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Introduction

"I came back to this place in 1936. About water. Our people we didn't worry about water. We used to go hunting and visit all the places we used to drink. In the creek, our children they used to swim, get something to eat – used to be. No building here in this area there used to be. We used to walk through bushes through Jim Jim, through Nourlangie, Mudginberri. Now road going through there, and this proper big mining here used to be camping ground (Ranger)! That big billabong there used to be hunting for our barramundi. We used to go down and live there during the Dry.
Now, our people are worried. More worry, because water. Water trouble. That why we asking you we want to really go through and prove his is good water. Because our food we are eating from billabong, plant, long neck turtle, and file snake. Used to be plenty there. Now why is file snake small? What happened?" (Neidje, 1990).

Bill Neidjie, Traditional Owner and resident of country downstream from Ranger Uranium Mine.

Foreword

This document is a submission to the World Heritage Committee, prepared by the Uranium Research Group, a voluntary team of concerned Australian citizens. We are deeply concerned for the long-term wellbeing of Kakadu National Park and its indigenous people. As Australians 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. Some remarkably pertinent documents were unavailable to our working group, and we request the committee to consider why such information was withheld from the public of Australia.

World Heritage Criteria

The scenic marvel that is Kakadu National Park boasts a 19,804km^2 mosaic of landscapes and interacting ecosystems of the Alligator Rivers Region. (see Map 1). Spectacular falls plunge down the sandstone escarpment that borders the Arnhem Land Plateau, feeding rivers that flow through forest lined gorges, savanna lowlands, open *eucalypt* forest, billabongs and freshwater floodplains. By the time these rivers have reached the coastal swamps, mangroves and estuaries, they will have passed through all the major habitat types of Northern Australia.

The activities of the uranium industry threaten all three of the natural criteria (ii, iii and iv) for which Kakadu National Park is listed as a World Heritage area.

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

(a) 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, and changing subsurface structural formations.

(b) 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.

(c) 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.*

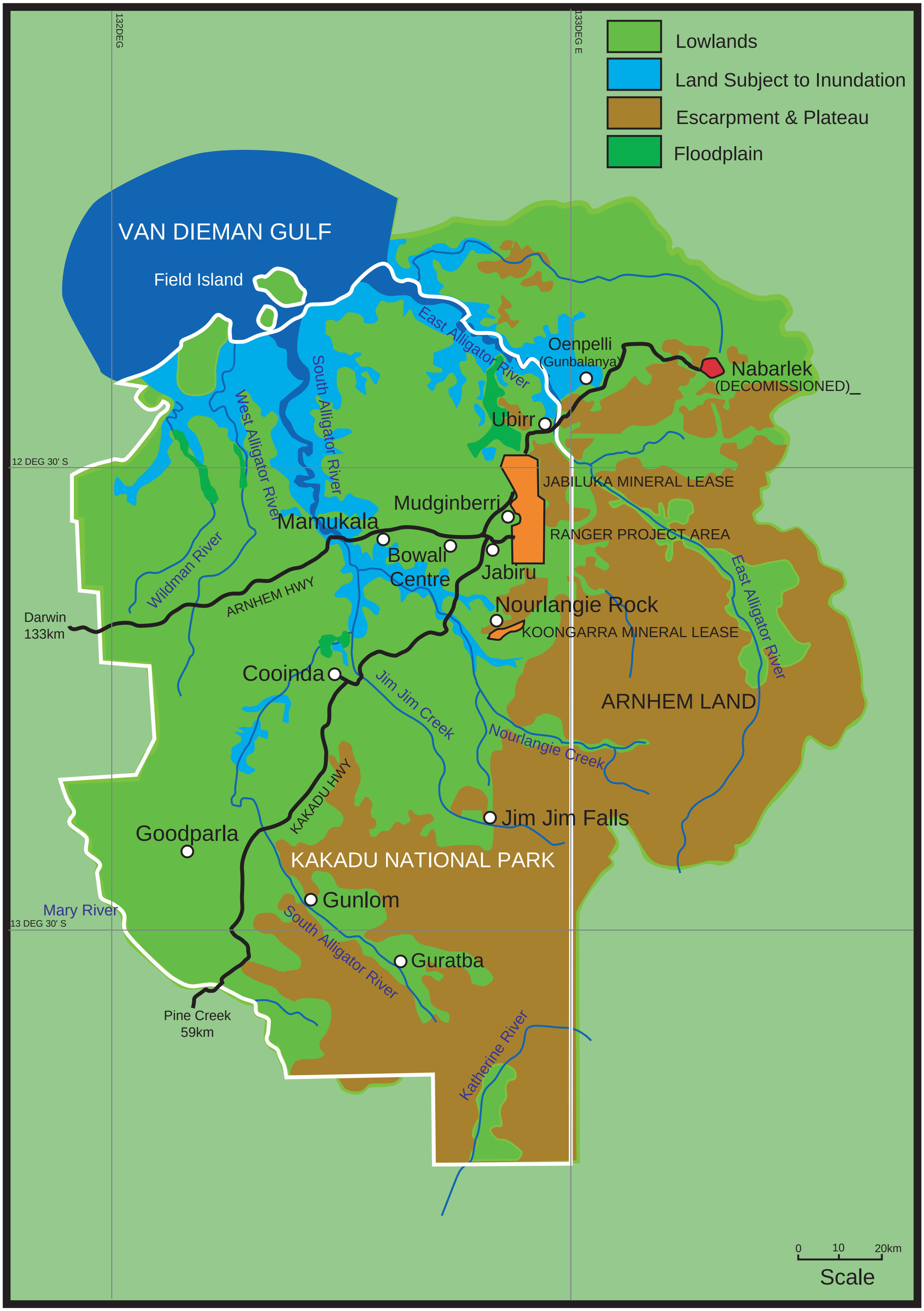
In terms of its natural beauty, Kakadu National Park especially when viewed from the air is one of the most spectacular and unique landscapes. Mining operations and related transport infrastructure create an ugly scar on this otherwise uninterrupted expanse of natural beauty befitting a World Heritage national park. The extent and visibility of this unacceptable blight is not insignificant.

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.

Topographic Features of Kakadu National Park and the Alligator Rivers Region



The Purpose of this Document

- To explain the threats posed to Kakadu National Park by the existing and proposed expansion of the uranium industry

- To provide details of factors that threaten the natural values of Kakadu National Park that meet the criteria of World Heritage Listing.

- To present information that shows how the impact of existing and proposed uranium activities meet the criteria set out by the World Heritage Committee that identify cases of ascertained or potential danger to the natural values of World Heritage Areas.

The Format of This Document

This document contains:

- An analysis of the incompatibilities of the uranium mining and milling industry and the preservation of World Heritage Values of Kakadu National Park.

- An outline of the existing and potential impacts of uranium and gold mining and milling in the Park.

- Detail of the geophysical and geochemical processes that occur in the region, including how they will be disrupted by mining activities, and how these processes provide dispersal mechanisms for contaminants.

- Explanation of the biological impacts of contaminants associated with mining activities.

- Summary of facts that proves the case of ascertained and potential danger to a World Heritage area.

Acronyms

ERA – Energy Resources of Australia Propriety Limited
OSS – Office of the Supervising Scientist
SSG – Supervising Scientist Group
ERISS – Environmental Research Institute of the Supervising Scientist
NTDME – Northern Territory Department of Mines and Energy
EIS – Environmental Impact Statement
PER – Public Environment Report
JMA – Jabiluka Mill Alternative
RMA – Ranger Mill Alternative
AMD – Acid Mine Drainage
ACF – Australian Conservation Foundation
ARR – Alligator Rivers Region
RRZ – Restricted Release Zone
TCZ – Total Containment Zone
BPT– Best Practical Technology
URG - Uranium Research Group

Measurements and Units Used in this Document

Radioactivity

Becquerels (Bq)
Grays (Gy)
Sieverts (Sv)

Distance and Area

Kilometres (km) [=1000 m]
Metres (m)
Hectares (ha) [= 10,000 m^2]
Square Metres (m^2)

Weight, Mass and Volume

Tonnes (t)
Kilograms (kg)
Grams (g)
Litres (l)
Cubic Metres (m^3)
Mega metres cubed (Mm^3)

Concentration

Parts Per Million (ppm)
Parts Per Billion (ppb)
Micrograms per gram ($\mu g g^{-1}$)
Micrograms per litre ($\mu g l^{-1}$)
Millimoles per Litre (mM)

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- State Reference Library (NT)

Chapter 1
Uranium Mining in the Alligator Rivers Region

There has been a culture of uranium mining in the Alligator Rivers Region since 1956. Environmental damage is a well-known adjunct to mining activities. All attempts at rehabilitation within the Alligator Rivers Region to date have been under-funded and largely unsatisfactory. Those mines pre-dated the listing of Kakadu National Park as a World Heritage property. Now we are faced with the continued expansion of the uranium extraction industry, both within the borders of the Park and in its catchments.

Recommendation:

We recommend that the World Heritage Committee

a) recognise that past and present uranium mining activities within the Kakadu region have compromised World Heritage values and that rehabilitation attempts have been manifestly inadequate and;
b) request that the Australian Government end all mining and milling activities within the vicinity, and inside of, Kakadu National Park.

The Alligator Rivers Region is in the central Top End of the Northern Territory. The Region covers an area of about 28, 000 km^2 extending east into Arnhem Land including the catchments of the West, South and East Alligator Rivers (see map 1). Much of the Alligator Rivers Region is Aboriginal land with a rich cultural heritage and many sites of particular significance to the indigenous people. The Alligator Rivers Region is so rich in natural resources and contains so many physical and biological features of high conservation value that it is a World Heritage Listed National Park. The purpose of this chapter is firstly to document the historical activities of the uranium industry in the region and therefore demonstrate its destructive legacy, and secondly, to briefly catalogue the threats posed by proposals for further mining development.

1.1 "Rehabilitated" Uranium Mines

1.1.1 Past Mining in the South Alligator Valley

In 1896 mineral exploration rights were granted in the upper South Alligator Valley minerals field (Kay, 1997). Between 1956 and 1964 13 relatively small uranium deposits were mined (Waggitt, 1998a). El Sherana, Coronation Hill and Palette were mined for gold, uranium and other metals (see Map 1). The other Uranium Development Province mines included Teagues, Rockhole, O'Dwyers, Sterrets, El Sherana West, Koolpin, Scinto 5 , Scinto 6, Skull, and Saddle Ridge. In the first years, ore was milled away from the mines, such as at Rum Jungle and Moline. Later small-scale milling was undertaken in the valley, producing numerous tailings deposits, merely dumped on the ground, some dispersing into the South Alligator Creek during high flows. These were subsequently abandoned and no rehabilitative work was required. The mines remained unrehabilitated on a pastoral lease until the area was added to the Kakadu National Park in 1987. However, in 1986, much of the tailings were transported to Moline for gold extraction, leaving small tailings deposits behind (Waggitt, 1998a).

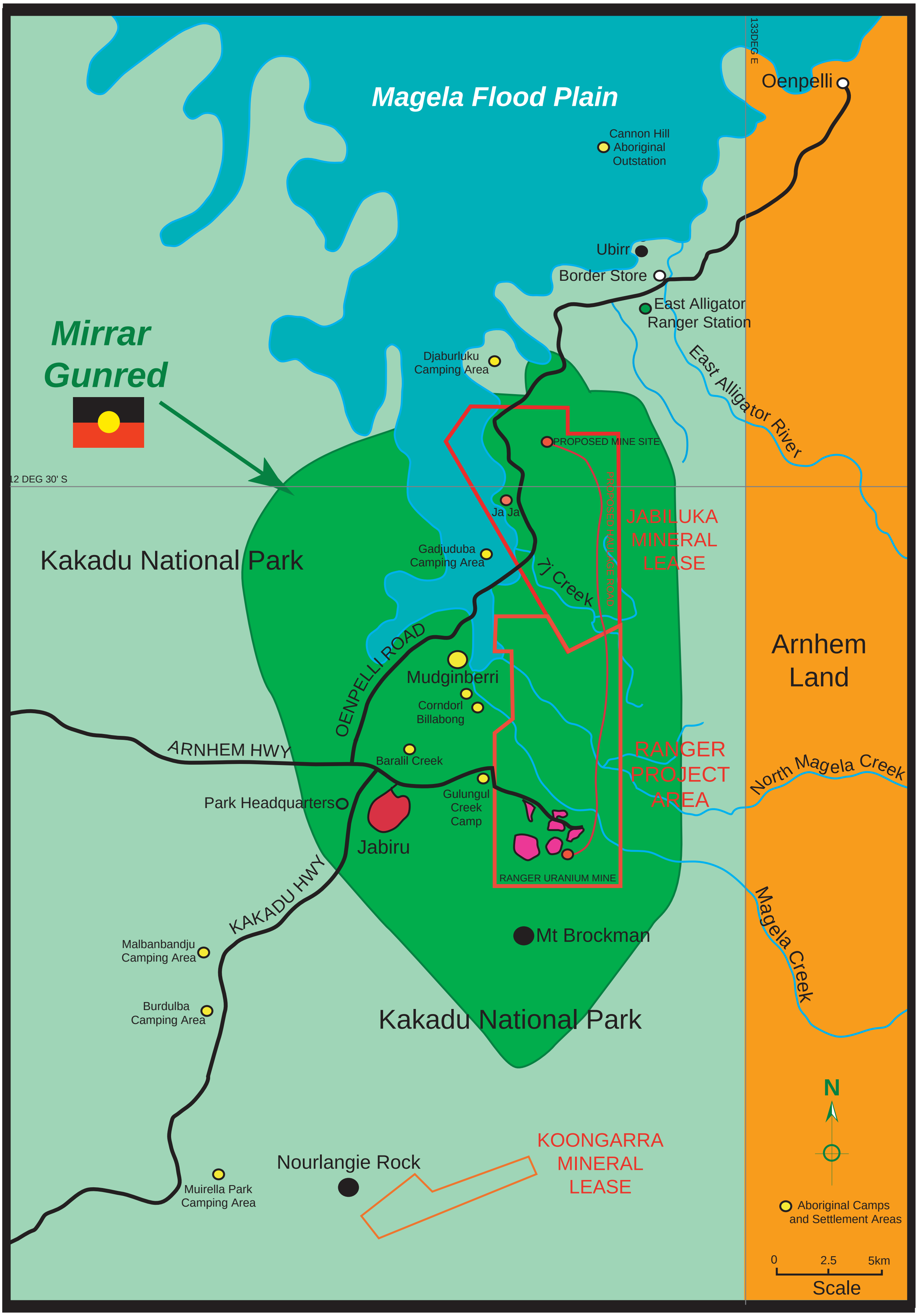
1.1.2 Attempts at Rehabilitation in the South Alligator Valley

Since 1988, hazard reduction works were undertaken, primarily to reduce physical and radiological hazards for visitors to the area. "*The main concern was to make the area safe as possible for casual park visitors*" (Waggitt, 1998a). This emphasis on reduction of *"hazards for visitors"* shows the federal governments' disregard for environmental, indigenous health and World Heritage values. The federal government did not supply sufficient funds for complete rehabilitation. Although most old shafts and adits were collapsed, several shafts at Rockhole and El Sherana were found to contain bat colonies and so were barred with grills and signs. Though there may not be alternative caves for the bats, it would seem potentially dangerous for the bats to dwell in old uranium mine shafts. The long-term effects to these populations could alter them from the other bat colonies of the region, thus interfering with their natural evolution in a National Park. Waggitt (1998a) did not discuss this.

Despite the suggestion to keep the old mill intact as a part of the Alligator Rivers Region's mining heritage, the only safe course was considered to be dismantling and burying it (Waggitt, 1998a). Interestingly, the mill was buried 1.5 km from its original setting, still deep in Kakadu National Park. All the refuse was covered in 1.5 metres of earth. The 1991 estimated dose rate at the mill area was found to be 6.6 mSv for full time occupancy, well above the target dose rate of 1 mSv/y. The El Sherana sites were also high at 12 mSv and 24 mSv for the weighbridge and battery respectively (Waggitt, 1998a). In 1992 further burying-type cleanup works were performed, reducing dose rates to "*acceptable*" levels. Further remedial patching and burying has been undertaken in subsequent years and seems to be an ongoing priority.

The case of the hazard reduction works in the South Alligator valley exemplifies the abilities of the environment to erode earthen covers to radioactive wastes, raising concerns for the long-term containment of the larger tailings dumps.

Location of Ranger Uranium Mine and the Proposed Mine at Jabiluka in Relation to Mirrar Gunred



1.1.3 Nabarlek Uranium Mine

Nabarlek is a decommissioned uranium mine and mill which is situated in western Arnhem Land in the Cooper Creek catchment, a tributary of the East Alligator River. The orebody was discovered in 1970, and open-cut mined in 1979 producing 2,330,000 tonnes of overburden. The 564,437 tonnes of ore at 1.86% U_3O_8 was processed from 1980 to 1988 (Wilde and Noakes, 1990). The 157,000 tonnes of below ore grade material at 0.05% U_3O_8 was stockpiled for later heap leaching (Wilde and Noakes, 1990). Decommissioning of the mill began in December 1994 and was completed in the dry season of 1995 (Kay, 1997). Contaminated items unable to be resold were buried below the base of the final cover of the pit, along with the tailings, evaporite and building foundations (Kay, 1997). Landscaping earthworks involved filling with waste rock and stockpiled topsoil, whilst revegetation involved seeding with *"a mixture of grass and a wide range of native species"* (Kay, 1997).

Following a visit to the site by one of the contributors of this document it became clear that the rehabilitation was still not complete. The old office and camp buildings are only semi-dismantled, diesel and water tanks and concrete pads are still there, (see Plate 1.1) (D. Hazell, pers. comm., 1998). It is not at all the epitome of rehabilitation that the uranium industry frequently suggests.

The revegetation is a slow ongoing process that has needed nurturing, but the weed situation is concerning. In 1994, it was found that on the waste rock dump at Nabarlek, some 30% of the herb species were weeds (Brennan & Bach, 1994). The weed infestation in 1997 was described as a *"few remaining spot infestations (mainly Mission Grass)"* and the weed control program would be repeated as required (Supervising Scientist, 1997).

There are still obvious infestations of weeds, notably *Pennisetum* spp (including mission grass), *Brachiaria mutica* (para grass) and *Passiflora foetida* (wild passionfruit) on and around the mine/mill site (see Plate 1.2) as well as 22 other species of alien plants. (D. Hazell, pers. comm., 1998). Even though there is apparently a high level of confidence that the rehabilitation objective (of establishing a landscape that matches as closely as possible the surrounding areas and would permit traditional food collection) (Waggitt, 1998b), until these weeds are eradicated this is unlikely. Instead of a weed eradication program, there is denial of their very existence! The 1997 Environmental Performance Review post-Wet season inspection of the Nabarlek mine site summary report concluded that *"no weeds were observed during the inspection"* (Supervising Scientist, 1997). Hence, the following questions must be asked, if the Environmental Performance Review inspection was thorough, did they not have the knowledge to identify the weeds, or do they not interpret these weeds (though none are native) as weeds, or did they lie? There are weeds there! Mission grass increases the intensity of fires whilst displacing native species (Russel-Smith, 1995). Para grass is notorious for altering floodplain vegetation and its presence at Nabarlek is a source for its distribution throughout the Cooper Creek catchment. Wild passionfruit vine smothers native vegetation (Smith, 1995) altering natural ecosystems at a dramatic rate.

The list of reported environmental breaches is in Appendix 1, but there is no mention of the methods used to assess the breaches as having "*no significant environmental impact*".

One of the concerns with Nabarlek is that *"...below ground deposition means that the tailings may be subject to transport by groundwater flows"* (Panter, 1997) allowing the pollutants to flow into Kakadu National Park. Another concern is that over time, the top cover could erode, allowing, particularly the radon gas in the tailings, to be dispersed. Planned use of clay layers within the pit above deposited tailings, to prevent escape of radon gas were not included in the final decommissioning of the site (http://www.erin.gov.au/portfolio/ssg).

1.2 Current Uranium Mining Activities

1.2.1 Ranger Uranium Mine

The Ranger Uranium Mine is the only operating uranium mine in the Northern Territory. Situated within Kakadu National Park, the Ranger Uranium Mineral Lease occupies 7,860ha, of which 660ha is directly disturbed by mining activities (Legislative Assembly of the Northern Territory, 1998). The operations are very close to the Magela Creek and a number of its tributaries, which flow into the East Alligator River (see Maps 1.1, 1.2). The proposal to mine Orebodies One and Three was jointly developed by the Australian Atomic Energy Commission (i.e. the Australian government) and Ranger Uranium Mines Pty Ltd. - a daughter company of ERA. Construction of the mine facilities began in 1979 and mining of Orebody One, using the conventional open pit mining method, began in May 1980. Orebody One, which contained 59,000 tonnes of uranium oxide, with an average grade of 0.24%, was mined out in 1994. Mining of Orebody Three commenced in 1997. Orebody Three contains 53,000 tonnes of uranium oxide at 0.28 % grade.
(http://www.erin.gov.au/portfolio/ssg/austuran/ranger.html)

For the first 16 years of mine operations, tailings were deposited in a 1km^2 tailings dam. The dam is now in the process of being emptied, as it is no longer considered Best Practicable Technology (BPT). Although assurances were given about the capability of the dam to withstand severe wet seasons which are typical in the Top End, a number releases of tailings water have occurred. The ecotoxicological impacts of these radioactive tailings on the Magela Creek watercourse and downstream environments that are within Kakadu National Park have not been placed in the public domain. We are left with no other conclusion than this data has been withheld to prevent independent analysis and therefore the drawing of independent conclusions.

Widespread and internal concern about the dams potential to collapse and inabilty to function and protect the environment from receiving tailwater, underlies its recent abandonment. The 180 x 750 m pit One is now the depository for tailings. However, work on containment in the permeable sections is still necessary (Kinhill, 1997). When the pit is filled with tailings, supposedly at the end of mining, plans are to allow it to dry, stabilise and cover it with clay and rock to a maximum height of 24 m above the surrounding landscape, and then revegetate the area (Kay, 1997). The waste rock dumps will also be large hills in an otherwise smooth landscape. Pit Three, which is under what was Djalkmarra billabong, is destined to be a lake again (Unger & Milnes, 1992), a dubious rehabilitation option. The mine is expected to be decommissioned in 2012.

Although the Supervising Scientist, the government authority charged with assessing the environmental performance of Ranger Uranium Mine, has recognised that there have been many breaches of quality control, it is asserted that there have been no significant environmental effects outside of the minesite (Kay, 1997). However, the operation of the Ranger Uranium Mine has involved incidents external to the mine project area that could well have been detrimental to the environment. The spillage of acid at the Darwin wharf and a sulphur fire at Noonamah were noted for their lack of mention during the December 1996 Ranger Uranium Mine Environmental Performance Review 6 (Supervising Scientist, 1997). In addition, cumulative effects from repeated incidents is a real possibility (Kay, 1997). There have been over one hundred breaches of the Environmental Requirements (see Appendix 2) and no known mention of cumulative impacts or description of what criteria and research was used to assess the apparent lack of environmental impacts. This is an untenable situation that illustrates the ineffective Environmental Impact Assessment (EIA) process in Australia, a process that needs improvement, not the insidious dilution that is occurring.

The main environmental issues concerning the Ranger Uranium Mine are tailings containment and water management, both resulting in contamination of the natural environment. The radioactive tailings are being dumped in leaky pits in the swampy region near one of Kakadu's important creeks, the Magela Creek. In this seasonally inundated environment punctuated by intense storms, rapid flooding, and accession of water into the watertable, leaching is occurring and will continue to occur. There already exists growing mineral plumes from the Ranger tailings dam. The Magela Creek, which now has double the pre-mining levels of uranium flows into the Magela floodplain, recognised for the immense flocks of water birds.

The water management situation is fraught with problems and dubious company exhortations, such as those given regarding the 1995 water release saga. ERA reported that it did not release its Restricted Release Zone (RRZ) Retention Pond 2 (RP2) contaminated water directly into the Magela because of Aboriginal community opposition (Kay, 1997). However, the truth is that while this incident was being considered in the courts, water flow in Magela Creek diluted the elevated concentrations to below required levels. ERA showed a complete lack of regard for aboriginal people when Traditional Owners living downstream of the mine were given no choice about refusing the release. Radioactive and heavy metal pollutants do not disappear when diluted. The same amount of long-term contamination remains after water has evaporated in the dry season. Dilution is NOT the solution to pollution as the uranium industry insists.

That releases are frequently made from three water storages at Ranger Uranium Mine is a demonstration that ERA and the Australian and Northern Territory Governments give a higher priority to economic gain, as opposed to their environmental responsibilities.

Retention Pond One was originally a small tributary of Magela Creek that overflows directly into Coonjimba Creek, and from which extractions were made in the construction of the dam walls at Ranger Uranium Mine. Today, runoff from waste-rock has resulted in poor water quality, with elevated levels of uranium, sulphates and electrical conductivity.

Retention Pond Four collects runoff coming from the below-grade ore and the waste-rock dumps. It contains elevated levels of magnesium, calcium, sulphur and sodium. When diluted it is periodically released into the Magela Creek via Djalkmarra Billabong.

Retention Pond Two is within the "*restricted release zone*" and contains runoff from the ore stockpiles, the pits and the process plant. This water is acknowledged as having unsafe contamination of uranium, and other elements. The original EIS was approved on the basis that this water would be contained at all times. It is now used for processing, to water the lawns and gardens, to suppress dust, and to revegetate some areas. Excess Retention Pond 2 water, which is also supposed to be kept contained, is sprayed on 35ha of the nearby woodland all dry season (irrigation) and released through local wetlands (wetland filter) to a flood irrigation area.

1.2.2 Jabiluka Uranium Mine

The highly controversial proposed Jabiluka Uranium (and possibly gold) Mine is under simultaneous environmental assessment and construction. Situated within Kakadu National Park, the Jabiluka lease occupies a 7,300ha area immediately adjacent to the Ranger lease (see Map 1.2). The Orebody one was discovered in 1971 but was determined to be economically unviable. Orebody two, discovered in 1973, contains an estimated 90,400 tonnes of uranium oxide (U_3O_8) at an average grade of 0.46%.

The original Environmental Impact Statement (EIS) was approved in 1982, but that proposal is no longer acceptable. Energy Resources of Australia bought the lease in 1991 and in October 1996 completed the second draft EIS for the Jabiluka Mine proposal for an underground mine. As the Senior Traditional Owner, Yvonne Margarula, refused permission for the transport of Jabiluka ore to Ranger, a new milling proposal was formulated. Thus a less thorough environmental assessment, the Public Environment Report (PER) was created for the option of milling at Jabiluka (Kinhill, 1998).

The area to be disturbed and the extent of associated environmental impacts depends on whether ore is processed at the existing Ranger Mill (the Ranger Mill Alternative (RMA)) or at a new mill on the Jabiluka site (the Jabiluka Mill Alternative (JMA)). The proponent and the respective governments favour the cheaper option of milling the Jabiluka ore at the Ranger mill. However, the added burden of very fine radioactive tailings (which are expected to be some 220m x 220m x 220m in size) will fill the Ranger pits above the highly permeable levels (Kinhill, 1997), which is an unacceptable outcome. In addition to all the transport problems, there is a potential for acid mine drainage from the Jabiluka ore (less likely from Ranger ore), raising the potential for increased mobilisation of contaminants into the biosphere (Kinhill, 1997).

