26 RADIATION

26.1 GENERAL

26.1.1 RADIOLOGICAL CONSIDERATIONS FOR THE NORTHERN TERRITORY TRANSPORT OPTION

Issue:

Clarification was sought on the process for controlling radioactive contamination during the transport of copper concentrate to the Port of Darwin, including any build-up that might occur.

Submission: 1 and 2

Response:

BHP Billiton would control the movement of its products, thus preventing radioactive contamination during transport, by using a fully enclosed concentrate transport system, as detailed in Sections 5.9.5, 22.6.10, Section E4.2.3 of Appendix E and Figure E4.5 of the Draft EIS.

The concentration of radionuclides in the copper concentrate that would be produced by the proposed expansion of Olympic Dam is low, but is nonetheless sufficient for the material to be classified as radioactive for transport purposes. This means that the transportation of the concentrate must conform to relevant South Australian and Northern Territory legislation on radioactive material, and in both cases there is a requirement to comply with the Code of Practice for the Safe Transport of Radioactive Material (ARPANSA 2008).

To minimise the possibility of contamination along the transport corridor, and to ensure potential exposures were as low as reasonably achievable (ALARA), BHP Billiton would adopt an 'enclosed system' for loading, transporting and unloading the copper concentrate. This system was described in Sections 5.9.5, 22.6.10, Section E4.2.3 of Appendix E and Figure E4.5 of the Draft EIS, and would incorporate the following components:

- an enclosed storage shed with dust extraction at Olympic Dam
- rail wagons fitted with dust and watertight lids
- an enclosed shed at the Port of Darwin with an automatic rail wagon unloading system
- an enclosed conveyor system for transferring concentrate between the storage shed and the ship
- rail wagon washdown facilities at both Olympic Dam and the Port of Darwin.

Wagons would be emptied by an automatic system, which rotates them individually on their long axis. No bottom-dumping wagons would be used.

The wagons would be specially designed for ease of cleaning, with smooth external surfaces and minimal horizontal surfaces on which spillage might collect.

The enclosed transport system would be designed so no concentrate could escape during routine operations. It is therefore anticipated that there would be no contamination along the rail line to the Port of Darwin from transporting the concentrate. BHP Billiton would undertake appropriate monitoring to verify this.

Concentrate may be spilled at Olympic Dam when wagons were being loaded. To mitigate this as a source of contamination, the exterior of each wagon would be washed once it had been loaded and the lid fitted. This washdown process would be repeated at the Port of Darwin once the wagons had been unloaded in the enclosed unloading shed. To ensure the adequacy of the cleaning process, the external surfaces of the wagons would be checked at random using a radiation contamination detector. In addition, every wagon would be visually checked to ensure it was clean. Any wagon that did not pass either check would be re-washed.

Any spillage at either Olympic Dam or the Port of Darwin would be cleaned up as part of the normal operating procedures. Spilt material at the Port of Darwin would be combined with product or returned to Olympic Dam for retreatment.

Issue:
The radiation control standards for the workers at the Port of Darwin, including those not involved in the BHP Billiton operations, was questioned, as was the level of radiation exposure to these workers.

Submission: 3

Response:

BHP Billiton would implement strict radiation controls at their East Arm wharf facilities at the Port of Darwin through design features such as enclosed material handling systems and proven management systems, similar to the systems that already exist at Olympic Dam. Radiation exposure to workers at the Port of Darwin, including those not involved in the BHP Billiton operations, are expected to be low (i.e. a measurable level but within compliance limits) to negligible (i.e. below detectable limits) and well within the international dose limits.

Set out below are details of the radiation controls that would operate at the Port of Darwin. An overview of radiation doses for non-BHP Billiton workers is also provided, together with further information on the doses to BHP Billiton workers and members of the public living in Darwin.

Radiation controls

BHP Billiton would operate the facility at the Port of Darwin in a similar manner to the existing operation at Olympic Dam. The strict controls for radiation exposure, together with other safety, health and environmental controls, were outlined in Chapter 22 of the Draft EIS.

BHP Billiton would define the port facility as a radiation work area, which means it would be fenced and access would be controlled. Workers who may come into contact with the copper concentrate would be required to change into work clothes at the beginning of the shift, and shower and change out of these clothes at the end of the shift. Workplace radiation and dust levels would be monitored and workers' radiation doses would be measured, monitored and assessed. Workers would also be trained in radiation safety to ensure that the control systems were effective and that they had adequate understanding of radiation protection and a sound knowledge of safe work procedures.

The basis of good radiation control is ensuring that the facility is adequately designed to minimise exposures to both workers and the general public. As noted in Chapter 5 of the Draft EIS, BHP Billiton intends to construct the port facilities to ensure that the copper concentrate remains enclosed at all times, thereby minimising the chance of the material escaping. The copper concentrate would arrive at the port in covered wagons, be emptied in an enclosed facility and stored in an enclosed shed (the fully enclosed transport system was detailed in Sections 5.9.5, 22.6.10, Section E4.2.3 of Appendix E and Figure E4.5 of the Draft EIS). The storage shed would be ventilated through a dust-scrubbing system. Open stockpiles would not be used.

During ship loading, the copper concentrate would be transferred to the ship hold from the BHP Billiton storage facility along an enclosed conveyor system onto a dedicated ship loader fitted with a telescopic chute. This process would ensure that all of the concentrate entered the hold, with no opportunity for spillage during routine operations.

Radiation doses – BHP Billiton employees and contractors

Potential doses to BHP Billiton workers and contractors at the Port of Darwin have been estimated and were presented in Section E 4.10.1 of Appendix E of the Draft EIS. These estimates indicate that doses would be similar to those received by plant workers at the Olympic Dam metallurgical concentrator, which is approximately 3 millisieverts per year (mSv/y) (noting that the recommended maximum occupational dose limit is 20 mSv/y).

Radiation doses – non-BHP Billiton worker at Port of Darwin (i.e. bystanders)

Radiation exposures for non-BHP Billiton workers at the Port of Darwin (bystanders) have been assessed for a possible exposure scenario involving the copper concentrate materials handling system. Exposures from each of the following exposure pathways have been assessed:

- irradiation by gamma radiation
- inhalation of copper concentrate dust
- inhalation of the decay products of radon emitted from the copper concentrate.

The system for moving copper concentrate from the storage shed to the ship would consist of an elevated enclosed conveyor system with dust suppression and spillage controls to handle approximately 1,200 tonnes per hour of concentrate (as per the description in Section 5.9.5 of the Draft EIS). The conveyor would be elevated (typically 5 m above ground) to allow vehicles to traverse the area.

In this scenario, exposures have been estimated assuming that a bystander was directly beneath the conveyor. This would be the closest that a person not working for BHP Billiton could get to the copper concentrate.

Gamma radiation
Section E4.10.2 of Appendix E5 estimated the gamma radiation exposure from a train carrying concentrate at 5 m distance to be 0.8 µSv/h. As a first estimate, the exposure geometry for a conveyor carrying concentrate is similar to that of a passing train carrying concentrate (even though it would provide a significant overestimate of the potential gamma exposure).

Based on this approximation, a bystander would have to remain under the conveyor for 1,250 hours a year (i.e. the equivalent of 156 eight-hour days) to receive the dose limit for members of the public of 1 mSv/y from gamma radiation alone.

Inhalation of concentrate dust
Under normal routine operations, the potential dust exposure for a bystander would be negligible, as the material handling system is designed to be fully contained and operate under negative pressure. However, if there was a dust leak, (which for the purposes of this assessment was at the NEPM standard of 50 µg/m^3, averaged over 24 hours), then the bystander would have to remain in the dust cloud (which would be noticeable) for approximately 1,000 hours in a year (i.e. the equivalent of 125 eight-hour days) to receive the recommended dose limit for members of the public of 1 mSv/y from dust exposure alone.

Inhalation of radon decay products
Potential doses from inhaling radon decay products emanating from the copper concentrate are considered to be negligible. This is based on estimates of doses to metallurgical plant workers at Olympic Dam, who receive approximately 0.1 mSv/y from exposure to radon decay products.

