Submission
No 20

Former uranium smelter site, Hunter's Hill

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Date received: 30/06/2008

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Monday, 30 June 2008

RE: Hunter's Hill Inquiry Submission

Dear Committee (GPSC5),

I congratulate you on beginning an inquiry into the Hunter's Hill radioactive waste site and the numerous issues associated with this problem. As an independent expert on uranium mining and related issues, my submission shall be brief and but focussed on the underlying technical issues as I understand the data and site. I also attached two key references in appendices : (i) journal paper published in 2005 which includes analysis of the Hunter's Hill site (as best as I could ascertain at that time); and (ii) a curriculum vitae of my experience and expertise.

I welcome the opportunity to elaborate further in public hearings.

Kind Regards,

Dr Gavin Mudd

GPSC5 Inquiry into the Former Radium-Uranium Smelter, Nelson Parade, Hunter's Hill, Sydney

1) Brief History of the Hunter's Hill Site

The history of the site is of clear relevance to three components of the terms of reference, namely (a), (b) and (c).

The most comprehensive history of the Hunter's Hill radium-uranium smelter is given by Mudd (2007) (provided in Appendix 1). The following below is paraphrased from this paper.

In the final decade of the 19th century, science proved the existence and nature of radioactivity – demonstrating that elements such as uranium were unstable and naturally disintegrated to different elements which were also unstable. One such element was radium – and it's intense radioactivity was quickly viewed as an important breakthrough for possible cancer treatment. By the first decade of the 20th century, soaring demand for the extremely rare radium had meant it was fetching £5000 per gram or some £155000 per ounce (for comparison, gold was only a few pounds per ounce).

In Australia, uranium ore was found proven in potentially economic quantities in South Australia at Radium Hill in May 1906 – Australia just might be able to enter the lucrative radium market. After disappointing initial results, the Radium Hill company was able to develop a treatment process to purify the radium from the ore, and built a metallurgical complex (the 'smelter') in 1911 at Hunter's Hill in Woolwich, Sydney (and also a small magnetic beneficiation plant at Radium Hill to concentrate the ore slightly to a higher grade before transport). Given the high public attention given to radium at the time, the project was well publicised in South Australia by their Department of Mines or SADM (but curiously not by the NSW Department of Mines). Photo's of the Hunter's Hill complex were published in the SADM's six-monthly journal the *'Mining Review'*, and are shown in Mudd (2007) (page 175).

With the breakout of war in Europe and the expensive nature of the operation, the Radium Hill Company went bankrupt and the Hunter's Hill complex closed in 1915 – probably having produced less than 2 grams of radium. Based on ***incomplete*** records published in the SADM Mining Review, as compiled in Table 7 in Mudd (2007), the Radium Hill mine excavated some several thousand tonnes of uranium ore, and sent at least 2,150 tonnes of beneficiated ore to Hunter's Hill for metallurgical and chemical processing. The approximate uranium grade of the material sent to Hunter's Hill appears to have about 0.5 to 2% U_3O_8 (uranium oxide). This means the ore or material still residing at Nelson Parade is significantly radioactive, with a **total specific radioactivity of 754 to 3,014 Bq/g**. ***This level of radioactivity in an urban residential setting can only be considered a major health hazard*** – and is higher grade than most former and current uranium mines in Australia.

After 1915, the adjacent tin smelter continued to operate until about 1965, at which time the entire site was re-developed and approved for residential housing by NSW authorities. The tin smelter processed ores which also included elevated radioactivity, due to the monazite in the tin ores. There was apparently minimal (or zero) remediation works directed at addressing the combined radioactive wastes from the former radium-uranium smelter or the tin smelter.

In the late 1970's, it was belatedly realised that the site was significantly radioactively contaminated, and was most likely leading to unacceptably high but unwitting public radiation exposure and the site required urgent intervention. At this stage the NSW Department of Health bought some Nelson Parade properties (but apparently not all affected).

Based on former published papers reviewed in Mudd (2007), plus the two SADM photo's, it appears clear that waste management practices were not environmentally sound – especially in light of more modern approaches to hazardous and radioactive waste management.

Unfortunately, there is exceedingly little on the public record as to the exact activities since the late 1970s at the Nelson Parade site.

There can be _NO DOUBT_ that the Hunter's Hill site still contains buried radium-uranium tailings and radioactively contaminated soils, and would almost definitely be giving rise to public radiation exposure in the immediate vicinity which is in _BREACH_ of relevant standards – such as the 1 mSv per year public radiation exposure limit.

2) Radiation Expsoure Scenarios for the Hunter's Hill Site

Radiation exposure is a complex issue, but it must be remembered that ***EXPOSURE IS CUMULATIVE*** – that is, the more exposure one receives the higher their risk of developing effects such as cancers and so on. Put simply, one needs to understand the radiation properties of the source (ie. how strong the source is), how much biological exposure one receives from the source and finally the likely effects of that biological exposure. This requires extensive studies, monitoring and assessment – and is not a trivial task.

It is completely inappropriate for radiation regulatory authorities to continually to downplay radiation exposure risks when they have failed to undertake adequate studies to even characterise that risk – as appears to be the clear case at Hunter's Hill.

The unit used to quantify radiation exposure is the 'Sievert' (Sv), with usual background exposure to natural radiation being about 0.002 Sv or 2 milli Sieverts (2 thousandths of a Sv). For nuclear industry workers, the international standards for exposure are set at 20 mSv per year averaged over 5 years, while public exposure standards are 1 mSv/year.

The radiation exposure associated with uranium tailings is complex to measure, monitor and estimate, but at Hunter's Hill there are perhaps three primary issues which need to be thoroughly investigated by the Inquiry:

- **Gamma radiation** – due to the multiple radionuclides present in uranium mill tailings, a constant barrage of gamma radiation is emitted. Gamma rays are more intense than x-rays, and therefore potentially more harmful. They are measured in 'micro-grays per hour' (μGy/hr), with a typical background gamma level being about 0.1 μGy/hr. This measures the source, and 1 μGy/hr is equal to 0.001 mSv/hr, meaning for a residence sitting atop a waste emitting say 10 μGy/hr, if they occupied the property say 50% of the time, this would lead to 10 μGy/hr times 24 hours/day times 365 days/year times 50%, this gives 43.8 mSv/year – in excess of even nuclear industry worker standards. It is critical to understand gamma levels at the Nelson Parade properties and the immediate vicinity.
- **Radium uptake** – Radium (^{226}Ra) is one of the radioactive decay products from uranium. Although it was initially welcomed by the medical community, it is realised as a potent carcinogen when ingested. Radium is perceived by the body as calcium – leading to significant radiation exposure pathways should radium be absorbed into soils or food products from the Nelson Parade properties. Although some studies in the past have examined radium uptake in backyard vegetable gardens, there is an urgent need to update the studies and place all known data on the public record.

- **Radon and progeny** – Radon (^{222}Rn) is the immediate radioactive decay product from radium. Radon is a noble gas, and is very chemically inert, but has an intense radioactive decay speed (ie. short half-life) and gives rise to multiple radioactive isotopes of polonium, bismuth and lead – each also intensely radioactive. Radon and progeny exposure is the most biologically damaging of radiation exposure derived from uranium-related wastes or activities. Exposures to high levels of radon gas and progeny has been linked to major increases in lung cancer incidence, based on several large epidemiological studies of cancer rates in former uranium or other miners across the world (including the Radium Hill uranium mine in the 1950s). In urban contexts, natural background radon can still lead to significant radiation exposures, as evidenced by the number of studies on indoor radon around the world (numerous references can be provided if desired).

Radon and progeny exposure is likely to be VERY HIGH at Hunter's Hill, especially for the properties closest to or over the source of the radioactive waste. <u>ALL RADON DATA HELD BY NSW OR OTHER AGENCIES SHOULD BE PLACED ON THE PUBLIC RECORD AS PART OF THIS INQUIRY.</u>

Unfortunately, this is not the only occurrence in the world where residential homes have been built over or even using former uranium mill tailings – which of course gives rise to major radiation exposures for those living in and near to such sites. For example:

- **Grand Junction and Mesa Counties, Colorado, USA** – approximately 312,000 tonnes of uranium mill tailings were used in construction materials throughout the vicinity for more than 4,000 houses, schools, churches, public and commercial buildings (the material was provided freely by the mill) (Hazle et al. 1982; Rael 1999);
- **Canonsburg, Pennsylvania, USA** – the site of both a radium refinery in the early twentieth century and later a uranium mill from 1942 to 1957, Canonsburg also saw some mill tailings taken from the site for construction purposes (USDoE 2001);
- **Eastern Germany (former GDR)** – waste rock from the former Crossen uranium mine was used in buildings in eastern Germany (Küppers & Schmidt 1994); another survey of 1700 homes in eastern Germany returned radon activities up to 15,000 Bq/m^3 with one extreme value of 115,000 Bq/m^3, with more than 50% of homes at Schneeberg greater than the local action limit of 250 Bq/m^3; (Vandenhove et al. 2006).

3) Impact of Radioactive Waste at the Hunter's Hill Site

It is hard to accurately assess or describe the impacts of the uranium mill tailings at Hunter's Hill without first understanding the source, its characteristics and exposures and so on.

As noted above, radiation exposure is cumulative, so for people living over or adjacent to the radioactive waste, this cumulative risk could be quite significant – especially with respect to current international standards for public radiation exposure (ie. the 1 mSv/year).

4) Proposed Strategy of Remediation for the Hunter's Hill Site

It is patently clear that the Hunter's Hill site contains several thousands of tonnes of radioactive waste that is, without any shadow of human doubt, completely inappropriate to be residing beneath residential properties. Given tha nature of radioactive waste and the unique problems such as gamma radiation and radon gas and progeny, it needs to be handled differently to normal types of hazardous and industrial wastes.

It is also difficult to comment further on the proposed strategy as there has clearly not been a sufficient recognition of the true nature of the site and its problems in the past by government agencies.

5) Disposal of the Hunter's Hill Radioactive Waste

Again, without thorough site studies being available in the public realm, I believe there is only one preferred approach for this waste : careful excavation and transport to the Lucas Heights complex in southern Sydney.

The Lucas Heights complex is Australia's only nuclear reactor and has facilities for storing and managing radioactive waste. It also minimises long-term transport risks.

SUMMARY

Overall, there is clear historical and current evidence for the presence of major quantities of radioactive waste at the Hunter's Hill site. This needs to be acknowledged by NSW agencies and appropriate action taken. The legacy of public radiation exposure also needs to be recognised, in combination with the fact that is most likely in excess of legal standards (eg. 1 mSv/year). The best solution is to excavate the waste from the site and transport it to Lucas Heights for long-term management.

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Appendix 1 :

Mudd, G M, 2005, *The Legacy of Early Uranium Efforts in Australia 1906 to 1945 : From Radium Hill to the Atomic Bomb and Today*. Historical Records of Australian Science, 16 (2), pp 169-198.

Appendix 2 :

Dr Gavin M. Mudd – Curriculum Vitae (May 2008, Brief version).

CSIRO PUBLISHING

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The Legacy of Early Uranium Efforts in Australia, 1906–1945: From Radium Hill to the Atomic Bomb and Today

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The existence of uranium minerals has been documented in Australia since the late nineteenth century, and uranium-bearing ores were discovered near Olary ('Radium Hill') and in the Gammon Ranges (Mount Painter) in north-eastern South Australia early in the twentieth century. This occurred shortly after the discovery of radioactivity and the isolation of radium, and a mining rush for radium quickly began. At Radium Hill, ore was mined and concentrated on site before being transported to Woolwich in Sydney, where the radium and uranium were extracted and refined. At Mount Painter, the richness of the ore allowed direct export overseas. The fledgling Australian radium industry encountered many difficulties, with the scale of operations generally much smaller than at overseas counterparts. Remoteness, difficulties in treating the ore, lack of reliable water supplies and labour shortages all characterized the various attempts at exploitation over a period of about 25 years to the early 1930s. Hope in the potential of the industry, however, was eternal. When the British were working with the Americans during the Second World War to develop the atomic bomb, they secretly requested Australia to undertake urgent and extensive studies into the potential supply of uranium. This led to no exports but it did lay the groundwork for Australia's post-war uranium industry that has dominated the nation's nuclear diplomacy ever since. Some three decades later, the modest quantity of radioactive waste remaining at Woolwich was rediscovered, creating a difficult urban radioactive waste dilemma. The history of both the pre-war radium–uranium industry and Australia's involvement in the war-time exploration work is reviewed, as well as the radioactive waste problems resulting from these efforts, which, despite their relatively small scale, persist and present challenges in more modern times.

Introduction

The Discovery of Uranium, Radioactivity and Radium

The element uranium is the heaviest naturally occurring element. It was first identified by the German chemist Martin Heinrich Klaproth in 1789 in mineral samples from the Erzgebirge ('Ore Mountains') in eastern Germany and Joachimstal in Bohemia (today's Czech Republic).[1] Although it was mainly of scientific curiosity for many decades, uses found for uranium included as a colourful glaze in ceramics and glassware, as a potent poison, and in alleged medical treatments (e.g. 'uranium wine') for diabetes, stomach ulcers and consumption.[2] The mining of uranium ores began to attract a limited commercial interest.

In early 1896, the French physicist Antoine-Henri Becquerel discovered the phenomenon of radioactivity in uranium minerals. Soon afterwards, his Polish assistant Marya Sklodowska (soon to become famous as Marie Curie) and her French husband Pierre Curie between 1898 and 1902 isolated the main sources of the radioactivity as the new elements polonium and radium.[3] The more intense radioactivity from radium was quickly seen as a potential aid in the treatment of cancer and interest multiplied in uranium ores as a source of radium.[4] Throughout Europe and North America, researchers raced to find the nature of 'radioactivity' and in the process gained new insights into the structure of the atom.

