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Radionuclides and metals in freshwater mussels of the upper South Alligator River

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Plain English summary

During an inspection of the Gunlom area in 1999, a staff member of the Supervising Scientist Division found a small amount of tailings near the road that had been uncovered by the rain and road works. The tailings that were found were leftover from uranium mining that took place in the 1950s and 1960s. In October 2000 the Environmental Research Institute of the Supervising Scientist (***eriss***) and Parks used an airborne survey to try and find all the tailings in that area.

To help with the information we needed to gather, ***eriss*** went down to the South Alligator Valley in November 2000 and spoke to Park Rangers and some Aboriginal people about the tailings. After this meeting it was decided that ***eriss*** would collect some mussels with Aboriginal people and Park Rangers from 6 locations along and in the South Alligator River. The mussels that were collected were taken back to the ***eriss*** laboratory for analysis. Since then ***eriss*** have spoken to some Park Rangers and some Aboriginal people about the results of the tests we conducted. This report is about the results of the tests on the mussels and what ***eriss*** told people about the mussels that were collected.

Mussels are good to analyse because if there is any radiation contamination in the water they collect it and when you analyse them they can give you an idea of how much contamination there is. We collected and analysed mussels from different places along the river so we could compare them. This was because some of the mussels were near the place where, if any of the tailings washed into the river, the mussels would show more contamination. Some of the mussels we collected were upstream of the tailings, so there would not be any of the tailings in them and we could compare the mussels from the two places.

What we found was that there was just a very small amount of contamination in the mussels near where the tailings enters the river at the Gunlom road in the wet and a small amount just downstream of where Rockhole Mine Creek joins the river. If people ate a total of 2 kg of mussel flesh from the places we collected the mussels from in a year they would get 0.08 millisieverts (mSv). A sievert (Sv) is a unit of radiation dose; there are 1000 mSv in a Sv. The maximum allowable dose to be received by a member of the public as a result of the mining operation is 1 mSv per year. To put these numbers in perspective and compare it with a common life event another way you could get a radiation dose is by a medical X-ray or by going on a plane flight. A chest X-ray has a dose of about 0.08 mSv, as does a return flight from Darwin to Sydney. Given that the doses calculated above for mussel consumption are considerably less than the 1 mSv per year, we can state that from a radiological point of view the mussels which we collected from all of the South Alligator River sites would have been safe to eat

Introduction

The purpose of this report is to summarise details of sample collections of mussels, fish and sediment from the upper South Alligator River valley carried out in November 2000 for mining impact studies, and to summarise the data available at the time of preparation of the report.

The South Alligator River valley in Kakadu National Park, Northern Territory, Australia (figure 1), is a popular destination for tourists. It is also of important cultural significance to local Aboriginals, the Jawoyn people. In the 1950s and 60s, however, it was mainly renowned for its mineral resources and uranium mining activities.

The upper South Alligator River valley's main uranium deposits were characterised by a high uranium content with concentrations up to 2.5% U_3O_8. During peak activity, at least 16 different uranium ore bodies were known in the area with 13 of them eventually mined (Waggitt 2001). Data on the location of known radiation anomalies in the region have recently been summarised by Pfitzner and Martin (2003a, b).

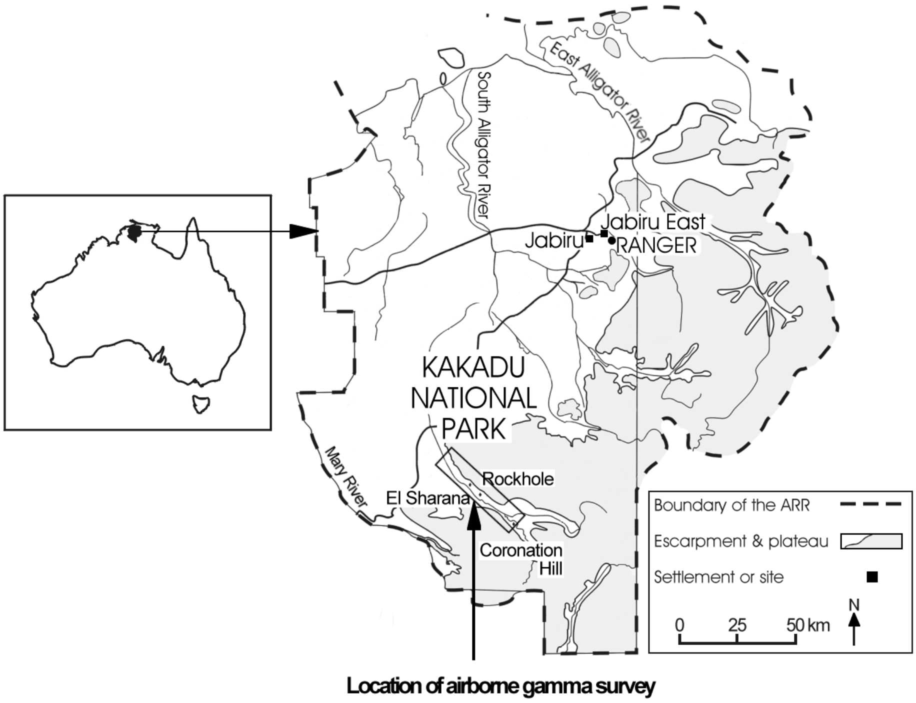

Figure 1 Map of Alligator Rivers Region NT encompassing Kakadu National Park and the location of the airborne gamma survey

Milling of the material extracted from some of the uranium ore bodies occurred at the South Alligator Mill between 1957–64. The mill was located a few hundred meters east of Rockhole Mine Creek, near its confluence with the South Alligator River. Tailings were deposited on the ground with very little containment. Mining in the upper South Alligator River valley ceased in 1964, the mine sites and camps were abandoned and no substantial effort was made to rehabilitate or clean up the area. In the period 1985–86 most of the tailings were removed by Pacific Goldmines to extract their gold content.

In 1991, a routine survey conducted by ***eriss*** and OSS staff revealed that uranium tailings had become exposed in an erosion gully next to the Gunlom road in Kakadu National Park, directly opposite the old South Alligator Mill tailings dam area. A limited attempt at rehabilitation was made, with the tailings area being covered by rock to prevent further erosion.

After seasonal road works in 1999, an inspection of the site by an OSS employee discovered that the road machinery had exposed tailings. A preliminary ground gamma survey was conducted during the dry season of 1999 (Tims et al 2000) by ***eriss*** and OSS staff. An airborne gamma survey funded jointly by SSD (Supervising Scientist Division) and PAN (Parks Australia North) was initiated and flown in 2000 (Pfitzner & Martin 2000) (figure 1). Data were evaluated for the Rockhole tailings site (Pfitzner et al 2001a) and the greater portion of the upper South Alligator Valley (Pfitzner et al 2001b) to quantify the magnitude and extent of radiological contamination arising from the mining activities. A radiological dose assessment report was prepared and reported by Bollhöfer et al (2002) after consultation with local Aboriginal people and PAN Rangers, as a response to the potential impact on human health from the exposed tailings.

As part of the radiological investigation and dose assessment studies, samples of freshwater mussels, *Velesunio angasi*, were collected in November 2000 from the South Alligator River (SAR), near and at the confluence of Rock Hole Mine Creek (RMC), adjacent to the exposed tailings. Collection sites for mussels, sediments and water were selected following consultations with PAN staff and local Aboriginal people. Radionuclide activities and activity ratios were determined by alpha and gamma spectrometry. Concentrations of a number of elements (including metals) and stable lead isotopes were determined by ICP-MS.

Velesunio angasi has previously been used as an indicator of bioaccumulation in the same area (Akber & Hancock 1990, Akber et al 1993, leGras & Humphrey 1998) and some historical data from this earlier work are presented in this report along with the data from the current 2000 study.

Sites

Freshwater mussels were jointly collected on 8 November 2000 by ***eriss***, PAN and Aboriginal Traditional Owners from six sites on the SAR. These sites are in the vicinity of the exposed tailings and RMC and are illustrated in figure 2. RMC is known to be polluted by acid rock drainage emanating from an old mine adit associated with the abandoned workings of the Rockhole Minesite (Akber & Marten 1990). In total, 177 mussels, 4 water and 6 sediment samples were collected from these sites. Details of the site locations are given in table 1. These sites were potentially exposed or unexposed to mine waste contaminants (figure 2).

Table 1 Site locations for the mussel samples collected from the upper South Alligator River, November 2000 collection. Site S0 is from the October 1989 sample collection.

Site	Location	Code	No. of mussels	Water sample	Sediment sample
Site 0	Rockhole Creek, 30 m from confluence with SAR (1989)	S0			✓
Site 1	20–30 m downstream RMC confluence, north bank of SAR	S1	3		✓
Site 2	0–10 m downstream RMC confluence, north bank of SAR	S2	27	✓	✓
Site 3	0–10 m upstream RMC confluence, north bank of SAR	S3	23	✓	✓
Site 4	0–10 m upstream to 40 m downstream RMC confluence, south bank SAR	S4	25		✓
Site 5	Tails inlet at gully into Sth Alligator roadside bank (north bank)	S5	78	✓	✓
Site 6	Well upstream of tails, downstream of bridge over SAR (Gunlom road)	S6	21	✓	✓

Methodology

Water samples

Surface water samples were collected in acid-washed plastic 5 litre containers. The samples were filtered in the laboratory to < 0.45 µm within 24 hours of collection and the filtrate acidified to ~1% HNO_3 (AnalR). The residue was digested with HCl and HNO_3 (AnalR).

Both the filtrate and digested residue were analysed for radioisotopes of polonium (^{210}Po), lead (^{210}Pb) and radium (^{226}Ra and ^{228}Ra) by alpha spectrometry (Appendix C). A sub sample of each filtrate (acidified with Aristar grade nitric acid) and digested residue solution was sent for ICP-MS (Inductively Coupled Plasma-Mass Spectrometry) analysis to determine the concentrations of barium (Ba), magnesium (Mg), manganese (Mn), iron (Fe), cobalt (Co), nickel (Ni), copper (Cu), zinc (Zn), lead (Pb), cadmium (Cd) and uranium (U). Results for these analyses are presented in Appendix B.

Sediment samples

Between 300 and 400 g of sediment were collected from each mussel collection site. The sediment matter the mussels were living in was taken from the bank of the river below the water line. The top 3–5 cm of sediment was scraped, placed in plastic bags and taken to the ***eriss*** laboratory in Jabiru for processing.

Sediment samples were oven dried at 60° C for 3 days, ground with a ring mill and cast in resin for determination of radioisotopes of lead (^{210}Pb), thorium (^{228}Th) and radium (^{226}Ra and ^{228}Ra) by gamma spectrometry (Appendix K). Sub-samples of the dried, ground sediments were analysed by ICP-MS for aluminium (Al), arsenic (As), barium (Ba), cadmium (Cd), calcium (Ca), chromium (Cr), cobalt (Co), copper (Cu), iron (Fe), lead (Pb), magnesium (Mg), manganese (Mn), nickel (Ni), potassium (K), rhenium (Re), rubidium (Rb), selenium (Se), sodium (Na), sulfur (S), uranium (U), zinc (Zn) (Appendix E), and stable lead isotopes (Appendix G).

Mussel samples

Mussels were collected by hand from the riverbanks then placed immediately into an acid washed container holding aerated host river water. After collection, mussels were transported to the ***eriss*** laboratory in Jabiru. The mussels were purged over several days at room temperature in aerated host river water. After purging, the mussels were measured for length and width (Appendix A), weighed and dissected to remove the visceral mass (flesh) using the methods of Allison and Simpson (1983), then placed onto aluminium trays for weighing and oven drying at 60°C for 7 days. The trays used may have influenced the ICPMS Al results and the results should be interpreted accordingly. After drying, the viscera of each mussel was re-weighed (= dry weight) and ground using a sample grinder and a mortar and pestle.

The age of each mussel was determined by placing the shell over an incandescent light source and counting the (annual) dark bands (annuli) (Humphrey & Simpson 1985). The ages of the mussels need to be adjusted by adding seven months to the number of annuli as most mussels are recruited during the wet season; hence in October they are N annuli and a half years of age. The dried and ground flesh of each mussel was combined according to age class and site, and a composite sample of each age class was cast in resin for determination of radioisotopes of lead (^{210}Pb), thorium (^{228}Th) and radium (^{226}Ra & ^{228}Ra) by gamma spectrometry (Appendix I & J). Mussels ≤ 1 year of age, or an age class with insufficient mass (< 2 g) for analysis by gamma spectrometry, were analysed by alpha spectrometry (Appendix H).

