Rehabilitation of Uranium Mine Waste Sites in Australia

Philip Crouch*, Richard S. O'Brien† & Geoffrey A. Williams†

*Papari Radiation Services, Kidney Street, Uraidla, South Australia 5142

†Australian Radiation Protection and Nuclear Safety Agency, Lower Plenty Road, Yallambie, Vic 3085, Australia

Introduction

Australia has a number of contaminated sites resulting from past and present uranium mining activities. The extent and nature of the contamination varies from site to site. There are also a number of known deposits where no mining has taken place, but where there is some contamination resulting from exploration and from test programs in ore extraction and processing.

The wide range of climatic conditions, from tropical monsoon conditions in the far north to dry, arid conditions over much of the centre means that it is difficult to apply a uniform set of standards, or waste management and rehabilitation requirements, across the whole country.

Significant uranium mining activity has occurred in Australia since the late 1940's and, as a consequence, wastes from these activities have been accumulating. This paper gives a brief introduction to the legal system governing such wastes, the status of waste from previous activities, and the management and rehabilitation proposed for wastes from current activities. Only the Northern Territory, South Australia and Queensland will be discussed, as no significant commercial uranium mining has occurred elsewhere in Australia.

Locations of past and present uranium mines and other deposits are shown on the accompanying figure. Further details of former and current uranium mines in Australia are available from the Uranium Information Centre web sites:
http://www.uic.com.au/fmine.htm
http://www.uic.com.au/emine.htm

Legislation

Australia is a federation, with jurisdiction resting with both the States and the Commonwealth of Australia. Generally mining, waste management and radiation protection are matters regulated by the States, but the Commonwealth has some powers in these areas.

The Commonwealth developed two Codes of Practice for uranium mining: the Radiation Protection (Mining and Milling) Code 1987, and the Management of Radioactive Waste (Mining and Milling) Code 1982 (http://www.arpansa.gov.au/nuc_codes.htm). An updated and combined Code of Practice and Safety Guide "Radiation Protection and Radioactive Waste Management in Mining and Mineral Processing 2004" will soon be promulgated. These Codes were originally developed under legislation giving the Commonwealth power to set standards for environmental protection in circumstances where Commonwealth action was required (for instance in the granting of export licences for uranium). The Codes are administered and enforced by the States.

The main provisions of the Codes are requirements for developing plans for radiation protection of both workers and members of the public, and for radioactive waste management. The plans must be consistent with the ALARA principle and, for waste management including decommissioning, use 'best practicable technology'. The plans must be submitted to the regulatory authority for approval, and then operations must be conducted in accordance with those plans. The Codes require compliance with the recommended ICRP dose limits.

Uranium mining in South Australia (SA) is controlled by a number of State legislative requirements. The most specific for uranium mining is the Radiation Protection and Control Act. This Act requires that uranium mining operations must hold a "licence to mine or mill", and the Codes of Practice referred to above are routinely applied as conditions on such a licence. This is the main mechanism by which the Codes are administered and enforced.

In the Northern Territory, the other main uranium-mining area in Australia, various Territory Acts govern the management and safety of current uranium-mining practices. Management of mining sites, and protection and safety of the environment, are administered under the Mining Management Act (2002) by the Territory Mines Division.

Under the new 2004 Code, a Radioactive Waste Management Plan (RWMP) must be developed to provide for the proper management of radioactive waste arising from the operations. The RWMP must include a plan for decommissioning the operation and the associated waste management facilities and rehabilitating the site.

The following guidance on cessation of operations is provided in the new Code and Safety Guide:

> The waste management plan should contain proposals for rehabilitation of the project as a whole and for individual components (for example tailings dams reaching their capacity). On decommissioning, these plans will need to be updated and engineering detail finalised.
>
> The regulatory authority will require assurance that the site remains in an acceptable condition until rehabilitation is complete, and that deterioration which might prejudice final rehabilitation does not occur. Inappropriate attempts at

rehabilitation may prejudice the ability to attain an acceptable final state, and thus no rehabilitation operations should not be attempted without authorisation.

