

Uranium Mill Tailings Wastes in Australia : Past, Present and Future Management - Research Report Summary

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*This paper is a brief summary of a 70 page research report.
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Abstract Australian governments have always sought to use the mining and export of uranium as a principal way to be involved in global nuclear affairs. A large government incentive and exploration program led to the establishment of five mining and milling projects by the late 1950s, with several small mines operated nearby to supply additional ore for treatment. The industry readily acknowledges that the devastating environmental impacts from these mines are unacceptable in modern times. The late 1960s saw a surge in nuclear power programs around the world, and Australia again explored intensely for uranium - with miraculous success. By the mid 1970s, major world-class deposits had been proven at the same time as public opposition to uranium mining and the nuclear industry started to become more widespread. After the completion of the Ranger Uranium Environmental Inquiry ('Fox Reports'), approval was again given for the mining and export of uranium. With the ascension of the Labour Party to power in March 1983, Australia's potential new generation mines were curtailed to three 'existing' sites at Ranger and Nabarlek in the Northern Territory and Olympic Dam in South Australia. A thorough analysis of the management of all the various uranium mining sites across Australia has not been previously compiled, especially with regards to the stability of the 1950s sites. The principal dangers from uranium tailings arise from gamma radiation, radon gas and chemical toxicity. A review of the successes and failures of the long term management of uranium tailings across Australia will be presented, focused on assessing whether long term management has yet been proven to standards acceptable to indigenous peoples of the affected areas and community expectations.

1 Historical Overview

- The dark days of World War 2 and the subsequent 'Cold War' nuclear weapons race saw Australia feverishly commence uranium exploration across the country in the 1940s-50s. With the big finds at Rum Jungle, Mary Kathleen and emerging prospects at Radium Hill and several smaller mines, governments of the day sought to use uranium mining and export as a basis for Australian influence in global nuclear politics. The British were even allowed to conduct nuclear weapons tests in WA, SA and the Pacific.
- By the early 1960s, uranium supply was much more abundant and the British and Americans no longer had a need for expensive Australian uranium. The industry freely admits that the deadly legacy left by most of these mining and milling sites are not acceptable in modern times. Only some of these sites have been rehabilitated to date.
- The late 1960s, however, finally saw the commercialisation of nuclear power on a large scale and exploration again hit fever pitch, with success beyond the wildest dreams of even the most optimistic of miners, and Australian nuclear prospects seemed boundless. Deposits found include Ranger, Koongarra, Jabiluka, Nabarlek, Yeelirrie, among others.
- By the mid 1970s, the nuclear threat had become a central Australian political issue, dominated by uranium mining, Aboriginal land rights, nuclear weapons and the increasingly understood dangers of ionising radiation. New mines were delayed as governments of the 1970s sought to examine the issues and try to satisfy public concern.



Figure 1 - Uranium Mines, Deposits & Former Nuclear Test Sites (adapted OECD, 1998)

- The Ranger Uranium Environmental Inquiry operated for 2 years, investigating the broad impacts of the nuclear industry and the potential impacts in the Kakadu region from uranium mining at Ranger, Jabiluka and others. It recommended a national park, land rights, and sequential development of uranium mining in the region.
- In South Australia by the late 1970s, plans were rapidly developing as the size and potential of the Olympic Dam Cu-U-Au-Ag orebody became realised. Plans were also being made for introducing In Situ Leach uranium mining to Australia at Beverley and Honeymoon. Trial mines were begun at Yeelirrie, Lake Way and Mulga Rock in Western Australia and Ben Lomond in Queensland around this time. Honeymoon was the site of Australia's first anti-nuclear blockade in May 1982.
- By 1983, with Mary Kathleen now closed, only Ranger and Nabarlek were operating, with development continuing at Olympic Dam in SA. With the election of the Hawke Labour government in March 1983, no new mines were approved and the focus gradually shifted to rehabilitation of Maralinga and earlier disasters like Rum Jungle.
- By the year 2000, Australia now has a total of ten sites containing uranium tailings. This paper is a summary of a detailed study of the environmental problems still existing at these sites. On the basis of both mass and radioactivity, the largest site is Olympic Dam (which will dwarf most sites around the world in the long term), while the smallest sites are Rockhole (on mass) and Radium Hill (on radioactivity). A brief summary of the tailings data for the various sites is given below. A review of the environmental hazards from uranium tailings and associated mine wastes will now be presented followed by a specific review of each site.

1970s-90s	t Ore Milled	t U ₃ O ₈	1950s-60s	t Ore Milled	t U ₃ O ₈
Olympic Dam	35,653,100	19,663.4	Moline	137,137	713.5
Ranger	20,037,000	57,974.7	Rockhole	13,155	139.7
Nabarlek	763,000	10,955	Mary Kathleen	9,200,000	8,892.36
Beverley	ISL ⁽¹⁾	32	Radium Hill	969,300	852.3
Trial Mines	various	>> 11	Rum Jungle	1,496,641	3,530
Total	68,269,333 t milled	>101,239,000 t waste rock ⁽²⁾			102,764 t U₃O₈

⁽¹⁾ - ISL involves chemical solutions only and no physical extraction of ore. ⁽²⁾ - includes low grade ore.

2 Environmental Hazards of Uranium Tailings : A Brief Review

The nature of uranium tailings, the finely ground rock left after extraction of the uranium, are fundamentally different from most other tailings produced in mining. This is largely due to the retention of most of the radioactivity in the tailings - about 85% due to the thorium, radium and residual uranium left after milling. Even if a tailings site is physically secure against wind or water erosion, intrusion by flora and fauna, earthquakes and chemically secure against contamination of surrounding soils, surface waters and groundwaters, the radiation emanating from the tailings may still give rise to an unacceptable risk to the local environment and nearby communities compared to pre-mining conditions. When uranium tailings are not stable, the potential for environmental impacts and elevated radiation exposures can become quite significant.

The principal radiation risks from uranium tailings are gamma radiation, dust and radon gas and its radioactive progeny (a source of multiple alpha, beta and gamma radiation). The inhalation of radon gas is a principal agent of lung cancer in uranium miners, an observation first made as early as the mid 16TH century in the Erz ('Ore') Mountains in eastern Germany (Birringucio, 1540; Agricola, 1556; Dalton, 1992). The United Nations Scientific Committee on the Effects of Atomic Radiation estimated that 75% of the global collective dose from the nuclear fuel chain was due to uranium mining and milling (UNSCEAR, 1993).