The figures presented here are conservative and indicate that doses to bystanders would be less than 1 mSv/y. Once operations commenced, routine monitoring of levels would occur to confirm actual doses.

Radiation doses – Darwin residents

Table E4.18 of Appendix E of the Draft EIS presented the estimated doses for residents of Darwin; the maximum potential dose was estimated as 0.2 mSv/y.

Since the publication of the Draft EIS, additional analytical work has shown that the original estimates of radon decay product exposure overestimated actual exposure levels by a factor of 20. (See Appendix M1 of the Supplementary EIS for details).

Dust levels in Darwin from operations at the BHP Billiton port facilities were reassessed and showed that the potential dose from dust would be approximately 0.05 mSv/y, which is lower than the figure published in the Draft EIS. This figure itself is also an overestimate as it assumes that dust would escape from the enclosed system. The revised dose estimates are provided in Table 26.1 of the Supplementary EIS.

Table 26.1 Revised assessment of dose for residents of Darwin (above natural background levels) per year

Dose assessment	Gamma (mSv)	Dust (mSv)	Radon decay product (mSv)	Total (mSv)	Dose limit (mSv/y)
Resident of Darwin (conservative case)	0	0.050	0.002	0.052	1.000
Resident of Darwin (likely case)	0	0	0.002	0.002	1.000

It is noted that radiation dose from natural background sources in Australia is about 2.4 mSv.

Issue:

The question was raised as to what the background levels of radiation are at and around the Port of Darwin.

Submissions: 1 and 3

Response:

An initial investigative study of radionuclide levels associated with the Northern Territory transport option began during the preparation of the Draft EIS, but the results were not available at the time of publication. The results are presented in this Supplementary EIS (see below for a summary and Appendix M2 of the Supplementary EIS for details).

The study involved:

- an initial survey of sediments in Darwin Harbour, just off the East Arm wharf and east of South Shell Island
- monitoring of radionuclides in airborne dust at the wharf site
- monitoring of radon concentrations at the East Arm wharf
- monitoring of radon in Alice Springs, adjacent to the railway line.

Darwin Harbour sediment radionuclide chemistry

Sediment was collected from nine sites on the southern side of the existing East Arm wharf load-out facility and four sites east of South Shell Island (see Figure 26.1 of the Supplementary EIS for locations). The South Shell Island sampling sites were about 1 km from the load-out facility.

Sediments were analysed for the major elements and isotopes of the ^{238}U decay chain, and the analytical results are summarised in Tables 26.2 and 26.3 of the Supplementary EIS.

Table 26.2 Elemental concentrations in Darwin Harbour sediments

Element (ppm)	Load-out facility		South Shell Island	
	Minimum	Maximum	Minimum	Maximum
Lead	7	16	5	12
Thorium	<2	6	<2	5
Uranium	<2	<2	<2	2

Table 26.3 Radionuclide concentrations in Darwin Harbour sediments

Radionuclides (units Bq/kg)	Load-out facility		South Shell Island	
	Minimum	Maximum	Minimum	Maximum
^{234}Th (^{238}U)	39	45	27	38
^{230}Th	30	54	31	39
^{226}Ra	17	19	12	18
^{210}Pb	52	65	27	39
^{210}Po	35	54	20	40

Note: ^{234}Th is used as an indicator of ^{238}U levels.

Hardege (2005) reports the results of marine sediment sampling elsewhere and shows radionuclide concentration ranges in 2003–2004 (total of 38 samples) of:

- ^{238}U 20 to 150 Bq/kg
- ^{226}Ra 20 to 130 Bq/kg
- ^{210}Pb 10 to 90 Bq/kg

The radionuclide levels found in Darwin Harbour are consistent with these levels.

Figure 26.1 East Arm and Darwin city sampling sites, HVAS and track etch monitors

Air sampling for metals and radionuclides in dust

A high-volume air sampler was used to assess air quality on East Arm wharf during the second half of 2009. Data were obtained for two sampling periods of greater than 150 hours. Dust collected on the sampler filters was analysed for metals and five radionuclides.

Table 26.4 of the Supplementary EIS provides the radionuclide results, together with other published results (UNSCEAR 2000, ODO 1988) for comparison purposes.

Table 26.4 Radionuclides in airborne dust at Darwin Harbour (including comparison with other airborne dusts)

Radionuclide (µBq/m³)	April 2009	June 2009	US (range) UNSCEAR 2000	European (range) UNSCEAR 2000	Olympic Dam (ODO 1988)
$^{234}Th(^{238}U)$	<MDL	160	0.9–5	0.3–18	1.5
^{230}Th	<MDL	<MDL	0.6	0.3–1.7	3.3
^{226}Ra	43	79	0.6	0.8–32	1.2
^{210}Pb	840	650	100–1,000	28–2,250	470
^{210}Po	140	180	10–40	12–80	145

Note: ^{234}Th has been used as an indicator of ^{238}U levels. <MDL is less than equipment minimum detectable level.

Air sampling for radon

Six track etch detectors were deployed on East Arm wharf and a further detector was placed at the AECOM office in Darwin proper between 31 July and 6 November 2009. (Track etch detectors are passive monitoring devices used to measure long-term concentrations of radon in air). A further six detectors were deployed in Alice Springs near the railway line between 21 August and 20 November 2009. An extra detector was deployed in a residence in Alice Springs for the same period.

The average radon concentration over the exposure periods ranged between 7 and 29 Bq/m³ for Darwin (East Arm wharf and office), and 12 and 33 Bq/m³ (Alice Springs railway line and residence).

These values are typical for continental Australia (the background radon levels at Olympic Dam before operations commenced ranged from 7 to 23 Bq/m³ [ODO 1988]) and are consistent with an annual background range of 1 to 100 Bq/m³ reported by the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR 2000).

Issue:
Information on the background radiation levels at Outer Harbor in Port Adelaide and at Pimba was requested.

Submissions: 2 and 22

Response:

Background gamma radiation levels range from 0.05 to 0.12 µSv/h at BHP Billiton's facility in Outer Harbour and 0.05 to 0.09 µSv/h at the proposed site of the intermodal facility in Pimba. Details of the monitoring are set out below.

Port Adelaide

BHP Billiton currently exports uranium oxide concentrate (UOC) from a berth at Outer Harbor in Port Adelaide. UOC is securely contained in sealed drums that are locked inside a shipping container. The containers are not opened en route, and therefore there are no opportunities for material to escape from the drums during routine transport.

Gamma radiation and surface alpha radiation surveys were conducted at the Olympic Dam UOC container handling facility at Port Adelaide. No containers of UOC were present when the sampling occurred in order to ensure that background levels were measured.

The gamma radiation results ranged from 0.05 to 0.12 µSv/h in the compound. Around the external perimeter, the levels were 0.07 µSv/h. These are typical of background levels, indicating there is no effect from UOC being exported through the facility. (Note that ARPANSA quotes an average radiation dose of 0.6 mSv/y from natural background gamma radiation for Australia, which equates to a gamma dose rate of 0.07 µSv/h).

The surface alpha radiation measurements inside the compound in the vicinity where UOC containers are stored did not identify any source of alpha radiation.

Intermodal facility site at Pimba

BHP Billiton intends to construct an intermodal facility at Pimba, as described in Section 5.9.3 of the Draft EIS. A preliminary radiation baseline survey of the area was conducted, including a gamma survey and soil sampling.

Gamma radiation levels range from 0.05 to 0.09 μSv/h, which is consistent with gamma radiation levels across most of Australia.

Radionuclide levels in soil samples from the area are provided in Table 26.5 of the Supplementary EIS.

Table 26.5 Background radionuclide levels in soils – Pimba intermodal facility site

Soils (Bq/kg)	Average	Minimum	Maximum
^{238}U	13	10	17
^{226}Ra	27	19	38
^{210}Pb	23	18	35

The soil radionuclide concentrations are consistent with previous sampling results from the general area (PPK Environment and Infrastructure 2002) and average results reported by UNSCEAR (2000) as provided in Table 26.6 of the Supplementary EIS.

