Part 4: Nabarlek

Assessment of ingestion doses to people accessing the Nabarlek site

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Introduction

The main tasks remaining for the radiological risk assessment of the rehabilitated Nabarlek site include the determination of ingestion doses to Aboriginal people who may potentially access or spend time in the vicinity of the site pursuing customary bushtucker harvesting activities. Previous studies in the Alligator Rivers Region have shown that during the operational phase of a mine site, when access to the operational area is restricted, the downstream surface water pathway is the main potential contributor to ingestion doses via ingestion of mussels that bioaccumulate ^{226}Ra (Martin et al 1998).

Until recently the Nabarlek site could be easily accessed, despite not yet having been closed out by the regulatory authority, and the ingestion of terrestrial flora and fauna could potentially be an important component of the total ingestion dose. However, as of 30 June 2008, the mineral lease and associated responsibilities for managemen of the site has been taken over by the Adelaide-based company Uranium Equities Ltd (UEL). UEL is conducting an active exploration drilling program on and off-site, to investigate potential for below ground uranium anomalies. This work may impose access restrictions to the site in the future.

A number of studies have been conducted over the years measuring radionuclide activity concentrations in traditional Aboriginal foods and determining uptake factors for radionuclides, including terrestrial fauna and flora (Martin et al 1998, Martin & Ryan 2004, Ryan et al 2005). However, most of the data were acquired in the vicinity of Ranger mine or Jabiru, as accessibility of Nabarlek during the wet season, which constitutes the main fruiting season for many bushfoods, is poor. However, soil radionuclide activities in the Nabarlek region and activities in sediments of the riparian zones are known (Martin et al 2006, Frostick et al 2008) and concentration factors determined from other studies in Northern Australia can be used to model ingestion doses. These concentration factors are reported in Section 2.2.4: *Radiation exposure pathways associated with ecosystem establishment*.

Methods

Diet assessment

The model diet presented here has been modified from a study by Altman (1984) who investigated the dietary habits and the protein and calory intake of inhabitants of the Momega outstation in Central Arnhem Land, approximately 85 km east of the Nabarlek area. It assumes that 80 per cent of the protein intake in the diet is from traditional bush foods. According to Altman (2003) the estimates are still in general agreement with more recent estimates of the daily game intake for people living on outstations in Arnhem Land.

ICRP Publication 23 states that the per caput estimate of food supplies for Reference Man from Oceania (Table 122, page 349) is 677 kg/yr. If the shop bought food contributed 20% to the total food intake as suggested by Altman (1984, 2003), this would give an annual bushfood intake of approximately 538 kg/yr. The estimated annual intake of bushfood of local

Aboriginal people was collated in tabular form and provided to Aboriginal people living near Maningrida, Central Arnhem Land, for comment and correction (Table 1). For a 10 year old child the intake has been halved.

The model diet reported here is somewhat different to the diet reported for Aboriginal people in the Northern Kakadu region (Ryan et al 2008) as shop bought food is more difficult to access for people living in Arnhem Land (although most of the traditionally consumed vegetables are now replaced by shop bought items (Altman 1984)). The annual intake of wallaby (*Macropus agilis*) and pig (*Sus scrofa*) is higher than in the Northern Kakadu area, as is the annual intake of fish. The intake of feral water buffalo (*Bubalus bubalis*) and cattle (*Bos taurus*, *Bos indicus*) is large(r) as well, as they are prevalent throughout Arnhem Land.

Table 1 Estimate of the annual intake of bushfood of local Aboriginal people in Arnhem Land

Food item	Kg/y per person
Buffalo	200
Pig	120
Wallaby	70
Fish	70
Magpie goose + waterfowl	30
Turtle	10
Goanna	0
File snake	3
Crocodile	1
Shrimp	2
Mussels	2
Yam	20
Fruit	8
Water lily	2
Total food kg/yr	538

Typically smaller family groups spread throughout Arnhem Land by late August, when surface fresh water supplies disappear. However, the groups have a relatively small range in the early wet season and are virtually sedentary during the wet (Kohen 1995, Altman 1984). Consequently, we have assumed 1 month access to Nabarlek during the dry season only, taken into account seasonal hunting times.

Dose estimate

To assess the terrestrial pathway it was assumed that animals such as buffalo with a relatively large range spend 90% of the time grazing on environmental areas other than the Nabarlek mine site. Wallaby, with a much smaller range, were assumed to spend most of their time on-site, whereas pigs were assumed to spend about half of the year along the riparian zones along Cooper Creek in the greater Nabarlek area.