Uranium ores, and therefore the tailings, are often associated with elevated concentrations of heavy metals, giving rise to the potential for chemical toxicity from surface water or groundwater contamination (Waggitt, 1994), particularly for many USA (Portillo, 1992) and Saskatchewan uranium deposits in Canada (see Langmuir *et al.*, 1999). The Saskatchewan deposits in particular often contain extremely high levels of arsenic, sometimes as high as 10%. The Moline tailings are also high in arsenic, averaging 0.144% and reaching 1% (see Section 3.3, Table 4). A schematic of the various risks are shown in Figure 2.

The milling of uranium ore removes most of the uranium, generally around 90%, but leaves the radioactive decay products in the tailings. The radioactivity of uranium tailings is therefore controlled by three principal radionuclides - thorium-234 (half-life, t_{1/2}, 24.1 days), thorium-230 (t_{1/2} - 75,000 years) and residual uranium (U-238, t_{1/2} - 4.51 billion years; U-235 t_{1/2} - 710 million years). Based on these half-lives, the radioactivity of uranium tailings will decrease by about 15% after about 4-5 months (due to ²³⁴Th decay), but will remain at this level for some 750,000 years (due to ²³⁰Th). After the residual ²³⁰Th has decayed, the radioactivity of the tailings will be controlled by the amount of uranium left after milling. For Nabarlek, where the mill efficiency was very high, the tailings radioactivity will be considerably lower than the ore, compared to Roxby, where uranium extraction efficiency is poorer, giving a high radioactivity in the long-term due to residual uranium.

Uranium Mill Tailings Hazards

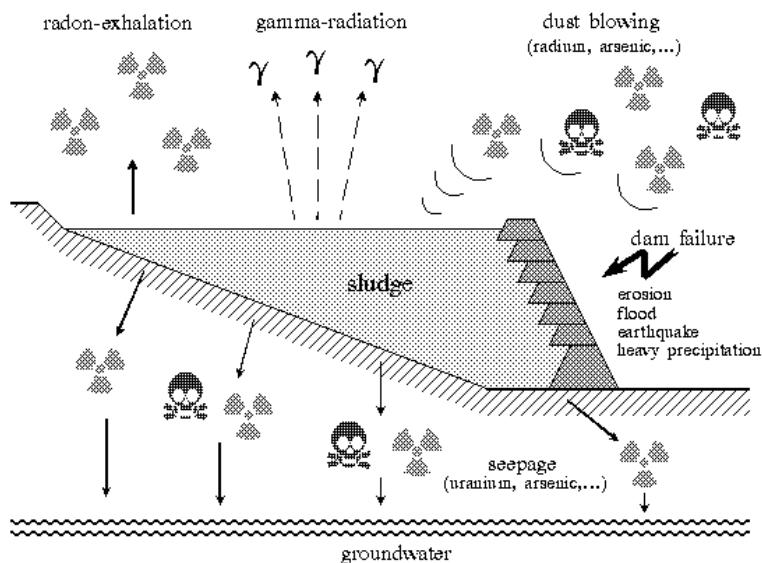


Figure 2 - Radiation and Heavy Metal Exposure Risks from Uranium Tailings (WISE-UP, 2000)

Assuming that all of the radioactive decay products are in equilibrium in the original ore, it is possible to calculate and compare the radioactivities of different uranium tailings around Australia, given in Table 1 and shown in Figures 3 and 4. The calculations are based on the mining and milling data from Tables A1 and A2 and the radionuclide data from Martin & Akber (1996), Langmuir (1997) and WISE-UP (2000).

There are also risks from waste rock dumps, the material rejected from a mine with low-grade or no uranium mineralisation or economic value. The engineering and rehabilitation standards applied to waste rock dumps are often less than that for tailings, and thus the long term stability of waste rock dumps is less certain. In eastern Germany, for example, waste rock with elevated uranium concentrations (50 mg/kg or ppm¹) was mixed with gravel and used for road and railroad construction, thereby dispersing elevated radioactivity over large areas (WISE-UP, 2000). Two Australian examples include the radioactive ore and waste rock from the Yeelirrie trial mine used for local road building and construction works, and the waste rock used from Radium Hill for railway ballast (NIC, 1996; WMC, 1997; SEA-US, 2000).

The gamma radiation and emanation of radon from different tailings will vary considerably, depending on such factors as ore/tailings mineralogy, crushing and milling treatment, climatic conditions and the extent of rehabilitation works (if any). Waste rock often has low-grade uranium mineralisation, and can thus also be important in assessing radiation rates and the effectiveness of rehabilitation works (planned or completed). For example, non-mineralised waste rock at the Ranger mine is defined as <0.023% U₃O₈, with low grade ore being between this and 0.10% U₃O₈ (or a similar mill cutoff grade).

Due to the low abundance of ²³⁵U in natural uranium (~0.719%; Langmuir, 1997), it generally comprises only a small fraction of the radioactivity of uranium ore and tailings, with ²³⁸U constituting the majority of radioactivity. The various decay products have quite different chemical properties, such as thorium being relatively insoluble compared to the more soluble radium, or radon - a gas. Since thorium isotopes control radioactivity over the first million years, it is critical to ensure that thorium's potentially more mobile decay products, such as radium and radon, are not exposed to physical or chemical conditions that promote mobility.