The primary demands for the limited radium supply were for scientific research

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and medical use, principally cancer treatment. Within a short time radium was attracting the staggering price of £5000 (US$120,000) per gram.[5] New deposits were soon discovered and techniques developed to extract uranium from older mines. The radium came mainly from the well-known Eastern European uranium deposits as well as increasingly from the USA, until the Belgian company Union Minière announced in 1922 its discovery of rich uranium ore at Katanga in the Belgian Congo, from which point the Belgians dominated the global radium market.[6] By this stage radium could be obtained more easily but still at a cost of some £10,000 per gram. The Australian Government ordered 10 grams of radium from the Belgians for cancer treatment in September 1927, at a cost of £100,000.[7] Rich uranium ores were discovered at Great Bear Lake in the Canadian Arctic in 1933, finally breaking the Belgian monopoly but again damaging dreams for an Australian radium industry.

Rapid progress in the scientific understanding of radioactivity and nuclear or 'atomic' physics continued in the 1930s. The year 1932 has been seen as an 'annus mirabilis' for nuclear physics — the neutron was discovered, atoms were 'split' using a new device called an accelerator, and the existence of deuterium was finally proved.[8] In 1934 tritium was discovered[9] and uranium was first made to undergo fission, though this was not recognized at the time.[10] In 1938 and 1939 experiments using neutrons and uranium were undertaken in numerous laboratories. By the outbreak of the Second World War in September 1939, the concept of a fission chain reaction and the theoretical potential for an 'atomic bomb' were clearly pictured by leading nuclear physicists around the world, though significant uncertainty remained as to the extent of the further research that would be needed and the time it would take, the likelihood of eventual success, and even the practicality of extracting energy from the nuclear fission process.[11]

It is against this backdrop in medical demand, fundamental science, nuclear physics and the eventual emergence of a strategic imperative that Australia attempted to carve a niche.

The First Discoveries of Uranium in Australia

The Australian continent has long been recognized to be endowed with rich mineral deposits. The South Australian Government Geologist, Henry Y. L. Brown, stated in 1903 that prospectors should not waste their time searching for radium due to the extremely low concentrations in which it was found in uranium ores ('one grain per ton' or 0.065 parts per million).[12] Others, however, were more hopeful. With uncanny foresight, the following comments on the discovery of uranium in mines in Cornwall, in England, were printed in the *Mount Barker Courier* on 8 November 1889:

> It has often occurred to me that scarcely sufficient attention is given to the collection of a variety of minerals in the colony. South Australia is so rich in all common minerals of commerce that anything not belonging to that category and not appearing to the uneducated eye to be of special value, is apt to be passed by as worthless. Why may there not be uranium in the colony?[13]

The first confirmation of uranium minerals in Australia is generally accepted as being at Carcoar, New South Wales, in 1894, published by George W. Card in 1896 (Fig. 1).[14] There had been an unconfirmed report of uranium in a small chromium deposit in South Australia in 1890 by Captain Stevens of the Mount Rhine Silver Mining Company,[15] and there was a further unconfirmed report of uranium minerals in the Flinders Ranges, South Australia, around Nickols Nob and Mount Ogilvie, in 1896.[16] Even earlier, in the Northern Territory, the 1869 Darwin survey teams under South Australia's

Surveyor General, George Woodroffe Goyder, noted an unidentified strange green mineral in association with malachite (a copper carbonate mineral) at Rum Jungle, about 65 km south of Darwin. In 1912, the Northern Territory's Government Geologist, Harald Jensen, reported the existence of uranium at Rum Jungle, but due to the lack of interest at the time did not continue the work to confirm the find.[17] Curiously, when the Mary Kathleen uranium deposit was discovered in July 1954, it was claimed by one of its discoverers that the prospect may have been first noted in 1914 or 1915, during working of a shallow copper mine in the area.[18]

After the discovery of radioactivity and of radium, radioactivity in several Australian minerals was studied by Douglas Mawson and Thomas H. Laby at the University of Sydney.[19] This work confirmed the presence of torbenite at Carcoar, euxonite at the Marble Bar tin fields and gadonilite at the Cooglegong River–Greenbushes tinfield in Western Australia, and radioactive monazite[20] in Western Australia's Pilbara region, at Tumberumba, Tooloon River, Broken Head/Richmond River, Torrington and Emmaville, New South Wales, and in Tasmania.

The pace of discovery was largely scientific until radium and uranium made

Figure 1. Locality map of Australian radium mining and milling.

public news in early May 1906. A prospector, Arthur John Smith, was working in the remote north-east of South Australia near Olary, close to the New South Wales border and Broken Hill. Smith had discovered what he hoped was tin ore in March 1906 and sent specimens to the South Australian School of Mines for analysis.[21] The analyst, Walter S. Chapman, recognized a coating of carnotite and some gummite on a darker mineral that Mawson, now at the University of Adelaide, later identified as a new mineral he named davidite.[22] Carnotite is a mixed oxide mineral of uranium and vanadium while gummite is a weathering product of pitchblende (uranium oxide), and both were fetching high prices on the world market at the time (for high ore grades).[23] Smith's discovery, made public on 3 May 1906,[24] was the first confirmed find in Australia of potentially economic uranium-bearing ore — and therefore of a potential source of the highly prized radium. Mawson's work helped cement his growing reputation as a pioneer in radioactive minerals.[25]

The finding of uranium created immediate and intense scientific interest, with lively debates at the University of Adelaide, the South Australian Department of Mines, the Royal Society of South Australia and elsewhere in Australia. South Australia's Government Geologist, Henry Y. L. Brown, visited the Radium Hill site on 3 May 1906, while Henry Gilbert Stokes from the Queensland Museum visited the site and through the press on 9 May 1906 stated publicly his doubt that the uranium was present as carnotite and his opinion that the site was of 'no commercial value'.[26] Many hoped that a commercial industry could soon prosper, and bulk samples were sent to Marie Curie in Paris and the Imperial Institute in London, as well as a minor quantity to the USA for research and promotion.[27]

The new uranium deposit was worked until 1908 by Smith, who had sunk an exploration shaft some 21 m, shown in Plate 1. The site was popularly known as 'Smith's Carnotite Mine', with Smith even awarded a 'Diploma for Gold Medal' by the Franco–British Exhibition of 1908.[28] After Smith pegged the area, 'he came to Mawson with an offer: half a share in whatever might develop in return for Mawson's footing all expenses and attending to investigation and exploitation of the find. Mawson agreed, subsequently identifying and naming the primary mineral there as davidite but finding that as a source of radium it was at that time uneconomical. The lease expired.'[29] The mine became popularly known as 'Radium Hill'.

At the time of the Radium Hill discovery, the assistant chemist at the Moonta copper mines northwest of Adelaide, S. Radcliff,[30] announced that he too had identified uranium minerals, in the rich copper ores at Moonta, but had been awaiting further test results before going public. Radcliff initiated his search in June 1905 and had apparently confirmed radioactivity and uranium mineralization in some ore zones by March 1906, possibly as early as October 1905. The uraniferous samples were tested in March 1906 at the University of Adelaide and often contained around 5% U_3O_8 and up to 10% U_3O_8. The mineralization was in small localized pockets, however, and mainly of mineralogical interest.[31]

A short time later Mawson was again to be associated with the discovery of a new uranium field in South Australia. The Gammon Ranges in the northern Flinders Ranges were roamed by a tenacious prospector by the name of William Bentley Greenwood ('Dolomite Bill') and his sons. In 1910 he sent some mineral samples, discovered by son Gordon ('Smiler'), to the South Australian Department of Mines for analysis where they remained unidentified (except for a trace of copper) and almost forgotten for several months.[32] In anger Greenwood took his samples to Douglas

Mawson, who at first failed to identify the odd minerals in the rock samples but eventually discovered the bright green mica-like mineral to be torbenite. The Mount Painter uranium field was thus revealed.[33] Curiously, at the time of Radium Hill's original publicity, Greenwood claimed that earlier samples from the Mount Painter area that he had collected in 1898 and 1899 had been thrown out by the South Australian Department of Mines without being examined.[34] Mawson moved quickly and sent one of his most promising geology students, Arthur ('Archie') Broughton, into the field to investigate. Broughton, discovering grades of 12.5% to 41% U_3O_8, quickly proclaimed that 'this will be the richest mine of its kind in the world'.[35]

Australian Efforts in Global Context

The presence of uranium deposits had now been established in Australia beyond mere speculation and mineralogical curiosity. There were intermittent but determined efforts to mine the ores over three decades but numerous factors combined to make the mines falter, including transport problems, labour shortages, lack of potable water, ore treatment, financing and marketing challenges. Hope remained, however, with the South Australian and Commonwealth Governments regularly promoting the Radium Hill and Mount Painter prospects at international exhibitions and congresses. Following the breakthroughs in nuclear physics in the late 1930s, the potential strategic importance of Radium Hill and Mount Painter seemed to open new opportunities.

A history of radium–uranium mining at Radium Hill and Mount Painter is now presented, focusing on the challenges encountered and the moderate radioactive waste problem that still lingers from this work. This will be followed by an account of the minor but determined attempts to exploit these uranium deposits for the British — thus documenting Australia's little-known but keen contribution in the development of the atomic bomb. This laid a foundation for the following decades of uranium mining and thus for a key plank in Australia's nuclear diplomacy in the post-war world.

Radium Hill

The promise of commercial radium–uranium mining at Radium Hill was quickly realised by many in the Adelaide scientific and mining community, highlighted by the wide interest displayed in 1906.

The initial assays through the South Australian Department of Mines returned results of 0.28% U_3O_8, and importantly, the secondary or weathered nature of the carnotite was recognized as suggesting that a larger body of primary or unweathered ore lay at depth below the site.[36] Further analyses were subsequently performed in Adelaide by Mawson, and in London, as well as in Paris at Marie Curie's laboratory. All tests confirmed the low-grade and generally uneconomic nature of the ore, as well as the difficulty in treatment to extract the radium and uranium from the titanium-rich ore.

Despite the poor test results, there was a 'flurry of activity on the Stock Exchange'.[37] A few companies were floated and activities slowly began to get under way at Radium Hill, including the sinking of shafts for exploration and mining, ore treatment research and testing, and marketing of the refined radium (uranium was a 'co-incidental' by-product in this work). The major company active on site at this time was the Radium Hill Company, formed in June 1909 to take over Smith's work, with other smaller but unsuccessful companies also active for brief periods of time.[38]

By September 1911 some 800 tonnes of ore were at the surface and 9000 tonnes were within sight of being mined, and the price for refined radium bromide had reached a staggering £13,000 per gram.[39]

Around this time Smith unsuccessfully sought a government reward of £1000.[40]

The milling and radium refining process was developed over twelve months through research on 44 tonnes of ore at the Bairnsdale School of Mines in Victoria, published by Radcliff in 1913.[41] The process was claimed to be relatively simple and allowed processing of the ore to try to compete with overseas radium projects. The work on site at Radium Hill continued, extending shafts and mining ore for beneficiation at a small on-site magnetic mill to pre-concentrate the ore. This mill led to some 30% of the ore being concentrated for further processing.[42] The concentrate was then transported to a newly constructed radium refinery at Woolwich in suburban Hunters Hill[43] in Sydney, which cost more than £15,000 to develop and had a capacity to process about 10 tonnes of concentrates per week.[44]

The Woolwich radium refinery operated from June 1911 to June 1915 (see Plate 1) and processed some 500 tonnes of concentrates of about 1.6% $_3O_8$ from Radium Hill, to produce up to 1.8 grams of high purity-radium bromide and possibly up to 7 tonnes of U_3O_8 in a slurry of about 75% purity.[45] Mining and milling data for Radium Hill and Woolwich are set out in Table 1, based mostly on records published by the South Australian Department of Mines. The operating costs of the project in late 1913, including mining, concentrating, transport and metallurgical treatment, were estimated at £29 17s 11d per ton. The radium content of 2% U_3O_8, assuming radioactive (secular) equilibrium, can be estimated as 5.44 mg, leading to an estimated radium value of £148 per ton of 2% U_3O_8 ore. (The New York market price paid for this ore by European buyers, however, was just £15 per ton, leading to eager demand.) It was the early recognition of the 'ratio of the cost of production to the intrinsic value of the ore' that led the Radium Hill Company to build its radium refinery at Sydney rather than Adelaide.[46]

Some of the radium bromide produced at Woolwich was sold on the London market to pre-eminent nuclear physicist Ernest Rutherford, who used it to undertake scientific research on radioactivity. In his report on the purity of the radium bromide, he stated it to be 'free of meso-thorium and other radio-active substances' (that is, to be pure ^{226}Ra).[47] The Mark Foys building at the University of Sydney has tiles that include Radium Hill uranium in the glaze.[48]

The outbreak of the First World War led to a downturn in demand for radium overseas, and with no viable market in Australia, operations ceased in 1915. An adjacent site at Woolwich processed and smelted tin ore and concentrates that contained uranium-bearing and thorium-bearing monazite minerals from 1895 to about 1966, when the land was made into a residential area. The tin ores, especially those derived from mines near Cairns in Queensland, contained elevated natural thorium (^{232}Th). The radioactive content of tin ores from Ravenshoe and Emmaville in New South Wales was relatively low in comparison.[49]

With the recovery in the radium price and market after the First World War, a fresh attempt was made at developing Radium Hill by the Radium and Rare Earths Treatment Company NL. In 1924, Mawson inspected the field and reported that some 1000 tonnes of concentrates were available, averaging 1% uranium oxide and 1% rare earths. The use of magnetic and gravity concentration was claimed to be successful.[50]

A metallurgical mill was constructed in 1923 at Dry Creek, just north of Adelaide, to extract titanium oxide for pigment production, with radium, uranium, vanadium and scandium as valuable by-products.[51] In 1924, despite marketing difficulties in Germany, a Belgian company, Société des Alliages Industriels, 'made an attractive offer' for a large quantity per annum, but the directors failed to proceed.[52] Every endeavour was apparently

