The Olympic Dam Mega-Expansion Without Uranium Recovery

Dr Gavin M. Mudd
Environmental Engineering, Monash University
December 2010

Primary Questions:

1) Can the next Olympic Dam expansion be developed without uranium recovery?

2) Will this scenario lead to net lower environmental impacts?

Overview

The Olympic Dam project in northern South Australia is based on a very large mineral deposit which contains copper (Cu), uranium (commonly expressed as uranium oxide, U_3O_8), gold (Au) and silver (Ag). The deposit was discovered in 1975, and after protracted political controversy and technical challenges, commercial production began in August 1988 based on an underground mine, flotation concentrator, hydrometallurgical complex, copper smelter and copper refinery (including precious metals). It has long been argued that the only valid approach for operating Olympic Dam is to extract the uranium along with the copper (and gold-silver), since these metals occur together in the ore. This, however, is not correct – it is eminently reasonable to propose a process flow sheet for Olympic Dam which does not include recovery of the uranium but still allows for copper, gold and silver to be produced. This report provides an up-to-date review of the performance of the Olympic Dam project to date, the current process flow sheet, as well as proposing a technically viable alternative for operating Olympic Dam in the next expansion which excludes uranium recovery. The principal environmental issue associated with this proposed configuration is then reviewed – namely concerns over the radioactivity of mine tailings and their long-term management (ie. >10,000 year time frames).

Current Olympic Dam Project

The Olympic Dam deposit was first discovered in 1975 by Western Mining Corporation (later to be WMC Ltd) and, after extended project difficulties and political controversies, production began in August 1988. The current configuration can be simply described as involving underground mining, ore grinding, flotation to produce a U-enriched Cu concentrate and U-rich tailings, acid leaching of the Cu concentrate, which is then processed in a smelter and then refinery, while the flotation tailings are also acid leached and the metal-rich solutions sent to a hydrometallurgical plant for processing to extract the majority of U (as 'U_3O_8') plus a small amount of Cu. Although there is more complexity to the total Olympic Dam process flow sheet for treating the ore and producing the four metals, the above description is reasonable (and based on normal descriptions; eg. Kinhill, 1982, 1997; BHPB, 2009), and is shown in Figure 1.

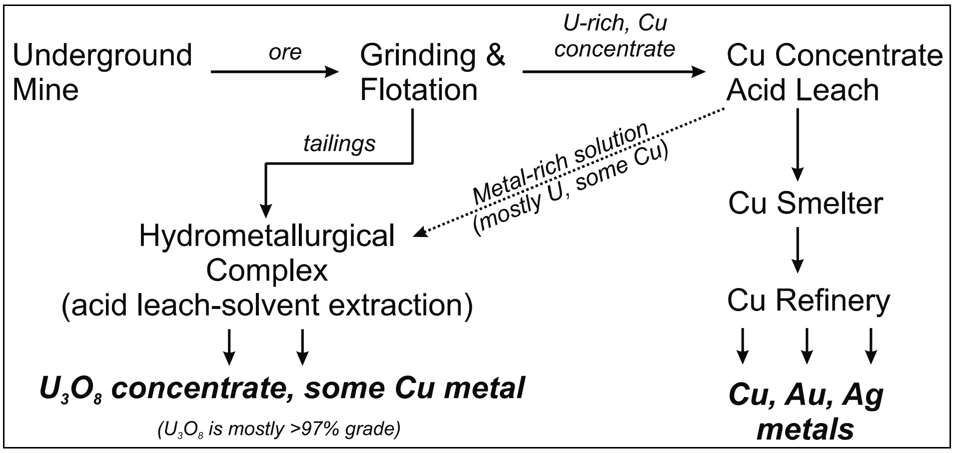

Figure 1: Conceptual representation of the current process for treating ore at Olympic Dam
(adapted from Kinhill, 1982, 1997; BHPB 2009)

By September 2010 the project had treated some 126.07 million tonnes (Mt) of ore, with average grades of 2.40% Cu, 0.069% U_3O_8 and about 5.8 g/t Ag and 0.56 g/t Au, to produce some 2.756 Mt of Cu, 57,912 t U_3O_8, 369.0 t Ag and 38.4 t Au (about 1.23 million ounces of gold). This gives an average extraction efficiency of 91.1% for Cu, 66.7% for U_3O_8, and about 50% each for Ag and Au[1]. The remaining resource is 9,075 Mt grading 0.86%Cu, 0.027% U_3O_8, 0.32 g/t Au and 1.50 g/t Ag.

Quarterly production data over time is shown in Figure 2, showing a gradual decline over time for all ore grades (except gold) and the relative difference in production scale between the first and second decades of the Olympic Dam project. The discrepancies in Cu production >100% are most likely a result of the timing of production between the mine, mill, smelter and refinery (but this remains unexplained). The annual proportional economic value for each metal is shown in Figure 3. The long-term average proportional economic value of production has been as 75.70% copper, 18.39% uranium, 5.13% gold and 0.78% silver.