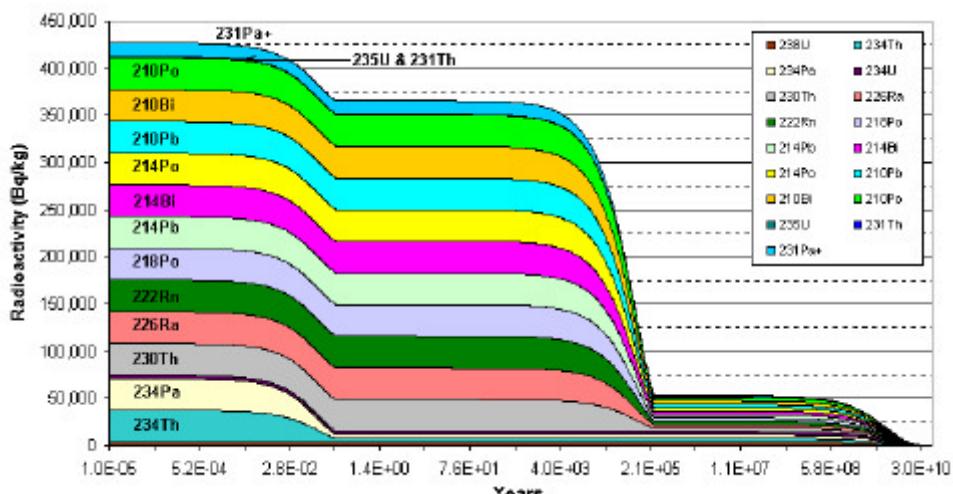
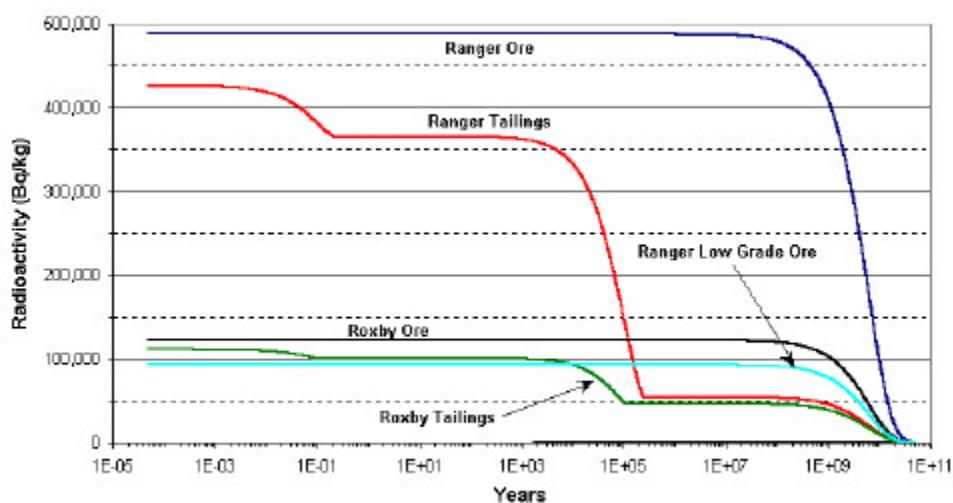
¹ - ppm is 'parts per million'; equivalent to mg/kg, mg/L, g/t, etc.

Table 1 - Radioactivity of Various Uranium Tailings Across Australia

	Ranger ⁽¹⁾	Rockhole	Moline ⁽²⁾	Nabarlek	Rum Jungle ⁽²⁾
Tailings (% U ₃ O ₈)	0.035%	0.048%	0.074%	0.046%	0.085%
Total Tailings (t)	20,037,000	13,155	~285,050	606,000	~2,687,300
Ore (Bq/kg)	490,749	1,670,955	775,413	2,769,871	483,373
Tailings (Bq/kg)	429,225	1,445,448	681,701	2,389,027	433,203
Total (Bq)	8.55x10 ¹⁵	1.90x10 ¹³	9.03x10 ¹³	1.45x10 ¹⁵	6.48x10 ¹⁴
Tailings at 10 ⁶ yrs (Bq/kg)	54,129	71,838	110,864	69,234	127,587

	Mary Kathleen	Radium Hill	Port Pirie	Olympic Dam ⁽¹⁾	Yeelirrie ⁽⁵⁾
Tailings % U ₃ O ₈	0.051% ⁽³⁾	0.0054%	0.24%	0.029%	0.03%
Total Tailings (t)	9,247,000	~820,000	~152,400	35,653,100	~130,000
Ore (Bq/kg)	195,697	195,697 ⁽⁴⁾	-	120,429	225,805
Tailings (Bq/kg)	173,923	8,129	1,204,292	109,917	200,330
Total (Bq)	1.61x10 ¹⁵	6.67x10 ¹²	1.66x10 ¹⁴	3.95x10 ¹⁵	2.60x10 ¹³
At 10 ⁶ yrs (Bq/kg)	41,285	8,128	366,038	43,888	45,153

⁽¹⁾ - milling data to June 30, 2000; ⁽²⁾ - average of all ores treated; ⁽³⁾ - based on as milled ore; ⁽⁴⁾ - based on ore grade as mined of 0.13%; ⁽⁵⁾ - assuming ore at 0.15% and 80% mill efficiency. (See data in Tables A1 & A2. Radioactivity calculations do not include base metal tailings).

Figure 3 - Radioactive Decay in Ranger Tailings from ²³⁸U and ²³⁵U Decay ProductsFigure 4 - Radioactive Decay in Uranium Tailings versus Ore
(Ranger Low Grade Ore, ~0.06%, based on half the current mill cutoff grade at 0.12%)

3 South Alligator Uranium Mines and Mills, NT

- A series of small but rich deposits mined and processed in the late 1950s to early 1960s. Two companies were operating in the region, with 2 separate mills (one at Rockhole in the region, the other at Moline to the southwest). Total uranium ore milled was about 150,300 t ranging between 0.2% to 2.5% U₃O₈.
- Acidic and radioactive tailings were discharged onto adjacent floodplains, dispersing directly into adjacent creeks and river systems. All mines, infrastructure and tailings sites were abandoned by the late 1960s. It is not accepted that this was simply the 'standard practice of the day' (due to the lack of legal requirements), since other mines were building and disposing of tailings in engineered dams.
- By the mid 1980s, when Coronation Hill was set to be mined again (for remaining gold), surveys revealed that significant radiation and physical safety risks still remained. Due to the high gold content of the Moline tailings, these were reprocessed and the gold extracted in the late 1980s.
- A poorly funded 'Hazard Reduction Works' program in the early 1990s reduced some of the dangers, but have not stood the test of time. High gamma radiation rates still persist in some areas, with erosion problems and perpetual maintenance required.
- Acid mine drainage still drains and impacts on Rockhole Creek from the old Rockhole mine, as well as the remaining tailings yet again eroding into a nearby creek over the popular tourist road of southern Kakadu.
- About 25% of the radioactive Moline tailings (~63,000 t) have eroded into local creeks, tributaries of the Mary River system. This radioactivity can be traced for tens of kilometres downstream of the old mill, settling in wetlands and floodplains and thereby concentrating in aquatic ecosystems that will be more exposed to bioaccumulation and bioconcentration of the radionuclides.
- Further rehabilitation works are urgently needed. After the stopping of Coronation Hill, the Jawyon and the government agreed that this work would occur to be agreed upon by December 2000 with all works complete by 2015. By the history of previous works, this time they will need to be properly funded and more appropriately engineered.