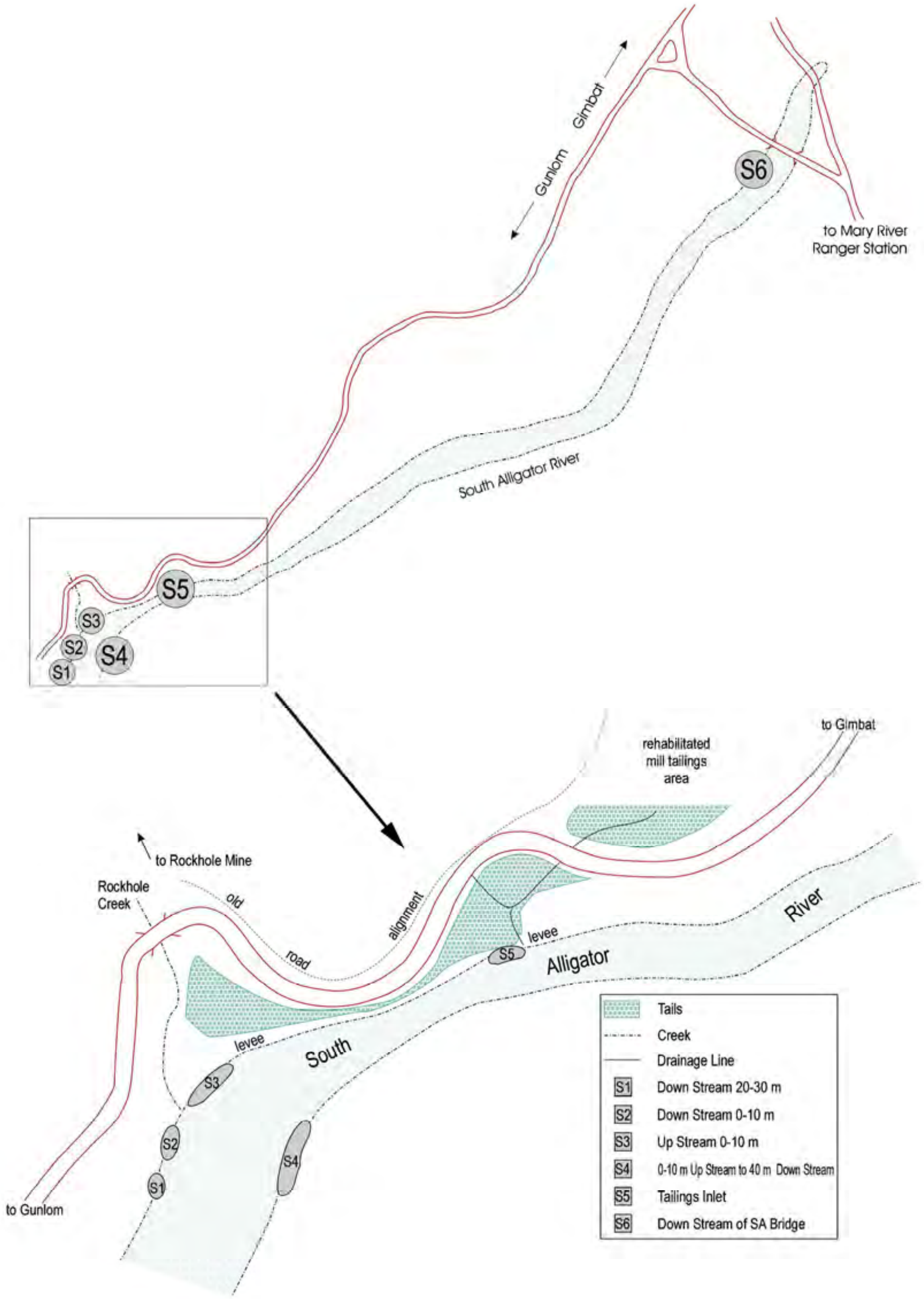

Figure 2 Map layout of sample collection sites November 2000 on the South Alligator River. Sites 1 and 2 are potentially exposed to both tailings and polluted Rockhole adit water, sites 3 and 5 potentially exposed to tailings only, S4 possibly unexposed under most flow conditions, while S6 is unexposed.

A sub-sample of dried and ground composite material of each age group from each site was analysed by ICP-MS for aluminium (Al), arsenic (As), barium (Ba), cadmium (Cd), calcium (Ca), cobalt (Co), copper (Cu), iron (Fe), lead (Pb), magnesium (Mg), manganese (Mn), nickel (Ni), potassium (K), rubidium (Rb), selenium (Se), sodium (Na), strontium (Sr), uranium (U) and zinc (Zn) (Appendix D & E). Sub-samples of a range of age class composites from each site were analysed for stable lead isotopes with ICP-MS with the results presented in Appendix G.

Analytical methods

For all sample types (water, sediment and mussels) radionuclide activities and radioisotope ratios were determined by either alpha or gamma spectrometry, or in the case of ^{238}U, by calculation from the ICP-MS value using the conversion factor of 1 Bq ^{238}U = 80.962 μg of natural U. Details of the alpha spectrometry methods are described in Martin and Hancock (1992) and the gamma spectrometry methods in Murray et al (1987), Marten (1992) and Pfitzner (1994).

Concentrations of metals in waters, sediments and mussels, and stable lead isotopes ($^{204, 206, 207, 208}$Pb) in sediments and mussels were determined by ICP-MS at either CDU (Charles Darwin University) or NTEL (Northern Territory Environmental Laboratories).

Error terms provided in the radionuclide summary tables, figures and text (±) are one estimated standard deviation based upon counting statistics only. Detection limits for each sample vary depending on sample size, detector efficiency and background, chemical recovery and background activity concentrations of the given nuclide. A value is deemed to be below detection limit if it is less than twice the standard deviation for that sample. In such cases a less than value is recorded being two times the standard deviation plus the calculated value (or zero if greater).

Results and discussion

Results are summarised in Appendices A to K. As the main purpose of this report is to provide a description of sample collection and sample analysis, and to summarise the results (in tabular form), only a brief analysis of the data is presented here. Further data analysis and interpretation are yet to be carried out.

Water samples

The chemistry data for water samples are provided in Appendices B and C. Table 2 provides a summary of Total Suspended Solids (TSS) and radionuclide results for 'total' (filtered and particulate) water. Recent rainfall may have had an effect on water quality with the Mary River Ranger Station recording 36mm of rainfall up to 0900 hrs for the 24 hr period on the 8th of November 2000. This was only the second rainfall event recorded by the Mary River Ranger Station for the 2000–01 wet season, with the previous event of 28 mm of rainfall being recorded on the 15th of September 2000.

Although the highest ^{226}Ra, ^{210}Pb and ^{210}Po values were obtained for S5 immediately downstream of the exposed tailings site, this does not necessarily imply influence from the tailings, as the results must be adjusted for suspended solids concentrations. For example, expressing the ^{226}Ra results obtained for the particulate sub-sample (Appendix C, table C2) as a ratio of the TSS results (ie giving Bq ^{226}Ra per kg of suspended solids) gives 207, 131, 169 and 288 Bq/kg for Sites 2, 3, 5 and 6, respectively; the highest activity concentration occurred at S6, unexposed to any mine contaminants. Water samples were not collected at sites 1 and 4 because of their close proximity to sites 2, 3 and 5 and the fact the river was flowing at a reasonable rate.

Table 2 TSS and radionuclide activity concentrations for total water by site, calculated by addition of results for filtered and particulate samples. ^{238}U results from U analysis by ICP-MS

Site code	TSS (mg/L)	^{238}U (mBq/L)	^{226}Ra (mBq/L)	^{210}Pb (mBq/L)	^{210}Po (mBq/L)
Site 2	6.28	3.3	2.4 ± 1.0	2.6 ± 0.6	4.5 ± 0.3
Site 3	15.71	4.4	3.1 ± 0.5	3.7 ± 0.5	7.2 ± 0.4
Site 5	24.59	4.0	6.3 ± 0.6	6.5 ± 0.7	12.6 ± 1.7
Site 6	3.47	6.6	2.9 ± 1.2	3.4 ± 0.5	4.5 ± 0.3

Sediment samples

A summary of analytical results for sediments is given in table 3. ^{226}Ra activity concentrations in the S5 sediment were slightly higher than for the other sediments, but this could be due to natural variability rather than the influence of tailings. Surprisingly, the ^{226}Ra activity concentration in the S2 sample immediately downstream of RMC confluence was the lowest of the four samples measured.

The $^{238}U/^{226}Ra$ ratio (table 3) is significantly lower than 1.0 in U mill tailings, and so if there was a substantial influence from the SAV mill tailings to the river sites (particularly that for S5) this would be reflected in the same ratio derived from river sediment. This ratio for S5 and S2 samples was lower than 1.0, but the analytical errors are large and so it is difficult to say whether this is significant.

The ^{228}Ra /^{226}Ra ratio (table 3) is also significantly lower than 1.0 in U mill tailings. The ^{228}Ra /^{226}Ra ratio followed the order S5 < S2 < S6 < S3 < S4 < S1, which may indicate an influence from the tailings (for S5) and Rockhole mine (for S2), but again the difference is small and could be due to natural variability.

In summary, there may be some small influence of the exposed tailings on the sediments for S5, and/or of Rockhole adit water on the S2 sediments, but this influence is not large and without replication it is not possible to determine whether the results are any more than natural variability in sediment radionuclide activity concentrations. Further investigations of the Pb isotope ratios presented in Appendix G on these samples could help to resolve this issue, as could the taking of further sediment samples from the riverbanks.

Table 3 Radionuclide activity concentrations and activity ratios for sediments by site

Site code	^{226}Ra (Bq/kg dry wt)	^{228}Ra (Bq/kg dry wt)	^{40}K (Bq/kg dry wt)	$^{238}U/^{226}Ra$	$^{228}Ra/^{226}Ra$
Gunlom road tails	18844 ± 136	62 ± 13	466 ± 45	0.01 ± 0.02	0.003 ± 0.001
RMC	151 ± 2	34 ± 3	289 ± 17	1.47 ± 0.13	0.23 ± 0.02
Site 1	104 ± 2	207 ± 4	156 ± 13	1.48 ± 0.17	2.0 ± 0.05
Site 2	39 ± 1	45 ± 3	183 ± 14	0.70 ± 0.20	1.17 ± 0.08
Site 3	62 ± 1	104 ± 2	197 ± 9	1.04 ± 0.10	1.68 ± 0.04
Site 4	35 ± 1	64 ± 3	136 ± 13	1.03 ± 0.41	1.82 ± 0.12
Site 5	79 ± 2	86 ± 3	241 ± 15	0.83 ± 0.12	1.09 ± 0.04
Site 6	50 ± 1	74 ± 2	242 ± 10	1.39 ± 0.12	1.49 ± 0.05

Mussel samples

Physical parameters

Table 4 shows that the predominant age range for mussels collected was 2 to 4 years. The maximum ages and life span of riverine (lotic) mussels (*V. angasi*) are known to be much shorter than many billabong (lotic) populations in the ARR (C Humphrey, pers obs), possibly due to the less stable riverine environment, for example, greater wet season scouring of riverine channels (and dislodging of mussels), greater susceptibility to predation in the shallower dry season waters, and so forth. Table 4 also shows the relative frequency of mussels collected from each age class by site and over all sites for the entire mussel collection.

Table 5 displays the mean weights (dry) of mussels within each age class for all sites, with the wet-dry weight ratio shown in table 6. The relative frequencies were used to calculate the total activity from the average activity concentrations as shown in table 7 using the following equation

$$A_{tot} = m \cdot \sum_i C_i \cdot p_i \cdot r_i \qquad (1)$$

with:

m: total weight of ingested mussels [kg]

C_i: average activity concentration of *i*-year old mussel [Bq/kg]

p_i: proportion of mussel from each age class (table 4)

r_i: dry/wet weight ratio (table 6)

i: 0, 1, 2, 3, 4, 5, 6, 7 and 10 year class

Table 4 Relative frequencies p_i of live mussels collected from each age class, by site and over all sites

	S1	S2	S3	S4	S5	S6	All sites
N	3	27	23	25	77	21	176
Age 0		0.04					0.01
Age 1	0.33	0.11		0.08	0.06	0.24	0.09
Age 2	0.33	0.19	0.13	0.36	0.18	0.33	0.22
Age 3	0.33	0.41	0.26	0.32	0.23	0.33	0.29
Age 4		0.19	0.52	0.20	0.31	0.05	0.27
Age 5		0.07	0.04	0.04	0.10	0.05	0.07
Age 6					0.04		0.02
Age 7			0.04		0.05		0.03
Age 10					0.01		0.01

Table 5 Mean and standard deviation of dry weight (g) for mussels collected from each age class, by site and over all sites. Standard deviation not indicated when n = 1.

	S1	**S2**	**S3**	**S4**	**S5**	**S6**	**All sites**
N	3	27	23	25	77	21	176
Age 0		0.087					0.087
Age 1	0.090	0.193 ± 0.21		0.178 ± 0.29	0.213 ± 0.42	0.235 ± 0.30	0.204 ± 0.46
Age 2	0.121	0.353 ± 0.75	0.274 ± 0.33	0.338 ± 0.16	0.352 ± 0.14	0.277 ± 0.94	0.330 ±0.124
Age 3	0.071	0.366 ±0.93	0.459 ± 0.16	0.399 ± 0.98	0.379 ± 0.91	0.440 ± 0.13	0.393 ± 0.11
Age 4		0.492 ±0.15	0.423 ± 0.95	0.545 ± 0.78	0.476 ±0.11	0.486	0.471 ± 0.11
Age 5		0.561 ± 0.21	0.455	0.700	0.503 ± 0.82	0.460	0.520 ± 0.88
Age 6					0.502 ± 0.13		0.502 ± 0.13
Age 7			0.733		0.688 ± 0.20		0.697 ± 0.17
Age 10					0.992		0.992

Table 6 Mean and standard deviation of dry/wet weight ratios for mussels collected from each age class, by site and over all sites. Standard deviation not indicated when n = 1.

	S1	**S2**	**S3**	**S4**	**S5**	**S6**	**All sites**
N	3	27	23	25	77	21	176
Age 0		0.088					0.088
Age 1	0.087	0.107 ± 0.017		0.088 ± 0.025	0.106 ± 0.016	0.111 ± 0.006	0.103 ± 0.015
Age 2	0.121	0.087 ± 0.016	0.091 ± 0.02	0.100 ± 0.031	0.101 ± 0.021	0.111 ± 0.21	0.101 ±0.023
Age 3	0.071	0.087 ±0.026	0.089 ± 0.013	0.097 ± 0.022	0.095 ± 0.017	0.116 ± 0.024	0.095 ± 0.022
Age 4		0.079 ±0.008	0.077 ± 0.01	0.089 ± 0.022	0.097 ±0.016	0.089	0.089 ± 0.017
Age 5		0.088 ± 0.002	0.061	0.127	0.086 ± 0.029	0.66	0.086 ± 0.027
Age 6					0.097 ± 0.011		0.097 ± 0.011
Age 7			0.098		0.093 ± 0.017		0.094 ± 0.015
Age 10					0.088		0.088

Table 7 Average ^{226}Ra and average decay-corrected ^{210}Pb activity concentrations for mussels in each age group, and the calculated total Bq for a diet of 2 kg of wet mussels using dry weights and proportions from South Alligator River 2000 mussel collection.