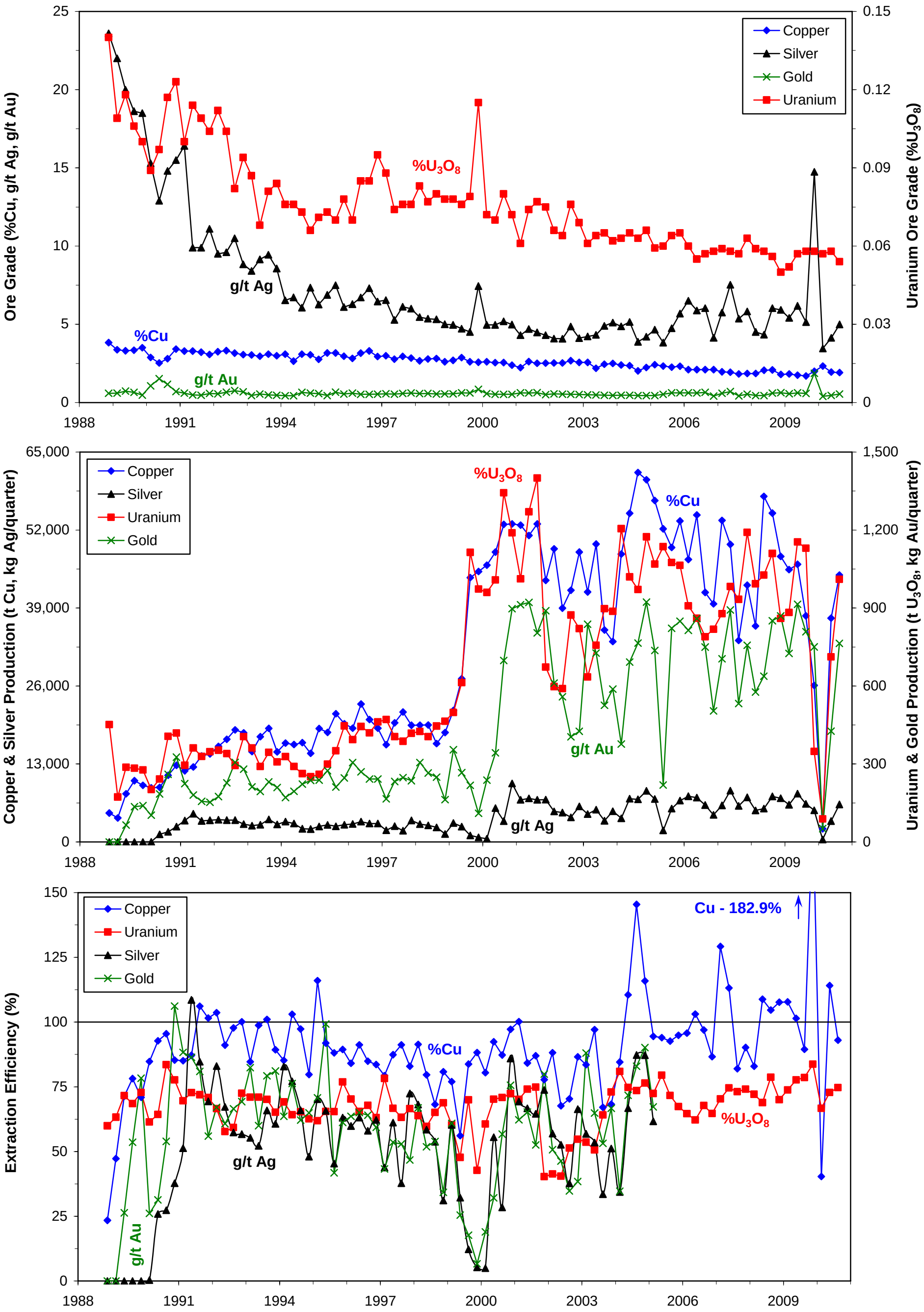

Figure 2: Production data for Olympic Dam (1988-2010) (data from Mudd, 2010a)

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[1] Since the takeover of WMC Ltd by BHP Billiton Ltd in August 2005, gold and silver grades in ore processed are no longer reported, hence Ag-Au ore grade and extraction efficiency estimates are long-term averages from 1988 to mid-2005.