4 Radium Hill & Port Pirie, SA

- A remote, mineralogically complex and difficult mining and milling project from the outset, Radium Hill was aggressively supported by the SA premier - Thomas Playford. The ore was separated by gravity into a preconcentrate at Radium Hill and chemically processed at Port Pirie, with the tailings adjacent to residential houses.
- In a 1980s survey, the Radium Hill tailings were found to be eroding in the strong arid climate and being wind blown across the pastoral property. During remedial work in 1981/82, whereby clay was dumped over the top, the site was also kept open for use as a low-level radioactive waste dump.
- A Port Pirie boy received bad acid burns to his leg over 10 years after closure of the mill (see Lackey, 1983) - demonstrating the persistence of the strong acidity used at Port Pirie. These burns were reported as 'radiation' burns, and represent a significant health impact.
- A king tide breached the tidal swamp lands of the Port Pirie tailings in 1981, and subsequent investigation after lobbying by concerned residents showed high radon emanation problems. The tailings were then covered with zinc slag, reducing radon levels.
- Significant doubt still exists as to the long term stability of both the Radium Hill and Port Pirie tailings sites.

5 Rum Jungle, NT

- Australia's first large scale uranium mining and milling operation, 65 km south of Darwin.
- After detailed investigation by the federal Bureau of Mineral Resources, a contract was signed with the UK-USA nuclear weapons programs for delivery of 1,440 t U₃O₈. Rum Jungle subsequently became the biggest industrial project in the NT since the war. The site also hosted several moderate-size base metal ore deposits. After the CDA contract, Rum Jungle was federally-subsidised and ~2,100 t U₃O₈ uranium stockpiled by the AAEC.
- The site was owned by the government, through the newly formed Australian Atomic Energy Commission (AAEC), but managed and operated by Territory Enterprises Pty Ltd (TEP), a subsidiary company of CRA Ltd (now Rio Tinto). Callous mismanagement by TEP of tailings, waste rock, water and milling wastes led to massive impacts on the Finniss River system and the destruction of over 100 km² of floodplains and rivers.
- The impacts were due to the massive loads of heavy metals (mainly Cu, Mn and SO₄) and radionuclides (especially ²²⁶Ra) leached from the tailings and waste rock dumps, which were producing large volumes of acid mine drainage (AMD).
- Acidic and radioactive tailings were discharged directly in 'Tailings Creek', which drains in the East Branch of the Finniss River. Up to 10% or 150,000 t had eroded by the mid 1980s. Due to mounting public pressure in the 1960s, tailings were re-directed to the mined out open cuts at Dysons and White's. The practice of diluting mine site waters with wet season flows by controlled discharges from the dams has been shown to have never worked.
- Major rehabilitation works were finally funded in the mid 1980s, although at taxpayers expense and CRA never paid a cent. The goals for reduction in pollution loads were set on what was considered economically realistic, and not on any ecological toxicity or impact criteria. An experimental approach was used to cover the waste rock dumps, compared to the requirement for proven technology at Ranger. Monitoring of the rehabilitation works has continued to the present, and shows less than the desired success.
- The lake at the former open cut mine at Rum Jungle Creek South (where the uranium ore had no surface radiological expression prior to mining), was discovered in the mid 1980s to be a significant public health risk with radiation doses to the public using the lake of about 5 mSv per year. This was above the new public dose limit of 1 mSv/year. Minor rehabilitation works were undertaken in 1991, although the results appear ineffective.
- Monitoring of the waste rock dumps has shown that pollution loads have been somewhat reduced, but the levels of heavy metals still leaving the Rum Jungle site are 2 to 3 orders of magnitude higher than those upstream in the Finniss River catchment.
- Importantly, the covers are starting to allow more rainfall to infiltrate and this will cause the pollution loads to increase again in the long term if nothing is done.
- ecological risk assessment studies by ANSTO continue to estimate that between 5 to 60% of species would be affected by the continuing discharge of heavy metals, and that the probability of exceeding the guideline values was close to 100% (Perera *et al.*, 1999);
- vegetation dieback has been expanding to 10-30% of the cover on Dyson's open cut, due to inadequate design and construction of the covers allowing acidic metal-laden pore waters to be drawn up to the surface soils through capillary action (Menzies & Mulligan, 1997);
- continuing subsidence and erosion problems of different severity at numerous sites - some threaten the integrity of revegetation while other eroding sites endanger the covers; these sites need annual maintenance (see Kraatz & Applegate, 1992; Kraatz, 1998);
- weeds are a major problem - introduced from contaminated soils sourced outside the mine area during rehabilitation as well as transport by wind, vehicles and birds (Kraatz, 1998).
- **SUMMARY - Rum Jungle has proven to be a continuing environmental disaster for half a century, a problem which is set to continue and possibly worsen. All this for an unprofitable mine at taxpayers expense.**