Mussel Age	**Average ^{226}Ra (Bq/kg)**	**Total ^{226}Ra (Bq)**	**Average ^{210}Pb (Bq/kg)**	**Total ^{210}Pb (Bq)**
Age 0	#108	0.2	#24	0.04
Age 1	273	4.9	#36	0.65
Age 2	283 ± 119	12.7	30 ± 17	1.33
Age 3	318 ± 46	17.1	59 ± 22	3.15
Age 4	437 ± 72	20.4	83 ± 37	3.88
Age 5	**698 ± 9	8.3	**59 ± 29	0.71
Age 6	*570	2.2	*99	0.38
Age 7	**671 11	3.9	**105 ± 40	0.61
Age 10	#717	1.3	#149	0.26
Total		71		11

Result taken from single mussel alpha analysis. The uncertainties are analytical uncertainties only. * Result calculated from simple linear regression. ** Standard deviation from single site, multiple mussels collected.

Radionuclides and metals

Figures 3 to 5 show radionuclide results (Appendix I) for mussels, measured by gamma spectrometry. As can be seen, results for ^{226}Ra activity concentration and load, and ^{228}Ra/^{226}Ra (Appendix I, table I1) and ^{228}Th/^{228}Ra activity ratios (Appendix J, table J4) are strongly age-dependent. ^{226}Ra activity concentrations (Appendix I, table I1) and load per mussel (Appendix I, table I2) increase with mussel age because the biological half-life of radium in mussels is long. In other words, radium is excreted at a lower rate than which it is taken up, thereby accumulating in mussel flesh.

The ^{228}Ra/^{226}Ra ratio decreases with mussel age due to faster decay of the ^{228}Ra isotope (half-life of 5.75 years) compared to the ^{226}Ra isotope (half-life of 1600 years), following uptake of radium by the mussel. The ^{228}Th/^{228}Ra activity ratio increases with mussel age because of ingrowth of the ^{228}Th daughter (half-life = 1.91 years) following uptake of ^{228}Ra by the mussel. Hence when comparing results, it is important to compare those for mussels of the same age.

If we look at the ^{226}Ra activity concentrations for the mussels from sites S2, S3 and S5 (potentially contaminated sites) and compare them with those for mussels of the same age from the S6 and S4 (control sites), then the results for the S2, S3 and S5 sites are invariably higher (see figure 3 and table 11).

If we look similarly at the ^{228}Ra/^{226}Ra ratios (figure 5 and table 11), they are lower for the S2, S3 and S5 sites than for the S6 and S4 sites which may indicate a tailings effect.

The ^{228}Th (figure 4b), ^{226}Ra (figure 3a) and ^{228}Ra (figure 4a) activity concentrations and ^{228}Th/^{228}Ra ratios (figure 5b) all increase with age at any one location. The ^{228}Ra/^{226}Ra ratios decrease with the exception of the variable ^{228}Ra/^{226}Ra ratios at the tailings inlet (figure 5a).

It is difficult to prove conclusively whether or not the differences we observe here are due to the past mining activities, because of the lack of pre-mining activity concentration and ratio data. However, the evidence is certainly consistent with a hypothesis that the tailings and/or RMC adit water have an influence on ^{226}Ra activity concentrations in the mussels.

The ^{226}Ra activity concentration results (table 4 and figure 2a) show no apparent significant difference amongst the three potentially-exposed sites for the 3-year old mussels; for 4-year old mussels the sequence is S2 > S5 > S3. Comparing the ^{228}Ra/^{226}Ra ratios (table 4 and figure 3a) for the different sites, then for both 3-year old and 4-year old mussels we find that the sequence is S5 < S2 < S3. Taking these two set of results together, it would appear that mussels at S3 are less affected than those at S2 and S5.

Overall, these results are consistent with a hypothesis that the tailings have an influence at least on ^{226}Ra levels in mussels at S5 (downstream tails), and that the effect of this is reduced by dilution between S5 and S3, which is downstream of the tailings but upstream of RMC confluence. Downstream of the confluence (S2) there is an additional influence of RMC. However, the evidence does not conclusively prove which of the tailings or RMC adit water has the greatest influence.

Comparable magnesium, copper and in particular, uranium concentration results in flesh of mussels collected from S1 November 2000 (0–10 m downstream RMC confluence, north bank of SAR) and Site 7 1989–90 (immediately downstream of the confluence of RMC and the SAR) and S6 November 2000 (well upstream of tails, downstream of bridge over SAR (Gunlom road)) and Site 4 1989–90 (2.5–3 km downstream of the confluence of the SAR and the seasonal tributary draining 'Back Valley', on the southern and western sides of Coronation Hill) are shown in Table 10. Three sites from the May 1995 SAR mussel collection are also in table 10, these are: north bank ~ 50 m D/S RMC confluence = S1, SAR/RMC confluence = S1 & S2 and south bank SAR = S4. The results shown for the three elements in table 10 are similar and without statistical analyses appear very similar for the different collections.

The radionuclide activity concentrations in mussels for the November 2000 collections from the three sites in the vicinity of RMC in 2000 (S3, S2 and S1) are higher than for the other three sites and may indicate an effect of adit water discharge from RMC. To reinforce this assumption using the historical collections of 1989-90 (***eriss*** Annual Research Summary 1992–94 (internal report 291, pp 71–73)) and the 1995 data collections (Appendix F) the data would need statistical analysis. The 1989-90 collection site 7 is the only site directly comparable to S2 from the November 2000 collections and S6 from November 2000 being marginally comparable to S4 1989-90 which was several kilometres upstream of S6. The mussel collection from 1995 has two sites that can be compared to S1 and one site that can be compared to S4. Table 12 shows summary data of uranium activity concentrations in 3-yr old SAR mussels from November 2000.

Table 8 Radionuclide activity concentrations in sediments. Results are in (Bq/kg, dry weight).

Date		**Nov 2000 site**	**^{238}U**	**^{230}Th**	**^{226}Ra**	**^{210}Pb**
18 May 90	Sediment	S0	2843 ± 71	891 ± 437	560 ± 15	548 ± 50
November 2000	Sediment	S0	221 ± 20	108 ± 69	151 ± 2	103 ± 9
15 Aug 89	Sediment	S2	19.4 ± 3.3	ND	21.1 ± 0.4	21.3 ± 7.1
November 2000	sediment	S2	31 ± 14	ND	39 ± 1	49 ± 10

Site 0 = Rockhole Mine creek (RMC)

Table 9 Radionuclide activity concentrations in water. Results are in (mBq/l).

Date	Nov 2000 site	Fraction	^{238}U	^{230}Th	^{226}Ra	^{210}Pb	^{210}Po
August 1989	2	Filtered	0.97±0.08	0.21±0.04	1.5±0.1	1.2±0.2	
May 1990	2	Filtered	*0.58				
November 2000	2	Filtered			1.10 ± 0.9	0.10 ± 0.5	1.39 ± 0.3
November 2000	2	Particulate			1.30 ± 0.2	2.48 ± 0.3	3.13 ± 0.2
November 2000	2	Total	*3.3				

*Calculated from ICPMS U result Appendix B

Table 10 Selected element concentrations for mussels for several sample collections from the South Alligator River (dry weight)

Collection	**Nov 2000 site**	**U (µg/kg)**	**Cu (µg/kg)**	**Mg (µg/kg)**
October 1989	S1	0.26 ± 0.08	18.0 ± 3.8	1380 ± 570
May 1990	S1	0.79 ± 0.2	15.4 ± 4.8	1440 ± 220
November 2000	S1	0.79	7.3	1173
May 1995	S1	0.50	9.9	
May 1995	S1 & S2	1.2	11.0	
May 1995	S4	0.38	11.3	
October 1989	S6	0.66 ± 0.19	18.8 ± 7.4	2190 ± 450
May 1990	S6	0.42 ± 0.1	14.6 ± 3.5	2020 ± 400
November 2000	S6	0.41	12.8	1132

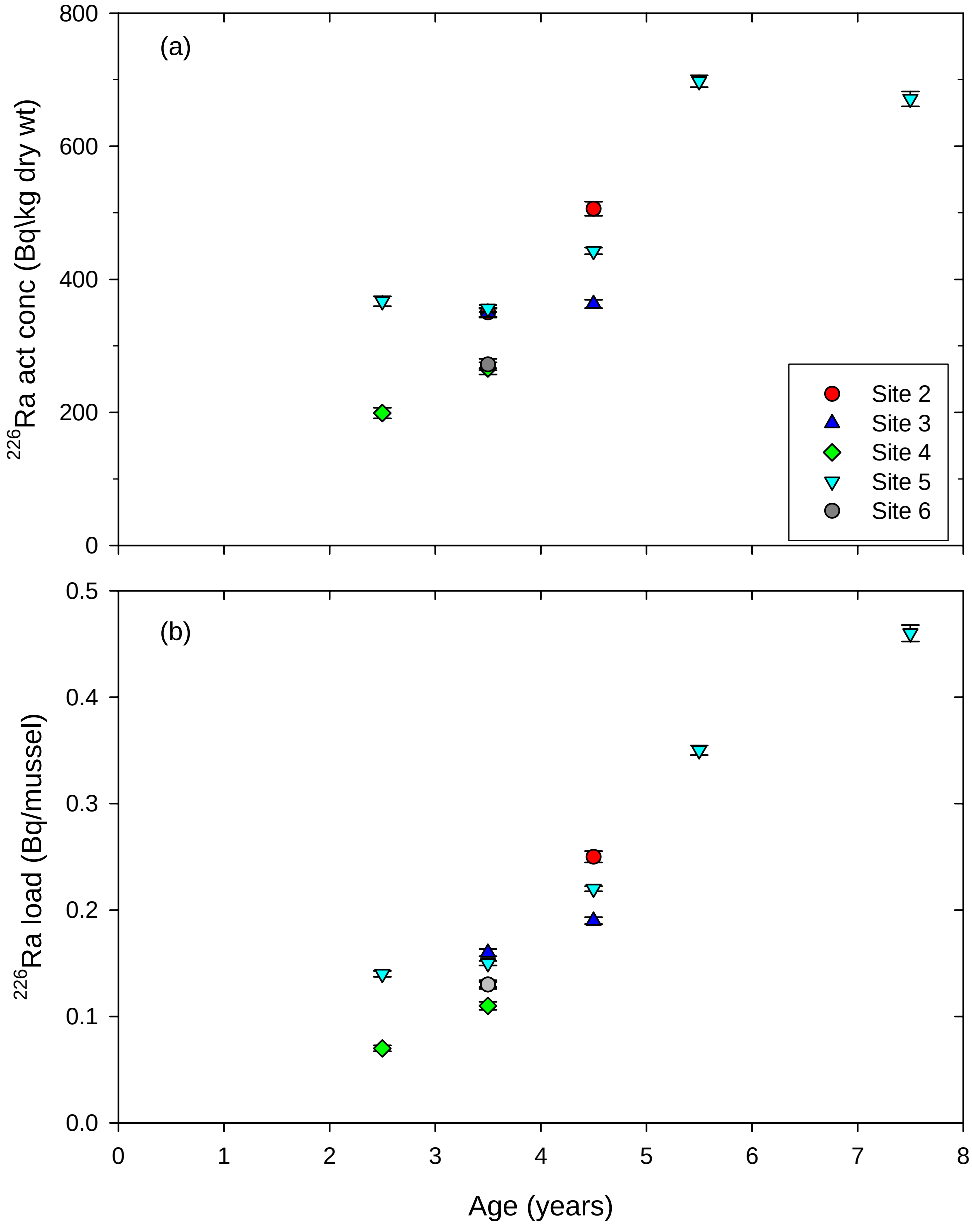

Figure 3 Radium results for mussel age groups from sites on the South Alligator River, November 2000 collection, analysed by gamma spectrometry: (a) ^{226}Ra activity concentration, and (b) ^{226}Ra activity load

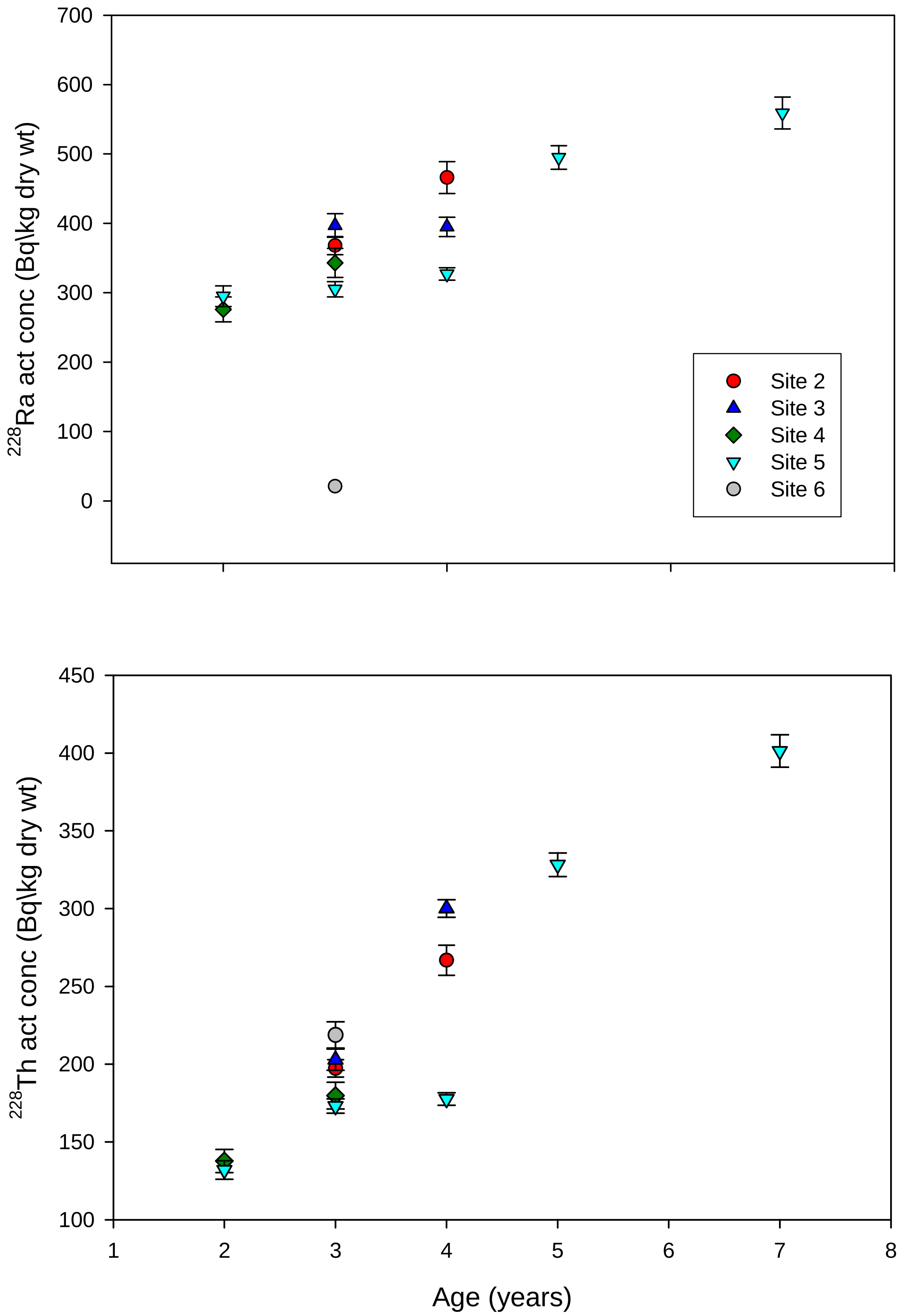

Figure 4 Radionuclide results for mussel age groups from sites on the South Alligator River, November 2000 collection, analysed by gamma spectrometry: (a) ^{228}Ra activity concentration, and (b) ^{228}Th activity concentration