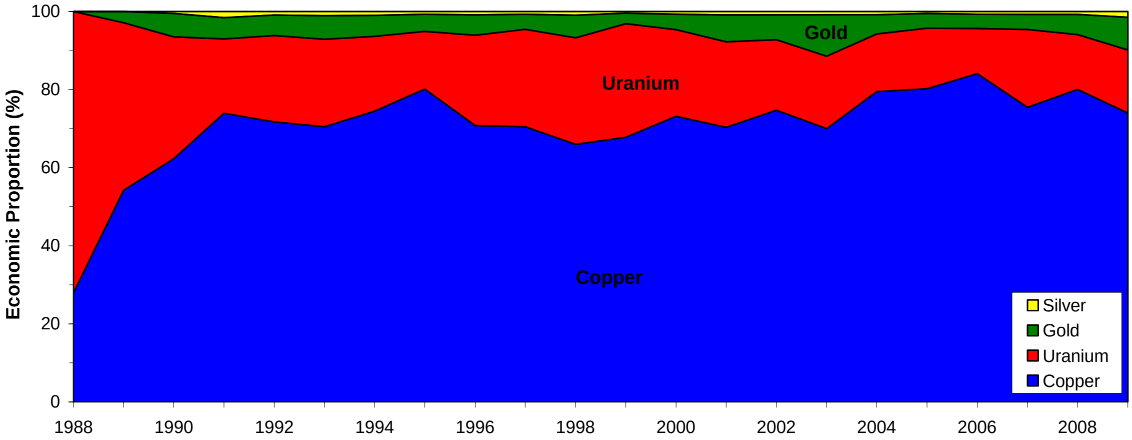

Figure 3: Proportion of revenue by metal for Olympic Dam (1988-2009) (data from Mudd, 2010a)

The major issues which are clear from the above figures are the variable production, long-term declining ore grades, approximately constant recovery efficiency (ie. proportion of metals extracted) and the impact of major accidents in March 1999 (Cu smelter explosion), October 2001 (hydrometallurgical complex explosion) or October 2009 (Whenan Shaft haulage failure).

For the current 'mega-expansion' (BHPB, 2009), BHP Billiton propose to stage the development to the point where most of the Cu concentrate would be exported to China, with only modest Cu smelting and refining at Olympic Dam. In all other aspects, the only major change is the conversion to a mega-scale open cut mine (the underground mine would continue for some years, depending on a variety of factors).

Olympic Dam WITHOUT Uranium Recovery

Part of the historic justification (and need) for uranium recovery onsite at Olympic Dam is to ensure marketable Cu-Au-Ag metals with low radioactivity and prevent significant occupational health and safety risks for workers in smelting radioactive Cu concentrate. Given that the concentration stage (using flotation) produces a mildly U-rich Cu concentrate as well as a U-rich tailings, the current processing complex has always included acid leaching of Cu concentrate to remove U and some radionuclides before smelting. The tailings are then acid leached to remove residual U as well as some minor residual Cu in the tailings. This process was shown in Figure 1 above.

For the current 'mega-expansion' (BHPB, 2009), the fundamental processing steps and overall configuration will not alter in any material sense. That is, the principal steps will still include mining, flotation milling, acid leaching of concentrates and flotation tailings, smelting concentrates and the refinery (as shown in Figure 1). The critical ***exception*** being that most of the U-rich Cu concentrate is planned to be exported to China (or perhaps India also, based on recent media speculation) and only a fraction fully processed through to refined metals onsite at Olympic Dam, shown in Figure 4.

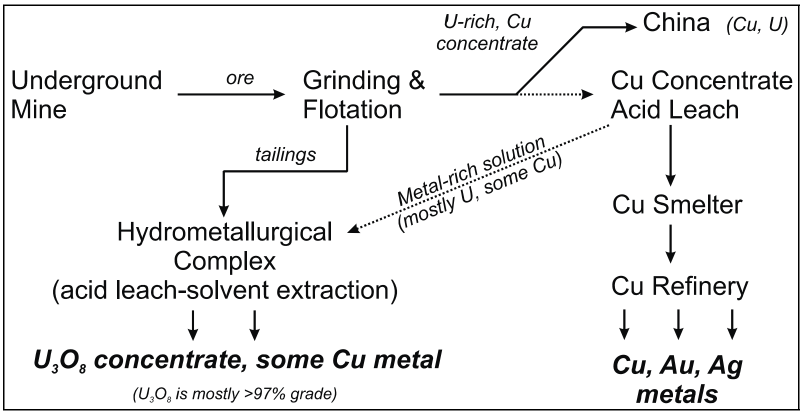

Figure 4: Conceptual representation of the proposed expansion process for treating ore at Olympic Dam and exporting U-rich Cu concentrate to China (adapted from BHPB 2009)

The recent Draft Environmental Impact Statement (BHPB, 2009) does not even consider or hint at the possibility of developing the next expansion without uranium recovery. Given the process steps and current (or even proposed expansion) configuration of Olympic Dam, it is relatively simple and straight forward to propose a process configuration which excludes uranium recovery – shown in Figure 5. A critical issue with this process flow sheet is the requirement for all smelting to be completed at Olympic Dam – this ensures that all uranium is retained on site and is not exported in Cu concentrate.