6 Mary Kathleen, QLD

- The Mary Kathleen uranium deposit was discovered in July 1954 the hey-day of feverish prospecting across northern Australia. Quickly realised as being of world significance, eventual control of the Mary Kathleen Uranium (MKU) project went to Rio Tinto of the UK, who secured a major contract with the UK Atomic Energy Authority for 4,080 t U₃O₈;
- After 5 years of operation, the UKAEA contract was filled quicker than expected and the project was mothballed. By the early 1970s, increasing world nuclear power allowed MKU to sign new contracts and re-open in early 1976. Lasting 6 years, a further 4,801 t U₃O₈. A major rehabilitation program was undertaken from 1982 to 1986;
- The MKU site is now a maze of waste rock dumps (both radioactive and non-radioactive), covered tailings and evaporation ponds, the old plant site (no plant or equipment is left), and an open cut filled with about 50 m of water (including contaminated materials dumped in the pit during rehabilitation works);
- Despite being portrayed as an excellent example of environmental management in mining, many problems were ignored or improperly accounted for in operation and rehabilitation :
 - one million litres of radioactive liquid was deliberately released in February 1984 from the mines' evaporation ponds during an unexpectedly intense wet season;
 - The cover material used for rehabilitation was mostly coarse waste rock - not engineered fine soils or clays to act as cover. This was essentially to lower costs;
 - The waste rock, it was argued, minimised radon emanation and therefore possible radiation exposures - however, it would not limit infiltration of rainwater through the tailings dam site, the evaporation pond, the mill site and other areas - therefore the potential for further groundwater contamination is of major concern;
 - During the 1982/83 and 1983/84 Wet Seasons, the volume of waste waters requiring treatment on site almost doubled to 700 million litres (ML);
 - At the evaporation pond, infiltration trenches were excavated in alkaline clays so that the excess acidic water, containing heavy metals and radionuclides would discharge through the clays into the adjacent creek - sorption on clays can be a weak and reversible geochemical process, and thus contamination remains inevitable;
 - The open cut was left as a final void, and allowed to fill with water - radioactivity was claimed to be "not a public health hazard". The predicted water quality of the pit lake, although initially quite good, was expected to deteriorate in the long term;
 - The pit lake also received the concentrated, acidic effluents from the rehabilitation of the tailings dam and evaporation pond - despite its unsuitability for this purpose;
 - Although attempts were made to prevent stock access (the site has now reverted to grazing), pedestrian or tourist access is still possible.
- Thus the closure of Mary Kathleen has led to the tailings being covered in situ and, importantly, above the natural ground surface. Although more subdued than Rum Jungle, water and waste rock management problems still exist.

7 Naborlek, NT

- Naborlek is a small but rich deposit, discovered in the early 1970s by Queensland Mines Ltd, and was a short-lived but intriguing example of a uranium mine tailings and waste management. After the Ranger Inquiry, approvals were quickly sought and received, with mining in 4 months during 1979. Production started in mid 1980, uniquely depositing the tailings directly back into the mined out pit (as recommended by the Inquiry for Ranger).
- A small but experimental heap leach project was trialled, though apparently not successful.
- After no new deposits were found, rehabilitation works were begun in late 1994.

- The main environmental problem encountered was contaminated water management and disposal (which gave rise to large areas of forest dieback, contaminated groundwater and creek impacts). Further problems discovered during rehabilitation works include poor revegetation properties of the stockpiled topsoils, weed infestation, poor settlement of tailings and increased gamma rates over the former project area.
- **Tailings** - Settlement problems were encountered, which although solved in the end, were time consuming and difficult to remedy. The biggest problem with ascertaining the safety of tailings is the issue of groundwater contamination. The fractured nature of the host rocks (aquifers) makes detecting and quantifying any contamination extremely difficult, proven by monitoring of groundwater downgradient of the evaporation ponds. Although radon does not appear to be a major concern, there is little pre-mining data to allow an accurate assessment of the effectiveness of rehabilitation on radon emanation rates. Some research has shown that termites are capable of breaching the cover on the in-pit tailings in just 1,000 years - thereby increasing long-term groundwater contamination and radon risks.
- **Water Management** - Nabarlek operated as a "no-release" mine and used 2 large evaporation ponds to dispose of excess mine site and process waters. These waters became highly saline and contained significant heavy metals and radionuclide content. After heavy wet seasons in the mid 1980s, QML disposed of this water on the airstrip and forest irrigation areas. The extremely high ammonia content of the water led to acidification of the groundwater, which discharges into local creek lines and has led to fish kills early in the wet season. All groundwater contamination was ignored during rehabilitation works.
- **Decommissioning & Rehabilitation** - This finally took place almost a decade after closure of the mill. Some infrastructure was left for the traditional owners, but most was removed or buried. Due to sterile topsoil (from too many years in storage), waste rock was used to reshape and revegetate the site. This has led to major problems with weeds infesting the site, as well as helping to increase the average gamma rate over the 98 ha site from 0.18 to 0.27 $\mu\text{Gy}/\text{hr}$ - an increase of some 50% compared to pre-mining. When used in radiation dose estimates, excluding radon and dust, this gamma dose rate is very close to exceeding the public exposure limits, meaning traditional owners are more at risk.
- **Summary** - The impacts on groundwater and surrounding ecology are only just beginning to be appreciated. Radiologically, there is a lack of extensive data prior to mining to allow a full evaluation of rehabilitation standards and effectiveness, especially for radon (which is critical). Clearly, further work is required to reduce gamma dose rates (closer to pre-mining levels), eliminate the weed problem, restore contaminated groundwater at the irrigation areas and undertake more detailed groundwater monitoring over the longer term to ascertain the chemical stability of the in-pit tailings and surrounding groundwater.

8 Ranger, NT

- The large Ranger Project triggered the debate about uranium mining in the mid 1970s. Discovered by Noranda in October 1969 on the Peko-EZ leases, the potential of the lease was quickly established by late 1970 as being of world-class. Peko-EZ acted fast to try and pre-empt the environmental impact assessment, national parks, uranium mining and Aboriginal land rights debates, but to no avail. Various government policies deferred mining lease decisions until the Ranger Uranium Environmental Inquiry was established in July 1975, reporting in October 1976 and May 1977.
- After cautious approval by the Inquiry reports, signing of an Agreement with the Northern Land Council (on behalf of the traditional owners, allegations of excessive duress still persist) and detailed design, construction finally began in 1979, opening in mid 1981.
- The Ranger Inquiry, however, was quite critical of many aspects of the Ranger Project, which subsequently forced many substantive design and management changes, including waste rock, water and tailings management and environmental monitoring.