At present the Federal Environment Minister has serious concerns about the proposed disposal of tailings, water management and the use of paste fill technology as detailed in the latest environmental assessment, the Public Environment Report (PER), and is awaiting amendments to the Jabiluka Mill Alternative (JMA) proposal. Nevertheless, ERA have proceeded with construction of the mine part of the project, without a chosen or approved disposal method. An estimated 19,300,000 tonnes of ore will need processing, and it is irresponsible to proceed with any mine works until an acceptable disposal method has been identified. One option that has yet to be considered, but which poses additional problems, is the "*out of Kakadu*" option. This has been ignored by ERA as being too expensive, illustrating that economic viability of Jabiluka Uranium Mine depends on sacrificing environmental and cultural values of a World Heritage Area. If the true ecological costs are factored into this mining operation, it would become an economically questionable project.

The water management concerns at Jabiluka Uranium Mine are similar to those at Ranger Uranium Mine, except it is still possible to avoid the pollution. The Jabiluka Uranium Mine site lies in the catchment of Maumudjimajali Creek which flows into the Magela floodplain 3km downstream. It currently has the highest rating for water quality, and is considered a pristine, unpolluted creek (Kinhill, 1998).

The hydrology, hydrogeology and climate of the Alligator Rivers Region are highly unpredictable and extreme. Despite these essential features of the Region and potential mine impacts, the NT Government over the last 10 years, has closed down more than half the hydrological gauging stations in the Kakadu region, including the Magela Creek floodplains. The lack of understanding about water flow events, surface-groundwater interactions and prolonged high watertables, combined with the demonstrated failures of water containment systems at Ranger Uranium Mine suggests that mining at Jabiluka would result in significant contamination of surrounding ecosystems. It is highly unlikely that total containment can be achieved within the Jabiluka Total Containment Zone, especially over the extended time span of contaminant toxicity.

Also situated on the Jabiluka Mineral Lease is the Ja Ja facility, within 200 m of the Magela wetands (see Plate 3.1). The sheds have housed radioactive core samples exposed to the open air for the last few decades. This disregard for the safe containment of these radioactive exploration wastes is typical of the uranium mining industry.

1.3 Proposed Uranium Mining Activities

1.3.1 Koongarra

Koongarra is a proposed uranium (and gold) mine with a lease of 12.5 km^2, which is within Kakadu National Park. The Koongarra deposit lies about 3km east of Nourlangie Rock, a well known tourist attraction featuring Aboriginal rock art galleries (one of the two major publicly-accessible art sites in the Park), dramatic cliffs, scenic lookouts and bush walks (see map 1.2). The Koongarra area is drained by the ephemeral Koongarra Creek that flows west into Nourlangie Creek, entering just south of Nawurlandja (the "Blue Paintings" site). Nourlangie Creek flows north to the Woolwonga wetlands and finally to the floodplain of the South Alligator River.

In the Koongarra No. 1 deposit there is some 3,453,000 tonnes of ore grading 0.44% U_3O_8 , though 94% of the uranium is contained in 1,831,000 tonnes of ore grading 0.795% U_3O_8 (Snelling, 1990). There is also 3.11 tonnes (100,000 oz) of gold mineralisation. The development plan includes a 450 by 250 metre open pit, about 100 metres deep. About 11,000,000 tonnes or 5 Mm^3 of ore and waste rock would be extracted (Snelling, 1990). In the 1978 draft Environmental Impact Statement, it was envisaged that the mill would operate continuously. The first proposal for storage of tailings in the draft EIS was for a valley fill impoundment near the pit, but this was changed to an above ground tailings dam of 70 ha with an average embankment height of eight metres.

The status of the proposed Koongarra mine is in active stasis. It is awaiting change of boundaries, negotiations with the Traditional Owners, and possible further environmental assessments. The Fox Report concluded that Koongarra should not go ahead under any other circumstances as it is *"so valuable ecologically that we would oppose in principle any mining"* (Fox, 1977). Because this proposed mine is in the South Alligator catchment, it is in the heart of a conservation zone, and should never be disturbed. The area is exquisitely beautiful.

1.4 Exploration for Uranium

Unfortunately, the listing of Kakadu National Park as a World Heritage Property has not halted investigation for further mineral development in the Alligator Rivers Region.

1.4.1 Other Uranium Deposits Within Kakadu National Park

There are many diverse mineral deposits in Kakadu National Park, usually uranium, gold and/or copper mineralisation. The Ranger 68 deposit is in the wetlands to the east of the Jabiluka deposit, within the ERA lease area. *"A quantification [of it] was required for submissions to Government"*, and they calculated a resource of 15,000,000 tonnes and speculation regarding further substantial deposits was described as *"highly encouraging"*. (Browne, 1990). It cannot be ruled out that permission to mine this deposit is granted in the future.

Other deposits between the South and East Alligator Rivers include gold at Ranger 43, copper-uranium at Ranger One Nos 2 and 9, and Rangers 34 and 52; nickel-copper at Ranger 39; lead-zinc-copper at Rangers 53, 54, 64, 65, 66, and 67; manganese at Ranger 37; nickel at Ranger 50; and over 70 uranium prospects (Browne, 1990). A continuation of mining-friendly government could well see a further expansion of mining in Kakadu National Park, with a change of Park and World Heritage boundaries being a possibility.

1.4.2 Western Arnhem Land

As depicted in Map 1.3, over a third of West Arnhem Land is under active mineral exploration, predominantly for uranium (Scott, 1998). Although Arnhem Land is freehold Aboriginal land, the Northern Land Council negotiates with mining companies on behalf of the Traditional Owners. Under *the Aboriginal Land Rights (NT) Act 1976*, once the title to explore for minerals has been granted by the Northern Land Council, the mineral companies are under no obligation to seek further consent before commencing mining a deposit. Thus much of the country east of Kakadu National Park, encompassing the East Alligator River, is open to mining development.

There are currently sixteen recently granted exploration licenses in the Arnhem Land portion of the Alligator Rivers uranium field and a further thirty under negotiation. All the contemporary files on the exploration licenses are being held in a "*closed*" state by the NT Department of Mining and Energy in order to withhold current commercially or politically sensitive information (Scott, 1998).

Any mines, in the upper or middle reaches of the East Alligator River, adjacent to Kakadu National Park, could be detrimental to the integrity of the Parks ecosystems. It is disappointing that the system for protection of this World Heritage property allows for almost unlimited minerals development in the catchment and vicinity of the Park.

1.5 A Culture of Mineral Exploitation

European development has brought a culture of mineral exploitation to the Alligator Rivers Region. There has been a tradition of using the land to extract minerals, exploiting Aboriginal labour (in the 1950s and 1960s) and blatantly ignoring the concerted opposition of indigenous people to exploitation of the country on which their livelihood and culture depends. There is an industry tradition of mining as quickly and cheaply as possible, without rehabilitation or compensation. This has led to the disciplines of mine-site rehabilitation, restoration ecology and constructed wetlands for waste-water treatment, and fuelled the mining industries' opinion that they are environmentally responsible. However, these are new initiatives and their long term effectiveness is yet to be demonstrated.

As illustrated in this report, the ingrained historical culture of exploitation and disregard for environmental values is still evident. The priority has not shifted from economic gain at ecological cost, to more sustainable and acceptable approaches. Contaminants are continuing to pollute the ecosystems of Kakadu National Park. The debacle and catastrophe of contamination from the Rum Jungle Uranium Mine (into the Finniss River) and the more recent lack of rigour with regard to the Nabarlek clean up operations give little hope as to the safety of future management and rehabilitation. Aesthetic impacts, weed invasions and scarring of the landscape are additional and not insignificant impacts.

Further, many international and national agreements have been systematically broken, indicating that mining is incompatible with environmental and cultural conservation. Multiple land use in sensitive ecosystems is clearly a contravention of agreements to protect World Heritage Values. This is purported to be the major reason why the Commonwealth Government did not accept World Heritage Listing of the Lake Eyre Basin in Central-Southern Australia. Confronted with the unanimous recommendations from leading scientists around the world, this remarkable decision has allowed continued exploration and mining to continue with less effective opposition, including uranium mining at Roxby Downs.

Chapter 2

The Aesthetic Values of Kakadu National Park

Kakadu National Park is renowned for its intense beauty. Beside the large number of people that come to view the spectacular scenery, the indigenous people are accustomed to its diverse natural splendours. Mining activities seriously jeopardise the natural and cultural beauty of this region.

Recommendation:

We recommend that the World Heritage Committee:

a) recognises that the aesthetic values of Kakadu National Park are degraded by mining and milling processes,
b) recognises that rehabilitation goals are unachievable and visually unacceptable; and requests that the Australian Government stops the destruction of aesthetic qualities and preserves the unique beauty of the area for future generations of people.

The focus of this chapter is to reveal the extent to which mining in the Kakadu National Park undermines the aesthetics of the Park, which is a breach of Natural World Heritage criterion (iii) *...areas of exceptional beauty.* The focus is on the already established Ranger Uranium Mine to highlight the general problems surrounding the recent Jabiluka Uranium Mine developments and possible Koongarra Uranium Mine. The examples demonstrate the infringement by mining companies on the aesthetic qualities of the Park, in particular the visual impact on the landscape. Other impacts such as noise pollution, presence of industry, and the effects of the proposed regeneration plan, add to the complexities of the threat to Kakadu's natural beauty.

2.1 Aesthetic Qualities of Kakadu National Park

The natural beauty and diversity of Kakadu National Park is one of the many reasons for its World Heritage listing. Kakadu National Park is in possession of some of the world's most exquisite examples of natural beauty. There are an infinite array of aspects of Kakadu National Park that are pleasing to view: from the delicate fern, moss and debris assemblages on speckled boulders, and the exquisite array of wildflowers and birds, to the ancient rolling hills, sea of savanna forest, sweeping floodplains, and splendid cloud formations. The lush wet season growth is stunning. The focal points of Kakadu National Park's great natural beauty lie in its wetlands, spectacular escarpments and outliers (Australian National Parks and Wildlife Service, 1991). The rivers wind grandly across the relatively new floodplains. These are a complex mosaic of magnificent paperbark swamp forests, seasonal herbfields with immense grass and sedgeland plains, waterlily swamps and billabongs, and mangrove forests with samphire salt flats (Russell-Smith *et al.,* 1995).

Vertical and stepped cliff faces up to 330 metres in height extend in an unbroken line for several hundred kilometres. This escarpment and its outliers have provided naturally formed galleries in which the Aboriginal Traditional Owners have been able to establish a chronicle of their culture for thousands of years. At least 3,500 art sites have been recorded from the escarpment (Australian National Parks and Wildlife Service, 1991). The inherent symbolic and aesthetic value of these works are intrinsically linked, and is not only fundamental to the Aboriginal culture, but holds significance to those outside the tradition for their sense of appreciation and understanding. "*The rock art of Kakadu is acknowledged as a significant body of art in an aesthetic sense. Some examples of art in the Park equal works of art anywhere in the world"* (Kakadu National Park Plan of Management, 1991).

The Jabiluka Lease site contains two outliers (see Plate 2.1). These rock formations are uncommon within the Park. They are a part of the relatively undisturbed Arnhem Land escarpment and offer close views of the lower Magela Creek wetlands. (refer to Plate 2.2) *'Together with the hills flanking the South and East Alligator Rivers, the Escarpments (Marrawal and Arnhem) provide the visitor with a sense of enclosure unusual in other easily accessible parts of Kakadu'* (Wood, 1990).

2.2 Critique of Criteria Fulfilment

One of the natural criteria for a World Heritage property is that it must have, "*unique, rare or superlative natural phenomena, formations or features or areas of exceptional natural beauty"* (Australian National Parks and Wildlife Service, 1991). The mining agreements for both the Ranger and Jabiluka Uranium Mines brought with them a conflict of the principles of aesthetics and the integrity values of the Kakadu National Park. It would appear that ERA's sense of aesthetics are guided only by what cannot be physically sighted from the main tourist routes. But the Traditional Owners must be suffering from the immense blights that are the physical manifestations of the uranium industry within their homelands.

ERA's distinct lack of understanding of these aesthetic values is evident in their Jabiluka uranium mine proposal. *"The predominantly open woodland between the road and the steep terrain of the outliers provides a dense visual screen in most locations so that lower elevations of lands further to the east cannot be* *seen from the Oenpelli Rd."* (Kinhill, 1996). It appears that concealing the industry from passing tourists with a cluster of trees is a sufficient enough response to protect aesthetic qualities to the high standards expected of a World Heritage property. The ERA proposal ignores the non-visual impacts on aesthetic values such as unnatural noise. It also disregards the scenic flights of an estimated 30, 000 visitors per year who fly over the lease areas (Kinhill, 1997). There are also ground level views other than the Oenpelli Road, for example from the escarpment. Possible sightings could be "*...ore stockpiles seen on the profile, colour/texture of the landscape; especially when viewed by bush walkers in more natural areas nearby and tourists on aerial tours of the Park" (*Kakadu Conservation Zone Inquiry Final Report, 1991). The mines and their support population mean that huge road trains are frequently thundering along the Arnhem and Oenpelli Roads, adding an unacceptable industrial feel to the otherwise peaceful surrounds.

There is no doubt that the Koongarra proposal would reduce the aesthetic qualities of the exceptional Nourlangie region. If heaven were as beautiful, there would be no evil.

2.3 Short Term Mining Impacts on the Aesthetics

The short-term impacts on the aesthetic values of Kakadu National Park include: major road construction and bridge building in a currently undisturbed area, vegetation clearance, increased erosion, weed invasion, impacts on surface water flows and quality as well as decreased air quality, especially during the dry season (Kinhill, 1997). The transportation of radioactive material and industrial chemicals in a national park appears contradictory to the aesthetic principles of the park as well as those considered important by the World Heritage Committee.

With regards to mining in the previously proposed mining in the upper South Alligator, the Australian Heritage Committee noted "*...that the physical impacts of further mining would diminish the zone's aesthetic value if further mining were to proceed. Noise, dust and adverse visual impact would adversely effect the perceptions of KNP"* (Kakadu Conservation Zone Inquiry Final Report, 1991). The same would be said for the possible Jabiluka and Koongarra Uranium Mines.

2.3.1 Visual Impacts of Mining on Aesthetics

The construction of Ranger Uranium Mine made the visual implications of mining apparent (see Plate 3.2). The use of open-cut mining is not only visually unpleasant but alters the landforms of the area permanently. The most visible modification to the landscape is the pit area and the associated immense tailings dam and waste rock dumps containing material excavated from the pit. Further impacts on the visual aesthetic principles of the Park are:

- Clearing of vegetation and possible indirect effects from the production of dust
- The industrial site and associated buildings
- Twenty-four hour lighting
- Trucks thundering down the roads of Kakadu National Park
- A decrease in animal abundance and possibly diversity in the vicinity of the mining operations.
- Construction and possible expansion of the town of Jabiru to service uranium mining in the region.

The Ranger Uranium Mine operations have entailed the destruction of 660 ha of previously intact country (Legislative Assembly of the Northern Territory, 1998). The construction at Jabiluka so far has involved the clearing of 11.4 hectares of land (see Plates 2.1 and 2.2) and is expected to be at least 159 hectares following permission to proceed. This area for direct destruction doesn't include the construction of a 22.5 km bitumen road between Jabiluka and Ranger Uranium Mines. This road is proposed to bridge the Magela and North Magela Creeks and other tributaries (Kinhill, 1997) in a completely undisturbed, predominantly wetland region.

The use of heavy road trains and trucks for mine and staff support related transport along the Arnhem Highway and Oenpelli Road creates additional impacts on the aesthetics of the Park. The Oenpelli Road leads to Ubirr Rock, a destination of significant visual appeal and a greatly revered site for owners and visitors alike.

2.3.2 Mine Related Noise Levels

The construction, operation and decommissioning of mines exposes Kakadu National Park to adverse noises and deprives the surrounding areas of their natural sound qualities. The noise from underground blasting at Jabiluka is the greatest threat to the loss of audio-aesthetics (Kinhill, 1997). Other noise pollutants resulting from mining exist at the backfill plant, the mobile plant, with the use of ventilation fans which reach 85 d.b.a. at a 3m distance (Kinhill, 1997), and electricity generators at the processing site. Although helicopters are used all year round, they are especially used during the Wet in conjunction with airboats, which will add further noise impact on the surrounding areas (T. Anderson, Project Manager of Jabiluka, pers. comm., 1998). Busy mines create a huge demand for trucks, which thunder along the roads of Kakadu National Park. In addition all the staff and their visitors vehicles create a lot of traffic entering and departing Kakadu National Park. All of these industrial sounds conflict with the native sounds within the Park. Noise levels will be higher during the dry season, and could be double current background levels at distances 5km from the pit. (Dames & Moore, 1988). At night, the trucks at Ranger Uranium Mine can be heard from fifteen kilometres away.

2.3.3 Vibration Effects on Sensitive Sites

The Jabiluka Project EIS states that two sites of significance to the Aboriginal owners are located in the vicinity of where the ground vibration of the blasts exceeds the accepted peak velocity criterion of 3 mm/sec. for archaeological sites (Kinhill, 1997). This demonstrates the disregard of the mining company towards the protection and conservation of sacred sites.

Such costs are considered acceptable because they are ‘part of the price of progress’ and some would say because they are also compensated by royalties. However, the short term time-frame and so called gain from the uranium mines in Kakadu National Park is possibly meaningless to aboriginal people, whose sacred sites, history and future is based on a significantly different scale, both temporal and spiritual.

There are reports of predicted damages up to 400 m from blasting operations at other mines, for example *"...legitimate claims of damage from blasting vibration… Repeated vibrations, such as those from a nearby quarry, may eventually cause damage"* (Sengupta, 1993).

The sanctity of these significant sites for their owners would most likely be detrimentally affected by the presence of nearby industrial activities.

2.4 Tourism and the Implications of Mining

According to a survey of visitor perceptions of Kakadu National Park (Australian Nature Conservation Agency, 1994), the main factors leading to visitor enjoyment are:

- Beautiful scenery
- Sighting of rock art
- Yellow Water cruises

Mining at the Jabiluka thus undermines one of the main reasons people come to enjoy the Park; that being the aesthetic appeal. Expansion of uranium mining will further undermine the aesthetic appeal of Kakadu National Park, having a detrimental affect on the world-wide eco-tourism marketability of the area.

The Jabiluka Project Environmental Impact Statement of 1997 stated that the Jabiluka region was of an exceptionally high visual standard. The Jabiluka Outlier has been identified as a feature of major visual quality, and is a scenic attraction for tourists visiting the Kakadu Region (Kinhill, 1997).

It seems apparent that the Ranger Uranium Mine has generated its own hybrid tourist industry over the last ten years. The company merchandising and the mine bus tours have attracted a significant proportion of the overall tourist population visiting Kakadu National Park. The subsidiary income has been invested into marketing and promotion, with the company printing postcards and advertisements that directly associate the World Heritage National Park with the uranium industry and are clearly pitched towards indigenous audiences. Such misleading and highly questionable practises undermines the motives and integrity of the World Heritage classification system and also threatens the existing criteria of Kakadu’s Ramsar Convention listing.

Likewise the projected development of the Koongarra lease, in full view of, and adjoining the significant sacred sites of Nourlangie Rock, highlights the industry's obvious disregard for these spiritual places. As well as being world renowned as a premier rock art gallery containing several significant anthropological landmarks, Nourlangie is first and foremost a cultural and religious symbol for Aboriginal people of the Alligator Rivers Region. The site is occasionally closed so that indigenous people can undertake their traditional activities and management.

2.4.1 Impact on Rock Art

The rock art of Kakadu is noted for its aesthetic and cultural value. Evidence suggests that mining within the vicinity of a site containing rock art exposes the artwork to damage. "*Chemical damage is caused by salts and airborne sulphur dioxide and trioxide which alters the chemical properties of the paints and rock support, visually obstructing and weathering the rock art*" (Kakadu National Park Plan of Management, 1991).

2.4.2 Impact of Post Mining Regeneration

The proposal from ERA to restore the land once mining has ceased is dubious and any effort towards restoring the Park’s natural beauty is a vague and somewhat naive promise. The mining companies plan to leave their mine sites with very large hills, in an otherwise flat landscape, which will reduce the natural beauty of the area. *‘In cases where the pits are backfilled, substantial artificial landforms often remain in the form of rehabilitated piles of waste materials’* (Kakadu Conservation Zone Inquiry Final Report, 1991). It is worth questioning the long-term aesthetic desirability of turning areas of Kakadu National Park into a series of radioactive waste dump hills. Increased weeds are an integral effect of mining and road disturbance. Weed infestations seriously detract from the innate beauty of the native vegetation communities, and ultimately undermine World Heritage integrity.

2.5 Beauty in Danger

Kakadu National Park is internationally recognised for its beauty. It is one of the three criteria that make it a natural World Heritage Listed property. Areas of priceless natural and cultural value such as Kakadu National Park, *"are set aside as enduring reminders of the earth's original beauty and Gaia"* (World Heritage Covenant- Rio Earth Summit) making the business of uranium mining and wilderness preservation hopelessly non reconcilable activities.

The presence and activities of the uranium industry is not compatible with the aesthetic qualities of the Park. The current Australian environmental assessment process neglects the importance and complexities of aesthetics. Besides the innate effects from industrialisation in natural regions, there are visual, audio, vibrational, tourism, and long term landform and pollution effects, all of which individually reduce the aesthetic values of Kakadu National Park. Overall, it can only be concluded that the World Heritage criterion (iii) is detrimentally affected. This certain danger is due to the severe deterioration of the natural beauty of the property by the cumulative effects of increased human settlement, industrial development and mining pollution. The Jabiluka and Koongarra lease sites must be reserved for conservation in order to retain all aesthetic values, thus retaining Kakadu National Park's international responsibilities.

Chapter 3
Environmental Effects of Mine Infrastructure

Existing development at the Ranger Uranium Mine along with the facilities of the township of Jabiru have brought significant damage to both the indigenous community and the environment of the area. Critical health and social problems including alcoholism and poverty among the indigenous people are at least aggravated if not caused by the presence of the mining industry. Roads and the influx of vehicles have increased the rates of road kills, and formed harmful barriers to the movement of fauna. Clearing vegetation and soil disturbance has degraded the soil fungi hampering rehabilitation. Weeds are an unacceptable consequence of mining and are not treated with seriousness proportional to their impacts.

Recommendation:

The World Heritage Committee should:

a) acknowledge that mine infrastructure is incompatible with World Heritage values and is having irreversible effects on Kakadu National Park, and
b) request that the Australian Government take immediate action to curb or prevent any further impact.

There are many significant effects of industrial infrastructure which are present in the Alligator Rivers Region as a result of the activities of the uranium industry. Effects include those of roads, the township of Jabiru, the introduction of exotic species, and the problems of post-mining vegetative rehabilitation. In addition, the health of the indigenous people is detrimentally affected by the close proximity of a mining township (KRSIS, 1997). Together, even these few examples throw into doubt the claims that uranium mining has no detrimental impact upon the outstanding natural values of Kakadu National Park. Indigenous councils and spokespersons have continually expressed concern about the adverse impacts of Ranger Uranium Mine on their people and the need for the problems to be addressed before ecological and cultural values are lost forever.

3.1 Impacts of Jabiru Township on Kakadu National Park

As well as the direct impact of mining in Kakadu National Park there are also the indirect impacts associated with housing a population of permanent and contract workers and their families at the township of Jabiru. Jabiru was designed in 1978 to service the Ranger, Jabiluka and Koongarra Uranium Mines (Kakadu Region Social Impact Study, 1997). It has changed over time from its beginnings as a closed mining town, to a town that now provides some services for Aboriginal people in the region as well as providing accommodation for tourists and park visitors. The original plan for Jabiru was for a town of 3500 people. Currently the population of Jabiru is approximately 1,800 people. People living in Jabiru include:

- Mine workers and their families
- ERISS workers and families
- Parks North staff and families
- Traditional Owners, friends and relatives
- Tertiary service workers and their families
- Tourists and staff to service the 200,000 Kakadu tourists annually

3.1.1 Jabiru – A Low Impact Town?

When Jabiru was planned it was recognised that Kakadu National Park was an extremely sensitive area and would require protection from impacts from poorly planned developments. The Ranger Uranium Environmental Inquiry insisted that strong environmental safeguards be imposed: *"It was particularly concerned that the township should be managed to make the negative social impacts on Aboriginal People in the region and environmental impacts on the surrounding park environment as small as possible"* (Australian Nature Conservation Agency, 1996,).

The town of Jabiru occupies an area of 13km^2, which is leased from Kakadu National Park. Stated aims for minimising environmental impact through such strategies as rubbish recycling, car pooling, and resident education campaigns, have either failed or not been implemented at all. From the inception of Jabiru all domesticated animals were banned, but under pressure from employed residents, this rule has lapsed and dogs are now common. They roam outside the township and breed with the native dingo, contributing to the loss of genetic integrity in this species. Similar pressure from residents has seen the introduction of exotic flora, in what was originally proposed to be a town with gardens of native plants. The introduction of weeds into Kakadu National Park is now a serious ecological issue (Cowie & Werner, 1988; Storrs, 1996; Storrs & Finlayson, 1997). An environmental audit of Jabiru was planned for 1995 but has yet to be implemented.

3.1.2 Environmental Impacts of Jabiru

Establishment of Jabiru has resulted in numerous impacts both within the town lease and also on the surrounding Park. Impacts with potential to affect World Heritage Values include:

- Town footprint – i.e. vegetation loss, habitat destruction, vehicle pollution.
- Gardens – leading to excessive use of water, pesticides, and fertilisers. There are also risks associated with the introduction of exotic plant species and fungal diseases from potting mix and soil imports (Reddell & Milnes, 1992).
- Pets – dogs, birds, fish may escape to form feral populations.
- Sewage plant – disposal into the Magela Creek.
- Rubbish dump – besides the rubbish and leakage of pollutants, rubbish attracts dingoes and birds of prey. Animals become dependent on non-natural foodstuffs as their dietary intake is altered.
- Water Supply – the three bores possibly deplete local groundwater aquifers.
- Jabiru Lake – this artificial lake has an impact on hydrology by acting as a retention pond for town runoff and needs to be topped up in the dry season. Pesticides and heavy metals are retained in the sediments.
- The township and the mine is powered by large fuel driven generators, which is extremely energy expensive and has associated air pollution problems.

The extent of these impacts are yet to be adequately investigated, although ERISS are planning further studies in the future (B. Prendergast, ERISS, pers. comm., 1998).

3.1.3 Plans for Future Development of Jabiru

Prior to construction of Jabiru there were plans by the NT Government to turn it into a large regional centre (Lea & Zehner, 1986). These plans were rejected by the Ranger Uranium Environmental Inquiry, which recommended Jabiru should remain a town of less than 3500 people. Recently, proposals to develop Jabiru into a large regional centre, a process described as 'normalisation', have been revived by the Jabiru Town Development Authority (Jabiru Town Development Authority, 1995). Further development of Jabiru is also included in the recent NT Government 'Darwin Rural Region Economic Development Strategy' (Darwin Rural Region Economic Development Committee, 1998). This report sets out the pro-development agenda of the NT Government as it relates to rural areas and states that; *"The encouragement of increased Aboriginal participation in the mainstream economy is important to the regions development"* (DRREDC, 1998).