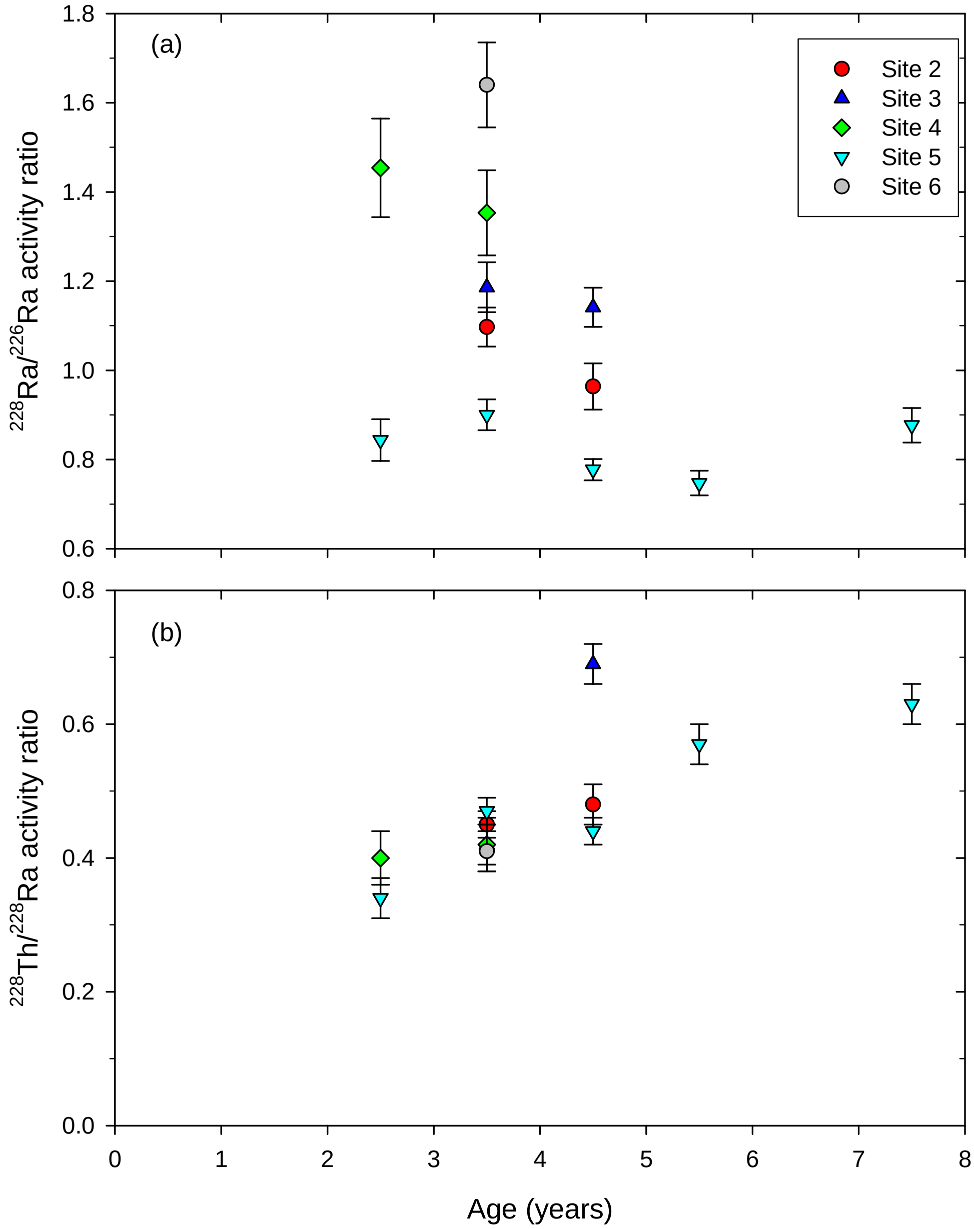

Figure 5 Radionuclide results for mussel age groups from sites on the South Alligator River 2000 collection, analysed by gamma spectrometry: (a) $^{228}Ra/^{226}Ra$ activity ratio, and (b) $^{228}Th/^{228}Ra$ activity ratio

Table 11 ^{226}Ra and ^{210}Pb (Bq/kg, dry weight) activity concentrations and $^{228}Ra/^{226}Ra$ activity ratios for mussels collected from the upper South Alligator River area, November 2000. The uncertainties are analytical errors.

Sample	*N*	^{226}Ra	$^{228}Ra/^{226}Ra$	^{210}Pb
2-yr old mussels				
S4 (south bank)	8	199 ± 8	1.454 ± 0.111	Nd
S5 (downstream tails)	11	367 ± 7	0.844 ± 0.047	46 ± 28
3-yr old mussels				
S4 (south bank)	7	266 ± 9	1.353 ± 0.095	Nd
S6 (U/S of tails)	6	272 ± 9	1.640 ± 0.095	94 ± 37
S5 (downstream tails)	14	356 ± 5	0.900 ± 0.034	54 ± 19
S3 (U/S RMC)	6	350 ± 7	1.186 ± 0.056	48 ± 29
S2 (D/S RMC)	9	350 ± 6	1.097 ± 0.044	53 ± 23
4-yr old mussels				
S5 (downstream tails)	20	443 ± 5	0.777 ± 0.024	48 ± 15
S3 (U/S RMC)	8	363 ± 6	1.141 ± 0.044	94 ± 24
S2 (D/S RMC)	5	506 ± 11	0.964 ± 0.052	121 ± 42
5-yr old mussels				
S5 (downstream tails)	8	698 ± 9	0.747 ± 0.028	68 ± 29
7-yr old mussels				
S5 (downstream tails)	4	671 ± 11	0.877 ± 0.039	113 ± 40

nd – not detected

The November 2000 U activity and elemental concentrations for the downstream tails mussels (S5) are similar to those from the two control sites (S4 and S6). This is not particularly surprising as uranium is removed during the uranium milling process (table K1, Appendix K). Consequently, although tailings uranium concentrations are higher than those for normal stream sediments, they are not as elevated as, for example, ^{226}Ra activity concentrations. Also, what uranium is present in tailings tends to be in a relatively insoluble form as it was unable to be removed effectively by the uranium mill extraction process.

While there may be some effect of RMC adit water on uranium activity concentrations in mussels in the vicinity of the confluence of RMC and SAR, statistical analysis of the full data set is needed to confirm this.

Table 12 Uranium activity and elemental concentrations for 3-year old mussels, November 2000, from Appendix E (dry weight)

Sample	U (ppm)	^{238}U (Bq/kg)
3-yr old mussels		
S4 (south bank, unexposed)	0.23	2.9
S6 (U/S of tails)	0.42	5.3
S5 (downstream tails)	0.31	3.8
S3 (U/S RMC)#	0.44	5.4
S2 (D/S RMC)*	0.95	11.6
S1 (20-30 m D/S RMC)	0.79	9.8

1. #Uranium concentrations from Appendix D

Conclusions

Although further analysis of the data is required to confirm our tentative conclusions here, there does appear to be an influence of the tailings on ^{226}Ra activity concentrations in mussels from S5, and of RMC adit water on ^{226}Ra activity concentrations in mussels from sites 2 and, to a lesser extent, S3. Data from Appendix F and tables 8, 9 and 10 provides some historical results and comparisons for selected elements with the November 2000 sediment, water and mussels.

Table 13 shows committed effective doses[1], which have been calculated on the assumption that a 10-year old child eats 2 kg (wet weight) of flesh from mussels from the SAR sites. These have been calculated on the basis of the ^{226}Ra (Appendix I) and ^{210}Pb results (Appendix J). The calculated doses are quite low and were calculated using the equation:

$$CED = D_{Ra} + D_{Pb} \qquad (2)$$

and

$$D = A \times DCF \qquad (3)$$

where :

D_{Ra}: calculated dose from ^{226}Ra, [μSv]

D_{Pb}: calculated dose from ^{210}Pb, [μSv]

A: Activity [Bq]

DCF: Dose conversion factor, μSv/Bq (ICRP 72, 1996).

Even in the extreme case of 7-yr old mussels collected from the downstream tailings site being eaten, the predicted dose is only 0.14 mSv.

Using the age, weight and proportional information from tables 4, 5 and 6, and predicting values for 6-yr old mussels using simple regression analysis, due to lack of data, a hypothetical bush food collection of 2 kg of mussels was used to calculate and estimate the committed effective dose for a 10-year-old child. The figure of 0.08 mSv in table 14 may be a more realistic approximation of the dose because of the variation of the size and weights of the mussels in a normal bush food collection scenario.

The corresponding doses arising from ^{238}U intake are extremely low. For example, assuming the worst case of a 10-year old child eating 2 kg (wet weight) of flesh from mussels from site S5, a committed effective dose is only 0.0001 mSv.

For comparison, the dose limit for a member of the public that applies to a practice (such as an operation uranium mine) is 1 mSv per annum additional dose to the background.

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[1] Committed effective dose is a technical term. It indicates that the dose has been calculated in a way that accounts for the long-term nature of the dose (i.e. the person is "committed" to receiving the dose over several years) as well as the type of radiation involved and the type of tissues irradiated.

Table 13 Committed effective doses calculated for a 10-year old child assuming the child eats 2 kg of mussel flesh from each site and age class, based upon activity concentrations of ^{226}Ra and ^{210}Pb in the samples from the upper South Alligator River and dose conversion factor from ICRP Report No 72.

Sample	Committed effective dose (mSv)
2-yr old mussels	
S4 (south bank)	0.04
S5 (downstream tails)	0.07
3-yr old mussels	
S4 (south bank)	0.04
S6 (U/S of tails)	0.09
S5 (downstream tails)	0.07
S3 (U/S RMC)	0.07
S2 (D/S RMC)	0.06
4-yr old mussels	
S5 (downstream tails)	0.08
S3 (U/S RMC)	0.07
S2 (D/S RMC)	0.10
5-yr old mussels	
S5 (downstream tails)	0.11
7-yr old mussels	
S5 (downstream tails)	0.14

Table 14 Committed effective dose calculated for a 10-year old child who eats 2 kg of mussel flesh, based upon average activity concentrations of ^{226}Ra and ^{210}Pb from all sites and age groups in the samples from the upper South Alligator River. Proportions of mussels used taken from Table 6.

Sample	Committed effective dose (mSv)
Average all age groups and all sites	0.08

References

Akber RA & Hancock G 1990. Bioaccumulation of radionuclides in aquatic organisms from the South Alligator River: First report, December 1990. Internal report 21, Supervising Scientist for the Alligator Rivers Region, Canberra. Unpublished paper.

Akber RA & Marten R 1990. Radioactivity of Rockhole Mine Creek. Internal report 13, Supervising Scientist for the Alligator Rivers Region, Canberra. Unpublished paper.

Akber R, Paulka S & Hancock G 1993. Bioaccumulation of radionuclides in edible aquatic organisms from South Alligator River: Activity concentrations measurements of Velesunio angasi mussel. Internal report 105, Supervising Scientist for the Alligator Rivers Region, Canberra. Unpublished paper.

Allison HE & Simpson RD 1989. *Element concentrations in the freshwater mussel, Velesunio angasi, in the Alligator Rivers Region.* Technical memorandum 25, Supervising Scientist for the Alligator Rivers Region, AGPS, Canberra.

Bollhöfer A, Ryan B, Pfitzner K, Martin P & Iles M 2002. A radiation dose estimate for visitors of the South Alligator River valley, Australia, from remnants of uranium mining and milling activities. In *Uranium mining and hydrogeology III*, eds BJ Merkel, B Planer-Friedrich & C Wolkersdorfer. Technical University, Bergakademie Freiberg, 931–940.

Humphrey CL & Simpson RD 1985. The biology and ecology of *Velesunio angasi* (Bivalvia: Hydiidae) in the Magela Creek, Northern Territory (4 parts). Open file record 38, Supervising Scientist for the Alligator Rivers Region, Canberra. Unpublished paper.

ICRP 1996. Age-dependent doses to members of the public from the intake of radionuclides: part 5. Compilation of Ingestion and Inhalation dose coefficients. ICRP Publication 72.

LeGras C & Humphrey C 1998. Concentration of elements in freshwater mussels for detection of short-term and long-term effects of mining in the upper South Alligator River. In Environmental Research Institute of the Supervising Scientist Annual Research Summary 1992–94, Draft Report (incomplete), July 1998, Internal report 291, Supervising Scientist, Canberra, 71–73. Unpublished paper.

Marten R 1992. Procedures for routine analysis of naturally occurring radionuclides in environmental samples by gamma-ray spectrometry with HPGe detectors. Internal report 76, Supervising Scientist for the Alligator Rivers Region, Canberra. Unpublished paper.