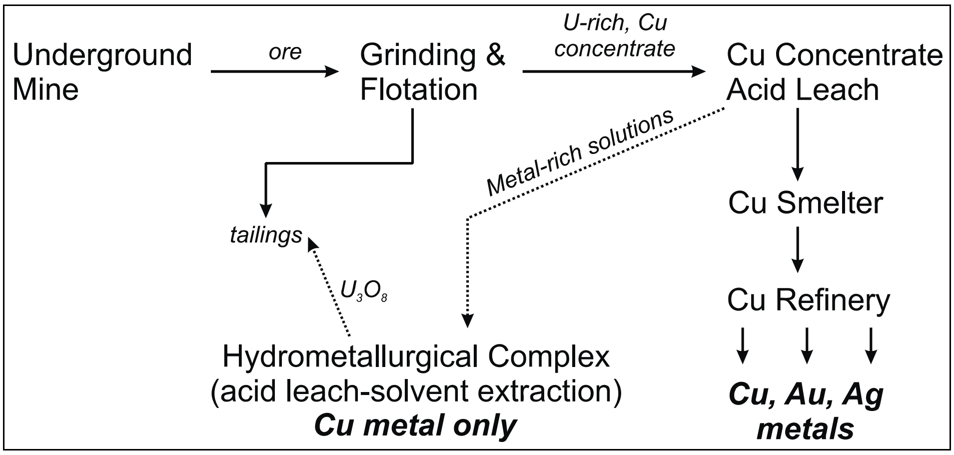

Figure 5: Conceptual representation of the **copper-only** production process for treating ore at Olympic Dam (including gold-silver)

The primary issue overall is the critical balance between economic and environmental aspects. For example, consider a possible scenario where nuclear power becomes uneconomic in the next decade or two, this would mean that the Olympic Dam project would have to survive on the basis of Figure 4 despite historically U being 18.4% of its revenue base. Of course, operating costs would be reduced since the large hydrometallurgical facility could be significantly downscaled (ie. a small amount of Cu only), although worker radiation exposure and long-term tailings management issues would remain.

At present, based on information in the three EIS's to date for Olympic Dam (Kinhill, 1982, 1997; BHPB, 2009), it is very difficult to ascertain the extent of energy/electricity, chemicals and water that would be required in a reduced hydrometallurgical plant only recovering Cu from liquors from the Cu concentrate leach plant since the current and proposed facilities are closely and tightly inter-connected. Furthermore, sustainability reporting only gives totals for the entire project and not a section by section breakdown.

For the existing operation, electricity and water requirements for the hydrometallurgical plant are 43 GWh/year and 26.2 ML/day, respectively, with an export of 3.6 ML/day of Cu-electrolyte solution direct to the Cu refinery to produce some 55,000 t Cu/year (Figure 2.3, page 31, BHPB, 2009). Together, this represents 5.2 and 50.4% of existing annual electricity and water consumption, respectively. For the combined operations in the proposed expansion, electricity and water requirements for the hydrometallurgical plant are 689 GWh/year and 43 ML/day, respectively, with the export of Cu-electrolyte solution to the refinery staying at 3.6 ML/day to produce some 20,000 t Cu/year (Figure 5.2, page 91, BHPB, 2009).

On this basis, a comparison is shown in Table 1 between the proposed expansion and a crude estimate of electricity and water requirements for a project configuration with no large hydrometallurgical plant extracting uranium and some copper.

Therefore, if the hydrometallurgical plant only extracted Cu and not U, it would appear that there is a substantial potential to reduce water consumption by 18.9 ML/day (some 10.7%) combined with useful savings in electricity consumption of 293 GWh/year (some 7.1%). Given the chemicals used during solvent extraction, precipitation and calcining of uranium oxide (eg. amines, ammonia), this would also represent further significant cost and environmental savings.

Table 1: Comparison of Approximate Electricity and Water Requirements[#]
for the Existing Configuration and Expansion Project With and Without Uranium Recovery

Project / Process Stage	**Existing**		**As Proposed in EIS**		***Without U Recovery***	
	Water	**Electricity**	**Water**	**Electricity**	**Water**	**Electricity**
	ML/day	**GWh/year**	**ML/day**	**GWh/year**	**ML/day**	**GWh/year**
Underground and/or Open Pit Mine	0.8	170	30	453	30	453
Concentrator	17.2	287	96	2,652	96	2,652
Hydrometallurgical Plant	26.2	43	43	689	~15[§]	~100[§]
Cu Smelter & Acid Plant	7.5	220	7.5	244	***16.6[‡]***	***540[‡]***
Cu Refinery	0.3	105	0.3	95	0.3	95
Total	***52.0***	***825***	***176.8***	***4,133***	***157.9***	***3,840***

Note: [#]data combined from BHPB (2009), Mudd (2009b) and this study. [§]Very approximate estimate only.
[‡]Assuming all 730,000 t Cu/year is smelted onsite (ie. (730,000/330,000)x244=540).

In addition, if 18.9 ML/day less water was delivered from the desalination plant (compared to the projected supply of 186 ML/day), this would lead to further savings in electricity consumption of ~25 GWh. Alternately, the 18.9 ML/day could be saved from the Great Artesian Basin, allowing the permanent closure of Borefield A and a significant reduction in extraction at Borefield B to about 11 to 15 ML/day (from the current ~30 ML/day).