However, further development of Jabiru, either as a result of the expansion of mining or tourism, would further impact on Kakadu National Park, and threaten World Heritage Values. This view is echoed by many Traditional Owners. *"Aboriginal people do not share the view that significant changes in local management arrangements would necessarily benefit them. On the contrary, they have advised [Parks North] that they are strongly concerned that their interests could be affected detrimentally and that they fear a long term result that the (Ranger Inquiry) specifically warned against" (ANCA, 1996).*

3.2 Health and Social Effects on Indigenous People

One of the natural criteria for a World Heritage listing is whether a property contains outstanding examples of human interaction with the natural environment. Kakadu is certainly not lacking in such examples. The local Aboriginal people have lived in close relation with their natural environment for tens of thousands of years, using fire and other traditional means to sustainably manage their resource base. At the same time they have expressed their spiritual attachment to the land in the form of rock paintings, particularly at sacred sites connected with their ancient dreaming mythologies. However, the integrity of this highly evolved relationship between people and nature has been put at risk by the activity of the uranium industry and the associated influx of non-Aboriginals.

3.2.1 Health Dangers

Aboriginal people maintain traditional practices in the region, including hunting and fishing. As is shown in Chapter 5, animals and plants absorb radioactive material, and may concentrate it, leading to potential exposure to both Aboriginal and other hunters.

Although solid data linking radiological exposure to the health status of the region's Aboriginal population is limited, Northern Territory-wide statistics indicate that there is a higher incidence of cancer, particularly leukemia, amongst Aboriginals than amongst the non-Aboriginal population. Evidence from uranium mining regions in the USA indicates that much of the radiation related diseases do not occur until 20 to 30 years after exposure. Therefore, it is conceivable that, evidence of disease directly attributable to mining at Ranger Uranium Mine (see Plate 3.2) would not yet have occurred, or would only be beginning to occur now.

3.5.2 Social Effects

The social impacts of uranium mining upon the local Aboriginal people were documented by Tatz (1984): *"the current civic culture is one in which disunity, neurosis, a sense of struggle, drinking, stress, hostility, of being drowned by new laws, agencies, and agendas are major manifestations. Their defeat on initial opposition to mining, negotiations leading to Ranger and Nabarlek, the fresh negotiations on Jabiluka and Koongarra, new sources of money, the influx of vehicles, together have led …to an unhappy verdict that this is a society in crisis".*

Societal instability may lead to a greater risk to individuals of excessive alcohol consumption. This has been in the continuing absence of adequate health support for alcohol problems and preventative care. The loss of sacred sites to mining development can also have profound psycho-spiritual effects on the traditional landowners.

The presence of miners and their families dwelling virtually permanently without Traditional Owner approval, can only add to the inherent disenchantment of an invaded community. There have been many studies that have warned that the Aboriginal people of Kakadu National Park are threatened by large mainstream townships (eg KRSIS, 1997). Yet the governments and industries don't take heed. This is a direct threat to the health and freedom of indigenous people, who need to be able to maintain their traditional activities. This disrespect for the needs of traditional communities is international, but they are one of the many reasons Kakadu National Park is World Heritage Listed.

3.3 Environmental Effects Associated with Roads

3.3.1 Roads as Barriers

The construction of new roads through ecosystems creates a barrier for some species. With the research emphasis on large vertebrate fauna, roads are often overlooked as barriers to small vertebrates and terrestrial invertebrates. Meffe and Carroll (1994) cite specific studies of roads acting as barriers. These include a nine year study in a Kansas (USA) grassland where very few voles or rats crossed a three metre dirt road. The proposed road linking Ranger and Jabiluka Uranium Mines is 13 metres wide consisting of cleared compressed gravel with further vegetation clearance to facilitate drivers' vision (Kinhill, 1996). Even in the absence of vehicle traffic many small fauna species will not cross this distance due to the lack of cover protecting them from predation and desiccation. Unfortunately species most affected are poorly sampled but could include non-flying invertebrates, small reptiles and mammals. The implications of roads as barriers are that they may restrict an animal's food, nesting or breeding area, reduce a home range, or inhibit dispersion or migration.

3.3.2 Habitat Fragmentation

The creation of new roads through an untouched area reduces the interior-edge ratio thus reducing the size of an undisturbed area and increasing the 'edge effects' (Meffe & Carroll, 1994). Negative types of edge effects include microclimate changes in light and temperature, increases in wind velocity and increased predation and competition from exotic pest species (Primack, 1993). The reduction of habitat connectivity reduces genetic flow and makes populations susceptible to local extinctions without the ability for recolonisation (Krebs, 1994). Even though the proposed Ranger Uranium Mine to Jabiluka Uranium Mine back-road is not in Kakadu National Park, it is very much a part of the regional environment and will contribute to habitat fragmentation in the Park which surrounds the leases. Thus any road constructed within the area effectively divides Kakadu National Park into smaller parcels, contributing to habitat fragmentation.

3.3.3 Road Kills

Any new mines within Kakadu National Park will result in increasing mine-related traffic and consequent road kills. Case (1979) estimated that up to 1.5 million animals were killed on US roads annually. It is estimated for the proposed Jabiluka Uranium Mine there will be an increase of over 2,000 trucks per year associated with chemical haulage alone (Kinhill, 1998). Furthermore, the proposed Jabiluka Uranium Mine could employ 110 personnel to become permanent residents within the boundaries of Kakadu National Park (Kinhill, 1998). These people will need to travel between their place of residence, work and recreation. The Jabiluka environmental assessment only addresses this by restricting mine traffic to speed limitations and day-time travel. This however will not prevent road kills of animals unsighted by drivers or those on public roads. Road-trains still travel through Kakadu National Park at night, as do shift workers. They often travel well above speed limits required to avoid animals on the road.

Reports of dead freshwater turtles (road-kills) during the breeding season are not uncommon. Dead file snakes, goannas and frogs are also extremely common (N. Rea, pers. comm., 1998). Two types of animals are likely to be adversely affected - those crossing the road, and those grazing on the roadside vegetation. Edges of roads often have increased vegetation growth and prolonged 'greenness' due to water run-off. Herbivores, and macropods in particular, are attracted to this source of food and are at increased risk. The uranium industry is indirectly contributing to the death of many native animals, and its expansion can be expected to further impact on these ecological components of Kakadu National Park. This is a direct threat to World Heritage Values and species of international significance such as the migratory waterbirds. It is inappropriate to have industrial traffic travelling through a World Heritage Listed National Park.

3.4 Problems with Vegetative Rehabilitation of Minesites

ERA continues to insist that post-mining vegetative rehabilitation will return the Ranger and Jabiluka Uranium Mine sites to their pre-mining natural state, thereby preserving the ecological integrity of the area. This confident assertion belies the fact that there are a number of unresolved problems with this process. An essential aspect of vegetative rehabilitation is an understanding of the complex interactions occurring amongst species and the processes and conditions that are necessary in their establishment and reproduction. However, very little has been published on the flowering and fruiting patterns of native plants in the Alligator Rivers Region (Brennan, 1996). Brennan suggests that the seed collection program at Ranger Uranium Mine will not be able to provide the range or quality of seed necessary to complete revegetation within current guidelines (Brennan, 1996). Little information appears to be available on the storage and use of topsoil in the tropics for vegetation establishment (Klessa & Legras, 1994). There are also significant difficulties in the reestablishment of plant communities in soil affected post mining areas in the Alligator Rivers Region (Ashwath, 1994). Knowledge about rehabilitation in the wet/dry tropics is sketchy and results to date are highly variable. The natural environment is being used for experimentation.

3.4.1 Effects of Post Mining Soil on Revegetation

In the wet-dry tropics, soil hardening can occur when sediments are exposed. This is largely because intense rain events lead to the rapid loss of any topsoil and compaction of sediments, causing poor infiltration and an altered air-water balance (Klessa & LeGras, 1994). This problem exacerbates the difficulties in getting plants to establish and survive. Ashwath *et al* (1993) suggest that there is evidence of an increase in soil salinity in some of the areas of the Coronation Hill Mine, due to the increase in pH and the associated affect on the plants ability to absorb certain minerals, one such mineral being $CaCl_2$. In Ranger, salinity in mine spoil is due to the excessive amounts of magnesium and SO_4 in the soil solution. The rise in the salinity of the soil means that many species of native plants find it difficult to survive or even begin to grow (Ashwath *et al.,* 1993).

Mine spoils also have low levels of nitrogen, which is an intrinsic element in the growth of plants. The use of large quantities of mineral nitrogen to improve plant growth on the spoils is considered undesirable in this region due to its potential adverse effects on the surrounding aquatic ecosystem.

3.4.2 Impacts on Mycorrhiza

Mycorrhiza fungi of Kakadu National Park are an ubiquitous component of the soil biota in all undisturbed woodland soils, with 90% of the flora having a symbiotic relationship with these fungi (Reddell & Milnes,1992). The fungi gather nutrients for their host plants which may give them sugars. It is well established that disturbance of soils can eliminate mycorrhizal fungi. Their absence can, in turn, affect the growth and survival of recolonising vegetation (Brundrett *et al,* 1994). It has been reported that low diversity of mycorrhiza species in disturbed sites has lead to colonization by invasive species (Termorshuizen, 1991). Non-mycorrhiza species such as Cyperaceae are pioneers of disturbed environments. These are prevalent in the revegetation areas on Ranger waste rock dumps (Reddell & Milnes, 1992).

Mycorrhiza are absent or poorly represented in the stockpiled topsoils and in some of the rudimentary soils formed in waste rock dumps at the Ranger mine site (Reddell & Milnes,1992). It has been demonstrated that different species of mycorrhiza fungi have different sensitivity ranges to the waste rock dump environment (Brundrett *et al.,* 1995). Some fungi species have the capacity to survive soil disturbances with propagules such as spores, pieces of rhizomorphs and sclerotia (Ba *et al.,* 1991). Human induced selection of species that form propagules may lead to a decrease in the microbiota diversity. This follows a cascade of changes in succession on all scales, that inevitably leads to a flora with a reduced or altered diversity.

Brundrett and Ashwath examined the effect of nutrient elevation on two host plants and the diversity of VAM fungi isolated from the Alligator River Region soils (Ashwath, 1994). Results have shown that a change in soil fertility could influence the production of mycorrhizal roots and spores. Extremes in soil fertility levels such as those found at the Ranger mine favoured fungi belonging to some genera more than others. Once again this human induced selection will be characteristic of the plants in the area.

Mycorrhiza fungi are known to be involved with the mineralisation of phosphorus. The available phosphorus around the Ranger Uranium Mine site can be as high as 21 ppm and in natural soils it is usually 7.6 ppm (Ashwath *et al.,* 1993). The presence of substantial amounts of phosphorus, released from Ranger waste rock dump has reduced the requirement of plants to have a mycorrhizal association on the mine sites (Brundrett *et al.,* 1994).

There is a possibility that invasive mycorrhiza fungi (and rhizobia) were introduced incidently with planting stock used to revegetate the two oldest areas of the Ranger waste rock dump (Reddell & Milnes, 1992). Fungi form intimate associations with plant roots and greatly augment their nutrient assimilation capacity. They may also act pathogenically, however, literally rotting away at roots of whole forests. Ecological disasters could arise if certain strains of fungi invade plants that have not co-evolved with such strains.

3.4.3 Impacts of Weeds on Rehabilitation

A serious management issue for Kakadu National Park is the invasion of weeds and replacement of native vegetation (Cowie & Werner 1988; Storrs 1996; Storrs & Finlayson, 1997). It is disturbing that mining companies use exotic species such as Rhodes grass, couch and *Stylosanthes* in their rehabilitation programs. Indeed, more than half the seeds identified in the Nabarlek Uranium Mine were exotic species (Klessa & Legras, 1994). The use of exotic species is being reconsidered at Ranger Uranium Mine because they do not require long term care, are resilient to fire and compete with native trees (Gray, 1994).

Environment Australia lists weeds as one of the threatening processes of biodiversity. The introduction of weeds into an ecosystem *"…has serious negative effects on native species, including the loss of genetic variation, reduction in distribution and abundance, and extinction"* (Environment Australia, 1998a). Since 1948 the number of weed species within the Park has increased by 1.6 species per year to the current number of at least 89, and is still expected to rise (Australian Nature Conservation Agency & North Australia Research Unit, 1995). Of the weed species Kinhill (1998) recorded on the Jabiluka lease area, *Salvinia molesta, Brachiaria mutica* and *Hyptis suaveolens* are three species of concern (Australian National Parks and Wildlife Service, 1991; Roeger & Russell-Smith, 1995).

The highly invasive *Mimosa pigra* is also scattered across the Kakadu floodplains with Environment Australia outlaying $400 000 pa over the last 10 years for its containment. On the floodplains adjacent and to the East of Kakadu National Park and downstream of Magela Creek floodplain (see Plate 3.1), *M. pigra* had invaded 7000 ha approximately. Over 8 years, more than $8 million of intensive weed control has only restricted this weed to half that area and if control were to cease, it would reinvade. *M. pigra* invasions are facilitated by disturbance to natural vegetation and the importing of soil for road and other works that contains its seed (N. Rea, pers. comm., 1998). These are both processes associated with mining that could see this weed spread further throughout the Park.

Weeds are difficult to contain and virtually impossible to eradicate, as they may be transported by a number of methods including human activity, animals, wind and water. Therefore any further development within the boundaries of the Park could increase the presence of weeds. ANCA & NARU (1995) reported that within Kakadu National Park weeds were more prevalent at sites disturbed by humans "such as settlements and roads" than elsewhere. Furthermore, an increase in the population of the township of Jabiru will add further pressure with already 256 exotic plant species being cultivated, of which 13 have become established in Kakadu National Park.

3.5 Far Reaching Effects

Often ignored or deemed insignificant, the effects on Kakadu National Park from the infrastructure associated with mining are of considerable importance. Jabiru as a settlement brings with it many of the problems of modern society. It is a transport orientated, rubbish and effluent producing society that consumes vast quantities of water, as well as introducing pollutants and exotic species. The indigenous communities are adversely affected by being marginalised on their own land. The building and growth of Jabiru township already has dramatically altered the environment. Prolonging the life of this short term town by opening Jabiluka and Koongarra Uranium Mines will cause substantial and irreversible long-term impact on Kakadu National Park.

The roads act as barriers, and produce habitat fragmentation and road-kills, which undeniably cause detrimental effects on native species. The difficulties involved in cleaning up the mess after the mine is closed are becoming more apparent. The weeds and exotic mycorrhiza are notoriously difficult to manage. In short, the infrastructure associated with mining has a large insidious and long-term impact on the World Heritage Listed Kakadu National Park.

Chapter 4

Environmental Contamination from Uranium Mining & Milling

Uranium mining and milling practices generate a variety of contaminants that, once released into the environment, can cause severe ecological damage. Radioactive materials stay radioactive for millions of years. The mining and milling process releases these contaminants from stable underground structures into the surrounding environment. Heavy metals contained in tailings waste can leach into aquifers and subsequently be dispersed into the wetland biota. Proposed management strategies for the containment of these contaminants are inadequate.

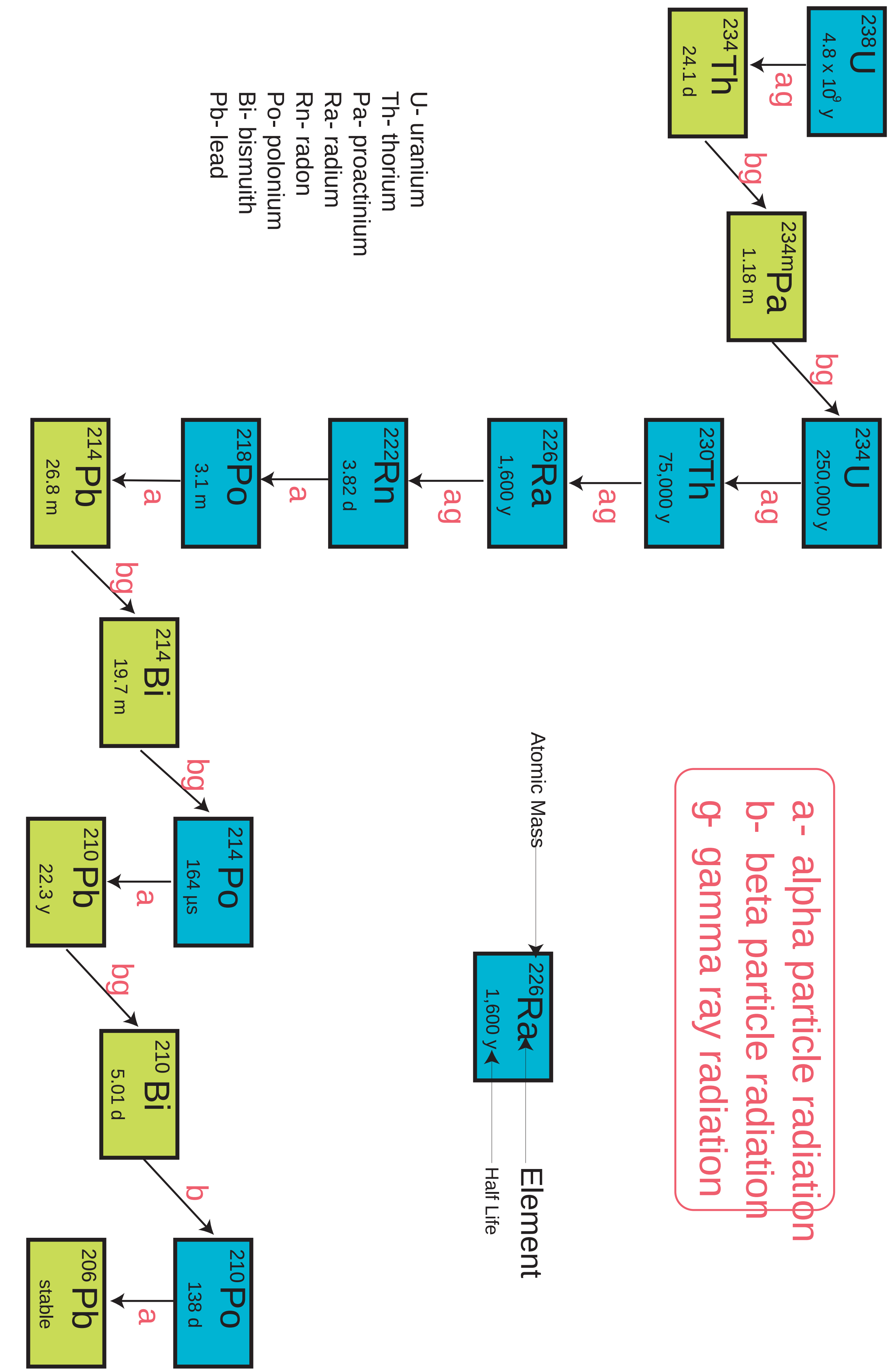
Recommendation:

We recommend that the World Heritage Committee

a) recognise that the best practice management strategies for the total containment of radioactive waste and contaminants for a minimum of 250,000 years, as necessary to eliminate contamination possibilities, are manifestly inadequate and;

b) request that the Australian Government take undertake immediate applied research into the absolute containment of the existing waste, and stop further contaminants and radioactive wastes being produced until failsafe methods for their safe containment have been proven.

Fig 4.1: Radioactive Decay Series of Uranium-238, Radionuclide Half Lives and Associated Radiation Release



4.1 Uranium Mining & Milling Operations

4.1.1 Geology of Uranium Orebodies in Kakadu

The Ranger and Jabiluka uranium orebodies are part of one stratigraphic horizon held within the eastern limb of a regional scale recumbent fold, known as the Pine Creek Geosyncline. The orebodies are located beneath an outlier of the Kombolgie Sandstone in Cahill schists (Kinhill, 1997). The bulk of the uranium ore occurs in breccia zones in weak graphitic schists, and therefore it is thought to have mineralised from ore bearing fluids during regional faulting. At least one major fault zone, the Hegge Fault, passes straight through the middle of the Jabiluka orebody (Kinhill, 1997).

The geology of the Jabiluka orebody, however, is not well understood. Therefore, whether the mined and milled ore rock waste can be safely contained in perpetuity is not known:

"The geological characteristics of the Jabiluka site which affect permeability of the ground have had little investigation due to access difficulties, but the data available indicate that transport of contaminants from tailings will occur much more freely than at Ranger because of the different underlying bedrock geology (fractured sandstone at Jabiluka, metamorphic rock at Ranger) and geological structure (extensive faulting)" (Environment Australia, 1998b).

The bedrock geology of the ore bodies alone suggests that the safe containment of contaminants at Jabiluka is very difficult, if not possible, to achieve.

4.1.2 Uranium Mining and Milling Waste Disposal Practices

Uranium mining and milling processes produce many types of waste material including waste rock, low grade ore rock, tailings wastes and runoff from ore stockpiles. Low grade ore and waste rock is stored above ground in huge piles for later use in mine site rehabilitation. Tailings waste at Jabiluka (as detailed in the proposed Jabiluka Mill Alternative) will be neutralised, mixed with cement paste, then pumped into tailings disposal pits or excavated areas (Kinhill, 1998). In contrast, tailings waste at the existing Ranger uranium mine (that were formerly pumped into the tailings dam) are pumped directly into a disused open cut pit. Ore stockpile runoff is captured in sediment collectors and pumped into tailings disposal pits.

4.1.2a Waste Containment Problems

The Ranger Mine is expected to produce 40 million tonnes of finely crushed tailings waste during its lifetime, the Jabiluka mine is expected to produce 20 million tonnes. The principal tailings waste management problem are the radionuclides and heavy metals that remain in tailings after milling. Radioactive elements other than uranium are not removed in the milling and extraction process. These elements constitute approximately 85% of the original radioactivity of the extracted ore (IAEA, 1992). The main reason for containment problems is that tailings pits are in the groundwater zone, where seepage of contaminants can occur. This effect is also enhanced by high seasonal fluctuations in rainfall, as is experienced in the Alligator Rivers Region, which enhances groundwater movements. *"It is generally considered unwise to place tailings in an area where the water table varies seasonally as the inflow and outflow may promote transport of contaminants to the environment."* (IAEA, 1992).

A necessary requirement for containing tailings waste is that it be located in a geologically stable and impermeable setting. This is not the case at the proposed Jabiluka mine

"The location of Pit No.1 (at the proposed Jabiluka Mine) is unfortunate in that it appears to be in a zone affected by faulting and deep weathering. Relatively low rock strength and high permeability could lead to pit slope stability problems, excessive water inflow or outflow of water held over the tailings during operation and subsequently unnecessarily high water flow past the cemented tailings. Overall, it would seem logical to seek a better position for Pit No. 1" (Waite *et al.*, 1998).

The annual wet season in the tropical zone around the Kakadu National Park is also associated with massive run-off, which becomes contaminated as it passes through ore stockpiles, low grade ore piles and waste rock heaps. This runoff water drains into retention pond two in Ranger waste rock dump. Run off has previously been discharged off site, reaching wetlands and aquatic ecosystems (see Appendix 2). Average manganese concentrations (1.62 mg L^{-1}) were found to be eight times higher in retention pond two irrigation water than recommended; and the maximum concentration (12 mg L^{-1}) was up to 60 times higher than that recommended for irrigation water (Ashwath, 1991). Ecological damage to ecosystems is inevitable if release of retention pond two water is continued until the end of the expected Ranger mine life time (Ashwath 1991).

4.1.2b Tailings Containment: Cement Paste Fill Technology

The latest published amendment put forward by ERA for the Jabiluka Mill Alternative, is that approximately 40 percent of the mill tailings will be mixed with between one and four percent cement to form a paste, which will be used to progressively backfill the completed sections of the underground mine. ERA also propose to excavate two shallow pits into which the remaining mill tailings will be placed. It is proposed that pit one will be filled over the first ten years and then the much larger pit two will be filled for the remainder of the project (Kinhill, 1998).

The cement paste fill technology associated with this tailings disposal technique is largely untried. Even in the Jabiluka PER it is states that *"the stability of the paste fill material under deep water disposal is not known at this time."* (Kinhill, 1998). It can not be claimed with any high degree of confidence that cemented backfill will decrease permeability and hence leaching of contaminants for any duration, especially in the post-mining phase (Kinhill, 1998). For example, it was found that by using three to six percent cement by weight of tailings in Canada, excessive dilution and instability occurred when the backfill was examined six months after application (Oullet, 1997).

"Tailings water composition (and particularly the presence of high concentrations of sulphate and magnesium) may deleteriously effect the curing, strength and permeability of the cement tailings paste" (Waite *et al.*, 1998)

Structural failure of the cement paste fill will occur due to chemical alteration and expansion processes. The reason for this is that the cemented tailings wastes are still highly porous, and the structure remains permeable. As a consequence, sulphate ions present in tailings react with free calcium ions produced by dissolved portlandite hydrates, resulting in the formation of swelling secondary gypsum and the highly expansive ettringite. Expansion, due to the formation of high crystalline pressures, results in fine fissuration of the paste backfill. This severely compromises its structural integrity, which has very serious side effects. It will certainly enhance permeability and movement of contaminants in water through the backfill, which facilitates the enhanced leaching of soluble radioisotopes and heavy metal ions.

4.1.2c Alternative Tailings Management Strategies

Any form of tailings disposal within either the proposed Jabiluka site, or currently at Ranger, remains problematic. This is mainly due to the lack of studies relating to potential seepage of contaminants from containment structures. One way of dealing with the immense quantity of tailings waste, that is currently not even being considered by the uranium industry, is the physical removal of contaminants. The removed contaminants would have a smaller volume and hence be able to be stored in a more secure manner. Radionuclide flotation can remove approximately 65% of the radium and thorium, following sulphuric acid processing. The extractant EDTA can remove radium and other metals from tailings, while another method can recover 90%. Many heavy metals, such as vanadium, nickel and copper can also be extracted. There are many other methods, with the advantages being environmental and in some cases economic as well (IAEA, 1992).

4.2 Contaminants Released by Uranium Mining and Milling

4.2.1 Indigenous and Introduced Contaminants

The mining and milling of uranium ore within Kakadu National Park introduces a wide range of contaminants into the surrounding environment. These contaminants can be of two broad types; indigenous and introduced. Indigenous contaminants are those contaminants that occur in the environment and are liberated by mining operations, or contaminants that are produced on site. These include radionuclides, heavy metals, suspended sediments and sulphates. Introduced contaminants, in contrast, comprise those contaminants brought in during the mining and extraction procedures and left behind after use. Some examples of chemicals that are introduced and used in the mining and milling of uranium ore include acetylene, tertiary amines, ammonia, quicklime, hydrogen peroxide, Isodecanol, glue substitute, magnafloc 351, kerosene, diesel, petrol, battery acid, and mechanical oils.

4.2.2 Radionuclides

One of the principal contaminants produced during mining operations in Kakadu are radioactive material known as radionuclides. Radionuclides are isotopes of radioactive elements, which emit alpha(α), beta(β) or gamma(γ) radiation during the radioactive decay process. There are three naturally occurring radioactive decay series; the uranium, thorium and actinium series. The uranium series, beginning with the parent isotope uranium-238, is of key interest in Kakadu, since it comprises of 96 percent of the total uranium present in the Ranger and Jabiluka ore bodies (see Figure 4.1).