Table 26.6 Background radionuclide levels in soils from other sources (averages in parentheses)

Soils (Bq/kg)	PPK Environment and Infrastructure 2002	UNSCEAR 2000
^{238}U	10–25	16–110 (35)
^{226}Ra	16–20	17–60 (35)
^{210}Pb	15–29	n.a.

26.1.2 GENERAL APPROACH TO RADIATION SAFETY

Issue:

It was suggested that if radiation was so important, there should have been a chapter dedicated to it in the Draft EIS.

Submission: 10

Response:

Radiation exposures at Olympic Dam have been managed, measured and controlled successfully for over 25 years, with doses maintained well below the applicable limits.

While radiation is and remains a management priority for BHP Billiton, radiation levels at Olympic Dam are low. From a health and safety perspective, radiation is but one of a number of hazards that must be managed. For this reason it was included as part of the Health and Safety chapter in the Draft EIS.

As described in Section 1.6.3 of the Draft EIS, the structure of the Draft EIS was developed to be generally consistent with that provided in Section 5 of the joint government guidelines for the preparation of an Environmental Impact Statement for the proposed Olympic Dam expansion (the guidelines were provided in full as Appendix A of the Draft EIS).

Radiation was incorporated into a broader chapter on health and safety (refer Chapter 22 of the Draft EIS) and a stand-alone appendix, entitled Uranium and Radiation, was produced (Appendix S of the Draft EIS), which provided an introduction to radiation, radiation exposure, dose assessments and control measures specific to Olympic Dam.

In response to the range of submissions received regarding radiation safety, this dedicated chapter has been provided in the Supplementary EIS to address specific concerns.

Issue:

Clarification was sought on the radiation monitoring program that would be implemented for the expansion.

Submission: 71

Response:

As indicated in Section 22.4.3 of the Draft EIS, the radiation monitoring program would be approved by the appropriate regulatory authority as required under the Mining Code 2005 (ARPANSA 2005).

In summary, the approach to radiation monitoring would be consistent with the existing approach, as was described in Chapter 22 of the Draft EIS. In general, monitoring is conducted for a number of purposes, including:

- assessing exposures and doses
- checking the effectiveness of the radiation control mechanisms (such as ventilation systems)
- obtaining high-quality data for long-term health studies.

This approach has been used effectively for the past 25 years at Olympic Dam, with worker radiation monitoring information being regularly provided to the South Australian regulator.

While the overall approach to radiation monitoring would remain consistent with the existing program, this program would be amended to cover the newly proposed project components (e.g. the open pit). Monitoring involves trained radiation technicians taking radiation readings in the workplace and sending results back to operational personnel. Investigations are initiated when significant changes in levels are detected.

Monitoring in the expanded metallurgical plant would be consistent with that undertaken currently: there would be an area monitoring program and a personal monitoring program.

Area monitoring includes:

- sampling airborne dust
- measuring gamma radiation
- sampling for airborne radon decay products
- conducting surface contamination checks of the workplace and 'clean areas' such as offices, work stations, lunchroom and change rooms.

Personal monitoring involves the use of monitoring devices such as:

- personal dust pumps
- a thermo-luminescent dosimeter (known as a TLD badge) for measuring gamma radiation.

Real-time sulphur dioxide (SO_2) monitoring would also be installed in the expanded smelter to assess the effectiveness of the ventilation systems, to identify process problems that may result in increased levels in the air, and to provide operational information for process personnel.

Operational experience has shown that sulphur dioxide is a good indicator of polonium-210 (^{210}Po) levels in the existing smelter as both are emitted during smelting of the copper concentrate and when disruptions occur with the ventilation of the tapping operations.

For the open pit mine, real-time monitoring equipment would be fitted to larger mining vehicles linked to the computerised fleet management system. Radon decay product levels, gamma levels and dust levels would be monitored in real time, with data downloaded automatically and available for radiation safety personnel and management to monitor. The system would also be configured to trigger alarms when preset levels were exceeded.

Personal monitoring would be undertaken as required for workers not using mining equipment. The level of sampling would depend on the likely exposure levels. Initially, higher levels of sampling would be undertaken and as data were collected the level of monitoring may be adjusted in line with the observed exposure levels. For example, geologists working in the open pit at ore-bearing rock faces could be initially fitted with dust pumps and automatic radon decay product monitors as well as TLD badges. The need for such equipment would then be reviewed following the analysis of collected data.

Area monitoring would also be conducted and would focus on dust levels and radon decay product levels.

The final radiation monitoring program would be developed by BHP Billiton and approved by the appropriate state regulator before mining reached the ore body (i.e. four to five years after the open pit was started).

Issue:

Clarification was sought on the expected long-term radiation exposure levels.

Submission: 21

Response:

In Section 22.6.5 and 22.6.6 and Appendix S of the Draft EIS, the predicted exposures for the workforce and members of the public for the expanded operation were presented and showed that all radiation doses would be well below the respective limits. Exposure levels in Roxby Downs township would increase as a result of the expansion but would remain well below dose limits. Post-closure long-term exposures from the operation are expected to be negligible.

For long-term radiation exposure from the expanded operation, there are different timeframes to consider:

- during operations
- post-closure.

Exposure levels during operations

Based on past experience, it would be expected that over time, occupational radiation exposures would improve (i.e. decrease). Through the normal business practice of continuous improvement and BHP Billiton's commitment to ALARA, systems would develop to maintain doses at low levels.

Exposure levels for members of the public over the operational period to date have been low and marginally above background levels (refer Section 22.4.3 of the Draft EIS). The exposures for members of the public in Roxby Downs as a result of the expansion are expected to increase (as described in Chapter 22 with more details in Section S2.5.2 of Appendix S of the Draft EIS), but still remain well below the dose limit.

Exposure levels beyond closure

Beyond closure, the potential sources of radiation would be the tailings storage facility (TSF), the rock storage facility (RSF) and the mine. However, as noted in the Rehabilitation and Closure chapter of the Draft EIS (Chapter 23), post-closure radiation emissions would be controlled through:

- removal and decontamination of infrastructure
- disposal of contaminated material
- covering of the TSF with adequate material to minimise radon emissions and to provide structural integrity in perpetuity
- ensuring that low-grade non-economic mineralised material was properly enclosed in the RSF, and that the structure of the RSF was secure
- adequate passive mechanisms to prevent intrusion.

Post-closure long-term exposures are expected to be negligible (see Section 26.5.2 of the Supplementary EIS for details).

Issue:

Clarification was sought on the standards that BHP Billiton would use to control radiation exposures in the expanded operation, particularly in the open pit. Further clarification on the use of dose constraints was also requested.

Submissions: 1, 10 and 21

Response:

Radiation controls in the open pit would conform to a number of requirements, in particular those outlined in the Mining Code 2005 (ARPANSA 2005), the recommendations of the International Commission on Radiological Protection ICRP 2007, the basic safety standard of the International Atomic Energy Agency (IAEA 1996), and existing site and BHP Billiton health and safety standards. These were outlined in Chapter 22 of the Draft EIS.

The specific standards that would be applied in the open pit would be inherently different from those used in the current underground mine, where 'action levels' are set for radon decay product concentrations. For example, when the concentrations exceed 2 $\mu J/m^3$, the workers on shift can remain in that area until the end of shift, but if levels are not reduced to below 2 $\mu J/m^3$ by the end of shift, then the new shift cannot enter that area. At 8 $\mu J/m^3$, personnel must clear the area immediately.

This particular operational procedure would not be applicable in the open pit.

In the underground mine, the ventilation system is designed so that when operating correctly, it maintains radon decay product concentrations well below 2 μJ/m^3. Concentrations rise above this level only when there is a defect in ventilation, and the level cannot be reduced until the defect has been rectified. The 'action levels' do not represent boundaries between 'safe' and 'dangerous', but represent a goal for well-managed conditions.

In the open pit, however, there is no mechanical ventilation system and so there is no 'defect' that needs to be rectified to reduce levels. Concentrations would automatically return to normal levels through changes in atmospheric conditions and natural ventilation would be re-established. Elevated levels of radon decay product may occur in the pit during temperature inversion conditions, but these would be expected to disperse quickly after sunrise as the natural heating from the sun dispersed the inversion (for further information refer Section 13.3.2 of the Draft EIS and Section 26.2.1 of the Supplementary EIS).