Martin P & Hancock G 1992. Routine analysis of naturally occurring radionuclides in environmental samples by alpha-particle spectrometry. Research report 7, Supervising Scientist for the Alligator Rivers Region, AGPS, Canberra.

Murray AS, Marten R, Johnston A & Martin P 1987. Analysis for naturally occurring radionuclides at environmental concentrations by gamma spectrometry. *Journal of Radioanalytical and Nuclear Chemistry, Articles* 115, 263–288.

Pfitzner J 1994. Sample collection and preparation manual for gamma-ray spectrometry analysis. Internal report 169, Supervising Scientist for the Alligator Rivers Region, Canberra. Unpublished paper.

Pfitzner K & Martin P 2000. Airborne gamma survey of the South Alligator River valley: First report. Internal Report 353, Supervising Scientist, Darwin. Unpublished paper.

Pfitzner K, Martin P & Ryan B 2001a. Airborne gamma survey of the upper South Alligator River valley: Second Report. Internal Report 377, Supervising Scientist, Darwin. Unpublished paper.

Pfitzner K, Ryan B, Bollhöfer & Martin P 2001b. Airborne gamma survey of the upper South Alligator River valley: Third Report. Internal Report 383, Supervising Scientist, Darwin. Unpublished paper.

Pfitzner K & Martin P 2003a. Mapping the upper South Alligator River valley using integrated datasets. Internal Report 444, July, Supervising Scientist, Darwin. Unpublished paper.

Pfitzner K & Martin P 2003b. An assessment of radiation anomalies in the Alligator Rivers Region – a review. Internal Report 446, July, Supervising Scientist, Darwin. Unpublished paper.

Tims S, Ryan B & Waggitt PW 2000. γ Radiation survey of exposed tailings in the area around Rockhole mine. Internal Report 332, Supervising Scientist, Darwin. Unpublished paper.

Waggitt PW 2001. Remediation of abandoned uranium mines in the Gunlom Trust Area, Northern Australia. In *Proceedings of 8th International Conference on Environmental Management ICEM'01*. Bruges, Belgium, 30 September – 4 October 2001, American Society of Mechanical Engineers.

Appendices

Appendix A Gravimetric and age data for mussels collected from South Alligator River.

Table A1 Gravimetric and age data for mussels collected from South Alligator River, November 2000

eriss ID	Location code	Wet Wt	Dry Wt	Age (est.)
ET0051	1	3.2044	0.3878	2
ET0052	1	2.3851	0.1692	3
ET0053	1	1.037	0.0901	1
ET0054	2	8.06	0.5869	4
ET0055	2	4.4063	0.6028	3
ET0056	2	3.2728	0.3061	4
ET0057	2	4.3622	0.3891	3
ET0058	2	6.4453	0.5756	5
ET0059	2	4.2208	0.3923	2
ET0060	2	3.9119	0.3137	3
ET0061	2	4.8781	0.4391	2
ET0062	2	6.3519	0.5465	5
ET0063	2	8.6317	0.6965	4
ET0064	2	6.1543	0.4548	4
ET0065	2	5.4653	0.4164	4
ET0066	2	4.3193	0.3584	3
ET0067	2	3.3068	0.2832	3
ET0068	2	3.1839	0.2969	3
ET0069	2	0.9916	0.0869	0
ET0070	2	2.9364	0.3629	3
ET0071	2	2.8877	0.2546	2
ET0072	2	3.8712	0.3348	3
ET0073	2	6.5671	0.3809	3
ET0074	2	6.1025	0.4356	3
ET0075	2	4.9904	0.2992	2
ET0076	2	5.6608	0.2673	3
ET0077	2	3.712	0.3792	2
ET0078	2	1.9416	0.1696	1
ET0079	2	1.7284	0.2114	1
ET0080	2	1.9883	0.1988	1
ET0081	3	6.3686	0.5214	3
ET0082	3	7.509	0.7325	7
ET0083	3	3.856	0.291	2
ET0084	3	4.6885	0.3804	3
ET0085	3	7.466	0.5069	4
ET0086	3	8.3517	0.5845	4
ET0087	3	7.4865	0.4546	5

eriss ID	Location code	Wet Wt	Dry Wt	Age (est.)
ET0088	3	4.1768	0.3733	4
ET0089	3	5.2864	0.4171	3
ET0090	3	5.3627	0.3898	4
ET0091	3	3.4662	0.2984	3
ET0092	3	6.497	0.7452	3
ET0093	3	4.3723	0.3344	4
ET0094	3	6.3792	0.4548	4
ET0095	3	5.5852	0.4542	4
ET0096	3	5.9963	0.5298	4
ET0097	3	2.0891	0.2361	2
ET0098	3	4.2573	0.3218	4
ET0099	3	5.37	0.3557	4
ET0100	3	3.524	0.2955	2
ET0101	3	4.4163	0.3934	3
ET0102	3	5.1156	0.4931	4
ET0103	3	4.0909	0.2766	4
ET0104	4	6.4967	0.6179	3
ET0105	4	7.3452	0.5653	4
ET0106	4	4.6045	0.4656	4
ET0107	4	7.0057	0.4723	4
ET0108	4	5.9961	0.4509	3
ET0109	4	7.0582	0.564	4
ET0110	4	5.2978	0.3841	3
ET0111	4	7.4301	0.6238	2
ET0112	4	3.756	0.2253	2
ET0113	4	3.1262	0.3498	3
ET0114	4	5.5109	0.7001	5
ET0115	4	2.9555	0.2412	2
ET0116	4	3.3533	0.2646	2
ET0117	4	3.0978	0.2274	2
ET0118	4	3.9561	0.6067	2
ET0119	4	4.2947	0.3658	3
ET0120	4	1.4877	0.1572	1
ET0121	4	3.5031	0.2999	3
ET0122	4	3.0168	0.3511	2
ET0123	4	2.805	0.1989	1
ET0124	4	3.1988	0.3691	3
ET0125	4	5.4124	0.6556	4
ET0126	4	2.1006	0.2446	2
ET0127	4	2.6398	0.3538	3
ET0128	4	1.9199	0.2573	2

eriss ID	Location code	Wet Wt	Dry Wt	Age (est.)
ET0129	5	5.6118	0.4498	5
ET0130	5	4.1005	0.4219	4
ET0131	5	5.9934	0.5392	3
ET0132	5	8.0531	0.9209	7
ET0133	5	9.8452	0.4998	5
ET0134	5	6.7977	0.4786	4
ET0135	5	4.2586	0.4881	4
ET0136	5	6.8771	0.5507	4
ET0137	5	5.8905	0.4786	3
ET0138	5	5.3079	0.3886	3
ET0139	5	5.8698	0.6786	4
ET0140	5	6.6111	0.5471	5
ET0141	5	6.323	0.6352	7
ET0142	5	2.0847	0.2751	2
ET0143	5	11.3145	0.9924	10
ET0144	5	3.4521	0.3899	3
ET0145	5	3.7901	0.4426	3
ET0146	5	Deceased		4
ET0147	5	3.4708	0.3292	2
ET0148	5	4.9677	0.4217	5
ET0149	5	4.8081	0.3921	4
ET0150	5	2.7562	0.2008	2
ET0151	5	3.1297	0.3084	2
ET0152	5	7.1485	0.6789	4
ET0153	5	3.8395	0.3568	3
ET0154	5	4.4128	0.3786	3
ET0155	5	6.3368	0.5176	4
ET0156	5	6.6798	0.5183	4
ET0157	5	3.5214	0.3495	3
ET0158	5	2.7556	0.3359	3
ET0159	5	3.8441	0.3021	4
ET0160	5	3.4396	0.2944	3
ET0161	5	4.0571	0.3199	3
ET0162	5	2.4808	0.2531	1
ET0163	5	2.8783	0.2861	2
ET0164	5	3.8477	0.5462	5
ET0165	5	5.3593	0.5197	4
ET0166	5	9.5112	0.7416	7
ET0167	5	4.2787	0.4332	5
ET0168	5	2.8429	0.3543	2
ET0169	5	3.8375	0.455	4

eriss ID	Location code	Wet Wt	Dry Wt	Age (est.)
ET0170	5	5.1191	0.3571	3
ET0171	5	5.0789	0.6839	4
ET0172	5	4.1702	0.4577	3
ET0173	5	3.9765	0.5664	2
ET0174	5	3.5919	0.3771	2
ET0175	5	4.6364	0.4726	6
ET0176	5	4.7918	0.4772	4
ET0177	5	1.7571	0.2355	1
ET0178	5	1.4217	0.1461	1
ET0179	5	5.5975	0.4546	7
ET0180	5	4.6417	0.4355	4
ET0181	5	4.7607	0.3977	3
ET0182	5	7.6443	0.6392	6
ET0183	5	3.7998	0.3951	6
ET0184	5	4.3709	0.5294	4
ET0185	5	7.145	0.6664	5
ET0186	5	4.8123	0.4827	3
ET0187	5	4.2148	0.4179	4
ET0188	5	4.341	0.4573	4
ET0189	5	8.8255	0.4571	5
ET0190	5	3.5793	0.4413	3
ET0191	5	5.2371	0.4763	4
ET0192	5	3.1347	0.2711	2
ET0193	5	4.4889	0.3869	2
ET0194	5	2.6035	0.2681	2
ET0195	5	2.2361	0.2473	3
ET0196	5	2.2565	0.2232	4
ET0197	5	3.7431	0.3851	4
ET0198	5	3.6981	0.3462	4
ET0199	5	5.7911	0.5676	4
ET0200	5	5.0172	0.4138	4
ET0201	5	2.1229	0.1985	1
ET0202	5	3.0846	0.3491	2
ET0203	5	9.1451	0.7268	2
ET0204	5	2.1349	0.1624	3
ET0205	5	2.7262	0.2223	2
ET0206	5	2.3992	0.2302	1
ET0207	6	2.217	0.2382	1
ET0208	6	3.5996	0.3687	3
ET0209	6	3.7051	0.3429	3
ET0210	6	5.4314	0.4859	4

eriss ID	Location code	Wet Wt	Dry Wt	Age (est.)
ET0211	6	4.1414	0.2885	2
ET0212	6	1.8551	0.2106	2
ET0213	6	2.636	0.2792	1
ET0214	6	1.7345	0.1975	1
ET0215	6	2.2875	0.2748	2
ET0216	6	7.0182	0.4595	5
ET0217	6	3.0747	0.2943	3
ET0218	6	2.0601	0.2188	1
ET0219	6	3.3535	0.3661	2
ET0220	6	5.6526	0.6249	3
ET0221	6	4.1859	0.5469	3
ET0222	6	1.7641	0.1798	2
ET0223	6	3.2852	0.4296	2
ET0224	6	3.4113	0.5454	3
ET0225	6	2.9412	0.3544	3
ET0226	6	2.0071	0.2414	1
ET0227	6	1.4192	0.1892	2

Table A2 Site, mussel identity and external analysis information

eriss ID	Site id	Ext. analysis	Notes
ET0043	site 6	CDU	Mussel collection water "Bridge"
ET0044	site 5	CDU	Mussel collection water "Tails Inlet"
ET0045	site 3	CDU	Mussel collection water "SAR u/s RMC"
ET0046	site 2	CDU	Mussel collection water "SAR-RMC"
ET0047	site 6		Mussel collection sediment "Bridge"
ET0048	site 5		Mussel collection sediment "Tails Inlet"
ET0049	site 3		Mussel collection sediment "SAR u/s RMC"
ET0050	site 2		Mussel collection sediment "SAR-RMC"
ET0051	site 1	Chem./NTEL	mussel 1
ET0052	site 1	Chem./NTEL	mussel 2
ET0053	site 1	Chem./NTEL	mussel 3
ET0054	site 2		mussel 4
ET0055	site 2		mussel 5
ET0056	site 2		mussel 6
ET0057	site 2		mussel 7
ET0058	site 2	CDU-Pb	mussel 8
ET0059	site 2	Chem./NTEL	mussel 9
ET0060	site 2		mussel 10
ET0061	site 2		mussel 11
ET0062	site 2	Chem./NTEL	mussel 12
ET0063	site 2		mussel 13
ET0064	site 2		mussel 14
ET0065	site 2		mussel 15
ET0066	site 2		mussel 16
ET0067	site 2		mussel 17
ET0068	site 2	Chem./NTEL	mussel 18
ET0069	site 2	CDU-Pb	mussel 19
ET0070	site 2		mussel 20
ET0071	site 2		mussel 21
ET0072	site 2	Chem./NTEL	mussel 22
ET0073	site 2		mussel 23
ET0074	site 2		mussel 24
ET0075	site 2		mussel 25
ET0076	site 2		mussel 26
ET0077	site 2	Chem./NTEL	mussel 27
ET0078	site 2		mussel 28
ET0079	site 2	Chem./NTEL	mussel 29
ET0080	site 2		mussel 30
ET0081	site 3		mussel 31

eriss ID	Site id	Ext. analysis	Notes
ET0082	site 3	CDU-Pb	mussel 32
ET0083	site 3	CDU-Pb	mussel 33
ET0084	site 3		mussel 34
ET0085	site 3		mussel 35
ET0086	site 3		mussel 36
ET0087	site 3	CDU-Pb	mussel 37
ET0088	site 3	Chem./NTEL	mussel 38
ET0089	site 3		mussel 39
ET0090	site 3		mussel 40
ET0091	site 3		mussel 41
ET0092	site 3		mussel 42
ET0093	site 3	Chem./NTEL	mussel 43
ET0094	site 3		mussel 44
ET0095	site 3		mussel 45
ET0096	site 3		mussel 46
ET0097	site 3		mussel 47
ET0098	site 3		mussel 48
ET0099	site 3		mussel 49
ET00100	site 3	CDU-Pb	mussel 50
ET00101	site 3		mussel 51
ET00102	site 3		mussel 52
ET00103	site 3		mussel 53
ET00104	site 4		mussel 54
ET00105	site 4		mussel 55
ET00106	site 4	Chem./NTEL	mussel 56
ET00107	site 4		mussel 57
ET00108	site 4		mussel 58
ET00109	site 4		mussel 59
ET00110	site 4		mussel 60
ET00111	site 4		mussel 61
ET00112	site 4		mussel 62
ET00113	site 4		mussel 63
ET00114	site 4	Chem./NTEL	mussel 64
ET00115	site 4		mussel 65
ET00116	site 4		mussel 66
ET00117	site 4		mussel 67
ET00118	site 4		mussel 68
ET00119	site 4		mussel 69
ET00120	site 4	CDU-Pb	mussel 70
ET00121	site 4	Chem./NTEL	mussel 71