4.2.2a Uranium and Thorium Isotopes

The ore in the Alligator Rivers uranium field is uranite, salerite and pitchblende, all of which are different forms of uranium oxide (U_3O_8). Uranium as an element has several isotopes, including uranium-234, uranium-235 and uranium-238. The longest-lived and most abundant isotope is uranium-238, which is also the most abundant in the ore body (it represents 96 percent of the ore). The half life of this isotope (which refers to the time taken for half of the original atoms to decay) is 4,800 million years. The decay series for uranium-238. Uranium-238, 235 and 234 is readily soluble in acid solution as uranyl UO_2^+ ions, or in neutral and alkaline solutions as dicarbonate $UO_2(CO_3)_2^{2-}$ ions or tricarbonate, $UO_2(CO_3)_3^{4-}$ ions (Deutscher, 1980). Uranium solubility tends to be highest in oxidising, high carbonate ground waters (Martin & Akber, 1996).

Thorium is also found in the uranium ore bodies, however it is not extracted in the milling process. Consequently, thorium and its decay products represent significant contaminants remaining in tailings waste after extraction. Decay products of the actinium series, beginning with uranium-235, also remain in tailings waste.

The presence of uranium-235 series radionuclides is naturally very low, as the natural activity ratio for ^{235}U: ^{238}U is only 0.046. It is however uranium-235 which is the sought after isotope for nuclear weapons and energy production but constitutes only 4% of total uranium. Similarly, in Ranger ores, the thorium series ^{232}Th: ^{238}U activity ratio is less than 0.05 (Martin & Akber, 1996). Both of these radionuclides whilst occurring at low levels still contribute to the pool of potential radionuclide contaminants. . *"For each 0.1% of uranium present, the ore has about 12.4 Bq (335 pCi) of each member of the ^{238}U series per gram of ore or about 174 Bq of total radioactivity per gram"* (IAEA, 1992).

4.2.2b Radon and its Progeny

Radon-222 is a heavy, inert gas with a half life of 3.8 days. It is released during uranium mining and milling operations as a product of the decay of uranium-238 (Figure 4.1). It is produced from the decay of its parent isotope radium-226, which has a half life of 1600 years. Decay of radium provides a very concentrated source of radon especially when exposed to the air as in ore stockpiles. The decay of radon produces breakdown products (radon progeny) are all solids. These radioactive isotopes include polonium-218, lead-214, bismuth-214, polonium-214 and lead-210 which can be carried as potent contaminants in wind and on airborne dust particles.

4.2.3 Heavy Metals

Heavy metal elements are frequently found to be associated with areas of uranium mineralisation. Molybdenum, lead and selenium are enriched in Jabiluka ore samples, and some parts of the orebody have elevated levels of arsenic, copper and antimony (Kinhill, 1998). The heavy metals cadmium, chromium, lead, manganese, nickel, zinc, and strontium are also present in smaller quantities in the uranium ore body. None of these metals are extracted from ore for use, and therefore remain as contaminants .in tailings waste.

The Jabiluka Two orebody contains a significant quantity of the toxic heavy metal mercury. Mercury vapour leakage from fault lines is considered a positive indicator when exploring for the presence of uranium bearing ores. Mercury levels in the Jabiluka two orebody average 1950 ppb. In the western part of the orebody where there are extensive areas of uranium/gold mineralization, levels of mercury reach 11,000 ppb. Native gold, occurring in isolated breccia zones in the Jabiluka Two orebody, is associated with mercury levels up to 450,000 ppb (Ryall & Binns, 1979). Mercury is mobilized into solution under acidic conditions.

The heavy metals cadmium, chromium, copper, lead, manganese, nickel and zinc, are present in uranium extraction wastes at levels higher than those indigenous to Kakadu National Park (Brennan *et. al.,* 1992). Iron, chromium and nickel are partly soluble in acidic water, and can therefore be mobilized into groundwater (IAEA, 1992). Copper is present in tailings waste at significant and is also strongly mobilized into solution with an increase in acidity.

4.2.4 Diesel Fuel and Other Hydrocarbons

Diesel and other hydrocarbon fuels form are an essential part of the construction and operation of uranium mines. Hydrocarbon fuels may contain a mixture of simple, branched and aromatic hydrocarbons, each of which have different characteristics with respect to biodegradation and leaching into the environment. Spillage or discharge of hydrocarbons into aquatic environments is especially to bird life.

The following quantities of hydrocarbon fuels are proposed to be stored at the Jabiluka site during mining operations;

Diesel Fuel (Vehicles)	1 x 20,000L tank
Diesel Fuel (Plant)	1 x 2,000L day tank
Petrol	4 x 200L containers
Transmission/Engine Oil	8 x 200L containers
Lube Oil	4 x 200L containers

(source: Kinhill, 1996)

4.2.5 Sulphur, Sulphur Dioxide, Sulphuric Acid and Sulphates

Large quantities of sulphur are used to produce the sulphuric acid that is required to extract the uranium from its ore. Huge yellow stockpiles of elemental sulphur can be seen at Ranger Uranium mine, openly exposed to the environment. To produce sulphuric acid, elemental sulphur is burned to produce the poisonous gas sulphur dioxide. Dissolving this gas in water at high concentration yields sulphuric acid. Release of this gas into the atmosphere is known to cause the occurrence of acid rain.

The extraction and clarification of the uranium from the ore mined at Jabiluka is expected to involve the use of 54 kg of sulphuric acid (H_2SO_4) per tonne of ore (Kinhill, 1996). As there is expected to be 19,328,000 tonnes of ore the quantity of sulphuric acid used to extract uranium from ore mined at Jabiluka could be as much as 1,043,71,000 kg. The acid remaining in tailings waste is expected to have the pH of only 1.8 which will require 20 kg of lime per tonne of ore to neutralize it (Kinhill, 1996). Neutralization of this acid takes away some of the problems associated with acid mediated mobility of contaminants in the short term, however the creation of acid in-situ over time by acid mine drainage means contaminants will still be mobilized in the long term. Neutralization of sulphuric acid produces large quantities of sulphate, and thus introduces another contaminant left as waste in tailings after mining operations.

4.2.6 In-situ Acid Production

Sulphuric acid is also produced in-situ in tailings waste. One such process is known as "acid mine drainage". Acid mine drainage is a term used to label a chain of reactions processes involving the oxidation of pyrite to produce sulphuric acid (see below). The Jabiluka and Koongarra orebodies contain high levels of pyrite, which remains as a waste product in tailings. This process is not limited to tailings waste, however, and can occur in waste rock piles, underground workings and pit walls (Harries, 1997).

Pyrite is a mineralized form of iron sulphide, and its oxidation rate is dependent upon pH, surface characteristics of the pyrite, and the presence of sulphide oxidizing bacteria. The rate of pyrite oxidation and hence acid production is higher when catalyzed by bacterial action, but it can occur without the presence of bacteria at high pH (Evangelou 1995, cited in Harries 1997);

$$4FeS_2\,(s) + 9O_2\,(g) + 10H_2O\,(l) \rightarrow 4Fe(OH)_3\,(s) + 4H_2SO_4\,(l)$$
$$H_2SO_4\,(aq) \rightarrow 2H^+\,(aq) + SO_4^{2-}\,(aq)$$

These processes are accelerated by the milling process, which drastically increases the surface area over which oxidation can occur. Acidic conditions produced by this process can then mobilize radionuclides and toxic heavy metals into solution

4.2.7 Suspended Solids

The mining and milling of uranium in Kakadu generates massive volumes of waste rock and tailings. Dust generated from ore milling processes, disturbed topsoil, wind erosion of top soil, and rock dumps is contained in mining wastes and represent a source of contamination. Fine dust particles become suspended in solution during rain events and watering of the mine site. They are also present as suspended solids in tailings waste.

Clay material is used to line the walls of tailings containment pits to provide a low permeability barrier. The clay used to line the tailings containment pits for the Jabiluka uranium mine is to be sourced from the Hades Flat area in Kakadu National Park. The removal of clay and sand for construction activities on the mine site will undoubtedly impact upon the natural pattern of erosion and deposition of sediments in Kakadu, and may increase the amount of sediment and hence turbidity in stream systems.

4.3 Contaminant Dispersal Mechanisms

The waste produced by the mining and milling of uranium ore within Kakadu National Park and its catchment areas are disposed of within the uranium mine lease areas. Supposedly, these wastes are contained within those areas. There is irrefutable evidence, however, that contaminants have and will continue to disperse into the surrounding environment (see Appendices 1 & 2). The pathways by which contaminants are dispersed into the Kakadu world heritage area is discussed below.

4.3.1 Water Dispersal of Contaminants

4.3.1a Leaching

Leaching is the process by which chemical compounds are transferred by water through solid substrates. When these substrates take the form of ore stockpiles, waste rock piles or tailings waste, leaching becomes an important mechanism for the movement of contaminants into the surrounding environment. There is direct evidence that contaminants from uranium mining do leach into groundwater. For example, water that seeped through very low grade ore stock piles at Ranger uranium mine was found to have significantly high levels of uranium, up to 18 ppm (Unger & Milnes, 1992). Also, plumes of concentrated contaminants in groundwater, have been identified by independent experts as originating from Ranger tailings dam (Martin & Akber, 1996).

Tests show that the quantity of uranium and other metals leached through the ground under tailings dams is dependent on the volume of solute passing through the tailings and the pH of the solute. Tailings wastes is exposed to the large volumes of rainwater (with a pH of 4.5) every wet season (Noller *et al.*, 1990). A consequence of this is that the pH of tailings will drop over time from 7.5 to around 6.0 and beyond. This in turn leads to resultant increases in the dissolution and leaching of radionuclides and heavy metals (Martin & Akber, 1996).

Uranium concentrations in the slightly acidic groundwater underlying the uranium orebody are naturally quite low, which is significant considering it is a large high grade mineralization. The reason for this is that the region is quite tectonically stable, which limits uranium seepage into groundwater (Deutscher, 1980). Undisturbed, the underlying rock structures of both the Jabiluka and Ranger orebodies provide relatively stable containment of uranium-238 and its radioactive progeny (Deutscher, 1980). The long half-lives of many of these progeny, however, means that once they are disturbed, it is impossible to guarantee their safe containment during the millions of years over which radioactive decay occurs.

4.3.1b Runoff into Stream Systems

Another way that contaminants are dispersed by water into the surrounding environment outside of the mine lease area is by suspension in runoff. An important meteorological feature of the Kakadu world heritage area is its annual monsoonal wet season. During heavy rain events, contaminants may be suspended in water and transported out of the mine lease areas into the surrounding environment. There are two small collectors proposed for the Jabiluka site, which are designed to contain suspended sediments (Kinhill, 1998). These are tiny in comparison to the size of the proposed ore and waste rock stock piles and are inadequate during extreme runoff events.

As well as involuntary release of runoff, water discharge from retention pond has been intentionally released from the Ranger Uranium mine into wetland areas in Kakadu. Water discharge supposedly has safe levels of contaminants, however increased concentrations of magnesium (4.2 mg L^{-1}), sulphate (17 mg L^{-1}) and uranium (1.7 mg L^{-1}) were detected in 1990-91 wet season in areas around Ranger (McBride, 1992).

4.3.2 Dispersal of Contaminants By Air

Atmospheric transport is the main means by which radionuclides and other solid contaminants generated by uranium mining and milling operations are dispersed into the surrounding environment (Thomas, 1997). The main atmospheric contaminants are radon gas and dust. Dust is generated in ore and waste rock stock piling, ore milling processes and topsoil disturbance. This dust is dispersed into the environment via wind erosion and atmospheric transport (Thomas *et al.,* 1994). This form of transport is especially significant from July through to mid-September, when high winds are common in the build-up to the wet season. Stock piles of ore also provide a potent source of radon gas emission, because the ore that is released from its stable natural structures and broken up by machinery has a larger surface area, which facilitates increased emission.

4.3.3 Dispersal of Contaminants through Soil

The method and speed of contaminant movement through soils is controlled by factors such as the amount of groundwater, soil porosity and permeability. In water-saturated rocks or soils, for example, radon generally moves only a few centimetres before decaying, but in dry soils it may move several metres before breaking down. As a result of the tectonic stability of the region, soils are ancient, strongly leached and highly weathered (Russell-Smith *et a.l*, 1995). These soils easily transport contaminants through soil horizons and into aquifers.

Radionuclides and other particulate contaminants that are dispersed through the atmosphere, eventually settle back on the Earth's surface, where they then accumulate in the topsoil and litter layers (Thomas *et al.,* 1994). Other contaminants, that are carried as suspended sediments in surface waters, also accumulate in the top horizons of terrestrial and wetland soils. Wetland floors can also be contaminated from the precipitation of solids out of solution in surface waters. Contaminants can then be re-dissolved into water and taken up by plants (which may be ingested directly by grazers).

4.3.4 Dispersal of contaminants by Biota

In the short term, the most obvious manner in which contaminants generated by uranium mining and milling could be dispersed into the surrounding environment is by dust carried on mine employees' clothing and dispersal by birds visiting the tailings dams and retention ponds (Johnston & Murray, 1983). Soil and water micro-organisms can also play a significant part in the short term dispersal of contaminants, as they absorb them and then travel significant distances through ground and surface water, especially during the wet season.

This dispersal at the bottom of the food chain facilitates more long term dispersal by other organisms. Long-lived animals, especially fish and birds, are vectors for heavy metal and radionuclide dispersal, as these contaminants accumulate in their tissues (Bishop, 1983). These highly mobile organisms can then transport contaminants over long distances. For example, in the early wet season, escarpment fish feed in the lowlands, while floodplain or mid-channel fish travel upstream (Press, *et al.,* 1995). Barramundi *(Lates calcarifer),* a common fish in the Alligator Rivers, migrate from estuaries to the sea to breed (Bishop, 1983). Contaminants generated in the mine lease area therefore have the potential to dispersed both upstream, downstream and into the marine environment.

4.4 Contaminant Dispersal into the Environment

The various physical and chemical forms of the contaminants generated by Uranium mining and milling activities means that there are different characteristic patterns of dispersal for each contaminant. These characteristics are examined below.

Acidification is the accumulation of hydrogen ions, and can be an ongoing process which can increase the solubility and hence mobility of toxic radionuclides and heavy metal ions in waste materials. Unless well contained, these contaminants will leach into the water table (Environment Australia, 1997) Levels of sulphuric acid in surrounding waters do increase as a result of uranium extraction by the process of acid mine drainage. Once initiated, acid production is a persistent and potentially severe source of contamination, which continues long after mining activities have ceased (Harries, 1997). This is well exemplified by the Rum Jungle uranium mine which, after the tailings dam burst released toxic levels of copper and zinc into the environment, with catastrophic effect on life the East

Finniss River and adjacent floodplains. This incident left a 10km section of the river biologically dead a $100km^2$ area of the floodplain hazardous to life. Subsequent cleanup and rehabilitation actions in the area in 1986 cost the Federal and Northern Territory Government an estimated $18.6 million (Caufman, 1987).

This contaminant dispersal mechanism is particularly important because the Jabiluka and Ranger orebody contains pitchblende and uranite (U_3O_8,). The increased acidity of groundwater in the vicinity of uranium mining activities in Kakadu will certainly increase the concentration of uranyl ions in solution. Over half of the thorium-230 contained in uranium ore will dissolve in acidic solutions (IAEA, 1992) The thorium-230 decay product radium-226 is of great concern due to its high radiotoxicity index (IAEA, 1992).

The absence of carbonates and bicarbonates in the surrounding rocks corresponds to a low level of alkalinity in as Maumudjimajali (Swift) Creek for example (Kinhill, 1997). Waters downstream of the Jabiluka mill site and mine would be highly susceptible to acidification due to reduction in buffering ability. Tests by ERA have shown that the ore materials provide poor buffering capacity. This means that the sulphuric acid, formed through oxidation processes in mine wastes, is likely to have a major long term effect on the pH of groundwater.

4.4.1 Radionuclides

Uranium, radium and radon are the three most frequent radionuclides observed at elevated levels in groundwater (Martin & Akber, 1996). If water passes through rock containing radioactive elements, it will have relatively high concentrations of those contaminants (Russel-Smith *et al.,* 1995). Dissolution of radionuclides into groundwater is the most significant form of contaminant dispersal, and it is increased when salinity and acidity of groundwater is high. High salinity levels in groundwater directly result in increased radium concentrations in the water. High salinity levels are evident at the Ranger mine, due to the presence of excessive amounts of magnesium and sulphate in the soil solution (Ashwath 1994; Martin & Akber, 1996). Groundwater may also carry radium and transport it long distances, where it is able to accumulate and concentrate. The subsequent decay of radium then provides a concentrated source of radon gas.

Radon gas and its particulate progeny are readily dispersed by wind. Being a heavy gas some seven times heavier than air it also collects in depressions. Wind allows pollutants to be distributed over considerable distances, easily transporting particulates and radon to local settlements and distributing it in the local area. Potent sources for atmospheric dispersion of radon at the proposed Jabiluka mill will be ventilation shafts from underground workings and surface ore processing facilities such as ore stockpiles, waste rock dumps, and tailings dams. Radon is also be emitted from rocks, soil and water. Large fluctuations of the water table during the wet season in Kakadu causes a pumping action that aids upward migration of radon (LeGrand, 1988). Radon gas can also escape from rocks and soils through interstitial fractures and openings.

4.4.3 Heavy Metals

Once mobilized by mining and milling processes, heavy metals pose a significant source of environmental contamination. These elements include iron, copper, zinc, cadmium, mercury, chromium, lead, tin and manganese. Of these cadmium, lead and mercury are especially toxic to the environment. Even uranium itself is a heavy metal.

Many of the streams that run past the large uranium deposits in Kakadu National Park are close to the mouth of their catchments. Characteristically, they have low alkalinity, slight acidity and low levels of suspended solids (Russel-Smith *et al.,* 1995). These conditions would tend to keep metals in solution (Fox, 1977).

Studies of the water quality of Magela Creek prior to the operation of Ranger uranium mine indicate the presence of naturally occurring metals, including copper, lead, zinc, manganese, uranium and radium (Fox, 1977). Water contamination from these metals, however, has greatly increased by the presence of uranium mining in the area (Russel-Smith *et al.,* 1995). This has been demonstrated by studies of bore water drawn from the vicinity of the Ranger and Nabarlek uranium mines. Manganese concentrations in some Ranger bores have increased from below 100 µg/L to above 600 µg/L in the period from 1983 to 1994 (Martin & Akber, 1996). Similarly, the concentration of manganese in water from some Nabarlek bores was around 1,400 µg/L, compared with background concentrations of around 500 µg/L (Treloar, 1982).

4.4.4 Diesel Fuels and Hydrocarbons

Leaching of hydrocarbons into the environment is largely dependent on the chemical composition of the hydrocarbon fuel. Simple short chain hydrocarbons are more water soluble and tend to leach at higher rates than their aromatic and branched counterparts (Genouw *et al* 1994., cited in Robertson et al 1997).

Not only is leaching a source of contaminant dispersal, but spillages into the Kakadu National Park will also occur, For example, operations at the Ranger Uranium mine have seen past spillage of diesel fuel into the park (see Appendix 2). Hydrocarbons do constitute a very significant source of environmental contamination.

Biodegradation of hydrocarbon contaminants is largely dependent on the presence and action of indigenous micro-organisms that break down these contaminants to methane and carbon dioxide (Robertson *et al.*, 1997). The process is not as simple as this, however, because the microbial breakdown of hydrocarbon contaminants can be incomplete. This is especially in the case of aromatic hydrocarbons, which are very stable and hence resistant to any form of breakdown. Furthermore, the breakdown of these contaminants may take decades, depending on the type of hydrocarbon and quantity released. By this time, a large proportion has already leached into the surrounding environment

4.4.5 Sulphates

Sulphate ions are not toxic, however, when they are introduced into the environment in large quantities they change the cation exchange characteristics of soils. This in turn can seriously alter the balance of available nutrients to plants and soil micro-organisms. Increased sulphate concentrations in water significantly increase the electrical conductivity of that water which in turn can have adverse effects on the organisms that inhabit it (Corbett, 1996).

Surface waters of the Northern Territory typically have very low sulphate (SO_4^{2-}) concentrations. This is because the soils are highly leached and the natural sulphate content in rainfall is low (Jabiru's mean sulphate content in rainfall is 0.35 mg/L) (Noller *et. al.*, 1990). Vast quantities of sulphuric acid (H_2SO_4) are used to extract uranium from ore, as a consequence sulphate is the main anionic species present in tailings waste. The release of tailings into the surrounding environment therefore markedly increases the levels of sulphate in surface waters.

There is also evidence that uranium mining leads to sulphate contamination of groundwater. For example, monitoring of deep-aquifer bores in the vicinity of the Ranger tailings dam has found that sulphate levels have been increasing since 1983 (Martin & Akber, 1996). Monitoring of groundwater bores downstream (north) of the Ranger tailings dam has shown a steady decline in water quality since 1983. Since then increases of up to 500 times for sulphate concentrations and up to 5 times for radium concentrations have occurred (Martin & Akber, 1996).

4.4.6 Suspended Solids

Increased erosion that results from mine construction (see Plates 4.1, 4.2) and mining operations in Kakadu will increase the suspended sediments in river and creek systems. The low slope angles, widespread surface gravel and weak crust forming nature of Kakadu National Park's soils means erosion is usually extremely low (Russel-Smith *et al.,* 1995). Any disturbance of the soil, however, allows significant erosion to take place, especially in the early wet season before the binding vegetation takes hold (Russel-Smith *et al.,* 1995).

There are two small sediment collectors proposed for the Jabiluka site, for containing sediment suspended in runoff (Kinhill, 1998). These are tiny in comparison to the size of the proposed ore and waste rock stock piles and are likely to be inadequate in the event of extreme runoff events.

4.5 Long Term Containment of Wastes

The long term containment of mine wastes is a very significant issue facing the mining industry worldwide. Heavy metal contamination associated with gold mining is already causing severe problems in the Amazon Basin. Past and present problems are also emerging in areas that have been previously or are currently being mined in the Alligator Rivers Region.

A wide range of contaminants are generated during uranium mining and milling processes. Sulphuric acid, diesel fuel and other chemicals are transported into and used within Kakadu National Park. Long-term tailings waste containment has proven to be a very difficult issue to manage for any mine, and becomes so much more important in such a significant world heritage area. Processes such as acid mine drainage, leaching and run off are all active processes that will occur in the areas where mining of uranium occurs. New and largely untried tailings paste technology, combined with a location of tailings disposal pits that is geologically unstable, have led to serious misgivings to the PER for the Jabiluka Project being expressed by key independent assessment bodies.

"At present time, the data required to make a decision on either proposal is simply not available, and when a matter as important as tailings management has not been resolved, environmental approval for the project should not have been given." (Farthing, 1998).

Existing and proposed mines within Kakadu will have to deal with radioactive contaminants that will be poisonous for hundreds of thousands of years.

Chapter 5

Biotic Effects of Contaminants from Mining & Milling Uranium

The areas bounded by Kakadu National Park and its surrounding catchment area are home to an extraordinary diversity of unique plant, animal, fungal and microbial lifeforms. Complex interactions between these elements form a pattern of interacting ecosystems that are highly sensitive to the effects of contamination by mining activities. Water regime in this extreme climate of the monsoonal wet/dry tropics is the driving force behind diversity and pattern. Natural water flows and water quality are essential to the survival of many species. Water is also a major vector for the transfer of contaminants into the environment.

Recommendation:

We recommend that the World Heritage Committee

a) recognise the gravity of risks posed to the biodiversity of Kakadu National Park by the release and subsequent bioaccumulation of contaminants generated by uranium mining and milling

b) request that the Australian Government instigate steps to eliminate these risks.

Uranium mines ultimately damage the health of the surrounding environment. Detrimental effects to ecosystems arise from the exposure of organisms to a range of contaminants. These include contaminants with chemical effects (heavy metals, salts), radioactive effects (radionuclide and decay progeny), and physical effects (excessive sediment loads). Effects on organisms include, amongst others, direct mortality, impairment of reproductive success and increased susceptibility to disease. Moreover, the characteristics of the local ecology in the Alligator Rivers Region make the flora and fauna extremely vulnerable to contaminant exposure (see Figure 5.1)

5.1 Biotic Uptake of Contaminants

Mining contaminants released into the environment will become available for uptake by the biota from the air, water, soil, and from dietary intake. Biota can acquire elements through absorption, adsorption, ingestion and inhalation and lose them via exchange, excretion and decomposition. The duration of time that an element is retained by an organism is a function of its uptake, retention and loss characteristics.

Some elements have similar chemical characteristics to biologically useful elements and thus become incorporated into organisms via transport mechanisms that regulate nutrient ions (Ripley *et al.,* 1996). For example it has been shown that radium-226 and lead-210 replace calcium in the bone matrix resulting in high concentrations of these elements in bone (Thomas *et al.,* 1994). Uptake is relative to the level of an element present in the environment (air, water, soil and food) and is influenced by factors such as pH, total element profile and stage of growth/development of the organism For example uptake of mineral nutrients by plants is influenced by soil acidity.

5.1.1 Bioaccumulation

The bioaccumulation of heavy metals and radionuclides from uranium mine wastes poses a great threat to natural ecosystems in the region. Bioaccumulation is the uptake of elements, such as heavy metals and radionuclides, and accumulation within the tissues of an organism. This process can have both lethal and sublethal effects on the organism. Bioaccumulation of radionuclides by organisms has been shown to occur as a result of exposure to uranium mine wastes. Swanson (1983) showed that fish in an impacted lake had radionuclide levels one to two orders of magnitude above levels in other uncontaminated lakes. Lichens have also been shown to be very efficient at accumulating airborne radionuclides (Thomas *et al.*, 1994).

Bioaccumulation allows elements to accumulate up the food chain; herbivores retain some of the contaminants present in their plant diet, and carnivores can bioaccumulate some of the contaminants present in their prey. Insects such as termites and grasshoppers are the major herbivores in Kakadu National Park (Press, *et al.,* 1995) and are an important food source for many animals. Consequently, they are likely to play an important role in the buildup of contaminants up the foodchain. Polonium-210, which has a half-life of 138 days, transfers easily along food chains because it tends to accumulate in internal organs of animals when eaten or inhaled (Thomas *et al.,* 1994). As lead-210 has a half-life of 22.2 years, it decays within the lifetime of many larger animals. Even in very low concentrations, radioactive materials in water can be harmful since they accumulate in body tissues until a damaging concentration may be reached (Foster & Mc Connah; cited in Connell, 1993).

Methyl-mercury is produced by microbial action on inorganic mercury compounds. Mercury is found in significant concentrations in the vicinity of gold deposits within areas of uranium mineralization, such as Jabiluka and Koongarra. Methyl-mercury is highly toxic and constitutes a great danger to the biosphere. Methyl-mercury is fat-soluble and hence easily transported across the phospholipid cell membranes of animal tissues. It then bioaccumulates in the aquatic food chain reaching the highest concentration in predatory fish and fish eating animals including mammals (Wren, 1986). It has neurotoxic effects (Clarkson, 1997).