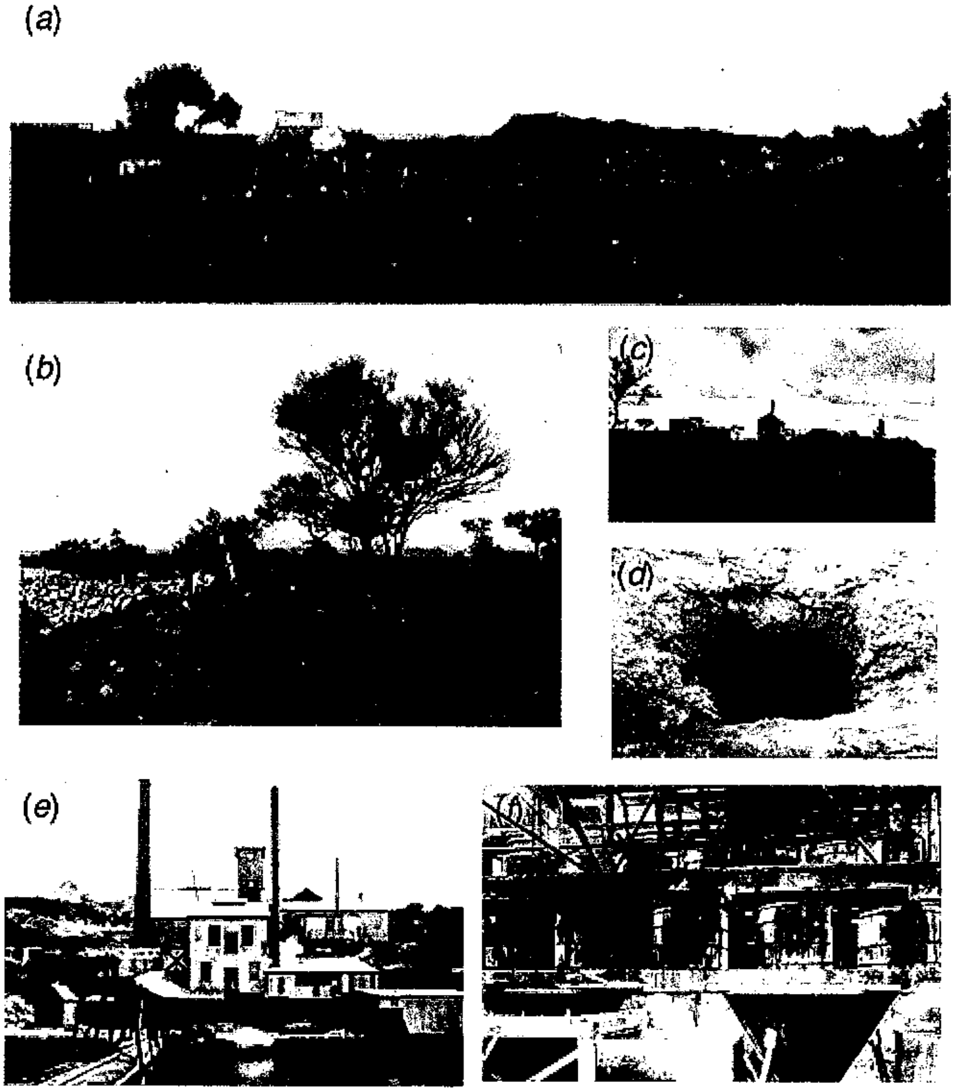

Plate 1. Radium Hill and Woolwich. (*a*) Radium Hill mine and magnetic mill, ~1912. SA Department of Mines, *Review of Mining Operations in South Australia*, No. 16 (June 1912), p. 9; (*b*) Radium Hill mine, ~1908. D. Mawson, 'The Nature and Occurrence of Uraniferous Mineral Deposits in South Australia', *Transactions of the Royal Society of South Australia*, 68 (1944), 334–357; (*c*) Radium Hill mine, January 1925. B. O'Neil, *In Search of Mineral Wealth: The South Australian Geological Survey and Department of Mines to 1944* (Adelaide, 1982); (*d*) Old stope, Radium Hill, 1944. R. C. Sprigg, *Geology is Fun* (Arkaroola, SA, 1989); (*e*) Woolwich radium refinery, Sydney, 1912. SA Department of Mines, *Review of Mining Operations in South Australia*, No. 17 (December 1912), p. 12. (*f*) Inside Woolwich, Sydney, 1912. SA Department of Mines, No. 17 (December 1912), p. 12. Photographs used with permission from Primary Industries & Resources South Australia (PIRSA), Arkaroola Pty Ltd and the Royal Society of South Australia (RSSA).

Table 1. South Australian radium mining and milling data

conc, concentrate; DC, Dry Creek radium refinery, Adelaide, SA; HH, Hunters Hill radium refinery, Woolwich, Sydney, NSW; RH/MP, Radium Hill/Mount Painter; RHN, Radium Hill North mine. All grades in %U_3O_8. References: S. B. Dickinson, *Report on Investigation of Uranium Deposits at Mt Painter, South Australia, June 1944 to September 1945* (Adelaide, 1945); B. O'Neil, *In Search of Mineral Wealth: The South Australian Geological Survey and Deparment of Mines to 1944* (Adelaide, 1982); SA Department of Mines, *A Review of Mining Operations in South Australia*, 1906–1947, and *Annual Report*, 1906–1947; 'Investigation: Mining, Radium', Series CP211/2/1, Control 32/1, NAA

Year	Radium Hill	Mount Painter	Value
1949		~0.45 t ore to USA	?
1934		18.0 mg Ra	£240
1932		72.0 mg Ra; 0.152 t '$NaUO_3$'[A,B]	£1050
1927 Dec. half year		45 mg Ra (£450); 0.187 t '$NaUO_3$'[A] (£118)	£1088
1927 Jun. half year		2.5 t ore conc; 52 mg Ra	
1926	No Ra	DC, 18.3 t (0.75%); DC, 3 t ore conc (2.6–3.8%); MP, 2.17 t ore conc (6.2%); 700 t ore at surface; no Ra	
1925	3 t ore conc; 7.01 mg Ra; 0.230 t '$NaUO_3$'[C]		£172.17
1918			£686
1915 Jun. half year	215 t ore milled, 41 t ore concentrate		
1914 Dec. half year	406 t ore milled, 41 t ore concentrate	6.1 t ore 'high' grade	£5215
1914 Jun. half year	132 t ore milled; >239 mg Ra	20.3 t @ 3.24%; 61 t @ ~1%; 3 t @ 0.8%; 0.8 t @ 5–20%. All to Europe	
1913 full year	167 t mined @ 1.4%	466 mg Ra	£3620
1913 Jun. half year		127 t ore to England @ ~2.6%	
1912 Dec. half year	RH mill @ 10 t/week	2.3 t ore 2.02% to Europe	
	HH, 122 t smelted	7 t ore ~2% to Europe	~£50
	HH, 96.5 t treated	0.5 t @ 25% (prior to 1913)	?
	RHN, 7.1 t ore mined; 350 mg Ra		
1911 Jun. half year	610 t ore at surface	5.1 t ore to Europe	
	44 t ore to Bairnsdale, Victoria		
1909 Dec. half year	31 t ore to Europe; ~3 t to USA		
Total	>2150 t ore milled, up to 1800 mg Ra, up to 7 t U_3O_8 by-product (?). Total value ~£8800	~933 t ore mined, ~2.1% U_3O_8,; ~666 mg Ra (£2338), ~3 t U_3O_8 (£213). Total value ~£10,000	£18,800

[A]Uranium produced as sodium diuranate (mineral formula $Na_2U_2O_7.6H_2O$) (R. G. Thomas, 'The Processing of Radium Ores in South Australia', *Australian Chemical Institute Journal and Proceedings*, 9(6) (1942), 122–133).
[B]Sold within Australia.
[C]Apparently the ore was mined at Radium Hill and treated at Dry Creek, which was later used mainly for Mount Painter ore.

made to establish synergies with the radium mining work at Mount Painter.

Despite the effort, Radium Hill again failed to prove a financial success, with work being suspended in early 1926. Later that year, the company was merged with the radium mining interests at Mount Painter to form the Australian Radium Corporation, and by 1932 all work at Radium Hill had ceased. The ore reserves estimated in July 1930 were about 6000 tonnes of low-grade ore.[53]

There was some fresh interest and potential funds from British entrepreneurs in 1929, although the main focus was Minerva Heights near Mount Painter. At this time the British Government was conducting an inquiry into radium supply for the Empire, through the Radium Sub-Committee of its Committee on Civil Research. It concluded that the prospects

> seem to be that there are but faint hopes that the Empire (so far as it has been prospected) holds any radium supplies of any importance at all. Of a very poor lot, the Mount Painter and Radium Hill deposits in South Australia show some mild promise, but are very low grade.[54]

Due to a declining world market and the refusal of the Australian Government to provide a proposed £20,000 subsidy, the project did not eventuate.[55]

The total value earned from Radium Hill ore was about £8800.[56] The 'radium-rich' mine waters were also sold at one time as a health tonic.[57] The facilities and wastes at Radium Hill were simply abandoned, with no community expectation or legislation to the contrary in place, and the site received virtually no attention thereafter.

In 1934, the Australian mining magnate W. S. Robinson, then of the Zinc Corporation, pegged the Radium Hill leases but to no avail.[58] The field lay dormant until 1940 when a Melbourne mining house, the Australian Mining and Smelting Company Ltd (AMS),[59] took up the leases at Radium Hill from 12 November 1940 for two years at a cost of £12 per year in rent plus a minimum of £500 per year of developmental work.[60] This latter work was requested by Robinson following his visit to Ernest Lawrence at the University of California at Berkeley, who was well known by this time for his work in nuclear physics. AMS sent ore samples to the UK and USA in 1941 for testing but to no avail: no government showed any official interest.[61]

During a visit to Britain in October–November 1943, Robinson heard 'Lord Cherwell (Professor Lindeman) refer to the possible developments of important uses of Uranium' and again in Britain in May 1944 Robinson heard of 'its chances of *very important* uses *by the enemy*' (original emphasis).[62] The critical phrase 'very important uses' could be interpreted in several ways. It is open to conjecture as to whether Robinson knew of uranium's potential for an atomic bomb, or of the existence or full extent of the Manhattan Project. Given Robinson's legendary industrial intelligence and close relationships with many key figures in both Britain and the USA,[63] such as British Prime Minister Winston Churchill[64] and Ernest Lawrence in California (who led the electromagnetic separation plant that produced the highly enriched uranium-235 for the Hiroshima bomb[65]), it can be argued that Robinson at least knew of the potential for an atomic bomb, even if he was unaware of the true extent of Allied progress in this regard.[66] As he noted in June 1944, 'rumours regarding the ability of one's enemies to destroy the Universe are admittedly common in War time, but some of those circulating in London on my last visit were certainly unpleasant'.[67] Robinson's trip in May 1944 coincided with Britain's formally requesting Australia's assistance in uranium procurement. Robinson quickly re-applied for leases at Radium Hill upon his return to Australia, but the application was denied since the opportunity had been closed by the Government's awakening to the strategic use of uranium (see later section). As we shall see, only minor attention was given to Radium Hill during the exploration and research work undertaken in Australia in 1944 and 1945.

Little is known about waste management practices at either Radium Hill or Woolwich at this time. There were some basic mine safety standards, largely covering the physical aspects of mining, but there were no regulations in place for environmental management or rehabilitation, or to protect workers' health from radiation.[68] The radioactive waste legacies are further discussed below.

Mount Painter

The Gammon Ranges region of north-eastern South Australia long held hope for mining entrepreneurs. Mawson's confirmation of torbenite (uranium) in samples found in 1910 by the prospector 'Smiler' Greenwood provided the latest opportunity to justify this optimism. The ensuing radium rush in the Mount Painter region between 1910 and 1914 saw a flurry of activity in both prospecting and mining, as well as at the Adelaide Stock Exchange. The principal company active in the region was the Radium Extraction Company of South Australia Ltd (RECSA), floated on 28 November 1910. Mawson was very closely involved with RECSA during this early period. A new area of high-grade ore was discovered by RECSA manager Harry Fabian in May 1911 and became the rich No. 6 Workings. Several locations were worked for uranium ore, with rich grades often found — up to 20% U_3O_8, though most grades were around 1–5% U_3O_8 as shown in Table 1. By mid-1912, Archie Broughton had used about 3.6 kg of high-

Cairn at Radium Hill: 'This memorial commemorates the discovery of the Radium Hill Mining Field by Arthur John Smith who pegged his first claim on 24th March 1906'. Photographed by author, September 2001.

grade ore to produce about 30 g of uranyl nitrate ('yellowcake') in the University of Adelaide mineralogical laboratory, primarily to carry out research on radium production. This is most likely the first time that yellowcake was produced in Australia. Although production details are incomplete, at least 233 tonnes of ore averaging 2% U_3O_8 were mined and sold to eager markets in Europe. Thus, while Mawson's contribution was important, the Greenwoods, Fabian and Broughton really deserve the credit during this period.[69]

Despite the rich grades found near the surface, the ore shoots or veins often vanished at shallow depths.[70] The remote and difficult nature of the terrain led to the use of camels to cart ore and supplies through the ranges and then by truck or rail to and from Adelaide (see Plate 2). It would appear that, except perhaps for the operators at the Stock Exchange, the individuals and companies involved, especially Greenwood and his family, did not make any fortunes.[71] In 1913, with dwindling funds, some ore was shipped to the Woolwich radium refinery, from which 466 mg of hydrated radium bromide was sold.[72] By 1914, with the First World War depleting the field of miners and with most of the ore having previously been sold to Germany, Mount Painter was without labour and markets and no longer viable. The various companies languished into liquidation by 1917, with RECSA alone having spent some £7000.[73]

Mawson recognized the scientific quality of many of the uranium mineral specimens and ensured that samples were traded (mostly without profit) to collections at various Schools of Mines, universities and museums around the world. A sample of torbenite was presented to Rutherford on his 1925 visit to Adelaide. Mount Painter was also promoted by the South Australian and Commonwealth Governments at various international mineral exhibitions.[74]

The Gammon Ranges, and the Mount Painter region in particular, are of great cultural significance to the Adnyamathanya traditional owners.[75] It is clear from my travels and meetings in the region that this early period and the subsequent uranium-mining activity in the region is of significant concern to Adnyamathanya elders.