An application for authorisation to rehabilitate should include the following information:

- the condition of the site to be rehabilitated, including the facilities and waste to be rehabilitated, levels of contamination, and quantities of waste;
- details of rehabilitation measures to be undertaken;
- management of waste generated during rehabilitation;
- the anticipated final state of the site after rehabilitation, including estimates of the levels of residual contamination;
- details on ongoing monitoring and surveillance that will be required after rehabilitation;
- contingency plans, and plans for remediation of any defects in the rehabilitation that may become apparent.

At the conclusion of the rehabilitation, the operator may wish to relinquish responsibility for the site. Generally the requirements and conditions for this step will be set in legislation. However, requirements and responsibilities for continuing monitoring and surveillance of the site, and of any remedial work that may become necessary, will need to be determined. Any land use restrictions that may be necessary, and the administrative mechanisms that will implement them, will also need to be determined.

Historical Mining and Milling Operations

Northern Territory

From 1956 to 1964 the upper **South Alligator valley**, an area about 200 km south-east of Darwin in the Northern Territory, was the location for 13 operating uranium mines and a number of prospects. These "boutique" mines contained mostly high-grade ore, and were worked mainly to extract uranium for the British nuclear weapons programme. The mining operations were a combination of open cut and underground operations. Processing of ore was initially carried out at other locations, notably Rum Jungle.

Later, small-scale processing was undertaken within the valley including a battery and gravity separation plant, gold separation and a small mill and solvent extraction plant.

When operations ceased in 1964 the proponents walked away from their sites with little attempt to remediate the environmental impacts they had caused. It must be emphasised that there were no rehabilitation requirements under the regulations in force at that time. The area lay within a pastoral lease and remained in private hands until the mid 1980's when it was determined that the valley would form part of the Kakadu National Park.

In 1986 a survey of abandoned mines was undertaken by the Commonwealth Government to establish the size and scope of a possible rehabilitation project. As the South Alligator Valley area lay within the proposed boundaries of Kakadu National Park, and visitor numbers were steadily increasing, it was decided that some form of works would be required to ensure the safety of visitors who would undoubtedly come to the newly opened area. In 1988, after discussions between the various agencies involved, it was agreed that a hazard-reduction program would be undertaken. This was to include reductions in physical as well as radiological hazards for visitors to the area.

As the main concern was to make the area as safe as possible for casual park visitors, the emphasis was on the reduction of physical hazards by fencing of open cuts, redirection of roads away from the edges of open cuts, collapsing of adits and shafts, and removal and burial of waste metal etc. At least two bat colonies were established in old workings, and consequently these adits and shafts were barred using heavy-duty grilles in such a way that the bats could still move in and out of the shafts whilst public access was barred.

The site of the abandoned South Alligator Uranium Mill had been subjected to an earlier radiological assessment. Apart from the residues in old reaction vessels and pipes, the main concern was tailings which had been deposited on flat ground on the banks of the South Alligator River. During monsoonal floods the tailings were often washed away by the runoff waters. In 1986 the bulk of the tailings were trucked elsewhere and reprocessed to extract gold. However, there were small pockets of tailings left behind which represented a potential hazard to Park visitors. Although the mill was considered by some to be an important part of the region's mining heritage, it was determined that dismantling and burial was the only safe course to take and this was done as part of the hazard-reduction program.

The minimum depth of cover was 1.5 m. The area was left over-filled to allow for subsidence and in a suitable state for seeding in the following wet season. Before the hazard-reduction program was completed, a detailed radiological survey of other associated sites was undertaken to ensure that all potentially troublesome radioactive materials were identified and a program agreed with the contractor to ensure that such wastes were dealt with in a satisfactory manner.

Following the rehabilitation works, a monitoring program has been set up to ensure that the hazard reduction continues to be effective. Regular inspections for erosion and revegetation are supplemented with periodic radiation surveys.