In the no uranium recovery scenario, all liquid wastes from the Cu concentrate acid leach and Cu solvent extraction plants would be high in uranium and associated radionuclides. The most appropriate way to manage this would be to discharge it to the tailings storage facilities.

A final aspect is the potentially significant reduction in radiation exposures of workers, since the areas of the hydrometallurgical plant dedicated for uranium production would not be required. There will be no effective change to radon fluxes or loads derived from the tailings, since this is dominantly controlled by radium-226 (^{226}Ra) behaviour. For example, ^{226}Ra activity in ore is about 7.2 MBq/t, and since there is no extraction of ^{226}Ra, the activity in tailings will remain the same (further technical details on radioactivity issues are provided later).

The above estimates are, of course, very approximate since the EIS does not even present a scenario for the expansion of Olympic Dam whereby uranium is not recovered and purified in any manner. The above table and discussion, however, clearly shows the potential to reduce water and electricity consumption.

Given the fundamental issues still plaguing nuclear power, such as intractable high level nuclear waste, ongoing major nuclear weapons risks by either state or non-state groups and major economic uncertainty, the scenario for no uranium recovery is clearly realistic and more than a mere possibility – especially when compared to growth trajectories, economies of scale and reducing capital and operating costs for various renewable energy technologies (especially baseload solar thermal plants; see Wright & Hearps, 2010).

The fundamental question is therefore not whether the next Olympic Dam expansion can be developed without uranium recovery – as this is clearly a realistic and technically feasible development option – but why both BHP Billiton and government agencies are not requiring this to be given detailed consideration in the environmental assessment process.

Key Environmental Issue: Radioactive Mine Tailings

The principal environmental impacts which require pro-active management for the current Olympic Dam project include: groundwater management of Great Artesian Basin borefields; energy consumption and associated greenhouse gas emissions; water consumption and quality; air emissions (dust, sulfur dioxide, fumes, etc); radiation exposure issues; mine waste and tailings management; biodiversity impacts; transport logistics; and hazardous waste management (eg. spent chemicals, process residues, contaminated equipment, etc). For the proposed expansion project, all of these remain except at a significantly larger scale, including major project components offsite such as the desalination plant proposed near Whyalla and energy/electricity supply.

If the Olympic Dam project were to proceed with no uranium recovery, the range of environmental impacts would essentially stay the same, with minor increases to the radioactivity of the mine tailings (due to no uranium recovery and liquid wastes from acid leaching of concentrates being discharged to the tailings) and slightly lower volumes of spent chemicals, process residues and contaminated equipment.

The long-term tailings management issues for Olympic Dam are unique in global mining terms, since the potential mass could be as high as some nine billion tonnes (9 Gt, or 9,000 Mt). Only the gold fields of the Witwatersrand Basin of South Africa, which also includes low grade uranium in the ore, come close at some 6.5 Gt of radioactive tailings (data updated from Mudd, 2007; Mudd & Diesendorf, 2008) – the vast majority of which remain above ground and surrounded by urban communities and informal settlements, shown in Figure 6. The Witwatersrand is also in a semi-arid climate somewhat similar to Olympic Dam.

To facilitate understanding of the radioactivity[2] of uranium tailings, the radioactive decay chains of the two primary uranium isotopes, uranium-238 and uranium-235, are shown in Table 2 (including the primary thorium-232 decay chain for comparison). Natural uranium contains about 99.3% ^{238}U and about 0.7% ^{235}U (Mudd, 2008). As can be seen, after uranium recovery, the dominant isotope after about a year is thorium-230 (that is, ^{234}Th and ^{234}Pa would have decayed completely). The generation of highly radioactive radon gas (^{222}Rn) is through the decay of ^{226}Ra, which in turn is governed by the residual ^{230}Th. Given that the half-life for ^{230}Th is 75,000 years, it would take at least 10 ten half-lives, or some 750,000 years, for the ^{230}Th to decay sufficiently to the reduced radioactivity level of its parent ^{238}U.

Table 2: Uranium (^{238}U, ^{235}U) and Thorium (^{232}Th) decay chains §

	Half-Life		**Half-Life**		**Half-Life**
^{238}U	4.51 billion years	**^{235}U**	710 million years	**^{232}Th**	14.1 billion years
^{234}Th	24.1 days	^{231}Th	25.5 days	^{228}Ra	5.77 years
^{234}Pa	70.2 seconds	^{231}Pa	32,500 years	^{228}Ac	6.12 hours
^{234}U	247,000 years	^{227}Ac	21.6 years	^{228}Th	1.91 years
^{230}Th	75,000 years	^{227}Th	18.5 days	^{224}Ra	3.64 days
^{226}Ra	1,600 years	^{223}Ra	11.4 days	^{220}Rn	54.9 seconds
^{222}Rn	3.82 days	^{219}Rn	4.01 seconds	^{216}Po	150 milli-seconds
^{218}Po	183 seconds	^{215}Po	1.8 milli-seconds	^{212}Pb	10.6 hours
^{214}Pb	28 minutes	^{211}Pb	0.602 hours	^{212}Bi #	1.01 hours
^{214}Bi	19.7 minutes	^{211}Bi	129 seconds	^{208}Tl	3.1 minutes
^{214}Po	164 micro-seconds	^{207}Tl	286 seconds	^{206}Pb	***stable***
^{210}Pb	22.3 years	^{207}Pb	***stable***		
^{210}Bi	5.01 days			^{212}Bi #	1.01 hours
^{210}Po	138 days			^{212}Po	0.304 micro-seconds
^{206}Pb	***stable***			^{208}Pb	***stable***

Approximately 64% of ^{212}Bi decays by α and 36% by β.