With the increasing price and growing market for radium, interest was revived in Mount Painter in 1924 by three companies, with Archie Broughton as General Manager for all of them. Following financial difficulties, they merged in September 1926 with activities at Radium Hill to form the Australian Radium Corporation NL (ARC), based in Melbourne.[76] A second rush developed, though with even less success than the first.

Due to the lack of permanent water at the mine site, the Dry Creek mill (see Plate 2) of the Radium and Rare Earths Treatment Company was apparently used; though the arrangements are unclear, they are likely to have been related to the 1926 merger. A crude ore concentrate was produced at Mount Painter (though often with unsatisfactory results) and this, together with hand-picked ore, was carted by camel and then lorry and train to Dry Creek. It would appear that very little additional ore was mined and treated at this stage (see Table 1), with most of the ore retrieved being remnant from earlier efforts. The estimated ore reserves were as small as 1000 tonnes of low-grade ore.[77]

The Commonwealth Government's decision in September 1927 to purchase 10 grams of Belgian radium, the single largest radium order ever placed to this time,[78] severely affected the prospects of the ARC, which was not given a chance to tender for the contract or even part of it.[79] Intense lobbying began, including a request that the Government should help directly with finance or at least help arrange for finance to be made available. Numerous claims were made, including that 'the radium was the purest in the world' and that it might be cheaper than the Belgian product.[80] At the time, radium was selling for around £10,000 per gram and ARC presented an economic analysis that suggested they could produce radium at about £7500 per gram, and also earn a further 15–25% from the sale of uranium oxides as by-products. ARC also claimed that Dry Creek was about 90% efficient in extracting the radium from the concentrates and that, since the Belgian Government had loaned Union Minière some £2 million to facilitate its work, it was in Australia's and the Empire's interests to finance radium.[81]

The Commonwealth requested that the South Australian Director of Mines, Dr L. Keith Ward, prepare a report on the proposed radium operations, and his confidential May 1928 report noted:

- a lack of proven high-grade ore (i.e. this had already all been mined);
- the unknown extent of low-grade ore and uncertain grades;
- the difficulty and uncertainty in concentrating the low-grade ores;
- that the Dry Creek plant was not designed to allow for these problems; and
- that there was a confidential push for an 'Empire' radium industry to break the Belgian monopoly.[82]

Following a meeting at Kurrajong House in Melbourne on 16 April 1928 between Dr Flecker and Mr Coates of ARC and the Commonwealth Government bureaucrat T. M. Owen, the latter noted

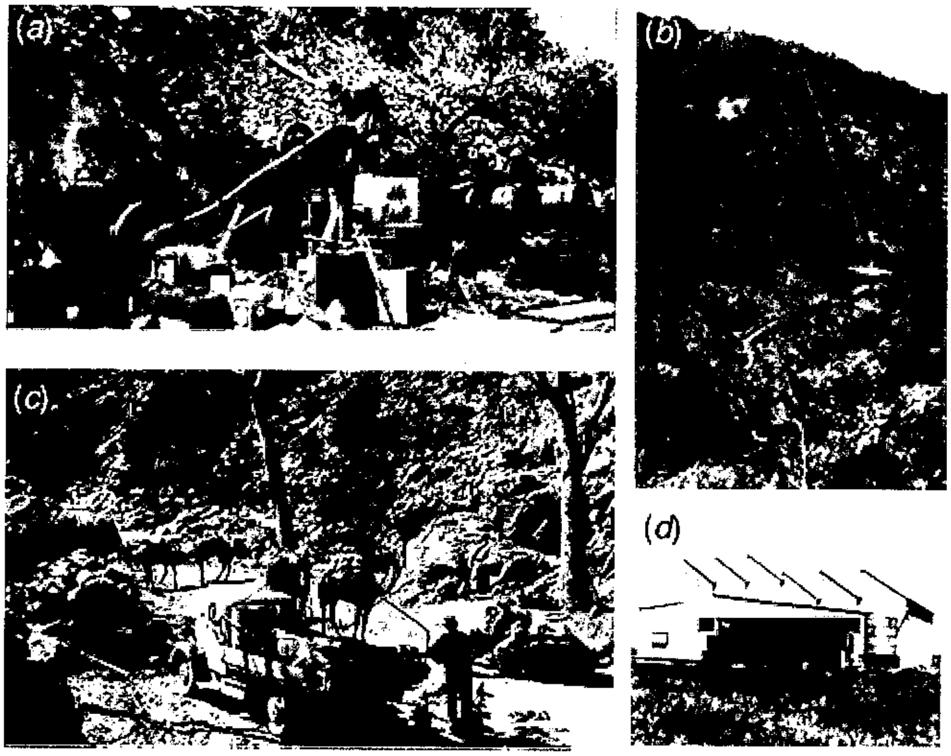

Plate 2. Mount Painter and Dry Creek. (*a*) No. 6 workings at Mount Painter, 1926. J. F. Drexel, *Mining in South Australia: A Pictorial History* (Adelaide, 1982); (*b*) No. 6 workings, 1930. (Drexel 1982); (*c*) Road construction and camels, August 1944. B. O'Neil, *Above and Below: The South Australian Department of Mines and Energy 1944–1994* (Adelaide, 1995); (*d*) Dry Creek mill, November 1925. (O'Neil 1995). Photographs used with permission from Primary Industries & Resources South Australia (PIRSA).

that 'Neither of these gentlemen is familiar with mining in any way. They are delightfully vague as to either the tonnages that may be available at the deposits, or its grade in U_3O_8 content.' The opinion of Dr David Rivett, Chief Executive Officer of the Council for Scientific & Industrial Research (CSIR), was also sought. He was generally unsupportive of radium mining at the time. Overall, the government recognized the high risk involved due to the lack of data on ore grades and to marketing problems arising from the effective monopoly held by the Belgians. The Commonwealth and South Australian Governments refused to assist in financing the project, insisting that if the project was as potentially profitable as ARC claimed, a bank would surely be happy to finance it.[83]

Despite the lack of political support and the difficulty of raising finance, ARC did proceed with some mining and treated some ore concentrates at Dry Creek. About half a tonne of crude sodium uranate ($Na_2U_2O_7$) concentrate was produced, valued at £213, and 194 milligrams of radium valued at £2338. The late 1920s saw interest from the UK Government and from British entrepreneurs, including attempts by the latter to arrange £20,000 for further field work and exploration to determine the viability of commercial operations. The focus was primarily on the Minerva Heights region near Mount Painter, but no work eventuated. The funds were contingent on obtaining government support, and this was still not forthcoming despite an optimistic new assessment in May 1930 of potential ore reserves of some 22,500 tonnes with 0.4–1.0% U_3O_8. As noted earlier, the Radium Hill and Mount Painter fields were regarded by the British Radium Sub-Committee as part of a 'very poor lot' of 'very low grade' prospects within the Empire. By 1932 all mining operations had ceased, and the ARC abandoned its leases in 1934. The total value of Mount Painter ore, based on radium content, was about £10,000.[84]

In 1940, AMS took up the leases at Mount Painter in conjunction with their work at Radium Hill, but they could not overcome apparent ore treatment problems[85] and surrendered the lease by 1942.[86] The latter stages of the Second World War and the Allied project to develop the atomic bomb revived interest in uranium from Mount Painter in May 1944 (see later section).

An interesting tangent, partly related to radium–uranium mining, is the Paralana Hot Springs near Mount Painter.[87] A well-known sacred site of the Adnyamathanya,[88] it was discovered in the mid-1920s to contain radioactivity.[89] A private spa and sanitorium was established in 1924, purporting to give medical benefits to visitors similar to other spa ventures of the time. Another example mentioned previously was the 'radium-rich' health tonic marketed from mine waters at Radium Hill. The Paralana Spa project was owned and promoted by the same company that was active at Mount Painter, the ARC, and Sprigg states that the venture was an attempt 'to save the faltering company'. The remote location, the uncertain nature of the supposed benefits, and especially the poor standard of its facilities, led to its quick failure in the Depression years. All subsequent attempts to develop spa or other tourist facilities at the springs have failed, sometimes spectacularly.[90]

Radium Mining across Australia

There is very little published information about radium mining in other parts of Australia. Often only the briefest of references are made, for example:

- In Western Australia, some occurrences of uranium mineralization were known for many years and in 1929, mining for radium was allegedly undertaken at Holleton, about 115 km south of Southern Cross (200 km west of Kalgoorlie).[91]

- In the Northern Territory, apparently in about 1908, there was 'a radium rush of five on packhorses to Tanumbirini Lagoons of the Limmen River', while in the early 1930s, 'radium ores were discovered at Mount Diamond, Wandi and Tanumbirini — visions of fabulous wealth at £565,000 an ounce — but of these pitchblende and uranium ores too little was known, now, alas! Too much.'[92]
- In New South Wales, interest was shown in Carcoar with the local *Blayney* newspaper reporting in an article titled 'Radium at Carcoar' on 12 August 1905, that:

> A wire from Carcoar to the 'Herald' says that for some considerable time past it has been known that the cobalt mine situated at the south east corner of the municipal boundary contained, in addition to cobalt, an ore called copper uranite. Samples of this ore have been tested and found to contain about 1.7 percent of uranium, the parent of radium. In order to ascertain what quantities could be obtained a number of samples of ore taken from various parts of the mine were collected on Saturday, and will be forwarded to Professor David this week for test. Mining authorities state that if the results prove satisfactory the value of the property will become great, as the present price of radium is stated to be 184,000 (pounds) per oz.[93]

According to Thomas, the total amount of radium produced across all of Australia probably did not even amount to 1 gram[94] — a rather minute quantity compared with the thousands of tonnes of ore and wastes generated. Australia's efforts to exploit uranium ores profitably to produce radium were almost entirely confined to South Australia, though there was clearly considerably more interest than has been recognized until now.

Back to Mount Painter: Australian Uranium and the Rush for the Atomic Bomb

It is commonly stated that Australia's attention to the strategic importance of uranium only began in 1944 when the British urgently requested Australia to explore Mount Painter and Radium Hill for the secret Anglo–American atomic bomb effort — the Manhattan Project.[95] A closer look at archival and other material, however, clearly shows that the Commonwealth and South Australian Governments, and also some well-placed individuals and mining companies, had been aware of the emerging significance of uranium at least as early as 1941, possibly earlier, and were carefully positioning themselves accordingly.

The need for military control of uranium was communicated to the Commonwealth Government in September 1941 by the Australian physicist Mark Oliphant (then playing a seminal role in the British war effort as well as lobbying to establish the Manhattan Project). Oliphant broke the sacred rule of military secrecy by discussing the British work on the atomic bomb, code-named Tube Alloys, with Richard G. Casey, Australia's representative to the USA in Washington DC. At Oliphant's request, Casey forwarded the information on 17 September 1941 to David Rivett of the CSIR. Together, Rivett and Oliphant found it difficult to convince officials of the need to safeguard Australia's uranium. Thereafter, Rivett kept in personal touch with British physicists working on the Manhattan Project and lobbied (albeit in vain) to try and gain greater access for Australian scientists to get directly involved.[96]

In August 1943, just before leaving Britain for the USA to work in the Manhattan Project, Oliphant broached the subject of uranium supplies with Australia's High Commissioner in London, Lord Bruce, who relayed this information to Australian Prime Minister John Curtin and asked him to start inquiries on the subject. From November 1943 to April 1945 Oliphant worked with Ernest Lawrence at Berkeley on the electromagnetic separation of uranium-235. (The final plant was built at

Oak Ridge, Tennessee, and supplied the fissile material for the Hiroshima bomb.)[97] Only two other Australian scientists worked on the Manhattan Project, Harrie S. W. Massey and Eric H. S. Burhop, despite efforts by Rivett for greater access and involvement.[98]

There were those who considered that Oliphant was over-enthusiastic in his optimism for the success of the atomic bomb project, though Burhop wrote to Rivett shortly after starting work at Berkeley that, in his view, Oliphant was not over-enthusiastic at all and that this eventual success had several profound implications.[99]

The need to consider thorium in a similar light to uranuim was also clear to Rivett and others, and it was noted around this time that Australia was possibly unwittingly exporting thorium to the USA in the form of monazite found in heavy mineral sands concentrates. It was thought that it might be prudent to consider regulating such exports, subject to the opinions and interest of the British of course.[100]

In September 1942 Rivett finally succeeded in bringing the issue of control of uranium before the wartime Production Executive Committee, which passed an order establishing Commonwealth control of uranium under the provisions of the National Security Act. There was no publicity. The Production Executive Decision (No. 133, 23 September 1942) was titled 'Control of Uranium-Bearing Ores' and included two main decisions:

(1) immediate action be taken to ensure that the control of uranium-bearing ores in the Commonwealth be reserved to the Crown and not allowed to pass into the hands of private individuals or companies; and
(2) the Division of Industrial Chemistry of the CSIR and the Minerals Survey Branch[101] of the Department of Supply and Development be asked jointly to prepare a report on our present knowledge of the occurrence of uranium-bearing ores in the Commonwealth.[102]

The committee had before it a memorandum dated 17 September prepared by Minister John Dedman that clearly pointed to the military significance of uranium. Rivett had been receiving 'certain secret information' for some time, which he guarded as most confidential and only shared with Dedman.[103] Rivett's source was Oliphant, who had urged this course of action during a 1942 visit to Australia.[104]

An initial report by the CSIR was completed in early November 1942. The report was used by Rivett as the basis for requesting the South Australian Department of Mines to reserve from private interests all uranium-bearing ores in the State — that is, Radium Hill and Mount Painter (over which the AMS leases, by coincidence, had just expired). A new, seven-page report was prepared by Herbert B. Owen (Mineral Survey Branch) and Richard Grenfell Thomas (CSIR) in early 1943.[105] Fortunately, Thomas had worked at Radium Hill and Dry Creek from 1925 to 1928, and his experience allowed the CSIR to proceed quickly.

