A Review of Australia's Uranium Mining and the *Proposed* Jabiluka Uranium Mine :

A Scientific Case for Placing Kakadu as

WORLD HERITAGE IN DANGER

A Technical Submission by the Anti-Uranium Collective
of Friends of the Earth (Fitzroy)
to the World Heritage Committee
May 1999

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Cover Photos - Top Left is the Moline uranium mill tailings in 1986, South Alligator; Top Right is the Magela Floodplain, Kakadu; Middle Left is the Arnhem Land escarpment near the Jabiluka lease; Bottom Left is the Jabiluka construction site in March 1999 (Source - Environment Australia - Kakadu Report 1999; see http://www.environment.gov.au/).

Note - The cover of this report has been altered slightly since release to decrease the PDF file size, and make 2 minor edits (in format only).

It is mined from deep mines, for it is material that nature hides from us, teaching us to leave it as harmful, but this does not cause the arrogant miners to leave it.

Birringucio, 1540[1]

When ores are washed, the water which has been used poisons the brooks and streams. Therefore the inhabitants of these regions, on account of the devastation of their fields, woods, groves, brooks and rivers find great difficulty in producing the necessities of life.

Georgius Agricola, 1556

"their opposition shall not be allowed to prevail"

Ranger Uranium (Fox) Inquiry, 1977

"Some of the worst fears of Aboriginal people of the 1970's have come to pass. … [living conditions of] some of the Aboriginal communities are acceptable, but others are as of the Third World."

Kakadu Region Social Impact Study, 1997

[1] - Birringucio was referring to arsenic mining in the Erz Mountains (between Saxony and Bohemia) where uranium was first discovered in 1789 and mined from the late 19[TH] century. Agricola noted in the 16[TH] century the high rate of lung cancer among miners in this region (Cothern, 1987).

Contents

Figures

Tables

Foreword

This document is a submission to the World Heritage Bureau concerning the Proposed Jabiluka uranium mine. The report has been prepared by members of the Anti-Uranium Collective on a voluntary basis for Friends of the Earth (Fitzroy) (FoEF). Much of the research has been prepared by university qualified scientists (for further detail, contact FoEF). As Australian citizens we are deeply concerned about the past, present and potential future impacts from uranium mining in the Kakadu National Park region and its effects on indigenous people. We consider we are stakeholders in the activities in our national parks and the treatment of our indigenous people.

The information contained in this document was derived from a variety of sources and contains a considerable portion of the available literature on the subject. It is intended to build on previous submissions made to the World Heritage Bureau during 1998, presenting new information, research and analyses undertaken since December 1998.

Several documents were requested to allow this submission to be thorough, however, many of these were withheld or no correspondence was received. Given the seriousness of the Australian Environment Minister's claims of bias and errors in science arising from the late 1998 UNESCO mission and meeting, we request the World Heritage Bureau to consider why such information - which would allow the efficacy of such statements to be ascertained - was withheld from the public of Australia.

The indigenous peoples of Australia have long recognised regions containing uranium deposits as "Sickness Country", whether this be in Kakadu, Western Australia or South Australia. Ancient warnings were presented by Georgius Agricola in the late 16th century concerning the environmental impacts of mining uraniferous and other ores (Cothern, 1987).

If we are to allow further uranium mining in the World Heritage Kakadu National Park it would prove conclusively that we are yet to comprehend these warnings and truly protect World Heritage for future generations.

Purpose and Objectives of this Report

- To present a review of past impacts from uranium mining in the Northern Territory (NT) and relevant aspects from former Australian uranium mines;
- To review the environmental performance of current uranium mines in the NT, covering hydrogeological and biological issues;
- To draw comparisons between the environmental impacts from past and current uranium mines;
- To establish a scientific case of how these impacts threaten the World Heritage values of Kakadu National Park

World Heritage Criteria

The Kakadu National Park is one of only a select number of areas worldwide that has World Heritage listing for both natural and cultural values. Past and present uranium mining in the Kakadu region has impacted and consistently threatens these values. If further uranium mining and exploration is allowed to continue within the Kakadu region, then the cumulative impacts and threats can only worsen.

The summary by URG (1998) of impacts and threats to the World Heritage values of Kakadu is repeated below :

Criterion (ii) *Outstanding examples representing significant ongoing (a) geological processes, (b) biological evolution and (c) man's interaction with his natural environment.*

The processes involved with mining, including land clearing, blasting, extraction of rock and altered hydrological regimes, alter natural geological processes by increasing erosion and deposition, changing subsurface structural formations, altering hydrogeological flow regimes and pre-mining geochemical conditions.

Biological evolutionary processes are sensitive to the impacts of mining and milling of uranium. Pollution of habitats by mining effluent can cause local extinction of sensitive species. This alters community structure and upsets natural patterns of evolutionary development. Increased ionising radiation is known to affect genetic integrity. Ecotoxicological studies in ecosystems surrounding and downstream of Ranger Uranium mine have detected mutations in fauna (OSS / ERISS monitoring). Alterations to genetic and biological diversity disrupts evolutionary processes. Mining related infrastructure isolates biotic populations by creating physical barriers, thereby reducing the opportunity for populations to maintain genetic diversity.

Human interaction with the floodplain environment is illustrated by the dependence of aboriginal people on this ecosystem for food, water and shelter. Degradation of this environment from mining and milling of uranium will have profound negative impacts on the health, diet and culture of local indigenous people.

Criterion (iii) *Unique rare or superlative natural phenomena, formations or features or areas of exceptional beauty.*

In terms of its natural beauty, Kakadu National Park especially when viewed from the air is one of the most spectacular and unique landscapes. Mining operations and related transport infrastructure create an ugly scar on this otherwise uninterrupted expanse of natural beauty befitting a World Heritage national park. The extent and visibility of this unacceptable blight is significant.

Criterion (iv) *The most important and significant habitats where species of plants and animals of outstanding universal value from the point of view of science and conservation still survive.*

Jabiru, Ranger Uranium Mine and the extent of construction of the Jabiluka Uranium Mine have resulted in the destruction of 1,370 hectares of virtually pristine habitat to date. This will be increased considerably if the proposed Jabiluka and Koongarra Uranium Mines proceed. Fragmentation of Kakadu National Park degrades its biological integrity and substantially reduces and degrades significant habitats for plants and animals. There are very few places in the world where landscape level processes still operate. The magpie goose, an icon species of the Kakadu wetlands, requires a mosaic of habitats across the riverine landscape to maintain its population size and genetic diversity (Whitehead *et al.,* 1990). Dispersal of pollution from uranium mines in the Alligator Rivers Region will, over time, by agents of wind, water and biota, extend into all habitats. This can only be detrimental to the integrity of the internationally important wetlands as well as the 117 migratory species listed under international conservation agreements, and the 14 fauna and 58 flora species of particular conservation significance (Press *et al*.,1995).

The habitat values and evolutionary properties within a variety of ecosystems has already been compromised by mining activities. Further expansion can only enhance the detrimental impacts and lead to even greater risks in the future for Kakadu's World Heritage.

Acronyms

AAEC	Australian Atomic Energy Commission (now ANSTO)
AIA	Airstrip Irrigation Area (Nabarlek mine)
AMD	Acid Mine Drainage
AMIC	Australian Mining Industry Council (now MCA)
ANSTO	Australian Nuclear Science and Technology Organisation
ARR	Alligator Rivers Region
AusIMM	Australasian Institute of Mining and Metallurgy
BPT	Best Practical Technology
CEC	Cation Exchange Capacity (meq / 100 g)
CRA	Conzinc Riotinto of Australia Ltd (now Rio Tinto)
EA	Environment Australia (Commonwealth Department)
EIS	Environmental Impact Statement
EP2	Evaporation Pond 2 (Nabarlek mine, also EP1)
EPR	Environmental Performance Review
ERA	Energy Resources of Australia Ltd
ERISS	Environmental Research Institute of the Supervising Scientist
FIA	Forest Irrigation Area (Nabarlek mine)
FoE	Friends of the Earth
IAEA	International Atomic Energy Agency
JMA	Jabiluka Mill Alternative
MCA	Minerals Council of Australia (now MCA)
OECD	Organization for Economic Cooperation and Development
OSS	Office of the Supervising Scientist (now SSG)
NT	Northern Territory
NT-DME	Northern Territory Department of Mines and Energy
PER	Public Environment Report
QML	Queensland Mines Ltd
RMA	Ranger Mill Alternative
RP2	Retention Pond 2 (Ranger mine, also RP1, RP3 and RP4)
RRZ	Restricted Release Zone
SEA-US	Sustainable Energy and Anti-Uranium Service Inc
SSCUMM	Senate Select Committee on Uranium Mining and Milling
SSG	Supervising Scientist Group
TCZ	Total Containment Zone
TDS	Total Dissolved Solids (ie - salinity)
UIC	Uranium Information Centre Ltd
UNESCO	United Nations Educational Scientific and Cultural Organisation
URG	Uranium Research Group
US-NRC	United States Nuclear Regulatory Commission
UU	United Uranium
WISE	Worldwide Information Service on Energy
WISE-UP	Worldwide Information Service on Energy - Uranium Project
WHC	World Heritage Committee

Measurements, Units and Miscellaneous

Radioactivity	Curie (Ci)
Becquerels (Bq)	Sieverts (Sv)
Distance and Area	Kilometres (km) (= 1,000 m)
Metres (m)	Square Metres (m^2)
Weight, Mass and Volume	Tonnes (t)
Kilograms (kg)	Grams (g)
Litres (L)	Cubic Metres (m^3)
Concentration	Milligrams per litre (mg/L)
Micrograms per litre (µg/L)	Milliequivalents (meq)
Prefixes	pico (p) 10^{-12}
micro (µ) 10^{-6}	milli (m) 10^{-3}
kilo (k) 10^{3}	mega (M) 10^{6}
giga (G) 10^{9}	tera (T) 10^{12}
Common Solutes	Sulphate - SO_4
Ammonium - NH_4	Nitrate - NO_3
Bicarbonate - HCO_3	Silica - SiO_2
Metal Symbols	Calcium - Ca
Copper - Cu	Uranium - U
Cadmium - Cd	Zinc - Zn
Manganese - Mn	Iron - Fe
Magnesium - Mg	Sodium - Na
Potassium - K	Lead - Pb

Acknowledgements

The research included in this submission is the result of the cumulative efforts of many active members of the Anti-Uranium Collective of Friends of the Earth (Fitzroy) (FoEF), from Melbourne, Australia. It is the result of years of methodical and continuing research. Further assistance has been given by the Australian Conservation Foundation, especially staff from the Melbourne office, members of the Uranium Research Group, Friends of the Earth (Sydney) (FoES) and Friends of the Earth Australia (FoEA).

Disclaimer

This report has been prepared in good faith. Every effort has been made to be thorough and extensive on the issues addressed and quote technical material accurately and fairly. However, Friends of the Earth (Fitzroy) will not be liable for any use, interpretation or action arising out of the use of this report.

It is trusted that this report will make a valuable contribution to the debate concerning World Heritage protection from mining, and particularly the proposed Jabiluka project within the confines of the Kakadu National Park ecosystems.

Contacting the Anti-Uranium Collective, FoEF

Comments can be sought on this report through the Anti-Uranium Collective of Friends of the Earth (Fitzroy).

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1.0 Former Uranium Mining in Australia

Australia has had an active involvement in uranium mining, beginning in the dark times of World War II. At the special request of the British government, the Australian government began a wide-ranging search for uranium deposits in 1944 to supply uranium for nuclear weapons research and development programs of the time. All uranium was the direct ownership of the Commonwealth government.

Initially the focus was centred on Australia's only known uranium deposits at Mt Painter and Radium Hill, both in South Australia (David, 1950). Only the Radium Hill deposit was found to be economic by the late 1940's, and exploration work at Mt Painter ceased in 1949. The South Australian government began development of an underground mine at Radium Hill began in the early 1950's, with the ore processed at nearby Port Pirie from 1956 to February 1962 (a lead-zinc smelting town north of Adelaide). The uranium from Radium Hill was used to build the nuclear weapons later tested at Maralinga, SA (SEA-US, 1999).

In 1949, a local prospector and farmer by the name of John Michael ("Jack") White recognised uranium on his leases at Rum Jungle, about 65 km south of Darwin in the Northern Territory. Exploration in the area revealed extensive uranium mineralisation and a mine and processing mill was developed by the Commonwealth government, with CRA (now Rio Tinto) managing the project.

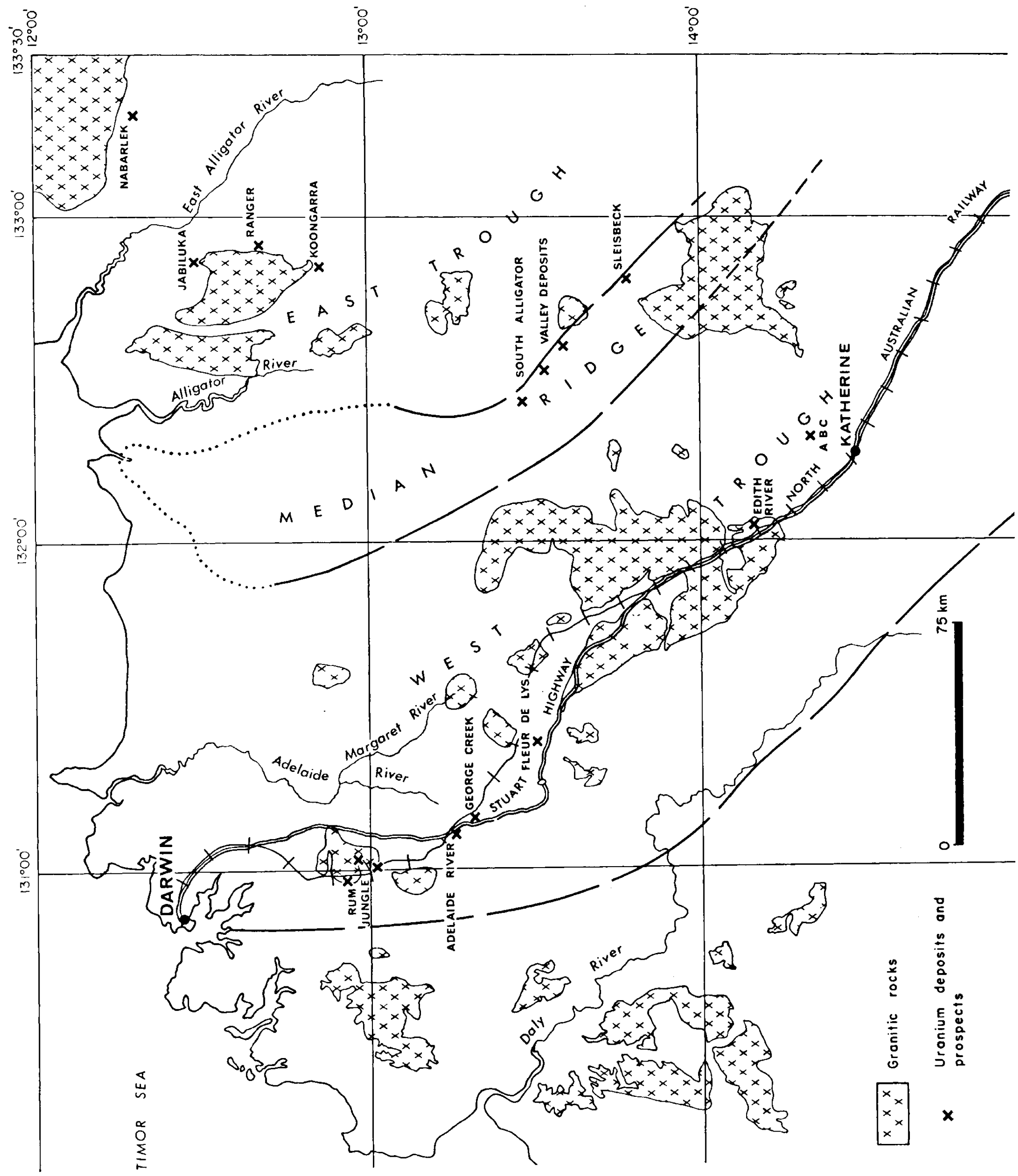
In the early 1950's, the Commonwealth relaxed the legislation concerning uranium mining and offered rewards for new discoveries of uranium deposits. This dramatically increased exploration and a new "gold rush" began across Australia with prospectors searching for radioactive rocks. Within a year major new discoveries were made in north-western Queensland (the Mary Kathleen, Skal, Valhalla, Westmoreland and Anderson's Lode uranium deposits and at Pandanus Creek and Cobar 2 nearby on the Northern Territory side of the border) and along the South Alligator Valley, near the Arnhem Land Aboriginal reserve. Several small uranium deposits were also found around the Darwin Katherine region.

Numerous companies were floated on the Stock Exchange virtually overnight to explore and mine uranium and their share price rose and fell dramatically in response to radioactive finds, sometimes even if they were only thorium.

There was a great deal of importance placed on the production of uranium for the British and American nuclear weapons programs and any concern for the environment and indigenous peoples were given a low priority.

The impacts at these former sites has ranged widely, while at some it reaches extreme (especially Rum Jungle and South Alligator). A brief review of these sites is pertinent to current and proposed uranium mining in the Kakadu region.

Figure 1 - Location of Uranium Mines and Deposits, NT
(Dodson & Prichard, 1975)



1.1 The Rum Jungle Project

A detailed account of the former Rum Jungle uranium-copper mine is given by the SEA-US[1] Rum Jungle background paper (SEA-US, 1999). This summary is based largely on the SEA-US research.

The first signs of mineralisation at Rum Jungle were noticed by Goyder in 1869, in his surveying mission for the South Australian government. He did not recognise the mineral as copper and the find remained an historical obscurity. The area was worked for copper prior to 1907, but proved uneconomic. With the recognition of uranium mineralisation in 1949 by local Jack White, the area was quickly transformed into a major mineral exploration and mining project, reflecting the urgent priority of the day given to uranium. The Commonwealth government assumed ownership of the project (through the newly formed Australian Atomic Energy Commission or AAEC, now ANSTO), and contracted out certain aspects to particular companies.

The exploration of the Rum Jungle site was undertaken by the Bureau of Mineral Resources and mining began in 1952 by a specially formed subsidiary of CRA (now Rio Tinto). A processing mill was built and began operation in 1954. There were also copper and lead-zinc-silver deposits in the Rum Jungle region, some of which were mined and either processed at the Rum Jungle mill or elsewhere. A blind[2] uranium orebody was found in 1960 to the south of the Rum Jungle field and was mined from 1961 to early 1963. A compilation of extracted ore is presented in Table 1.

Table 1 - Uranium and Copper Production at Rum Jungle (SEA-US, 1999)

Mine Site	Ore	U_3O_8		Copper	
	(t)	(%)	(t)	(%)	(t)
White's [3]	270,000	0.33	891	3.4	9,180
	40,000	0.28	112	-	-
Dysons	154,000	0.34	524	-	-
Intermediate	360,000	-	-	0.33	10,000
Rum Jungle Creek South	653,000	0.41	2,677	-	-
Mt Burton	6,000	0.21	12.6	1.04	62.4
	1,400	-	-	2.66	37

The Rum Jungle site was clearly operated without any concern for the environment and was simply abandoned in 1971 upon the exhaustion of stockpiles and the cessation of mineral processing.

No attempt was made at rehabilitation of the site at this time. The Rum Jungle Creek South open cut was left to flood and was left open for unrestricted recreational use, despite exposed waste rock dumps. The lake became quite popular due to it being the only crocodile-free water body in the Darwin region.

1 - SEA-US - Sustainable Energy and Anti-Uranium Service Inc. is a non-profit, community organisation.
2 - "Blind" means that no radiometric expression of the uranium was observable at the surface.
3 - About 279,000 tonnes of copper-cobalt ore were mined and treated, grading 2.8% Cu, producing a further 7,812 tonnes of Cu. About 76,000 tonnes of lead ore at 5.4% Pb was also mined, but not treated.

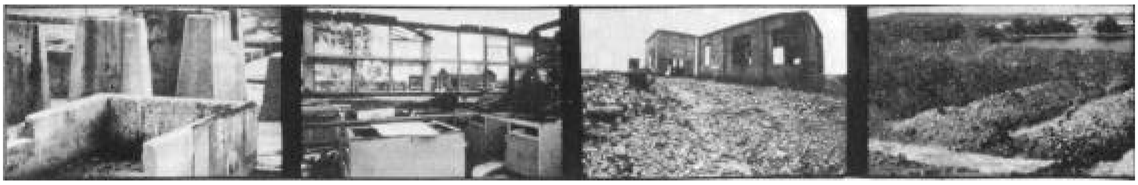
The waste rock at Rum Jungle contained up to 3% pyrite, and with the monsoonal climate and lack of engineering of waste rock dumps, conditions were perfect for the generation of Acid Mine Drainage (AMD) (Richards *et al.*, 1996).

During the early 1970's, public awareness of the extreme pollution caused by mining and milling at Rum Jungle increased as the debate over Kakadu, Ranger, nuclear power and uranium mining became a major national issue.