Note: micro is one millionth, milli is one thousandth. § Other minor decays not shown.

Radon gas is a particularly potent hazard of uranium mining, and is the principal cause of elevated lung cancer rates in exposed miners. This is due to the high energy of radon's decay progeny leading to significant biological damage when inhaled (see Mudd, 2008 for a more thorough review of radon issues).

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[2] Radioactivity is measured in becquerels, which is one radioactive decay per second, and given the symbol 'Bq' (1 MBq = 1,000,000 Bq, 1 kBq = 1,000 Bq). Radioactivity based on complete ^{238}U and ^{235}U radioactive decay series.

Figure 6: Radioactive gold tailings in the West Rand, Johannesburg, South Africa, showing major dust, radiation, safety and acid mine drainage problems (October 2010; all photos author).

The radioactivity of Olympic Dam ore (assuming secular equilibrium[3] from uranium only), based on the average grade to date of 0.069% U_3O_8 (or 690 g/t), can be estimated at about 104 MBq/t, while current tailings are about 94 MBq/t (based on 66.7% extraction efficiency; all data taken from Mudd, 2010). For comparison, natural soils and rocks contain uranium at about 3 g/t, giving radioactivity of about 0.5 MBq/t, while Witwatersrand ores typically contain 0.01 to 0.05% U_3O_8 for radioactivities 15 to 75 MBq/t.

When the uranium is removed from its original ore, the decay product radionuclides remain (such as thorium, radium, etc; see Mudd, 2008), meaning that the series is now in 'disequilibrium'. For example, both ^{230}Th and ^{226}Ra would stay at ~7.2 MBq/t while the ^{238}U isotope would reduce to ~2.4 MBq/t. It would take at least 10 half-lives (or ~750,000 years) for the radioactivity of ^{230}Th to reduce to the parent isotope and re-establish secular equilibrium (ie. ~2.4 MBq/t).). That is, the tailings will remain close to the radioactivity of the original ore for at least 750,000 years even if uranium is extracted – especially with respect to radon gas generation rates.

In any realistic human or ecological timeframe (eg. centuries to millennia, let alone ~750,000 years and beyond) the tailings therefore MUST be considered as low-level radioactive waste, irrespective of whether uranium is extracted or not.

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[3] Secular equilibrium is where all radioactive decay products from the parent uranium isotope are in radioactive equilibrium – that is, all decay products are at the same unit radioactivity as ^{238}U (or ^{235}U).

The elevated radioactivity in Olympic Dam tailings is indeed very rare in the global mining industry (outside of the uranium sector), and is some 200 times natural background levels. The tailings therefore need to be considered as low-level radioactive waste – not merely normal mine tailings from gold, copper or iron ore projects. Given that the half-lives of the various radioactive decay products range from days to millions (or even billions) of years, this means that the tailings will remain radioactive above normal background levels for considerable periods of time – certainly far longer than any realistic human, biological or ecological time scale.

The principal impacts from uranium tailings (and ore also) relate to its radioactivity, especially radon gas and its progeny (decay products), as well as normal heavy metals, salts, and dust with copper mine tailings. It is well established in scientific literature that increased exposure to radon progeny increases lifetime lung cancer risk, based on various studies of the health of former uranium mine workers or varying background radon activities (Mudd, 2008). For this reason, regulators have often set much higher standards for uranium tailings management than conventional mine tailings.

At the Ranger project, the Ranger Uranium Environmental Inquiry (Fox *et al.*, 1977) argued strongly that due to the uniqueness of radioactive tailings, they should be stored back below ground surface by using in-pit tailings management after mine closure. Following completion of mining and milling activities at Ranger (presently expected by January 2021), tailings are required under the current authorisation to be returned to mined out pits (clause 5.4.4) and rehabilitated in such a manner that[4]:

- *the tailings are physically isolated from the environment for at least 10,000 years (clause 5.4.1);*
- *any contaminants arising from the tailings will not result in any detrimental environmental impact for at least 10,000 years (clause 5.4.2).*

The amount of tailings produced at Ranger to date is about 41 Mt (and will approach some 60 to 100 Mt by closure in 2021, depending on expansion plans currently being investigated) – compared to Olympic Dam's present total of some 126 Mt. The present management of Olympic Dam tailings is above ground storage facilities (about 92%, with ~8% used as backfill in underground mine voids), as shown below in Figure 7, with plans for eventual rehabilitation and closure progressively over the project's life. Given the potential for some 9,000 Mt (ie. 9 billion tonnes) of radioactive tailings on the surface in perpetuity, it is imperative that the same principles used at Ranger to justify long-term in-pit management of uranium tailings is applied at Olympic Dam.