5.1.2 Uptake of Contaminants by Plants

Terrestrial plants that have their roots embedded in sediment are exposed to contaminants in the sediment. Aquatic plants are also exposed to contaminants in water over the surfaces of their roots, stems and leaves. Uptake of contaminants by aquatic herbs is well documented, but there is little information on other plants. For example, *Melaleuca cajuputi* and *M. leucadendra paperbark* forest swamps are subject to waterlogging for most of the year yet the ERISS library computer has no reference to *Melaleucas* or their involvement in the uptake of metals (pers. com. Joan Mount, ERISS librarian).

Despite this, the effectiveness of heavily vegetated creeks and wetlands at taking up contaminants is well demonstrated (Noller *et al*, 1994). Magnesium, sulfate, radium and uranium were taken up in a 'wetland filtration' trial at Ranger uranium mine, where waste-rock runoff water from RP4 was passed through or held in Djalkmarra Billabong, (Unger & Milnes, 1992; Noller *et al,* 1994). Importantly, they suggested it was possible that some elements might be remobilized during the following wet season, after the wetland dried out. (Unger & Milnes, 1992; Noller *et al,* 1994).

Aquatic plants seem to gather most of the contaminants. For example, water from a Ranger uranium mine bore contained approximately 110 µg/L of dissolved uranium, but after a 2.5 km stretch of densely vegetated Georgetown creek and billabong, the uranium concentration found to be less than 1 µg/L (Noller *et al,* 1994). Similarly, at a Northern Territory gold mine, arsenic, iron, cobalt, nickel, copper, zinc, lead, and uranium were all reduced by 90% two kilometres downstream of the mine water discharge point, and manganese by 75%, with very little dilution (Noller *et al,* 1994).

It is unfortunate that wetlands are exploited to "*improve*" water quality, yet the many studies totally ignore the impact on the vegetation that is taking up the toxic substances. In addition, the ability of wetlands to sustain the exposure of waterborne contaminants is not understood (Unger & Milnes, 1992). The practice is to assess the efficiency of each wetland filter, once the process of releasing contaminants is underway (Noller *et al*, 1994). This outrageous experimentation with ecological contamination occurred at Nabarlek and is still happening at Ranger uranium mine. What they neglect to point out is that this immensely effective uptake of contaminants by wetland vegetation proves that contaminants move directly and effectively straight into the biosphere.

In Canada, where environmental effects of uranium extraction seem to be comprehensively studied, plants that aren't part of the human food chain or for water quality improvement were tested for radionuclides. In the broad vicinity of a uranium extraction plant, trees were found to accumulate radionuclides over time. In this study, twigs and foliage of spruce trees accumulated uranium-238 from about three to five fold, from young to old samples (Thomas, 1997). Similarly radium-226 accumulated with age, but concentrations of lead-210 declined, (Thomas, 1997) perhaps becoming remobilised. Thus it is possible that at least older gymnosperms, in the vicinity of uranium mines of Kakadu National Park, such as the cypress pine *Callitris intratropica* could accumulate radionuclides too.

5.2 Effects of Contaminants on the Biota

Algae**,** present in the waters of the Kakadu National Park, are important at the base of food chains and have been observed to die after exposure to levels of copper as low as 0.1 µg g^{-1} (Connell, 1993).

Studies of organisms exposed to chronic radiation doses reveal that animals are the most sensitive to radiation induced genetic damage and congenital birth defects. Plants and micro-organisms show a higher tolerance to radiation exposure, but genetic effects have been demonstrated in nearly all organisms well below the lethal threshold of 3.6 Gy/year (Rose, 1992). A continuum of biological effects on a variety of organisms is shown in Table 5.1

Dose (Gy/ year)	Effect
0.01	Detected by Planarian worms; reduces population density of young flies.
0.02	Reduces the growth of Primula plants.
0.03	Changes the cellular structure of gonads in tundra voles.
0.06 to 0.07	Reduces the sexual reproduction of liverworts; death of mice oocytes.
0.1 to 1	Reduced viability in Tulip Tree seeds; reduced epididymal sperm counts in mice; death of squirrel monkey oocytes.
1 to 5	Reduces the growth rate of pitch pines, scarlet and white oaks; increases the number of growth abnormalities on the stems of broad beans; death of oocytes of pigs, guinea pigs, rats and mice.

Table 5.1: Sensitivity of Various Organisms to Chronic Radiation (Rose, 1992)

Some non-radioactive elements produced by uranium mining are considered to become toxic only after exceeding a threshold dose. For example, copper, an essential trace element nutrient for many organisms, becomes toxic if an organism is exposed to levels in excess of its capacities to safely store or excrete it. Determination of the toxicity of different elements is complicated by the fact that their effects are dependent on the presence of other elements. For example*, "copper and molybdenum are antagonistic and the action of molybdenum in blocking the metabolism of copper is augmented by high levels of sulphate"* (Davy & Conway*.,* 1974). Copper, molybdenum and sulphate are present together in tailings waste

5.2.1 Effects of Contaminants on Plants

Copper, manganese, uranium and zinc are known to be toxic to plants. Sub-lethal effects of these contaminants include stunted roots, dead leaves, stem and petiole lesions, dwarfing, and abnormal numbers of chromosomes in cell nuclei (Ripley *et al.,* 1996). However, few studies have investigated the effects of contaminants on plants in Kakadu National Park. Samples of couch grass *Cynodon* sp. at Ranger Uranium Mine were found to have copper concentrations between 150 and 220 µg g^{-1}, which are considerably in excess of levels regarded as toxic in most plants (Unger & Milnes, 1992).

Elevated concentrations of manganese and uranium in Ranger Uranium Mine irrigation water from Retention Pond 2 are detrimental to plants (Ashwath, 1991). This is inevitable if the land application is continued until the end of the expected Ranger Uranium Mine life (Ashwath, 1991). A similar water management procedure for the Jabiluka Uranium Mine would exacerbate the situation. Build-up from the seepage of these contaminants would also be detrimental to plants.

Retention Pond 2 manganese concentration has reached 12 mg L^{-1} which is up to 60 times higher than that recommended for irrigation water (Ashwath, 1991). Similarly, average manganese concentrations in plants in Ranger uranium mine's RP4 in the dry season were significantly above levels (600 µg g^{-1}) which is considered to be toxic to many agricultural plants (Unger & Milnes, 1992).

On the basis of the response of agricultural crops to manganese toxicity, it could be expected that at least some of Kakadu National Park's leguminous species will accumulate foliar manganese concentrations to toxic levels and exhibit toxicity symptoms (Ashwath, 1991). High levels of exchangeable magnesium lower the availability of the essential nutrients potassium and calcium to plants through cation antagonism (Mengel & Kirkby, 1978). This may lead to potassium and calcium deficiency in some plant species (Baker & Eldershaw, 1993). At Nabarlek Uranium Mine magnesium to calcium ratios are as high as 350:1 (Ashwath, 1994), and are also excessive at Ranger Uranium Mine. For the normal growth of crop plants, a magnesium to calcium ratio between 1:3 and 2:1 is considered acceptable. The presence of high magnesium concentrations in the soil contributes to changes in plant communities (Ashwath, 1994).

Nitrogen concentrations, in contrast, are deficient in Retention Pond 2 water and the land application area (Ashwath, 1991). This gives the plants little benefit as the overall growth of plants depends on the element that occurs at the lowest concentration. This nutritional imbalance may lead to slow growth of plants which inevitably leads to excessive accumulation of some elements such as manganese (Ashwath, 1991). Acute deficiencies of zinc were also detected in the one Ranger Uranium Mine soil in which this was examined. It is quite likely that other nutritional problems such as deficiencies, imbalances, and toxicities occur in mine soils (Reddell & Milnes, 1992).

Salinity is also evident at the Ranger mine soils, due to the presence of excessive concentrations of magnesium sulphate in soils which could produce osmotic effects on plants, as these species normally occur on non-saline soils (Ashwath, 1994). The presence of magnesium sulphate (4 to 160 mM) has been shown to affect the germination of twenty species native to Kakadu National Park in either a severe, moderate or tolerant way (Ashwath, 1994). This can only lead to a loss in diversity if the most tolerant species have invasive characteristics. In addition, the irrigation with highly saline tailings water of a Nabarlek *Eucalypt* dominated woodland caused significant tree death in some species (Green *et al.,* 1992).

Plants take up radionuclides when exposed to contaminated water. During irrigation at Ranger Uranium Mine, young shoot accumulation of radionuclides (uranium-238, radium-226 and lead-210) was up to 6,200 times greater than the pre-irrigation period, and up to 30 times greater than the post-irrigation period (Akber & Marten, 1992).

5.2.2 Effects of Contaminants on Aquatic Invertebrates

The presence of mine-related contaminants, especially heavy metals, in surface waters downstream from the Alligator Rivers Region uranium mines present a potential hazard to freshwater organisms (Humphrey, 1990). Cadmium, copper, manganese, lead, uranium and zinc have been recognised as being of ecotoxicological concern in the aquatic ecosystems of tropical Australia, largely as a consequence of mining activities (Markich & Camilleri, 1997).

Many aquatic invertebrates are sensitive to heavy metals and radionuclides, particularly in their early life stages. Copper is particularly toxic. Studies on juvenile yabbies have shown copper sensitivity levels at least ten times higher than that of adults (Skidmore & Firth, 1983). Freshwater mussel larvae are also highly sensitive to heavy metals (Skidmore & Firth, 1983). Such juvenile sensitivities are concerning for the survival of populations when contaminants rise even slightly. Most studies however, document the acute toxicity concentrations for mature organisms.

Boorooboo'oo Billabong, situated downstream of the tailings dam at Ranger, reached copper concentrations of 3.7 µg/L at the onset of tailings deposition. The creek that feeds this billabong, Gulungul, had reached copper concentrations of 8 µg/L (Williams, 1983). The atyid shrimp *Caridina* sp. is extremely sensitive to copper, dying at levels of only 2 ug /L (Williams, 1983). These levels, even just at the start of milling, determine the distribution of this shrimp (Williams, 1983).

Although it has been reported that Kakadu's freshwater mussel *Velesunio angasi* are "*very resistant to copper*", the mussels perceive very low concentrations of copper (as low as 37 µg Cu/L) and actively avoid poisoning by clamming shut. Thus the statement that *V. angasi* is resistant is misleading, merely indicating that the valve closure delays the toxic effects of the copper (Skidmore & Firth, 1983). In addition, Kakadu National Park's *Macrobrachium* sp. prawns were found to be fairly sensitive to copper with half the individuals dying at 160 µg Cu/L (Skidmore and Firth,1983). Untreated Retention Pond 4 water is toxic to the cladoceran *Moinodaphnia macleayi,* increasing adult mortality and reducing fecundity (Unger & Milnes, 1992).

Snails are also known to be very sensitive to copper. For example the snail *Physatra gibbosa* (of New South Wales), succumbs at 31 µg Cu/L after 7 to 9 days (with no variation across lifecycle) (Skidmore & Firth, 1983).

5.2.3 Effects of Acidification on the Aquatic Organisms

The deleterious effects of increased acidity on freshwater organisms and ecosystems have been well established, primarily in terms of reduced number of individuals and species (Allen, 1995). Acidification of water decreases photosynthetic production in aquatic plants and phytoplankton, thus reducing the primary productivity of the system. Many fish, amphibians and many freshwater invertebrates fail to reproduce in acidified waters (Ripley *et al.*, 1996). Some species may avoid entering acidified waters if they have an alternative. Some species of insects have been noted to avoid depositing eggs, thereby reducing an important food source for other species. Studies show that below a pH of approximately 4 is directly toxic to the roots of plants (Ripley *et al.,* 1996). Similarly, reductions of pH have been shown to increase mortality of animals, and to cause failure of eggs to develop, due to an inability to regulate ion transfer (Allen, 1995).

5.2.4 Effects of Contaminants on Fish

Changes in fish community structure were reported in Gadjerigamundah Creek, near Nabarlek Uranium Mine. These impacts were suggested to be due to the remobilised salts from the Nabarlek irrigation area in Gadjerigamundah Creek. The water contained additional solutes such as ammonium (3.6 mg N /L), sulphate (73 mg /L) and nitrate (66 mg /L) (McBride, 1992).

Fish are extremely sensitive to copper. Concentrations of copper as low as 42 and 17 µg Cu/L were found to be acutely toxic to the Penny-fish *Denariusa bandata* and the Eel-tailed Catfish *Porochilus rendahli* respectively (Williams, 1983). Kakadu's Chequered Rainbowfish *Melanotaenia splendida inornata* and the Chanda Perch *Ambassis* sp. have been found to be reasonably sensitive to copper; half of the individuals tested died at copper concentrations between 120 and 200 µg Cu/L (Skidmore & Firth,1983; Williams, 1983). It should be noted that survival rates for *M. splendida* sharply declined when the water temperature was raised (Williams, 1983). Such increases in temperature are common in waterbodies of Kakadu during the late dry season.

Fish are also sensitive to radionuclides. An increase in malformation rate in fish eggs in some species has been demonstrated at radiation levels as low as 10^{-12} Ci/g (approx 0.01 Bq/g) (IAEA, 1976). Radiation levels of between 10^{-11} and 10^{-8} Ci/g (1 to 102 Bq/g) have been shown to have deleterious effects on fish. These effects include increases in the mortality rate of fish embryos, reduced size of juvenile fish, decreases in cell division at the gastrula stage, and chromosome aberration of fish eggs (IAEA, 1976). Toxic effects resulting in reduced fecundity may compromise the survival of populations.

A neglected aspect of toxicology is that of the enhanced effect of radiation and/or heavy metals on organisms which already have health problems. Epizootic Ulcerative Syndrome or 'red spot' disease has been identified in fish from a number of river systems in the Northern Territory, including the West, South and East Alligator river systems (and the Magela Creek). This condition has been recorded in Archer Fish (*Toxotes chartareus*), Primitive Archer Fish (*Toxotes lorentzi*), Barramundi (*Lates calcarifer*), Bony Bream (*Nematolosa erebi*), Fork-tailed Catfish (*Arius sp*.), Long Tom (*Strongylura kreffti*), Mouth Almighty (*Glossamia aprion*), Red Scat (*Scatophagus argus*), Saratoga (*Scleropages jardini*), Rainbow Fish (*Melanotaenia splendida*), Sleepy Cod (*Oxyeleotris lineolata*), Spangled Perch (*Leiopotherapon unicolor*), and Striped Grunter (*Amniataba percoides*) (Pearce, 1990). This condition is frequently fatal to juvenile fish (Pearce, 1990). The potential for increased occurrences of this disease resulting from additional stresses such as increased sediment load or exposure to one or more toxins is a distinct possibility (Wedemeyer, *et al.,* 1976). Little work on this subject has been undertaken.

Not only wetland fish would be affected by contamination. Extensive contaminant induced damage in the lowlands, utilised by some highland fish for wet season feeding, breeding and nursery grounds would also threaten escarpment country communities (see Plate 5.1) (Bishop, 1983).

5.2.4 Effects of Contaminants on Frogs

The international recognition of the responsiveness of frogs to environmental pollution makes frogs likely candidates for environmental impact studies. Baseline studies of frogs in the vicinity of Ranger Uranium Mine found a relatively high percentage of frogs (7.3%) (a few individual populations showed very high rates) with obvious morphological abnormalities (Tyler et *al,* 1981). It has been claimed that there is no evidence to indicate that uranium mining has been detrimental to frog populations in Kakadu (Kinhill, 1996). However, the studies have been intermittent, and are limited in their scope, focusing predominantly on adult frogs and suffering from low sample sizes. Studies investigating the acute effects of gamma and x-ray radiation on the frog *Limnodynastes tasmaniensis* (which is not found in the Alligator Rivers Region) concluded that the fertilised egg and the tadpoles of this species were the most radio-sensitive life stages (Panter, 1983). On the basis of this result it may be argued that early life stages are the least likely to survive to be surveyed, making detection of effects such as abnormalities difficult. Although it was suggested that chronic effects of radiation on frogs, such as that due to Ranger uranium mine contaminants, would be similar to the acute effects, (Panter, 1983) the inappropriateness of the study still hasn't been discussed. Due to the limitations of frog research, the finding of lack of impacts can hardly be conclusive.

Further studies are needed to assess potential effects of mining activities on frog populations. Not only do frogs spend much of their lifecycle in aquatic habitats, some spend time in the sediments as well. Kakadu's marbled frog, *Limnodynastes convexiusculus*, survives the dry season in muddy sites (Press, *et al.,* 1995) making it highly susceptible to the absorbtion of contaminants in sediment.

5.2.5 Effects of Contaminants on Reptiles, Birds and Mammals

Downstream from the uranium deposits and tailings depositories, the Magela and Nourlangie floodplains are the homes to millions of waterbirds in the dry season (Press, *et al.,* 1995).). Little curlews, *Numenius minutus*, arrive in large numbers from Siberia to feed on the drier floodplains (Press, *et al.,* 1995). These birds are at considerable risk from contamination by the Ranger and proposed Jabiluka uranium mines. For example, concentrations of lead in the dried liver in birds of as little as 1 to 2 µg/g have been shown to produce sublethal effects (Edens *et al.,* 1976; Dieter, 1979; cited in Brennan *et al.,* 1992).

The carnivorous northern snake-necked turtle *Chelodina rugosa* feeds on invertebrates and small fish on flooplains (Press, *et al.,* 1995). If these food sources are depleted or contaminated, turtles may be affected. Similarly, the saltwater crocodile, *Crocodylus porosus*, and the freshwater crocodile, *Crocodylus johnstoni*, which inhabit Kakadu National Park's freshwater streams and billabongs are dependent on many animals for food. These reptiles could also absorb contaminants as they spend long periods in the mud.

Due to its consumption of mussels and other invertebrate organisms the otter-like water-rat *Hydromys chrysogaster* is also a prime candidate for contaminant accumulation (Skidmore & Firth, 1983).

The agile wallaby *Macropus agilis* could receive large doses of contaminants by consuming grasses that are known to uptake heavy metals and radionuclides. However wallabies do not seem to have been investigated despite being prominent on the menu of the local human inhabitants (Martin, *et al.*, 1995). However, there are many species that require further studies. For example, reports of pigs foraging in the Djalkmara billabong, which has long been the site of Retention Pond 2 water releases, oil spills and is now pit 3, would suggest pigs in the vicinity should be studied for contaminant uptake. Pigs are omnivorous.

5.2.6 Mining Activities and Endangered Species

There are some species that were observed to be likely to be adversely threatened by the mining activities. Some species such as the Northern quoll (*Dasyurus hallucatus)*, the Spectacled hare-wallaby *(Lagorchestes conspicillatus)* and the Gouldian finch (*Erythrura gouldiae)* are both found at Jabiluka and currently undergoing range contractions.

Factors such as loss of habitat and competition with introduced invasive species pose immediate threats to endangered species. Although loss of habitat such as wetlands is considered the most severe threat, problems of invasive species are often the most worrying, since they are frequently the most difficult to control (IUCN, 1994).

Disturbance such as that associated with mining increases the likelihood of invasive weeds. Invasive weeds are detrimental to the survival of rare and endangered species. For example, the two dryland flora species which are classified as rare on the Jabiluka mineral lease (Kinhill 1998; Brennen, 1996) could be affected by invasive weeds following rehabilitation. Weeds are a significant problem in the Alligator Rivers Region, and have still not been removed from now decommissioned and supposedly Nabarlek Uranium Mine. Concerted and sustained effort, rarely seen at rehabilitated mines, can however, remove weeds. In contrast, loss of integrity of Kakadu's wetlands due to uranium mining and milling contaminants will be impossible to control.

One of the ways of dealing with endangered species is to protect their habitat in reserves such as National Parks. This is also one of the methods used to reduce the onset of being in danger of extinction. Therefore it is disappointing when illogical goals such as multiple land use and maximisation of industry are applied to areas supposedly intended for conservation of native species.

5.3 Effects of Contaminants on Humans

Studies have been undertaken in the Alligator Rivers Region with the ultimate aim of protecting humans from the unhealthy effects of pollutants released into the environment and subsequently accumulated in food (Martin *et al.,* 1995). Ignorantly, it is considered that if humans are safe then the environment will be also. These studies have not addressed the effects of radionuclides on the organisms themselves, or on their ecological relationships with other species including humans.

5.3.1 Accumulation of contaminants in Traditional Aboriginal Foods

Kakadu National Park supports several resident groups of Aboriginal people who use the floodplains as a source of foods. Elevated concentrations of the radionuclides radium-226, lead-210, polonium-210, uranium-238, uranium-234, thorium-230, thorium-232 and actinium-227 have been found in the edible flesh of foods from the Magela and Cooper Creek systems, including fish, buffalo, pig, magpie goose, filesnake, goanna, turtle, freshwater shrimp and crocodile (Martin *et al.,* 1995).

The greatest dose is estimated to arise via consumption of freshwater mussels, *Velesunio angsi* (Akber & Hancock 1990) which efficiently accumulate radium-226 and lead-210 (Jeffree, 1983). This mussel is abundant in the Magela Creek system and is a common food of the indigenous people (see Plate 5.2). However, during mining operations the effects of radium-226 are not expected to be great due to the effects of magnesium and calcium. Radium, calcium and magnesium are expected to increase as a result of uranium extraction effluent. Elevated levels of magnesium and calcium, both in combination and singly, reduce the rate of accumulation of radium-226 as it behaves as a metabolic analogue of calcium. It should be noted however, that mortality is increased in mussel populations subject to high concentrations of calcium and magnesium (Jeffree, 1983). After the abandonment of mining, calcium and magnesium are expected to leach quickly from the waste rock, but the radium-226 is expected to leach more slowly, becoming a greater problem in subsequent years to those that eat these mussels (Jeffree, 1983).

The common waterlily, *Nymphaea violacea,* may make radium-226 bioavailable by remobilizing radionuclides in the sediment (Pettersson, 1993). This is important as the waterlily is abundant on the floodplain and the sediment is the major contaminant sink (Pettersson, 1993). Consumption of unpeeled *N. violacea* rhizomes could become dose-limiting within 50 years (Twining, 1993).

Two traditionally hunted waterbird species include the Green Pygmy Goose *(Nettapus pulchellus)* and the Wandering Whistling Duck *(Dendrocygna arcuata).* They were found to have liver copper concentrations exceeding National Health & Medical Research Council recommended standards by a factor of 10 (Brennan *et al.,* 1992). It was concluded that a fatal human dose would only occur if other components of the diet also contained such high levels of copper. No discussion of the effects to the birds themselves was entered into.

Salmon Catfish *Arius leptaspis,* collected from the Ranger project area, were found to have zinc levels above those recommended by the National Health and Medical Research Council (Ranger Uranium Mines Pty Ltd; cited in Bishop, 1983). People still fish from the waters in the vicinity of Ranger Uranium Mine, and are advised that they are safe.

Humans could be detrimentally affected by ingesting radionuclides after mining has ceased particularly in respect to the effects of the build-up of the medium term radionuclides: radium (half-life 1600 years) and thorium (half -life 75, 000 years) (Johnston & Murray, 1983; Miskiewicz, 1992).

Methyl-mercury is a neurotoxin and can cause damage to foetal brains (Clarkson, 1997). As it is readily transferred across placental membranes, it is recommended that women of childbearing age in areas of risk should not consume more than 350g of fish per week (Koos & Longo, 1976). Fish and fish eating animals constitute a large proportion of the diet of the indigenous people of Kakadu National Park, making any form of mercury pollution from mining activities potentially disastrous for the aquatic ecosystems of this area and the people who rely on them for their survival.

5.3.2 Effects of Ionising Radiation

Radiation is considered ionising when it has the capacity to accelerate the electrons in matter. Radioactive decay of radionuclide contaminants releases alpha(α), beta(β) and gamma(γ) radiation. Alpha decay results in the release of alpha particles which whilst not highly penetrative are most ionising of the three radiation types and consequently the most damaging to living cells. Beta radiation releases energy in the form of high speed electrons, which can penetrate living matter more deeply than alpha radiation. Gamma radiation takes the form of high energy electromagnetic waves. Although gamma radiation is highly penetrating it is only weakly ionising and hence it is the least damaging to living cells.

Ionizing radiation at levels similar to those released by uranium mining and milling can produce free radicals and DNA damage resulting in genomic instability and mutations. Mutations in the genome of somatic body cells form a point of initiation of carcinogenesis, whilst mutations in reproductive cells provide a pathway to birth defects (Edwards, 1998). A radiation dose of 1 gray (Gy) causes approximately 200 000 ionisations within the mammalian cell, of these around 1% occur in DNA (Franks & Teich, 1991). Ionizing radiation can initiate cellular damage at the molecular level after even one millionth of a second's exposure. Radiation interacts with matter in three main phases according to the duration of exposure as shown in Table 5.2.

Time Interval	Effect
Physical Phase	
10^{-18} - 10^{-17} sec	fast particle traverses small atom or molecule
10^{-16} sec	ionisation $H_2O \rightarrow H_2O^+ + e^-$
10^{-15} sec	electronic excitation $H_2O^+ \rightarrow H_2O$
10^{-13} sec	molecular vibrations and dissociations
10^{-12} sec	rotational relaxation $e^- \rightarrow e^-_{(aq)}$
Physico-Chemical & Chemical Phase	
10^{-10} - 10^{-7} sec	reactions of $e^-_{(aq)}$ with other free radicals
10^{-7} sec	homologous distribution of free radicals
10^{-3} sec	free radical reactions largely complete
seconds/minutes/hours	biochemical changes to vital enzyme reactions
Cellular and Tissue Damage Phase	
Hours	cell division inhibited in microorganisms and mammalian cells, reproductive death
Days	damage to gastrointestinal tract and central nervous system
Months	Bone marrow cell death, acute organ damage
Years	carcinogenesis and expression of genetic damage in offspring

Table 5.2: Cellular interaction with radiation (Franks & Teich, 1991).

People in the vicinity of an area in Texas where there has been extensive uranium mining and milling for over 30 years, were found to have a significant reduction in DNA repair response and a corresponding small increase in the rate of chromosomal aberrations (McConnell *et al.*, 1998).

The current maximum permissible radiation dose allowable for the general public under Australian Government regulations is 1 mSv/yr in excess of natural background radiation (Margetts & Lees, 1997). Not only does this dose not include medical exposures, it does not take in to account natural high variability as can be found in Kakadu National Park (approximately 2 mSv/yr). When considered with the widely accepted truth that no level of radiation exposure is safe, a blanket safe exposure level is absurd (Margetts & Lees, 1997).

Inhalation of radon gas represents an additional risk to human health, and is responsible for most of the cancer deaths attributable to uranium mining and milling (Schnelbogl, 1998). In addition, a synergistic relationship has been demonstrated between cigarette smoking and radon exposure (World Health Organisation, 1990). Since smoking is common in the populations of indigenous people that inhabit Kakadu National Park, the risk of developing lung cancers amongst these people is likely to increase in the vicinity of uranium mines.

5.4 Ecosystem Effects

The release of contaminants into the biosphere of Kakadu National Park has been demonstrated to be detrimental to a wide range of organisms that inhabit the area. Undoubtedly the system of interconnected ecosystems that comprise this region will be affected by contaminants generated by uranium mining activities. A wide ecosystem study found a reduced number of taxa present in Djalkmarra Billabong compared to other billabongs in the area. This is likely to be due to the effects of the mine contaminants (Corbett, 1996). This wetland, now dug out for Pit #3 was subject to the direct release of contaminated water from Ranger Uranium Mine Retention Pond Two, which collects water off the ore stockpiles, processing plant and pit.