In summary, the environmental impact of historical uranium mining activities in the South Alligator Valley of the NT was relatively low. However, the sites were not

rehabilitated at the end of operations and a variety of safety hazards resulted which became of concern when the area was opened up as part of the Kakadu National Park. Physical hazards were managed by a combination of fencing, barring tracks, filling of shafts and burial of waste and scrap. Radioactive hazards were managed by burial of identified wastes at specific locations in conjunction with gamma-radiation surveys and some radon measurements. On-going monitoring programs indicate that the aims of the program are still being met many years after the program began. Minor erosion at containment sites has been repaired and revegetation is proceeding in a generally satisfactory manner.

The **Rum Jungle** uranium deposit was discovered in 1949 and the site, some 64 km south of Darwin, became the major Northern Territory uranium mine in the 1950's. It opened in 1953, and continued producing uranium until 1963, although copper production continued for several more years. Main production was from three open pits, all in close proximity to the East Finniss River. Overall production was about 3500 t of uranium from 860,000 t of ore (that is, an average ore grade of about 0.4%).

Tailings management appears to have been minimal in the early years of operation, but later tailings were discharged into an abandoned open pit. Minimal rehabilitation was carried out on closure; on completion of mining in 1971 it was decided by the Commonwealth Government that funds should not be made available for any rehabilitation, so the area was simply abandoned.

Within a few years the Rum Jungle mine had become one of Australia's most notorious pollution problems, due to oxidation of sulphides by bacteria and the consequent release of acid and metals into the East Finniss River. Areas of the site were regularly flooded during the monsoonal wet season, with annual rainfall of 1500 mm.

In 1983 a program to reduce the environmental impacts was commenced, with principal aims of neutralising the tailings and reducing the associated heavy metal pollution. Most of the tailings and other waste areas were capped, and erosion control measures introduced. Further rehabilitation work was performed in 1990-91.

Nabarlek was a small high-grade uranium deposit some 350 km east of Darwin. The ore body (600 000 t with average grade of 2%) was mined in four months in 1979, and the stockpiled ore was treated in subsequent years, production finishing in 1988. All tailings were returned to the pit. Following completion of processing, the tailings were allowed to drain, and then covered with below ore-grade material and allowed to consolidate. Plant and equipment that could not be decontaminated and salvaged were also buried in the pit.

Final capping was carried out in 1995 and the area subsequently revegetated with a mixture of grasses and native species. Vegetation is now well established and there has been little erosion. Monitoring and research will continue, as Nabarlek represents the first rehabilitation of a uranium mine according to current principles and practice.

South Australia

The main historical operation in SA was at **Radium Hill** in a remote, arid area in the east of the State. It operated from 1954 to 1961 (that is, long before the Codes discussed above were developed) and approximately one million tonnes of ore averaging 0.13% U_3O_8 were mined. A physical (heavy media) concentration process was conducted at Radium Hill, and the resulting concentrate railed to Port Pirie on the coast for conventional chemical extraction of the uranium.

The wastes that remain at Radium Hill are some 800,000 t of heavy media tailings. These have approximately 50 ppm U. In contrast to the chemical extraction of uranium, the physical concentration process removed all elements of the uranium decay chain, and so the concentrations of radium-226, thorium-230 and other radionuclides are also low. These wastes were contained in two above-ground tailings storage dams, with little containment, and were subject to both wind and water erosion.

In 1981-2, the tailings dams were rehabilitated by cover with local clay soil: the cover thickness was approximately 3 m on the sides and 1m on the top. No rock armouring to control water erosion was incorporated. At a later stage, some drummed residues from test work on uranium ores were buried in the top of the cover. The site is inspected regularly, and repairs made as required.

Approximately 200,000 t of conventional uranium mill tailings remain in clay-lined basins on the edge of the city of **Port Pirie**, where extraction of uranium occurred. The site is far from ideal, being on tidal mudflats, and was subject to flooding at extreme high tides. No significant rehabilitation work was carried out until the 1980's, when the tailings were covered by about 1.5 m thickness of granulated smelter slag from an adjacent lead smelter, some topsoil (up to 1 m) and revegetated. Subsequently a large quantity of slag was placed on the seaward side of the tailings dams, effectively eliminating the risk of flooding (under current conditions). Additional slag was used to cover contaminated areas of the processing plant, contaminated tanks and other equipment debris.