eriss **ID**	**Site id**	**Ext. analysis**	**Notes**
ET00122	site3 4		mussel 72
ET00123	site 4	CDU-Pb	mussel 73
ET00124	site 4		mussel 74
ET00125	site 4	CDU-Pb	mussel 75
ET00126	site 4		mussel 76
ET00127	site 4		mussel 77
ET00128	site 4		mussel 78
ET00129	site 5		mussel 79
ET00130	site 5		mussel 80
ET00131	site 5		mussel 81
ET00132	site 5		mussel 82
ET00133	site 5		mussel 83
ET00134	site 5		mussel 84
ET00135	site 5		mussel 85
ET00136	site 5		mussel 86
ET00137	site 5		mussel 87
ET00138	site 5		mussel 88
ET00139	site 5		mussel 89
ET00140	site 5		mussel 90
ET00141	site 5		mussel 91
ET00142	site 5		mussel 92
ET00143	site 5	CDU-Pb	mussel 93
ET00144	site 5		mussel 94
ET00145	site 5		mussel 95
ET00146	site 5		mussel 96
ET00147	site 5		mussel 97
ET00148	site 5		mussel 98
ET00149	site 5		mussel 99
ET00150	site 5		mussel 100
ET00151	site 5		mussel 101
ET00152	site 5		mussel 102
ET00153	site 5		mussel 103
ET00154	site 5		mussel 104
ET00155	site 5		mussel 105
ET00156	site 5		mussel 106
ET00157	site 5		mussel 107
ET00158	site 5		mussel 108
ET00159	site 5	Chem./NTEL	mussel 109
ET00160	site 5	Chem./NTEL	mussel 110
ET00161	site 5		mussel 111

eriss ID	Site id	Ext. analysis	Notes
ET00162	site 5		mussel 112
ET00163	site 5		mussel 113
ET00164	site 5		mussel 114
ET00165	site 5		mussel 115
ET00166	site 5		mussel 116
ET00167	site 5		mussel 117
ET00168	site 5		mussel 118
ET00169	site 5		mussel 119
ET00170	site 5		mussel 120
ET00171	site 5		mussel 121
ET00172	site 5		mussel 122
ET00173	site 5		mussel 123
ET00174	site 5		mussel 124
ET00175	site 5		mussel 125
ET00176	site 5		mussel 126
ET00177	site 5		mussel 127
ET00178	site 5		mussel 128
ET00179	site 5		mussel 129
ET00180	site 5		mussel 130
ET00181	site 5		mussel 131
ET00182	site 5		mussel 132
ET00183	site 5		mussel 133
ET00184	site 5		mussel 134
ET00185	site 5		mussel 135
ET00186	site 5		mussel 136
ET00187	site 5		mussel 137
ET00188	site 5	CDU-Pb	mussel 138
ET00189	site 5		mussel 139
ET00190	site 5		mussel 140
ET00191	site 5		mussel 141
ET00192	site 5	Chem./NTEL	mussel 142
ET00193	site 5		mussel 143
ET00194	site 5		mussel 144
ET00195	site 5	Chem./NTEL	mussel 145
ET00196	site 5	Chem./NTEL	mussel 146
ET00197	site 5		mussel 147
ET00198	site 5		mussel 148
ET00199	site 5		mussel 149
ET00200	site 5		mussel 150
ET00201	site 5		mussel 151

eriss ID	Site id	Ext. analysis	Notes
ET00202	site 5		mussel 152
ET00203	site 5		mussel 153
ET00204	site 5		mussel 154
ET00205	site 5		mussel 155
ET00206	site 5	CDU-Pb	mussel 156
ET00207	site 6		mussel 157
ET00208	site 6		mussel 158
ET00209	site 6		mussel 159
ET00210	site 6	CDU-Pb	mussel 160
ET00211	site 6		mussel 161
ET00212	site 6	Chem./NTEL	mussel 162
ET00213	site 6		mussel 163
ET00214	site 6		mussel 164
ET00215	site 6		mussel 165
ET00216	site 6	CDU-Pb	mussel 166
ET00217	site 6	Chem./NTEL	mussel 167
ET00218	site 6		mussel 168
ET00219	site 6	CDU-Pb	mussel 169
ET00220	site 6		mussel 170
ET00221	site 6		mussel 171
ET00222	site 6	Chem./NTEL CDU-Pb	mussel 172
ET00223	site 6		mussel 173
ET00224	site 6		mussel 174
ET00225	site 6		mussel 175
ET00226	site 6		mussel 176
ET00227	site 6		mussel 177
ET00228	site 2		Composite mussel Sample of ET0061, ET0071 and ET0075
ET00229	site 2	CDU	Composite Mussel Sample of ET0078 and ET0080
ET00230			Composite Mussel Sample of ET0055 and ET0059
ET00231			Composite Mussel Sample of ET0125 and ET0132
ET00232		NTEL	Composite Mussel Sample of ET0128 and ET0151
ET00233			Composite Mussel Sample of ET0157, ET0163 and ET0164
ET00234			Composite Mussel Sample of ET0161 and ET0177
ET00235	site 2		9 x 3 y/o combined mussels s/n ET0055,57,60,66,67,70,73,74,76
ET00236	site 2		5 x 4 y/o combined mussels s/n ET0054,56,63,64,65
ET00237	site 3		6 x 3 y/o combined mussels s/n ET0081,84,89,91,92,101
ET00238	site 3		7 x 4 y/o combined mussels s/n ET0085,86,90,94,95,96,102,103
ET00239	site 4		8 x 2 y/o combined mussels s/n ET0111,112,115,116,118,122,126,128
ET00240	site 4		7 x 3 y/o combined mussels s/n ET0104,108,110,113,119,124,127

eriss ID	Site id	Ext. analysis	Notes
ET00241	site 5		11x 2 y/o combined mussels s/n ET0147,151,163,168,173,174,193,194,202,203,205
ET00242	site 5		14x 3 y/o combined mussels s/n ET0131,137,138,144,145,153,154,157,158,170,172,181,186,190 BR & TF
ET00243	site 5		20x 4 y/o combined mussels s/n ET0130,134,135,136,139,149,152,155,156,165,169,171,176,180,184,187,191, 197,199,200
ET00244	site 5		8x 5 y/o combined mussels s/n ET0129,133,140,148,164,167,185,189
ET00245	site 5		4x 7 y/o combined mussels s/n ET0132,141,166,179
ET00246	site 6		6x 3 y/o combined mussels s/n ET0208,209,220,221,224,225
ET00247	site 2	CDU	Sub-Sample of s/n ET0235 Sending to CDU for analysis
ET00248	site 2	CDU	Sub-Sample of s/n ET0236 Sending to CDU for analysis
ET00249	site 3	CDU	Sub-Sample of s/n ET0237 Sending to CDU for analysis
ET00250	site 3	CDU	Sub-Sample of s/n ET0238 Sending to CDU for analysis
ET00251	site 4	CDU	Sub-Sample of s/n ET0239 Sending to CDU for analysis
ET00252	site 4	CDU	Sub-Sample of s/n ET0240 Sending to CDU for analysis
ET00253	site 5	CDU	Sub-Sample of s/n ET0241 Sending to CDU for analysis
ET00254	site 5	CDU	Sub-Sample of s/n ET0242 Sending to CDU for analysis
ET00255	site 5	CDU	Sub-Sample of s/n ET0243 Sending to CDU for analysis
ET00256	site 5	CDU	Sub-Sample of s/n ET0244 Sending to CDU for analysis
ET00257	site 5	CDU	Sub-Sample of s/n ET0245 Sending to CDU for analysis
ET00258	site 6	CDU	Sub-Sample of s/n ET0246 Sending to CDU for analysis
ET00259	site 2	CDU	ET0228 Sent to CDU
ET00260	site 2	NTEL	ET0228 Sent to Chem. North
ET00261		CDU	ET0230 Sent to CDU
ET00262		NTEL	ET0230 Sent to Chem. North
ET00263		CDU	ET0231 Sent to CDU
ET00264		NTEL	ET0231 Sent to Chem. North
ET00265		CDU	ET0233 Sent to CDU
ET00266		NTEL	ET0233 Sent to Chem. North
ET00267		CDU	ET0234 Sent to CDU
ET00268		NTEL	ET0234 Sent to Chem. North
ET00269	IAEA	CDU	IAEA Reference Material 134 Cockle Flesh - sent to CDU
ET00270	IAEA	NTEL	IAEA Reference Material 134 Cockle Flesh - sent to Chem. North

CDU-Pb – analysed for recovery yield of internal Pb tracer as part of the Pb-210 by alpha spectrometry method.

Chem – ***eriss*** chemistry department

Appendix B South Alligator River ICPMS (CDU) results for water (μg/L).

Table B1 Elements in water determined by ICP-MS – filtered water fraction (<0.45 μm).

eriss ID	Site	Fraction	Ba	Mg	Mn	Fe	Co	Ni	Cu	Zn	Cd	Pb	U
ET0046	Site 2	filtered	7.92	3140	9.8	233	0.067	0.529	0.542	14.7	0.012	0.564	0.161
ET0045	Site 3	filtered	7.69	3140	13.0	278	0.122	0.784	0.654	13.6	0.012	0.254	0.109
ET0044	Site 5	filtered	8.04	3120	1.2	296	0.080	0.599	0.504	5.5	0.013	0.277	0.079
ET0043	Site 6	filtered	7.58	3330	3.5	299	0.219	0.731	0.550	20.5	0.022	0.477	0.104

Table B2 Elements in water determined by ICP-MS – particulate fraction (<0.45 μm).

eriss ID	Site	Fraction	Ba	Mg	Mn	Fe	Co	Ni	Cu	Zn	Cd	Pb	U
ET0046	Site 2	particulate	2.01	36.5	27.2	660	0.252	0.59	0.55	2.39	0.007	0.47	0.108
ET0045	Site 3	particulate	5.74	82.7	36.2	1218	0.478	1.00	1.09	3.33	0.008	0.97	0.249
ET0044	Site 5	particulate	8.41	125	43.7	1500	0.632	1.39	1.40	3.84	0.010	1.05	0.246
ET0043	Site 6	particulate	1.69	33.6	22.6	581	0.188	0.96	0.48	1.68	0.004	0.65	0.432

Appendix C Alpha spectrometry results for ^{210}Po, ^{210}Pb and ^{226}Ra for South Alligator River water (mBq/L)

Table C1 Corrected ^{210}Po, corrected ^{210}Pb and ^{226}Ra activity concentrations for filtered fraction of water samples

eriss ID	Site	Fraction	^{226}Ra	^{210}Pb	^{210}Po
ET0046	Site 2	filtered	1.10 ± 0.94	0.10 ± 0.48	1.39 ± 0.26
ET0045	Site 3	filtered	1.07 ± 0.06	0.21 ± 0.38	2.12 ± 0.29
ET0044	Site 5	filtered	2.13 ± 0.52	0.59 ± 0.36	1.64 ± 0.22
ET0043	Site 6	filtered	1.86 ± 1.21	1.32 ± 0.46	1.94 ± 0.25

Table C2 Corrected ^{210}Po, corrected ^{210}Pb and ^{226}Ra activity concentrations for particulate fraction of water samples

eriss ID	Site	Fraction	^{226}Ra	^{210}Pb	^{210}Po	TSS (mg.l-1)
ET0046	Site 2	particulate	1.30 ± 0.24	2.48 ± 0.28	3.13 ± 0.15	6.3
ET0045	Site 3	particulate	2.06 ± 0.48	3.52 ± 0.37	5.10 ± 0.24	15.7
ET0044	Site 5	particulate	4.16 ± 0.33	5.88 ± 0.56	11.0 ± 1.7	24.6
ET0043	Site 6	particulate	1.00 ± 0.19	2.08 ± 0.28	2.51 ± 0.14	3.5

Appendix D ICPMS results for South Alligator River mussels November 2000 (μg/g dry weight)

Table D1 Metal results for composite samples sent to NTEL

eriss ID	Comp id	Site id	Age	Mg	Ca	Sr	Cd	Ba	Pb	U
ET 00232	ET00232	4 & 5	2	697	13863	71.5	0.14	763	4.0	0.4
ET 00260	ET00228	2	2	664	12421	82.8	0.87	1002	2.8	1.0
ET 00262	ET00230	2	2, 3	783	13898	106.5	0.27	1574	4.0	0.4
ET 00264	ET00231	4	5, 7	687	15122	114.0	0.18	1700	3.9	0.3
ET 00266	ET00233	5	2,3,4	789	13354	89.7	0.28	1115	5.2	0.4
ET 00268	ET00234	5	1,3	852	15233	100.3	0.31	1156	5.3	0.4
ET 00270	Ref 134			1868	2792	30.1	0.41	67	4.6	0.2