- Experience since opening of the mine has shown that the original designs overestimated evaporation while underestimating rainfall - leading to higher volumes of contaminated mine waters to be stored on site. This in turn has led to pressure for irrigation on some areas, which have now become contaminated with salts and radionuclides. In some years, there has been enormous pressure placed on the traditional owners to approve the release of contaminated waters - which the traditional owners vetoed most strongly.
- Over the last 25 years, an increasing trend for sulfate, uranium and magnesium in Magela Creek and the heavily impacted creeks and billabongs in the Ranger project area is clear. Significant uncertainty exists as to the long term effects of these chronic exposures.
- Despite a clear and absolute recommendation from the Ranger Inquiry for final, below ground disposal of tailings, ERA spent several years trying to research ways to rehabilitate the above ground tailings dam - all research showed it would eventually fail before 1,000 years and so ERA have now accepted below ground disposal back in the mined out pits as the best approach. Several million tonnes of tailings still remain in the original dam and awaits the completion of mining of Pit #3 and the future of Jabiluka before they will be returned to the pits. Before using Pit #1, ERA did not line the pit to minimise seepage.
- The interpretation of groundwater contamination from the original tailings dam and Pit #1 is complex. Rapid seepage pathways exist (such as the Magela Fault system and fractured rock aquifers), but the chemistry is of the most importance. Salinity is migrating through groundwater, but radionuclides appear to be retarded to date, although conflicting data from the company and regulatory authorities clouds the true picture.
- It is clear that the best long-term option for Ranger tailings is for below ground tailings disposal. The potential for groundwater contamination is increased by ERA's failure to properly line Pit #1, and depending on the final configuration of Pit #3, there does not appear to be much prospect for improved management of uranium mill tailings at Ranger. Some of the greatest concerns of the author are the standards applied to waste rock dumps and the potential for Pit #3 to be left as an open lake. The Ranger site will need to be carefully guarded for many, many decades before any degree of confidence with the management of its radioactive tailings, waste rock and mining legacy can be asserted.

(Note : A detailed research report on Ranger is due out in November 2000, contact this author).

9 Jabiluka, NT

- Jabiluka missed the chance to open in the early 1980s, but after being bought by ERA in 1991, was again put on the agenda in 1996 with the change in government policy. This time, the proposal was to truck the ore to Ranger for milling, thereby increasing the burden on Ranger (and Kakadu and the Mirrar) considerably.
- After obtaining EIS approvals and defeating several court injunctions, ERA constructed minimal site facilities in 1998, including a water management pond, underground access decline and associated facilities (diesel tanks, power generators, roads, offices, workshops, etc.). Two waste rock dumps have been created to date - one within the 'Total Containment Zone' (TCZ) containing uraniferous material ($>0.023\% \text{ U}_3\text{O}_8$) or potentially acid-forming materials ($>0.5\% \text{ sulfide}$), and the second dump containing inert rock material dumped outside the TCZ (less than the above 2 criteria) (NTS, 1999).
- The traditional owners, the Mirrar, have vetoed the Ranger milling option until 2005, meaning to progress Jabiluka in the near term ERA will have to build a mill, water and tailings infrastructure on site.
- Consistent criticisms by several eminent scientists have been made of the scientific basis for the Jabiluka Project, including water management, tailings disposal (both in the interim and long-term), radon emanation from the ventilation shafts and general site disturbance.

- By early 2000, ERA were already experiencing problems with their water management pond (due to 2 heavy wet seasons and limited pond capacity). The pond also contained significant uranium levels. High sediments load in runoff from the site were also recorded.
- For tailings disposal for the Jabiluka Mill option, ERA were forced to accept underground disposal back in the mine using cement paste technology - an unproven technology for uranium tailings. Since the 'tailings silos' would need to be excavated in the mine first before disposal, the way ERA intend to manage tailings in the interim is unclear.
- Jabiluka remains uncertain - clear environmental problems relating to existing facilities remain, as well as continuing gaps in baseline ecological data. The Mirrar continue to strongly oppose Jabiluka, and, hopefully, there will be no need to assess future tailings.

10 Olympic Dam (Roxby Downs), SA

- The Olympic Dam ² polymetallic deposit was originally discovered by WMC in July 1975, since proving to be one of the world's largest mineral deposits containing copper, uranium, gold, silver and rare earths. Quickly becoming a hot political football, Roxby gained approvals and special enabling legislation by early 1983, with exploration, pilot plant and construction work escalating until opening in August 1988. The last count for the size of Roxby was some 2,320 million t of ore remaining, giving Roxby >50 years left in life.
- The two biggest issues of concern with Roxby centre on its water supply borefields near sensitive Mound Springs at Lake Eyre South (150 km to the north) and the long-term disposal of tailings in unlined and above ground storage facilities.
- Within a decade, the Roxby tailings will loom as the largest uranium mill tailings deposit in the world - stored above ground, with no plans to return the tailings underground. Due to the inefficient nature of uranium extraction in the mill, the tailings have a high uranium content at about 0.03% U₃O₈ - quite high for surface soils of the arid region.
- After prompting by the SA Health Commission, in February 1994, WMC publicly announced that up to 5 billion litres of tailings waters had leaked from the tailings dam. The SA government instituted a major public inquiry, which was quite critical of both current operations and the secretive process used to design and construct the tailings dam in the mid 1980s. The inquiry found that the engineering design was defective in concept and construction, failed to properly account for rainfall and mine dewatering management, lack of informed supervision, and other systematic problems with tailings at Roxby.
- WMC argued to the inquiry that the underlying limestone would neutralise the acidic tailings, however, the research on the geochemical interactions between tailings liquors and the limestone have shown that this approach cannot be sustained for very long, with the acidic liquors eventually leaching through. Given the projected longevity of the Roxby project, one cannot maintain confidence in the Inquiry's conclusion that no environmental impacts have occurred to date nor are they likely in the future.
- There was no radiological expression of the copper-uranium ore at Roxby Downs before mining. The disposal of the tailings - above ground - will therefore lead to an overall increase in the radioactive burden on the surface environment at Roxby, predominantly radon but also dust and gamma. Pre-mining radon emanation rates are very low.
- Roxby's unique size and scale appears to be its nemesis - it has proven difficult to demonstrate effective containment of tailings liquors and open questions remain about radon releases, gamma radiation rates, physical stability and rehabilitation techniques. As the largest single producer of uranium mill tailings in the world, greater attention must be paid to safeguarding the environment of the region and the interests of the traditional owners, who have mostly opposed Roxby from the outset.

² - the deposit is located on Roxby Downs pastoral station, which is also the name of the township. The mine is colloquially called Roxby Downs.