Queensland

The **Mary Kathleen** uranium deposit in far north-west Queensland was discovered in 1954. Mining commenced at the end of 1956 and the treatment plant was commissioned in June 1958. Tailings were emplaced in a 12 hectare tailings dam in a small valley west of the plant. This overflowed into an evaporation pond of some 60 hectares.

At the end of 1982 the mine was depleted and finally closed down after 8880 tonnes of uranium oxide concentrate had been produced. During 12 years of operations (in two phases) about 9 million tonnes of ore was mined.

Notwithstanding the minimal conditions imposed on the original (1954) leases, the company took the view that it should conform to relevant current environmental and occupational health standards. Consequently, before the recommissioning for the second phase of operations in 1976, a full environmental impact study was undertaken and this incorporated a rehabilitation plan for the 64 hectares of waste dumps, 29 hectares of tailings dam and 60 hectares of evaporation ponds. Mary Kathleen then became the site of Australia's first major rehabilitation project of a uranium mine, which was completed at the end of 1985 at a cost of some A$19 million. In 1986 this work won an award from the Institution of Engineers Australia for environmental excellence. Further information on the rehabilitation can be found at http://www.uic.com.au/mku.htm.

Current Uranium Mining Operations

Ranger (NT)

Ranger is a large open-pit mine, situated in the catchment area of the East Alligator River approximately 250 km east of Darwin. The mine is on a 7860 hectare lease which is surrounded by the World Heritage listed Kakadu National Park of 1.98 million hectares. The mine is in a monsoonal part of Australia, with pronounced wet season from December to April (an average 1540 mm of rain falls in the wet season). Operation commenced in 1980 at a rate of about 3300 tonnes per year of uranium oxide concentrate. Processing is carried out on site. The ore is crushed, ground, and leached with sulphuric acid to dissolve the uranium. The liquid is then separated from the solid tailings and passed through a solvent extraction plant where the uranium is removed, in a standard uranium-extraction process.

There is a large tailings dam on the site. As this is a high-rainfall area, there is considerable public concern about contamination of surface and ground water. The Commonwealth Government, through the Office of the Supervising Scientist (OSS), conducts a number of monitoring and research programs to monitor and assess the impact of the Ranger mine on the surrounding environment.

Until 1996 tailings from the treatment plant were emplaced in the engineered dam on the lease, but they are now being deposited into the worked-out #1 pit. No process or other contaminated water is released from the site, under normal operations.

The vegetation at Ranger is tropical open eucalypt forest, similar to much of the Kakadu National Park, and the Company operating the mine has a substantial environmental division. Current environmental projects include maintenance of biodiversity, fire management including control burning, terrestrial and aquatic weed control, feral animal control and rehabilitation of disturbed areas (including rock waste dumps, etc). Issues being studied include artificial wetland filters, soil formation from waste rock, and hydrology.

The project area is leased from the Aboriginal traditional owners, and among Ranger's long-term research priorities are projects which are relevant to eventual use of the land by its Aboriginal owners. As a guarantee of successful rehabilitation of the Ranger site, even if the operation were to close prematurely, the Company has lodged some A$31 million in a trust fund administered by the Commonwealth Government; an amount which covers all existing liabilities.

Olympic Dam (SA)

The Olympic Dam project is a large copper/uranium mine, with associated processing plant and smelter, in an arid area of central South Australia. It has operated since 1988, and currently about 10 million tonnes are mined per annum, producing 230,000 t of copper and 4200 t of uranium. The uranium ore grade is low (approximately 650 ppm), but it is the world's largest known uranium deposit (and sixth largest copper deposit).

The tailings are stored in two large "sub aerial" tailings retention structures. These have a total area of 360 hectares, and a design height of 30 m and currently hold over 50 Mt of tailings. The ore reserves will support mining at the current rate for at least another 70 years, and so a considerable extension of the tailings area is to be expected.