The South Australian Department of Mines acted without hesitation after receiving Rivett's request of 13 November, though they apparently did not understand the basis for this action. On 19 November 1942, through the *SA Government Gazette*, 'all uranium-bearing areas in South Australia' (that is, Radium Hill and Mount Painter) were removed from the operation of the Mining Act and private interests. Dedman noted in July 1943 that, due to the prompt South Australian action, no further Commonwealth action to control uranium ores was necessary for the time being.[106]

On 17 May 1944, the British Chancellor of the Exchequer, Sir John Anderson, approached Prime Minister John Curtin while the latter was visiting London for the Empire Prime Ministers' meeting, and briefed him on the atomic bomb effort and of the dire need for uranium for 'Empire and War purposes'.[107] The British, responsible for Empire uranium under the Combined Development Trust arrangements created following the August 1943 Quebec Agreement for the Manhattan Project, requested the Australian Government to undertake an urgent and intensive investigation for uranium at Mount Painter and Radium Hill.

The full extent of Curtin's verbal briefing from Anderson on the atomic bomb is not available, only Anderson's general 'aide memoire' on Australian uranium, dated 15 May 1944 and cabled back to Australia after the 17 May meeting.[108] Curtin was most likely already informed on the broad aspects of atomic bomb developments by Oliphant via Rivett, but it is not clearly documented whether this British request was formally on behalf of the Manhattan Project. Given the improved Anglo–American co-operation by this time (not forgetting the Belgians and Canadians) and the already sufficient supply of uranium, it would appear that Britain was most likely acting (perhaps optimistically) in its own post-war interests and not to procure additional uranium for the Manhattan Project. The various books and archival material examined attribute the request to the UK Government alone with no mention of the USA, while American sources never mention potential Australian uranium or associated work.[109]

From London, Curtin promptly cabled Acting Prime Minister Frank M. Forde in Australia and relayed the information he had received, stressing the urgency and his personal interest in the project.[110] There was no time wasted, with Mawson[111] leading a party to Mount Painter within a week. Personnel from South Australian and Commonwealth departments together with various military and mining industry specialists started work in June 1944. The top-secret project was given urgent priority, giving it virtually unlimited capacity to draw on labour and expertise as required. Curtin in late June 1944 agreed to export the uranium from the project, given the alleged urgency for the allied war effort, even though the terms, conditions and Australia's possible needs after the war did not appear to have been thoroughly considered. The Mount Painter province, with potentially higher-grade ore known to be more amenable to existing treatment processes, was given the highest priority.[112]

The work was highly secret, with no clear statement as to its purpose. It was probably with the wisdom of hindsight that Sprigg later wrote of how 'all that any of us could learn was that the target element, uranium, had the potential for the creation of "atomic suns". For had not European scientists in 1939 ... actually demonstrated in the laboratory the splitting of the U235 uranium atom and established a first chain reaction for the release of relatively large quantities of energy?'. Ben Dickinson, promoted to become South Australia's Government Geologist and Director of Mines in March 1944, was probably reporting more accurately when he recalled that they 'weren't told it was for the bomb. We were told it was for some obscure purpose.' Given the veil of secrecy over all things atomic at the time, it is unlikely that the intended use of any uranium produced would have been divulged to the workers in the field (especially remembering Britain's probable post-war intentions).[113]

The people involved in or aware of the secret uranium project included mining industry luminaries such as Maurice Mawby, W. S. Robinson and Gordon Lindesay Clark,[114] all associated with the Zinc Corporation (later to become Conzinc Riotinto Australia and now Rio Tinto) or Western Mining Corporation (WMC), or both; government scientist-bureaucrats like Harold Raggatt, Ben Dickinson, David Rivett and Richard Grenfell Thomas; and numerous geologists and geophysicists like Reg C. Sprigg, Robert F. Thyer, D.

Edward Gardner, C. John Sullivan and Edward Broadhurst. The roles played by many of these people in later, post-war uranium exploration and in projects such as Rum Jungle, Mary Kathleen[115] and Radium Hill cannot be underestimated. The role played by Australian mining companies has long been overlooked, with the Zinc Corporation/Rio Tinto, AMS and WMC becoming pivotal in the post-war uranium industry, primarily led by figures such as Robinson, Clark and Mawby. These companies, due to their direct involvement in the logistics and to the personal involvement of their geologists, geophysicists and managers, were able to position themselves well in advance of other mining companies. A key aspect was the emerging importance of geophysics in mineral exploration and geological survey work.[116] Foreshadowing the future, Robinson stated in an internal Zinc Corporation letter of 22 June 1944 to A. J. Keast:

> We have spent much time and several thousand pounds on our efforts to assist in making Uranium available and it would not be unreasonable to expect that, if the Government of Australia desired any outside help, The Zinc Corporation may be given an opportunity to participate.[117]

Sure enough, the Zinc Corporation was later, in August 1952, given the contract to operate the Rum Jungle uranium project on behalf of the Commonwealth Government, a contract it held until April 1971.

At Mount Painter, the Americans provided a bulldozer — the first seen by many geologists working on the project — that drove the access track through to the base camp. Although some new uranium finds were made, including around former uranium workings at East Painter, the results were mostly disappointing as rich surface veins again faded out at depth. As early as October 1944, it was realised 'that it is most problematical as to whether we will locate any worthwhile quantity of material', leading to the conclusion that uranium reserves at Mount Painter were small and insufficient.[118] The British advised the Australian Government on 22 February 1945 that, based on a review of uranium production requirements, the small potential Australian uranium production of 20 tonnes a year was no longer of any interest. By this stage the urgency had eased somewhat since the allies had been able to procure sufficient uranium from Belgian Congo, Canadian and United States mines. The Manhattan Project secured 4010 tonnes of U_3O_8 from the Belgian Congo (pitchblende ore >25% U_3O_8), and 1000 tonnes of U_3O_8 each from Canada (pitchblende ore ~10% U_3O_8) and the USA (Colorado carnotite ore <1% U_3O_8). By this time Britain also felt reasonably assured of an adequate and continuing supply of uranium under the Combined Development Trust arrangements.[119]

The estimated cost of the Mount Painter project was about £57,750 (after the sale of residual assets) and was paid for by the British; only £1000 was spent on work at Radium Hill. The total number of people who worked on the project was 31.[120]

The total ore reserves did 'not exceed 500 tons containing 0.33% UO_3' (about 508 tonnes at 0.32% U_3O_8) and with an extraction efficiency of '60% being assumed this would yield on treatment 2000 lbs of uranium' (about 0.91 tonnes of U_3O_8). This would give only 6.5 kg of ^{235}U — not nearly enough for one atomic bomb (let alone several). The final project report, edited by Ben Dickinson and completed in November 1945, after the bomb project had become public knowledge, also noted that the uranium could be used for an atomic bomb.[121]

With the nuclear attacks on Hiroshima and Nagasaki in Japan on 6 and 9 August 1945, respectively, the world would forever know (and fear) the awesome power of uranium. The fieldwork in South Australia wound down by the end of 1945, with the State Government under pro-nuclear

Premier Thomas Playford continuing to explore both Mount Painter and Radium Hill as potential uranium mines for the near future. All work was abandoned at Mount Painter by 1949, in favour of developing the Radium Hill prospect, which by this stage had enough proven resources for a potentially economic project, with some of the ore treatment problems becoming manageable.

Although it is stated by some that high-grade uranium ore from Mount Painter was supplied to the USA during 1944 and 1945, this has not been verified and there is nothing on the public record concerning the quantity exported, if any.[122] According to the South Australian Department of Mines, only 'small quantities of ore won for laboratory and ore-dressing research' were supplied.[123] Based on the amount used by Thomas, the CSIR and others for metallurgical research, it appears that the total amount of ore used was of the order of several tonnes at most.[124] There was apparently no ore supplied from Radium Hill during the war-time exploration and research work.[125]

The Legacy: Urban Radioactive Wastes

Overview

As noted previously, very little is known about the practices for waste management at the various mine and smelter sites at Radium Hill, Mount Painter, Woolwich, Dry Creek and Bairnsdale. It must be pointed out that for most of the early period of radium mining, there were no formal national or international standards for radiation protection for workers and the public. The first such standard was proposed as a voluntary code in 1934 by the International Commission on Radiation Protection (ICRP), based on the emerging evidence at that time of the risks associated with exposure to radiation. The review below collates and analyses the available information, mainly focused on Woolwich due to the availability of a reasonable amount of data about this site.

A collage of photographs from the Radium Hill and Woolwich sites is given in Plate 1, with Mount Painter photographs in Plate 2.

Radium Hill

The overall scale of operations at Radium Hill was very small, even for the mining industry of the times — that is, compared with the numerous gold and coal fields and metal mines in Australia. There is very little known or published about practices, with the only clear information that can be ascertained being from various photographs, mostly published by the South Australian Department of Mines (see Plate 1). As was standard mining practice of the day, it would appear that ore was stockpiled before concentration, with the tailings most likely discharged adjacent to the mill (see 1912 and 1925 photographs). Beyond this, there are insufficient data on radiation levels or other issues to make any reasonably informed judgement, especially as there were no legal or other requirements for rehabilitation of mined land at this time.

An assessment of the scale and nature of the radioactive waste remaining at Radium Hill from the radium era is also problematic due to the development of a large-scale uranium mining and milling project after the Second World War. The traces of the earlier history would have been subsumed within a larger radioactive waste problem that is outside the scope of this paper.[126]

Woolwich

Although the origin of the need to assess the extent of radioactive waste at Woolwich is a matter of some debate, there is a reasonable quantity of data compared with what is available for other radium-era sites. As the location of one of Australia's first attempts at remediation of a radioactively contaminated site and disposal of associated wastes, it is important to document it here, both for completeness and because it relates to the radium industry some decades earlier.

Gandy states, presumably on the basis of Radcliff's 1913 paper,[127] that the liquid wastes at Woolwich would probably have been discharged to the adjacent harbour while solid wastes, including impure and unwanted uranium oxide by-products, were stored or dumped nearby. Assuming radioactive equilibrium for the ore and 86% efficiency, the amount of radium dumped was calculated by Gandy as 10 GBq (280 mg), though this was not based on a complete assessment of the various wastes.[128]

The Woolwich site was built on reclaimed harbour frontage land on the Parramatta River and extended up a cliff face with rough, rocky and sloping terrain (see Plate 1). The re-development for residential purposes would therefore have seen several walls and terraces constructed, the moving of much of the dumped solid waste and soils contaminated from liquid wastes from the old radium refinery, and their use as fill materials.[129] At the time of the proposed change to residential land in 1965, the site was investigated for radiation exposure levels, measuring gamma radiation doses and the uptake of radium in vegetables grown on soils at the site.

Although several locations showed high gamma dose levels and some radium uptake in plants and vegetables, the site was determined to be safe for residential use and investigations ceased in 1966.[130] The gamma radiation data are shown in Table 2. No sampling or analyses for radon gas and its decay products was performed. Slag from the adjacent tin-smelting site contaminated with ^{232}Th was used in the construction of residential roads, some substantially,[131] though the contamination was allegedly unknown at the time of the 1965 and 1966 radium surveys. All data is combined in Table 2.

In 1976, in the light of public debate on nuclear and radiation issues, the New South Wales Health Commission re-investigated the Woolwich site. It was now considered that the main reason for concern was possible exposure to radon and its radioactive progeny, not gamma radiation as previously thought.[132] The house built on the site of the refinery's laboratory was the main focus of investigation, that included water and sediment sampling, radon studies and further gamma radiation readings, as set out in Table 2.

Comparing these data to available uranium ore and mill tailings data[133] shows that many of the soil and sediment samples from Woolwich are of equivalent activity to uranium ore and therefore a major source of radon and a significant health risk. The sampled soil was estimated to account for about 8.9 GBq of radium (~0.24 g) or about 86% of that dumped by the old refinery. A significant amount of radioactivity was thought to have been dumped in the water.

Based on the data available at the time for the house over the old laboratory, Gandy[134] calculated that the annual gamma radiation doses of about 1.8 mSv were only marginally above background and required no action, while annual radon doses were between 12 and 24 mSv, making radiation exposure significantly above the then public standard of 5 mSv per year.[135]

After this work was presented, the soil samples were also found to be elevated in thorium, consistent with the elevated uranium and thorium in the monazite-bearing tin ores as well as in the uranium ore processed. This suggested that as time progressed, the radium activity would increase as the decay of thorium (^{230}Th) would lead to more radium (^{226}Ra) and therefore radon (^{222}Rn).[136] This situation is different from common forms of radioactive waste that gradually decline in specific radioactivity over time, whereas that at Woolwich would slowly increase. Clearly, the most rational solution was to remove the contaminated soil and wastes permanently from such valuable real estate.