Practical measures for hastening this process are limited (see Section 26.2.1 of this chapter for details). However, it is possible that additional radiation protection measures may be implemented when higher-than-expected concentrations of radon decay product existed. For example, one possible measure could be to require all personnel to either remain in air-conditioned (filtered) cabs or to wear respiratory protection during such conditions. This approach would be consistent with the As Low As Reasonable Achievable (ALARA) principle, which is implemented by BHP Billiton.

The specific operational standards which would apply in the open pit would be developed in line with the existing radiation management plan.

Dose constraints

The definition of dose constraints has changed since it was originally introduced. Dose constraints were defined in the Mining Code 2005 as:

- a prospective restriction on anticipated dose, primarily intended to be used to discard undesirable options in an optimisation calculation
- in occupational exposure, a dose constraint may be used to restrict the options considered in the design of the working environment for a particular category of employee
- in public exposure, a dose constraint may be used to restrict the exposure of the critical group from a particular source of radiation.

More recently, dose constraints have been used for protecting workers from particular sources of radiation exposure.

The definition of a dose constraint in ICRP 2007 is:

'A prospective and source-related restriction on the individual dose from a source, which provides a basic level of protection for the most highly exposed individuals from a source, and serves as an upper bound on the dose in optimisation of protection for that source. For occupational exposures, the dose constraint is a value of individual dose used to limit the range of options considered in the process of optimisation. For public exposure, the dose constraint is an upper bound on the annual doses that members of the public should receive from the planned operation of any controlled source.'

In practice, BHP Billiton has committed to an internal goal of 50% of the dose limit. This represents a goal for occupational exposure of 10 mSv/y above background for all individuals. Should this goal be exceeded (or was likely to be exceeded), appropriate action would be taken to reduce the dose to levels to ensure that doses remained as low as reasonably achievable.

This dose constraint would represent an internal exposure level above which BHP Billiton would instigate positive action to immediately reduce exposure and below which further optimisation would occur, in accordance with the ALARA principle.

Issue:

It was noted that in the Draft EIS, BHP Billiton committed to the goal of 50% of the current radiation standard.
It was questioned whether this goal would continue to apply if the limit was lowered.

Submissions: 1 and 10

Response:

BHP Billiton has committed to a goal of 50% of the current radiation standard and would continue to comply with the recognised radiation dose limits.

Dose limits are one part of the overall system of radiation protection (ICRP 2007), which includes justification of the radiation exposure, ensuring that any radiation exposure is optimised, and establishment of a set of limits.

The principle of 'optimisation' is a primary means of radiation control and aims to ensure that all doses are as low as reasonably achievable with social and economic factors being taken into account.

In the case of any future reductions to dose limits, BHP Billiton would determine an appropriate revised goal.

26.1.3 VERIFICATION OF DRAFT EIS RADIATION INFORMATION

Issue:

Verification of radiation-related information provided in the Draft EIS has been requested, specifically:

- radon and dust emissions from the tailings, the open pit and stockpiles
- dose estimates for workers and the public.

BHP Billiton has also been asked to explain why radon emanation estimates provided in the Draft EIS are different from the US Environmental Protection Agency (EPA) 'rule of thumb' for radon emanation.

Submissions: 1, 2, 13 and 318

Response:

This issue has been addressed in two parts:

- verification of radiation estimates
- additional information to support radiation exposure estimates.

The rule of thumb referred to in the submission is from the United States Environmental Protection Agency (US EPA 1986) and refers to US government guidance for closure of uranium tailings facilities in the absence of real data.

It is noted that 'rules of thumb' are generally used where actual data are not available. BHP Billiton has undertaken emanation monitoring from tailings over many years and therefore uses actual results in its assessments rather than rules of thumb.

Verification of radiation estimates

Table 26.7 of the Supplementary EIS provides a summary of the estimated radiation figures for the expansion as presented in Chapter 22 and Appendix S of the Draft EIS. It also summarises how the estimates were calculated.

More detailed information justifying the radon emanation figures is provided in Appendix M1 of the Supplementary EIS.

Table 26.7 refers to 'first principles'. First principles are calculations made directly from established physical and mathematical laws. In the case of radiation, this includes such laws as radiation emission constants and the inverse square law (Cember and Johnson 2009).

Table 26.7 Radiation dose information

Radiation parameter (Draft EIS section)	Value	How estimates were determined (and where referenced in Draft EIS)
Doses to miners (22.6.5)	3.5 mSv/y (av) 8 mSv/y (max)	Gamma dose based on first principles and consideration of exposure rates at other mines Dust doses based on estimate of dust concentrations at other open cut mines combined with standard dose conversion factors Radon decay product doses based on estimate of modelled radon levels in pit (including a range of atmospheric conditions) Appendix S 2.2
Doses to smelter workers (22.6.5)	4–5 mSv/y (av) 9 mSv/y (max)	Based on data from existing operations but incorporating improved ventilation design and real-time monitoring Appendix S 2.3
Doses to other metallurgical plant workers (22.6.5)	Less than 3 mSv/y (av) 5 mSv/y (max)	Data from the existing operation
Member of public doses in Roxby Downs (22.6.6)	Less than 0.18 mSv/y	Gamma doses based on existing operation information Dusts doses based on modelled airborne dust concentrations in Roxby Downs combined with standard dose conversion factors Radon decay product doses based on modelled concentrations in Roxby Downs combined with standard dose conversion factors Appendix S 2.5.2
Dose to Indigenous people from consumption of local bush tucker (22.6.6)	0.01 mSv/y	Comparison of doses at Ranger and factored for much lower amount of time spent in the region of Olympic Dam (Appendix S2.5.3)
Dose from regular consumption of locally grown beef (22.6.6)	0.02 to 0.04 mSv/y	Conservative calculation based on modelling of consumption of beef cattle grazing on vegetation close to Olympic Dam (Note – see Section 26.6.1 of Supplementary EIS for updated information)
Member of public at edge of rail easement as train passes (E4.10.2)	0.0008 mSv/y	Gamma estimates based on first principle calculations. Subsequently confirmed with measurements of gamma dose rate from copper concentrate (see Section 26.1.1 of Supplementary EIS)
Member of public living near rail easement (E4.10.2)	0.0018 mSv/y	Gamma estimates based on first principle calculations. Subsequently confirmed with measurements of gamma dose rate from copper concentrate (see Section 26.1.1 of Supplementary EIS)
Member of public living in Darwin (E4.10.2)	0.02 mSv/y	Conservative assessments of doses based on first principles (Note – see Section 26.1.1 of the Supplementary EIS for revised assessment based on more realistic data)
Doses to UOC truck drivers	0.7 mSv/y	Doses based on actual measurements in cabins of trucks and a worst-case number of trips that one driver might make

Additional support information

Appendix M1 of the Supplementary EIS provides further information on the calculations and assumptions involving radiation dose assessment and a summary of the key points is provided in Table 26.8 of the Supplementary EIS.