Table D2 Metal results for composite samples sent to CDU

eriss ID	Comp id	Site id	Age	Mg	Ca	Sr	Cd	Ba	Pb	U	Mn
ET00229	ET078, ET080	2	1	451	5400	30.8	0.25	339	1.37	0.376	1450
ET00247	ET235	2	3	549	8500	62.4	0.23	801	1.24	0.533	2310
ET00248	ET236	2	4	577	8770	64.8	0.90	1050	2.57	0.558	2680
ET00249	ET237	3	3	990	13700	95.8	0.66	1310	1.65	0.437	4120
ET00250	ET238	3	4	637	10400	79.1	0.24	971	1.44	0.478	2730
ET00252	ET240	4	3	981	12900	93.2	0.26	1150	1.59	0.294	3590
ET00253	ET241	5	2	413	7070	45.9	0.12	579	1.25	0.121	1830
ET00254	ET242	5	3	377	6240	46.8	0.11	680	1.21	0.137	1590
ET00255	ET243	5	4	894	16600	134.0	0.23	2040	3.43	0.277	4930
ET00256	ET244	5	5	425	7650	55.8	0.11	815	1.33	0.128	2000
ET00257	ET245	5	7	981	19600	157.0	0.26	2270	3.43	0.263	6490
ET00258	ET246	6	3	822	11800	88.8	0.87	1160	3.25	0.283	3460
ET00259	ET228	2	2	1030	14900	102.0	0.51	1130	2.15	1.000	3880
ET00261	ET230	2	3,2	1230	18200	145.0	0.27	2090	4.96	0.378	5820
ET00263	ET231	4,5	4,7	1140	20600	152.0	0.18	2130	4.02	0.319	5630
ET00265	ET233	5	3,2,5	447	6300	42.9	0.14	521	2.37	0.200	1590
ET00267	ET234	5	1,3	1290	18200	115.0	0.33	1190	7.91	0.456	4910
ET00269	Ref 134			2450	2620	29.8	0.43	11.4	2.66	0.230	59
IAEA	Ref 140			9070	12730	750.0	0.54	20.2	2.19	0.730	56
Result				10000	11000	892.0	0.61	10.9	2.30	0.716	59
ET270	Ref 134									0.328	
Result				2980	3050	34.0	0.48	11.2	3.05	0.260	64
NIST	1566a			1180	1960	11.1	4.15	Nc	0.37	0.132	12
Result				1240	1600	11.6	4.68	2.1	0.38	0.131	12
NIST	1515			2710	15260	25.0	0.01	49.0	0.47	0.006	54
Result				2810	12400	26.1	0.02	49.0	0.44	0.007	52

Appendix E *eriss* Environmental Chemistry group's metal analysis for mussels and sediments November 2000 submitted to NTEL (µg/g dry weight)

Table E1 ICPMS metal results for mussels from NTEL

***eriss* id**	**Site**	**Age**	**Mg**	**Ca**	**Cd**	**Ba**	**U**	**Mn**	**Al**	**As**	**Co**	**Cu**	**Cr**	**Fe**	**K**	**Na**	**Ni**	**Rb**	**Re**	**Se**	**Zn**
ET0051	1	2	1118	16889	4.37	834	0.58	5481	22	3.1	1.10	7.8	0	5909	2051	1759	2.6	7.09	0.00	3	335
ET0052	1	3	1318	25157	0.45	1371	0.79	5520	23	3.5	1.46	7.4	0	10143	2235	2766	1.8	6.73	0.00	3	350
ET0053	1	1	1084	15514	0.48	532	0.72	2774	38	2.4	0.87	6.8	0	3881	2576	2353	1.5	8.33	0.00	3	281
	Mean		1173	19187	1.77	912	0.70	4592	28	3.0	1.14	7.3	0	6644	2287	2293	2.0	7.38	0.00	3	322
ET0059	2	2	869	11549	0.25	669	0.69	2223	89	3.3	0.60	7.8	0	7469	1954	1954	0.9	4.95	0.00	2	253
ET0062	2	5	1361	27380	0.40	1912	1.46	7053	46	3.9	1.74	6.4	0	14515	1530	2257	2.2	4.03	0.00	3	331
ET0068	2	3	1140	16875	0.38	984	0.98	3557	25	3.2	0.94	10.4	0	11907	1849	1983	1.2	6.27	0.00	3	211
ET0072	2	3	1048	17085	0.38	1463	0.91	3897	10	3.7	0.88	10.9	0	14382	1674	2036	1.4	4.76	0.00	2	270
ET0077	2	2	709	12907	0.10	529	0.18	2306	10	2.2	0.55	5.1	0	4759	1066	1568	0.7	3.55	0.00	1	131
ET0079	2	1	983	14755	0.40	843	1.19	3255	10	2.2	0.64	7.4	0	11097	1926	1443	1.0	5.03	0.00	2	212
	Mean		1018	16759	0.32	1067	0.90	3715	32	3.1	0.89	8.0	0	10688	1667	1874	1.2	4.77	0.00	2	235
ET0088	3	4	1007	18264	0.25	1196	0.43	3550	10	4.3	0.89	6.5	0	14804	1652	1945	1.1	5.11	0.00	3	281
ET0093	3	4	925	19364	0.73	1611	2.67	3903	57	3.6	1.01	13.7	0	19142	1730	2465	1.6	5.92	0.00	3	318
	Mean		966	18814	0.49	1404	1.55	3727	34	4.0	0.95	10.1	0	16973	1691	2205	1.4	5.52	0.00	3	300
ET0106	4	4	1007	16814	2.31	1139	0.26	4197	10	4.0	0.68	9.7	0	13085	1798	2754	1.2	4.91	0.00	2	289
ET0114	4	5	1281	23233	0.13	1232	0.20	4868	24	3.6	0.60	5.7	0	10502	1641	1437	1.6	4.30	0.00	2	264
ET0121	4	3	1054	15925	4.86	830	0.23	4488	10	2.3	0.65	8.1	0	5077	1767	1917	1.2	4.92	0.00	3	293
	Mean		1114	18657	2.43	1067	0.23	4518	15	3.3	0.64	7.8	0	9555	1735	2036	1.3	4.71	0.00	2	282
ET0212	6	2	1025	16062	0.31	1008	0.46	3034	10	3.3	0.84	10.2	0	9904	1734	3142	2.5	4.11	0.00	2	340
ET0217	6	3	1381	24266	0.69	1507	0.42	4812	10	4.0	1.06	11.1	0	13887	1515	3168	2.2	4.21	0.00	2	382
ET0222	6	2	991	17457	2.78	992	0.35	3765	67	5.2	0.92	17.2	0	12218	1756	3739	3.4	4.25	0.00	3	349
	Mean		1132	19262	1.26	1169	0.41	3870	29	4.2	0.94	12.8	0	12003	1668	3350	2.7	4.19	0.00	2	357

eriss id	Site id	Age	Mg	Ca	Cd	Ba	U	Mn	Al	As	Co	Cu	Cr	Fe	K	Na	Ni	Rb	Re	Se	Zn
ET0159	5	4	737	15957	0.17	1796	0.37	2975	140	3.6	0.91	9.9	0	24920	1487	2202	1.8	3.69	0.00	3	224
ET0160	5	3	989	20823	0.46	1725	0.31	4759	10	2.9	0.86	8.7	0	12082	1969	2725	1.4	5.37	0.00	3	349
ET0192	5	2	1112	21974	0.16	973	0.27	4344	28	2.8	0.74	9.1	0	7460	1642	3730	1.8	4.43	0.00	1	306
ET0195	5	3	1066	25268	0.19	2110	0.33	5195	10	2.2	1.14	7.7	0	23816	1570	2623	1.7	4.64	0.00	3	271
ET0196	5	4	839	15543	0.15	764	0.29	2815	10	3.1	0.74	10.9	0	7537	1589	2791	1.2	4.09	0.00	1	239
	Mean		949	19913	0.23	1473	0.31	4018	40	2.9	0.88	9.3	0	15163	1651	2814	1.6	4.44	0	2	278

Table E2 ICPMS metal results for sediments from NTEL

eriss id	Site id	Al	As	Ba	Ca	Cd	Co	Cu	Cr	Fe	K	Mg	Mn	Na	Ni	Pb	Rb	Re	S	Se	U	Zn
ET 0047	6	4365	<0.5	28.8	575	<0.05	3.92	5.2	16	8372	409	1094	59.9	<50	7.3	5.7	8.4	<0.05	34	0.6	1.86	13.7
ET0048	5	7769	<0.5	53.0	677	<0.05	6.59	9.4	24	14071	707	1839	104.1	<50	11.1	9.5	13.9	<0.05	94	0.8	1.97	20.9
ET0049	3	4047	<0.5	22.7	437	<0.05	4.49	5.2	14	7497	393	912	48.9	<50	6.6	5.8	8.1	<0.05	81	0.5	1.62	11.9
ET0050	2	2591	<0.5	20.3	322	<0.05	3.19	3.3	10	6123	299	747	42.8	<50	4.5	4.3	6.5	<0.05	<20	0.4	1.15	9.1

Appendix F: Recent and historical ICP-MS and radionuclide data for South Alligator River mussels and water

Table F1 A summary of recent and historical ICP-MS data for South Alligator River mussels for November 2000, May 1995, October 1989 and May 1990 collections, (µg/g dry weight)

Site and Year	Mg	Ca	Cd	Ba	Pb	U	Mn	Al	As	Co	Cu	Fe	K	Na	Ni	Rb	Se	Zn
November 2000																		
Site 1	1173	19187	1.77	912	2.09	0.70	4592	28	3.0	1.14	7.3	6644	2287	2293	1.97	7.38	3.0	322
Site 2	1018	16759	0.32	1067	1.67	0.90	3715	32	3.1	0.89	8.0	10688	1667	1874	1.23	4.77	2.2	235
Site 3	966	18814	0.49	1404	2.34	1.55	3727	34	4.0	0.95	10.1	16973	1691	2205	1.35	5.52	3.0	300
Site 4	1114	18657	2.43	1067	2.16	0.23	4518	15	3.3	0.64	7.8	9555	1735	2036	1.33	4.71	2.3	282
Site 5	949	19913	0.23	1473	2.68	0.31	4018	40	2.9	0.88	9.3	15163	1651	2814	1.58	4.44	2.2	278
Site 6	1132	19262	1.26	1169	4.92	0.41	3870	29	4.2	0.94	12.8	12003	1668	3350	2.70	4.19	2.3	357
May 1995																		
North Bank ~50 m D/S RMC confluence (cf. Site 1)			1.63	727	3.13	0.50	5425	244	4.8	1.05	9.9	13828			2.95	5.75	4.1	272
SAR/RMC confluence (cf. Site 1 & 2)			1.72	924	3.09	1.20	5583	168	4.5	1.21	11.0	17015			3.02	5.10	4.0	313
South Bank SAR (cf. Site 4)			0.44	879	1.85	0.38	4837	171	4.4	1.06	11.3	13179			2.61	5.45	4.1	311
October 1989																		
D/S RMC confluence (cf. Site 1 & 2)	1300	16100	1.59		2.49	0.29	3900		3.4	1.05	17.3	8700	2300	3500	1.10	9.49	1.4	429
Camp Creek (cf. Site 6)	2300	25100	4.38		7.27	0.65	4400		4.2	1.29	16.8	13600	1800	4800	1.78	8.88	2.6	515
Coronation Hill Causeway (cf. Site 6)	2100	24700	3.91		6.31	0.83	5100		3.6	1.40	10.9	14100	2100	5900	1.42	6.92	2.0	498
1 km D/S Pul Pul (cf. Site 6)	2100	26800	5.84		7.65	0.76	6700		4.2	1.77	18.1	13900	2200	5400	1.83	10.50	2.2	588
May 1990																		
D/S RMC confluence (cf. Site 1 & 2)	1400	13800	0.91		1.97	0.92	4600		3.5	0.91	17.7	7600	2600	3800	2.06	6.75	2.1	411
Camp Creek (cf. Site 6)	2000	21200	4.18		3.67	0.60	2900		5.2	0.95	9.6	9700	2000	5200	1.27	7.84	2.2	312
Coronation Hill Causeway (cf. Site 6)	1800	17800	3.00		5.52	0.68	3200		5.5	1.02	14.0	14000	2300	4200	1.83	9.30	2.2	344
1 km D/S Pul Pul (cf. Site 6)	1900	17100	3.55		4.55	0.49	4700		5.0	1.03	16.7	13600	2300	5000	2.01	9.93	2.0	375

Table F2 ICPMS data for water collected from Site 7 November 1989 and May 1990 collections, (ug/L)

Nov 2000 site	Na	Mg	Al	K	Ca	Fe	Mn	Cu	Zn	Rb	Ba	Cr	Co	Ni	As	Se	Cd	Pb	U
Nov-89	1700	9800	144	730	640	268	36.5	0.35	0.062	3.7	18	0.41	0.1	0.37	0.49	0	0.034	0.66	0.047
May-90	1600	8300	100	670	500	190	26	0.53	0	2.1	14	0.24	0.07	0.46	0.24	0.099	0.004	0.15	0.076

Table F3 Rockhole Creek sampling sites for radiation survey on 25 October 1989

Site	Description	Distance (m)*
0	Rockhole Creek, 30 m from confluence with South Alligator River.	-20
1	First large pool from road bridge, still and shallow water, little Fe-deposition.	0
2	'The Rockhole', large and deep rock-pool with steep walls, some fish present, discolouration due to Fe-deposits evident.	80
3	Three small pools in monsoon forest patch.	130
4	Wide round pool at narrow part of the River valley, fait H_2S-smell, much Fe-deposition as a very bright orange precipitate.	180
5	Two large pools separated by rock bridge, intermediate depth, murky green water, strong H_2S-smell, very distinct Fe-deposition around wall and run-off between pools, shady area.	210
6	Small pool with shallow water directly below adit no. 1 entrance, receiving mine effluent, clear water.	320
7	Adit no. 1 seepage run-off area, above creek bed, water clear, yellow deposition on ground.	330
8	Close to adit entrance, below 'Hopper', waste rock material.	
9	Upstream of site no. 6, clear of mining disturbance.	400
10	Adit no. 1 entrance.	
11	Adit no. 2.	

* Distance is a best estimate only.

Table F4 Radionuclide activity concentrations in Rockhole Creek and Rockhole Mine adit no. 1 sediments. Results are in (Bq/kg dry weight) ± 1 standard deviation.

Date	Site	^{238}U	^{230}Th	^{226}Ra	^{210}Pb
18 May 90	0	2843±71	891±437	560±15	548±50
25 Oct 89	1	3064±225	339±13	391±11	314±34
	2	8412±609	276±11	2603±33	579±71
	4	4328±301	184±7	267.4±8.3	161±26
	5	1651±112	529±126	57.6±2.1	343±21
	6	6060±405	863±224	134.3±3.8	862±52
	7	376±32	7946±1010	727.3±4.8	1390±50
	10	835±19	21013±2464	150.0±1.0	141±12
	A1	2833±77	36049±4285	375.5±4.3	435±67
	A2	940±57	1292±179	1595±12	1576±28
	B	315±23	59179	386.13.8	446±11
	C	540±32	771±111	401.1±4.7	412±14
15 Aug 89	R	19.4±3.3	–	21.1±0.4	21.3±7.1

Extra sampling sites:

A1 Beside 'Hopper', yellow ferruginous material.
A2 Beside 'Hopper', black rocks from waste rock dump.
B Creek bed upstream adit no. 1, seepage entrance area, yellow material scraped from hard gravel.
C Adit no. 2, black rocks.
R South Alligator River at Rockhole Creek inlet.