Table 2 in 'Bioaccumulation of radionuclides in terrestrial plants on rehabilitated landforms shows the concentration factors used in our assessment, and their origin' (this volume, 152–159).

^{226}Ra and ^{232}Th soil activity concentrations of 63 Bq·kg^{-1} and 20 Bq·kg^{-1}, respectively, determined from groundtruthing an airborne gamma survey (AGS) upstream of the Nabarlek site were used to provide a local background (environmental baseline) value. Area weighted soil activity concentrations within the fenced area (on-site) are 454 Bq·kg^{-1} and 41 Bq·kg^{-1}, respectively (Martin 2000). In addition, soil activity concentrations measured in sediment cores taken from overflow areas along Cooper Creek and the estimated contribution from the Nabarlek mine site (1 Bq·kg^{-1} for U and 2 Bq·kg^{-1} for ^{226}Ra) (Frostick et al 2008) were used as environmental and mine influenced soil activity concentrations, respectively, for pigs (and also for water lily), in conjunction with the respective concentration factors.

Radioactive equilibrium of all progeny in the soils was assumed, unless measurements of progeny were available, and average flesh radionuclide activity concentrations have been calculated from known concentration factors.

Buffalo/Cow: concentration factors (CFs) for feral buffalo from the Magela floodplain (Martin et al 1995, 1998) were used as an analogue for cattle, in combination with environmental and on-site soil activity concentrations.

Pig: CFs are from Martin et al (1998, 1995) from the Magela floodplain.

Wallaby: CFs have been determined from measurements of flesh activity concentrations in wallaby from around Ranger mine and Maningrida in western Arnhem Land (Ryan 2002, unpublished) and were used in the dose calculations, in combination with environmental and on-site soil activity concentrations.

Fish: CFs are form Martin et al (1995, 1998) and flesh activity concentrations have been estimated using the measured ^{226}Ra activity concentration in water in Cooper Creek.

Magpie goose + waterfowl: Magpie Geese flesh activity concentrations from animals collected at Red Lily Billabong in the South Alligator disctrict and from Maningrida in Western Arnhem Land (Ryan 2002, unpublished) were used in the dose calculations.

Turtle: CFs for turtle have been determined for animals collected at Bowerbird Billabong (Martin et al 1998). These have been used in conjunction with ^{226}Ra activity concentration in water in Cooper Creek.

File Snake/Crocodile: CFs for file snake and crocodile flesh are from Martin et al (1998).

Shrimp: Freshwater shrimp activity concentrations were calculated from CFs in Martin et al (1998) and Cooper Creek water activity concentrations.

Mussels: Actual mussel flesh activity concentrations from mussels collected from the Goomadeer River in western Arnhem Land were used, rather than using concentration factors determined previously, as concentration factors depend on the location where mussels are sampled. It was furthermore assumed that for 1 month mussels were collected in Cooper Creek (activity concentration data for mussels are available from the 1980s), whereas the remaining 11 months mussels are collected from Goomadeer River, approximately 35 km east of Nabarlek.

Yams: CFs were used from Ryan et al (2005). In addition, it was assumed that a person spending 1 month at Nabarlek collects all yams consumed from the mine site.

Fruit: CFs were used from Ryan et al (2005). In addition, it was assumed that a person spending 1 month at Nabarlek collects all fruit from the mine site.

Flesh and plant activity concentrations were calculated using the input parameters described above. Using the model diet from Table 1, radionuclide activities (Bq) ingested per year per

adult not accessing the Nabarlek site were estimated (Table 2). Radionuclide activities (Bq) ingested per year per adult accessing the site for one month are compiled in Table 3. It was assumed that children would consume about half the amounts eaten by an adult. The results for chilren are not shown here.

Using ingestion dose coefficients given in ICRP72 (1996) and the estimated annual consumption, total annual doses received via the ingestion of various bush foods for adults (and children) have been calculated and are shown in Figure 1.