Important environmental facts (Lichacz & Myers, 1977; Moody, 1992; Richards et al., 1996; SEA-US, 1999) :

- From 1954, there was uncontrolled discharge of tailings and acidic liquid effluents into the adjacent Old Tailings Creek, and thence to the East Finniss River system;
- **An average of 1,000,000 million litres of liquid effluents were discharged each day to Old Tailings Creek, with a pH of 1.5**;
- Tailings solids settled on the floodplains, but proved to be highly erodible;
- Attempts were made to contain tailings, but efforts were largely ineffective - a total of 3,000 tonnes of tailings per year was estimated to have eroded from the tailings sites until rehabilitation in the mid 1980's;
- In November 1960 an officer of the Northern Territory Administration reported that ***'trees along the banks of one stream are dying and water holes [are] devoid of fish'***. Similar reports of the Finniss River being biologically dead were made in March 1962 and January 1963;
- Infrastructure was re-designed in the early 1960's and new dams were built for tailings containment whereby controlled release during the Wet Season was introduced. This was thought to dilute the pollution - recent calculations have shown it could never have worked;
- The annual release of pollutants from the weathering of tailings was approximately 4.7 tonnes copper, 3.5 tonnes of manganese and 320 tonnes of sulphate, although during the 1973-74 Wet Season between 95-142 tonnes of copper, 70-80 tonnes of manganese and 30-56 tonnes of zinc were estimated to have been released;
- The estimate for **radium release was 450 Ci or 16.7 TBq** (ie - *about 450 g of pure radium*) - **at least one quarter of which is known to have directly entered the Finniss River system** (Lichacz & Myers, 1977) **- *a radioactive "anomaly" could be tracked for tens of kilometres*** (Lowson *et al.*, 1998);
- The East Branch of the Finniss River was devoid of life for nearly 10 km downstream of the mine site - there was a complete absence of fish populations in the East Finniss and periodic fish kills were often associated with early storms during the Dry Season;
- The pollution extended over a 100 km^2 region of the Finniss River floodplain, with levels of copper and manganese in particular that were close to the borderline of stock injury (Kraatz, 1992);
- The old Rum Jungle Creek South open cut, left as a popular recreational lake for locals (it was the only crocodile free water hole in the Darwin region), gave **public radiological exposures of about 5 mSv** (Kvasnicka, 1986) - the average modern exposure for uranium workers. This area previously had no radioactivity.

Figure 2 - Views of the Abandoned Rum Jungle Site (Dalton, 1983)



The environmental impacts were thus caused by erosion of the tailings and acidic liquors carrying dissolved heavy metals and radionuclides leaching out from the surface and base of the waste rock dumps and entering the Finniss River system, including radiation releases to the environment (which otherwise did not contain such radioactivity).

The Commonwealth government allocated $18 million for rehabilitation in the late 1970's and after research trials the adopted program was undertaken in the mid 1980's. The operator of the site, CRA, has yet to contribute any costs towards this cleanup and instead Australian taxpayers have had to subsidise their gross incompetence and callous disregard for the environment.

Richards *et al.* (1996) estimated that without rehabilitation the waste rock dumps would have continued to pollute the Finniss River for some thousands of years, by which stage the pollution load would have only decreased by a factor of 10. This would still be above pre-mining loads in the Finniss.

Figure 3 - View of Old Tailings Dam and Tailings Creek Before and After Rehabilitation (Allen & Verhoeven, 1986)

Top : Old Tailings Dam in June 1983; Old Tailings Dam in May 1986 after rehabilitation (L-to-R).
Bottom : Tailings Creek in August 1984; Tailings Creek in September 1984 (L-to-R).

The rehabilitation program involved a series of separate works to mitigate the different parts of the former site, such as the open cuts, waste rock dumps, tailings sites, and processing mills. A variety of approaches were adopted, including the use of engineered cover systems that attempted to minimise the ingress of water and oxygen into pyritic waste rock dumps. The design life for all rehabilitation works was set at just 100 years.

The rehabilitation was demonstrably successful in limiting the ingress of oxygen and water into the waste rock dumps, and the rate of acid drainage emanating from these dumps has consequently slowed.

Despite the extensive nature of the rehabilitation works, the open cuts, particularly White's, continue to be significant sources of pollution (Richards *et al.*, 1996). Bennett *et al.* (1992) estimate that it will take some years of leaching before there is any improvement in groundwater quality at the site.

Thus it appears the policy of "dispersal" as an environmental management philosophy is still being followed at Rum Jungle, along with the demonstrable impacts associated with this approach.

Site maintenance and minor repairs at Rum Jungle still cost some $20,000 annually (Richards *et al.*, 1996). Problems encountered to date include subsidence on the cover at Dyson's Open Cut and feral pigs and buffalos.

The Rum Jungle site provides important implications in the debate about pollution loads from former mine sites. Firstly, unrestricted mining can lead to devastating pollution that can extend over vast areas. Secondly, even after rehabilitation, pollution from an individual mine site can persist at environmentally unacceptable levels for periods much longer than the operational period of the mine (Richards *et al.*, 1996). Lastly, it demonstrates that it is critical to assess the rates, persistence and cumulative impacts of potential pollution sources from mining.

Perhaps of more direct relevance to Ranger and Jabiluka, is that experience with rehabilitation at Rum Jungle is providing a benchmark for the works undertaken at Nabarlek and research for future works at Ranger (eg. Woods, 1994 and others).

Several authors continue to promulgate myths about Rum Jungle, arguing that the pollution was a minor local problem and mostly due to base metals released from copper extraction, and not uranium (eg. Allen, 1986; Richards *et al.*, 1996; Lowson *et al.*, 1998; UIC, 1999).

The behaviour of uranium and many radionuclides can be chemically similar to that of heavy metals who are in the same group on the Periodic Table of the Elements (Fetter, 1993). The tailings may be toxic to the environment irrespective of their radiological hazard (Riley & Rippon, 1997).

Even ignoring radiological releases from Rum Jungle, radium for example can bioaccumulate through the food chain and contribute to pollution problems due to chemical similarity to barium, calcium and strontium (Bedient *et al.*, 1994). The ability of different organisms to accumulate uranium is often used in exploration (IAEA, 1988).

The proposed US-EPA standard for uranium in drinking water, based on radiological toxicity, is 20 μg/l (Fetter, 1993). Some workers propose a much lower standard of 2 μg/l, due to the chemical toxicity of uranium (Diehl, 1998).

Richards *et al.* (1996) state that no studies have yet been conducted on the uptake of heavy metals and radionuclides by vegetation at and surrounding the Rum Jungle site.

The continuing and recent claims about Rum Jungle do not bode well for the scientific integrity concerning rehabilitation at the Ranger uranium mine and further proposed uranium mines.

1.2 The South Alligator Uranium Mines

A detailed account of the former South Alligator uranium mining field is given by the SEA-US South Alligator background paper (SEA-US, 1999). This summary is based largely on the SEA-US research.

The first signs of radioactivity were discovered on June 2, 1953, by a Bureau of Mineral Resources geologist named Bruce Walpole. As the day was the of Coronation of Queen Elizabeth, the uranium discovery was named Coronation Hill. It was the first of a series of near-surface uranium discoveries in the South Alligator Valley region, in what is now the southern most region of Kakadu National Park.

During the 1950's a total of 13 uranium mines were operated by two companies in this small area. There was also active exploration at a number of anomalously radioactive prospects. Minor quantities of ore were sold to the AAEC at Rum Jungle, but the majority was processed at the former gold processing mill at Moline, near Katherine. A small uranium processing plant was also built at Rockhole in 1958. After uranium ore, smaller quantities of lead-zinc-silver, copper and gold ores were processed at Moline.

Table 2 - Uranium Production in the South Alligator Valley
(SEA-US, 1999; Mudd, 1999)

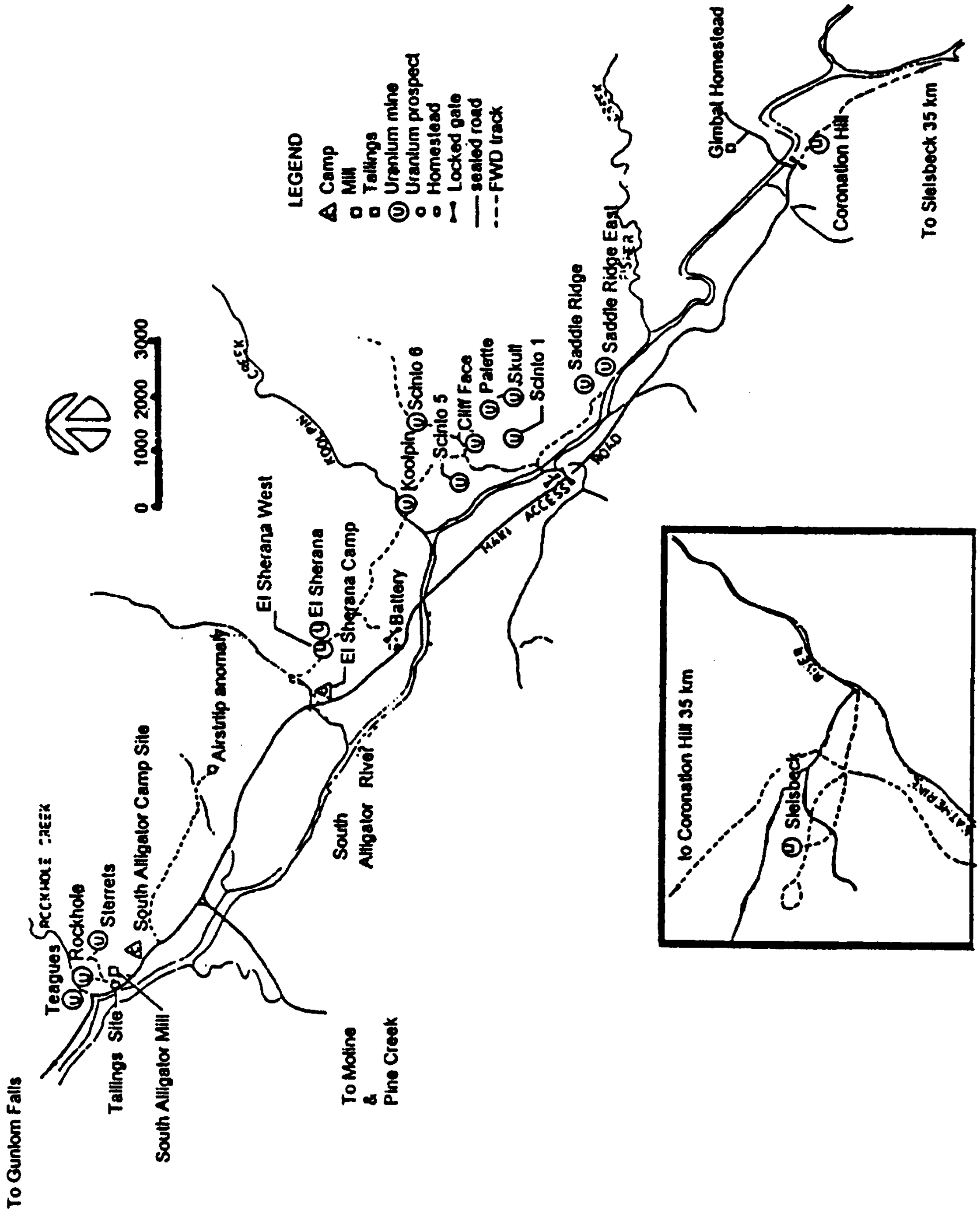
Mine Site	Ore	Grade	U_3O_8	Ra^{226}	Company
El Sherana	38,400	0.55%	226 t	81,000	United Uranium NL (UU)
El Sherana West	21,300	0.82%	185 t		United Uranium NL
Rockhole-Teagues-O'Dwyers	13,200	1.12%	152 t		South Alligator Uranium NL
Palette	4,700	2.46%	124 t	310,000	United Uranium NL
Saddle Ridge	29,800	0.24%	78 t	31,000	United Uranium NL #
Coronation Hill	25,700	0.26%	75 t	33,000	United Uranium NL
Scinto V	5,700	0.37%	22 t	46,000	United Uranium NL #
Koolpin Creek	2,300	0.12%	3 t	17,000	United Uranium NL #
Skull	530	0.5%	3 t	62,000	United Uranium NL #
Sleisbeck	600	0.45%	3 t		North Aust. Uranium Corp.
Scinto VI	1,700	0.15%	2 t		United Uranium NL #

Note - Ra^{226} activity in Bq/kg. # - UU mine assumed based on production data.

The mine sites and processing plants were all abandoned by 1964 with the cessation of atmospheric nuclear weapons tests and the dramatic drop in demand for uranium. Although no legal requirements for rehabilitation existed at the time, this can not be used as an excuse for the damage caused.

Although the environmental impacts have not been as severe as those at Rum Jungle, this is arguably a simple fact of the smaller scale of the operations. There have been significant environmental impacts at these sites, and sufficient funds for rehabilitation were not provided by the Commonwealth government during the 1980's. Hence a minimalist program of "hazard reduction works" was undertaken in the early 1990's (Waggit, 1998).

Figure 4 - Map of the South Alligator Uranium Mining Field (Waggit, 1998)



The majority of the remaining tailings in the South Alligator Valley were removed in 1986 and transported to Moline for the extraction of remnant gold mineralisation.

The Supervising Scientist Group undertook a survey of the abandoned South Alligator field in the early 1980's, with a view to determining rehabilitation requirements for the mine sites and processing plants. Their research uncovered some significant environmental and radiological impacts, and is summarised in Cull *et al.* (1986) and Waggit (1998).

The limited rehabilitation program consisted of fencing off open cut areas, diverting some roads away from former mine sites, earthworks to minimise further erosion problems, shallow trench burial of contaminated or radioactive materials, dismantling of the old South Alligator mill, the erection of warning signs and concreting in custom made large diameter steel tubes to block off adit and shaft entrances.

The shallow trenches were simply covered with a minimum of 1 metre of soil. There was no detail of engineering design or construction presented in Waggit (1998), and thus no assessment can be made of the long-term containment of the radioactive wastes buried within. The cover was not presumably engineered like those applied at Rum Jungle to minimise the ingress of water and oxygen.

At the completion of the "hazard reduction works" a total of five containment sites had been constructed. A radiation survey was undertaken by the Supervising Scientist Group in 1992, shown in Table 3.

Table 3 - Radiological Conditions After Hazard Reduction Works in the South Alligator Valley (Waggit, 1998)

Location	Gamma Dose Rate (μGy/hr)		Dose Rate
	Max	Min	mSv
South Alligator Mill area	1.8	0.9	**6.6**
El Sherana Weighbridge	6	1.5	**12**
El Sherana Battery	14	2.8	**24**
Containment	0.22	0.18	<1
Background	0.15	0.15	<1

Note - Dose assuming full time occupancy.

The intended goal for radiological exposure was 1 mSv/year, and since this was clearly not achieved at some of the sites, further works were undertaken and radiological exposures were apparently lowered to the target levels, although no data is supplied by Waggit (1998).

Annual inspections are now undertaken by the Supervising Scientist. Site inspections during the mid 1990's revealed some persistent erosion problems, although on-site maintenance has appeared to reduce these concerns at specific sites. Some tension/subsidence cracks were noticed at the El Sherana battery site, along with distress in the Eucalyptus trees (undetermined).

Important environmental facts (Cull et al., 1986; Waggit, 1998, SEA-US, 1999) :

- Although small amounts of tailings were deposited at short distances downstream, the majority had eroded further downstream directly into the Mary River, the southern boundary of what is now World Heritage Kakadu;
- Tailings sediment can be traced downstream from Moline due to the "labelling" by radioactive uranium and associated decay products - a radioactivity almost certainly above pre-mining levels;
- Tailings at the Moline processing plant was discharged to a flood plain, adjacent to the rather inaptly named Tailings Creek - **by 1982, erosion had removed 63,000 tonnes of tailings or about 25% of the total**;
- **The Ra^{226} activity of the eroded tailings was 34,500 Bq/kg** (assuming equal mixing with other processed ores at Moline) - this compares to the **US-EPA standard of 185 Bq/kg for top soil and 555 Bq/kg for deeper soil** at rehabilitated uranium sites (the 40 CFR 192 regulations; WISE-UP, 1999);
- The **activity of Ra^{226} could be observed at depths of 50 cm in sediments of the Eureka Creek floodplain, the highest observed activity was 40,000 Bq/kg** (this was thought to be due to tailings particle migration through the sediments);
- During the 1984/85 Wet Season, sediment loads of 94 g/l were recorded downstream of Moline in Tailings Creek - equivalent to an erosion rate over the tailings area of 4 mm/year or 100 times estimated natural erosion rates;
- The Moline site is conveniently described as ***"most interesting"*** and that the ***"multi-coloured little environmental disaster has provided a rather unique opportunity research opportunity into sediment transport"*** (Burton, 1986);
- Bat populations remained in some of the underground shafts at former mines (Rockhole and El Sherana) - these were sealed with concrete grills to allow the bats to continue using the radioactive homes;
- The long term biological stability of the bat populations may be threatened by their use of former underground uranium mine shafts;
- The water table in the region varies from near-surface in the Wet Season to 10 m depth at the end of the Dry Season - perfect conditions to interfere with the radioactive containment sites along the South Alligator Valley. **The intrusion of groundwater could enhance migration of uranium and decay products thereby increasing the radioactive burden in Kakadu**.
- There were also many cases of interference with sacred sites during the exploration and mining, with bones removed and other instances (Annabel, 1977) :

  "Although the area was rich in Aboriginal history, they were not seen by the miners at this time. One look at what Toby Becker and his men had done to their hunting grounds was probably enough to send them scurrying deep into the Arnhem Land reserve."

Curiously, the local Jawoyn Aboriginal people knew the South Alligator Valley as "Sickness Country". Further exploration was undertaken at Coronation Hill in the 1980's by a BHP-led Joint Venture, discovering large gold, platinum and palladium mineralisation. The JV proposed to re-mine Coronation Hill in the late 1980's and early 1990's. The proposal was rejected on the strength of the cultural heritage of the region and the Jawoyn opposition to direct desecration of Sickness Country. The area, inaptly named the "Conservation Zone", was then incorporated into Kakadu National Park.

Figure 5 - The Jawoyn "Sickness Country" of the South Alligator Valley
(adapted from AMIC, 1991)

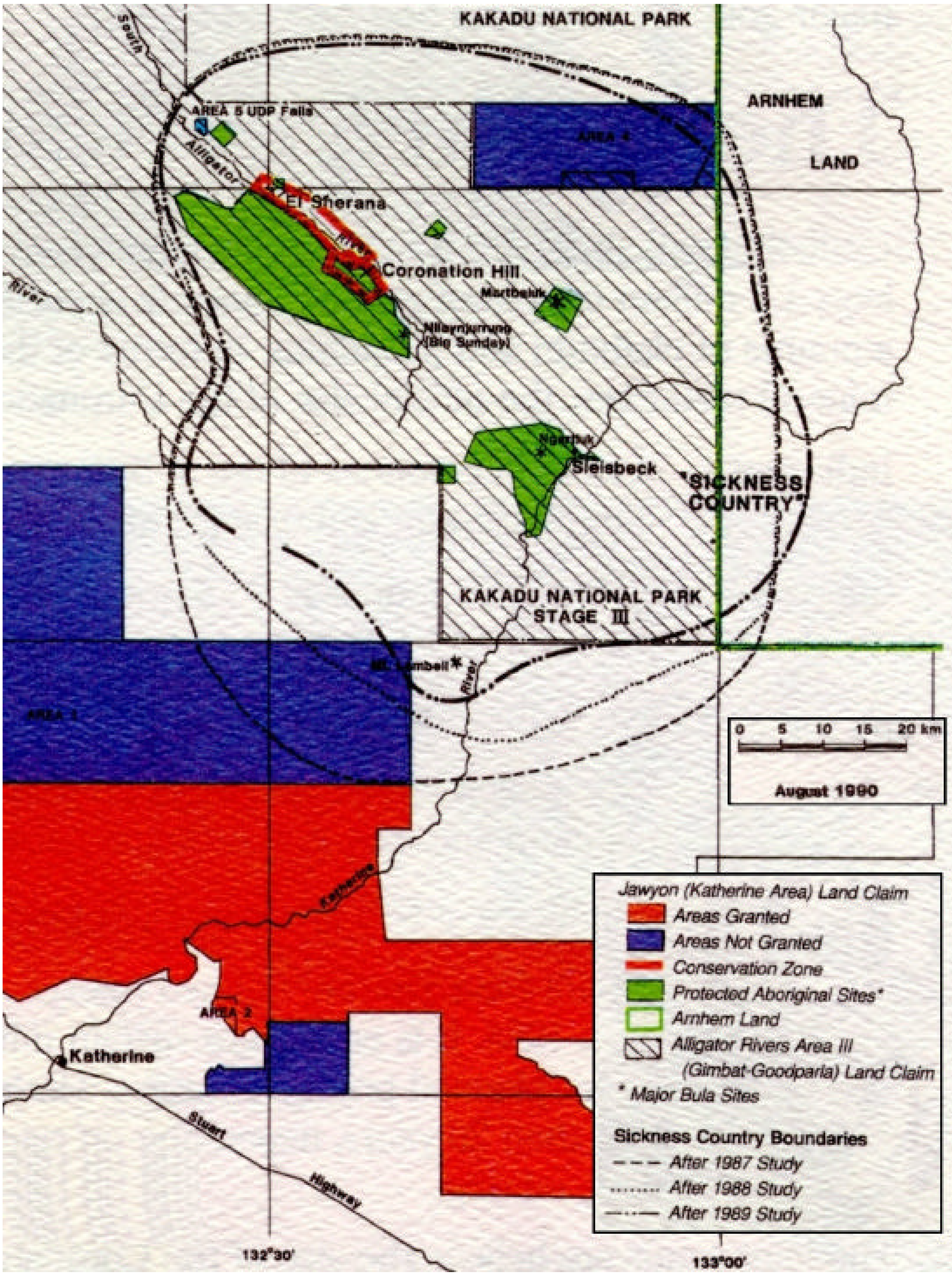
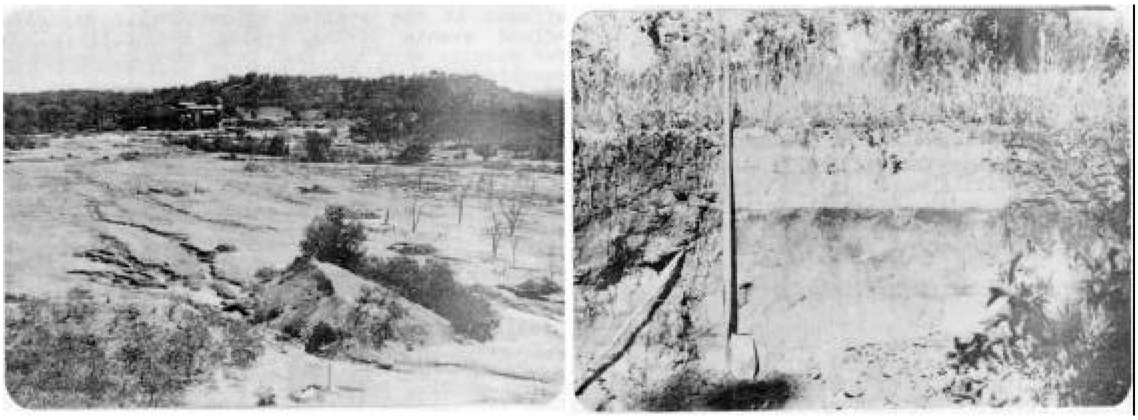


Figure 6 - The Former Moline Uranium Processing Mill 1986 (Cull *et al.*, 1986)



Note - (Left) There is a lack of vegetation covering the tailings, the clear erosion occurring, and (Right) the 30 cm depth of eroded tailings downstream.

