon (*Mogurnda mogurnda*) and the chequered rainbowfish (*Melanotaenia splendida inornata*), have been reported to be less sensitive.

The effect of uranium exposure to *A. cumingi* is shown in Figure 3.4. Based on four definitive tests, *A. cumingi* was found to be highly sensitive to U, with an IC_{10} of 22 (lower/upper 95% confidence limits: 6/46) µg/L U and an IC_{50} of 250 µg/L U (an upper confidence limit could not be calculated). Based on these data, *A. cumingi* appears to be more sensitive to U than most other species that have been tested. Of the five species already used to derive the current U TV, only the water flea, *Moinodaphnia macleayi*, has been found to exhibit similarly high sensitivity to U. It is noteworthy that although the within-treatment responses of *A. cumingi* tend to be inherently highly variable (as evidenced by the large error bars in Figure 3.4), the between-test concentration-response relationships are quite consistent (data not shown here).

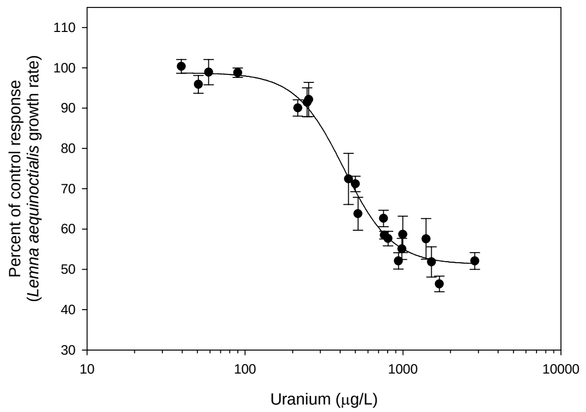

Figure 3.3 Effect of uranium on the growth rate of *L. aequinoctialis*, expressed as a percentage of the control response (Control growth rates for the three tests were 0.43, 0.42 and 0.45, respectively). The fitted curve represents a 4 parameter loglogistic model (r^2 = 0.98, n = 20, P<0.0001).

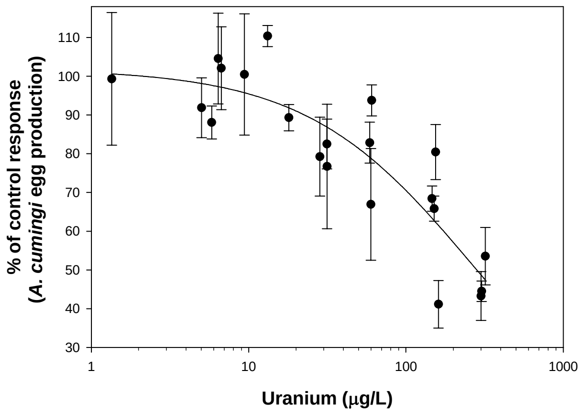

Figure 3.4 Effect of uranium on the egg production of *A. cumingi*, expressed as a percentage of the control response (Control egg numbers for the three tests were 198, 133 and 241, respectively). The fitted curve represents a 3 parameter loglogistic model (r^2 = 0.75, n=21, *P*<0.0001).

3.3 Bioaccumulation of radionuclides in terrestrial plants on rehabilitated landforms

3.3.1 Background

Over the last 25 years radiological data have been gathered on bush foods throughout the Alligator Rivers Region of the Northern Territory. Early studies were focused on aquatic animal and plant species due to the identified importance of the aquatic transport pathway for bioaccumulation of radionuclides in bush foods, particularly during the operational phase of uranium mining operations in the region. However, the terrestrial food component also needs to be included in a complete radiological dose assessment model.

Following rehabilitation of the Ranger mine site, food sources growing on the footprint of the former operational area may become an increasing proportion of the diet of the local indigenous people. It can reasonably be assumed that the highest dose rates to humans will be received from the consumption of foods growing in the vicinity of a contamination source and this aspect needs to be addressed as a component of the radiological protection issues associated with land use by local Aboriginal people. Measurements of the concentrations of radionuclides in the fruits and tubers of terrestrial plants growing in soils spanning a range of concentrations of radionuclides are thus required to provide guidance for the development of soil quality closure criteria. and to enable a radiological risk assessment to be carried out for the rehabilitated site at Ranger.

The issue of radiological content of bush foods also needs to be addressed and assessed for the rehabilitated Nabarlek mine and the abandoned uranium mines in the South Alligator Valley. The dose assessment needs to be site specific, and the radiation dose model has to include local habits and human land use, and land use expectations. This information needs to be coupled with the data being collected and analysed on estimates of terrestrial bush food consumption by local Aboriginal people and site occupancy estimates to develop robust dose assessment models for these locations.