The environmental assessment of the Jabiluka Project suggested that since the fauna surveys in the region have over time demonstrated a persistence of most populations, they are unlikely to be adversely affected by mining (Kinhill, 1996). However, the long-term ecological effects of contaminants in this environment are quite different from the historical threats. Whether it is reduced resistance to disease, reduction in fecundity or straight lethal doses, the whole web of life is adversely affected.

5.5 Contamination of the Biosphere

In the long term, prevention of contamination to Kakadu National Park's wetlands will be critical to the survival of many species. The importance of these wetlands for the conservation of an immense amount of species cannot be understated. The immense biodiversity and intact ecological processes of the wetlands are likely to be significantly altered and reduced by contaminants generated uranium mining activities. It is difficult to completely describe the full spectrum of these impacts as little is known about the physiology of the biosphere in the presence of these contaminants. The dispersal, uptake, and bioaccumulation of contaminants is simply not beneficial to the magnificent biosphere of Kakadu National Park.

The unique natural and cultural values of Kakadu National Park are already at risk from existing mines. The effects may not yet appear obvious, but the disturbance is relatively recent. The proposed Jabiluka and Koongarra uranium mines not only threaten the protection of water quality in terms of human use, but also impinge upon the long-term intrinsic rights of the wetland biota. The development off new mines serves only to exacerbate the problems that have been created for tens of thousands of years to come.

Chapter 6

The Effects of Climate Change on the Alligator Rivers Region

Climate change is an important issue facing all ecosystems on a global level. The Alligator Rivers region consists of a network of delicately balanced aquatic and terrestrial ecosystems. The low lying floodplain areas are extremely susceptible to rises in sea levels and within the time-frame of the proposed Jabiluka mine, floodplain water levels could rise and encroach on the mine-site. Forecast climate induced changes include more intense storms and cyclones and an overall increase in annual rainfall (presently mean range is 1.5-2.8m, which falls over an annual 4-6 month wet season). It is surprising, if not irresponsible, that the environmental impact assessment process did not consider the consequences of Jabiluka in the context of forecast climate change. This is particularly important with considering the additive impacts of Ranger and Jabiluka together and the long life of contaminants generated by these activities.

Recommendation:

We recommend that the World Heritage Commission:

a) support the need for an immediate and independent investigation of the interaction between climate change in the Top End of Australia and uranium mining and milling, and

b) advise the Australian Government to apply the Precautionary Principle in dealing with this extremely serious, and as yet, unaddressed issue.

Climate changes occur both cyclically and through human induced factors. Long term variations in the Earth's orbit produce cyclic changes in temperatures, leading to climate change. Currently, the Earth is entering a period of glaciation, which is likely to continue in strength for the next 60,000 years. In the shorter term, however, human induced change through the increase in CO_2 and other greenhouse gas levels are likely to be the main influence on climate. This chapter points out the problems associated with these climate changes for the management of water and tailings at the current and proposed uranium mines in the Alligator Rivers Region.

6.1 Global Climate Change

6.1.1 Uncertainty in Levels of Change

The difficulty of the task of predicting climate change is widely acknowledged (Bayliss *et. al.,* 1997; Butterworth, 1995; Pickup *et. al.,* 1983; Suppiah *et. al.,* 1998; Strider, 1992). The principal problems experienced are the lack of highly specific data; the natural variability of climate conditions; the difficulty in modelling highly complex situations over long periods of time and the potential for CO_2 feedback mechanisms to occur.

Positive feedback mechanisms include the death of Northern hemisphere boreal forests, large releases of CO_2 and methane from currently frozen soils in northern tundra regions, and an increase in bacterial activity when they thaw. Negative feedback mechanisms include the potential for increased cloud cover from enhanced evaporation at the equator, and hence increased areas of snow cover (Strider, 1992).

6.1.2 Greenhouse Induced Changes

Firstly, an immediate change, taking place over a 1000-year timeframe associated with global warming and increasing levels of atmospheric CO_2, is likely to occur. Changes due to global warming are expected to become more apparent in the next 10-50 years, and are likely to continue for a much longer period until the period of glaciation sets in. Increases in temperature will produce changes to the whole atmospheric circulation regime, possibly resulting in dramatic and undesirable impacts. Rates of sea level change due to global warming are dependent on different CO_2 stabilisation scenarios (Beer & Ziolkowski, 1995).

An illustration of the dramatic potential of short-term change can be seen in the potential for CO_2 positive feedback mechanisms to occur (Strider, 1992). The potential for much larger change emerges when the global warming effects on the Antarctic Ice Cap are considered. Sea level rises of this magnitude have the potential to dislodge ice caps from the bedrock. Such a scenario has the potential to increase sea levels by 5-7m (Pickup *et al.,* 1983).

6.1.3 Orbital Variation

Climate change is also related to variations in astronomical orbits. A likely outcome of these variations are extended period of cooling and glaciation, leading to a substantial long-term reduction in sea levels over time. This is likely to occur during a period of 1000 years to 60,000 years. Climate change during this period will most closely resemble change experienced during the last interglacial period (123,000 years ago). Changes included global cooling, drying, and a lowering of sea levels by 60m. Likely weather features in Kakadu during this period will include weaker monsoons, but stronger westerlies and trade winds (Pickup *et al.,* 1983).

6.2 Climate Change in Kakadu National Park

6.2.1 Projected Impacts of Climate Change

Several studies on the impact of climate change on the Alligator Rivers Region describe future climate scenarios for the region in the short and long term (Bayliss *et. al.,* 1997; Butterworth, 1995; Pickup *et. al.,* 1983; Suppiah *et. al.,* 1998; and Strider, 1992).

There will be an increase in both frequency and intensity of extreme events, such as more very hot days, more floods, and more dry spells. The following changes in climate and sea level are suggested, based on 1990 levels. It is estimated that temperature will rise between 0.3 and 1 degree C each decade (Suppiah *et. al.,* 1998). The frequency of extremely hot days in Jabiru is expected to increase by at least 50% by 2030 (Bayliss *et. al.,* 1997). Differing predictions for rainfall change exist depending on the models used. Seasonality effects are postulated to be more pronounced and evaporation is expected to increase by 5-15% by 2030 (Bayliss *et. al.,* 1997).

Topographic effects could increase rainfall by possibly 2-3 times (Bayliss *et al.,* 1997). An example of a local topographic effect would be the Bureau of Meterology's observation that slopes of 50-400m windward and facing the sea are observed *to "'trigger thunderstorms and sometimes also appear to hold them in place"* (1984). The Arnhem Land escarpment adjacent to Ranger and Jabiluka uranium mines falls into this category.

Although there is no consensus, tropical cyclones could increase moderately in intensity and travel further south (Suppiah *et al.,* 1998). Stronger monsoon westerlies and stronger winds accompanying severe storms are also likely (Bayliss *et al.,*1997).

Sea levels are expected to rise. The best estimate for sea level rise for Australia by 2030 is 20-30 cm above 1990 levels. In the year 2080, sea levels are expected to be 25-80 cm above current levels. *"There will be local variations in levels due to changes in weather and currents, especially affecting magnitude and frequency of extreme events such as storm surges, waves and estuarine flooding"* (Bayliss *et al.,*1997).

6.2.2 Destabilisation of the Magela Floodplain

Because the Magela Floodplain is extremely flat (approximately 2 metre fall in 35 km) even a small rise in sea level would result in significant topographical changes that are likely to *"destabilise alluvial structures, eroding and re-mobilising sand stored in levees, braids, terraces and floodplains"* (East, 1985).

Three consequences that are anticipated to result from the predicted change in climate and rise in sea level are shoreline retreat, saltwater intrusion and increased flooding. Titus and Barth (cited in Bayliss *et al.,* 1997) related saltwater intrusion to land subsidence. All of these may be applicable to the ARR, with saltwater intrusion being particularly significant.

"A one metre rise of sea level in 100 years or so would turn the South Alligator plains and wetlands to swamp, samphire, and salt flat from the coast through to a zone about 20km south of the Arnhem Highway, and that other parts of Kakadu National Park would be similarly affected" (Bayliss *et al.,* 1997).

In the longer term *"a global cooling and a fall in sea levels would greatly enlarge the present backwater plain causing instability in the Magela Creek channels. Manifestations of stream channel instability include channel incision and gullying; growth of first-order tributaries by headward erosion; nick point development and the lateral migration of channels"* (East, 1985).

6.3 Uranium Mining and Climate Change

Due to the imminence of climate change, there is little room for complacency about potential impacts (Suppiah et al., 1998). Given the inherent risks involved in uranium extraction and the vulnerability of the region to climate change, it would be expected that climate change scenarios would figure prominently in the planning of all mining activities. Alarmingly, climate change has been neglected in planning regarding the operational safety and environmental impacts of Nabarlek, Ranger and Jabiluka uranium mines. This assumption of underlying environmental stability represents a major oversight that is likely to lead to unexamined adverse environmental impacts both in the short and long term.

6.3.1 Planning for Extreme Events

Problems can be found in the assessment of climate data used to design the water management system, and risks from extreme events even before dynamic appraisal of climate change are considered. The climate data used in the Jabiluka E.I.S. and P.E.R. is based on rainfall records taken at Jabiru Airport during the years 1972 - 1997. On the basis of 25 years of rainfall records, *"10,000 years of wet seasons have been generated using normally distributed random numbers and the log mean and log standard deviation"* (Kinhill, 1998). This data was then used as a basis for the design criteria of the proposed Jabiluka uranium mine.

Aspects of the mine designed on this data include:

- The positioning of the mine in relation to existing watercourses.
- The Water Management System and Water Balance Equations
- The design of the Sediment Control Zone, Catchment Runoff Zone, Total Containment Zone
- All contaminant traps, drains, road culverts, contaminated water storage ponds, and bunding.

The flood frequency estimation at Jabiluka is inadequate due to insufficient data sets, the high variability between different decades of hydrometeorological conditions and the arbitrary handling of extreme events (Pickup *et al.,* 1983).

The dangers of extrapolating from limited data were experienced at Ranger Uranium Mine on the 4th February 1980, while the complex was under construction. Due to a 5hr 226mm high rainfall event, there was an overtopping of the tailings dam. This in turn created a risk that the tailings dam would collapse (Fokkema, 1980). An emergency cut was made near the top of the tailings dam, allowing a greater escape of contaminated water. In this instance the rainfall recorded at Jabiru Airport was up to 60mm lower than that which occurred at the mine site, illustrating the variability in rainfall between sites approximately 3km apart.

Little is known about the incidence, magnitude and consequences of natural hazards in this part of the Northern Territory (Blong & Mitchell, 1996). Only a limited number of hazard scenarios for the Jabiluka Uranium Mine have been examined, and the probabilities of occurrence have been underestimated during the lifetime of tailings impoundment. Other commonly occurring natural hazards that occur in the area are tropical cyclones, bushfires, and drought. Seismic activity, although irregular, is also a potential hazard. "*The conjunction of extreme events provides another significant issue. El Nino occurrences bring intensified wild fires, vegetation destruction and more pervasive droughts, leading to ground cracking, differential settlement and enhanced erosion when the drought breaks with "flooding rains"* (Blong & Mitchell, 1996).

6.3.2 Challenges to Water Management Systems by Climate Change

In addition to the incomplete risk analysis component of the PER is the omission of short-term climate change predictions in the assessment of the Jabiluka Mill Alternative. Climate change is expected to increase during the operational life of the Jabiluka uranium mine, significantly changing the parameters that have been assumed in the mine proposal. Considerable damage to infrastructure could be expected, if adequate consideration of climate change is neglected (Bayliss *et al.,* 1997).

Changes to the dry season are expected to be more pronounced in the future, with the dry season being drier and warmer. Given the likelihood of *"excessively high temperatures and prolonged droughts"* it is probable that the water balance equations be changed. This may result in the rate of removal of water from bores increasing and consequent impacts to the local environment (Bayliss *et al.,* 1997; The Select Panel of the Public Inquiry into Uranium, 1997).

6.3.3 Threats to the Tailings Containment Structures

The half-lives of thorium-230 and its subsequent radioactive products require that structures for the containment of uranium mill tailings remain stable for long periods of time. Additionally, the fine particle size of the tailings, which constitute the primary source of mine related contaminants means that mobilisation and leaching could occur in the long term with detrimental environmental effects (East, 1985).

The stability of the tailings impoundments needs to be considered in the light of "*climate change, tectonic activity, sea level fluctuations, stream base levels change, and the anthropogenic modification of landforms and vegetation*" as these processes affect hydrological, erosional and depositional changes (East, 1985).

As the uranium mines in the Alligator Rivers Region are located in the headwaters of their catchments, the longer term stability of these tailings deposits are at risk from the tendency of headwater growth. The expected long-term fall in sea level (of at least 20m) is likely to trigger incision, drainage and consequent oxidisation of these sediments on the floodplains. Subsequent acidification would mobilise many of the deposited radionuclides and heavy metals, making them biotoxic (Pickup *et al.,* 1983). In short, the long range forecast for Kakadu National Park does not look too promising if uranium mining continues.

Chapter 7
Failings of the Environmental Impact Assessment Process

Serious flaws in the environmental assessment process combined with imitations to current modelling and monitoring capabilities make it next to impossible to ascertain the real risks posed by mining World Heritage areas in Kakadu.

Recommendation:
We recommend that the World Heritage Committee:
(a) address the issue about Australia's environmental assessment process and scientific methods being incapable of determining the environmental impacts of mining and
(b) request that the Australian Government review the EIS process, and adopt the Precautionary Principle and approaches that minimise risk.

The Australian process of Environmental Impact Assessment (EIA) is notoriously contentious. Each application of this process is another stark reminder of the inadequacies and failings. Application of the process to the Jabiluka proposal is no less an example of these failings, particularly considering the nature and degree of impacts posed by uranium mining and the immense quantities of radioactive waste that is generated. The Federal Government has the view that if the hazards of mining and milling uranium can be properly regulated and controlled then the industry is acceptable. It appears that the Government's strong wish for uranium mining to proceed is backed up by a process of environmental assessment that will show uranium mining and milling to be safe. The Government is also supportive of an expanded uranium mining industry in more areas with high conservation value.

7.1 The Environmental Impact Assessment (EIA) Process

In Australia, proposed projects that could be detrimental to the environment undergo either an Environmental Impact Statement (EIS) or a less comprehensive Public Environment Report (PER), both being components of the Governments' EIA or environmental impact assessment process. They are almost never rejected. As such, EIA is regarded as a 'rubber-stamping' process. There is inadequate requirement for formal review, with no process for checking whether forecast levels of impact were underestimated or overestimated. The EIS or PER is undertaken by the proponent, who obviously wants a project to go ahead. Proponents are at liberty to withhold information and formulate the impact assessments so that the chances of approval are maximised. This clearly lacks independent analysis and objective rigour. The assessment process involves some public consultation, but the time frame is always limited and restrictive and the comments finally assessed by the respective Government departments that make the final approvals. To date, proposals to mine uranium in the World Heritage listed Kakadu National Park have been accepted, irrespective of whether they are demonstrated ecologically safe or not.

Recent downgrading of the national environmental legislation has weakened the effective management of Kakadu National Park. The *Environment Protection and Biodiversity Conservation Bill 1998* replaced five existing laws being the *World Heritage Properties Conservation Act 1983, Environment Protection (Impact of Proposals) Act 1974,* the *Endangered Species Protection Act 1992,* the *National Parks and Wildlife Conservation Act 1975*, and the *Whale Protection Act 1980* (Environment Centre of the NT, 1998a). The environmental responsibilities are delegated to the states, (through secretly negotiated agreements) significantly reducing the powers of the federal government.

7.1.1 Problems with the Assessment of the Jabiluka Project

In 1996, without consent from the relevant traditional Aboriginal owners, ERA sought permission from the Federal Government to mine uranium from Jabiluka and mill it at their Ranger Uranium Mill. Of the 82 submissions to the Jabiluka draft Environmental Impact Statement, 79 were critical of the quality and scope of the assessment performed. This is highly significant and raises serious concerns given the serious nature and consequences of the proposal as well as the substantial resources held by the proponent and therefore ability to produce a thorough and rigorous document. One submission stated that "*The tipping of ore from mine haulers onto stockpiles is likely to generate significant quantities of dust, but no mention of this is made*" (The Australian Radiation Laboratory Submission). The 1997 supplement to the draft Jabiluka EIS formed the final report and made very few changes, most of them minor to the project as originally proposed, such as sealing the road.

In 1997, the Australian Government accepted the proposal by ERA to mine uranium at Jabiluka. They ignored statements such as the one from the World Heritage Unit, which is within the Governments Environment Department: *"Australia's obligations under the Convention apply not only to actions which take place within areas inscribed on the World Heritage List but also to actions outside a listed property which have the potential to adversely affect World Heritage values. This is of particular relevance in this case given that the Jabiluka Mineral Lease is completely surrounded by land inscribed on the World Heritage List."*

ERA's preferred Jabiluka Uranium Mine project option, and the subject of the original Environmental Impact Statement, was to mine the ore at Jabiluka and truck it 22 kilometres to the existing Ranger mill for processing. As the Ranger Mill Alternative (RMA) was clearly vetoed by Traditional Owners, ERA were forced to reject this option. However, the EIS barely considered the impacts of the 'fall-back position' of building a whole new processing plant and tailings storage at the Jabiluka site – known as the Jabiluka Mill Alternative (JMA).

In August 1997 the Supervising Scientist Peter Bridgewater recommended that a full EIS should be performed for the Jabiluka Mill Alternative. *"If ERA were to proceed with their Jabiluka Mill Alternative, I would recommend in the strongest possible terms to the Minister for the Environment, that ERA be required to prepare a new environmental impact statement as required by the* Environmental Protection (Impact of Proposals) Act 1974*. Statements by ERA have indicated that it believes that a new EIS would be required in order to proceed with the Jabiluka Mill Alternative"* (Bridgewater; cited in Hallam, 1998). Bridgewater, under pressure from the Environment Minister, Senator Robert Hill, later backed down on this statement and suggested that a Public Environment Report (PER) would be a sufficient level of impact assessment for the Jabiluka Mill Alternative. A PER is a much lower level of environmental assessment.

There were over 2000 public submissions to the PER, which was presented to the Environment Minister in July 1998. The Minister sought a three week delay before announcing his recommendations. The reason is now obvious. ERA's preferred option to dispose of half the radioactive tailings at Jabiluka in an evaporation pit and place the other half back into disused sections of the mine shaft after mixing it with cement paste was deemed '*scientifically uncertain'* by the Ministers' own department (Environment Australia, 1998b). This should have been enough to stop the project, however during the three week delay period an entirely new tailings system was devised. This involved placing 100% of the tailings as paste backfill in the mine shaft. This option was not raised in either the EIS or the PER. Therefore, this option has received no public comment, which contravenes the requirements of the EIA process. Nevertheless, this option was approved by the Resources Minister Senator Warwick Parer. This untenable situation is in line with the refusal by the Environment Minister, Senator Robert Hill to release vital documents that shed considerable doubt on tailings management as outlined in the Jabiluka PER. These documents withheld for political purposes prevent adequate scrutiny of the environmental assessment process as it relates to the proposed Jabiluka Uranium Mine. These documents are:

- Environmental impact of portal construction on sediment loads entering Swift Creek, Unpublished ERISS Report, 1998.
- Environment Australia, Environmental Assessment of the Jabiluka Mill Option, 1998.
- Unisearch (UNSW) report into tailings management for the Jabiluka Mill Option commissioned by Senator Hill, 1998.
- Mishaps and Breaches at Jabiluka, Confidential Supervising Scientist Group Internal Report, 1998.

Following acceptance of the environmental assessment, in which the entire process was highly questionable and for which the Government has not been held accountable, uranium mines in the Alligator Rivers Region are subject to a list of Environmental Requirements (ERs). Ongoing monitoring strategies to determine environmental impacts are required. Breaches to these Requirements are, however, all too common, are often overlooked and always go unprosecuted (see Appendices 1 and 2). Thus there is virtually no accountability once the EIS approval process is complete, and proponents are in charge of self-regulating their operations, with little or no independent review. ERA is required to ensure that there will be no significant damage to the natural values of Kakadu National Park for at least 10,000 years. The lack of reliable data on long term ecological impacts is a hindrance to even short term monitoring (Environment Centre NT, 1998b).

7.1.2 Environmental Assessment of the Koongarra Project

In 1977, the Ranger Uranium Environmental Inquiry concluded: *"if uranium mining proceeds it should be restricted west of the Arnhem Land Reserve to one drainage basin, so that environmental damage from mining can be geographically contained…the Woolwonga area is so valuable ecologically that we oppose in principle any mining development upstream of it."*

Despite this strong statement, the Koongarra Project had a Draft Environmental Impact Statement prepared in 1978. The region surrounding the Koongarra Project Area was subsequently listed as a National Park of World Heritage status. To allow space for milling facilities, a change of boundaries was required. The *Koongarra Project Area Act 1981* was passed, but still is unproclaimed. Mining, however, was delayed due to federal government policy, but this is no longer the case.

The French Government utility, COGEMA, is currently investigating mining uranium at Koongarra. There are ongoing negotiations with the Northern Land Council (representing the Traditional Owners) regarding the COGEMA's request for consent to acquire exploration licences. One of the licences covers an area that is currently part of World Heritage Listed Kakadu National Park, yet the NTDME supports this mining activity.

7.2 Ongoing Environmental Assessment

ERA's operations at Ranger Uranium Mine are meant to be conducted within the guidelines set down by the Environmental Requirements agreed upon by the NT and Commonwealth Governments and the Supervising Scientist (SSG). Authority to enforce the Environmental Requirements lies ultimately with the Commonwealth, but this power is rarely invoked. For the most part, ERA monitors its own operations and passes on data to the Supervising Scientist, which can then make recommendations to the NT Minister of Mines and Energy. This arrangement places all the onus for environmental monitoring onto ERA and in turn, the government appointed SSG. The lack of independent assessment of ERA's environmental management is obvious.

Infringements of the Ranger Uranium Mine's Environmental Requirements, must also be reported by ERA and investigated by the Supervising Scientist. In 1996-97 there were eight so-called '*technical divergences*'. The Supervising Scientist was at one point prompted to write to ERA expressing concerns over the ability of the Company *"… to execute the mine's environmental management plan to the high levels expected by the government and the community"* (Supervising Scientist, 1997). Again, the onus is on ERA to report incidents that have adverse environmental impacts.

7.2.1 Shortcomings of the Environmental Research Institute of the Supervising Scientist

The main objective of the Environmental Research Institute of the Supervising Scientist (ERISS) is to: *"Conduct environmental research and provide environmental advice on the protection and management of sensitive areas nominated by Government so that the Australian community can be assured that regions which it values highly are being protected."* (Panter, 1997).

The ERISS as part of Environment Australia (the federal Department of Environment) is answerable to the Environment Minister. The Director of ERISS considers it important that the organisation is perceived as an independent entity. However, the history of ERISS suggests that this perception will be hard to gain. The reality of uranium mining in a World Heritage listed area remains a highly contentious and politicised issue and the ERISS at times has come under considerable political pressure which can override environmental protection mandate.

Since it was established, the focus of research at the ERISS has been changed a number of times and its agenda broadened considerably. Meanwhile the funding has declined dramatically falling 25% between 1994 and 1996 (Drinkwater, 1997). ERA now provides some 30% of the ERISS funding (P. Wellings, ERISS, pers. comm., 1998).

Imminent plans to relocate ERISS to Northern Territory University (NTU) in Darwin have the potential to create problems in the effective assessment of environmental impact by reducing the presence of ERISS on-site in Kakadu. It hence is arguable that the transfer of the majority of ERISS staff to Darwin would result in a reduced ability of ERISS to monitor impacts of uranium mining on Kakadu, and an increased dependency on data from ERA employed scientists. A further issue of potential conflict of interest also exists in this relocation. Approximately $5 million of funds for construction of ERISS facilities in Darwin will be allocated from proceeds resulting from the sale of ERISS housing in Jabiru to ERA. It is clearly in ERA's interest not to have this semi 'watch-dog' monitoring agency nearby, and this deal removes a further obstacle to the development of Jabiluka Uranium Mine.

There are several potential problems associated with the role of the ERISS as overseers of uranium mining in Kakadu National Park. These problems result in a situation where ERISS cannot confidently assure the public and Traditional Owners of the safety of uranium mining in Kakadu. As a result of these problems Traditional Owners of the Jabiluka mineral lease do not trust ERISS. Requests to ERISS for information pertaining to Jabiluka or Ranger Uranium Mine construction and operation are frequently met without comment and a referral to the Minister for Environment's Canberra office. Repeat enquires to the Minister's office regarding access to this information have been ignored. ERISS recently refused (on instructions from the Environment Minister) to provide the Traditional Owners of the Jabiluka site with a copy of the environmental impact of portal construction on sediment loads entering Swift Creek (Gundjehmi Aboriginal Corp., pers. comm., 1998). This attitude only highlights the questionable accountability of the Government and is utterly unacceptable.

7.3 The Scientific Paradigm and 'Significant' Environmental Impact

Concepts of World Heritage, planetary ecology and environment belong to a territory of knowledge that has been conquered by 'experts' in Western Science. The voices of other traditions and their experiences, some spanning tens of thousands of years, are systematically excised and silenced by this particular tradition. Classical Newtonian science is not self-reflective. The values of the people who produce 'science' are unspoken and hidden in a glamour of 'objectivity'. Western science itself may represent part of the problem of environmental destruction rather than part of the solution.

Western science operates from a system of classical logic that perceives the world as fragmented and different events as logically unrelated. It provides a conservative framework for scientific 'experts' to situate their discourse within while maintaining unspoken inter-relationships with institutional, economic, corporate, military and geo-political concerns.

The philosophy of reductionism-dualism that exercises hegemony in science, is not the only paradigm available. The Copenhagen Interpretation of the 1920s, Bell's Theorem of 1964 and Scattering Matrix Theory provide fundamental scientific reinterpretation of 52 within and between all systems. For this reason, ecological systems cannot be contained and analysed within the limits of the reductionist paradigm. They are not reducible to sequential cause and effect modelling.

Caulfield (1995) describes the unspoken assumptions that exist within the language of environmental science. *"To a scientist there is no absolute certainty, no immutable fact – only probabilities and an evolving understanding of how the world works. A simple statement, such as…'radiation levels here are within the internationally-accepted safety limits', may mean very different things to the layperson and the scientist. A scientist will recognise the unspoken provisos in the statements and know that a more accurate rendering would be…'due to technical and financial restrictions, we have not actually measured radiation levels in the* *area, but our computer programs indicate that radiation levels will be within international safety limits'."*

The first Supervising Scientist (Robert M Fry) set high standards for environmental protection by setting a goal of 'zero' impact of uranium mining in the Alligator Rivers Region environment (Drinkwater, 1997). Over time the SSG approach to environmental protection has changed. Initially their mandate was that no *'detectable'* environmental impact should occur; i.e. the natural environment outside the project area should remain essentially in its pre-mining state. Since then, the focus has changed to one of no *'significant'* environmental impact. This is a fine example of things starting out as 'the thin edge of the wedge'. If Jabiluka were to proceed, what could possibly stop Koongarra and other uranium mines in this World Heritage area ? In addition, ERISS have never defined what constitutes a *'significant'* environmental impact. The lack of a working definition for *'significant'* environmental impact is recognised as a problem by ERISS, and they are currently working on a definition (A. Johnston, pers. comm., 1998). However, in the meantime, this situation has been extremely convenient for ERA throughout the assessment process.