Table 26.8 Summary of additional radiological assessment information

Radiation parameter	Summary additional information
Mine gamma dose rates	Potential doses were initially determined from Thomson and Wilson (1980). Estimates were compared to other open pit mines and current Olympic Dam underground radiation levels
Mine dust levels and potential doses	Dust concentrations were based on estimates from other open pit operations. The uranium grade of the ore dust and non-mineralised dust was combined to provide an average radionuclide concentration for the dust. The dose conversion methods as outlined in the Mining Code 2005 (ARPANSA 2005) were used to determine potential doses
Radon emanation rates	Radon emanation rates were determined for both unbroken and broken rock. The unbroken rock rates were determined from measured results. For broken rocks, the emanation rate was determined from first principles, taking into account the uranium grade of the rock, the emanation coefficient and an estimated conservative diffusion coefficient. For the purposes of the modelling, broken rock volumes were assumed to be minimal (due to all broken ore being removed from the pit for processing).
Radon in pit	The estimated equilibrium concentration of radon in the pit is based on a combination of the emanation rate, the emanating surface area of the pit and pit ventilation rate.
Radon levels under normal atmospheric conditions	Estimates of pit concentrations were made based on the formula of Thompson (1994), which calculates an air-in-pit residence time based on surface wind speeds. For the predominant wind speed at Olympic Dam, the estimated pit concentration of radon was 8.8 Bq/m^3
Radon levels under inversion atmospheric conditions	Inversion conditions occur on the surface at Olympic Dam, and are predicted to exist in the pit during cold, still atmospheric conditions. Conservative estimates of the depth and the frequency of probable inversions were made, resulting in estimates of potential doses under inversion conditions. Additional work outlined in Section 26.2.1 of Supplementary EIS confirms this.
Radon emanation from the TSF	The Draft EIS provides a radon emanation rate of 0.5 $Bq/m^2/s$ for the TSF in 2000 (Akber 2001). This figure is based on actual measurements and has been confirmed with measurements of radon emanation from earlier studies at Olympic Dam (see Appendix M1 of the Supplementary EIS).

Where possible, estimates have been based on direct measurements as these more accurately represent the exposure situation.

The exact geometry of the proposed pit varies and for the purpose of the dose assessment modelling, the following pit dimensions were assumed:

- pit depth – 1.2 km
- pit radius – 2 km
- pit volume – 6 km^3
- top 350 m of pit is cover (no radon emanation)
- surface area for radon emanation – 7.5 Mm^2

For an assumed wind speed of 2m/s, it has been calculated that it takes approximately 2 hours for the air in the pit to changeover (see section M1.2.3 of Appendix M1 of the Supplementary EIS).

Given the varying grade within the pit, it was also assumed that the average ore grade for the entire pit (excluding cover material) was 200 ppm (giving an average emanation rate of 1 Bq/m^2s).

Note that for the air quality modelling, the total pit emission was initially estimated to be 8.6 MBq/s. Calculating the emission using the above assumptions gives a slightly lower emission rate. Estimated pit radon concentrations are based on the broad assumptions above.

It should also be noted that the estimated concentrations are in addition to naturally occurring radon concentrations.

Issue:

Details and access to the air quality modelling undertaken for the Draft EIS for the open pit were requested.

Submissions: 2 and 318

Response:

Chapter 13 and Appendix L of the Draft EIS provided considerable detail on the air quality model used for the proposed expansion of Olympic Dam. This information is sufficiently detailed to make an assessment of the air quality issues related to the expanded operation.

The models have been subject to extensive peer review and have been utilised in multiple studies of air quality. The model has been verified via independent processes and against other models and monitoring data for other operations.

Issue:

Clarification was sought on how dose conversion factors are calculated.

Submission: 1

Response:

The dose conversion factors are based on the recommendations of the International Commission on Radiological Protection (ICRP). The ICRP is the peak scientific body that continually reviews the scientific data on radiation and its effects and recommends the appropriate system of radiation protection, including dose conversion factors. The ICRP dose conversion factors and the methods for calculating them are then incorporated into international guidance documentation, such as the International Basic Safety Standards for Protection against Ionizing Radiation and for the Safety of Radioactive Sources. The factors are then incorporated into national and state legislation and guidance documentation.

The standardised occupational dose conversion factors (DCF) used in the Draft EIS are specified in the Mining Code 2005 (ARPANSA 2005).

There are three main exposure pathways for workers at Olympic Dam:

- inhalation of radioactive dusts and fumes
- inhalation of radon decay products
- irradiation by gamma radiation.

Another exposure pathway exists through ingestion of radioactive material. This pathway is minor and controlled by workplace cleanliness, worker training and good hygiene practices.

Dose conversion factors are used to convert exposure levels (which are measured with radiation monitoring equipment) into a standardised measure of dose (Section S1.6.3 of Appendix S of the Draft EIS described how dose conversion factors are used and Section S3.2 provided details on the factors used).

For gamma radiation, the exposure is generally equal to the dose, so no dose conversion factor is required.

For radon decay products, the exposure is a measure of the concentration of the radon decay products in air multiplied by the amount of time a person is exposed to that concentration. A standard factor is applied to the time-based exposure to calculate the dose that the person receives. For radon decay products, the Mining Code 2005 recommends a DCF of 1.4 mSv/mJ.h/m^3.

For radioactive dusts, the dose depends on a number of factors, not only on the amount of radioactivity in the dusts. Factors such as chemical characteristics, including solubility and radionuclide composition, and physical characteristics such as particle size need to be taken into account to determine the DCF for dusts.

In the mine, the dust cloud would be relatively homogeneous, and the concentration of the radionuclides in the dust is predictable and in secular equilibrium (that is, the activity of each radionuclide is equal). The Mining Code 2005 (ARPANSA 2005) recommends a dose conversion factor for mine dusts that depends on the particle size. Where no particle size information is available, then a conservative activity median aerodynamic diameter (AMAD) of 1 micron is used.

Even though the dust particle size for the current underground operation is known, it may not be applicable to the open pit, (due to, for example, larger blasts and less confined spaces) therefore a particle size of one micron was assumed.

As an example, for a dust concentration of 2.5 mg/m^3 containing 500 ppm of uranium, the activity of each radionuclide in the ^{238}U

decay chain is 6.5 Bq/g. Using a breathing rate of 1.2 m^3/h for 2,000 hours, giving a total volume of inhaled air of 2,400 m^3, results in an estimated annual intake of 39 Bq (each radionuclide) giving an alpha activity of 195 alpha Bq (since there are five long-lived alpha emitters). Using the conversion factor 7.2 μSv/ alpha Bq, the resulting annual dose is 1.4 mSv.

In the metallurgical plant, the radionuclide composition of the dust is more complex since the ore is subject to physical and chemical processes. BHP Billiton has undertaken extensive characterisation of the existing dusts from the Olympic Dam process and has a good understanding of the dusts produced from the different process streams.

Table 26.9 of the Supplementary EIS provides a summary of the standardised radionuclide composition of the dusts.
As the processing is not expected to change in the proposed expansion, these factors have been used for estimating doses from dusts in the expansion.

Table 26.9 Relative radionuclide content of Olympic Dam dusts (note that the units are Bq per long-lived alpha disintegration per second)

	^{238}U	^{234}U	^{230}Th	^{226}Ra	^{210}Po	^{210}Pb
Concentrator	0.21	0.21	0.17	0.19	0.22	0.38
U_3O_8 Handling	0.49	0.49	0.00	0.00	0.02	0.01
Smelter	0.00	0.00	0.00	0.00	1.00	0.37
Mine	0.19	0.19	0.19	0.30	0.13	0.38

The doses from environmental exposures were calculated based on the following:

- using age-dependent dose conversion factor values from ICRP 72 (ICRP 1996)

dust with 1 μm AMAD and 'S' lung absorption classification (ICRP 1996).

This results in the following factors for a standardised dust cloud of 1 μg/m^3:

0.51 μSv for adults

0.44 μSv for 10-year-old children

0.30 μSv for one-year-old children.

These factors were then applied to the modelled dust concentrations calculated from the air quality dust model (refer Chapter 13 of the Draft EIS) for the relevant locations.

Issue:

The question was asked whether Olympic Dam workers receive radiation dose reports, and whether these results are sent to an independent third party for verification.

Submission: 16

Response:

All radiation workers at Olympic Dam are personally and regularly notified of their radiation exposures. Workers can also access their own records, or the records of monitoring results, which are kept by BHP Billiton's radiation safety section. In all cases, personal confidentiality requirements are observed. This would be the case for the expanded operation.

Currently, worker doses are stored on a central database and the information it contains is provided to the Radiation Protection Branch of the South Australian Environment Protection Authority (EPA).

At a broader level, BHP Billiton is a supporter of the Australian National Radiation Dose Register for Uranium Workers (ARPANSA 2008–2009) and has already commenced uploading worker dose data into the register. The ANRDR is an initiative of the Australian Government and, through ARPANSA, aims to establish a national register for the collection and storage of radiation exposures for all uranium industry workers. Data from Olympic Dam is being uploaded into the register and it should be formally declared operational within the 2010–2011 financial year.