It would appear that perpetual monitoring of the Moline and South Alligator sites will be required to ensure long term containment of the radioactive wastes and isolation from the biosphere of Kakadu.

The lessons from the former frenzied uranium mining in the South Alligator Valley appear to have been ignored. The strong cultural heritage of the area (especially known as "Sickness Country") and the extent of environmental and radiological impacts are yet to be fully acknowledged.

> ***Given the criticism one can justifiably make of mining ventures just 40 years ago, what will our current record endear to future generations trying to protect the ecological and cultural values of World Heritage Kakadu ?***

1.3 Facts from Former Mines Across Australia

1.3.1 Miscellaneous Uranium Mines in the Northern Territory

Despite having a much lower profile than the Rum Jungle and South Alligator uranium mining fields, there have been several other uranium mines throughout the Northern Territory. The majority of these were along the Stuart Highway near the Rum Jungle and South Alligator fields (see Figure 1), although there was also active uranium mining and exploration in the Pandanus Creek region in the Gulf Country near the Queensland border.

The Pandanus Creek mine was only operated for a brief period by South Alligator Uranium NL (the same company involved in the Rockhole mines). The ore was hand picked at the extraordinary average grade of 8.37%, and sold to the AAEC at Rum Jungle (SEA-US, 1999). **The spoil dumps abandoned on-site contained approximately 3,000 tonnes, averaging over 1% U_3O_8** (Morgan, 1965).

The mines near Katherine and Rum Jungle, ranged from exploratory costeans, drilling, shafts and adits to small scale mines (SEA-US, 1999). The largest of these was the Adelaide River project, which sold extracted ore to the AAEC for processing at Rum Jungle.

The limited rehabilitation budget allocated in the 1980's, mainly for the South Alligator Valley, was to include rehabilitation works at these other sites. Waggit (1998) mentions this in passing, but no discussion or reference is made to actual or proposed rehabilitation works.

Table 4 - Miscellaneous Uranium Production, NT (Mudd, 1999)

Site	Ore	Grade	t U_3O_8	Year	Company
Cobar 2	78 t	0.477%	0.37	1956-57	North Aust. Uranium Corp.
Pandanus Creek / Eva	312	8.37%	26.1	1960-62	South Alligator Uranium NL
Fleur de Lys	??	??	0.2		Unknown
George Creek	120 t	0.26%	0.3		Unknown
Adelaide River	3,860 t	0.5%	19.3	1954-57	Aust. Uranium Corp. NL

Note - All ore from these sites was apparently sold to the AAEC for processing at Rum Jungle.

To the authors' best knowledge - there has been no information or reports published concerning the rehabilitation of the Pandanus Creek and other former uranium mines across the Northern Territory.

1.3.2 Rehabilitation at the Mary Kathleen Uranium Mine, Queensland

There are some important lessons to be learned from the rehabilitation undertaken at the former Mary Kathleen uranium mine, in the Cloncurry region of north-western Queensland.

The Mary Kathleen uranium orebody was discovered in 1954, with control of the deposit eventually gained by Rio Tinto. An open cut mine and processing mill was developed and commenced in June 1958. With the cessation of nuclear weapons testing in the early 1960's, demand for uranium collapsed and Mary Kathleen was mothballed in 1963. With the onset of new demand in the early 1970's the mine and mill were recommissioned and opened in February 1976 (SEA-US, 1999).

With the exhaustion of ore reserves and difficult times pervading the world uranium industry, the mine and mill were permanently closed in late 1982. The total production of uranium oxide from Mary Kathleen was 4,887 tonnes (SEA-US, 1999). Thus the Mary Kathleen site became the first large scale uranium mine required to meet modern expectations and requirements for rehabilitation.

Some important rehabilitation issues (SEA-US, 1999; UIC, 1999; Ward *et al.*, 1983; Flanagan *et al.*, 1983) :

- The cover material used for rehabilitation was simply coarse waste rock - *not fine soils or clays to act as cover* - **this was essentially to lower costs**;
- The waste rock, it was argued, minimised radon emanation and therefore possible radiation exposures - ***however, it would not limit infiltration of rainwater through the tailings dam site, the evaporation pond, the mill site and other areas - therefore the potential for further groundwater contamination is of major concern***;
- During the and 1982/83 and 1983/84 Wet Seasons, the volume of waste waters requiring treatment on site almost doubled to 700 million litres (ML);
- At the evaporation pond, infiltration trenches were excavated in alkaline clays so that the excess acidic water, containing heavy metals and radionuclides would discharge through the clays into the adjacent creek - **sorption on clays is often a weak and reversible geochemical process, and thus contamination of this environment remains inevitable**;
- The open cut was left as a final void, and allowed to fill with water - radioactivity was claimed to be *"not a public health hazard"* (Ward *et al.*, 1983);
- The predicted water quality of the pit lake, although initially quite good, was expected to deteriorate over a long period of time - although a degree of uncertainty was expressed over ultimate pit water quality;
- The pit lake also received the concentrated, acidic effluents from the rehabilitation of the tailings dam and evaporation pond - despite its unsuitability for this purpose;
- Although attempts were made to prevent stock access (the site has now reverted to grazing), pedestrian or tourist access is still possible.

The rehabilitation of the Mary Kathleen site was completed in 1985, and in 1986 this work won an award from the Institution of Engineers Australia for environmental excellence.

Figure 7 - Rehabilitation of the Evaporation Pond (UIC, 1999)

Figure 8 - Rehabilitation of the Tailings Dam (UIC, 1999)

Note - The coarse nature of the cover material (1988), and the lack of a complete grass cover in these areas.

It has to be noted that the standards of using coarse waste rock for engineered cover systems at tailings dam and evaporation pond sites, and leaving the final void open as a public recreation lake are completely incompatible with environmental standards and engineering technology in the 1990's.

The author's argue that rehabilitation technology used for potentially acid-generating mine wastes, such as capillary barrier and oxygen-limiting cover systems, are the currently the most efficient way to reduce radon emanation from uranium mine sites. This is consistent with the emerging approaches of bodies such as the IAEA (eg. - IAEA, 1998).

There is minimal ongoing monitoring of the Mary Kathleen site, if any.

As with the Rum Jungle and South Alligator sites, there has yet to be satisfactory rehabilitation of this former uranium mining and milling site.

1.3.3 Uranium Mining and Milling in South Australia

Australia's first effective uranium mine was found at Myponga ("Wild Dog Hill"), 25 km south of Adelaide, South Australia (SEA-US, 1999). The site contained patchy but often extremely rich lodes of pitchblende and was mined from 1953 to 1955. The small quantities of ore were trucked to and stockpiled at the new Port Pirie uranium processing mill, under construction at the time.

The Myponga project was simply abandoned and still remains unrehabilitated.

Port Pirie was chosen as the site for a uranium processing mill in South Australia due to its long history of smelting lead-zinc concentrates from Broken Hill, New South Wales. It was also located on the north-eastern edge of the Spencer Gulf with an available sea port.

The main uranium mining project established in South Australia was at Radium Hill, north-east of Adelaide. The site was a former radium mine for the Curies in France in the early part of this century (SEA-US, 1999). The uranium was present as extensive low-grade mineralisation and an underground mine was developed. The ore was concentrated at Radium Hill and refined to yellowcake at the specially built uranium mill in Port Pirie.

The tailings, totalling 200,000 tonnes, were simply dumped on a tidal flat adjacent to the Spencer Gulf. The project completed contracts for nuclear weapons programs of the day and had ceased operations by 1962.

The local council permitted the construction of residential housing next to the tailings. **Until townspeople raised the alarm, children played in the water holes among the tailings. Only grudgingly and after considerable public protests did the authorities fence off the area.**

The Radium Hill mine is also one of the small number of uranium mines worldwide that has had epidemiological studies undertaken long after closure. The study by the South Australian Health Commission and University of Adelaide lasted nine years and presented its final report in 1991 (SEA-US, 1999).

The researchers found that, after tracing 600 of the 3,000 employees from the site who had worked at Radium Hill for a period of two years or more, **40% had already died from lung cancer** (SEA-US, 1999).

2.0 Uranium Mining in the Kakadu Region

There has been active uranium mining now in the Kakadu region for twenty years. The Nabarlek uranium mine, owned by Queensland Mines Ltd (QML), began operation in 1979, while construction began at Ranger began in 1980 and full operation in 1981. The Ranger operation is continuing, owned by Energy Resources of Australia Ltd (ERA) while the Nabarlek mine ceased operations in 1988. The decommissioning and rehabilitation of the Nabarlek site did not occur until the mid-1990's.

These mines are consistently portrayed by their respective companies, the mining industry and both federal and state governments as shining examples of world's best practice mining, with no demonstrable impacts (especially beyond their site boundaries).

However, despite Ranger and Nabarlek arguably being among the most supervised mining operations in the world, the full impacts and threats from these mines are only now beginning to be understood. The potential for impacts in the future remains largely unresolved due to uncertainties of containing radioactive waste materials in aggressive tropical biomes.

In order to understand the context of possible threats to the World Heritage Values of Kakadu from the proposed Jabiluka mine and mill, it is critical to demonstrate the impacts and threats from the Ranger uranium mine.

2.1 Ranger Uranium Mine

2.1.1 Introduction

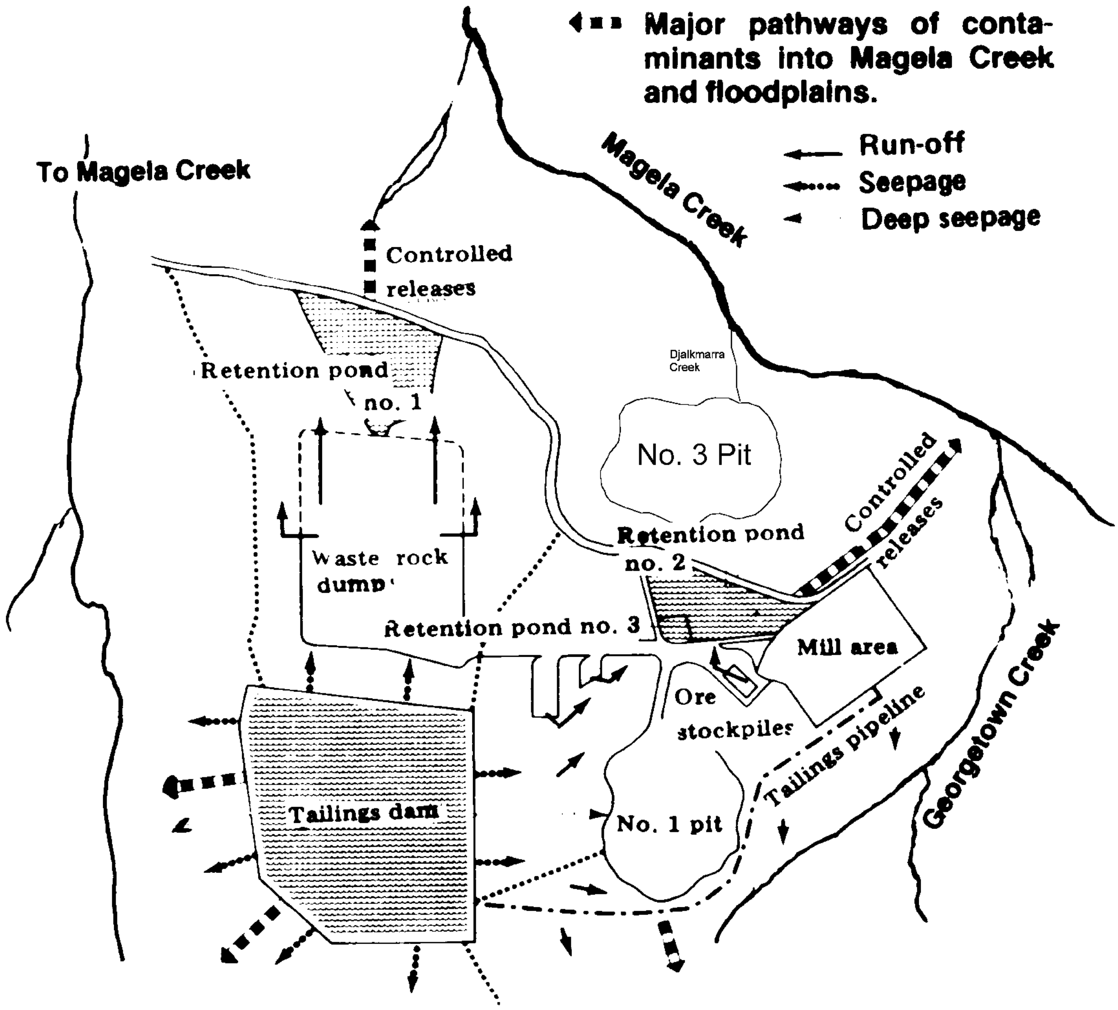
The Ranger uranium mine is one of Australia's highest profile mining operations, due to the complex confluence of uranium, world heritage, national park and Aboriginal concerns. Despite being discovered in 1970, a mine and mill did not begin full operation until 1981, and is expected to continue until about 2010.

The history of the Ranger uranium mine is well documented and will not be repeated here. For further detail, refer to SEA-US (1999), UIC (1999), URG (1998), SSCUMM (1997a, 1997b & 1997c), Kinhill (1996 & 1997), Moody (1992), Eupene *et al.* (1975), among others.

The Uranium Research Group's 1998 submission to the World Heritage Committee (WHC) (URG, 1998) covered the environmental aspects and impacts from the Ranger uranium mine in great depth. This submission is worthy of further consideration by the WHB.

It is not intended to repeat this work here, but suffice to say that this current submission will expand on the environmental engineering, hydrogeological and biological aspects of Ranger's operations. A conceptual presentation of environmental pathways at Ranger is given in Figure 9.

Figure 9 - Environmental Release Pathways at Ranger (Dalton, 1983)



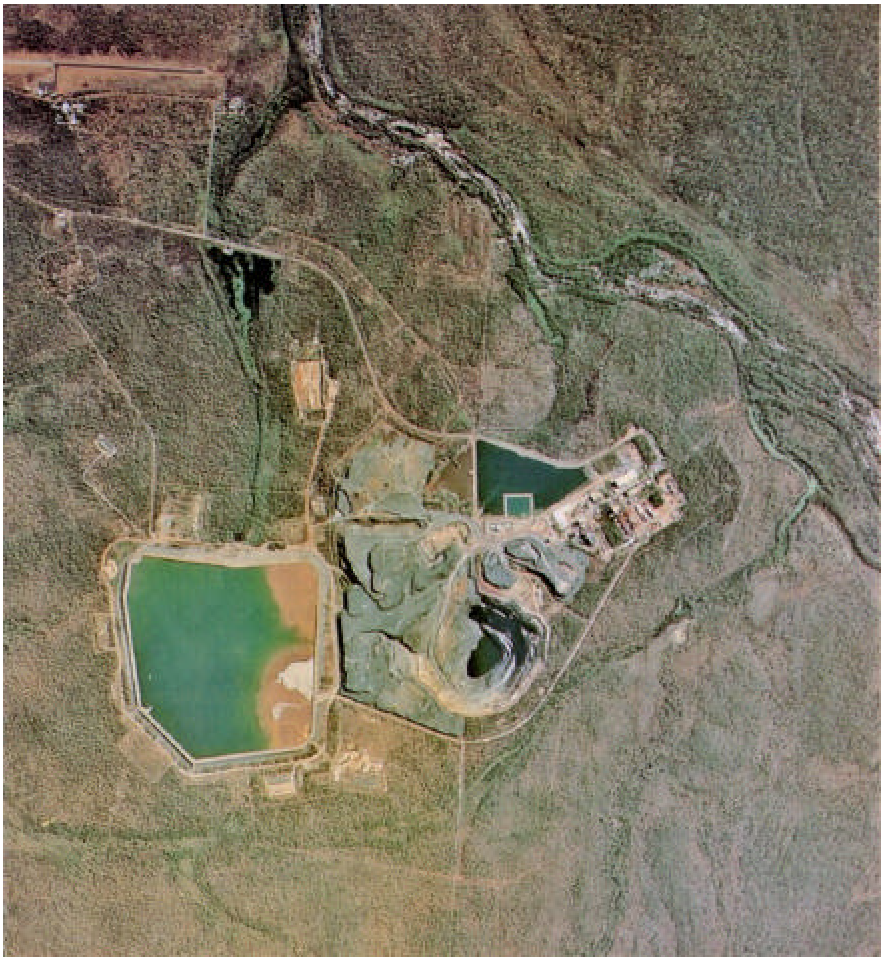
2.1.2 Geology

The geology of the Ranger uranium deposits and mine area is described by Kendall (1990), Hegge *et al.* (1979) and Eupene *et al.* (1975). Further detail on regional geology is available in Needham *et al.* (1979), Needham & Stuart-Smith (1979) and Needham & De Ross (1990). The Ranger #1 and #3 orebodies have formed the basis of the Ranger Uranium Project, although several uranium prospects are also included in the Ranger Project lease area (Kendall, 1990).

There is a distinct possibility that with further exploration and proving of economic orebodies, approvals will be sought for mining of these prospects at some point in the future.

The Ranger deposits are located in altered microgneiss, schist and silicified carbonate near the base of the lower Cahill Formation (Needham & Stuart-Smith, 1979). The upper parts of the deposits consist of chloritised schist and microgneiss while deeper they consist of silicified carbonate (Hegge *et al.*, 1979).

Figure 10 - Aerial View of the Ranger Site, May 26, 1995 (OSS, 1995)



2.1.3 Hydrogeology

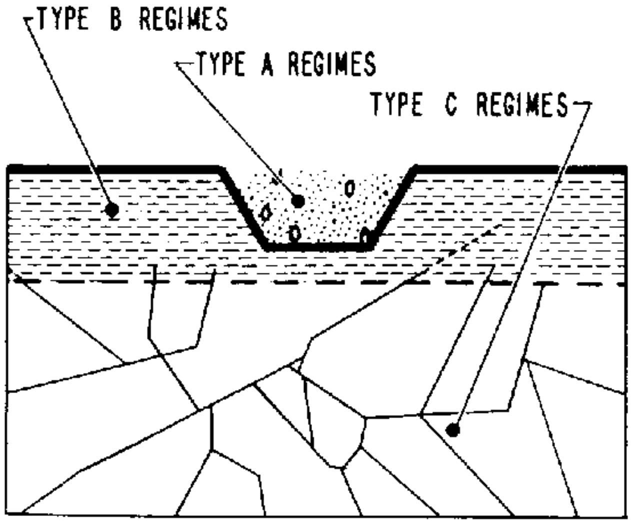
The hydrogeology of the Ranger mine area is complex but relatively well studied, both by ERA and the Supervising Scientist. However, there have been very few published works examining the natural or pre-mining behaviour of groundwater in the Ranger area (eg. - Airey *et al.*, 1983; Ahmad & Green, 1986).

Ahmad & Green (1986) describe the hydrogeology as consisting of three basic groundwater occurrences, illustrated in Figure 11.

The nature and extent of each aquifer in a particular area will depend on local geology and weathering history. The interconnection of the different aquifers will largely be controlled by the presence of semi-confining clay layers, although it is probable all three types are hydraulically connected due to similar pressure levels (Ahmad & Green, 1986).

The water levels in all types of aquifers undergo a seasonal fluctuation of between 3 to 5 m related to recharge during the Wet Season and evapotranspiration during the Dry Season (Ahmad & Green, 1986). The water levels usually relate to surface topography (Ahmad & Green, 1986).

Figure 11 - Hydrogeological Systems at Ranger (Ahmad & Green, 1986)



Type A - groundwater in the loose sands and gravels occupying the present day stream channels;
Type B - groundwater in the weathering profile, ie - laterite and clayey sands and weathered rock mass;
Type C - groundwater in the relatively fresh fractured rocks occupying open fractures and/or other cavities.

All aquifers generally have excellent potable water quality, with a Total Dissolved Solids (TDS; ie - salinity) less than 500 mg/L and near neutral pH, although Type A groundwater is often mildly acidic (Ahmad & Green, 1986).

The water chemistry is generally of a bicarbonate-sodium-calcium type with minor chloride, sulphate and potassium, a typical range is given in Table 5. The average heavy metal and radionuclide content is quite low.