In early 1978, the New South Wales Government announced its desire to remove about 3000 tonnes of radioactive wastes from the six house blocks, but no site was found for their permanent management. Efforts to relocate the waste to Manara in rural New South Wales or to South Australia were unsuccessful,[137] due to active opposition from the Bakandji Aboriginal people and the local community. Following a government directive on 22 June 1982, the New South Wales Department of Health purchased three of the residential blocks. One of these was then remediated and 'made safe', with the contaminated soil removed and transferred to the adjacent blocks for storage. The remaining blocks were 'fenced off, re-vegetated and warning signs ... erected'.[138] In September 1992, a house on one of the remaining two blocks was demolished with some soil removed and sealed in three 205-litre drums that remain under the control of the New South Wales authorities.[139] No remedial decontamination

Table 2. Gamma radiation, radon activities in air and radium contamination at Woolwich

Compiled from A. P. S. E. Cardew, '^{232}Th Contamination from Tin Smelting', *Radiation Protection in Australia*, 2 (1982), 108–116, and G. F. Gandy, 'Radium Contamination of Residential Areas', *Radiation Protection in Australia*, 2 (1982), 117–129

Year	Radiation source/type	Unit	Average	Range	Background
1965	Gamma	μGy/h	0.4	0.14–1.4 (86^{A})	~0.1
1976	Gamma	μGy/h	?	0.14–1.4	~0.1
	Radon	Bq/m^3	259	237–2916;	?
	?			7400–11,100^{B}	
	Radon progeny	WL^{C}	0.13	0.002–0.32	
	Radium (soils)	Bq/kg	34,743	851–244,200	?
	?			(51,800,000^{D})	
	Radium (sediments)	Bq/kg	1240	259–4070	?
1977^{E}	Thorium-234 (^{234}Th)	Bq/kg	31,890	574–271,987	?
	Radium-226 (^{226}Ra)		36,467^{F}	851–326,969^{F}	
	Lead-214 (^{214}Pb)		36,615^{G}	740–346,320^{G}	
1977^{H}	Thorium-232 (^{232}Th) – slag	Bq/kg	4206	2812–6364	?
	Thorium-232 (^{232}Th) – ore	Bq/kg	–	1110 and 2516 and 12,876	
	Gamma	μGy/h	1.7	0.1–3.3	~0.2
	Gamma (1 m height)	μGy/h·	1.1	0.2–2.8	
1999^{J}	^{238}U, ^{230}Th, ^{210}Pb, ^{226}Ra	Bq/kg	–	3000–7000	–

[A]Gamma dose rate directly above a dump site.
[B]Radon activities in air beneath the floorboards.
[C]Working Level or WL is a measure of the radioactivity of radon progeny in air. (mWL is mill WL or 10^{-3} WL.) 1 WL = 3746 Bq/m^3 of radon in equilibrium with its progeny or equilibrium equivalent concentration (EEC).
[D]Single sample only, most likely an area of liquid waste disposal.
[E]Average of the AAEC analyses of both February and June 1977, total of 21 soil samples.
[F]Average excludes single value of 53,280,000 Bq/kg.
[G]Average excludes single value of 54,020,000 Bq/kg.
[H]Data for tin smelting site and surrounds (for comparison).
[I]Tin ores from Emmaville, Ravenshoe and Cairns, respectively.
[J]Letter, Plues to Author, 10 March 2005.

works were undertaken, however, at the tin-smelting site.[140]

The New South Wales regulatory authorities appear to have been monitoring the Woolwich site at Hunter's Hill since this time, as measurements of gamma dose rates and radon exhalation rates are given by Lenzen and McKenzie. The gamma radiation exposure from the residual contamination at the site was stated as about 1 μSv/h, while radon exhalation rates were about 2.6 times higher than nearby uncontaminated rocks.[141]

According to Lenzen and McKenzie, the ICRP's recommended maximum gamma level for full-time exposure was 0.57 μSv/h, with the re-named 'Kelly's Bush' site rated as low-risk.[142] Assuming full-time occupation, this equates to 8.8 mSv/year, or 2.9 mSv/yr for typical one-third occupation. The ICRP figure of 0.57 μSv/h relates, however, to a public dose of 5 mSv/year, not the 1 mSv/year now in use.[143]

In its formal response to a 2004 Joint Parliamentary Inquiry on Nuclear Waste, the New South Wales Government has agreed to 'complete the inventory of non-ANSTO storage sites as a matter of urgency identifying, in particular, those sites where upgrading of facilities is required'.[144] The Woolwich site clearly fits into this category.

As the Woolwich saga demonstrates, it takes only a small quantity of radioactive waste from uranium (or radium) mining, in the right context (e.g. in an urban area), to give rise to significant radiation exposures and on-going waste management dilemmas. The extent of the cancer risk from this additional radiation exposure is only a small increment above background radiation levels, but it does point to the need for final remediation works rather than permanent site management.

Bairnsdale

As noted earlier, the initial ore-treatment research was undertaken at Bairnsdale by the Director of the Bairnsdale School of Mines, S. Radcliff, who was formerly at Moonta. There is no formal public record of the fate of the radioactive waste after the closure of the School of Mines.[145] Nothing further is known about the history of and current radiation levels at the site.

Mount Painter and Dry Creek

There is considerably less information available on the residual contamination and wastes from the various phases of Mount Painter work than for the Woolwich site. The field still retains many exposed waste dumps, shallow open cuts and underground mine workings, often used for geological research and occasionally for tourist purposes. There is no known information on the approach adopted to radioactive waste management and radiation protection during the war-time exploration work, although this period would have added to the existing workings scattered throughout the immediate region. Further uranium exploration work in the area in the late 1960s and early 1970s clearly exacerbated this legacy, as noted by Commonwealth and South Australian Parliamentary Inquiries.[146]

A residential house, apparently in inner-suburban Adelaide, was discovered to be contaminated with radium in the early 1980s, the late resident having been a laboratory technician for radium production from Mount Painter in the 1920s (presumably at Dry Creek). The problem was identified after a 'radium needle' was found. One room where 'some laboratory work' was probably performed contained some 10 MBq of radium (~0.28 mg). It was concluded that the radium had been in solution, and had been heated in the fireplace and spilled on the floor. The contamination data is given in Table 3. After cleaning of the chimney and removal of the floorboards, the residual contamination was not thought to be a significant risk, and no further action was taken. The radioactive wastes were dumped at an unnamed 'industrial waste disposal site'. The Dry Creek wastes were dumped at Radium Hill during this time though there are no data on the public record concerning waste volumes or level of radioactivity.[147]

Moonta Copper Tailings

The tailings from the former Moonta copper mine present a side story related to the urban radioactive wastes arising from Radium Hill, Woolwich and Mount Painter. As noted previously, radioactivity was confirmed by Radcliff at select parts of the Moonta copper deposit in early 1906, before Radium Hill was discovered. In the early 1980s, regional uranium exploration by WMC revealed that significant radiation emanated from the Moonta copper tailings. Certain sections of the tailings dump gave readings exceeding the Code of Practice for Radiation Protection in Uranium Mining and Milling,[148] based on a 40-hour working week and fifty weeks per year. According to Hill, this was recognised as a public health hazard though no radiation exposure or other data was provided.[149] The area was fenced and allowed to revegetate. As part of mining heritage activities, a railway was built through Moonta and has apparently been successful in reducing the number of people walking over the old tailings dumps.

Conclusion

The history of early attempts to mine uranium ore in Australia primarily for its radium content, is full of unrewarded promise. Despite optimistic efforts, the mining and milling of uranium-bearing ores from Radium Hill and Mount Painter in South Australia failed to be commercially viable. Labour shortages, the tyranny of distance, ore treatment difficulties, lack of strong political support, and the tenuous nature of the radium–uranium market all conspired against success. There was no government support forthcoming for the fledgling industry, though both the South Australian and Commonwealth Governments promoted the rare ores involved at appropriate international exhibitions. This period, however, was instrumental in placing Australia in a perceived advantageous scientific position when the breakthroughs in nuclear physics in the late 1930s led to uranium becoming a strategic element for governments around the world in the 1940s.

Thus, when the British desperately wanted to procure uranium during the Second World War to secure their post-war defence interests, the famous, once-rich

Table 3. Gamma radiation, alpha activities and radon in air at 'house'

Compiled from T. Passmore, 'Radioactivity in a Private Residence', *Radiation Protection in Australia*, 1 (1983), 52–54

Radiation	Unit	Average	Range	Background
Gamma – cont. room	μGy/h	0.25[A]	(two spot samples both 1.0)	~0.08
Gamma – chimney	μGy/h	~0.4	0.11–0.90[B]	–
Alpha contamination[C]	kBq/m^2	30–60	Up to 600	?
Radon progeny	mWL	6.9	1.5–15[D]	0.5–8 (2)[E]

[A]Gamma dose rate at waist height.
[B]Depending on location in or near the chimney.
[C]An indication of radium activity, which decays by alpha decay (including some of the radon progeny).
[D]Largely dependent on the ventilation conditions within the room and house.
[E]Measured in a nearby similar house, the average is in parentheses.

ores of Mount Painter in Australia were an obvious choice — and Australia's mining industry and bureaucrats responded with full zeal and endeavour. It is clear that, despite the lack of uranium exports at this time, Australia was a willing, co-operative and active participant in the project that established the permanence of the nuclear weapons menace.

Australia's radium industry, relatively minor in global terms, had fomented glowing expectations around the world and laid the foundation upon which Australia, starting with the war-time exploration work, could base a post-war uranium boom. Indeed, uranium mining and export, especially to the UK and USA, has remained a dominant theme of Australia's global nuclear diplomacy since this time. The history suggests, however, that we are yet to account properly for or to manage in a sustainable way the radioactive wastes deriving from this period. There is still no appropriate facility for long-term stewardship of the Woolwich wastes; numerous waste rock dumps, exploration tracks, adits and shallow open cuts still litter the Mount Painter region; and Radium Hill was later developed into a considerably larger radioactive waste problem.

With regard to the post-war uranium industry, three key conclusions emerge: (i) the relatively minor radium industry was crucial in developing local scientific expertise; (ii) the war-time exploration work involved key figures and mining companies and, although it did not lead to uranium exports at the time, was pivotal for the rapid development of industry interest in uranium following the end of the war; and (iii) the legacy of radioactive waste has still not been solved, especially within an urban context.

Acknowledgments

This research has been undertaken by the author mostly in his own time over several years. Special thanks to Les Dalton and to the librarians of Victoria University, Monash University, the National Library of Australia, the National Archives of Australia, the University of Queensland and the South Australian Department of Primary Industries and Resources (PIRSA). Dr Geoff Brand helped with the R. G. Casey letters. Dr Peter Burns of ARPANSA provided a concise history of public radiation exposure standards that was most useful and appreciated. Permission to reproduce photographs was granted by PIRSA, the Arkaroola Wilderness Sanctuary and Resort, and the Royal Society of South Australia. The response of the Radiation Control Section of the New South Wales Department of Environment and Conservation is duly noted and appreciated. Finally, the Editor is thanked for his generous patience and attention to detail that has helped to make this paper more thorough and precise.

PostScript: Prefixes and Units

μ	micro	10^{-6}	Gy	Gray – gamma radiation exposure
m	milli	10^{-3}	Sv	Sievert – biological effect of radiation exposure
M	mega	10^{6}	Bq	Becquerel – one radioactive decay per second
G	giga	10^{9}	U_3O_8	Uranium oxide
WL				Working level – activity and exposure to radon progeny

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56. SA Department of Mines, *Mining Review*, No. 84, June 1946, p. 5.
57. Sprigg, *Geology is Fun*, p. 242.
58. King, 'Uranium Prospecting', *AusIMM Bulletin*, 171 Supplement (1954), 2. W. S. Robinson was heavily involved in many mining companies and was also instrumental in forming Western Mining Corporation (WMC) in 1933.
59. AMS was soon after to become a subsidiary of Consolidated Zinc Corporation or 'ConZinc', formed by the 1949 merger of the Australian mining icon, the Zinc Corporation, and the British Imperial Smelting Company. ConZinc later merged with the Australian interests of Rio Tinto Zinc (RTZ) of the UK to form Conzinc Riotinto Australia or CRA in 1962, with RTZ the majority shareholder. RTZ–CRA merged fully in the 1990s to form Rio Tinto. CRA–RTZ–Rio Tinto and their subsidiaries have been very active in Australian uranium since 1940 (e.g. at Rum Jungle, Mary Kathleen, Kintyre, Westmoreland, and more recently at Ranger/Jabiluka, etc.).
60. Maurice Mawby to G. Lindesay Clark, 20 December 1940, p. 157, Series A1146/1, N13/13A Part 3, NAA. See also King, 'Uranium Prospecting', p. 2.
61. Parkin and Glasson, 'The Geology of the Radium Hill Uranium Mine, South Australia', *Economic Geology*, 49(8) (1954), 815; Sprigg, 'Geology of the Radium Hill Mining Field', p. 8; W. S. Robinson to A. J. Keast, 22 June 1944, p. 75, Series A1146/1, Control N13/13A Part 3, NAA.
62. W. S. Robinson to A. J. Keast, loc. cit.
63. For example, Robinson, *If I Remember Rightly: W. S. Robinson Memoirs* (Melbourne, 1970); see also Ralph, 'The Origins of Western Mining Corporation and Some of the Men Who Shaped It', in *AusIMM Centenary Conference* (Adelaide: Australasian Institute of Mining and Metallurgy, 1993), pp. 367–368; Hudson, Kelly, Robinson and Way, eds, *Documents on Australian Foreign Policy 1937–49* (Canberra, 1988).
64. Following the end of the Second World War, a Holy Bible in honour of Robinson was given to Scotch College (his former school). The inscription by Winston Churchill and Brendan Bracken read, in part, 'in the six relentless years of war that preceded the victory of 1945 the services manifold of William Sydney Robinson to the British Commonwealth were beyond computation'; Dew, *Mining People: A Century: Highlights of the First Hundred Years of the AusIMM 1893–1993* (Parkville, Victoria, 1993), p. 281.
65. See Smyth, *Atomic Energy for Military Purposes: The Official Report of the Development of the Atomic Bomb under the Auspices of the United States Government 1940–1945* (Princeton, NJ, 1946); Groves, *Now It Can Be Told: The Story of the Manhattan Project* (London, 1963).
66. Further to this, the British were sure that mining companies were alert to the use of uranium as a potential source of power and were being very careful in all of their uranium procurement efforts (the price was already rising); see Gowing, *Britain and Atomic Energy*, p. 181. It is therefore hard to believe that a person of Robinson's political connections and entrepreneurial calibre was not aware of similar interests and potential imperatives for Australia's uranium.
67. W. S. Robinson to A. J. Keast, 22 June 1944, pp 75, Series A1146/1, Control N13/13A Part 3, NAA.
68. The first radiation exposure standards for workers were recommended in 1934 by the International Commission on Radiological Protection (ICRP) (see later section).
69. Dickinson, 'Part I – Uranium Investigation, Mount Painter', pp. 5–6; Randall and Driver-Smith, 'Uranium Mines of the Arkaroola, Mt Painter Province', pp. 22–23; Sprigg, *Arkaroola-Mt Painter: The Last Billion Years*, pp. 5, 229.