11 In Situ Leach Uranium Mining on Trial

- In Situ Leach or 'Solution' Mining involves no physical extraction of the ore. Instead, it involves the use of hundreds of groundwater bores to inject the chemical process solutions typical of a mill directly into the ore zone to dissolve the uranium 'in situ'. This uranium-rich solution is then pumped back to the surface and processed. In essence, the mined groundwater becomes the final tailings waste.
- After 2 brief trials at Honeymoon, SA, in 1982 and Manyingee, WA, in 1985, renewed efforts at Honeymoon and Beverley (SA) have rekindled Australian ISL mines from 1996.
- Some ***advantages*** of ISL technology are :
 - reduced hazards for the employees from accidents, dust, and radiation;
 - low capital and operational costs;
 - no need for large uranium mill tailings dams;
 - applicability to small, low-grade otherwise uneconomic deposits.
- Some ***disadvantages*** of ISL technology are :
 - risk of groundwater contamination from the movement of leaching solutions outside of the control of the mine area;
 - impact of the leaching solutions on the geology of the deposit is difficult to predict;
 - impossibility of restoring natural groundwater conditions after completion of mining.
- Either alkaline or acidic leaching chemistry can be used, combined with an oxidising agent, the choice of which is dependent on the nature of the orebody, environmental requirements and a company's preference.
- Internationally, alkaline ISL mining has been extensively used in the United States compared to extensive acid ISL mining in various countries that formed the Soviet Block. Although the USA sites have had their problems with groundwater contamination and difficult restoration, the Soviet sites have led to extreme problems with contamination of groundwater and the environment.

11.1 Honeymoon, SA - The Trial Continues

- After a decade of geological drilling and hydrogeological investigation, Honeymoon began developing as Australia's first proposed ISL mine in 1979. A small ISL trial in 1982 found several difficulties with leaching chemistry, blocked pipes, jarosite and gypsum formation.
- The Honeymoon trial mine site saw Australia's first anti-uranium blockade in May 1982. After election of the SA Labour government, approvals were withdrawn and the project was mothballed. In 1997, a new Canadian company bought the project and began again developing the site including a new 2 year trial.
- Hydrogeology at Honeymoon consists of a three-layered sand system, with clay between each layer of sand. The clay is not very thick and is often absent altogether. The water level in all 3 sands is the same, thereby suggesting direct connection of the different layers. This means that the solutions, which will mine the bottom sand for uranium, will be difficult to control and a contamination of groundwater in the other sands is likely.
- Water quality is saline, with the bottom sand with the uranium containing the highest salinity at 16,000 mg/L and the top sand at 10,000 mg/L. The various companies over the years have argued that due to this salinity, the water can be polluted by their ISL mining. Given the use of saline groundwater up to 20 times more saline in numerous mining operations in WA, there is always an economic use for water at any salinity. For example, Kangaroo Island, off the SA coast, processes seawater to produce drinking water. Therefore, in an arid region, it is imperative to protect all sources of water for future use.
- The data from the 1982 and 1998-2000 trials have not been released, thereby preventing any realistic assessment of actual impacts and if their claim of 'natural attenuation' works.

- One obscure admission in the new Draft EIS (SCRA, 2000) relates to the radiological impacts of the former site works at Honeymoon. On page 10-6, the average gamma dose rate for the Honeymoon site is stated as 0.06 $\mu\text{Gy}/\text{hr}$, compared to the location of the 1980s tests which registered 0.161 $\mu\text{Gy}/\text{hr}$ - a three-fold increase presumably due to leaks, spills and/or direct discharges of radioactive materials on the surface.

11.2 Beverley, SA

- A large sedimentary deposit discovered in 1969, initially Beverley was planned as an open cut mine and mill, which proved uneconomic. In the early 1980s, given the work proceeding at Honeymoon, Beverley was planned as an ISL mine, although the change in SA government policy in March 1983 prevented any trials and development at that time.
- New owners General Atomics began rapid development of an ISL mine in early 1996, a project that has received heated allegations over their relationship and dealings with the traditional owners, the Adnyamathanha, has been the subject of heated allegations concerning excessive police force, legal threats and complete disregard for the cultural heritage and concerns of the Adnyamathanha.
- The Beverley deposit comprises three main ore zones (Northern, Central and Southern) in a sand channel system about 100 to 140 m deep, although the nature of these sands and where they flow outside of the ore zones remains unknown. The aquifer sands have very low organic carbon and pyrite present. The groundwater is less saline than Honeymoon, ranging from 3,000 mg/L in the northern ore zone to 16,000 mg/L in the southern ore zone.
- General Atomics established a field trial in late 1997, which operated for about 1 year. The data from this trial has never been released, and therefore it is not possible to assess their claim concerning impacts on groundwater and 'natural attenuation'. This is direct contrast to USA standards, where the results from a trial are used to permit a commercial mine.
- After releasing their new EIS in June 1998 - before the trial was completed, Beverley gained final government approvals in early 1999 and has succeeded in becoming the western world's first acid ISL mine with no restoration of groundwater, thereby making it decisively easier for other ISL projects to follow in its wake.
- Importantly, their EIS and subsequent approvals relied heavily on the concept of 'natural attenuation', although no geochemical mechanism or other scientific basis was argued and no data given. In theory, this could be provided by ion exchange, precipitation or oxidation-reduction reactions over time and would necessitate the presence of active reducing agents such as organic matter or sulfides (ie. pyrite) or abundant chemically reactive surfaces like iron oxyhydroxides or clays (Buma, 1979). The main key was for active reductants to be present. Beverley, with low concentrations of these minerals, therefore has no ability to 'naturally attenuate' its high strength acidic pollution. The large groundwater problems at ISL mines in the Former Soviet Union, where conditions exist in theory for attenuation, suggests these mechanisms are not able to attenuate such pollution.
- Curiously, the final approvals included provisions that liquid waste reinjection only occur in the Northern ore zone - the zone of least exploration drilling and, importantly, the region of the best quality groundwater at 3-6,000 mg/L.
- Beverley is currently undergoing commissioning and is expected to begin production by late 2000, and through its approvals process, has established 'World's Worst Practice' as the basis for ISL mining in Australia. The 'tailings' from Beverley will have a high degree of scientific uncertainty about their environmental stability over time.