Table 5 - Average Groundwater Quality, Ranger Mine Area (Ahmad & Green, 1986)

(mg/L)	pH	TDS	Ca	Mg	Na	K	Fe
Range	5.6-8.7	10-320	2-40	2-33	1-31	1-20	0.1-25
Average	7.27	154	9.6	11.6	14.5	3.9	2.7
Std. Dev.	0.7	75.0	8.1	8.5	13.3	3.9	5.9

(mg/L)	HCO_3	SO_4	Cl	F	NO_3	SiO_2
Range	9-250	1-21	3-24	0.1-1	1-3	1-107
Average	107.9	4.1	9.2	0.25	0.9	46.7
Std. Dev.	64.9	3.9	9.2	0.17	0.6	29.9

(µg/L)	Cu	Pb	Mn	U	Ra
Range	0.01-5.2	0.04-55	0.1-60	0.1-11	0.015-0.16
Average	0.76	4.29	12.1	2.4	0.05
Std. Dev.	1.1	11.9	16.6	5.7	0.04

Notes - Std. Dev. Is "Standard Deviation". Ra in pCi/L. No Rn analyses presented.

Despite aggressive hydrogeologic and geomorphic conditions, the natural rates of uranium transport through groundwaters is known to be quite slow, evidenced by the very low background concentration of uranium in groundwater through the Magela area between 1.3 and 8.4 μg/L (Airey *et al.*, 1983)

The extent of groundwater recharge during the Wet Season still enjoys a degree of conjecture, due to high evapotranspiration rates during the Dry Season. Airey *et al.* (1983), using environmental isotope data, show that the Ranger #1 pit area is a source of local groundwater recharge, due to a fault providing the conduit for recharge. The recharge issue will be discussed further in Section 2.1.6.

2.1.4 Seepage from the Ranger Tailings Dam

The extent of seepage from the Ranger Tailings Dam has been a constant source of conjecture, especially concerning it's impacts on groundwater quality and possible connection to surface water systems.

There is no debate about the fact that seepage is occurring - a series of bores that attempt to intercept most of the seepage and pump the water back to the tailings dam are clear testimony to this. The debate centres around two critical issues - geotechnical stability and the propensity for large scale failure, and impacts on groundwater quality beyond the influence of the interceptor bores.

The geotechnical stability issue, while the cause of much concern in the early years of Rangers' operation, has essentially ceased to be an issue due to the switch to tailings deposition within the void of the old No. 1 open cut. There are, of course, concerns with seepage from the pit and impacts on groundwater quality from this approach (cf. Wasson *et al.*, 1998).

The question of groundwater quality impacts, however, apparently remains unresolved - even by researchers and workers from Ranger. For example, at the Uranium Mining and Hydrogeology II conference in Freiberg, Germany in late 1998, there was one paper (Lowson *et al.*, 1998) and one poster (Woods & Foley, 1998) which covered the tailings dam seepage at the Ranger site.

Woods & Foley (1998) agreed that there was migration of some conservative species, such as magnesium and sulphate, but stated there was no migration of radionuclides beneath the tailings dam.

However, Lowson *et al.* (1998), stated that the concentration of uranium in seepage water beneath the Ranger tailings dam was 0.5 mg/L, although no radium activity was given. The seepage was occurring along the preferential flow path of a fault line, and could be delineated due to the radioactive signature of the seepage.

The author has seen a laboratory analysis of the seepage water showing a **uranium concentration in seepage water of 14 mg/L** (source confidential).

The higher uranium concentrations are more consistent with those of Langmuir (1997), who states that the average uranium content in groundwater rarely exceeds 20 µg/L, even in uraniferous regions, although the content in uranium deposits and mines may reach up to about 120 µg/L and between 10 to 20 mg/L in seepage and leachates at uranium tailings sites.

The 0.5 mg/L uranium is significantly higher than the reported background range of 0.001 to 0.011 mg/L, by a factor of 50 to 500.

Another paper by Brown *et al.* (1998) reports uranium and other contaminant levels from Retention Pond 2 (RP2) water, comparing these with background water quality in the vicinty of the land application area (refer to Section 2.1.7). The maximum uranium concentration in the land application area is given as 7.8 µg/L (Brown *et al.*, 1998).

Given that the land application area is near Orebody No. #3, the low background concentration of uranium in groundwater close to the orebody demonstrates that natural (or pre-mining) hydrogeologic processes minimise the migration of uranium.

Another potential problem in the groundwater monitoring of the tailings dam seepage is **possible stratification of the plume within the aquifers**. That is, due to minimal vertical dispersion as the seepage plumes migrates horizontally, the seepage is found within a discrete section of the total aquifer thickness.

If groundwater bores in the vicinity of the tailings dam area are screened across the thickness of the aquifer, or even if they have large size screens, any sampling of groundwater from these bores will mix seepage water and cleaner water from depth, **effectively diluting concentrations of all contaminants and solutes**.

The land application area for RP2 water contains a distinct stratification signature, as demonstrated by Brown *et al.* (1998). A total of six multi-level piezometers were installed for this work with one metre intervals between screens. One bore showed decreasing sulphate concentrations of 504, 409, 163, 133 and 163 mg/L.

Another example is given by the September 1993 Report of Environmental Surveillance Monitoring for the Alligators Rivers Region (NT-DME, 1993 [4]). It was noted in groundwater monitoring around the tailings dam that observation bore **OB13A has recorded high uranium concentrations at 900 mg/L**, although **"after pumping for additional sampling in mid 1993 the concentration fell to less than 20 mg/L, but subsequently rose when pumping and sampling returned to normal"**. This is strong evidence for stratification of the seepage plume and inadequacies in current monitoring.

Given the possibility for large size bore screens to dilute contaminants in plume monitoring (cf. Barber, 1999; Fetter, 1993), it may be possible that seepage impacts are not being accurately assessed.

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[4] - Northern Territory Department of Mines and Energy.

One must question why, after nearly two decades of operation, there is still confusion about uranium and radionuclide content in groundwater beneath the Ranger tailings dam between papers presented at the same international conference (cf. Lowson *et al.*, 1998; Woods & Foley, 1998).

> **This represents a demonstrable, detrimental impact on groundwater quality in the Kakadu region.**

2.1.5 Long Term Rehabilitation and Geomorphological Issues

There are many complex questions surrounding long term rehabilitation of the Ranger facilities, centred around the issues of the water balance and hydrological behaviour, and the physical and biochemical effects of releases from the rehabilitated landforms. The landforms will contain uranium mill tailings below-ore-grade uranium material, waste rock and materials arising from site decommissioning. A review of previous and current research is provided by Unger *et al.* (1996).

Riley & Rippon (1997) present a general overview of the results of the research to date - ***much of their brief paper is worth repeating in full, but will only be paraphrased for this report.***

There has been active research on the geomorphological stability of rehabilitated landforms at Ranger by the Supervising Scientist Group (SSG) and the Environmental Research Institute of the Supervising Scientist (ERISS), as well as academics from universities across Australia. The research has incorporated analogue studies at similar sites in the Alligator Rivers region (eg. - Riley & Rich, 1998), hydrogeomorhpic modelling (eg. - Riley, 1994) or simplistic comparisons with rehabilitation at Rum Jungle (eg. - Woods, 1994).

The above-ground option for tailings, waste rock and open cut rehabilitation involves a final landform 4 km^2 in area and 17 m above the pre-mining lowland surface (Riley & Rippon, 1997). The waste rock is intended to be used as the final cover layer, although since it is a highly chloritised schist, it weathers rapidly in the wet, tropical climate (Riley & Rippon, 1997).

Summary of important environmental points from Riley & Rippon (1997) :

- There is a paucity of data for the impact of released water and sediment constituents on relevant species, and even less concerning toxicity assessment of the contained materials;
- There can be no absolute assurance of ecological security because it is not possible to test the impact of potential contaminants on all aspects of the environment, including the complex interactions among species;
- Geomorphic modelling of one proposed above-ground rehabilitation structure at Ranger shows that there is substantial erosion in it's central area and on the margins of the steeper slopes - ***in some areas the predicted erosion exceeds 7 m in depth after 1,000 years*** (covers are about 1-2 m);
- The fine-grained nature of the tailings facilitates rapid erosion;

- **Assuming an erosion rate of only four times the natural rate, the proportion of tailings on the back water plain would constitute 40% of the total sediment deposit** (Wasson, 1992);
- A loss of 5,000 tonnes per year of tailings or eroded material from the containment structures **would double the sedimentation rate of the backwater plain immediately below Mudginberri Billabong** (Riley & Waggitt, 1992);
- The likely deposition sites for eroded tailings and waste rock include major stream courses, billabongs and 30 km^2 section of the backwater plain of the Magela Creek below Mudginberri;
- Deposited tailings and waste rock fines may be subjected to cycling between extremes of ecological and geochemical conditions, such as pH, redox, thermocline development, flood plain and billabong hydrology, microbial activity, nutrient cycling - especially if seasonal conditions are extreme;
- Deposited materials can also undergo chemical changes related to complex geochemical processes, possessing the potential to disrupt ecosystems through effects on any number of species;
- **The volumes of particulates released from rehabilitated landforms will far exceed those that would have been eroded from the lowlands prior to mining and rehabilitation**;
- **The tailings may also present subtle physical impacts at deposition sites, such as altering the infiltration characteristics of soils, which in turn impact water availability to plants and soil fauna, which influences plant growth and reproduction**;
- The physical impact of the eroding rehabilitated structure is likely to be high, leading to loss of habitat and changes in the spatial distribution of ecosystems. Infilling of wetlands and billabongs may be noticeable over time;
- Atmospheric and groundwater issues were not addressed;
- ***It is unlikely that a complete understanding of flood plain ecosystems will ever be achieved***;

Wasson *et al.* (1998) state that these processes will be exacerbated by the presence of acid-sulphate soils in the Magela flood plain. The low pH, acidic conditions could mobilise heavy metals, seriously impacting ecosystems.

It is a sobering warning.

An early confirmation of the impacts of erosion was given by Airey *et al.* (1983), who estimated that uranium released from natural erosion was at least two orders of magnitude higher than transported in groundwater.

Despite presenting such compelling evidence of substantial long term possible impacts to the World Heritage Kakadu ecosystems, **Riley & Rippon (1997) bluntly state that concern and opposition to uranium mining by a “section” of the Australian community is merely a factor of “outrage”** (after Sandman (1993), the corporate propaganda specialist; see Sandman (1998) for more “outrage”). Remarkably, they state unequivocally that :

> ***"Previous studies suggest that the risk of failure of the proposed rehabilitation structure at Ranger Uranium Mine over a 1,000 year period is high but that the direct environmental bio-chemical hazard of released tailings is low."***

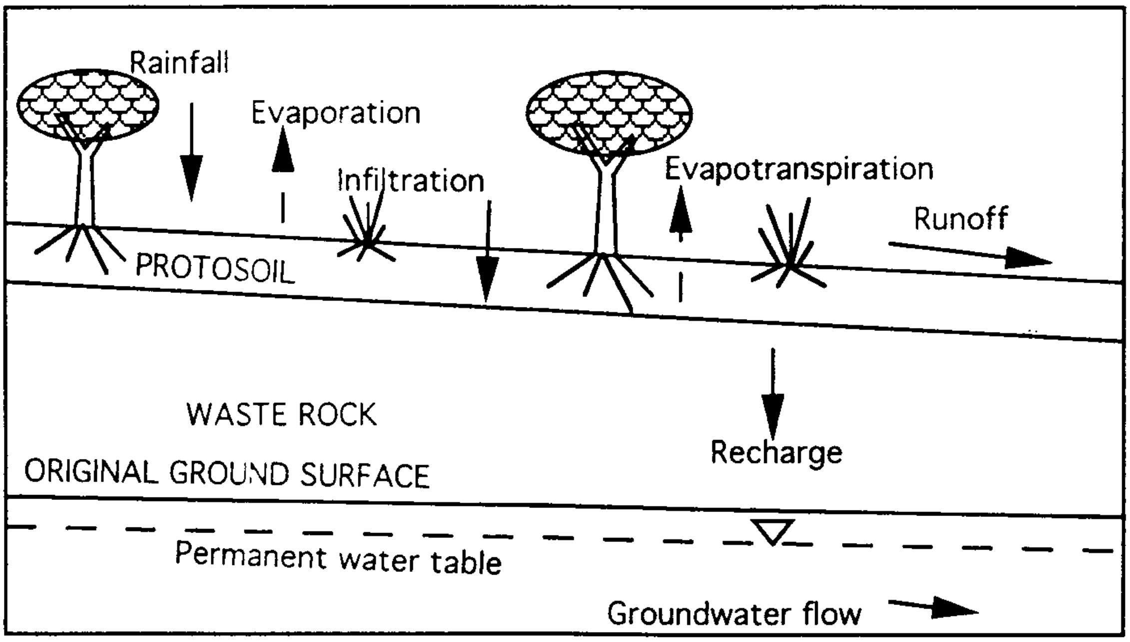
Such statements are entirely in the political realm and not based on the wealth of strong scientific evidence associated with the environmental impacts of mining, especially the mining of radioactive ores.

> ***This research work demonstrates significant and long-running impacts to the geomorphologic and ecologic values of Kakadu.***

2.1.6 Long Term Hydrogeological Issues

The groundwater issues following rehabilitation have been discussed briefly by Woods (1994). By comparing the chloride balances and groundwater monitoring of the Jabiru water supply borefields, the field lysimeters operating at Ranger and those installed during rehabilitation works at Rum Jungle, he estimates that **recharge rates will be in the vicinity of 2-5% of the incident rainfall, or about 25-65 mm per year**. The conceptual hydrologic diagram from Woods (1994) is shown in Figure 12.

Figure 12 - Cover System Concepts for Rehabilitation at Ranger (Woods, 1994)



The cover systems, likely to be made of waste rock materials from the Ranger site, weather quite rapidly and are expected to become hydrogeologically comparable with fractured-rock groundwater systems (Woods, 1994).

The potential for these preferential flowpaths to alter the hydrologic behaviour of rehabilitated structures remains ignored. The seepage that reaches deeper groundwater beneath rehabilitated structures, combined with slower reaction rates at depth, will remain a potential source of contaminants for decades or even centuries (Woods, 1994).

2.1.7 RP2 Waste Water Treatment by Spray Irrigation

The problems with water management at Ranger are well known (cf. Jones *et al.*, 1997; Krockenberger, 1996). The original design of the project underestimated rainfall and overestimated evaporation rates, producing a recalcitrant problem of excess contaminated water on the Ranger site.

Despite persistent attempts to directly release this contaminated water into the wetlands of the Magela Creek and Kakadu and against the wishes of the traditional owners, ERA have never been permitted to do this (although releases have still occurred; refer to URG, 1998).

To solve this problem, ERA have been irrigating excess water from Retention Pond 2 (RP2) at a Land Application Area (LAA) since July 1985, located between the Magela Creek and mine facilities (refer Figure 13) (Brown *et al.*, 1998). The average composition of this water is given in Table 6.

The underlying principle for land application is based on the assumption that radionuclides will be adsorbed by soils of the irrigated land and not impact on groundwater (Akber & Marten, 1991).

Table 6 - Average Composition of Retention Pond 2 Water Used For Irrigation Disposal at Ranger (Brown *et al.*, 1998; Willett *et al.*, 1993)

(mg/L)	pH	Na	K	Ca	Mg	Cl	SO_4	Mn
Average	8.0	37	2.8	18	88	4.8	**437**	2.1
Std. Dev.	0.2	15	0.5	4	5	1.0	59	2.1
Potable [1]	~7	300				400	400	0.1
Irrigation [1]						30-700		0.2 [2]

(µg/L)	Cu	Pb	Zn	U	Th^{230}	Pb^{210}	Ra^{226}
Estimate	4	1.5	12.4	**1,190** **3,100** [3]	0.03 - 0.1	0.15 - 0.25	1.2
Std. Dev.				900			0.6
Potable [1]	1,000	50	5,000	20 [4]			0.74 [4]
Irrigation [1]	200	200	1,000 [5]	10			

Note - Ra^{226}, Th^{230} and Pb^{210} activity in Bq/L. [1] - Water quality criteria from ANZECC (1992). [2] - Value for acid soils (2.0 mg/L otherwise). [3] - Value from McBride (1991). [4] - Proposed US-EPA values (Fetter, 1993). [5] - Value for acid sandy soils (2,000 µg/L otherwise).

There has been active research concerning the spray irrigation or land application of excess RP2 waste waters. The principal environmental concerns include the potential for groundwater impacts and the migration of heavy metals and radionuclides. Some of the main reports, proceedings and papers include those of Akber (1991), Chartres *et al.* (1991), Willett *et al.* (1993) and Brown *et al.* (1998).

The area of the LAA steadily increased from 14.25 hectares (ha) in July 1985 to 33 ha in May 1986 and 35 ha in September 1986 (Noller & Zhou, 1991). By 1995 the area had increased further to 55 ha (Nisbet, 1995). McBride (1991) provides a summary of irrigation volumes and mass of applied solutes at Ranger to mid-1991, given in Table 7.

Table 7 - Loads of Selected Solutes in Irrigated RP2 Waters (McBride, 1991)

Year	Volume (ML)	Mg (tonnes)	Ra (kBq)	SO_4 (tonnes)	U (kg)
1985	63	2.3	63	12	14
1986	743	36	670	190	100
1987	215	17	410	97	340
1988	150	13	170	63	170
1989	460	43	260	190	920
1990	0	0	0	0	0
1991 [1]	149	22	270	90	460
Total	1,780	133.3	1,843	642	2,004

[1] – to June 30, 1991, only.

Over the period from 1985-1995, a total of 3,350 million litres (ML) has been irrigated at this site (Brown *et al.*, 1998). To put this into perspective, one can estimate the total loads of uranium and radium alone irrigated on the soils as 4.02 tonnes (122 g/m^2) and 4.02 GBq (122,000 Bq/m^2), respectively. The annual loading uranium and radium loading rate given by Willett *et al.* (1993) is 2.14 g/m^2 and 2,200 Bq/m^2, respectively.

Even accounting for variability over the ten years of irrigation, there is significant disagreement between these figures.

The soils of the LAA have been found to have a high propensity to retain uranium but a low ability to retard conservative contaminants such as sulphate, calcium and magnesium (Brown *et al.*, 1998). This is thought to be due to adsorption of uranium on the high iron and aluminium content in surface soils. The uranium is typically adsorbed within the surface 0-5 cm of the LAA soils (Brown *et al.*, 1998; Noller & Zhou, 1991; Willett & Bond, 1991).

Brown *et al.* (1998) state that the adsorption behaviour of uranium appears to be confirmed by a groundwater uranium concentration of 7.8 μg/L - essentially background. Noller & Zhou (1991) give background uranium concentrations of 0.1 to 1.3 μg/L, while uranium concentration in surface water seepage emanating from the LAA was 0.1 to 0.6 μg/L.

Noller & Zhou (1991) also state that increased uranium concentrations in groundwater in 1987 and 1989 at the LAA corresponded to higher uranium loadings in these years, although no groundwater data is presented.

This can hardly be considered as demonstrable proof of the efficiency of uranium sorption by LAA soils ! It's not supposed to reach groundwater !

Higher concentrations in groundwater exist, however, for sulphate, calcium and magnesium of 298, 15 and 58 mg/L, respectively (Brown *et al.*, 1998). The multi-level monitoring bores installed at the site demonstrate that the majority of the salt loads stay near the top of the aquifer, that is, the plume is stratified (Brown *et al.*, 1998).

Further research on the Land Application Area has been published by Bond & Willett (1991). They showed that over half of the irrigation water - or 58% - drains through surface soils directly into groundwater, almost doubling the rate or quantity of groundwater recharge at the LAA.

The majority of solutes in RP2 water were not strongly adsorbed by the top 50 cm of LAA soils, with all of the Na and Cl leaching past 50 cm depth, while 80% of the Mg and SO_4, 50% of the K and 20% of the Ca migrated pass this depth (Bond & Willett, 1991; Willett & Bond, 1991). It was concluded that irrigation with RP2 waste water would lead to a significant increase in accessions to groundwater, as the adsorption capacity of the top 50 cm of LAA soils were exhausted by the first season of irrigation and further irrigation would lead to leaching of solutes from the soil to groundwater (Bond & Willett, 1991; Willett & Bond, 1991).