70. This was a common complaint about Mt Painter ores; see Thomas, 'Processing of Radium Ores', p. 123.
71. Sprigg, *Arkaroola-Mt Painter: The Last Billion Years*, p. 231.
72. Brugger, Ansermet and Pring, 'Uranium Minerals From Mt Painter', p. 18.
73. Drexel, *Mining in South Australia*, pp. 284, 289; Sprigg, *Arkaroola-Mt Painter: The Last Billion Years*, p. 230; Randall and Driver-Smith, 'Uranium Mines of the Arkaroola, Mt Painter Province', p. 24; Coats and Blissett, *Regional and Economic Geology of the Mount Painter Province* (Adelaide: SA Department of Mines, 1971), p. 148.
74. Thomas, 'Processing of Radium Ores', p. 124; Sprigg, *Arkaroola-Mt Painter: The Last Billion Years*, p. 230; Randall and Driver-Smith, 'Uranium Mines of the Arkaroola, Mt Painter Province', p. 23; Sprigg, 'Colourful and Exotic Minerals of the Flinders Ranges', in *Natural History of the Flinders Ranges*, ed. Davies, Twidale and Tyler (Adelaide, 1996), p. 32; Brugger, Ansermet and Pring, 'Uranium Minerals From Mt Painter', pp. 18–19.
75. Sprigg, *Arkaroola-Mt Painter: The Last Billion Years*, pp. 29–48; Tunbridge, *Flinders Ranges Dreaming* (Canberra, 1988), p. 126.
76. O'Neil, *In Search of Mineral Wealth*, p. 275; Randall and Driver-Smith, 'Uranium Mines of the Arkaroola, Mt Painter Province', p. 25.
77. Drexel, *Mining in South Australia*, p. 289; pp. 19 and 39, Series A786/2, Control J64/8, NAA.
78. Richardson, *Australian Radiation Laboratory*, p. 2.
79. Personal Papers of Prime Minister Bruce; Deputation representing the Radium Company, 16 November 1927, Series CP362/2/1, Control 33; p. 35, Series CP211/2/1, Control 32/1; NAA.
80. This is probably related to the earlier report from Rutherford. See also p. 2, Series CP362/2/1, Control 33, NAA; SA Department of Mines, *Mining Review*, No. 18, June 1913, p. 11.
81. pp. 39, 41 and 42, respectively, Series CP211/2/1, Control 32/1, NAA.
82. Memorandum to Development and Migration Commission, 14 May 1928, p. 25, Series CP211/2/1, Control 32/1, NAA.
83. Notes of Interview, 16 April 1928, p. 35, Series CP211/2/1, Control 32/1; and Note for Mr Tonkin, p. 29, Mines and Mining M–Z, Radium, Series A786/2, Control J64/8; NAA.
84. Dickinson, 'Part I – Uranium Investigation, Mount Painter', p. 8; O'Neil, *In Search of Mineral Wealth*, p. 276; H. J. Lipman to J. Gunn, 12 May 1930, p. 81, and 'Radium Corporation – Additional Capital Sought', p. 163, Series A786/2, Control J64/8; NAA; North and Hudson, eds, *My Dear PM: R. G. Casey's Letters to S. M. Bruce, 1924–1929*, p. 464; Coats and Blissett, *Geology of Mount Painter*, p. 149.
85. AMS focused on physical concentration of the ore, as done previously at Radium Hill — acid leaching was already known to be feasible if one ignored the lack of water; see Sprigg, *Geology is Fun*, p. 243, or Cablegram Curtin to Forde, 17 May 1944, pp. 43–44, Series A571/141, Control 1944/1789, NAA.
86. O'Neil, *Above and Below: The South Australian Department of Mines and Energy 1944–1994* (Adelaide, 1995), p. 73.
87. For example, see Sprigg, *Arkaroola-Mt Painter: The Last Billion Years*, pp. 249–254, and Sprigg, *Geology is Fun*, pp. 114–125.
88. Tunbridge, *Flinders Ranges Dreaming*, p. 126; Sprigg, *Geology is Fun*, pp. 122–123.
89. Dalton, *Radiation Exposures*, p. 92. See also Mawson, 'The Paralana Hot Springs', *Transactions of the Royal Society of South Australia*, 51 (1927), 191; Kerr-Grant, 'Radioactivity and Composition of Water and Gas of the Paralana Hot Spring', *Transactions of the Royal Society of South Australia*, 62 (1938).
90. O'Neil, *Above and Below*, p. 375; Sprigg, *Arkaroola-Mt Painter: The Last Billion Years*, p. 250; Mincham, *The Story of the Flinders Ranges*, pp. 208–209; Sprigg, *Geology is Fun*, pp. 122–123; also *Advertiser* (Adelaide), 25 May 1946.
91. Stewart, 'An Assessment of the Search for Uranium in Australia', in *8th Commonwealth Mining and Metallurgical Congress*, ed. Woodcock (Melbourne: Australasian Institute of Mining & Metallurgy, 1965). However, according to Carter, 'Mineral Deposits of Western Australia: Uranium', in *Mining in Western Australia*, ed. Prider (Perth, 1979), claims about radium mining at Holleton are misleading (p. 162).
92. Hill, *The Territory* (Sydney, 1970), pp. 256, 418. Attempts to verify this have not been successful, but it is reported for completeness. It is unclear if this is the Mount Diamond that was mined for copper and gold by United Uranium NL in the 1960s.
93. Courtesy of historical research by Robyn Ryan (email 8 March 2002).
94. Thomas, 'Processing of Radium Ores', p. 132.
95. For example, see Battey, Miezitis and McKay, *Australian Uranium Resources* (Canberra: Bureau of Mineral Resources, Geology

& Geophysics, 1987), p. 2; Dunn, Battey, Miezitis and McKay, 'The Distribution and Occurrence of Uranium', *Geological Aspects of the Discovery of Some Important Mineral Deposits in Australia*, ed. Glasson and Rattigan (Melbourne, 1990), p. 455; McKay and Miezitis, *Australia's Uranium Resources, Geology and Development of Deposits* (Canberra, 2001), p. 6. See also Uranium Information Centre, 'Uranium Exploration in Australia', Mines Paper 7, last updated 10 May 2005; http://www.uic.com.au/explor.htm (accessed 19 June 2005).

96. Cockburn and Ellyard, *Oliphant*, pp. 112–123; Cawte, *Atomic Australia*, pp. 2–3, 6–7; Reynolds, *Australia's Bid for the Atomic Bomb*, (Parkville, Victoria, 2000), p. 27; Gowing, *Britain and Atomic Energy*, p. 315.
97. Cockburn and Ellyard, *Oliphant*, pp. 112–123; Cawte, *Atomic Australia*, pp. 2–3, 6–7; Reynolds, *Australia's Bid*, p. 27; Gowing, *Britain and Atomic Energy*, p. 315. See also Smyth, *Atomic Energy for Military Purposes*, and Groves, *Now It Can Be Told*.
98. On 5 January 1944, Rivett wrote to F. W. G. White of the CSIR stating that Oliphant had requested an Australian or two to work on 'Tube Alloys', the British side of the atomic bomb project. Massey was already working at Berkeley; Rivett nominated Burhop who went to America in May 1944; see Hudson, Kelly, Robinson and Way, eds, *Documents on Australian Foreign Policy*, pp. 7–8, 398–399, 527, 594.
99. *Ibid.*, pp. 344–345, 398–399. Burhop also noted that any opportunity to get more people involved in the work would be beneficial.
100. A. V. Smith to D. Rivett, 17 July 1944, p. 77; H. G. Raggatt to A. V. Smith, 13 July 1944, pp. 81 and 147–148, Series A1146/1, Control N13/13A Part 3, NAA; p. 38–39, Series A571/141, Control 1944/1789, NAA.
101. Following the war this became the Commonwealth Bureau of Mineral Resources, Geology & Geophysics (BMR, now Geoscience Australia). The BMR went on to complete major uranium exploration work in the following decades.
102. Production Executive Decision No. 133, 23 September 1942, p. 259, Series A1146/1, Control N13/13A Part 3, NAA.
103. David Rivett to A. V. Smith, 23 May 1944, pp. 196 and 270, Series A1146/1, Control N13/13A Part 3, NAA. Dedman was Minister for War Organisation of Industry and the CSIR in the Curtin Labor Government (see http://www.aph.gov.au accessed 12 October 2004).
104. Hudson, Kelly, Robinson and Way, eds, *Documents on Australian Foreign Policy*, pp. 7, 344; Gowing, *Britain and Atomic Energy*, p. 315. Although there is no evidence that either Massey or Burhop was lobbying or informing Rivett (Cawte, *Atomic Australia*, p. 6), later in 1944 Burhop was certainly advising Rivett of the benefits of further involvement of Australian scientists.
105. *Uranium Minerals in Australia*, pp. 237–243, 254–258, Series A1146/1, Control N13/13A Part 3, NAA. Thomas had been another student of Mawson's at the University of Adelaide in the 1920s and was considered an expert on mineral processing, with a particular knowledge of uranium and monazite (indeed these were listed as some of the fifty projects he recommended for research upon joining the CSIR in 1941); see Bear, Biegler and Scott, *Alumina to Zirconia: The History of the CSIRO Division of Mineral Chemistry* (Clayton South, Victoria, 2001), pp. 5–7, 21–23.
106. L. K. Ward to A. V. Smith, 20 November 1942, p. 248; David Rivett to L. K. Ward, 13 November 1942, p. 252; and Note to Production Executive, 29 July 1943, by John Dedman, p. 232, Series A1146/1, Control N13/13A Part 3, NAA.
107. See Hudson, Kelly, Robinson and Way, eds, *Documents on Australian Foreign Policy*, pp. 324–325.
108. This 'aide memoire' is available from various sources, e.g. *Ibid.*, pp. 324–325; also pp. 43–44, Series A571/141, Control 1944/1789, NAA.
109. See Gowing, *Britain and Atomic Energy*, pp. 187, 315; Hudson, Kelly, Robinson and Way, eds, *Documents on Australian Foreign Policy*, pp. 534–535; Series A571/141, Control 1944/1789, NAA.
110. Dickinson, 'Part I – Uranium Investigation, Mount Painter', p. 1; Cawte, *Atomic Australia*, p. 4.
111. Mawson's 1944 paper was published quickly in November 1944, presumably as part of this project: 'Now that there is a revival of interest in uranium ... circumstances have arisen which deem it expedient for me to publish immediately', Mawson, 'Uraniferous Mineral Deposits in South Australia', p. 334. Ayres states that after 'World War 2 Mawson would feel understandably "sore" that "considering [he] was fundamental in establishing the presence of uranium in the Mt Painter and

Radium Hill fields and had spent so much money and time thereon the Government ... closed the door for exploitation by anybody else"' Ayres, *Mawson: A Life*, p. 41.

112. Cawte, *Atomic Australia*, pp. 4–6; O'Neil, *Above and Below*, pp. 73–75; Brugger, Ansermet and Pring, 'Uranium Minerals From Mt Painter', p. 20; p. 32, Series A571/141, Control 1944/1789, NAA.
113. Sprigg, *Geology is Fun*, pp. 233–234; Sprigg, *Arkaroola-Mt Painter: The Last Billion Years*, p. 231; O'Neil, *Above and Below*, pp. 74–76; see also Reynolds, *Australia's Bid*, p. 63.
114. Then Deputy Controller of Mineral Production for the Commonwealth.
115. A history of the first phase of development at Mary Kathleen, 1954–1963, is given by Harding, *Wholeheartedly and At Once: A History of the First Operation of Mary Kathleen Uranium Ltd 1954–1964*.
116. The BMR (see earlier), replaced the MSB, and throughout the 1940s had a 'virtual monopoly' on geophysics expertise in Australia. The extensive geophysics work by the BMR, for uranium as well as other minerals, helped to lead the uptake of geophysicists in Australia; see Wilkinson, *Rocks to Riches: The Story of Australia's National Geological Survey* (St Leonards, NSW, 1996).
117. p. 76, Series A1146/1, Control N13/13A Part 3, NAA.
118. p. 25, Dept of External Affairs to Commonwealth Government Respresentative, London, 13 October 1944, Series A571/141, Control 1944/1789, NAA.
119. Sprigg, *Arkaroola-Mt Painter: The Last Billion Years*, p. 283; Cawte, *Atomic Australia*, p. 7; SA Department of Mines, *Mining Review*, No. 82, June 1945, p. 13; Eisenbud, 'Early Occupational Exposure Experience with Uranium Processing', in *Conference on Occupational Experience With Uranium, ERDA 93* (Arlington, VA: US Energy Research & Development Administration, 1975), p. 18; Gowing, *Britain and Atomic Energy*, pp. 307–19. It is interesting to note that the operation of the USA–UK Combined Development Trust was extended well after the end of the Second World War, with most Australian uranium production being sold into it in the 1950s.
120. Dickinson, 'Part I – Uranium Investigation, Mount Painter', p. 5; SA Department of Mines, *Mining Review*, No. 82, June 1945, pp. 11–13; Randall and Driver-Smith, 'Uranium Mines of the Arkaroola, Mt Painter Province', p. 29; pp. 2–4, Series A571/141, Control 1944/1789, NAA.
121. Dickinson, 'Part I – Uranium Investigation, Mount Painter', p. 16.
122. For example, a *Sydney Daily Telegraph* article on 8 August 1945 (see Cawte, *Atomic Australia*, p. 7), as well as Mason, *No Two the Same*, Publication 3/94 (Melbourne, 1994), pp 149. Wayne Reynolds reports that he found no evidence in various national archives suggesting any export of uranium ore from Mount Painter for the Manhattan Project (email 5 April 2002)
123. SA Department of Mines, *Mining Review*, June 1945, p. 13.
124. See all project reports in Dickinson, ed., *Report on Investigation of Uranium Deposits at Mt Painter, South Australia, June 1944 to September 1945 undertaken at the request of the British Government by the Government of the Commonwealth of Australia in conjunction with South Australian Government, November 8, 1945* (Adelaide, 1945).
125. Harrington and Kakoschke, *We Were Radium Hill*, pp. 1–3.
126. See O'Neil, '"National Heroes, Not National Villains": South Australia and the Atomic Age', in *Playford's South Australia: Essays on the History of South Australia, 1933–1968*, ed. O'Neil, Raftery and Round (Adelaide, 1996) and O'Neil, *Above and Below*. A review of the radioactive waste management problems for the 1950s–1960s uranium project at Radium Hill is given by Mudd, 'Remediation of Uranium Mill Tailings Wastes in Australia: A Critical Review', in *2000 Contaminated Sites Remediation Conference* (Melbourne: CSIRO Centre for Groundwater Studies, 2000). More recently, a draft management plan has been prepared by the South Australian Government, see McLeary, *Radium Hill Uranium Mine and Low Level Radioactive Waste Repository Management Plan: Phase 1 – Preliminary Investigation* (Adelaide: Primary Industry & Resources SA [PIRSA], 2004).
127. Radcliff, 'Extraction of Radium'.
128. Gandy, 'Radium Contamination of Residential Areas', p. 118.
129. *Ibid.*
130. *Ibid.*, p. 119.
131. Cardew, '^{232}Th Contamination from Tin Smelting', *Ibid.*, pp. 108, 111.
132. Gilpin, 'Uranium: Bang or Whimper?' in *The Australian Environment: 12 Controversial Issues* (South Melbourne, Victoria, 1980), p. 128; Dalton, *Radiation Exposures*, pp. 86–87.