That is, all tailings should be returned to below ground – especially for the expansion open cut project.

Another similar site to Olympic Dam, in terms of climate, is the former Radium Hill uranium project in north-eastern South Australia. The deposit was discovered in 1906 and mined intermittently for radium in the 1910s to 1930s, and was developed into a large scale mine in the 1950s to supply the British nuclear weapons program at the height of the Cold War. The Radium Hill project closed in early 1962, and the tailings simply abandoned. Given ongoing erosion problems and the dispersion into the surrounding environment and pastoral stations, rehabilitation work was completed in 1982, mainly by covering the tailings dams with soil covers. By the 2000s, however, major new erosion scars had formed, exposing the radioactive tailings again for dispersion into the environment (Lottermoser & Ashley, 2006), as shown in Figure 8.

As can be seen at Johannesburg as well as Radium Hill, leaving radioactive tailings above ground in arid environments requires permanent and active maintenance as well as high quality rehabilitation – although at both sites these basic community expectations are yet to be achieved. The best place, therefore, is below ground management – in accordance with the findings of the Ranger Inquiry (see Fox *et al.*, 1977).

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[4] Sourced from Ranger Authorisation 0108-10 (available from the Northern Territory Department of Resources (DoR) or the Commonwealth Office of the Supervising Scientist (OSS)).

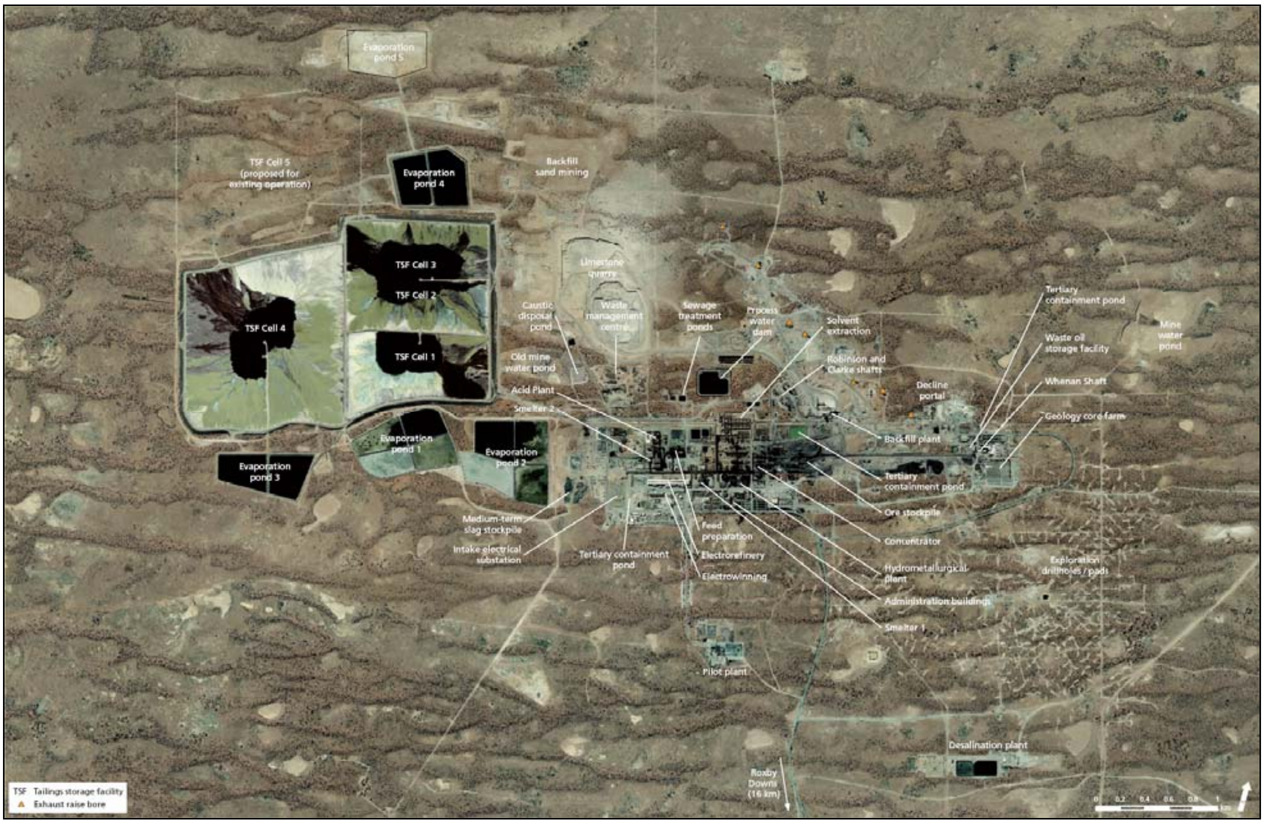

Figure 7: Aerial view of the Olympic Dam project (BHPB, 2009).
(Note the scale of the existing tailings storage facilities or 'TSF' cells, ie. ~2.5 km east-to-west)