BHP Billiton would submit recorded doses on an annual basis in line with current submissions to state authorities.

The dose assessment process, the calculations and the dose records are verified by the state regulator (the SA EPA) and regular audits.

Issue:

Clarification was sought on whether the estimated doses to members of the public provided in Table S3 (in Section S2.5.2 of Appendix S of the Draft EIS) included background plus impact from the expanded operation.

Submission: 1

Response:

Table S3 in Appendix S of the Draft EIS represented radon contour levels and did not include the natural background levels. This is consistent with the limitation requirements for radiation protection, which say that limits apply above natural background levels.

It is noted that the natural background radon levels vary significantly with time of day, atmospheric conditions and time of year. Further information on this natural variation is provided in Section 26.6 of the Supplementary EIS.

Issue:

Comment was made that the Mining Code 2005 referred to in the Draft EIS is not publicly available.

Submission: 318

Response:

The Mining Code 2005 (ARPANSA 2005) (published as the Code of Practice and Safety Guide, Radiation Protection and Radioactive Waste Management in Mining and Mineral Processing (2005)) is publicly available at the web address: <http://www.arpansa.gov.au/Publications/codes/rps9.cfm>.

Issue:

Further information was requested to enable inputs into the WISE dose assessment system to estimate radon emanation from the TSF.

Submission: 318

Response:

The verification of the radon emanation rate from the proposed TSF is described in Section 26.1.3 of the Supplementary EIS. The figure used in the Draft EIS was 0.5 $Bq/m^2/s$, which was based on actual measurements from Akber (2001).

The 'WISE' website <http://www.wise-uranium.org/index.html> provides a collection of radiation-related assessment calculators. These calculators provide an initial assessment of potential radiation parameters for various situations based on calculations from first principles.

Using the WISE website radon emanation calculator and the default sample data provided, a calculated radon emanation rate for the Olympic Dam tailings can be obtained. With an estimated ^{226}Ra activity of 7 Bq/g, the calculator provides an average ^{222}Rn flux of 0.27 Bq/m^2. This compares favourably with the BHP Billiton estimate of 0.5 Bq/m^2 based on actual measurements.

Given the various practical factors that influence actual levels, real measurements are usually the better source of information.

Issue:

It was suggested that the definitions presented in Appendix S1 of the Draft EIS are not consistent with those provided by the IAEA and that the Mining Code has been misinterpreted. Clarification was also requested on the role of regulators.

Submission: 1

Response:

Comparison of Definitions

Appendix S1 of the Draft EIS was provided as a general introduction to radiation and its concepts for the benefit of the general public. No formal technical definitions were included. The simplified definitions developed for the Draft EIS and provided in Appendix S of the Draft EIS are, however, consistent with the IAEA Safety Glossary technical definitions (IAEA 2007).
A comparison of the definitions is included below.

Activity

Draft EIS description
Activity is the measure of the amount of radioactive material. Its unit is the becquerel (Bq), which is defined as the amount of radioactive material that produces one radioactive decay per second. It may be applied to either a single radionuclide or to a mixture. The activity concentration is the amount of radioactivity in a unit mass (or volume) of material and is measured in becquerels per gram (Bq/g) or per litre (Bq/L).

IAEA description
The quantity A for an amount of radionuclide in a given energy state at a given time, defined as:

$A(t) = dN/dt$

where dN is the expectation value of the number of spontaneous nuclear transformations from the given energy state in the time interval dt.

Absorbed dose

Draft EIS description
Absorbed dose refers to the physical amount of ionisation produced in matter by the radiation, as might be directly measured by an instrument such as a Geiger counter. The unit of absorbed dose is the gray (Gy). Absorbed dose may refer to the dose to an object, a person, or parts of a person (organs or tissues).

IAEA description
The fundamental dosimetric quantity D, defined as:

$D = de/dm$

where de is the mean energy imparted by ionising radiation to matter in a volume element and dm is the mass of matter in the volume element.

Effective dose

Draft EIS description
Effective dose includes factors that take account of the biological effects of radiation on a person. These factors include the type of radiation (alpha, beta or gamma) and the different sensitivities of organs or tissues to radiation. The unit of effective dose is the sievert (Sv). For whole body gamma radiation the absorbed dose (in Gy) equals the effective dose (in Sv).

The effective dose (Sv) gives a measure of the effect (or 'detriment') of radiation on the human body. One mSv has the same detriment no matter if it is, for example, 1 mSv of gamma radiation to the whole body, or 1 mSv to the lung only, or any combination. The limits on dose (to people) that are most relevant in uranium mining are expressed in terms of effective dose, and where the term 'dose' is used alone, 'effective dose' is usually meant.

IAEA description

The quantity E, defined as a summation of the tissue equivalent doses, each multiplied by the appropriate tissue weighting factor:

$$E = \sum_{T} w_T H_T$$

where HT is the equivalent dose in tissue T and wT is the tissue weighting factor for tissue T. From the definition of equivalent dose, it follows that:

$$E = \sum_{T} w_T \sum_{R} w_R D_{T,R}$$

where wR is the radiation weighting factor for radiation R and $D_{T,R}$ is the average absorbed dose in the organ or tissue T.

Role of regulators

Under the Mining Code 2005 (ARPANSA 2005) regulatory authorities are responsible for setting objectives as well as ensuring that approved Radiation Management Plans (RMP) and Radioactive Waste Management Plans (RWMP) are adequate to meet the objectives of the Code.

The relevant regulatory authority (in South Australia, the EPA) is also responsible for auditing compliance with the objectives of the Code.

BHP Billiton recognises that it is primarily responsible for radiation safety and radioactive waste management and in particular for proper implementation of the approved RMP and RWMP. BHP Billiton recognises that the role of the regulator is to monitor compliance with approved plans and to audit that compliance regularly.

26.1.4 BASIS OF RADIOLOGICAL PROTECTION

Issue:

It was questioned how the acceptable radiation risk for workers and the public was determined.

Submission: 45

Response:

The current system of radiation protection, including the principles of limitation based on risk, is the result of intensive scientific research and continual review. The United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) periodically reviews all relevant scientific information on radiation protection. This information forms the basis of recommendations by the ICRP aimed at managing risks. These international standards then form the basis of national and state regulations and guidance. This defines the overall system of radiation protection, including the level of acceptable radiation risk with which all practices involving radioactivity must comply.

All human activities involve some risk, and the question of what level of risk is acceptable in particular circumstances is very complex. However, risk is not unique to situations involving radiation exposure. Acceptable levels of risk for radiation are determined by the expert authorities noted above in a manner similar to that used in setting other limits, such as for road speed and food additives.

Issue:

It was suggested that the ICRP has no legitimacy and is undemocratic, unrepresentative and biased towards nuclear energy.

Submission: 318

Response:

BHP Billiton recognises the ICRP as the pre-eminent independent international body on radiological protection. This is a view held by Australian and international governments and regulatory, private and scientific bodies.

The ICRP is an independent organisation established in 1928 that works to provide well-balanced scientific and quantitative advice on protection against ionising radiation.

The ICRP consists of a Main Commission together with five Standing Committees on:

- radiation effects
- doses from radiation exposure
- protection in medicine
- the application of ICRP recommendations
- protection of the environment.

Committees consist of eminent international scientists, including biologists, medical practitioners and physicists, who are appointed by the commission under strict rules. The committees are supported by Working Parties that contain specialists from outside the ICRP membership, thereby ensuring balance and objectivity. In all, there may up to 100 scientists actively involved with the ICRP at any one time.

The ICRP publishes its recommendations, which are universally recognised as the basis of radiation protection, and take into account fundamental physical and biological principles and quantitative research. National radiation protection bodies that are responsible for developing policy and regulatory frameworks invariably use the ICRP recommendations.

The ICRP is primarily funded by voluntary contributions from national and international radiation protection bodies (Lindell et al. not dated).

Issue:

Clarification was sought as to why the ICRP ALARA ('optimisation') principle had not been adhered to and considered in the Draft EIS.