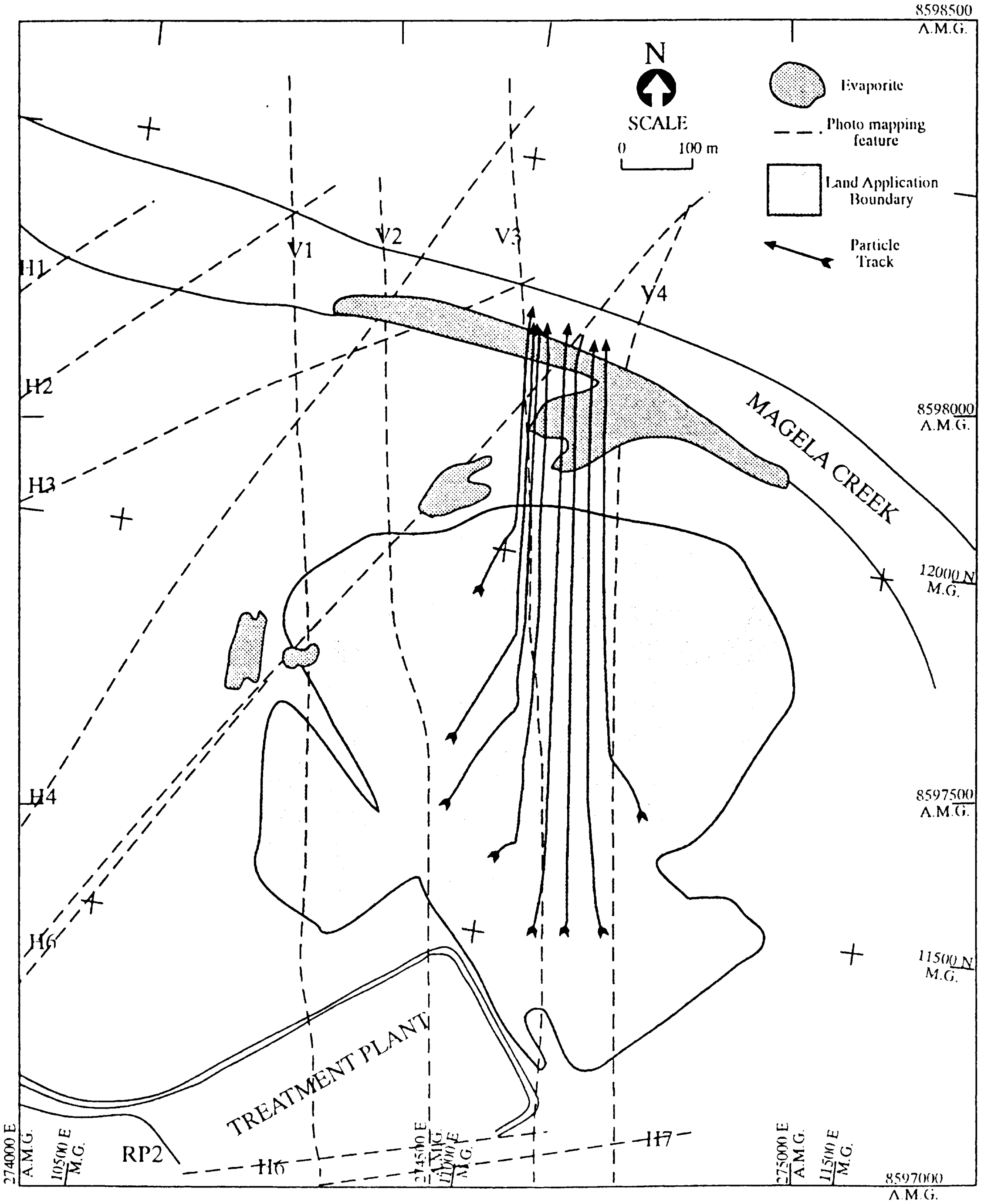
One of the principal problems with the salt loadings in the groundwater at the LAA is the presence of a fracture or fault zone which is thought to be related to the formation of Magela Creek (Brown *et al.*, 1998). This allows preferential flow within the groundwater system for contaminants from the LAA. This zone is only a few hundred metres away from the Magela Creek.

McBride (1991) states that it remains uncertain if the mobile solutes have migrated laterally towards Magela Creek or are continuing downwards to deeper groundwater systems.

The figure presented in Brown *et al.* (1998) (cf. Figure 13) shows an evaporite zone along the southern bank of the Magela Creek, with no explanation given. Thus it is uncertain whether this area is part of a natural geomorphic process, or is in response to use of the LAA for the irrigation of excess RP2 water.

Brown *et al.* (1998) state that the conservative contaminants that migrate from the LAA are merely diluted within Magela Creek during the Wet Season, continuing the tradition from Rum Jungle and South Alligator that "dilution is the solution to pollution".

Figure 13 - Hydrogeological Features of the Land Application Area (Brown *et al.*, 1998)



With regards to uranium adsorption, a further complication not adequately addressed by the Supervising Scientist Group and others, is that the **retention of the uranium within the surface soils of the LAA makes it biologically available to the ecosystem**.

Noller & Zhou (1991) state that there was measurable uptake of both uranium and radium in the plants of the LAA. Ashwath (1991) presented plant tissue concentrations of uranium, radium and radioactive lead before, during and after an irrigation event. The data, given in Table 8, demonstrates remarkable accumulation of these radionuclides in plant tissues due to land application of RP2 waste water. The apparent reduction after the trial was not explained.

It should be pointed out, however, that detailed investigation of vegetation dynamics and radionuclide uptake was not the norm in LAA monitoring. Indeed, despite land application beginning in the mid 1980's, intensive research was only being proposed and research plans developed by 1992.

Further to the lack of vegetation monitoring is the lack of vegetation community data before, during and after irrigation experiments. The changes in community structure due to varied individual species response to the toxicity of RP2 water is therefore unknown.

Table 8 - Radionuclide Concentrations in Plants at the LAA (Bq/kg) (Ashwath, 1991)

Time of Irrigation	Plant Species	Activities in Young Shoots		
		^{238}U	^{226}Ra	^{210}Pb
Before	Trees	0.9	12.7	3.4
	Grasses	1.8	12.7	9.2
During	Trees	**2,076**	**4,512**	**21,100**
	Grasses	**6,152**	**18,700**	**47,600**
After	Trees	95	794	964
	Grasses	231	971	1,527

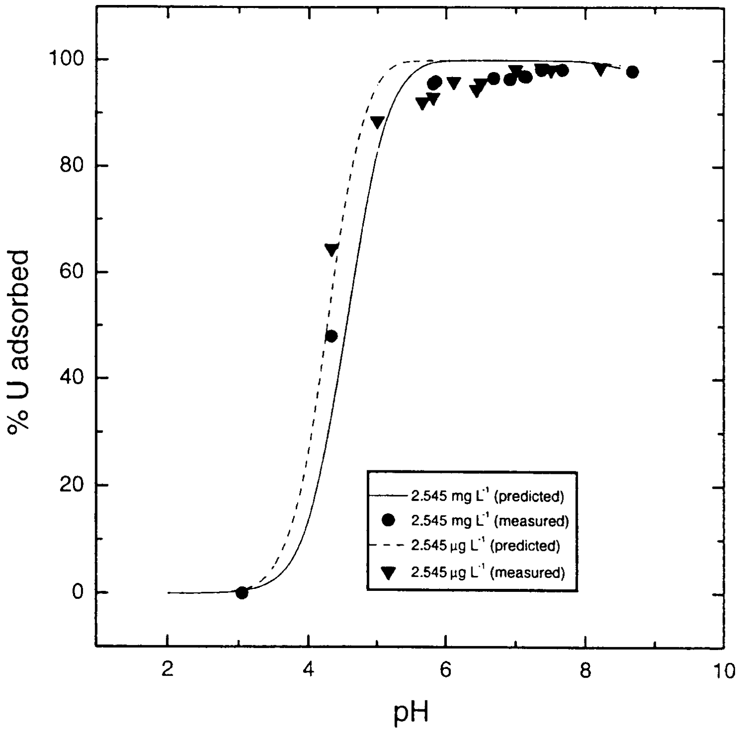
The problem of surface erosion and remobilisation of uranium from the LAA during the Wet Season was acknowledged by Willett *et al.* (1993), although large uncertainties and lack of accurate data precluded a firm conclusion or quantification of this pathway. Direct measurements of uranium in runoff were required to resolve the issue.

The potential for vertical downward migration of adsorbed uranium and radium from the surface 0-5 cm of LAA soils was considered by Willett & Bond (1991). They concluded that there was no potential for further downward leaching and migration of uranium and radium - leaving it available within reach of vegetation and aggressive tropical ecosystem climates.

Brown *et al.* (1998) presented a uranium adsorption curve based on a potentiometric titration technique (shown in Figure 14). The curve demonstrates the high efficiency of uranium adsorption at alkaline pH values (RP2 water is around pH 8), although this rapidly approaches zero efficiency below a pH of about 5.5.

Further complications arise in the long term projections of the adsorption capacity of LAA soils. Willett & Bond (1991) state that the LAA soils have a sufficient adsorption capacity of uranium for several years, suggesting that over the life of the Ranger project uranium and radium will be retained in the first 10 cm of LAA soils.

Figure 14 - Experimental Uranium Adsorption Curve for LAA Soils (Brown *et al.*, 1998)



Although this may not necessarily impact or threaten groundwater in the LAA, it does lead one to the question of the total quantity of uranium and radium remaining in the LAA soils after rehabilitation and their mobilisation due to natural environmental processes ?

Ashwath (1991) provided a limited data set to give a brief insight into this critical question, given in Table 9. As expected, it shows strong accumulation within soils compared to unaffected soils outside the LAA.

Table 9 - Concentrations in Soils Inside and Outside the LAA (Ashwath, 1991)

	Area - Up Slope North (Unit II)					
	pH	EC	CEC	Mn	U	SO_4
Out	5.43±0.06	17.0±1.20	11.0±2.40	146.0±13.5	3.5±0.31	268.0±103
In	5.7±0.13	103.0±24	14.2±2.6	183±18.1	43±5.6	668±187

	Area - Up Slope South (Unit II)					
	pH	EC	CEC	Mn	U	SO_4
Out	5.43±0.09	18.5±1.19	8.3±2.4	132.5±9.4	2.5±0.25	150±22.7
In	6.3±0.14	55±9.8	14.9±4.6	589±43.3	78.2±29.8	298.8±76.8

Notes – EC in mS/cm; CEC is "Cation Exchange Capacity", in meq / 100 g; Mn, U & SO_4 in mg/kg. Based on the average of 4 samples from April 1989, November 1989, April 1990 and November 1990.

There is published data on available rainfall water quality in the Kakadu region. Langmuir (1997) gives a rainfall pH of below 5.7 due to equilibration with atmospheric carbon dioxide and sulphur dioxide and nitrous oxides from the burning of fossil fuels, while URG (1998) give a rainwater pH of 4.5 for the Kakadu region. Further research by the SSG has shown a pH range from 3.5 to 5.2, derived from both strong and weak acids (Noller *et al.*, 1987).

The soils of the LAA region are naturally acidic before irrigation, with a pH of about 5 to 5.5 (Chartres *et al.*, 1991; Willett *et al.*, 1993). During irrigation, the alkaline RP2 water is expected to increase the soil pH, and thus also increase the cation exchange capacity of the soil and it's ability to retain solutes.

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At ambient rainfall pH, before buffering reactions between soil minerals and RP2 water, there is significant potential to leach the adsorbed uranium from the LAA due to the low pH. The continuing and aggressive acidity of tropical rainfall will only enhance the ability to overcome buffering reactions within soils.

The methodology of almost all research cited in this section is based on batch tests. The kinetic and long term behaviour over many years has yet to be studied in the laboratory or the field. Put simply, no one can quantify the effects over time, let alone the thousands of years the radioactivity will remain.

Given that the uranium is still likely to be in an oxidised and more soluble state of U(VI), desorption, re-mobilisation and bioaccumulation within the Kakadu ecosystems is a real and substantial threat.

Akber & Marten (1991) stated that confirmation of the percentage radionuclide adsorption in LAA soils compared to application rates was difficult to quantify accurately due to uneven sprinkler irrigation, obstruction of sprays by trees and shrubs and wind directions affecting spray efficiency.

Given these uncertainties, they estimated that approximately 10% of the radionuclide content had been remobilised by just two wet seasons. How many wet seasons will it take to reach 100% remobilisation ?

McBride (1991) states unequivocally that the higher rates of uranium application from RP2 irrigation in the late 1980's to early 1990's are cause for much concern. Using simplified calculations based on 1989 mean annual flow rate in Magela Creek and assuming all applied solutes reach Magela Creek, the "hypothetical" increase in uranium concentration would be 10 μg/L. This compares to the background concentration of uranium of 0.1 μg/L (McBride, 1991). That is, assuming all uranium is released from the LAA to the Magela Creek, **the concentration would increase by a factor of 100**.

Despite being a critical issue in risk management of both Kakadu National Park and mining ventures in northern Australia, the issue of seasonal bushfires is little acknowledged and even less studied. Perhaps even more pertinent, is that bushfires actually encroached onto the Nabarlek mine site in 1992 and again 1996 (refer to Section 2.2.8). The potential for mobilisation of radionuclides from ashes essentially remains an uncertain issue.

These are demonstrable threats and impacts on groundwaters and surface waters - a situation that is untenable adjacent to a World Heritage national park such as Kakadu.

2.1.8 Wetland Treatment Systems

The Ranger mine has recently developed yet another approach to disposing of it's excess waste water - the use of artificial wetlands to remove solutes of concern such as Mg^{2+}, Mn^{2+}, SO_4^{2-} and UO_2^{2+} (Jones *et al.*, 1996). The concept is based on earlier research which showed that water quality improved as it flowed through natural billabongs (cf. Akber *et al.*, 1992).

The environmental problems of using wetlands for waste water treatment is reviewed by URG (1998), while more technical data and processes are given by Jones *et al.* (1996) and Payne *et al.* (1998). A general review is also provided by Nisbet (1995).

Figure 15 - Wetland Filter at Ranger (OSS, 1996)

Note - The northern wall of the Ranger tailings dam in the background.

The principle solute removal mechanisms are adsorption by plants or clays, or maintenance of reducing conditions within the sediments to form relatively insoluble metal sulphides (Jones *et al.*, 1996). However, it has been found that uranium can be easily removed while sulphate, magnesium and manganese are more recalcitrant and difficult to remove (Jones *et al.*, 1996).

The removal of the uranium begs the important question of where it is removed to, and what is the subsequent environmental mobility or leachability ?

Payne *et al.* (1998) reviewed the adsorption behaviour of uranium on wetland sediments. It was found that the sediments strongly adsorb uranium, dependent upon complex factors such as pH, uranium and other solute concentration, mass loading of the sediment and organic carbon content.

The experimental data suggested that the sulphate concentration could affect uranium sorption, due to formation of a soluble uranium-sulphate complex. A large proportion of the sorbed uranium, however, was still available in labile forms, leading Payne *et al.* (1998) to conclude that **"anthropogenic disturbances or other changes may release labile U from wetland sediments"**.

The problem of predicting the future stability of wetland water chemistry, and thus uranium stability and release, was acknowledged by Payne *et al.* (1998).

One remaining aspect of wetland waste water treatment systems is the question of biological uptake of uranium. It is widely accepted that uranium can be accumulated within plants, aquatic and terrestrial organisms, although this behaviour is also exhibited by radium, cesium and many radionuclides (cf. URG, 1998; Wasserman, 1998; Jones *et al.*, 1996; Fetter, 1993; IAEA, 1988).

The Australian *Eucalyptus* tree, for example, is well known for its strong ability to accumulate uranium (IAEA, 1988). It is also known that aquatic plants are known concentrators of heavy metals and other elements found in mine waste waters (Noller, 1995). The ability of aquatic plants to accumulate metals also far exceeds that of terrestrial plants (Outridge & Noller, 1991).

Jones *et al.* (1996) report on two wetland treatment trials operated with RP2 water during late 1994 (six weeks) and late 1995 (five months). The first trial consisted of three flow-through ponds and a flow rate of 0.5 to 0.9 ML/day, while the second expanded the wetland to include a total of six small ponds and three large ponds at a flow rate of 3.5 to 5.0 ML/day. The experimental wetland was adjacent to Retention Pond 1.

The first wetland trial demonstrated excellent an uranium removal of 98%, with an estimated 2% remobilised upon the first flush of the Wet Season (Jones *et al.*, 1996). However, it was considered unlikely that the uranium was reduced from soluble U(VI) to the insoluble U(IV) state since conditions were not reducing (due to a paucity of organic matter) (Jones *et al.*, 1996).

Instead, the most probable uranium removal mechanism given by Jones *et al.* (1996) was adsorption by epiphytes growing on the stems of *Eleocharis* stems, *Eleocharis* itself, or by adsorption by benthic algae growing on the bed of the wetland. The uranium content of plant tissues from Jones *et al.* (1996) is given in Table 7. The ratio of uranium in plant tissues after and before the trial ranged between 0.2 (decrease) to a 25-fold increase in algae.

The first trial provided no effective removal of magnesium and sulphate, with an intermediate removal of manganese (Jones *et al.*, 1996). The second, expanded wetland treatment trial demonstrated less effective uranium removal, although essentially complete removal of manganese was achieved (Jones *et al.*, 1996). There was little removal of sulphate, thought to be due to the low organic matter content of wetland sediments and the immaturity of the wetland ecosystem (Jones *et al.*, 1996).

Table 10 - 1994 Wetland Treatment Trial : Uranium in Plant Tissues (mg/kg in ashed samples) (Jones *et al.*, 1996)

	Wetland Cell / Location					
Eleocharis Root	Cell 1	Cell 1	Cell 2	Cell 2	Cell 3	Cell 3
Before	134	242	1,500	513	1,140	574
After	1,770	2,430	3,620	978	2,840	1,790
Increase #	**13.2**	**10.0**	**2.4**	**1.9**	**2.5**	**3.1**
Eleocharis Stem	Cell 1	Cell 1	Cell 2	Cell 2	Cell 3	Cell 3
Before	67	189	169	71	302	466
After	1,110	1,100	95	93	57	110
Increase	**16.6**	**5.8**	0.6	1.3	0.2	0.2
Algae	Cell 2	Cell 3	Cell 3	Cell 3		
Before	1,340	-	592	-		
After	8,850	2,400	14,800	6170		
Increase	**6.6**	-	**25.0**	-		

- Simply the concentration after the trial divided by that before (not included in Jones *et al.*, 1996).

Initially for the first 15 days of operation, more than 80% of the uranium was removed, while after this period the removal rate declined to a steady state value of 50% (Jones *et al.*, 1996). The high initial removal rate of uranium was presumably due to saturation of initial sorption sites in clays and soils of the wetland sediments (Jones *et al.*, 1996). The lower removal rate indicated that the retention time for the system to be too low (Jones *et al.*, 1996).

Jones *et al.* (1996) also presented a limited study of the potential for remobilisation of solutes and uranium from natural wetland sediments collected from Djalkmara Billabong.

In the tropical monsoonal climate, remobilisation can occur through two main processes. Firstly, scouring and resuspension of sediment can occur in response to the turbulent energy of catchment runoff during the Wet Season. Secondly, desiccation and oxidation of the wetland sediments during the long Dry Season (also known as acid sulphate soils).

Based on laboratory batch experiments, Jones *et al.* (1996) conclude that less than 1% of the uranium is released by these processes. This is in marked contrast to the research of Payne *et al.* (1998) that demonstrates a marked ability for uranium from wetland treatment systems to remobilise within surface ecosystems due to anthropogenic or natural disturbance to sediments. There was no analyses presented in Jones *et al.* (1996) of wetland sediments from before and after the two trials, to compare adsorption rates.

There may be any number of hypotheses available to differentiate between the methodology and results of Jones *et al.* (1996) and Payne *et al.* (1998) (such as differences in sediment mineralogy, kinetic behaviour).

However, it is worth noting that the transfer of some radionuclides (cf. radium and cesium) have higher biological transfer factors from sediments to plants in the tropics than in temperate climates (Wasserman, 1998). That is, the bioconcentration of elements such as radium and cesium in plant tissues occur more easily in tropical climates. It is known that radionuclides within traditional Aboriginal foods is a concern (URG, 1998). Any further risks are unacceptable.

To the authors' best knowledge, there has been no assessment of the actual rates and potential for long term bioaccumulation within wetland food chains and ecosystems.

> **The long term geochemical and ecological isolation of uranium, radium and heavy metals can therefore never be guaranteed. Indeed, it is demonstrable that these will eventually become biologically available within the ecosystems of Kakadu.**

2.2 Nabarlek Uranium Mine

2.2.1 Introduction

The Nabarlek uranium deposit was a small but relatively high grade uranium deposit. Discovered in early 1970 by Queensland Mines Ltd (QML), the deposit and attempts to gain corporate control of it form a sad chapter in Australia's mining history with insider trading, misinformation to the Stock Exchange and shareholders, and bitter internal power struggles between directors (SEA-US, 1999; Sykes, 1978).

QML were taken over by Pioneer International Ltd in 1981, and with QML ceasing to trade during the 1997-98 financial year, all liability and responsibility for the Nabarlek site has now reverted to Pioneer (SEA-US, 1999).

After publication of the Second Report of the Ranger Uranium (Fox) Inquiry in May 1977, approvals for Nabarlek were quickly forthcoming and preparations began immediately for mining. The uranium was mined in 143 days in 1979, with processing of the stockpiled ore from August 1980 to June 1988. The mill tailings were directed back into the open cut - a unique occurrence in mining.

The total production from the Nabarlek mill was 10,858 tonnes of U_3O_8 (Waggit & Woods, 1998; UIC, 1999). As with Ranger, Nabarlek is promulgated as a fine example of environmental management in uranium mining.