Rill erosion exposing tailings (grey), Radium Hill (top left, Lottermoser & Ashley, 2005); Similar erosion scar, ~2.5 m (bottom left, photo author); physical dispersal of pale grey-blue tailings at Radium Hill (above; Lottermoser & Ashley, 2005)

Figure 8: Ongoing erosion problems exposing radioactive tailings at the rehabilitated Radium Hill project, north-eastern South Australia

Conclusions and Summary

The Olympic Dam project presently extracts copper, uranium, gold and silver from a large mining and processing complex. Based on very large mineral resources (~9 Gt ore), a further expansion is being proposed by owner BHP Billiton Ltd to convert Olympic Dam to a large open cut project with associated increases in processing on-site but exporting most of the U-rich Cu concentrate to China (or possibly even India). It is technically possible, however, to process Olympic Dam ore without uranium recovery by removing the acid leach step for tailings and not purifying the uranium during the hydrometallurgical processing of Cu concentrate liquors (ie. only recovering Cu from this step). Developing the next Olympic Dam expansion in this manner, by not recovering uranium, would require all infrastructure and processing to occur on-site also – rather than exporting the hazardous smelting stage to China (or India). This leaves all uranium and its associated radioactive decay products to deport to the tailings. In reality, this will only mean a very minor change to the radioactivity of the tailings – which must be managed as low level radioactive waste in any case. There is a scientifically strong case to emplace all tailings in the former mine pit once mining has ceased, to ensure the safest long-term management regime for the (potentially) billions of tonnes of radioactive mine tailings. Overall, not recovering the uranium is not only technically feasible but could also help reduce energy and water inputs as well as pollution outputs for the next expansion, as well as helping to address the various environmental, public health, environmental and security hazards associated with uranium and the nuclear chain in general.

Acknowledgements

This report was peer reviewed by environmental experts in minerals processing from Australia and Spain (5 in total). The normal convention in peer reviewed journals is for anonymous acknowledgement – and in this regard their frank but fearless comments were well received, appreciated and helped to improve this report considerably. ***No peer reviewer was paid for their work, nor was the author.***

References

BHPB, 2009, *Olympic Dam Expansion – Draft Environmental Impact Statement 2009*. BHP Billiton Ltd (BHPB), Adelaide, SA, May 2009.

Fox, R W, Kelleher, G G & Kerr, C B, 1977, *Ranger Uranium Environmental Inquiry – Second Report*. Australian Government, Canberra, ACT, 17 May 1977, 415 p.

Kinhill, 1982, *Olympic Dam Project – Draft Environmental Impact Statement*. Prepared by Kinhill-Stearns Joint Venture for Roxby Management Services Pty Ltd, Adelaide, SA, October 1982, 551 pp.

Kinhill, 1997, *Olympic Dam Expansion Project – Environmental Impact Statement*. Kinhill Engineers Pty Ltd (Kinhill) for Western Mining Corporation (WMC), May 1997, Adelaide, SA.

Lottermoser, B G & Ashley, P M, 2005. *Assessment of Rehabilitated Uranium Mine Sites, Australia*. Proc. “Uranium in the Aquatic Environment: Uranium Mining and Hydrogeology IV (UMH-4) – 4th International Conference”, (Editors B J Merkel, A Hasche-Berger), September 2005, pp 357-362 (Springer: Freiberg).

Lottermoser, B G and Ashley, P M, 2006. *Physical Dispersion of Radioactive Mine Waste at the Rehabilitated Radium Hill Uranium Mine Site, South Australia*. Australian Journal of Earth Sciences, 53 (3), pp 485-499.

Mudd, G M, 2007, *Global Trends in Gold Mining : Towards Quantifying Environmental and Resource Sustainability?* Resources Policy, 32 (1-2), pp 42-56.

Mudd, G M, 2008, *Radon Sources & Impacts: A Review of Mining and Non-Mining Issues*. Reviews in Environmental Science & Biotechnology, 7 (4), pp 325-353.

Mudd, G M, 2009, *The Sustainability of Mining in Australia : Key Production Trends and Environmental Implications*. Department of Civil Engineering, Monash University and Mineral Policy Institute (MPI), Research Report No. 5, Revised Edition, April 2009.

Mudd, G M, 2010, *Compilation of Uranium Production History and Uranium Deposit Data Across Australia*. SEA-US Inc, Last Updated October 2010, 46p.

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

Wright, M & Hearps, P (Lead Authors), 2010, *Australian Sustainable Energy – Zero Carbon Australia Stationary Energy Plan*. Beyond Zero Emissions (BZE) and Melbourne Energy Institute, University of Melbourne, Melbourne, VIC, www.beyondzeroemissions.org.