Table 2 Ingested activities (Bq/y) from various bush foods and total annual ingestion dose in mSv for a person from Western Arnhem Land not accesing the Nabarlek site, using the model diet above

	^{226}Ra	^{210}Pb	^{210}Po	^{238}U	^{234}U	^{230}Th	^{228}Ra	Dose
Buffalo	1.5	2.0	61.8	0.4	0.5	0.2	0.5	0.08
Mussels	126.2	13.7	181.9	18.4	18.4	18.4	77.3	0.32
Pig	0.7	0.4	82.2	0.2	0.1	0.2	0.2	0.10
Magpie Goose	0.5	0.4	10.2	0.2	0.1	0.1	0.2	0.01
Fish	21.0	3.9	30.7	2.4	3.3	0.4	8.4	0.06
Wallaby	0.2	0.2	51.4	0.1	0.1	0.1	0.1	0.06
Yams	44.9	9.1	9.2	1.4	1.4	4.0	14.3	0.04
Turtle	1.3	1.8	46.3	0.2	0.2	0.1	0.5	0.07
Fruit	0.8	0.7	0.7	0.2	0.2	0.2	0.7	0.00
Filesnake	2.8	1.3	1.8	0.3	0.3	0.8	0.9	0.00
Crocodile	0.1	0.0	0.7	0.0	0.0	0.1	0.0	0.00
F/W shrimp	0.5	0.1	7.2	0.0	0.0	0.0	0.2	0.01
Water	1.3	0.2	7.2	0.4	0.6	0.5	0.3	0.01

Table 3 Ingested activities (Bq/y) from various bush foods and total annual ingestion dose in mSv/y for a person from Western Arnhem Land accessing the Nabarlek site for 1 month, using the model diet above

	^{226}Ra	^{210}Pb	^{210}Po	^{238}U	^{234}U	^{230}Th	^{228}Ra	Dose
Buffalo	1.6	2.1	65.0	0.4	0.5	0.2	0.5	0.08
Mussels	150.4	14.9	181.9	18.4	18.4	18.4	92.0	0.34
Pig	0.7	0.4	82.4	0.2	0.1	0.2	0.2	0.10
Magpie goose	0.5	0.4	10.2	0.2	0.1	0.1	0.2	0.01
Fish	26.2	4.9	38.2	3.1	4.1	0.6	10.5	0.07
Wallaby	0.3	0.3	77.9	0.2	0.2	0.2	0.1	0.09
Yams	68.2	13.8	13.9	2.1	2.1	6.0	21.6	0.06
Turtle	1.6	2.2	57.7	0.2	0.3	0.1	0.6	0.08
Fruit	0.8	0.7	0.7	0.2	0.2	0.2	0.7	0.00
Filesnake	4.3	2.0	2.7	0.4	0.4	1.2	1.4	0.01
Crocodile	0.1	0.0	0.9	0.0	0.0	0.1	0.1	0.00
F/W shrimp	0.6	0.1	9.0	0.0	0.0	0.0	0.2	0.01
Water	1.6	0.3	9.0	0.6	0.7	0.6	0.4	0.01

It can be seen from Tables 2 and 3 and Figure 1 that in terms of terrestrial food items, wallaby and yams are the biggest contributors to above environmental background ingestion doses. This is a worst case scenario, as it was assumed that during one months access only yams growing on-site were eaten, and that wallaby that are hunted in that month spent most of the year grazing on the actual fenced Nabarlek area. Mussels also contribute to above background doses however the mussel data set for the Nabarlek area is small, and actual doses are poorly described by the data set. Doses from the ingestion of fish are also above background, however, more surface water data are needed to perform a robust upstream-downstream comparison for aquatic food items as only little information on water radionuclide activity concentrations in Cooper Creek is available.