Final rehabilitation plans have not been completed. Research is to be undertaken to determine optimum wall slopes, cover thicknesses, armouring options, and revegetation techniques. Using this information, a rehabilitation plan will be developed, which must be approved by the regulatory authorities.

Approaches to decommissioning and rehabilitation being considered include the implementation of long-term closure measures, necessitating sufficient expenditure to relinquish the lease and leave the community no on-going liability (a "sustainable" solution that does not bequeath a problem to future generations), or to allow for indefinite on-going maintenance. The difficulty with the latter is how to ensure that any future maintenance organisation, and its funding, could endure for as long as maintenance is reasonably required.

Beverley (SA)

Beverley is an *in-situ* uranium mine, which has been operating since 2001, and currently producing 750 t of uranium per annum. Reserves are approximately 21 000 tonnes, with ore grade of 0.18%U. As an *in-situ* mine, there are no conventional 'tailings', waste rock or similar wastes. Small quantities (approximately 100 t per annum) of solid wastes accumulate in lined below-grade evaporation ponds. Other wastes, of the order of 100 cubic metres per annum, include contaminated filter media and similar material.

Upon decommissioning a wellfield, wells are sealed and capped, pipes are removed and the surface revegetated progressively. Again final disposal and rehabilitation plans have

not been finalised, but it is expected that the wastes will remain in the retention pond, which will then be backfilled to grade, armoured and revegetated. These plans must be approved before they can be implemented. At the end of the mine's life, process facilities will be removed and after discussion with the stakeholders the land can revert to its previous uses. The operating Company has provided financial guarantees to the SA government in respect to ongoing mine site rehabilitation up to the final completion of mining.

Honeymoon (SA)

Honeymoon is a small uranium deposit in the east of the state, with reserves of approximately 3000 t. It is currently in care and maintenance following a pilot scale operation, but options for bringing the project into commercial operation are being actively pursued.

Again, final waste management and rehabilitation plans have not been developed, but are expected to be similar to those in the case of Beverley, and will also require regulatory approval.

Conclusions

In common with many other parts of the world, uranium mining, and in particular the management of wastes, was not well controlled in the middle of last century. In many cases management of tailings and other wastes was minimal or non-existent, or wastes were sited in inappropriate areas, and generally no rehabilitation was carried out on closure. In some cases, notably Rum Jungle, there were serious detrimental effects on the environment, both from radiological and non-radiological contaminants.

As the consequences and potential consequences of this attitude were recognised, attempts were made to rehabilitate the wastes and abandoned sites. These have generally been successful, but in a number of cases continuing remedial actions will be required for the foreseeable future.

It is now recognised that waste management is an integral part of any uranium mining operation, and regulatory requirements are currently in place for all Australian uranium mining operations to ensure that wastes are managed in accordance with current best practice, and that long term rehabilitation measures will be taken as currently operating facilities are closed. Final rehabilitation plans consistent with these regulatory requirements are being developed for wastes generated by current operations. Nabarlek in the NT was the first Australian uranium mine for which this regime was in place, and the successful rehabilitation that has been achieved there indicates the effectiveness of this approach.

Figure showing locations of past, present and future uranium mines and deposits in Australia is shown here – see details below.

Former mine category includes Nabarlek, Rum Jungle and South Alligator in the Northern Territory; Mary Kathleen in Queensland; and Radium Hill in South Australia.

Deposit and prospective mine category includes Jabiluka, Angela and Koongarra in the Northern Territory; Westmoreland, Valhalla and Ben Lomond in Queensland; Honeymoon in South Australia; and Manyingee, Kintyre and Yeelirrie in Western Australia.

Mine and concentrator category includes Ranger in the Northern Territory; and Olympic Dam and Beverley in South Australia.

7700 by 1675 feet in dimension (about 265 acres), and attains a heath of 180 feet. The Castle Mountain Mine, which was comprised of three open pits, one of which was backfilled.

Figure 5b. The two reclaimed pits at the Castle Mountain Mine exceed 500 feet in depth. The backfilled pit is situated in the upper right portion of the image, where a portion of the pit rim is still evident.