7.4 Limitations of Modelling and Monitoring in the Detection of Environmental Impact

7.4.1 Inadequate Modelling and Monitoring at Ranger

Despite the importance of preventing radioactive waste leakage into the surrounding environment at Ranger Uranium Mine, there is a distinct lack of modelling employed in the design of containment structures. The only modelling has been on the stability of the capping used to cover the uranium tailings leftover from the mine (Evans *et al.,* 1996). However, the model oversimplifies a complex environmental reality by failing to incorporate site specific variables related to topography, hydrology and geomorphology. It does not take into account the effects of parameters such as plant roots, termites, extreme rainfall events and climate change. Moreover, the model only predicts environmental outcomes 1000 years into the future, a timeframe that is entirely inconsistent with the radioactive half-life of uranium tailings.

Even with these inadequacies, the model predicts that the tailings will be exposed if vegetation cover is interrupted during the 1000 year scenario. However, the regional climate ensures that vegetation is regularly disturbed, killed, stressed and impacted upon by fire, ~~cyclones~~ and intense storm~~s~~ activity. To ensure that vegetation cover is intact appropriate monitoring and management of the site will be required well in excess of current timeframes. At present ERA are in agreement to monitor rehabilitation for a period of only 5 years after ceasing operations. The main argument used in the defence of uranium mining activities in the Alligator Rivers Region (ARR) is that, despite 18 years of operation of the Ranger uranium mine, current assessment processes have not detected any *significant* environmental impacts on surrounding ecosystems. We question the effectiveness of current assessment programs in detecting and predicting environmental impacts arising from uranium mining and milling operations, and in particular those arising from the dispersal of waterborne contaminants into surface waters and the food chain. Past experience has shown that even the most rigorous environmental monitoring programs are only capable of detecting effects after major environmental changes have occurred (Underwood, 1990).

Shortcomings of the current monitoring process are:

- Current knowledge and understanding of the ecology of freshwater ecosystems in the Alligator Rivers Region is still rudimentary (Lake, 1995; Pidgeon & Humphrey, 1995), posing severe limitations on our ability to detect and predict environmental change.
- Monitoring programs put in place by ERISS and ERA are limited in their scope, due to logistical and economic constraints, and fail to adequately address long-term and/or cumulative impacts of mining on ARR ecosystems.
- There is no formal requirement for reviewing forecast scenarios: for example if a prediction was underestimated, a mine activity could need to be curtailed.

The present monitoring process has not factored in the forecast scenarios for climate change in this region: eg higher wet season rainfall, and more intense storms and possibly cyclones.

7.4.2 Shortcomings of Biological Monitoring Programs

The mining company ERA and the regulatory authority, the NT Department of Mines and Energy, have invested very little effort in biological monitoring (Bywater, 1988). ERISS is the only institution monitoring potential environmental impacts associated with mining in the Alligator Rivers Region. Biological monitoring programs developed by ERISS involve investigations of responses of organisms to mine waste water releases and monitoring of aquatic communities (Humphrey *et. al.,* 1990; Humphrey & Dostine, 1994).

7.4.2a Limitations in the Detection of Short-Term Effects of Contaminants on Aquatic Organisms

Biological "*early detection systems*" put in place by ERISS involve creekside monitoring (i.e. organisms are placed in containers on the side of the creek) of the responses of two fish and two snail species to mine discharge waters, and in-situ monitoring (i.e. organisms are placed in the creek bed) of freshwater mussels (Humphrey *et. al.,* 1990; Humphrey & Dostine, 1994).

Biomonitoring programs have, at times, been successful in detecting short-term responses of aquatic organisms to water releases from Ranger mine. In-situ monitoring techniques detected impairments in the reproductive success of the freshwater mussel *Velesunio angasi* at a site downstream from Ranger as a result of the release of water from Retention Pond No. 4 during the 1984/85 Wet season (Humphrey, 1995). Unfortunately, the implementation of such techniques has been fraught with difficulties; for example, in-situ monitoring is impossible during conditions of high flow (coincidental with the release of mine waste discharges) because of the difficulty in accessing the test organisms (Humphrey *et. al.,* 1990). Shortcomings regarding current creek-side monitoring programs have also been identified; for example, some test organisms such as fish larvae currently used in these programs are not always sensitive to mine waste-waters (Humphrey & Dostine, 1994). A lack of response by these organisms to mine waste-waters does not guarantee, therefore, the protection of more sensitive species of which little is known.

7.4.2b Limitations in the Detection of Long-term Effects of Contaminants on Aquatic Organisms

Community-based monitoring programs in the ARR have only been implemented since 1995. Until then detection and assessment of possible impact of mine discharges on aquatic ecosystems relied solely upon results from studies of short-term organism-based responses (Humphrey & Pidgeon, 1998). To date, no rigorous assessment of potential impacts of mine waste discharges on macroinvertebrate communities of the seasonally flowing channel of the Magela creek has been attempted. This is due to the lack of a consistent sampling design between years, as well as to the lack data available for unaffected streams (Humphrey & Pidgeon, 1998).

The monitoring of possible effects of mine water releases on the aquatic biota of the floodplain are beyond the resources of ERISS. This is due to the vast size of the floodplain area to be examined (the Magela floodplain covers at least 200 sq km during the Wet season), and the difficulty of access and sampling during the wet season.

Despite the fact that heavy metal bioaccumulation and biomagnification constitute a potential hazard to organisms in freshwater ecosystems in the Alligator Rivers Region proper evaluation of such risks has never been undertaken (Humphrey & Dostine, 1994). Furthermore, potential cumulative effects arising from the uptake of contaminants arising from mining at Jabiluka have not been assessed. Some studies have been conducted in order to determine baseline concentrations of chemical elements in tissues and organs of long-lived organisms such as fish and freshwater mussels (reviewed in Humphrey *et. al.*, 1990). While these studies constitute the first step in a process of assessing the extent of heavy metal bioaccumulation by aquatic organisms (i.e. fish, mussels), they are not designed to detect potential increases in the concentration of elements in animal tissues resulting from the release of mine wastes. ERISS researchers have addressed limitations in their chemical monitoring program in a recent report on biological monitoring to the ARRTC (Humphrey & Pidgeon, 1998) by recommending the implementation of further bioaccumulation studies as a priority for future research.

Accumulation of heavy metals in the flood plain sediments of the Alligator Rivers Region may result in toxic effects to sediment-dwelling organisms. Unfortunately, there is no published information pertaining to the toxicity of different contaminants on these organisms in tropical freshwater ecosystems, and consequently no ecotoxicological tests have yet been developed to assess the toxicity of sediments to organisms in such systems. A test is currently being developed by a PhD student at ERISS on the toxicity of uranium and copper to one species of chironomid. This test, once developed, will form the basis for further assessment procedures. This situation illustrates how monitoring and understanding about ecological impacts and ecological change have taken place in retrospect. Why is that 16 years after mining and milling began, the ecological tests for measuring impacts are in such a rudimentary stage of development. Researchers at ERISS have estimated that adequate biological monitoring techniques require from 3 to 5 years baseline data for their implementation to freshwater ecosystems (i.e. macroinvertebrate communities) in the Alligator Rivers Region (Humphrey *et. al.*, 1995; Faith *et. al.*, 1995). Clearly, the lack of baseline community data on streams draining the Jabiluka mineral lease prevents the accurate assessment of any potential impacts to these communities arising from mine construction and mining activities.

7.4.3 Limitations of Risk Assessment

Whilst becoming an increasingly important and effective area of research, like most other scientific disciplines, ecotoxicology and risk assessment carry the potential dangers of being misused, and in particular, used beyond their capabilities. This is especially pronounced in ecotoxicology due to the large number of assumptions that must be relied upon when transferring information from laboratory studies, to a variety of natural environments. Some of the major assumptions and limitations are:

At its very best, Risk Assessment can only *estimate* the likelihood of impacts occurring. When scientists mention “*safe limits*”, this cannot be construed as anything other than *estimates* of safe limits.

Threshold limits to toxicant concentrations are derived from laboratory tests which determine points such as LOEC (lowest observed effect concentration), as the name suggests, “*observed effects*” only refer to observed effects. Long-term effects (e.g. genetic defects) may be overlooked. Another threshold limit is LC50 (lethal concentration for 50% test animals / samples). LC50’s do not consider sublethal effects e.g. lower fertility, lower fecundity, later onset of maturity, vulnerability to other stresses. Furthermore, even low levels of stress-induced mortality may eliminate particular genotypes, reducing genetic diversity, and hence, threatening long-term species viability.

An important assumption underlying the integrity of ecotoxicology research is that the test animal must be representative of not only (1) wild clones of the same species, but also, (2) other species of the same trophic level. These fundamental short-comings also ignore the finding that even different laboratory clones of the same species can have extremely varying tolerances to toxicants, and in some cases, can differ by up to an order of magnitude.

Very few laboratory studies have investigated effects from compounding factors. Such synergistic forces include: multiple pollutants (which is invariably the case with waste water etc), or other stresses in the environment which may lower the organisms ability to tolerate the specifically tested for toxicant.

Environmental variation, both within (i.e. natural seasonal, catastrophic events) and between, different communities is ignored in laboratory based results.

Very little ecotoxicological research has been performed in the tropics; the vast majority has been developed in temperate environments. Hence, many assumptions must be made in transferring results from such markedly differing ecosystems. As well as the obvious differences which could potentially have significant effects (e.g. different species / interactions), variation in factors such as water parameters (e.g. pH, conductivity, alkalinity etc) and temperature, are known to effect marked changes in levels of toxicity.

No sediment toxicity tests have been performed, so far, in Australia. Currently, results from overseas studies are being used. Should there be a catastrophic event such as a waste spillage, such a lack of information or misconstrued assumptions could compound already devastating effects.

Due to the many assumptions and limitations of ecotoxicology tests, large safety margins are used. However, these are not empirically derived but are arbitrary factors, thought to cover unforeseen variations and effects. Due to this uncertainty, Risk Assessment must be coupled with a thorough Biological Monitoring program to retrospectively assess whether the predictions were realistic, and if impacts can be detected. Successful Risk Assessment could therefore arguably be seen as relying heavily on good fortune, and the fact that it is a relatively young disciple of science, not yet having survived the scrutiny of long-term monitoring.

"*Risk*" is a subjective evaluation, based not only on perceived likelihood of possible outcomes, but also on the gravity and nature of these various consequences. Each case should therefore be decided not only on the probability of detrimental effects, but also the perceived value of the region at stake.

7.5 Is Any Risk to World Heritage Acceptable?

As previously mentioned for a number of reasons the Supervising Scientist Group cannot adequately fulfil its environmental protection mandate, and thus ensure the integrity of the World Heritage listed natural values of Kakadu National Park. This supposedly independent organisation suffers from a lack of staff and resources, and must tip-toe its way through a veritable minefield of political and economic vested interests. As a consequence there is insufficient data available to accurately assess the short and long term ecological effects of uranium mining. A huge shadow of doubt is cast upon both ERA's assertion that Ranger Uranium Mine has had no detrimental environmental impacts, and upon the credibility of the current environmental assessment process for the Jabiluka Uranium Mine proposal.

Chapter 8
Summary of Threats to World Heritage Criteria

In summary, this document presents evidence that uranium mining and milling has considerable impacts on the environmental values of Kakadu National Park.

The flaws in protecting Kakadu's natural World Heritage values are in addition to the serious infringements on cultural heritage.

They undermine all three of the natural criteria for which Kakadu National Park received World Heritage Listing.

8.1 World Heritage Values are Threatened

8.1.1 World Heritage *Criterion 24(ii)* is threatened

Kakadu National Park is listed under the Natural World Heritage Criterion 24 (ii): *"Outstanding examples representing significant ongoing geological processes, biological evolution and man's interaction with his natural environment."*

Stream bank stability and flow patterns will be altered due to the collection of large quantities of clay for mine construction and rehabilitation. Weathering of waste dumps and the mine site will increase erosion and the amount of sediment entering creeks and floodplains. Changes in depositional processes and water turbidity effect habitat and in turn the composition and abundance of flora and fauna. Sedimentation processes in Kakadu National Park are an integral part of the geological processes listed as deserving World Heritage protection under criterion (ii). This ancient environment is highly leached. The clearing of vegetation and addition of mining pollutants further degrades the soil structure and soil nutrient balance. This destroys a medium that is fundamental to the dynamic ecosystems balance that characterises Kakadu National Park. Pollution of the soils and waters of Kakadu National Park from uraniummining is occurring and will continue in a slow but steady manner. As a clean environment is essential tointact ecosystems, pollution from mining will be detrimental to all three of the listed criteria.

Disturbance within the ecosystem will inevitably disrupt the ongoing biological evolution that is integral to the long term viability of this conservation reserve. Loss of biodiversity is associated with contamination from mining, and will be ongoing if pollution is to increase and spread. Kakadu National Park is listed as a World Heritage property (under criterion (ii)) for its outstanding examples of ongoing evolution. Evolutionary processes must be protected at all levels (species, habitat, ecosystem, landscape) to survive in perpetuity. Factors that threaten evolutionary processes and which are related to mining activities include the spread of invasive weeds, road barriers, complete destruction of the minesite area and long term pollutant seepage. So ecological processes are already in danger, but the severity will increase with time, insidiously intensifying the detrimental effects.

Ongoing human interaction with the environment listed under criterion (ii) is already detrimentally affected by the presence of mining in the Alligator Rivers Region. Complex social and health problems are caused or exacerbated by the mere presence of mining and miners on the ancient sacred lands of the indigenous inhabitants. The slicing of the land with roads and the noisy developments detract from the essence of the country. Management of land for development causes changes to the fire management regime. Fire management is one of the responsibilities of the indigenous people, and excessive burning, as was seen on the Jabiluka Lease in the dry season of 1998, is upsetting to the Traditional Owners (Yvonne Margarula, pers. comm., 1998). In addition, the accumulation of contaminants in traditional food sources places Aboriginal people at risk.

8.1.2 World Heritage *Criterion 24(iii)* is Threatened

Kakadu National Park is listed under the Natural World Heritage Criterion 24 (iii): "*contain superlative natural phenomena, formations or features, for instance, outstanding examples of the most important ecosystems, areas of exceptional natural beauty or exceptional combinations of natural and cultural elements"*

The expansion of the mineral industry is detrimental to the natural beauty and qualities of wilderness for which Kakadu is famous. Loss of both ecological integrity and natural beauty in the extensive wetlands will occur over time through the addition of polluted water coming from the mine sites. The proposed construction of the Koongarra mine would result in the loss of the exceptionally breathtaking views in the Nourlangie Rock area. In the north eastern escarpment unsightly development due to mining is already evident and planned to increase. These are direct threats to World Heritage natural criterion (iii).

8.1.3 World Heritage *Criterion 24(iv)* is Threatened

Kakadu National Park is listed under the Natural World Heritage Criterion 24 (iv): "*contain the most important and significant natural habitats where threatened species of animals or plants of outstanding universal value from the point of view of science or conservation still survive."*

Chapter 5 documents how species, habitats and ecosystems are all threatened by the activities and consequences of uranium mining. One of the key values of universal significance is the extensive nature of the park and the maintenance of processes over a landscape level, thereby protecting biological and genetic diversity.

The highly predictable and dramatic wet season, where 1.5 to 3 m of rain falls each year, disperses water across all these systems. In particular, the temporarily inundated and permanent waterbodies are at risk from bioaccumulation of contaminants, genetic mutations and changes to breeding systems and population size. These adverse changes threaten scientific and conservation values. Importantly, this criterion is also threatened by the highly flawed environmental assessment process, which does not identify or attempt to minimise risk to natural values. This process means that neither ERA or the Australian or NT Governments can guarantee that the environment can be protected.

Species with limited and restricted ranges or seasonal dependence on the habitats that will be polluted by the effects of mining are likely to be affected. This will be a transgression of the protection of the World Heritage natural criterion (iv) involving habitats and species of outstanding value. Icon species of KNP, such as the Magpie Goose, the Jabiru and crocodiles, all depend on floodplains and natural water regimes and good water quality. As discussed, the threats from uranium mining activities can be either direct or indirect.

8.2 Kakadu is in Danger

The List of World Heritage in Danger Criteria Article 79: in the case of natural properties includes:

(i) ASCERTAINED DANGER – The property is faced with specific and proven imminent danger, such as:

(a) *A serious decline in the population of ... species of outstanding universal value which the property was legally established to protect,... by man-made factors...*

(b) *Severe deterioration of the natural beauty or scientific value of the property, as by human settlement,...industrial development,...mining, pollution.*

(c) *Human encroachment on boundaries on boundaries or in upstream areas which threaten the integrity of the property.*

(ii) POTENTIAL DANGER – The property is faced with major threats which could have deleterious effects on its inherent characteristics. Such threats are, for example:

(a) *A modification of the legal protective status of the area;*
(b) *planned...development projects within the property or so situated that the impacts threaten the property;*
(c) *the management plan is lacking or inadequate, or not fully implemented.*

8.2.1 The Case for Ascertained Danger *Criterion 79 (i) a*

The wetland ecosystems of Kakadu National Park are listed for protection under two national and five international treaties, conventions and laws. These include Australian National Heritage List, Australian National Park status, World Heritage List, Ramsar Convention, JAMBA (Japan and Australia Migratory Birds Agreement) and CAMBA (China and Australia Migratory Birds Agreement). As such they are of outstanding universal value, and besides international agreements, they were intended to be protected by Australian law (Australian National Parks and Wildlife Act 1975).

The human created impacts that threaten these wetlands include uranium mining and its associated infrastructure. Article 25 (3) of the World Heritage Guidelines states that – *"the sites described in 24 (iii) should contain those ecosystem components required for the continuity of the species or of the other natural elements or processes to be conserved."* Uranium mining and milling within Kakadu National Park contaminates the downstream wetland ecosystems. The contaminants of the millions of tonnes of uncontainable uranium mill tailings are highly likely to be deleterious to the protected species of the wetlands. The probabilities that a serious decline in the species of outstanding universal value are such that experimentation and assumptions that they are safe should not be tolerated.

8.2.2 The case for Ascertained Danger Criterion 79 (i) b

Mining development projects are offensive amongst the otherwise intact beauty of Kakadu national Parks forests and riparian communities. The Ranger Uranium Mine and the construction of the Jabiluka Uranium Mine are certainly detrimental to the aesthetic qualities of Kakadu national Park. The mining traffic, including thousands of lumbering road-trains are adverse to the sanctity of Kakadu National Park. In addition, the proposed Koongarra Uranium Mine, adjacent to the well visited and intensely spectacular Nourlangie Rock is in imminent danger of losing much of its aesthetic appeal. Contamination of the wetlands due to the uncontainable millions of tonnes of radioactive uranium milling waste is expected to cause decline in the health of the downstream wetlands. As such there is anticipated severe deterioration in the natural beauty of Kakadu National Park due to uranium mining and milling.

The industrial development that constitutes uranium mining, along with its human settlement and pollution are causing severe deterioration to the scientific value of Kakadu National Park. Some of the scientific values include largely intact ecosystems along with their geological, ecological and evolutionary processes and outstanding biodiversity. As this paper documents, there are complex processes that constitute severe deterioration of these fundamentally important scientific values.

8.2.3 The case for Ascertained Danger *Criterion 79 (i) c*

Uranium extraction processes and supports constitute human encroachment. Uranium is being or is planned to be extracted both within and next to Kakadu National Park boundaries. These uranium mines are in catchments of streams that flow into the Park. Article 14 of the World Heritage

Guidelines states that – "*Whenever necessary for the proper conservation of a cultural or natural property nominated, an adequate 'buffer zone' around a property should be foreseen and should be afforded the necessary protection.*" There is no protected buffer zone around Kakadu National Park; indeed it is riddled with extractions for mining and mining infrastructure. The dangers of the uranium industry constitute a serious threat to the integrity of the property.

8.2.4 The Case for Potential Danger *Criterion 79 (ii) a*

The political framework encompassing environmental conservation, indigenous land rights and mining is open to rapid and substantial change. For example, there is currently a review of the Aboriginal Land Rights (NT) Act 1976, which could remove the power of Aboriginal people to veto mining on their homelands. Yet the traditional responsibilities of Aboriginal clans is to protect their land for future generations; they are custodians more than landowners. This will put Kakadu under even more threat especially with the dramatic increase in minerals exploration occurring in the surrounding catchment.

Further, there is a passed but unproclaimed Commonwealth law called the *Koongarra Boundary Change Act 1982*. This entails changing the Kakadu National Park and World Heritage area boundaries to allow the French company Cogema to mill ore and dump 11 000 000 tonnes of tailings and low-grade rock from their actively proposed Koongarra Uranium Mine. The Act is expected to be proclaimed following an agreement between the federal minister for Aboriginal and Torres Straight Islander Affairs and the leader of the Northern Land Council. This constitutes a serious modification of the legal protective status of the Nourlangie area, part of the South Alligator River catchment. The South Alligator is the primary river in Kakadu and is almost completely within its boundaries. An uranium mine, mill and radioactive tailings depository in this otherwise untainted region constitutes a serious potential danger.

8.2.5 The Case for Potential Danger *Criterion 79 (ii) b*

The planned development projects within Kakadu National Park include both a uranium and potentially a gold mine at Jabiluka and a uranium and possibly a gold mine at Koongarra. These developments also entail mills and immense tailings depositories. If there were all three mines (including Ranger Uranium Mine) simultaneously, expansion to Jabiru would be necessary. There is extensive mineral exploration mostly for uranium, in eastern Arnhem Land, just across the border of Kakadu National Park. These are potentially development projects. These development projects would have deleterious effects on the inherent characteristics of Kakadu National Park.

8.2.6 The case for Potential Danger *Criterion 79 (ii) d*

The fundamental flaws of the environmental assessment process, the biological monitoring, and the modeling of tailings containment and climate change, means that there is inadequate understanding about the threats posed by uranium mining. This political and scientific smokescreen serves to reduce the perception of risk involved, whereas in reality the risks to the environment are immense.

Perhaps this lack of acknowledgement of threats or the belief that political boundaries are true boundaries is the cause of the Kakadu Management Plans ignoring the uranium mines withintheir Park. In combination with the problems of monitoring impacts and the other failings of the environmental assessment process, it could be said that the management plan is lacking, inadequate or not fully implemented.

There are many aspects of the management of Kakadu National Park as a conservation reserve that require extra attention. For example many weeds are presently ignored, and eradication of many pests neglected. This is primarily due to insufficient funding. Worse still, money for conservation management is noticeably declining, whilst more ecological invaders, such as the infamous cane toads, are soon to arrive. Tourism also continues to demand attention. Whilst management dollars are diverted towards appearing to mitigate the effects of industrialization (in this case uranium mining), secondary effects (such as invasive species) are inadequately managed. There is only a finite source of fundsavailable, so using them on avoidable damages is negligent.

8.3 Help us Save Kakadu!

The ecological effects of uranium mining will last for hundreds of thousands of years. The intertwined processes of cultural and natural evolution, for which Kakadu received its World Heritage listing, will never be the same. It is not enough to simply excise a few enclaves from the surrounding Park, call them Mineral Lease Areas and allow uranium mining to proceed. The science of ecology demands a more holistic understanding of wilderness preservation. Water flows beyond cultural and political boundaries. Animal life cannot be contained within lines drawn arbitrarily on maps. The World Heritage Listing was intended to preserve the natural values of Kakadu National Park in its entirety, in perpetuity. These values are now in serious danger.

Our evidence strongly concludes that the threats posed by the proposed Jabiluka and Koongarra Uranium (and possibly gold) Mines break the World Heritage agreement to which Australia is bound by, as a signatory to the World Heritage Committee. We recommend that the issues highlighted in this document be addressed during a moratorium on further uranium mining in Kakadu National Park. Failure of the Australian Government to address the issues that pose significant threats to environmental values demonstrate a breach of international agreements. It is apparent that international pressure is needed to bring about a fairer and more thorough environmental protection process.

Protection of the environment is the noblest of goals. Uranium mining and conservation are immiscible and Kakadu National Park is not suitable for experimentation. Therefore any responsible management of this World Heritage Listed National Park would ensure all possible threats are removed. Uranium mining is undeniably contaminating the environment. The only intelligent option is for all present and proposed mining activities to be banned from Kakadu National Park, both within its boundaries and in its vicinity.

As such, we urge the World Heritage Committee to do whatever is in its powers to protect Kakadu National Park.

Recommendation: *We recommend that the World Heritage Committee add Kakadu National Park to the list of World Heritage Properties in Danger.*

References

References

Akber, R. and Marten, R. (1992). Radiological impact of radionuclide uptake by plants in the land application area. In: *Proceedings of the Workshop on Land Application of Effluent Water from Uranium Mines in the Alligator Rivers Region.* Jabiru, 11-13 Sept. 1991. Aus. Gov. Pub. Serv., Canberra.

Akber, R., and Hancock, G. (1990). *Bioaccumulation of Radionuclides in Aquatic Organisms from the South Alligator River,* First Report, Supervising Scientist for the Alligator Rivers Region.

Allen, J. D. (1995). *Stream Ecology: Structure and Function of Running Waters*. Chapman & Hall, London.

Ashwath, N. (1991). Revegetation research in the Alligator Rivers Region. In: *Growback '91*. Eds. T. Offor, and R. J. Watson, Fitzroy, Vic. Growback Publications.

Ashwath, N. (1994). *Key results of the research undertaken by the revegetation section of the ERRIS, EPA:1990-1994.* Internal Report No. 171, Supervising Scientist for the Alligator Rivers Region, Australia.

Ashwath , N., Cusbert, P., Bayliss, B., McLaughlin, M. and Hunt, C. (1993). Chemical properties of mine spoils and selected natural soils of the Alligator Rivers Region – Implications for establishing native plants on mine spoils. In: *Proceedings of the Waste Rock Dump Symposium.* 128-142. Darwin NT. Aust. Gov. Pub. Serv., Canberra.

Australian Nature Conservation Agency and Northern Australia Research Unit (1995*). Kakadu. National and Cultural Heritage and Management.* ANCA and NARU, Australian National University, Darwin.

Australian Nature Conservation Agency (1994). *Kakadu National Park 1993 Visitor Survey.* ANCA, Jabiru.

Australian National Parks and Wildlife Services (1991). *Nomination of Kakadu National Park by the Government of Australia for Inscription in the World Heritage list.* Prepared by the Australian National Parks & Wildlife Service, Department of the Arts, Sport, the Environment, Tourism & Territories, Canberra.

Ba, M. A., Garbaye, J. and Dexheimer, J. (1991). Influence of fungal propagules during the early stages of the time sequences of ectomiccorhizal colonisation on *Afzelia africana* seedlings. *Can J. of Bot.* 69: 2442-2447.

Baker, D. E. and Eldershaw, V. J. (1993). *Interpreting soil analysis for agricultural land use in Queensland* (Project Report (Queensland Dept Primary Industries); QO93014 Dept of Primary Industries, Brisbane.

Bayliss, B., Brennan, K., Eliot, I., Finlayson, M., Hall, R., House, T., Pidgeon, B., Walden, D. and Waterman, P. (1997). *Vulnerability assessment of predicted climate change and sea level rise in the Alligator Rivers Region*, Northern Territory Australia, Supervising Scientist Report 123, Commonwealth of Australia.