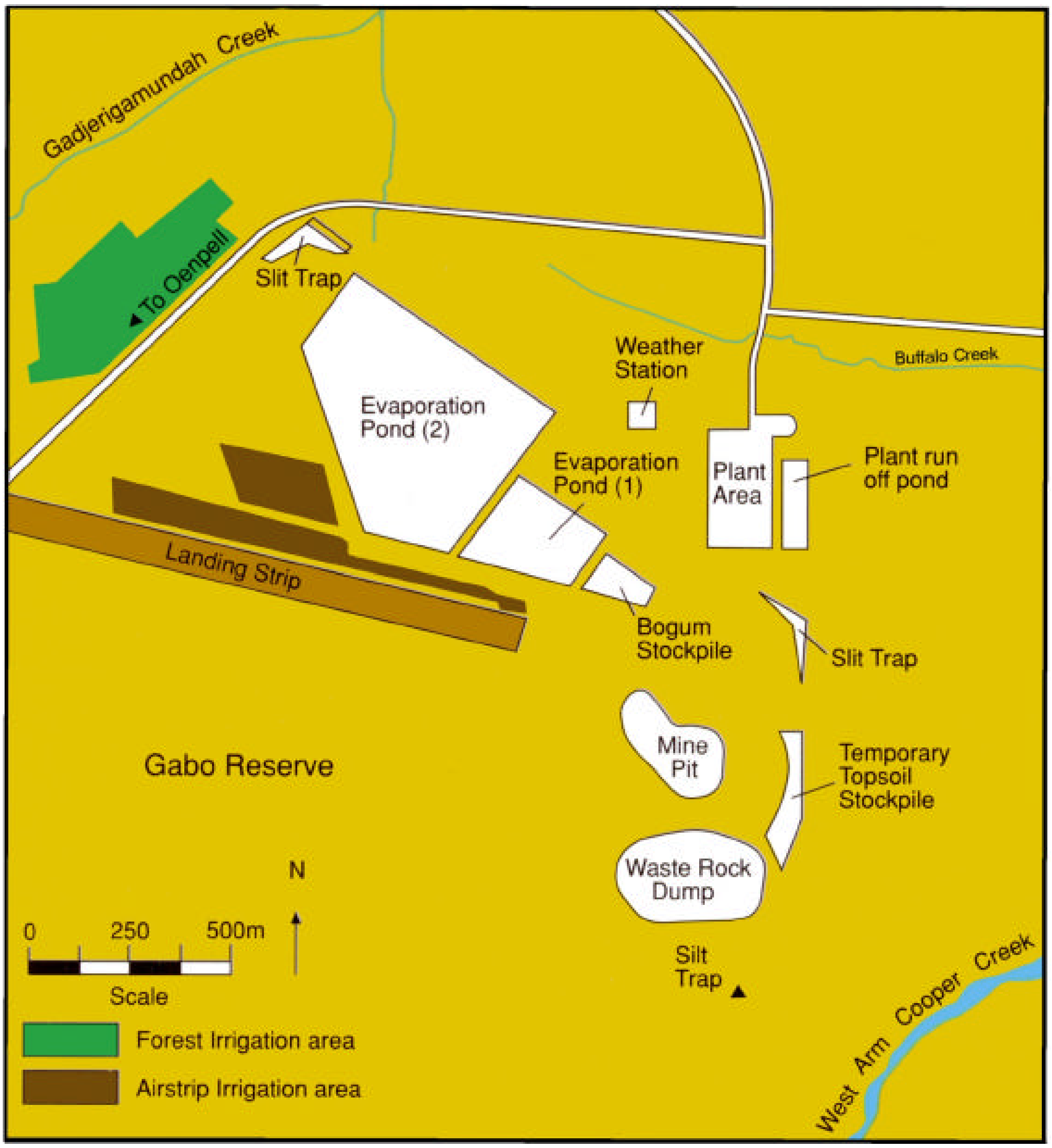
Nothing could be further from reality.

Gabo-djang, Dreaming Place of the Green Ants, is only 1 km from the mine, and there have been numerous documented conflicts with traditional owners of the area (SEA-US, 1999; Land, 1998; Greens NT, 1998; Moody, 1992). These included several conflicts over roads, sacred sites, an Aboriginal blockade at the start of the operation and refusal for mining of the lesser known (and presumably not economically important) Nabarlek 2 orebody. QML also proposed to discharge contaminated mine waste waters directly into adjacent creeks - an option bitterly opposed by Traditional Owners.

There have also been noteable environmental problems at the site, which are often dismissed outright by government and the Supervising Scientist. The site is within the catchment of the East Alligator River - an area recommended by the 1998 UNESCO Mission to be considered for inclusion in Kakadu (UNESCO, 1998).

A review of the environmental problems at Nabarlek is therefore directly relevant to any analysis of the ***proposed*** Jabiluka uranium project. The experience also helps to ascertain the veracity of claims made concerning the technical, engineering and scientific aspects of Jabiluka.

Figure 16 - Site Layout of the Nabarlek Uranium Mine (EA, 1998a)



Note - Buffalo Creek added from McBride (1995). Gadjerigamundah Creek is also known as Kadjirrikamarnda Creek.

2.2.2 Geology

The geology of the Nabarlek uranium deposit and mine area is described by Wilde & Noakes (1990), Wilde & Wall (1987) and Anthony (1975). The deposit is hosted by amphibolite and semipelitic schist of lower Proterozoic age, unusual for uranium deposits of the Alligator Rivers Region (ARR). The ore minerals are predominantly uraninite, deposited during intense hydrothermal activity. The main gangue mineral is chlorite.

Figure 17 - Aerial View of the Nabarlek Site, 1995 (OSS, 1995)

2.2.3 Hydrogeology

Groundwater at Nabarlek can generally be considered to behave in two systems or aquifers (Waggit & Woods, 1998). The geology consists of fractured and highly weathered rocks, and most movement of deep groundwater is along these fractures and at the weathering boundary where secondary porosity has developed in the early stages of weathering (Waggit & Woods, 1998; Grounds, 1983). The system is discontinuous, generally 5 m thick and below 10 m in depth (Waggit & Woods, 1998; Grounds, 1983).

The overlying soil, laterite and colluvium/alluvium are quite permeable and form a second, shallow aquifer (Waggit & Woods, 1998). A clay layer separates the two aquifers, acting as an effective aquitard although it is discontinuous and can be saturated (Waggit & Woods, 1998). In some places, sandstone is the bedrock and can form a single aquifer with derived sandy soils (Waggit & Woods, 1998).

The groundwater quality is generally quite fresh, with a salinity less than 500 mg/L (Waggit & Woods, 1998). Due to the complexity of groundwater flow and recharge, four distinct water chemistries can be distinguished (Table 8) (Waggit & Woods, 1998). The levels of most trace metals is low (Waggit & Woods, 1998). The dissolved silica content is an important component of groundwaters.

Table 11 – Typical Groundwater Quality at Nabarlek (Waggit & Woods, 1998)

Aquifer Type	pH	EC	Cations	Anions	Silica (as SiO_2)
Dolerite	6.7-8.0	440	Ca, Mg > Na	HCO_3 >> Cl > SO_4	70 mg/L
Schist	7.5-8.0	470	Mg > Ca > Na	HCO_3 >> Cl >> SO_4	46 mg/L
Sandstone	4.0-6.0	32	Na > Mg = Ca	HCO_3 > Cl > SO_4	10 mg/L
Alluvium	3.5-5.5	21	Na > Mg > Ca	Cl > HCO_3 = SO_4	12 mg/L

Note – EC is "electrical conductivity", related to salinity, in (µS/cm).

The groundwater in the Nabarlek area is also known to have direct relationships to surface creeks, such as discharge to Kadjirrikamarnda and Buffalo Creeks (Waggit & Woods, 1998; McBride, 1991).

2.2.4 Impacts on Groundwater Resources

Waggit & Woods (1998) summarised the impacts on groundwater resources as due to three main activities - the open cut creating a groundwater sink or discharge zone (where the aquifer previously existed), extraction by the borefield and seepage from the evaporation ponds and irrigation areas.

The open cut was excavated to about 16 to 20 m below the water table, although due to the low permeability of the chloritised schist that hosted the ore, inflows were small (approximately 50,000 litres per day) and the steep gradients in the water table only extended for a few hundred metres beyond the open cut (Waggit & Woods, 1998).

By 1986 the tailings and water level in the pit reached the pre-mining water table level and the pit ceased to be a groundwater sink (Waggit & Woods, 1998). It could therefore be a source of contamination due to flow through and discharge from the pit.

The borefield extracted water for the mill, although technical information is scarce to say the least. Data on changes in water levels, quality and any impacts are not reported in the available literature.

There were ascertained impacts on groundwater from the evaporation ponds at Nabarlek. The levels of the water table below the ponds began rising soon after they first received water in 1980, and by 1982 there was no unsaturated zone beneath the ponds (Waggit & Woods, 1998). That is, the ground beneath the ponds was fully saturated and provided a direct conduit for contaminated groundwater. The pre-mining water table was just 5 m below the surface (Waggit & Woods, 1998).

The principal difficulty associated with detecting and monitoring the impacts on groundwater quality at the evaporation ponds was due to the fractured nature of the rocks providing preferrential pathways (Waggit & Woods, 1998).

It was observed that groundwater bores some tens to hundreds of metres apart, yet an equal distance down gradient from the ponds, contained significantly different concentrations of contaminants (Waggit & Woods, 1998).

For example, monitoring bores OB2D, OB3D and OB4D, each about 50 m down gradient of Evaporation Pond 2 and about 180 m apart, had sulphate concentrations in December 1990 (after ten years of operation) of 488, 12 and 1,260 mg/L, respectively (Waggit & Woods, 1998). The background level of sulphate was <5 mg/L (Waggit & Woods, 1998). The impact on groundwater quality from the irrigation areas is discussed in the next section.

The behaviour of ammonium and heavy metals, including uranium, radium and manganese, appear to be adsorbed within the clayey weathered zone beneath the evaporation ponds (Waggit & Woods, 1998). The potential for remobilisation by vegetation and aggressive tropical climates has been ignored, in much the same vein as at Ranger.

However, there was "evidence of a contaminant pulse in the groundwater within the Buffalo Creek catchment", according to the December 1997 Environmental Performance Review (EPR #7) (EPR, 1997). It goes on to state that "Depending on location, the pulse is mainly associated with elevated sulphate, ammonia or uranium. Uranium levels appear to have been attenuated with distance from the pit and have decreased since 1996."

Unfortunately the full EPR has not been made available on the SSG website, and the concentration data is thus not available for analysis and comparison. However, it casts significant doubt on rhetorical statements that uranium and other heavy metals will simply be "adsorbed" or "attenuated" - **if they are appearing in the Buffalo Creek catchment, this demonstrates mobility !**

2.2.5 Land Application of Waste Waters

Queensland Mines Ltd (QML) began land application of excess mine waters on a small experimental scale in 1984, a year before similar activities at the Ranger mine (McBride, 1991). Initially small volumes of Evaporation Pond 2 (EP2) water were irrigated at an area of 16 hectares adjacent to the airstrip, aptly known as the "Airstrip Irrigation Area" (AIA). In 1986 a smaller "Forest Irrigation Area" (FIA) of 10 hectares was developed. This continued for a further three years until 1987, when activities ceased due to the imminent closure of the site (McBride, 1991).

Table 12 - Volumes of Waste Water Irrigated at Nabarlek (ML) (McBride, 1991)

Year	1984	1985	1986	1987	Total
Airstrip Area	24	44	78	199	345
Forest Area			356		356

The major solutes in the irrigation water was NH_4 and SO_4, including smaller but significant quantities of Ca, Mg and Mn (McBride, 1991). The average salinity of EP2 water was 7,400 mg/L (McBride, 1991). This compares to the salinity of RP2 water at Ranger of about 600 mg/L (cf. Table 6, p 27).

The environmental effects of saline water irrigation have been devastating and has led to tree kills and lasting impacts on groundwater quality and adjacent creeks (URG, 1998). Some simple comparisons can illustrate the cavalier attitude taken to "protect" the ecosystems at Nabarlek's irrigation plots.

Some points of note from McBride (1991) :

- the average rate of salt application was 170 tonnes per hectare for the AIA, and 260 tonnes per hectare for the FIA (consisting of some 1,900 tonnes of sulphate, 370 tonnes of ammonium and quantities of manganese, calcium and magnesium);
- in the agricultural application of ammonium sulphate fertiliser, it is normal to apply about 50-100 kg N / ha / harvest - **about 0.1% of that used in the FIA**;
- no radium or uranium data is given;
- assuming the ammonium sulphate is a dry salt (ie - $(NH_4)_2SO_4$) and a density of 1,769 kg/m^3, **the FIA would be covered in a solid salt layer about 16 mm thick**.

Given the simplicity of these calculations and the extremely high salt loadings applied, one must ask the question of how such a scheme could be approved and yet no detrimental impacts were expected ?

The extension into the FIA in 1986 produced the most dramatic environmental impacts. Despite the earlier irrigation trials being regarded as a success, by 1987 some tree deaths had been observed, sulphate and nitrate levels in groundwater had increased noticeably and pH was decreasing markedly (Waggit & Woods, 1998).

By 1988 it was realised that large proportions of the remaining trees were either dying or showing symptoms of stress which would lead to death - irrigation of EP2 water was discontinued (Waggit & Woods, 1998). Attempts to ameloriate the problem with irrigation of low salinity groundwater proved largely unsuccessful as tree deaths continued (Waggit & Woods, 1998).

The vegetation structure was noticeably different to surrounding areas by 1990 and the decision was made to clear all dead trees to reduce fuel load and the risk of seasonal bushfires (Waggit & Woods, 1998). The area was re-seeded and re-growth established, however, the emergence of weeds has become a significant problem (URG, 1998), despite the apparent claims of successful rehabilitation (cf. Waggit & Woods, 1998).

It is also perhaps strikingly obvious that such high application rates of soluble salts that undergo little adsorption will lead to severe impacts on shallow groundwater.

However, McBride (1991) admitted that detecting and assessment of solute migration in groundwater was somewhat limited by the complexity of seasonal variation and a shortage of monitoring bores in the expected paths of transport. The groundwater pollution that was detected and monitored perhaps proves the extremities of the damage caused.

The impact on groundwater from irrigation at the FIA was almost immediate, with bores show sharp increases in contaminants within months. The main groundwater contaminants included NH_4 and SO_4 (McBride, 1991; Waggit & Woods, 1998). The background levels of these contaminants are generally below or near chemical detection limits, yet at the FIA concentrations of up to 830 mg/L and 5,600 mg/L of NH_4 and SO_4 were found (McBride, 1991).

A further problem with the groundwater pollution at the FIA related to oxidation of the ammonium to nitrate (NO_3) (Waggit & Woods, 1998). The reaction is a critical environmental process, known as nitrification, and can be represented as (Manahan, 1991) :

$$2O_2 + NH_4^+ \rightarrow NO_3^- + 2H^+ + H_2O$$

Consequently, there is extensive nitrate pollution in groundwaters beneath and down gradient of the FIA. High nitrate concentrations in groundwaters of the Alligator Rivers Region (ARR) has only ever been observed emanating from mining operations (McBride, 1991).

The nitrification of groundwater has been accompanied by a significant decrease in pH (an increase in acidity) (Waggit & Woods, 1998), as suggested by the above reaction. This has also had the unwelcome effect of allowing higher aluminium concentrations (Waggit & Woods, 1998).

As with Rum Jungle, South Alligator and Ranger, the philosophy of **"dilution and dispersion"** of contaminants widely into the environment was followed at Nabarlek, and still is (cf. McBride, 1991; Waggit & Woods, 1998).

2.2.6 Impacts on Surface Water Systems

The impacts on surface waters and creeks in the vicinity of the Nabarlek site is closely related to impacts on groundwater quality. The land application of saline evaporation pond waters has led to a reduction in water quality in Buffalo Creek, to the north-east of the mill complex, as well as Kadjirrikamarnda Creek to the north-west.

Monitoring of Buffalo Creek has been incomplete and irregular, although levels of NO_3 and SO_4 up to 10 mg N/L and 25 mg/L, respectively, have been observed (McBride, 1991).

The levels of NO_3 and SO_4 in Kadjirrikamarnda Creek, however, are considerably higher, due to discharge of FIA-affected groundwater. The water quality worsened considerably almost immediately after irrigation of the FIA with saline evaporation pond water. The level of SO_4 reached over 300 mg/L, NO_3 at 10 mg/L and NH_4 nearly 40 mg/L (McBride, 1991). The trend for nitrate concentration by 1992 was still increasing, despite the cessation of irrigation five years earlier (McBride, 1991).

The average annual fluxes of ammonium, nitrate (as N) and sulphate discharging through Kadjirrikamarnda Creek from 1986-90 were estimated at 15, 13 and 28 tonnes respectively (McBride, 1991). This represents about 13% of the sulphate and 17.5% of the ammonium applied to the FIA (McBride, 1991). This demonstrates that it will take many more years before the salts are “diluted and dispersed” and pre-mining loads are re-established.

The pH graph of bore SP029 given in Waggit & Woods (1998) appears to have stabilised around 4 compared to a pre-irrigation level of about 6.5, while the decline in electrical conductivity appears to be asymptoting towards a minima above the pre-irrigation level.

Over time, the impact of the FIA, nitrification in the groundwater and salt loadings is decreasing. However, the rate of this decrease is also diminishing with time, meaning that it will take some years before salt loads return to pre-mining levels. As bluntly stated in OSS (1995) : “It is impossible to predict how long this will take”.

2.2.7 Final Rehabilitation and Site Decommissioning

The final decommissioning and rehabilitation of the Nabarlek site began in December 1994, as approval was refused by Traditional Owners for mining and milling of the smaller Nabarlek 2 ore (which was presumably of little economic significance). The federal policy of the then Labour government, restricting mining specifically to Ranger, and Olympic Dam, South Australia, would presumably have precluded development of any new orebody at Nabarlek.

The decommissioning works included dismantling of the uranium mill, significant landscaping and earth-moving works, covering the tailings pit (which included dumped scrap from the decommissioning process), and establishing revegetated ecosystems on all disturbed areas. Some infrastructure remained, such as the accommodation village, workshops, some roads and the airstrip, as per the prior agreement with Traditional owners.

The design of the cover system for the tailings pit perhaps opitimises the philosophy of cost cutting during the site decommissioning and rehabilitation.

The design of engineered covers for uranium mill tailings usually calls for complex multi-layered systems including radon barriers, erosion control layers, drainage layers, etc (Waggit & Woods, 1998). Indeed, the original design for Nabarlek included a clay layer to act as a radon barrier (Hinz, 1989).

However, during the final design phase it was realised that the tailings would remain below the water table, which was at about 5 m depth (Waggit & Woods, 1998). The water table was thought to reduce radon emanation, and so a revised design was approved by supervising authorities without an engineered radon or clay barrier (Waggit & Woods, 1998). The new design relied entirely on the tailings being saturated at depth and the approximately 13 m of earth above.

Data to ascertain the levels of radon emanation before mining and post-rehabilitation are very scarce, indeed detailed pre-mining or baseline radon emanation data is absent (OSS, 1997). Hence the success of rehabilitation cannot be independently assessed.

As already highlighted, the deposition of tailings below the water table provides the opportunity for long-term groundwater transport and impacts - supported by Panter (1997). However, the recalcitrant problems of transport by preferrential flowpaths remains unacknowledged by the company, the Supervising Scientist and others. Given the recognition of the difficulty in monitoring groundwater in the FIA due to fracture transport (refer Section 2.2.4), any assumption of “successful” decommissioning of the Nabarlek tailings pit is clearly flawed.

Further problems encountered during site rehabilitation included revegetation. The original tube stock from topsoil was found to be largely sterile and less successful than direct seeding methods (Waggit & Woods, 1998). The topsoil was also of little value for sustaining vegetative growth (Waggit & Woods, 1998). Studies by QML had shown that local seed species were not suited to long storage periods (Hinz, 1990).

Figure 18 - Decommissioning Progress of Nabarlek (OSS, 1994; 1995)

Note - (Top Left) View looking north-west over the Nabarlek tailings pit, November 1993; (Top Right) View of the Nabarlek mill area with foundation removal in progress, June 20, 1995; (Bottom) Tailings pit showing indiscriminate dumping of contaminated mill components.

Despite consistent assertions about the return of vegetation to the Nabarlek site (cf. SSG, 1997; Waggit & Woods, 1998), there is significant and recalcitrant problems with weeds invading new ecosystem communities, former silt traps, and other areas of mine infrastructure (URG, 1998).

Figure 19 - Pictorial Timeline of the Nabarlek Decommissioning (OSS, 1996)

Note - Top is an aerial view of the Nabarlek site before the commencement of decommissioning works in 1994; Middle is an aerial view in February 1996 with earthworks completed but not revegetated; Bottom shows growth of vegetation by July 1996 (note the coarse nature of cover soils in places).

2.2.8 Bushfires at the Nabarlek Site

In typical style, the different bushfire incidients have been summarily dismissed by the Supervising Scientist and QML, either as the usual “no significant environmental impact” or that it “did not constitute an infringement of the Nabarlek Authorisation or a breach of the Environmental Requirements” (SSCUMM, 1997a). This is hardly rigorous regulation of a dangerous environmental process, especially given the propensity of fire within Australian ecosystems.

In late August 1992, a bushfire damaged a number of buildings and destroyed eleven demountable buildings and an ablution block at the Nabarlek camp (SSCUMM, 1997a). As expected, it is stated that “there was no risk to the mine and mill complex” (SSCUMM, 1997a) - **this is despite it being only 1,500 m away !**

If the bushfire had continued towards the mill complex and tailings pit - which were both yet to be decommissioned - the potential for release of radionuclides in aerosols, particulates and in dissolved forms after the next rains, could have been catastrophic. The question of residual bushfire damage to the tailings pit and milling complex could be equally disastrous.

To make matters worse, another bushfire occurred in the Nabarlek area in September 1996 (SEA-US, 1999). This time, however, it swept through the revegetation area, although an independent expert concluded that less damage had been done than first thought (SEA-US, 1999), it hardly proves that fire is not a significant risk.

The impact of the fires on ecosystems, community structure and weed dynamics has yet to be studied or reported on - the company still planned to use the same measures as previously to prevent fire accessing the revegetation areas next dry season.

2.3 Summary of Environmental Impacts and Threats

The research presented on the Ranger and Nabarlek uranium mines has been a substantial review of the environmental problems, impacts and rehabilitation issues at these sites. Much of this information, from publicly and academically available literature, has never been compiled to paint the true picture.

It is hardly a good report card and can only be interpreted as one of the most damning indictments of current uranium mining activities in the Kakadu region to date. A schematic diagram summarising the numerous environmental contamination pathways is given (see next page).