Submission: 318

Response:

The optimisation principle was adhered to and considered in the Draft EIS. Specifically, Section 22.6.5 of the Draft EIS outlined the approach to optimisation that BHP Billiton would adopt for the proposed expansion. This included:

- conducting radiation training and awareness for design personnel
- conducting radiation risk assessment
- establishing specific radiation-related design criteria
- developing a research program to obtain further information on the radiation-related parameters of the proposed expansion.

In addition, BHP Billiton committed to conducting an optimisation study during the detailed design phase of the open pit and metallurgical plant.

Issue:

Clarification was sought as to why the ICRP 'justification' principle had not been adhered to and considered in the Draft EIS for the whole of the proposed Olympic Dam expansion (including the nuclear fuel cycle).

Submission: 318

Response:

Whether a project is justified is a question to be determined by the Australian, South Australian and Northern Territory governments, based on their assessment of the information contained in BHP Billiton's Draft EIS, Supplementary EIS and the public consultation process. This is in accordance with the process recommended by the ICRP.

'Justification' is the name given by the ICRP to one of the three elements of its 'Principles of radiation protection'. In ICRP publication 103 (ICRP, 2007), the following is noted:

- 'The principle of justification: Any decision that alters the radiation exposure situation should do more good than harm.' (paragraph 203).

- ‘No planned exposure situation should be introduced unless it produces sufficient net benefit to the exposed individuals or society to offset the radiation detriment that it causes.’ (paragraph 205).
- ‘The consequences to be considered are not confined to those associated with the radiation – they include other risks and the costs and benefits of the activity. Sometimes, the radiation detriment will be a small part of the total.’ (paragraph 205).
- ‘... the responsibility for judging the justification usually falls on governments or national authorities to ensure an overall benefit in the broadest sense to society ... input to the justification decision may include many aspects that could be informed by users or other organisations or persons outside of government. As such, justification decisions will often be informed by a process of public consultation ... There are many aspects of justification, and different organisations may be involved and responsible. In this context, radiological protection considerations will serve as one input to the broader decision process.’ (paragraph 208).

The current EIS process follows this guidance. BHP Billiton has produced the Draft EIS based on guidelines produced by the Australian, South Australian and Northern Territory governments and the Supplementary EIS to address issues raised from the Draft EIS. These two documents include discussion of the potential harm (radiological and other) that might be expected to arise from proceeding with the project, and information on the benefits that are expected from the project. There was a ‘process of public consultation’, with the Draft EIS being publicly released to allow ‘other organisations or persons’ to comment on it and for BHP Billiton to provide further information in response to these issues.

Relevant agencies of the Australian, South Australian and Northern Territory governments will review these two documents, including the estimates of harm and benefit, and information provided by other bodies, and on the basis of their evaluation decide whether there is ‘an overall benefit in the broadest sense’. If so, the project can be considered ‘justified’ and approval to proceed would be granted, perhaps with specified conditions.

The EIS process being undertaken is therefore in accord with the recommendations of the ICRP.

Issue:

It was suggested that BHP Billiton has not considered the recommendations and findings of the European Committee on Radiation Risks (ECRR) and the Institute for Energy and Environmental Research (IEER).

Submissions: 10, 45 and 318

Response:

BHP Billiton follows the guidelines, recommendations and standards of the recognised radiological protection organisations such as the International Commission on Radiological Protection (ICRP), the United Nations Standing Committee on the Effects of Atomic Radiation (UNSCEAR), the International Atomic Energy Agency (IAEA) and the Australian Radiation Protection and Nuclear Safety Agency (ARPANSA). These institutions, and the guidance they provide, also form the basis of the accepted regulatory framework.

In addition, guidance and support for radiation protection professionals is available from recognised professional associations such as the Australian Radiation Protection Society and the US Health Physics Society.

Issue:

It was suggested that with specific regard to the assessment of radiation, the ‘precautionary’ principle had not been adhered to or considered in the Draft EIS.

Submissions: 45 and 318

Response:

In general, the precautionary principle is applied where there is uncertainty in the scientific evidence. For radiation, the risk and effect are directly calculable from a well-understood and conservative dose-response relationship and, based on this, limits are set that are deemed to be acceptable. Where there is no evidence of any effect (below about 50 mSv), a conservative approach, which assumes an effect even though no effect has been seen, is used, based on effects seen at the higher levels.

Section 25.5 and Appendix E2 (Section 2.5) of the Draft EIS discussed the precautionary principle for the broader project proposal in the context of a sustainable development framework.

The specific issue raised in these submissions is in relation to the application of the precautionary principle to the impacts of radiation on people and the environment. The submissions assert that there is insufficient scientific information available to be able to properly understand the impacts of radiation and, therefore, the precautionary principle must be applied, with the implication that there should be no radiation exposure.

The effects of radiation on human health are well understood and extensive scientific evidence supports this (Cember and Johnson 2009).

From a radiation protection perspective, the principles of the ICRP are consistent with the precautionary principle. In fact, the precautionary approach to radiation protection was first laid down by the ICRP in 1928 and later formalised as the ICRP principles of radiation safety (ICRP 2007). These are:

- justification – the notion that human activities which lead to exposure to radiation should be justified before they are permitted to take place, by showing that they are likely to do more good than harm
- optimisation – the process of maximising the net benefit arising from human activities which lead to exposure to radiation (known as the ALARA principle)
- limitation – the requirement that radiation doses and risks should not exceed a value regarded as unacceptable.

BHP Billiton applies the philosophy and recommendations of the ICRP in its approach to radiation protection, as outlined in Chapter 22 and Appendix S of the Draft EIS.

ARPANSA has issued a statement on the precautionary principle in relation to radiation protection, where it notes that the ALARA principle 'can be considered to be a form of the precautionary principle'. (RHSAC 2002)

Issue:
It was claimed that the 'collective dose' from the expansion would result in a large number of deaths.

Submission: 318

Response:

Care must be exercised in the use of 'collective dose'.

The term 'collective dose' refers to the total amount of radiation dose that might be received by a population exposed to a particular activity, and is obtained by multiplying the number of people exposed by the average dose they might receive and then extended out to a specified time.

It is usually used as part of the optimising of a process and is included in decision making.

ICRP 1997 comments on the misuse of collective dose when dealing with small individual doses spread over long timeframes, and these comments are reiterated in ICRP 75, ICRP 101 and Dunster (2000). The comments are best summarised by the Australasian Radiation Protection Society (ARPS), which recommends caution when using collective dose, noting the following (Higson 2007):

'Estimates of collective dose to groups or to populations should be used with caution. In view of the uncertain association between low doses and risk, estimates of collective dose arising from individual doses that are less than some tens of millisieverts in a year should not be used to predict numbers of fatal cancers for the exposed group or population.'

Issue:
It was asserted that BHP Billiton did not acknowledge that radiation exposure limits are lowering all the time and did not say what would happen if the radiation limit was lowered.

Submissions: 10, 44 and 85

Response:

BHP Billiton takes its responsibilities on radiation protection very seriously. BHP Billiton's radiation limit goals have been set well below the ICRP's maximum dose limit and have sufficient allowance built in to accommodate reductions in any dose limits.

The estimates of exposures and doses were assessed conservatively in the Draft EIS (and presented in Chapter 22 and Appendix S of the Draft EIS). The results show that doses are within acceptable levels.

The health effects of radiation are well known. As society demands higher and higher levels of protection, so the limits decrease. It is similar to a lowering of the speed limit. The acceptable 'risk' reduces and therefore the limits reduce (Cember and Johnson 2009).

In terms of radiation effects, there has been a gradual refining of the dose limits. For example, in 1990 ICRP issued a revision of the limits, saying that the annual occupational limit had reduced from 50 to 20 mSv/y, with a maximum of 50 mSv in any one year. The most recent new publication of the ICRP did not further reduce the limits.

Radiation limits have been set conservatively below the threshold of observable effects.

In Section 26.1.2 of the Supplementary EIS, BHP Billiton discusses its commitment to a goal of 50% of the current dose limit and acknowledges this goal would be reassessed if limits changed in the future.