Table F5 Radionuclide activity concentrations in Rockhole Creek and Rockhole Mine adit no. 1 waters. Results are in (mBq/L) ± 1 standard deviation.

Date	Site	^{238}U	^{230}Th	^{226}Ra	^{210}Pb
18 May 90	0	177±17	–	30.5±1.3	9.6±3.3
	1	161±16	–	27.4±1.3	10.4±3.3
25 Oct 89	1	24±20	0.81±0.19	71.5±2.6	–
	2	90±21	1.07±0.16	54.1±2.4	–
	5	760±58	0.96±0.16	262.0±4.0	–
	7	8340±561	254±10	1002±11	–
15 Aug 89	R	0.97±0.08	0.21±0.04	1.5±0.1	1.2±0.2

Note: R = South Alligator River at Rockhole Creek confluence.

Appendix G South Alligator River mussel ICPMS stable lead data for November 2000 collection (μg/g dry weight)

Table G1 Stable lead isotope concentrations and ratios

eriss ID	Site	Age	^{204}Pb	^{206}Pb	^{207}Pb	^{208}Pb	$^{208/206}Pb$	$^{207/206}Pb$	$^{206/207}Pb$	$^{208/207}Pb$	$^{206/204}Pb$
ET0053	1	1	0.01	0.25	0.26	0.59	2.36	1.04	0.96	2.27	25.0
ET0051	1	2	0.04	0.67	0.68	1.55	2.31	1.01	0.99	2.28	16.8
ET0052	1	3	0.03	0.48	0.50	1.20	2.50	1.04	0.96	2.40	16.0
ET0079	2	1	0.02	0.25	0.24	0.52	2.08	0.96	1.04	2.17	12.5
ET0059	2	2	0.02	0.35	0.33	0.78	2.23	0.94	1.06	2.36	17.5
ET0077	2	2	0.01	0.14	0.13	0.33	2.36	0.93	1.08	2.54	14.0
ET0068	2	3	0.04	0.45	0.45	1.03	2.29	1.00	1.00	2.29	11.3
ET00072	2	3	0.03	0.48	0.44	1.05	2.19	0.92	1.09	2.39	16.0
ET0062	2	5	0.05	0.68	0.68	1.53	2.25	1.00	1.00	2.25	13.6
ET0088	3	4	0.03	0.40	0.40	0.90	2.25	1.00	1.00	2.25	13.3
ET0093	3	4	0.05	0.70	0.66	1.54	2.20	0.94	1.06	2.33	14.0
ET00121	4	3	0.05	0.87	0.88	2.10	2.41	1.01	0.99	2.39	17.4
ET00106	4	4	0.02	0.32	0.31	0.72	2.25	0.97	1.03	2.32	16.0
ET00114	4	5	0.02	0.27	0.28	0.64	2.37	1.04	0.96	2.29	13.5
ET00192	5	2	0.03	0.42	0.43	0.95	2.26	1.02	0.98	2.21	14.0
ET00195	5	3	0.06	0.94	0.90	2.12	2.26	0.96	1.04	2.36	15.7
ET00160	5	3	0.03	0.68	0.59	1.40	2.06	0.87	1.15	2.37	22.7
ET00196	5	4	0.03	0.38	0.36	0.88	2.32	0.95	1.06	2.44	12.7
ET00159	5	4	0.05	0.76	0.70	1.73	2.28	0.92	1.09	2.47	15.2
ET00212	6	2	0.03	0.42	0.40	0.95	2.26	0.95	1.05	2.38	14.0
ET00222	6	2	0.13	1.98	2.01	4.68	2.36	1.02	0.99	2.33	15.2
ET00217	6	3	0.05	0.94	0.96	2.21	2.35	1.02	0.98	2.30	18.8

Table G2 Stable lead isotope concentrations and ratios sediments

***eriss* id**	**Site id**	**Pb204**	**Pb206**	**Pb207**	**Pb208**	**Pb tot**
ET 0047	Site 6	0.1	1.3	1.2	3.1	5.7
ET0048	Site 5	0.1	2.2	2.1	5.1	9.5
ET0049	Site 3	0.1	1.4	1.3	3.0	5.8
ET0050	Site 2	0.1	1.0	1.0	2.3	4.3

Appendix H ^{226}Ra alpha spectrometry results for individual mussels collected from South Alligator River in November 2000 (Bq/kg dry weight)

Table H1 ^{226}Ra activity concentrations for the South Alligator River

***eriss* ID**	**Site code**	**Age (est.)**	**^{226}Ra**
ET0069	Site 2	0	108 ± 26
ET0058	Site 2	5	338 ± 20
ET00100	Site 3	2	70 ± 17
ET0083	Site 3	2	33 ± 4
ET0087	Site 3	5	477 ± 25
ET0082	Site 3	7	558 ± 35
ET00123	Site 4	1	273 ± 53
ET00125	Site 4	4	289 ± 21
ET00188	Site 5	4	272 ± 16
ET00143	Site 5	10	717 ± 34
ET00219	Site 6	2	166 ± 11
ET00210	Site 6	4	524 ± 29
ET00216	Site 6	5	455 ± 43

Appendix I ^{226}Ra and $^{228}Ra/^{226}Ra$ activity ratios gamma spectrometry results for South Alligator River mussels (Bq/kg dry weight)

Table I1 Total ^{226}Ra activity concentrations, and $^{228}Ra/^{226}Ra$ and $^{226}Ra/^{228}Ra$ activity ratios for site and age groups

eriss ID	Site Code	Age	^{226}Ra	$^{228}Ra/^{226}Ra$	$^{226}Ra/^{228}Ra$
ET 00235	Site 2	3	350 ± 6	1.097 ± 0.044	0.91 ± 0.04
ET 00236	Site 2	4	506 ± 11	0.964 ± 0.052	1.04 ± 0.06
ET 00237	Site 3	3	350 ± 7	1.186 ± 0.056	0.84 ± 0.04
ET 00238	Site 3	4	363 ± 6	1.141 ± 0.044	0.88 ± 0.03
ET 00239	Site 4	2	199 ± 8	1.454 ± 0.111	0.69 ± 0.05
ET 00240	Site 4	3	266 ± 9	1.353 ± 0.095	0.74 ± 0.05
ET 00241	Site 5	2	367 ± 7	0.844 ± 0.047	1.19 ± 0.07
ET 00242	Site 5	3	356 ± 5	0.900 ± 0.034	1.11 ± 0.04
ET 00243	Site 5	4	443 ± 5	0.777 ± 0.024	1.29 ± 0.04
ET 00244	Site 5	5	698 ± 9	0.747 ± 0.028	1.34 ± 0.05
ET 00245	Site 5	7	671 ± 11	0.877 ± 0.039	1.14 ± 0.05
ET 00246	Site 6	3	272 ± 9	1.640 ± 0.095	0.61 ± 0.04

Table I2 ^{226}Ra load per mussel for site and age group

eriss ID	Site Code	Age	^{226}Ra (Bq)
ET 00235	Site 2	3	0.132 ± 0.002
ET 00236	Site 2	4	0.249 ± 0.005
ET 00237	Site 3	3	0.161 ± 0.003
ET 00238	Site 3	4	0.191 ±0 003
ET 00239	Site 4	2	0.070 ± 0.003
ET 00240	Site 4	3	0.110 ± 0.004
ET 00241	Site 5	2	0.139 ± 0.003
ET 00242	Site 5	3	0.147 ± 0.002
ET 00243	Site 5	4	0.222 ± 0.003
ET 00244	Site 5	5	0.351 ± 0.005
ET 00245	Site 5	7	0.462 ± 0.008
ET 00246	Site 6	3	0.126 ± 0.004

Appendix J ^{228}Th, ^{228}Ra and ^{210}Pb activity concentrations (Bq/kg dry weight) and ^{228}Th/^{228}Ra activity ratios gamma spectrometry results for South Alligator River mussels.

Table J1 ^{228}Th activity concentrations for mussels by site and age group (date corrected)

***eriss* ID**	**Site Code**	**Age**	**^{228}Th**
ET 00235	Site 2	3	173 ± 7
ET 00236	Site 2	4	236 ± 12
ET 00237	Site 3	3	174 ± 8
ET 00238	Site 3	4	284 ± 7
ET 00239	Site 4	2	115 ± 9
ET 00240	Site 4	3	153 ± 11
ET 00241	Site 5	2	105 ± 7
ET 00242	Site 5	3	151 ± 6
ET 00243	Site 5	4	152 ± 5
ET 00244	Site 5	5	298 ± 9
ET 00245	Site 5	7	372 ± 13
ET 00246	Site 6	3	182 ± 11

Table J2 ^{228}Ra activity concentrations by site and age groups (date corrected)

***eriss* ID**	**Site Code**	**Age**	**^{228}Ra**
ET 00235	Site 2	3	384 ± 14
ET 00236	Site 2	4	488 ± 24
ET 00237	Site 3	3	416 ± 17
ET 00238	Site 3	4	414 ± 14
ET 00239	Site 4	2	289 ± 19
ET 00240	Site 4	3	360 ± 22
ET 00241	Site 5	2	310 ± 16
ET 00242	Site 5	3	320 ± 11
ET 00243	Site 5	4	344 ± 10
ET 00244	Site 5	5	521 ± 18
ET 00245	Site 5	7	589 ± 24
ET 00246	Site 6	3	446 ± 22

Table J3 ^{210}Pb activity concentrations by site and age groups (date corrected)

eriss ID	Site Code	Age	^{210}Pb
ET 00235	Site 2	3	49 ± 24
ET 00236	Site 2	4	116 ± 43
ET 00237	Site 3	3	44 ± 30
ET 00238	Site 3	4	90 ± 24
ET 00239	Site 4	2	18 ± 34
ET 00241	Site 5	2	41 ± 28
ET 00242	Site 5	3	50 ± 19
ET 00243	Site 5	4	43 ± 15
ET 00244	Site 5	5	59 ± 29
ET 00245	Site 5	7	106 ± 40
ET 00246	Site 6	3	92 ± 37

Table J4 $^{228}Th/^{228}Ra$ activity ratios by site and age group

eriss ID	Site Code	Age	$^{228}Th/^{228}Ra$
ET 00235	Site 2	3	0.45 ± 0.02
ET 00236	Site 2	4	0.48 ± 0.03
ET 00237	Site 3	3	0.42 ± 0.03
ET 00238	Site 3	4	0.69 ± 0.03
ET 00239	Site 4	2	0.40 ± 0.04
ET 00240	Site 4	3	0.42 ± 0.04
ET 00241	Site 5	2	0.34 ± 0.03
ET 00242	Site 5	3	0.47 ± 0.02
ET 00243	Site 5	4	0.44 ± 0.02
ET 00244	Site 5	5	0.57 ± 0.03
ET 00245	Site 5	7	0.63 ± 0.03
ET 00246	Site 6	3	0.41 ± 0.03

Appendix K Gamma spectrometry results for South Alligator River sediments (Bq/kg dry weights)

Table K1 Radionuclide activity concentrations for sediments by site

eriss ID	Site code	^{238}U	^{226}Ra	^{210}Pb	^{228}Ra	^{228}Th	^{40}K
ET04004	Gunlom Rd tails	-	18844 ± 136	18479 ± 139	58 ± 12	28.3 ± 4.8	466 ± 45
ET04003	Site 0	221 ± 20	151 ± 2	103 ± 9	32 ± 3	31 ± 1.4	289 ± 17
ET04001	Site 1	155 ± 17	104 ± 2	82 ± 9	196 ± 4	185 ± 2	156 ± 13
ET0050	Site 2	27 ± 8	39 ± 1	46 ± 10	45 ± 3	43 ± 1	183 ± 14
ET0049	Site 3	64 ± 6	62 ± 1	73 ± 8	104 ± 2	102 ± 1	197 ± 9
ET04002	Site 4	36 ± 14	35 ± 1	34 ± 7	60 ± 3	60 ± 2	136 ± 13
ET0048	Site 5	66 ± 9	79 ± 2	116 ± 11	86 ± 3	81 ± 2	241 ± 15
ET0047	Site 6	70 ± 6	50 ± 1	78 ± 7	74 ± 2	70 ± 1	242 ± 10

RMC- Rockhole Mine Creek

Table K2 Radionuclide activity ratios for sediments by site

eriss ID	Site code	$^{238}U/^{226}Ra$	$^{210}Pb/^{226}Ra$	$^{228}Ra/^{226}Ra$	$^{40}K/^{226}Ra$
ET04004	Gunlom Rd tails	-	0.98 ± 0.01	0.003 ± 0.001	0.025 ± 0.0024
ET04003	Site 0	1.42 ± 06	0.68 ± 0.06	0.23 ± 0.02	1.9 ± 0.12
ET04001	Site 1	1.3 ± 0.08	0.79 ± 0.08	2.0 ± 0.05	1.5 ± 0.13
ET0050	Site 2	0.70 ± 0.20	1.18 ± 0.26	1.17 ± 0.08	4.7 ± 0.4
ET0049	Site 3	1.04 ± 0.10	1.18 ± 0.13	1.68 ± 0.04	3.2 ± 0. 2
ET04002	Site 4	1.33 ± 0.19	0.98 ± 0.21	1.82 ± 0.12	3.86 ± 0.41
ET0048	Site 5	0.83 ± 0.12	1.47 ± 0.15	1.09 ± 0.04	3.0 ± 0.2
ET0047	Site 6	1.39 ± 0.12	1.55 ± 0.15	1.49 ± 0.05	4.8 ± 0.2

RMC- Rockhole Mine Creek