Figure 6. Canyon Resources Briggs Mine is located in the Panamint Range of Southern California. The pit encompasses about 140 acres, and the cyanide leach pads encompass about 137 acres.

Figure 7a. The Rand Mine located near Randsburg, California. Two open pits are evident, along with a cyanide leach pad in the lower right, and two large waste piles in the central portion of the image. The larger cyanide leach pad in the upper right of the image is about 1.8 by 2.1 miles in extent.

Figure 7b. Close-up view of a portion of the Rand Mine located near Randsburg, California.

Figure 8. Abandoned Morningstar Mine located in the Mojave National Preserve.

Figure 9. Reclaimed Coliseum Mine located in the Mojave National Preserve, north of Clark Mountain. The main pit is approximately 650 feet in depth.

Figure 10. The active Mesquite Mine located about 52 miles northwest of Yuma, Arizona. Three pits, intervening waste dumps and a large cyanide leach pad is evident.

Figure 11a. Glamis Pichacho Mine located in westernmost Imperial County, California, approximately eighteen miles north of Yuma, Arizona.

Figure 11b. A vertical view of the main pit of the Glamis Picacho.

Figure 12. American Girl Mine located in the Cargo Muchaco Mountains in southeastern Imperial Valley, Southern California. About 200 acres are disturbed.

APPENDIX

Appendix A. The Board's Reclamation Regulations, California Code of Regulations, Article 9, Reclamation Standards, Section 3704.1

Report on Backfilling of Open-Pit Metallic Mines in California

Stephen M. Testa[1] and James S. Pompy[2]

Thirty years ago, Congress required that coal mines be backfilled as a routine element of reclamation when it passed the Surface Mining Control and Reclamation Act (SMCRA). Until recently, the concept has not been generally applied to non-coal surface mines. In 2003, California's State Mining and Geology Board (Board) evaluated reclamation of open-pit metallic mines in the state. With few exceptions, it was determined that open pits were not being reclaimed, despite California's Surface Mining and Reclamation Act of 1975 (SMARA) that went into effect in 1976. Upon recognizing that open pits were not being reclaimed, the board set forth regulations for the backfilling of open-pit metallic mines. The need for such regulation reflected several issues. Open pit metallic mineral mines often create very large excavations with at least equally large overburden and rock waste piles, with the creation of overburden and rock waste piles having greater volumes than the pit from which the material was excavated by as much as 40 percent. In addition, metallic mineral mines that employ the cyanide heap leach method for mineral segregation and collection frequently generate very large leach piles. These features remain on the landscape following the conclusion of mining operations, and recent re-evaluation of so called reclaimed sites have been shown to pose adverse soil and groundwater contamination conditions. In summary, leaving large, open pits in the surface surrounded by millions of cubic years of waste rock does not leave the site in a useful condition, and clearly leaves the site in a less useful and beneficial condition than before it was mined. It is the intent of SMARA that completed mine sites present no additional dangers to the public health and safety, and that the mined lands are returned to an alternate, useful condition. To date, no large, open pit metallic mines in California have been returned to the conditions contemplated by SMARA, and these sites continue to pose significant environmental problems. The goal of the Board's regulations was to require mining companies to address the problems identified above and to take responsibility for cleaning up their mine sites after the completion of surface mining operations, and return them to a condition that allows alternative uses and avoids environmental harms, thereby meeting the purpose and intent of SMARA. Board regulations, which took effect in 1993, establish performance standards for reclamation pursuant to SMARA, including standards for backfilling which provide that, where backfilling is required for resource conservation purposes, fill material must be backfilled "to the standards required for the resource conservation use involved".

[1]Stephen M. Testa (CEG No. 1613), Executive Officer, California State Mining and Geology Board, 801 K Street, Suite 2015, Sacramento, CA 95814.
[2]James S. Pompy, Manager of the Reclamation Unit, Department of Conservation, Office of Mine Reclamation, 801 K Street, MS 09-06, Sacramento, CA 95814