133. Mudd, 'Remediation of Uranium Mill Tailings Wastes in Australia: A Critical Review', in vol. 2, p. 779.
134. Gandy, 'Radium Contamination of Residential Areas'.
135. The 5 mSv per year public radiation exposure limit was recommended in 1966 by the ICRP and adopted by the National Health and Medical Research Council (NHMRC) in 1967 (email, Dr Peter Burns, ARPANSA, 27 June 2003); also ICRP, *Recommendations of the International Commission on Radiological Protection*, 1966.
136. Gilpin, 'Uranium: Bang or Whimper?', p. 128.
137. *'No Time to Waste': Report of the Senate Select Committee on the Dangers of Radioactive Waste* (Australian Senate, Canberra, 1996), p. 54.
138. L. Plues, NSW Department of Environment and Conservation, to author, 10 March 2005; Panter, *Radioactive Waste Disposal in Australia* (Parliamentary Research Service, Department of the Parliamentary Library, Canberra, 1992), p. 5. Curiously, the Commonwealth's proposal for a national low-level radioactive waste dump near Woomera, South Australia, fails to mention the Hunters Hill radioactive waste despite its being larger in volume and of similar radioactivity to the Fishermen's Bend waste currently stored on a temporary basis at Defence facilities in Woomera (see *National Radioactive Waste Repository Draft EIS: Main Report & Appendices*, prepared by PPK Environment & Infrastructure Pty Ltd for the Commonwealth Department of Education Science & Training, Sydney, 2002).
139. Plues to author, 10 March 2005 (see previous note).
140. Cardew, '^{232}Th Contamination from Tin Smelting', p. 115.
141. Lenzen and McKenzie, 'Comparative Measurements of ^{222}Rn Exhalation', refer to 'Ashton, W. and others, 1986, *Kelly's Bush Landscape and Management Plan.* NSW Department of Environment and Planning by Travis Partners Pty Ltd', p. 21. The units given are mSv/h though units of μSv/h are more likely to be correct.
142. *Ibid.*, p. 16.
143. ICRP, *Recommendations of the International Commission on Radiological Protection* (1977); ICRP, *Recommendations of the International Commission on Radiological Protection* (1990); NHMRC, *Recommendations for Limiting Exposure to Ionizing Radiation and National Standard for Limiting Occupational Exposure to Ionizing Radiation* (Canberra, 1995). According to the ICRP, an exposure of 3 mSv/year equates to a cancer risk of 1 in 10,000 per year.
144. NSW Government Response to the Inquiry into the Transportation and Storage of Nuclear Waste, Recommendation 6; Joint Select Committee on the Transportation and Storage of Nuclear Waste, Parliament of New South Wales, 2004).
145. According to an unconfirmed news report, the radioactive waste was dumped in a nearby mine shaft and the school redeveloped as a TAFE; N. Papps, 'Secret Nuclear Hazard on City Streets', *Herald Sun* (Melbourne), 12 March 2001.
146. For example, see Brugger, Ansermet and Pring, 'Uranium Minerals From Mt Painter', or photographs in Drexel, *Mining in South Australia*. In 1970, the Australian Senate Select Committee on Water Pollution noted evidence from Dr K. R. Miles, South Australian Government Geologist, that work at Mount Painter was leading to water quality problems; Report of the Senate Select Committee on Water Pollution (Australian Senate, Canberra, 1970), Evidence and Transcript, p. 629. In 1972, a South Australian Government Environmental Inquiry noted that 'if the [recent] exploration had been conducted under the provisions of the latest legislation, much less despoilation of the landscape might have occurred'; *Report of the Committee on Environment in South Australia* (Adelaide, 1972), pp. 192–193.
147. Passmore, 'Radioactivity in a Private Residence', *Radiation Protection in Australia*, 1(2) (1983), 52, 54; O'Neil, *Above and Below*, p. 375. The dump site was most likely the radioactive waste facility at Radium Hill, gazetted in April 1981 though with no environmental impact assessment.
148. The 1980 Code of Practice was the Australian regulatory standard for radiation protection.
149. The Moonta tailings radiation problem was discussed by Hill, 'Mine Closures in South Australia', in Australian Mining Industry Council Environmental Workshop, Launceston, 1986.

Dr Gavin M Mudd

Brief Curriculum Vitae : May 2008

Current Position

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Dr Gavin M Mudd has been an active researcher and advocate on the environmental impacts and management of mining for over a decade. He has been involved with many aspects of industry with a particular specialty in brown coal wastes, uranium mining and environmental management. His work has been showcased in several international journals and conferences. Gavin maintains an independent perspective, and has undertaken research for mining companies, community groups and aboriginal organisations. In particular, Gavin has had extensive involvement in examining the underlying scientific issues associated with uranium mining in Australia, with detailed knowledge of the Australian uranium mining sector as well as globally. With strong qualifications and experience, he has developed a unique understanding of the multidisciplinary nature of the environmental aspects of mining in Australia and globally, culminating in a distinctive view on how to quantify an apparent oxymoron – that of "sustainable mining". Additionally, Gavin has active research interests in urban groundwater issues, groundwater management and assessment, especially with respect to climate change and sustainability.

Qualifications

	Doctorate (PhD)	Victoria University of Technology (awarded Oct. 2001)
	B. Env. Eng. (Hons)	RMIT University (awarded May 1995)

Previous and Current Appointments

- January 2006 to present – **Lecturer/Course Director in Environmental Engineering**, *Civil Eng*, *Monash University*, including a wide range of teaching and research.
- May 2003 to December 2005 – **Assistant Lecturer in Environmental Engineering**, *Civil Eng*, *Monash University*, including a wide range of teaching and research.
- Approximately 20 months **consulting experience** - contaminated sites, environmental assessment, groundwater, solute transport and unsaturated flow modelling, laboratory testing of mine wastes, liaison with government and industry organisations, working with and for Aboriginal people.
- July 2000 to April 2002 - **Research Fellow in Mine Waste Hydrology**, *Civil Eng*, *University of Queensland* - theoretical studies, laboratory testing and modelling of mine wastes and tailings, student research supervision, lecturing in geomechanics.
- March to July 1998 (Semester One) - **Lecturer in Earth Sciences/Geomechanics**, Victoria Uni.
- March 1995 to June 2000 - **PhD Research** - groundwater geochemistry, solute transport modelling, field studies of coal ash leachability, modelling of leaching, unsaturated flow and evaporation processes in ash disposal.

Professional Memberships

- Society for Sustainability and Environmental Engineering (part of professional body Engineers Australia)
- International Association of Hydrogeologists (IAH)
- Australian Mining History Association (AMHA)

Research Interests

- **Urban Groundwater** – groundwater geochemistry, aquifer storage & recovery (ASR), groundwater-dependent ecosystems, biofilters, modelling.
- **Sustainable Mining** – environmental impacts, management of mine wastes, acid mine drainage, sustainability frameworks.
- **Groundwater Resources** – groundwater sustainability, modelling.
- **Waste Management** – geochemistry & leachability, modelling, remediation.

Research Grants & Involvement (Current)

- **Urban Groundwater** – aquifer storage & recovery (ASR) and groundwater geochemistry in alluvial aquifers of Melbourne : *Institute for Sustainable Water Resources* (ISWR) Project.
- **Facility for Advancing Water Biofiltration (FAWB)** – urban water biofilters *Institute for Sustainable Water Resources* (ISWR) Project (funded through Vic Govt STI).
- **eWater CRC** – groundwater-surface water interaction project.

Post-Graduate Research Supervision

- **4 PhD Students** – various projects, including aquifer storage and recovery (ASR), biofilter modelling, groundwater recharge-climate change links and biosolids re-use; **1 Masters Student** – indigenous water resource management on Roti Island, Indonesia.

Publications

- **16 journal papers, 25 refereed and 24 non-refereed conference papers/presentations**, with numerous more conference/journal papers under review or nearing completion.

Undergraduate Teaching

- **Environmental Engineering** – Environmental Impact Assessment & Management Systems (ENE3608), Risk Assessment (ENE4607), Research Projects (ENE4603 & ENE4604).
- **Civil Engineering** – Groundwater (CIV3248), Research Projects (CIV4210).
- **Guest Lectures** – 1st Year Environmental Science (ENE1022), CIV3203, CIV4261.

Administration

- **Course Director – Environmental Engineering** (BEnvEng)
- **Double Degree Adviser** – BEng/BSci, BEng/BComm, BEng/BArts, BEng/BLaw (for Civil Eng)
- **Engineering Academic Progress Committee (APC)**

Committees

- **Present** (Nov 2006 to present) - **Society for Sustainability and Environmental Engineering (Victorian Branch)** – Victorian committee of national society, part of Engineers Australia.
- **Prior** (May 2004 to Dec 2006) - **Great Artesian Basin Co-ordinating Committee (GABCC)** – national inter-governmental committee for oversight of groundwater management of the GAB.

Consulting

- **Uranium Mining** – active role in providing detailed technical review and advice on uranium mining issues in the Kakadu National Park world heritage area (Ranger, Jabiluka).
- **General Mining** – as requested, providing technical advice on environmental issues and mining (eg. gold mining in WA, Indonesia and Papua New Guinea; copper heap leaching; mineral sands mining).
- **Groundwater** – as requested, providing technical advice on groundwater chemistry and impacts from mining or other sites, groundwater resources and management.

Publications – Journal Papers (peer reviewed)

Mudd, G M, 2008, *Sustainability Reporting and Water Resources : A Preliminary Assessment of Embodied Water and Sustainable Mining.* **Mine Water & Environment**, In Press (June 2008).

Mudd, G M & Diesendorf, M, 2008, *Sustainability of Uranium Mining : Towards Quantifying Resources and Eco-Efficiency.* **Environmental Science and Technology**, 42(7), pp 2624-2630.

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Mudd, G M, 2007, *An Assessment of the Sustainability of the Mining Industry in Australia.* **Australian Journal of Multi-Disciplinary Engineering**, 5 (1), pp 1-12.

Mudd, G M, Chakrabarti, S & J Kodikara, 2007, *Evaluation of Engineering Properties for the Use of Leached Brown Coal Ash in Soil Covers.* **Journal of Hazardous Materials**, 139 (3), pp 409-412.

Falk, J, Green, J & **Mudd, G M**, 2006, *Australia, Uranium and Nuclear Power.* **International Journal of Environmental Studies**, 63 (6), pp 845-857.

Mudd, G M, 2005, *A Detailed Analysis of Radon Flux Studies at Australian Uranium Projects.* **Radiation Protection in Australia**, December, 22 (3), pp 99-119.

Mudd, G M, 2005, *The Legacy of Early Uranium Efforts in Australia 1906 to 1945 : From Radium Hill to the Atomic Bomb and Today.* **Historical Records of Australian Science**, 16 (2), pp 169-198.

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Christine Nguyen - CWT ITINERARY FOR YOUNG - DEP - 03JUL

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Thu, Jul 3
Flights: QANTAS AIRWAYS, QF 0450
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    Departure Terminal: TERMINAL 1
    To: SYDNEY, AUSTRALIA (SYD)               Arrives: 5:50pm
    Arrival Terminal: TERMINAL 3 DOMESTIC
    Class: Economy                            Seat(s): Check-In Required
    Status: Confirmed                         Airline Confirmation: 3Q58EG
    Meal: Refreshment - Complimentary         Smoking: No
    Aircraft: BOEING 767 JET                  Mileage: 427
    Duration: 1 hour(s) and 20 minute(s)
    Please verify flight times prior to departure

Fri, Jul 4
Flights: QANTAS AIRWAYS, QF 0447
    From: SYDNEY, AUSTRALIA (SYD)             Departs: 4:00pm
    Departure Terminal: TERMINAL 3 DOMESTIC
    To: MELBOURNE, AUSTRALIA (MEL)            Arrives: 5:30pm
    Arrival Terminal: TERMINAL 1
    Class: Economy                            Seat(s): Check-In Required
    Status: Confirmed                         Airline Confirmation: 3Q58EG
    Meal: Refreshment - Complimentary         Smoking: No
    Aircraft: BOEING 767 JET                  Mileage: 427
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FARE BASIS - YPTNSW03
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GST	- AUD	64.14
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