11.3 Manyingee, WA

- Manyingee was discovered in 1974 and a moderately sized uranium deposit was subsequently delineated which was considered economically attractive for an ISL mine. Due to the high carbonate (eg. limestone / siderite, CaCO_3 / FeCO_3) content of the host sands (Valsardieu *et al.*, 1981), acid solutions have always been considered unsuitable and alkaline chemistry investigated.
- French company, Total Mining, conducted a small trial for 169 days in 1985, leaching one 5-spot pattern with 40 million litres of alkaline solutions. The data from this trial still has not been released, and thus one cannot assess the efficacy of alkaline mining. It is understood that there was no restoration of groundwater.
- The groundwater quality is of moderate salinity at 3,400 mg/L (similar to the Northern ore zone at Beverley), consisting of mainly sodium and chloride with minor magnesium, bicarbonate and sulfate (Valsardieu *et al.*, 1981).
- New owner, uranium hopeful Paladin Resources, are actively planning a new ISL mine.

11.4 In Situ Leach Uranium Mining - It Sucks, Literally

The unconventional mining technique of In Situ Leach uranium mining appears set to finally become a reality in Australia at Beverley and Honeymoon, with Manyingee waiting in the shadows. At all sites, the field trials have denied open and transparent public accountability on the grounds of commercial confidentiality. The full results of the various trials must be released if a realistic scientific analysis is to be made of the claims by the companies (with government support) regarding the impacts on groundwater quality during operation and about post-mining conditions. Based on the site specific characteristics of the different deposits, it can be seen that at the very least, many of the company claims are not likely to hold true. The limited evidence available to date suggests that the impacts on the mined groundwater systems will be long-lasting and, as 'tailings' sites, they will be far from stable. For the arid regions of Australia which are almost entirely dependent on groundwater, the standards approved for acid ISL uranium mining suggest that this groundwater has no 'economic' value (ignoring environmental considerations) and can therefore be consciously degraded. This increases the burden on future generations - in areas which are likely to be even more reliant on groundwater in the coming centuries. Acid ISL mining can justifiably be considered as 'World's Worst Practice', and would certainly not be approved in the USA.

12 Pilot-Scale Mining and Milling

Across Australia there has been a literal plethora of sites where great hope was held for a new uranium mine from the 1950s up to more modern times. The older sites in particular have generally never been rehabilitated and thus remain a hazard for local land users, visitors and local ecosystems. More modern sites appear to be doing better, but data is generally scarce to assess radiation safety and environmental management. They are summarised in the full research report. As can be seen, the potential impacts from the radioactive wastes from uranium mining and milling is not just limited to the sites where processing has occurred. Well over a dozen sites around Australia, if not dozens, have undergone detailed evaluation, exploration and or pilot scale mining and milling. This has led to contaminated materials being stored at the surface compared to below ground beforehand. The vast majority of these sites have yet to be cleaned up to modern community expectations and scientific and radiological standards. On the available evidence, it appears at most sites that the radiological hazards appear to have been exacerbated by the various activities carried out.

13 Assessment of the Management of Uranium Mill Tailings Wastes

The management of uranium mill tailings and associated mining wastes has clearly improved in Australia since the uranium boom (and bust) of the 1950s and 1960s. The legacy of most of these older sites continues to prove challenging to modern management techniques with ongoing associated environmental and radiological impacts. In comparison, the modern 1980s generations of uranium mines appear to be doing better, but still have continuing problems, albeit of a different nature and scale. By June 2000, some 68.3 million tonnes of tailings have been generated across Australia, along with considerably more low grade ore and waste rock. Although perhaps small in comparison to countries such as the USA, Canada, eastern Germany and former Soviet Block countries, the potential quantity of tailings in the future could reach as much as 2,500,000,000 t if the full size of the deposits are mined and milled (especially Olympic Dam and Jabiluka). This eclipses all other countries around the world by at least an order of magnitude. It must be remembered that the Olympic Dam tailings will remain permanently above ground.

The environmental costs of this uranium mining and production have often been poorly accounted for in their regulation and approvals, even ignoring the full life cycle of uranium producing nuclear waste and the links to nuclear weapons, which would serve to make the preceding analysis in this review even more compelling as to the environmental impacts arising from the nuclear fuel chain. The problems can be grouped into the following general areas, with examples from above :

- **Radon Emanation** - radon behaviour is complex, but despite being a major contributor to radiation dose, the limited data is still very poor in assessing the factors controlling emanation rates. Unrehabilitated tailings sites can have very high radon emanation rates compared to pre-mining (eg. Rockhole, Moline, Port Pirie);
- **Gamma Radiation Increases** - although data to compare pre-mining gamma rates to post-mining is missing in most cases, the available evidence suggests that either large or subtle increases will persist (eg. Nabarlek, abandoned NT mines, WA calcrete sites). Importantly, this also increases the risk from dust exposure;
- **Erosion** - at many sites wind and/or water erosion is an ongoing problem (eg. Rockhole, Moline, Rum Jungle, Radium Hill, abandoned NT mines, Jabiluka). This will also pose a significant problem for rehabilitation at Ranger in the long term;
- **Groundwater Contamination** - either from saline waste waters arising from evaporation ponds (eg. Mary Kathleen & Nabarlek), from waste rock dump seepage, tailings, open pit lakes (eg. Rum Jungle & Ranger), or ISL mines which do not restore groundwater after mining. Groundwater is generally ignored in decommissioning and rehabilitation works;
- **Biological Intrusion** - the limited available evidence suggests in the Top End that the humble termite is quite capable of interfering with the integrity of cover systems engineered over the surface of a tailings disposal site (eg. Nabarlek, Koongarra). Open questions remain, therefore, about the ability of plants to invade tailings sites.

The shining outcome of this review is that the best environmental and radiological option for all uranium mill tailings wastes is below ground disposal. In the long-term, this appears to be the most likely method of minimising the potential for erosion, gamma and radon impacts. The evidence is still not conclusive as to the impacts on groundwater. The experience to date at Mary Kathleen, Olympic Dam, Rum Jungle, Nabarlek, Ranger, Beverley, Honeymoon and so on, strongly indicates that the protection of groundwater resources is consistently given a very low priority. There is no scientific certainty to claim that all tailings sites are being well protected and managed. Indeed, it will take a committed and co-ordinated approach from the companies currently producing tailings, the various government departments involved, traditional owners and the broader community to bring about change to better manage our current inventory of uranium mill tailings wastes. Prevention still appears to be the best cure.

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15 References - All references are listed in the Research Report.