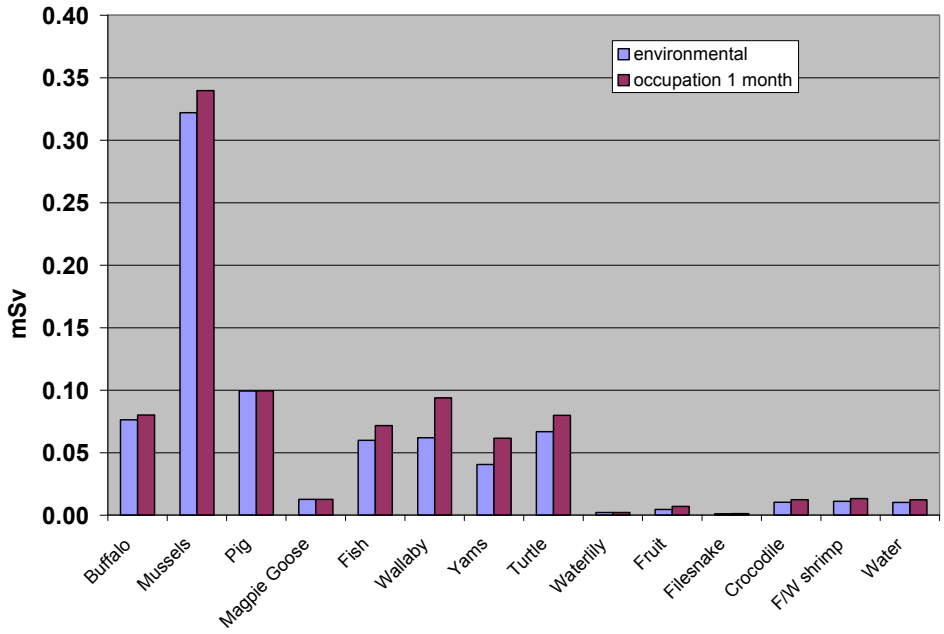

Figure 1 Typical background (environmental) annual doses from the consumption of various bush foods in Arnhem Land compared with doses received when harvesting bushtucker for one month from within the currrent fenced area at Nabarlek

In total the above background ingestion doses for one month's occupancy of the site would amount to approximately 0.1 mSv per annum.

Outstanding tasks

A robust upstream-downstream surface water dataset is needed to enable a true upstream downstream comparison for aquatic food items. Preliminary data, based on dry season sampling, indicate that downstream activity concentrations for radium are higher in Cooper Creek than upstream. However, more samples need to be collected from Cooper Creek, in collaboration with UEL, over the coming wet season to determine the median difference between upstream and downstream activity concentrations. In addition, mussels will be collected opportunistically to extend our data set and improve the accuracy of the contribution of this food item to the dose assessment.

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References

Altman JC 1984. The dietary utilisation of flora and fauna by contemporary hunter-gatherers at Momega Outstation, north-central Arnhem Land. *Australia Aboriginal Studies* 1984(1), 35–46.

Altman J 2003. People on country, healthy landscapes and sustainable Indigenous economic futures: The Arnhem Land case. *The Drawing Board: An Australian Review of Public Affairs* 4(2), 65–82.

Frostick A, Bollhöfer A, Parry D, Munksgaard N & Evans K 2008. Radioactive and radiogenic isotopes in sediments from Cooper Creek, Western Arnhem Land. *Journal of Environmental Radioactivity* 99, 468–482.

ICRP 1975. *Reference man: Anatomical, physiological and metabolic characteristics*. International Commission on Radiological Protection Publication 23, Pergamon Press, Oxford.

ICRP 1996. *Age-dependent doses to the members of the public from intake of radionuclides. Part 5: Compilation of ingestion and inhalation coefficients*. International Commission on Radiological Protection Publication 72, Pergamon Press, Oxford.

Kohen JL 1995. *Aboriginal environmental impacts*. UNSW Press, University of New South Wales, Sydney.

Martin P 2000. Radiological impact assessment of uranium mining and milling. PhD thesis. Queensland University of Technology, Brisbane.

Martin P, Hancock GJ, Johnston A & Murray AS 1995. *Bioaccumulation of radionuclides in traditional Aboriginal foods from the Magela and Cooper Creek systems.* Research report 11, Supervising Scientist for the Alligator Rivers Region, AGPS, Canberra.

Martin P, Hancock GJ, Johnston A & Murray AS 1998. Natural-series radionuclides in traditional north Australian Aboriginal foods. *Journal of Environmental Radioactivity* 40, 37–58.

Martin P & Ryan B 2004. Natural-series radionuclides in traditional Aboriginal foods in tropical northern Australia: A review. *TheScientificWorldJOURNAL* 4, 77–95.

Martin P, Tims S, McGill A, Ryan B & Pfitzner K 2006. Use of airborne γ-ray spectrometry for environmental assessment of the rehabilitated Nabarlek uranium mine, northern Australia. *Environmental Monitoring and Assessment* 115, 531–553.

Ryan B, Martin P & Iles M 2005. Uranium-series radionuclides in native fruits and vegetables of northern Australia. *Journal of Radioanalytical and Nuclear Chemistry* 264(2), 407–412.

Ryan B, Medley P & Bollhöfer A 2008. Bioaccumulation of radionuclides in terrestrial plants on rehabilitated landforms. In ***eriss*** *research summary 2006–2007*. eds Jones DR, Humphrey C, van Dam R & Webb A, Supervising Scientist Report 196, Supervising Scientist, Darwin, NT, 99–103.