3.3.2 Results

An earlier investigation of uranium series radionuclides in native fruits and vegetables has shown that ^{226}Ra and ^{210}Po make the highest percentage contribution in fruits and yams to committed effective dose from the ingestion of long lived members of the uranium decay series (Table 3.1). This is primarily due to the relatively high dose conversion factors of these two radionuclides. Consequently, subsequent research efforts have focussed on determining concentration factors for ^{226}Ra and ^{210}Po in terrestrial plants.

TABLE 3.1 ESTIMATED PERCENTAGE CONTRIBUTION TO COMMITTED EFFECTIVE DOSE FROM THE INGESTION OF FRUITS AND YAMS FOR LONG-LIVED MEMBERS OF THE URANIUM DECAY SERIES

Species	^{238}U	^{234}U	^{230}Th	^{226}Ra	^{210}Pb	^{210}Po
Fruits	0.5	0.5	1.9	37	17	42
Yams	0.1	0.1	0.3	50	17	33

As part of the development of a dose assessment model, a knowledge management tool called the Bushtucker Spatial Information System (SIS) has been developed to collate and integrate the historical radiological data. The results can be graphically displayed together with contextual data such as satellite imagery, photographs and maps (Figure 3.5). The system has facilitated a quality assessment of the available radionuclide data, recent and historic, aquatic and terrestrial, and has assisted in identifying gaps in knowledge about radionuclide uptake in flora and fauna. It is also highlighting the lack of bush food radionuclide information currently available worldwide.

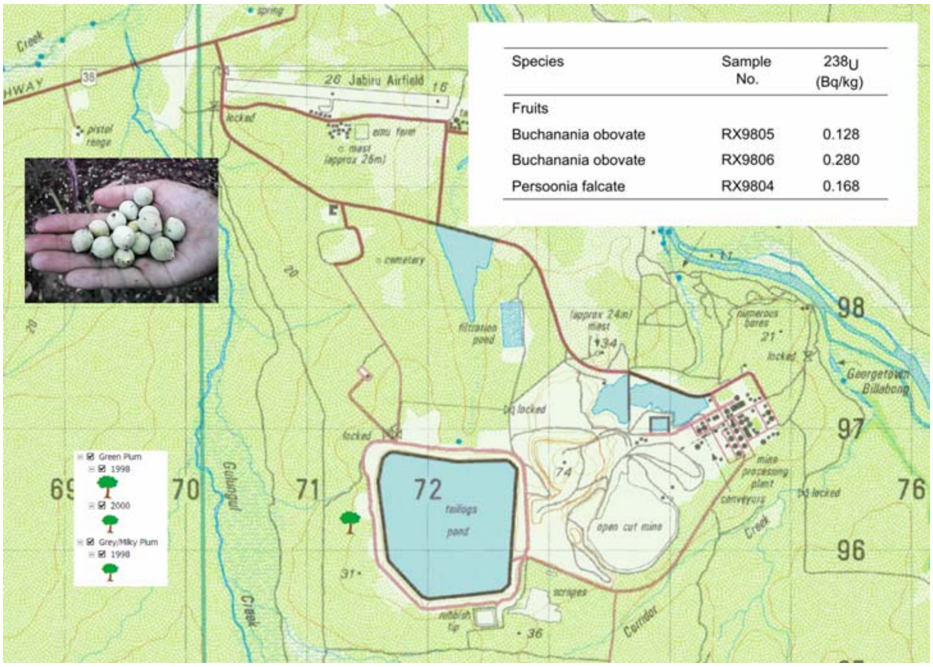

Figure 3.5 Screen shot of the bushtucker SIS showing uranium activity concentrations in terrestrial bush food samples collected in 1998 around the Ranger mine site

The Bushtucker SIS is of particular interest and importance to the local Aboriginal people who rely on traditional bush food sources, as it provides reassurances to people that bush food sources are safe to eat. It is also being used as a communication tool to graphically display and simplify the complex results of radionuclide analyses of food and other associated items in the Region.

The data gathered over the years has made it possible to replace some International Atomic Energy Agency (IAEA) default radionuclide concentration factors for temperate environments with locally derived radionuclide concentration factors for the unique flora and fauna in the Top End region of the Northern Territory. Applying IAEA reference values for fish concentration factors for instance, overestimates thorium and ^{210}Pb uptake and thus the effective dose to people from the consumption of fish in the Alligator Rivers Region. The locally derived values provide a more accurate and realistic estimate.

Gaps identified in our knowledge of radionuclide uptake in terrestrial flora and fauna have resulted in the development of a strategic sampling design that focus future research effort on better defining radionuclide uptake pathways for terrestrial food items. Terrestrial bushtucker samples will continue to be collected and analysed from the Ranger mine site, the rehabilitated Nabarlek mine and the South Alligator Valley.