Significant environmental impacts and issues :

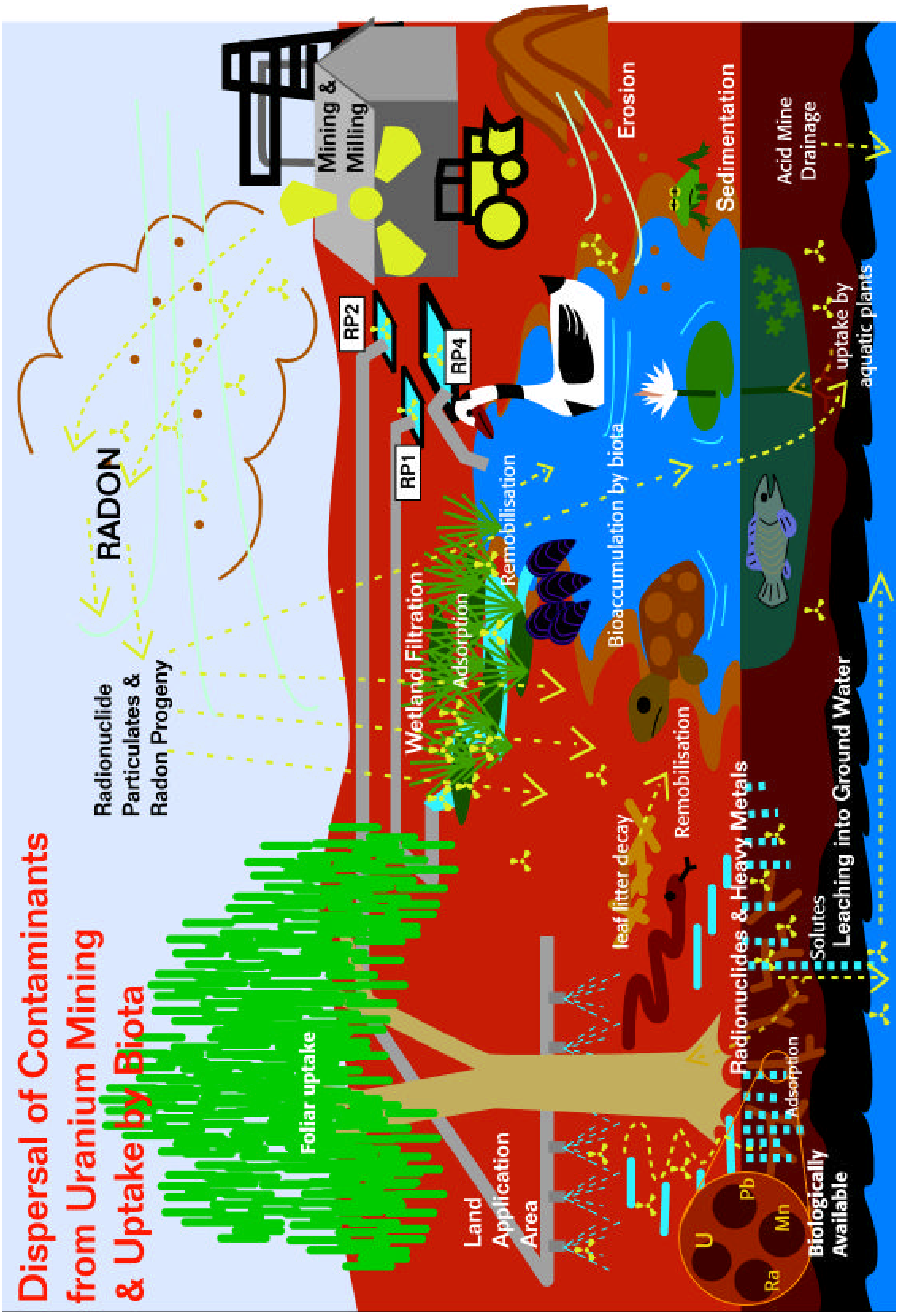
- **Surface Waters** - there has been demonstrable impacts on surface waters adjacent to the Ranger and Nabarlek mines. The principal issue is the salt discharges from waste water disposal/treatment regimes, but perhaps it is only a matter of time before radionuclides begin to appear.
- **Groundwater Quality** - seepage from tailings dams, retention/evaporation ponds and land application (irrigation) areas have all led to detrimental impacts on groundwater quality. The evidence for radionuclide migration is often contradictary and ambiguous, and typically dismissed. This is despite uranium concentrations alone up to 1,000 times higher then pre-mining levels. The philosophy is usually “dilute and disperse”.
- **Aquatic Ecosystems** - the worsening water quality in some creeks, and the use of artificial wetlands for waste water treatment, are leading to direct and long term bioaccumulation of heavy metals and radionuclides in aquatic plants and ecosystems. The long term rates and movement through the food chains and ecosystems of Kakadu remains ignored.
- **Rehabilitation** - the decommissioning and rehabilitation of the Nabarlek site is hardly the shining example it is portrayed to be. Modelling and other studies for proposed rehabilitation designs at Ranger demonstrate long term and substantial impacts to the Magela Floodplain and ecosystems of Kakadu. This is dismissed as a factor of “outrage”.

When will the government “authorities” and companies acknowledge the fundamental scientific evidence their own research is demonstrating ? It is hardly that the scientists and engineers are not capable of performing the research and understanding the technical issues - so why are these issues continuing to be talked around, directly ignored or dismissed as “outrage” ?

Given the requirement to safeguard the tailings for tens of thousands of years, it is worth pointing out that regular water quality monitoring has already been substantially reduced for Nabarlek. Will Ranger do the same ? How can they can demonstrate their “rehabilitation” if they are not monitoring!

Enough is enough.

All mining, especially uranium, must cease in Kakadu.


Dispersal of Contaminants from Uranium Mining & Uptake by Biota
RADON
Radionuclide Particulates & Radon Progeny
Mining & Milling
RP2
RP4
RP1
Erosion
Sedimentation
Acid Mine Drainage
uptake by aquatic plants
Remobilisation
Bioaccumulation by biota
Wetland Filtration
Adsorption
leaf litter decay
Remobilisation
Radionuclides & Heavy Metals
Solutes
Leaching into Ground Water
Foliar uptake
Land Application Area
Adsorption
Biologically Available
U
Pb
Mn
Ra

3.0 Future Uranium Mining in the Kakadu Region

The Alligator Rivers Region (ARR) has been of world importance for uranium for close to fifty years. Whether it continues to be a prominent producer of uranium remains to be seen. However, the future of the ARR beyond the Jabiluka project could continue if deposits such as Koongarra, Hades Flat, Austatom and the miscellaneous Ranger deposits are proposed to be mined and development approved, given an ideologically supportive government.

A brief review of the remaining uranium deposits in the ARR is warranted to ascertain future proposals. It is worth noting that exploration for uranium and other mineral wealth is continuing to accelerate in the ARR, especially in western Arnhem Land (Scott, 1998).

3.1 Miscellaneous Uranium Deposits of the ARR

The wave of exploration across the ARR in the late 1960's to the mid 1970's led to the discovery of four major deposits (Ranger, Jabiluka, Nabarlek and Koongarra) as well as a host of less explored deposits and prospects. Some of these are now effectively excluded from further exploration and mining developments due to their inclusion in Kakadu National Park, while others are within the Ranger and Jabiluka mineral leases. A compilation by Mudd (1999) is given in Table 13.

Table 13 - Miscellaneous Uranium Deposits of the ARR (Mudd, 1999)

Deposits & Prospects	Discovered	t U_3O_8	Grade (%)	Cutoff (%)	Ore Mt	Current Company
Hades Flat	??	700	-	-	-	ERA
Austatom	??	10,000	-	-	-	-
Ranger 2	1970's ?	-	-	-	-	-
Ranger 4	1970's ?	-	-	-	-	-
Ranger 68	Nov. 1976	5,500	0.357	0.10	1.5	-
Koongarra 1	Late 1969	15,195	0.44	0.02	3.453	Cogema
	Late 1969	14,550	0.795	0.09	1.831	Cogema
Koongarra 2	Late 1969	-	-	-	-	Cogema

Notes – Hades Flat lies within the southern part of Jabiluka mineral lease; Austatom and Rangers' 2, 4 & 68 are within Stage 1 of Kakadu NP.

It is worth noting that the Ranger 4 and 68 deposits are directly within the Magela Floodplain.

The continuation of supportive governments and policies could well see further exploration at these sites to expand and prove in-situ resources. Approvals for development of these sites, as a way to extend the life of uranium mining and milling in the ARR, can never be ignored.

3.2 Koongarra Uranium Deposit

The Koongarra uranium deposit was the first of the large uranium deposit in the Alligator Rivers Region to be discovered in late 1969 by aerial radiometric surveys flown by Noranda Australia (Foy & Pederson, 1975). It was confirmed on the ground by July 1970 (Foy & Pederson, 1975). The same aerial survey also identified the Ranger #1 and #3 sites (Eupene *et al.*, 1975).

The Koongarra uranium deposit consists of two orebodies, the #1 and #2 orebodies, with a high average grade but low tonneage (refer Table 13). The geology of the deposits is reviewed by Foy & Pederson (1975), Snelling (1979), Dickson & Snelling (1979), Ewers & Ferguson (1979) and Snelling (1990). There have also been several university theses completed on Koongarra (cf. Tucker, 1975; Snelling, 1980; Johnston, 1984; Wilde, 1988; Short, 1988).

The geology can be briefly described as consisting of Lower Proterozoic sediments with interlayered tuff units resting on a late Archaean granitic basement (Waite & Payne, 1993). The lower sediments are dominated by thick dolomite (Waite & Payne, 1993). The uranium mineralisation is associated with carbonaceous horizons within the overlying chloritised quartz-mica schist (Waite & Payne, 1993). The dominant structural feature is a reverse fault system that trends almost the entire SE side of the Mt Brockman and outlier of the Kombolgie Formation (Waite & Payne, 1993). The ore contains minor volumes of sulphide minerals (to 5%), including galena and lesser chalcopyrite, bornite and pyrite (Waite & Payne, 1993; Snelling, 1990). The potential for acid mine drainage (AMD) from this ore material is uncertain.

The hydrogeology reflects the typical extremes found in the tropics, with the water table rising and falling by 15 m due to the cyclical Wet and Dry Seasons (Waite & Payne, 1993). The hydrogeology is further complicated by the influence of the reverse fault, the fractured nature of the rocks and the aquitard layers separating the different aquifers, much of which is “poorly understood” (Waite & Payne, 1993).

The groundwater quality was given by Waite & Payne (1993), and demonstrates that the water is of excellent quality with quite low heavy metal and radionuclide content. The uranium concentration is mostly between 0.25 to 15 μg/L, although higher values have been sampled up to 308 μg/L.

The exposure of high grade uranium ore near the natural surface to aggressive tropical climates has led to extensive weathering, mobilisation and deposition of uranium over a small region up to 100 m from the primary ore. This forms a low grade mineralised ore envelope. This process has taken tens of thousands of years to progress, and left alone the mobilisation of the uranium is not likely to migrate at high rates.

The site is perhaps one of the most studied uranium deposits in the world. Indeed, the attractiveness of Koongarra as an analog study site for nuclear waste was the behaviour of uranium in the weathered ore zone.

The high grade and active weathering zone is seen as an analogue for high-level nuclear waste. The long-term study, funded by the US Nuclear Regulatory Commission (US-NRC) from 1981, was managed by ANSTO, and was broadened in 1987 under the auspices of the Organization for Economic Cooperation and Development (OECD) to include funding from ANSTO, Japan, Sweden, United Kingdom and the US-NRC (Waite & Payne, 1993).

Koongarra has always been one of the most difficult mines to develop of the four deposits in the ARR. The Ranger Uranium (Fox) Inquiry categorically argued that the deposit should never be developed under any circumstance given it's proximity to the Woolwonga birdlife area and Nourlangie Rock (SEA-US, 1999). However, this did not stop a Draft and Final Environmental Impact Statement being submitted and approved (SEA-US, 1999).

This area was excised from the National Park by the Koongarra Project Area Act 1981, but this has not yet been proclaimed (UIC, 1999). In the mid 1980s, and again in 1991, the company negotiated Aboriginal agreements, but these were not approved by the Federal Minister for Aboriginal Affairs (UIC, 1999).

The current owner of the Koongarra lease is French nuclear giant Cogema (SEA-US, 1999). They have stated that they are re-evaluating the project but describe it as being in “active stasis” (URG, 1998). Given Cogema’s extensive shareholdings in the large, high grade uranium mines and new projects in Saskatchewan, Canada (which have just increased considerably; UI, 1999), it is highly unlikely that Cogema will proceed with any attempt to develop Koongarra for some time.

The future for Koongarra is uncertain. To proceed from this point, the project would need a new Environmental Impact Statement, approvals, proclamation of the Koongarra Project Area (1981), as well as an agreement with the local traditional owners of the site. It is perhaps more likely that Cogema will either sell the project to another company, such as Energy Resources of Australia (ERA), or simply seek compensation from the federal government and allow the lease to finally be incorporated into Kakadu National Park, thus claiming its rightful place as part of World Heritage.

The Koongarra site is immense cultural and ecological importance. It is hoped that these values will remain in perpetuity for all future generations.

4.0 The Proposed Jabiluka Project

4.1 Overview

The Jabiluka uranium project has become one of the most potent symbols of the commitment to the environment or previous governments, but nothing more so than the current Coalition government.

The first uranium orebody, Jabiluka I, was discovered by Canadian company Pancontinental Mining in 1971, but was too small and close to the floodplain to be economically viable (URG, 1998). Further exploration in the vicinity located the massive Jabiluka II deposit further to the east in 1973. Although Pancontinental discovered the Jabiluka I deposit by investigating a low order radiometric anomaly, **the much larger Jabiluka II deposit showed no surface radiometric expression** - indeed, **an airborne radiometric survey in 1970 did not give a significant radiometric response** (Hancock *et al.*, 1990).

The Ranger Uranium Inquiry, which considered mining of all four of the newly found uranium deposits, halted any development plans until the late 1970's. An Environmental Impact Statement (EIS) was prepared by Pancontinental and approved, and after intense and often bitter negotiations, an "alleged" agreement was signed with the traditional owners, the Mirrar, by late 1982.

However, the project was decisively halted by the election of the Hawke Labour government in March 1983 and the introduction of the "Three Mines Policy", which restricted uranium mining and processing to the already operational sites at Ranger and Nabarlek, and the massive Olympic Dam copper-uranium mine under construction and development in the South Australian arid lands.

There were repeated attempts by Pancontinental to coerce Labour into changing their policy to allow development of Jabiluka, however, common sense and community pressure always prevailed. Frustrated and with still no return on their investment at Jabiluka, Pancontinental sold the lease to Energy Resources of Australia Ltd (ERA) in 1991. ERA promptly changed the name to "North Ranger", again attempting to circumvent the federal Labour policy, and yet again common sense and community pressure prevented the insanity that has now engulfed the project.

The election of the arguably the most pro-nuclear government the Australian people have ever contended with in March 1996 opened the flood gate for ERA to mindlessly pursue development of their nest egg at Jabiluka. Their preferred plan, on cost alone, was to truck the ore mined from Jabiluka to the Ranger mill, aptly known as the "Ranger Mill Alternative" (RMA).

However, this would require consent from the Mirrar, the traditional owners. They flatly refused as they are diametrically opposed to any development. Hence ERA are sought and received approvals for milling the ore at Jabiluka through a "Public Environment Report" (PER), aptly known as the Jabiluka Mill Alternative (JMA).

ERA are now in a dire predicament as to build a new mill at Jabiluka would be exhorbitantly expensive, and given the current delays and the depressed state of the world uranium market, cannot be justified on economic grounds. The consistent opposition by the Mirrar, the Australian and international community has essentially removed the benefit of receiving government approvals.

Figure 20 - Development of the Jabiluka Mine Decline and Retention Pond (no date given, approximately August 1998) (ERA, 1998)

Figure 21 - Jabiluka Mine Site in the Early 1998/99 Wet Season (EA, 1999)

The share price of ERA has plummeted over 70% from 1996 to late 1998, placing significant financial strain on ERA as investors gradually abandon the risky company (Mudd, 1998a). Construction of the access decline for the underground mine has begun nonetheless, and ERA are still attempting to determine their way forward.

This section will present an overview of the proposed Jabiluka project, using the detailed research on Nabarlek and Ranger to ascertain the veracity of claims made by both the federal government and ERA concerning the environmental standards, impacts and threats arising from the Jabiluka project to the World Heritage values of Kakadu National Park.

4.1.1 Geology

The geology of the Jabiluka site has been described in detail by the Pancontinental EIS (Pancontinental, 1979) and the new 1996 EIS prepared by Kinhill Engineers and ERA Environmental Services (an ERA wholly owned subsidiary) (Kinhill, 1996). Further detail on the geology of the Jabiluka deposits is given by Hancock *et al.* (1990), Ewers & Ferguson (1979), Binns *et al.* (1979), Rowntree & Mosher (1975).

The geology can be briefly described as a layered sedimentary sequence consisting of a lower layer of dolomitic and magnesic carbonate, a middle layer of graphitic schist and an upper layer of quartz muscovite schist and amphibolite (Kinhill, 1996). The basement is formed by the Archaean to Early Proterozoic basement complex of granitic gneiss and biotite schist (Kinhill, 1996). The sedimentary sequence is unconformably overlain by the Kombolgie Sandstone (Kinhill, 1996).

The Jabiluka uranium deposits are contained within the same stratigraphic horizon as those at Ranger, and thus considered to be similar in many respects (Kinhill, 1996).

Although ERA state they have no current intention to extract the gold from the Jabiluka deposit (Kinhill, 1996), the possibility of future extraction can never be ignored. The estimated gold resource is 1.1 Mt at the average grade of 10.7 g/t, totalling over 400,000 oz of contained gold (Hancock *et al.*, 1990).

Compared to the numerous gold mines in Western Australia (WA) and elsewhere in Australia, this is indeed a sizeable resource. The gold extracted from the South Alligator and other sites across the northern stretches of the Northern Territory was from significantly smaller and lower grade resources (cf. Nicholson & Eupene, 1990; Needham & De Ross, 1990; Carville *et al.*, 1990; Miller, 1990).

The gold mineralisation at Koongarra contains an estimated 100,000 oz at low grades (Snelling, 1990), while gold mines in WA also operate on generally lower gold grades than that at Jabiluka II.

The severe environmental problems and risks of gold extraction of within the Kakadu area, presumably by cyanide process technology, are acknowledged by ERA (cf. Kinhill, 1996). It is worth pointing out that cyanide does eventually biodegrade[5], and although the rates may be debateable, it is of the order of years to maybe a century - **this is in stark contrast to radioactive uranium ores and tailings being dangerous for hundreds of thousands of years !**

4.1.2 Hydrogeology

The hydrogeology of the Jabiluka deposits is given in Pancontinental (1979), Kinhill (1996) and Kinhill (1998), and further detail can be found in Deutscher (1979). Due to similarities between the geology of the Ranger and Jabiluka deposits, there are subsequent similarities in the hydrogeology at each site.

There are typically two types of aquifers present at Jabiluka - the shallow alluvial and unconsolidated sediments and the underlying bedrock which behaves as a fractured rock aquifer (Kinhill, 1996). The fractures and faults in the bedrock aquifer systems can yield significant flows of groundwater, and the presence of numerous springs at the base of the Kombolgie Formation Escarpment suggests that the sandstone is an important aquifer (Kinhill, 1996).

It has been admitted by ERA that the degree of connection between the deep and shallow aquifer systems is not able to be clearly defined from the available data (Kinhill, 1996). The general water table and pressure levels within the different aquifers is thought to be a subdued reflection of the topography (Kinhill, 1996). The important implication of this is that groundwater will generally flow towards low relief areas, such as floodplains, where it could either mix with billabongs or discharge through springs.

The quality of the groundwater is generally quite good, with low salinity, heavy metal and radionuclide content (Kinhill, 1996; Deutscher *et al.*, 1979). Despite being known for over 25 years, ERA only presented the data from 9 samples of groundwater in the vicinity of Jabiluka in the 1996 EIS, given in Table 14. The data from the PER was not any more extensive.

4.2 Hydrogeological Impacts and Issues

It is clear that the studies performed to date for the Jabiluka project have only ever been for minimum operational and environmental assessment needs, and by no means represent the extensive monitoring and field testing that should be expected for a project of it's kind.

For example, on page 6-28 of Kinhill (1996), it is stated that "the degree of connection between the deep and shallow aquifer systems is not able to be clearly defined from the available data".

[5] - For further information on cyanide management, refer to EA (1998b).

Table 14 - Groundwater Quality at Jabiluka (Kinhill, 1996)

(mg/L)	pH	TDS	Ca	Mg	Na	K	Fe
Bore 170	7.0-7.2	62-99	1-3	7-12	1-2	1-3	7-28
Mean	7.1	72	2	8	1	1	17
Bore 189	6.9-7.0	213-216	2	29	2	1	0.7-16
Mean	6.9	214	2	29	2	1	6
Floodplain[1]	3.6		105	190	360	34	200

(mg/L)	$CaCO_3$[#]	SO_4	Cl	F	NO_3	SiO_2
Bore 170	32-54	2	6-8	0.2-0.4	1	6-9
Mean	39	2	7	0.3	1	7
Bore 189	124	3-8	8	0.4-0.5	1	18
Mean	124	6	8	0.4	1	18
Floodplain		2,084	615	1.1		37

(μg/L)	Cd	Cu	Pb	Mn	U	Zn
Bore 170	0.35-2.4	3.3-13.7	2.6-7.4	0.1	0.33-3.2	0.5-20
Mean	1.3	8.0	4.0	0.1	1.1	14.0
Bore 189	0.5-2.1	3.0-40	2.0-29	0.1	4.2-76	81-224
Mean	1.1	17	11	0.1	25	127
Floodplain	24[2]		129		4	51

Notes [1] - Floodplain data in Kinhill (1996) is the same as Deutscher *et al.* (1979); [2] - described as a "high natural occurrence"; [#] - $CaCO_3$ is hardness.

Furthermore, on page 6-9 of Kinhill (1998), it states that "degree of connection between these two aquifers has yet to be tested comprehensively, but will depend on the presence of faults and fractures which persist upwards from the unweathered sandstone into the weathered sandstone and is expected to vary across the site".