Beer, T. and Ziolkowski, F. (1995). *Environmental Risk Assessment: An Australian Perspective*, Supervising Scientist Report 102, Commonwealth of Australia.

Bishop, K. A. (1983). Fish movement as a possible regional dispersal mechanism. In: *Environmental Protection in the Alligator Rivers Region*. Paper 72 of scientific workshop held at Jabiru, NT 17-20 May. Supervising Scientist for the Alligator Rivers Region.

Blong, R. and Mitchell, P. (1996). *Extreme natural events and the Ranger Uranium Mine,* NHRC Seminar Day.

Brennan, K. (1996*). An annotated checklist of the vascular plants of the Alligator Rivers Region, Northern Territory, Australia*. Supervising Scientist Report 109. Commonwealth of Australia,. Darwin.

Brennan, K. and Bach, C. (1994). *A Vegetation Survey of the Waste Rock Dump.* Internal Report No. 165, Supervising Scientist of the Alligator Rivers Region, Canberra (unpublished).

Brennan, K. G., Noller, B. N., Legras, C., Morton, S. R. and Dostine, P. L. (1992). *Heavy metals in waterbirds from the Alligator Rivers floodplain, Alligator Rivers Region, Northern Territory, Australia*. Technical Memorandum 36. Supervising Scientist for the Alligator Rivers Region. Aust. Gov. Pub. Serv., Canberra.

Browne, A. L. L. (1990). Ranger 68 uranium deposit. In*: Geology of the mineral deposits of Australia and Papua New Guinea* 795-797.

Brundrett, M. C., Ashwath, N. A., Jasper, D. A., Malajczuk, N. and Bougher, N. (1994). Mycorrhiza associations in the Alligator Rivers Region. *Final Report, Part II Experimental Results.* Internal Report 121, Supervising Scientists for the alligator Rivers Region, Canberra.

Brundrett, M. C., Ashwath, N. A., Jasper, D. A., Malajczuk, N. and Bougher, N. (1995). Mycorrhiza associations in the Alligator Rivers Region. *Final Report, Part II Experimental Results.* Open File Report, Supervising Scientists for the alligator Rivers Region, Canberra.

Bureau of Meteorology (1984). *The estimation of probable maximum precipitation in Australia for short durations and small areas*, Bureau of Meteorology Bulletin 51, Aus. Gov. Pub. Serv., Canberra.

Butterworth, I. (1995). A review of Northern Territory wetland rainfall: Current and projected. In: *Wetland research in the wet-dry tropics of Australia*, Finlayson, C. M. (ed.) Supervising Scientist Report 101, Commonwealth of Australia, pp212-217.

Bywater, J. (1988). Biological screenings of mine wastes at Ranger Uranium Mines Pty Ltd, Australian Mining Industry Council. In: *Environmental Workshop-1998, Proceedings* 1:1-13.

Case, J. F. (1979). *Biology.* Second edition, Macmillan, New York.

Caufman, P. (exec. prod.) (1987). *Cold Comfort.* Open Channel - Community Education Publications Association (CEPA).

Clarkson, T. W. (1997). The Toxicology of Mercury. *Crit Rev Clin Lab Sci*i: 34: 369-403.

Connell, D. W. (1993). *Water pollution: Causes and effects in Australia and New Zealand*. University of Qld. Press, Brisbane.

Corbett, L. (1996). *Aquatic Studies at Ranger Mine: A Whole-Ecosystem Approach.* Final Report, CSIRO, Australia.

Cowie, I. D. and Werner, P. A. (1988). *Weeds in Kakadu National Park: A survey of alien flora. Phase II, CSIRO Division of Wildlife and Ecology.* Unpublished consultancy report to ANPWS, Jabiru.

Dames and Moore (1988). *Draft Environmental Impact Statement. Coronation Hill, Gold, Platinum and Palladium Project*. Sydney.

Darwin Rural Region Economic Development Committee (1998). *Darwin Rural Region Economic Development Strategy – July 1998*. DRREDC, NT Printing Office, Darwin.

Davy, D. R. and Conway, N. F. (1974). *Report III, Environmental Studies NT Uranium Province.* Alligator Rivers fact finding Study, June, AAEC (E305), Jabiru.

Deutscher, R. L. (1980). Groundwater geochemistry in the vicinity of the Jabiluka deposits. In: *Proceedings of the International Uranium Symposium on the Pine Creek Geosyncline*. International Atomic Energy Agency, June 4-8, Sydney.

Dieter, M. P. (1979). Blood delta aminolevulinic acid dehydratase (ALAD) to monitor lead contamination in canvasback ducks *Aythya valisineria*. In: Animals as monitors of environmental pollutants. In: *Proc. Nat. Acad. Sci*. Washington DC., 177-191.

Drinkwater, D. (1997). The Office of the Supervising Scientist. In: *The Report of the Senate Select Committee on Uranium Mining and Milling.* Commonwealth of Australia, Canberra.. 2:21-40.

East, T. (1985). Geomorphological assessment of sites and impoundments for the long term containment of uranium mill tailings in the Alligator Rivers Region. In: *Coasts and Tidal Wetlands of the Australian Monsoon Region*, K. Bardsley, J. Davie and C. Woodroffe (eds). A.N.U. North Australian Research Unit, Mangrove Monologue Number 1, pp63-80.

Edens, F. W., Benton, E., Bursein, S. J. and Morgan, G. W. (1976). Effect of dietary lead on reproductive performance in Japanese quail *Coturnix japonica*. In: *Tox and App. Pharm.* 38:307-314.

Edwards, R. (1998). The sins of the fathers. In: *New Sci.*, 15th Aug.: 49.

Environment Australia (1997). *Proposal to Extract, Process and Export Uranium from Jabiluka Orebody No. 2: the Jabiluka Proposal.* Environmental Assessment Report. Environment Assessment Branch, August, Environment Australia.

Environment Australia (1998a). *Australia's National Report to the Fourth Conference of the parties to the Convention on Biological Diversity.* Environment Australia. Canberra.
URL: www.biodiversity.environment.gov.au/biocon/natrep/state.htm

Environment Australia (1998b). *The Jabiluka Mill Alternative at the Jabiluka No. 2 Uranium Mine.* Environmental Assessment Report Environment Assessment Branch, July, Environment Australia (unreleased).

Environment Centre of the Northern Territory (1998a). Commonwealth sidesteps environmental responsibilities. *EnvironmeNT,* July 1998, Darwin.

Environment Centre of the Northern Territory (1998b). ERA – still without a project option. *EnvironmeNT,* September 1998, Darwin.

Evans KG, Saynor MJ, Willgoose GR & Unger CJ 1996. Landform erosion assessment. In: *Mining Environmental Management.* Dec: pp. 23-25.

Faith, D. P., Dostine, P. L. and Humphrey, C. L. (1995). Detection of mining impacts on aquatic macroinvertebrate communities: results of a disturbance experiment and the design of a multivariate BACIP monitoring program at Coronation Hill. *Aust. J. Ecol*. 20:167-180.

Farthing, R. H. (1998). Personal correspondence with the Northern Land Council, 21 Sept. 1998, Environmental Consulting and Analytical Services (ECAS), Victoria.

Fokkema, A. (1980). *Ranger Uranium Mines Pty Ltd operation at Jabiru during flood of 4th February 1980 (Final Report)*, OFR 31, Supervising Scientists Office, Commonwealth Department of Housing and Construction.Jabiru.

Fox, R. W. (1977). *Ranger Uranium Environmental Inquiry: Second Report.* Aust. Gov. Pub. Serv., Canberra.

Franks and Teich, N. M. (1991). Radiation carcinogenesis. Ch. 7 In: *Introduction to the Cellular and Molecular Biology.*

Gray, E. J. (1994). *Evaluation of the growth responses of selected native grass species for use on the ERA Ranger uranium mine waste rock dump, Jabiru, NT.* Open file record 114, Supervising Scientist for the Alligator Rivers Region, Canberra.

Green, N., Eamus, D. And Duff, G. (1992). Descriptions of research into irrigation affected vegetation at Nabarlek. In: Akber, R. A. (ed) *Proceedings of the Workshop on Land Application of Effluent Water from Uranium Mines in the Alligator Rivers Region* 229-315*.* Aust. Gov. Pub. Serv., Canberra.

Hallam, J. (1998). *Friends of the Earth Sydney Comments on the Jabiluka Mill Alternative Public Environment Report.* Friends of the Earth, July, Sydney.

Harries, J. (1997). *Acid Mine Drainage in Australia: Its Extent and Potential Future Liability.* Supervising Scientist Report 125, Supervising Scientist, Canberra.

Humphrey, C .L., (1990). Development of biological monitoring programs to detect mining waste. In: *Mitt. Internat. Verein. Limnol*., 24: 293–314.

Humphrey, C. L. (1995). *Reproduction in the freshwater mussel,* Velesunio angasi *in response to the release of water from the Ranger Uranium Mine to Magela Creek*. Technical Memorandum no. 49, Supervising Scientists for the Alligator Rivers Region, Aust. Gov. Pub. Serv., Canberra.

Humphrey, C. L., Bishop, K. A. and Brown, V. M. (1990). Use of biological monitoring in the assessment of effects of mining wastes on aquatic ecosystems in the Alligator Rivers Region, Tropical northern Australia. *Env. Mon. and Ass.*14:139-181.

Humphrey, C. L. and Dostine, P. L. (1994). Development of biological monitoring programs to detect mining-waste impacts upon aquatic ecosystems of the Alligator Rivers Region, Northern Territory, Australia. *Mitt. Int. Verein. Limnol.* 24:293-314.

Humphrey, C. L., Faith, D. P. and Dostine, P. L. (1995). Baseline requirements for assessment of mining impact using biological monitoring. *Aust. J. Ecol,.* 20: 150-166.

Humphrey, C. L. and Pidgeon, B. (1998). *Development of biological monitoring programs used to assess mining impact in the Alligator Rivers Region: A report to the Alligator Rivers Region Technical Committee, (December 1997).* Internal Report No. 286, Supervising Scientists for the Alligator Rivers Region, Canberra.

International Atomic Energy Agency (1976). *Effects of Ionizing Radiation on Aquatic Organisms and Ecosystems.* Technical Report Series No.172, IAEA, Vienna.

International Atomic Energy Agency (1992). *Current Practices for the Management of Uranium Mill Tailings.* Technical Report Series No. 335, IAEA, Vienna.

International Union for the Conservation of Nature (1994). *Encyclopaedia of Endangered Species*. M. Emanoil, and IUCN (ed.s) – The World Conservation Union, Gale Research Inc., Detroit.

Jabiru Town Development Authority (1995). *Development Strategy for the Normalisation of Jabiru*, as incorporated with Kakadu National Park Plan of Management Submission, unpublished report to ANCA, Darwin.

Jeffree, R. A. (1983). Radium-226 studies in the freshwater mussel. In: *Environmental Protection in the Alligator Rivers Region*. Paper 79 of scientific workshop held at Jabiru, NT 17-20 May. Supervising Scientist for the Alligator Rivers Region.

Johnston, A, and Murray, A. S. (1983). The fate of radionuclides in the environment. In: *Environmental Protection in the Alligator Rivers Region*. Paper 76 of scientific workshop held at Jabiru, NT 17-20 May. Supervising Scientist for the Alligator Rivers Region.

Kakadu Conservation Zone Inquiry Final Report (1991). *Potential Impact of Mining on Aesthetic Values.* Submission 76, (RAC Consultancy Series). Aust. Gov. Pub. Serv., Canberra. 1: 100.

Kakadu National Park Plan of Management (1991). *Sacred Sites* Ch 7, ANPWS, Jabiru.

Kakadu Region Social Impact Study (1997). *Report of the Study Advisory Group.* Supervising Scientist, July 1997, Canberra.

Kay, P. (1997). Australia's uranium mines, past and present. In: *The Report of the Senate Select Committee on Uranium Mining and Milling.* Commonwealth of Australia, Canberra.. 2: 1-20.

Kinhill (1996). *The Jabiluka Project Draft Environmental Impact Statement.* Energy Resources of Australia Ltd.

Kinhill (1997). *The Jabiluka Project, Supplement to the Draft Environmental Impact Statement*. Energy Resources of Australia Ltd.

Kinhill (1998). *The Jabiluka Project Jabiluka Mill Alternative Public Environment Report*. Energy Resources of Australia Ltd.

Klessa, D. A. and Legras, C. A. A. (1994). *The effects of soil storage on soil properties, and the soil seed bank and its implications for the soil emplacement in the rehabilitation of Nabarlek Mine Site: a Review of the literature and plan of study.* Internal Report 153, Supervising Scientist for the Alligator Rivers Region.

Koos, B.J. and Longo, L. D. (1976). Mercury toxicity in the pregnant woman, foetus and newborn infant. A review. *Am. J Obstet. Gynecol*., 26:390-409.

Krebs C. J. (1994) *Ecology: The Experimental Analysis of Distribution and Abundance*. Fourth ed.ition. Harper-Collins, New York.

Lake, P. S. (1995). Wetlands research and management in the wet-dry tropics – some thoughts on ecological patterns and processes. In: *Wetland Research and Management in the Wet-Dry Tropics of Australia.* C. M. Finlayson, (ed.). Supervising Scientist Report No. 101. Supervising Scientist, Canberra.

Lea, J. and Zehner, R. (1986). *Yellowcake and Crocodiles – Town planning and government and society in Northern Australia*, Allen and Unwin, Sydney.

Legislative Assembly of the Northern Territory (1998). *Sessional Committee on the Environment.* Report, August 1998.

LeGrand H. E. (1988) A predictive model for indoor radon occurrences - a first approximation. In: G. Graves (Ed.) *Radon, radium and other Radioactivity in ground water.* Lewis Publishers.

Margetts, D. and Lees, M. (1997). *Senate Select Committee on Uranium Mining and Milling, Minority Report*, In: *The Report of the Senate Select Committee on Uranium Mining and Milling.* Commonwealth of Australia, Canberra..

Markish, S. and Camilleri, C. (1997). *Investigation of metal toxicity to tropical biota: Recommendations for revision of the Australian Water Quality Guidelines*, Supervising Scientist for the Alligator Rivers Region.

Martin, P. and Akber, R. A. (1996). *Groundwater seepage from the Ranger Uranium Mine tailings dam: radioisotopes of radium, thorium and actinium.* Supervising Scientist Report No. 106, Supervising Scientist for the Alligator Rivers Region, Canberra.

Martin. P., Hancock. G. J., Johnston, A., and Murray, A. S. (1995). *Bioaccumulation of radionuclides in traditional Aboriginal foods from the Magela and Cooper Creek Systems,* Research Report 11, Supervising Scientist for the Alligator Rivers Region, Aust. Gov. Pub. Serv., Canberra.

Martin, P., Hancock, G. J., Johnston, A. and Murray, A. S. (1998). Natural-series radionuclides in traditional northern Australian aboriginal foods. In: *J. of Env. Rad.*, 40: 37-58.

McBride, T. P. (1992). Fate of solutes applied to land application areas. In: *Proceedings of the Workshop on Land Application of Effluent Water from Uranium Mines in the Alligator Rivers Region.* Jabiru, 11-13 Sept. 1991. Aus. Gov. Pub. Serv., Canberra.

McConnell, M. A., Sadagopa Ramanujam, V. M., Alcock, N. W., Gabehart, G. J. and Au, W. W. (1998). Distribution of uranium-238 in environmental samples from a residential area impacted by mining and milling activities. *Env. Tox. and Chem*., 17: 841-850.

Meffe, G. K. and Carroll, C. R. (1994). *Principles of Conservation Biology*, Sinauer Associates, Massachusetts.

Mengel, K. and Kirby, E. A. (1978). *Principles of Plant Nutrition.* International Potash Institute, Worbaufen-Bern, Switzerland..

Miskiewicz, A. G. (ed.) (1992). *Proceedings of a Bioaccumulation Workshop: Assessment of the Distribution, Impacts and Bioaccumulation of Contaminants in Aquatic Environments*, Water Board and Australian Marine Sciences Association Inc., Sydney.

Neidjie, B. (1990). *An Aboriginal Residents View on Water Management in the Alligator Rivers Region.* Proceedings of the 29th Congress of the Australian Society of Limnology, Australian National Parks and Wildlife Services, Jabiru.

Noller, B. N., Currey, N. A., Ayers, G. P. and Gillett, R. W. (1990). Chemical composition and acidity of rainfall in the Alligator Rivers Region, Northern Territory, Australia. *Sci. Total Env.* 91: 23-48.

Noller, B.N., Woods, P. H. and Ross, B. J. (1994). Case studies of wetland filtration of mine waste water in constructed and naturally occurring systems in Northern Australia. *Wat. Sci. Tech.* 29 : 257-65.

Oullet (1997). *Mechanical, Mineralogical and Chemical Characterization of a Paste Backfill.* University of Quebec, Canada. 139-146.

Panter, H. C. (1983). Radiation effects on the amphibian *Limnodynastes tasmaniensis*, Paper 67 In: *Environmental Protection in the Alligator Rivers Region*. A scientific workshop held at Jabiru, NT, 17-20 May. Supervising Scientist for the Alligator Rivers Region.

Panter, R. A. (1997). The Environmental Institute of the Supervising Scientist. In: *The Report of the Senate Select Committee on Uranium Mining and Milling.* Commonwealth of Australia, Canberra. 2:41-58.

Pearce, M. (1990). *Red Spot.* Fishnote. 1/5/1990. NT Department of Primary Industries and Fisheries.

Pettersson, H. B. L. (1993). Uptake of uranium and thorium series radionuclides by the waterlily, *Nymphaea violacea*. In: *J. Environ. Radioactivity* 19: 85-108.

Pickup, G., Wasson, R., Warner, R. and Tongway, D. (1983). *Geomorphic Research for the Long Term Management of Uranium Mill Tailings (Final Report)*, OFR 21, Supervising Scientist for the Alligator Rivers Region.

Pidgeon, R. T. and Humphrey, C. L. (1995). The ecology of freshwater ecosystems in the Alligator Rivers Region: current status of knowledge and data needs for future management. In: C. M. Finlayson, (ed.) *Wetland Research in the Wet-Dry tropics of Australia.* Supervising Scientist Report No. 101, Supervising Scientist, Canberra.

Press, T., Brock, J. and Anderson, A., (1995). Fauna. Ch 6 in: *Kakadu natural and cultural heritage and management*. Press, T., Lea, D., Webb, A. and Graham, A. (ed.s). Australian Nature Conservation Agency, North Australia Research Unit, Darwin, Griffin Press.

Primack, P. R. (1993). *Essentials of Conservation Biology*. Sinauer Associates, Massachusetts.

Reddell, P. and Milnes, A. R. (1992). Micorrhizas and other specialised nutrient-acquisition strategies: their occurrence in woodland plant from Kakadu and their role in the rehabilitation of waste rock dumps at the local uranium mine. *Aust. J. of Bot*. 40:223-242..

Ripley, E. A., Redmann, R. E. and Crowder, A. A. (1996). *The Environmental Effects of Mining*. St. Lucie Press, Florida.

Roeger, L. and Russell-Smith, J. (1995*). Developing an Endangered Species Program for Kakadu National Park: Key Issues 1995-2002*. Australian Nature Conservation Agency, Canberra.

Robertson, A. M., Burns, M., Stanley, I. M. and Talbot, S. (1997). Bioremediation of hydrocarbon contaminated soil at Mt Lyell. In: *Proceedings of Demonstrating Environmental Excellence 97; 22nd Annual Environmental Workshop.* 12-17 Oct., Minerals Council of Australia, Dickson, ACT.

Rose, K. S. B. (1992). Lower limits of radiosensitivity in organisms excluding man. *J. Env. Radioactivity* 192: 113-133.

Russel-Smith, J. (1995). Flora Ch. 5. In: *Kakadu natural and cultural heritage and management*. T. Press, D. Lea, A. Webb, and A. Graham (ed.s). Australian Nature Conservation Agency, North Australia Research Unit, Griffin Press, Darwin.

Russel-Smith, J., Needham, S., and Brock, J. (1995). The physical environment. Ch 4. In: *Kakadu natural and cultural heritage and management*. T. Press, D. Lea, A. Webb, and A. Graham (ed.s). Australian Nature Conservation Agency, North Australia Research Unit, Griffin Press, Darwin.

Ryall, W. R. and Binns, R. A. (1979). Mercury distribution in the Jabiluka two orebody and its host rocks. In: *Proceedings of International Uranium Symposium on the Pine Creek Geosyncline.* International Atomic Energy Agency, June 4-8, Sydney.

Scott, G. (1998). Uranium exploration in west Arnhem Land. In: *EnvironmeNT* (Environment Centre of the Northern Territory Newsletter), Environment Centre of the Northern Territory, Sept.1998, Darwin.

Schnelbogl, P. (1998). *Submission to the PER on the Jabiluka Mill Alternative.* Lismore.

Sengupta, M. (1993). Blasting. Ch. 9. In: *Environmental Impacts of Mining- Monitoring, Restoration and Control,* Lewis Pub, Boca Raton.

Skidmore, J. F. and Firth, I. C. (1983). Prediction of the toxicity of heavy metals to Australian aquatic animals. Paper 63 In: *Environmental Protection in the Alligator Rivers Region*. A scientific workshop held at Jabiru, NT, 17-20 May. Supervising Scientist for the Alligator Rivers Region.

Smith, N. M. (1995). *Weeds of Natural Ecosystems. A Field Guide to Environmental Weeds of the Northern Territory.* Environment Centre of the Northern Territory, Darwin.

Snelling, A. A. (1990). Koongarra uranium deposits. In: *Geology of the Mineral Deposits of Australia and Papua New Guinea.* F. E. Hughes, (ed.) Australasian Institute of Mining and Metallurgy, Melbourne.

Storrs, M. J. (1996). *A Weed Management Strategy for Kakadu National Park 1996-2001.* Unpublished report to the Australian Nature Conservation Agency, Jabiru.

Storrs, M. J. and Finlayson, C. M. (1997). *Overview of the Conservation Status of Wetlands of the Northern Territory.* Supervising Scientist Report 116, Supervising Scientist, Barton, ACT.

Strider (1992). *The Ecological Impact of Climate Change on Land Health in Northwest Australia.*` The Environment Centre, N.T.

Supervising Scientist (1997). *Annual Report 1996-1997.* Aus. Gov. Pub. Serv., Canberra.

Suppiah, R., Hennessy, K., Hirst, T., Jones, R., Katzfey, J., Pittock, B., Walsh, K., Whetton, P. and Wilson S. (1998). *Climate Change Under Enhanced Greenhouse Conditions in Northern Australia*, CSIRO.

Swansan, S. M. (1983). Levels of ^{226}Ra, ^{210}Pb, and total uranium in fish near a Saskatchewan Uranium Mine and Mill. *Health Physics*, 45: 67-80.

Tatz, C. (1984). *Aborigines and Uranium: Consolidated Report to the Minister for Aboriginal Affairs on the Social Impact of Uranium Mining on the Aborigines of the Northern Territory.* Australian Institute of Aboriginal Studies. Uranium Impact Steering Committee. Australian Department of Aboriginal Affairs. Aust. Gov. Pub. Serv., Canberra.

Termorshuizen, A. J. (1991). Succession of mycorriza fungi in stands of pinus sylvestrus in the Netherland. *J Veget. Sci.* 2:555-564.

The Select Panel of the Public Inquiry into Uranium (1997). *The Report of the Public Inquiry into Uranium*, The Conservation Centre S.A.

Thomas, P., Sheard, J. W., and Swanson, S. (1994). *Uranium series radionuclides, polonium-210 and lead-210, in the lichen-caribou-wolf food chain of the Northwest Territories.* Environment Canada. on the Environment Canada website.

Thomas, P. A. (1997). *The ecological distribution and bioavailability of uranium series radionuclides in terrestrial food chains: Key Lake uranium operations, Northern Saskatchewan.* Environment Canada, on the Environment Canada website.

Treloar,.J. M. (1982). *Seepage Plume Characteristic and Movement at Nabarlek*. Dept. Mines and Energy, Environment Protection Branch.

Twining, J. R., (1993). A study of radium uptake by the water-lily *Nymphaea violacea* (Lehm) from contaminated sediment. *J. Environ. Radioactivity* 20: 169-189.

Tyler, M. J., Watson, G. F, Davies, M. and Crook, G. A. (1981). *Frogs as Environmental Monitoring Organisms. Program A: Abnormalities in frogs.. Final report.* OFR 24. Supervising Scientist for the Alligator Rivers Region.

Underwood, A. J. (1990). Biological monitoring for human impact: how little it can achieve. In:

Proceedings of the 29th Congress of Australian Society for Limnology, Jabiru, NT. Aust. Gov. Pub. Serv., Canberra.

Unger, C. J. and Milnes, A. R. (1992). Rehabilitation at Ranger uranium mines. Ch 24. In: *Conservation and Development Issues in North Australia.* I. Moffatt, and A. Webb (ed.s). North Australia Research Unit, Australian National University. Aust. Gov. Pub. Serv., Canberra.

Waggitt, P. W. (1998a). Hazard reduction works at abandoned uranium mines in the upper South Alligator Valley, Northern Territory. In: *Radiological Aspects of the Rehabilitation of Contaminated Sites.* R. A. Akber, and P. Martin, (ed.s). Office of the Supervising Scientist, Darwin.

Waggitt, P. W. (1998b). The decommissioning and rehabilitation of the Nabarlek Uranium Mine. In: *Proceedings of Environmental Issues and Waste Management in Energy and Mineral Production.* Pasamehmetoglu and Ozgenoglu (ed.s). Balkema, Rotterdam.

Waite, T. D., Dudgeon, C. and Fell, R. (1998). *Review of Jabiluka Mine Alternative Tailings Management Proposal.* Environment Australia (unreleased).

Wedemeyer, G., Meyer, F. and Smith, L., (1976). Diseases of fishes (Book 5). In: *Environmental Stress and Fish Diseases*. TFH Publishers, Neptune, NJ.

Whitehead, P. J., Wilson, B. A. and Bowman, D. M. J. S. (1990). Conservation of coastal wetlands of the Northern Territory of Australia: The Mary River floodplain. *Biological Conservation.* 52: 85-111.

Wilde, A. R. and Noakes, J. S. (1990). Nabarlek uranium deposit. In: *Geology of the Mineral Deposits of Australia and Papua New Guinea.* F. E. Hughes, (ed.) Australasian Institute of Mining and Metallurgy, Melbourne.

Williams, N. J. (1983). Toxicity of copper to three Magela Creek fishes and a shrimp in simulated Gulugul Creek water. *Environmental Protection in the Alligator Rivers Region*. Paper 65 of scientific workshop held at Jabiru, NT 17-20 May. Supervising Scientist for the Alligator Rivers Region.

Wood, J. (1990). *The Use of the Kakadu Conservation Zone for Recreation and Tourism.* Kakadu Conservation Inquiry: Consultancy Series (RAC Consultancy Series). Aust. Gov. Pub. Serv., Canberra.

World Health Organisation (1990). *Cancer: Causes, Occurrence and Control*. International Agency for Research on Cancer, IARC Scientific Publications No.100, Lyon.

Wren, C. D. (1986). A review of metal accumulation and toxicity in wild mammals. *Env. Research* 40: 210-244.