Some principal issues associated with development of the underground mine at Jabiluka and associated surface facilities include :

- the unpredictable nature of hydraulic connections between shallow and deep aquifers, such as the lack of clay barriers or fault and fracture zones;
- difficulties in ascertaining the effects of fractures and faults on groundwater flows - despite assertions in Kinhill (1996) and related documents, it is not believed that yields will be low and a non-issue. More detailed and long term field studies need to conducted before a degree of certainty can be provided to satisfy technical uncertainties;
- oxidation processes are dominant within the surface environment, which may exacerbate the release of heavy metals and radionuclides (cf. Wasson *et al.*, 1998; Wasson, 1992).

It has been argued for many years now that the depth of the Jabiluka deposit has kept it relatively isolated from the more reactive weathering zones at the surface - indeed, the lack of chemical reactions, it is argued, has allowed the persistence of such a large uranium deposit to remain geologically stable (cf. Deutscher *et al.*, 1979; Kinhill, 1996).

However, the Jabiluka project will not leave such natural processes intact after mining - the ore will be exposed at the surface and undergone aggressive oxidation to extract the uranium. Even after being returned underground, it is unlikely that the rock materials and tailings will remain chemically unreactive – the intelligent debate is the degree to which this reactivity causes a reduction in groundwater quality.

It is quite misleading to suggest that mining Jabiluka ore maintains the same chemical inertness over the life of the project.

Furthermore, the storage of large quantities of contaminated water from surface facilities will inevitably lead to contamination of large volumes of groundwater over the life of the Jabiluka project. For example, there was no technical information presented in the PER pertaining to engineered liner systems of the surface tailings pits and waste stockpiles (Mudd, 1998b). **Relying on the natural permeability of fractured aquifers is dangerous indeed !**

The experience at Ranger and Nabarlek demonstrates that this will include recalcitrant problems with salt loadings to groundwater, and may lead to migration of radionuclides. This water may in turn affect surface water features such as nearby creeks and the ecosystems therein.

Extensive monitoring of such pollution at Ranger and Nabarlek has been difficult due to the presence of faults and fracture zones. Given the geological similarity at Jabiluka, such problems can hardly be downplayed or ignored.

In true ERA style, all issues are being addressed as work progresses using a **“trial-and-error”** philosophy. This is in stark contrast to the preventative or pro-active approach the mining industry is trying to implement across the board for environmental management (cf. AMIC, 1992).

4.3 Boywek Hydrogeological Issues

This review of the Boywek sacred site will present evidence based on a “Eurocentric” understanding of science. It will not address cultural aspects considered by the Mirrar. However, the cultural heritage of the Mirrar and their right to protect their indigenous culture are fully respected - a review of the potential impacts to spring flow based on a scientific analysis of ERA’s proposals and data should help to ascertain some threats and potential impacts.

The Boywek sacred site is a spring on the margin of the Magela Floodplain. The Mirrar have consistently stated that it is part of a larger sacred site complex known as the Boywek-Almudj complex, which the Jabiluka project will destroy and threaten. ERA also propose to establish a borefield in Mine Valley to extract potable water for operational purposes, which may exacerbate impacts at Boywek.

The PER for the JMA (Kinhill, 1998), went to great lengths to argue that impacts on the Boywek site would be minimal, if at all. Predictably it is contradictory and fails to assess the potential for impacts on the spring.

The first comment made on the technical aspects of the hydrogeology of the Boywek area, on page 6-10 of Kinhill (1998), states that "drilling was not permitted to be conducted in the Mine Valley area".

How can one assess the hydrogeology of an area without field testing ? You can't ! Therefore the discussion following that initial statement in the PER, including Appendix E specifically dealing with Boywek, is largely irrelevant since no direct hydrogeologic connection has been established.

Given the complex nature of the controls on groundwater flow in the area, it would be reasonable to assume that Boywek Spring will be adversely affected by groundwater extraction in the Mine Valley for potable water supplies and mine dewatering purposes.

4.4 Tailings Disposal and Long-Term Integrity

The issue of tailings disposal has been one of the most contentious aspects of the Jabiluka project. For the JMA, ERA proposed to use cement paste fill technology for tailings disposal, placing 50% underground as mine backfill and 50% in custom excavated surface tailings "pits" (Kinhill, 1998).

Only approvals for complete underground disposal were given, and if ERA were to seek any surface disposal of tailings further studies were required to overcome "scientific uncertainties" (EA, 1998c). Apparently, the current ERA preferred option is to excavate large "silos" within the underground mine specifically for excess tailings disposal.

4.4.1 Physical Containment Issues

The approved option of subsurface tailings disposal still raises significant issues of heavy metal and radionuclide mobility, as well as long term physico-chemical integrity. The use of paste fill was covered in depth by URG (1998).

Firstly, the issue of tailings particle size is critical (Mudd, 1998b). At the Olympic Dam copper-uranium mine in South Australia, which is also an underground mine, it is only the coarse sand fraction which is extracted from tailings and used for cement backfill (Mudd, 1998b). The accumulation of heavy metals and radionuclides would be expected to be in the fine fraction, not the coarse grains, since finer particles have a greater surface area and typically more reactive mineralogy.

The strength of merely cemented ground tailings may not be able to withstand the underground conditions at Jabiluka. The PER did not state what state the cement paste would be placed at either - although paste fill is becoming by accepted by some regulatory authorities, there is often no requirement for curing of the cement paste fill (Mudd, 1998b).

The paste fill could remain “chemically stabilised” but not physically solidified, meaning that the potential for seepage and mixing of paste-fill pore water, infiltration and groundwater will remain.

The surface tailings pits were also to act as retention ponds for excess wet season runoff, exacerbating any ability of the cement paste to cure. The mildly acidic rainfall and runoff in the Kakadu region would only de-stabilise the tailings pits over time (Mudd, 1998b). Perhaps it is no wonder the surface proposal was not approved !

Further points concerning tailings disposal (Mudd, 1998b) :

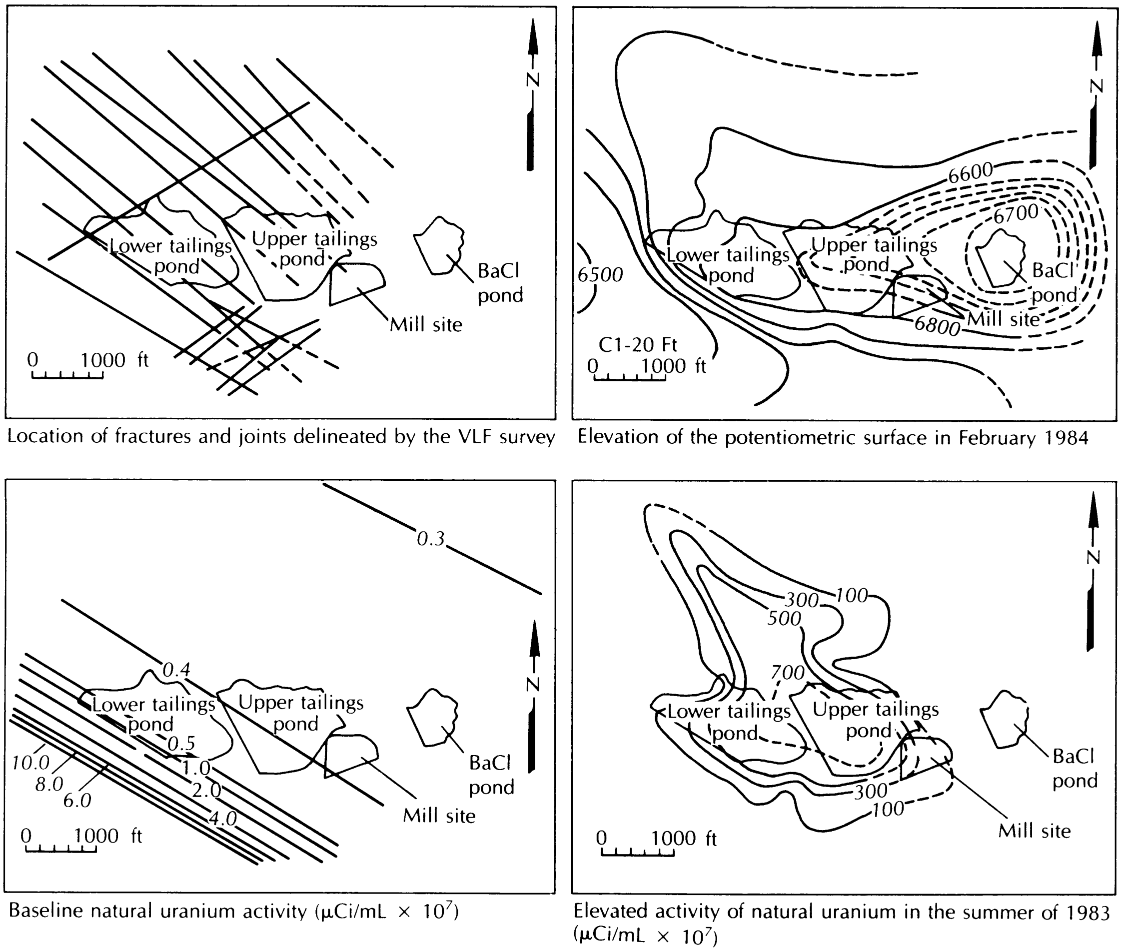
- any seismic event can induce tension cracks within the tailings silos - such cracks would make the overall low permeability of the paste-fill irrelevant as the waste would develop secondary porosity and subsequently the hydraulic conductivity could be dramatically increased by up to several orders of magnitude;
- the consolidation of the cement and possible cracking or fracturing due to increased overburden stresses over time (ie - an increase in effective stress) are ignored;
- the overall permeability, including that due to secondary porosity created from tension cracks and fractures, should be effectively lower than 10^{-10} m/s or more than 100 times lower than the surrounding liner and sediments and rocks it is built within in order to minimise seepage;
- the fractures of the surrounding sandstone that the silos are excavated into are ignored as potential contaminant migration paths.

The issue of fractures is inherently more complex than admitted by ERA and the government. The physical and chemical behaviour of fractures in groundwater flow and contaminant transport are extremely difficult to study and predict – groundwater monitoring at Nabarlek conclusively proved this within the Kakadu region, however, perhaps a more pertinent case study in this regard is a former uranium mill site in Utah, USA.

The tailings facility of the mine was located on highly fractured sandstone, and the direction of groundwater flow was to the southwest. The primary direction of fractures was northwest. Despite the direction of groundwater flow, seepage led to the migration of radionuclides away from the tailings facility along fracture lines, and not with the flow of groundwater along expected hydraulic gradients, shown in Figure 22 (White & Gainer, 1985; Fetter, 1994).

The physico-chemical behaviour of cement paste tailings has yet be demonstrated under conditions of high hydraulic heads (Kinhill, 1998). A related issue is that chemical reaction rates can be faster under higher pressures, a fact well documented from In Situ Leach uranium mines where a minimum hydraulic of 15 m is required for successful mining, and up to 75 m is preferred (Mudd, 1998c).

Figure 22 - Radionuclide and Contaminant Transport in Fractured Sandstone at a Uranium Mill, Utah, USA (White & Gainer, 1985; Fetter, 1994)



4.4.2 *Geochemical Issues*

The long term geochemistry of radioactive tailings can never be proven without the passage of time - engineering is based on experience, and there can never be a time frame established to prove the long term chemical integrity of any tailings disposal system, let alone an emerging technology such as cement paste fill (Mudd, 1998b).

The research by Oullet *et al.* (1998) demonstrated that at a Canadian mine (unnamed), the presence of pyrite that undergoes oxidation or high sulphate levels in the tailings will react with free calcium to form gypsum and highly expansive ettringite. The reaction is represented as Oullet *et al.* (1998) :

$$FeS_2 + 9O_2 + 12Ca(OH)_2 + 2Al_2O_3 + 56.5H_2O \rightarrow$$

$$3Fe(OH)_3 + 2(3CaSO_4.3CaO.Al_2O_3.32H_2O)$$

The end result was that the strength was reduced, fissurisation promoted, which further enhanced the ingress of water and oxygen (Oullet *et al.*, 1998). The Jabiluka ore is known to contain some pyrite which has the potential to generate acid mine drainage. The uranium milling process to be used by ERA, whether at Ranger or a new mill at Jabiluka, uses sulphuric acid to dissolve the uranium. Which ever way ERA decide to proceed, it is likely that high sulphate levels will remain in the tailings, making the use of cement paste highly problematic.

There is no guarantee that the high porosity of cement paste fill will immobilise or reduce radon emanation from tailings disposal sites.

It is curious to note that no technical, conference or journal papers were presented in Kinhill (1998) for the immobilisation of radionuclides, such as uranium and radium. Only hypotheses are presented.

Radium is also more soluble under highly alkaline conditions (Langmuir, 1997), a property well established from the operation of In Situ Leach uranium mines in the USA that all use alkaline leaching chemistry (Mudd, 1998c). The enhanced solubility from radium-calcium co-precipitation is also ignored. **The potential for migration of radium from the cement paste fill would be uncertain, and is ignored in the PER.**

Even if one assumes that heavy metals are immobilised in relatively insoluble mineral forms, the process of diffusion through residual pore water would still occur, and could lead to eventual discharge to surrounding groundwater, although the rates would potentially be slow, there is not enough information presented in the PER to allow an assessment of such rates compared to natural groundwater processes (Mudd, 1998b).

4.4.3 Tailings Summary

The message is simple - the long term disposal of radioactive tailings within a World Heritage area only presents fundamental challenges to human ingenuity that are yet to be demonstrably met. **It is patently absurd for humankind to require something to be safely engineered for 10,000 years - a target which stretches anything humankind has thus far achieved (Wasson *et al.*, 1998). To assess the likely stability of tailings disposal in this light is therefore highly problematic.**

> **The physical and geochemical isolation of radioactive Jabiluka tailings from the World Heritage wonders of Kakadu can never be guaranteed. If the research at Ranger and Nabarlek is the yardstick by which to guide our projections for Jabiluka, indeed, it will eventually become part of Kakadu - the only question is *when.***

4.5 Supervising Scientists' Analysis of Jabiluka

A brief response to the report prepared for the World Heritage Committee by the Supervising Scientist on Jabiluka (SSG, 1999) is presented herein. Based on the research presented within this report on Ranger, Nabarlek and Jabiluka, there are serious misgivings about the approach they use to make the politically necessary statement that :

> *"contrary to the views expressed by the Mission, the natural values of Kakadu National Park are not threatened by the development of the Jabiluka uranium mine and the degree of scientific certainty that applies to this assessment is very high."*

This submission will concentrate it's criticisms to specific aspects of the hydrogeological modelling undertaken for tailings disposal.

4.5.1 Hydrogeological Modelling

Detailed numerical modelling of tailings disposal for Jabiluka was undertaken by Kalf & Dudgeon (1999), for the SSG. Their report utilises various two and three dimensional models, as well as incorporating stochastic approach with Monte Carlo simulations. They conclude :

> "The results indicate that west of the mine it is possible, although improbable, that significant concentrations of uranium and radium could occur in groundwater about one kilometre from the mine. For non-reactive contaminants such as magnesium sulphate, the distance could be several kilometres. However, in this case the contaminated groundwater would be entering an area of known poor water quality and could not be considered to have a significant adverse effect on the water quality.
>
> Weak upward components of groundwater flow are indicated both east and west of the mine. It is considered that any such flow which reaches the shallow alluvial or weathered rock zone will be diluted and flushed away by the annual surficial Wet season flows."

When will the philosophy of "dilute and disperse" be rejected as unacceptable within a World Heritage area ?

However, there are some significant assumptions used in Kalf & Dudgeon (1999) that beg further comment.

Firstly, there is only limited available data on the physical hydrogeological characteristics of the Jabiluka area - a point acknowledged several times by Kalf & Dudgeon (1999). It is simply not possible to undertake computer based modelling of a groundwater system without a sound, technical understanding of dominant flow mechanisms and realistic constraints on boundary conditions based on reliable field data.

The limited data includes a lack of porosity measurements, limited hydraulic conductivity and water level measurements of the numerous aquifers across the Jabiluka site. This data is absolutely essential to contaminant transport modelling in groundwater and can have a direct bearing on the results obtained.

Secondly, in order to undertake contaminant transport modelling, Kalf & Dudgeon (1999) make various assumptions concerning the geochemical behaviour of the specified contaminants of concern (magnesium, sulphate, uranium, radium and manganese). The most important aspect is the approach used to quantify adsorption parameters for modelling.

Kalf & Dudgeon (1999) state that there is no data available for adsorption behaviour of manganese, uranium and radium within cement pastes. Magnesium and sulphate were thought to undergo little adsorption. The adsorption properties of soils and solutes is also strongly dependent on the pH, acknowledged by Kalf & Dudgeon (1999) and SSG (1999).

The behaviour of radium at the Ranger tailings dam, used for comparative purposes, was thought to be difficult to interpret due to complex adsorption-desorption phenomena and formation of a barite co-precipitate phase.

Without adequate, real data, any modelling is essentially guesswork and therefore irrelevant.

Thirdly, there is acknowledgement of the importance of fractures and faults in controlling groundwater through-flow and leaching rates of contaminants from tailings disposal sites. However, the fractures are simply assumed to be an equivalent porous medium on the scale of the model undertaken for Jabiluka !

Compare this to the actual behaviour of fractures at the uranium mill site in Utah, and any confidence in the modelling results of Kalf & Dudgeon (1999) is severely compromised.

The fundamental limitations outlined above show that the modelling of Kalf & Dudgeon (1999) can only be thought of as conceptual at best. The fact that the modelling indicates a small probability that transport of uranium and radium only 1 km west towards the Magela floodplain is extremely worrying. Again, the salt loadings of magnesium and sulphate are dismissed and “dilute and disperse” is the environmental paradigm pervading the work.

4.6 Jabiluka Places Kakadu In Danger

This report has not sought to analyse the entire spectrum of complex environmental and cultural issues relevant to the Jabiluka project. However, the many and varied claims of both the company (ERA), the federal government and the Northern Territory administration are not based on the reality of scientific evidence freely available in industry and academic literature.

The Jabiluka site lacks basic engineering data essential for the investigation and design of such a large project. For example, there is inadequate data on hydrogeological properties of the different aquifers, especially with regards to hydraulic connections between the shallow and deep aquifers. This has numerous implications, ranging from possible impacts on the Boywek sacred site, seepage from contaminated retention ponds and tailings disposal options.

The same inevitable problems with waste water treatment will also prevail at Jabiluka, should it proceed, as currently happens with Ranger and devastated parts of the Nabarlek site. Land application treatment will lead to increased uranium availability and discharge to surface water systems, as well as concentrating in the soils and plants of the area under irrigation. Alternatively, wetlands treatment will allow direct discharge and concentration within aquatic ecosystems of Kakadu.

In any independent scientific analysis of Jabiluka, the end conclusion will always be that mining and processing of uranium ore from Jabiluka will inevitably lead to increased radionuclide levels within the ecosystems of Kakadu.

The scientific uncertainty only relates to the rate and level of increased radionuclide concentrations.

The threats and impacts posed by the Jabiluka project are very real. With ERA's costs escalating, delays constantly troubling the project, opposition growing globally, the future is far from certain for Jabiluka, Kakadu and the Mirrar.

5.0 Social, Political & Environmental Ramifications

This report has demonstrated clearly that uranium mining is unequivocally incompatible with the ecological and cultural values the Kakadu World Heritage area. Already the Ranger uranium has had significant environmental impacts, and the threats posed from just 1,000 years of tropical weathering are perhaps the greatest threat one may identify to any World Heritage-listed property on planet Earth.

The simpleton philosophy of the current federal government, the Supervising Scientist and ERA is that a “significant” environmental impact only relates to a massive collapse of the tailings dam, rampant acid mine drainage, an explosion of the processing mill or a failure of the “no-release” water management system leading to millions of litres being directly discharged to Kakadu in the middle of Wet Season (although tens of thousands of litres seem to be acceptable). Unfortunately there precedents for almost all of these scenarios for different uranium mines around the world, including Australia.

Such a philosophy can only be interpreted to have a callous regard for World Heritage areas such as Kakadu.

Further, the underlying assumption is that slow releases over extended periods of time are perfectly acceptable, exemplified by the (in)famous Supervising Scientist quote from OSS (1989) :

> **“Almost all of the radioactivity from the original ore bodies will be contained in the tailings and … a potential health hazard remains for several hundred thousand years.”**

However, it should be crystal clear that the long term releases are just as damaging as an accute, devastating accidental release. The difficulty of accurately estimating the long term fluxes and ecological behaviour of radionuclides over the times required for uranium tailings is patently obvious.

The activity of mining and milling uranium alters the natural processes in a region and is more likely to lead higher contaminant fluxes through surface ecosystems compared to pre-mining conditions.

A recent guest editorial in the reputable journal Ground Water by Heath (1998) included this statement :

> **"the fact that hydrogeology, because it deals with the unseen and the unseeable, is especially susceptible to interpretation of the facts to meet a client's needs"**

Heath (1998) was writing in regards to hydrogeological and environmental consultants in the United States. The sentiment is perhaps even more relevant to the analysis of radioactive mining operations and the insidious nuclear industry, given the “unseeable” nature of ionising radiation.

The Precautionary Principle, one of the guiding lights of sound environmental management, should lead one to conclude that the risks from uranium mining in a World Heritage area are fundamentally unacceptable.

It is imperative that the World Heritage Committee recognise that :

- the impacts from former uranium mines within Kakadu’s title boundaries is ongoing, has compromised World Heritage values and that further rehabilitation works are necessary;
- the impacts from current uranium mines has been severely underestimated by ideology rather than rigorous application of environmental science and principles;
- the projected future impacts over 1,000 years from the rehabilitation of current uranium mines only make the situation worse, even given “world’s best practice” rehabilitation;
- further uranium mining within the ecosystems of Kakadu, at Jabiluka and elsewhere, places direct, substantial and tangible impacts and threats on the ecological and cultural World Heritage values of Kakadu.

STOP JABILUKA !

SAVE KAKADU !

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