Recently the ICRP has issued, as a draft for comment, a report discussing radon risk and related dose conversion factors. The report is based on work undertaken by UNSCEAR, and recommends an increase in the dose conversion factor for radon decay products. At the time of completing the Supplementary EIS, the ICRP report remained in draft and open for comment. However, BHP Billiton acknowledges the ICRP as the pre-eminent body on radiological protection and would adopt any changes once finalised. The impact of the proposed changes on expected doses to both workers and members of the public is low, mainly because overall doses are low. Factoring in the changes proposed in the draft from the ICRP, predicted doses for the expanded operation would continue to comply with the relevant radiation limits and also the BHP Billiton internal radiation exposure goal.

26.1.5 RADIATION CONTROLS IN CHINA

Issue:

The controls for radiation in China were questioned.

Submissions: 37, 44, 141 and 161

Response:

Published information indicates that the People's Republic of China (PRC) maintains a well-controlled and competent system for radiation protection and nuclear safety.

Qu (2009) summarises the nuclear and radiation safety regulatory framework in China which include:

- Regulations of the PRC on Nuclear Materials Control (1987)
- Rules for the implementation of Regulations on Nuclear Materials Control (1990)
- Rules of Physical Protection for Nuclear Materials International Transport (1994)
- Rules on Inspection of Nuclear Materials Control (1997)
- Rules on Security of Nuclear Power Plants (1997)
- Regulations of the PRC on the Control of Nuclear Exports (1997)
- Regulations of the PRC on the Control of Nuclear Dual-Use Items and Related Technologies Export (1998)
- Rules on Radioactive Items Import and Export Licence Application and Cooperation Safeguards (2002)
- Law on Prevention and Control of Radioactive Pollution (2003).

Overall responsibility in China lies with the central government (known as the state) through the National Nuclear Safety Administration (NNSA), which is part of the State Environmental Protection Administration (SEPA). The NNSA is advised by the Nuclear Safety Advisory Committee and the Radiation Environment Review Committee (Guo and Li 2005).

In addition to these institutions, there is also the China Institute for Radiological Protection (CIRP) and the China Institute for Atomic Energy (CIAE), whose roles are to provide safety assessment, training, monitoring and research. The CIRP is a scientific organisation that works with research and development related to health physics, nuclear safety, life science, environmental protection, radioactive waste management, irradiation technology, biotechnology and electronics.

China has a demonstrated capability in environmental radiological monitoring, as evidenced in Wolbarst and others (2008), which describes a statewide radiological monitoring system. Data from the system is published and China intends to make information available over the internet.

Guo and Li (2005) provided a brief overview of radiation protection systems in China and noted that these regulations are based on a Chinese basic safety standard, which itself is based on the radiation protection publications of the IAEA and the ICRP.

Published data shows that doses to workers in nuclear installations are on average well controlled, with average annual doses between 1990 and 2000 being less than 3 mSv, which is comparable to doses in other countries (Wolbarst et al. 2008).

China has also agreed to conduct an occupational radiation protection appraisal through the IAEA (<http://www-ns.iaea.org/appraisals/radiation-appraisals.htm>) which aims to:

- provide the host country with an objective assessment of the provisions for occupational radiation protection
- identify the strengths in the host country which are unique and worthy of bringing to the attention of others
- promote the use of self-assessment by the host country
- identify areas where performance should be improved to meet international standards
- make recommendations on actions to be taken to achieve such improvements.

At the Forum for Nuclear Cooperation in Asia (FNCA) 2009 Workshop on Radiation Safety and Radioactive Waste Management (FNCA 2009), an overview of the recent Chinese regulatory systems around radiation protection and nuclear safety was provided. It was noted that China maintains a 'very intensive' legal framework for the control of radioactive waste, including controls for Technologically Enhanced Naturally Occurring Radioactive Materials (TENORM), which must be contained at the facility where they were produced.

Further information on China's nuclear commitments is provided in Chapter 27, Product Stewardship, of the Supplementary EIS.

26.2 RADIATION SOURCES

26.2.1 WIDER RADIOLOGICAL ASPECTS OF THE OPEN PIT

Issue:
It was suggested that the open pit would significantly increase radon and radioactive dust levels, vastly increasing the hazard.

Submissions: 1 and 10, 21 and 85

Response:

Chapters 13 and 22 of the Draft EIS described the potential emissions from the expanded operation and showed that, while the quantity of released radioactivity is expected to increase compared to the existing operation, the impact of that increase would be small.

A summary of the information on impacts of the emissions of radon and radioactive dust to members of the public is described below. Additional information on emissions is provided in the Supplementary EIS at Sections 26.2.2, 26.2.3 and 26.5.

Radon

The annual emissions of radon from the fully expanded Olympic Dam operation would be less than 1% of the natural radon emissions that occur in South Australia every year (see Appendix M1 of the Supplementary EIS for calculations). The expected radon release, as discussed in Appendix S (Section S3), is used as an input into the air quality model (described in Chapter 13 of the Draft EIS) to estimate radon concentrations in the environment. The results of this were shown in Figure S2.7 of Appendix S of the Draft EIS.

The increase in concentrations at population centres as a result of the proposed expansion would be very small.

At approximately 20 km south of the operation, radon generated from the fully expanded project would result in a radon concentration estimated to be 2.5 Bq/m^3, with the levels approximately halving every 4 km (refer to figure S2.7 of Appendix S of the Draft EIS). Therefore, the radon concentration at about 50 km south of the operation as a result of the project is estimated to be less than 0.1 Bq/m^3. Concentrations of radon from Olympic Dam at greater distances (for example, Port Augusta or Adelaide) would be negligible.

This small increase should be seen in the context of the naturally occurring levels, which are reported to vary between 5 and 40 Bq/m^3. These figures represent hourly averages, so instantaneous levels could be substantially higher or lower (WMC 1996).

Dose estimates to the residents of Roxby Downs from radon decay products have been estimated at 0.12 mSv/y, or just over one tenth of the ICRP recommended dose limit of 1 mSv/y.

Radioactive dust

The radiological impacts of emissions of radioactive dusts from the expanded operation have been assessed as negligible. Estimated doses as a result of these emissions to residents of Roxby Downs were provided in Table S4 of Appendix S of the Draft EIS. At full operation, dust doses are expected to be less than 0.3% of the member of the public annual dose limit in Roxby Downs.

Another way of assessing the impact of these emissions is to consider dust deposition. The modelling of deposition from the expanded operation showed that the dust fallout on Roxby Downs would be approximately 2.4 $g/m^2/y$. The radionuclide component of the fallout dust is based on the figure presented in Section S2.1 of Appendix S of the Draft EIS, which is 100 ppm uranium for mine dust emissions, which is a combination of both mineralised and unmineralised dust emissions.

Over 40 years, at a fallout rate of 2.4 $g/m^2/y$, the total accumulated dust would be approximately 100 g/m^2. Therefore, at 100 ppm of uranium, there would be approximately 10 mg of uranium deposited per square metre.

If it is assumed that, over the 40-year life of the mine, the fallout dust mixed into the top 100 mm of the soil, then the total concentration of uranium would increase by approximately 3%. This is based on natural average uranium in soil concentration of 3 ppm (UNSCEAR 2000) and well within natural variation.

Issue:

Clarification was sought on the release rate of radon during mining and the radon and radon decay product levels expected to be in the pit as a result.

Submissions: 1 and 45

Response:

The information requested on this issue was provided in Appendix S of the Draft EIS and is summarised here. Reference is also made to Section 26.12.3 of the Supplementary EIS, in which verification of the radon emanation levels is provided.

In summary, the total radon emanation from the mine at full production was calculated to be 8.6 MBq/s. The final long-term average radon concentration in the pit was calculated to be 8.8 Bq/m^3, which equates to a dose of 0.14 mSv per year (mSv/y) for workers in the pit.

The release rate of radon during open pit mining is related to the emanation of radon from the rock surfaces. This includes radon from the solid surfaces, such as the mine pit floor and walls, through to emanation from the broken rock piles. In the latter case, the radon emanation, per unit area, is larger because the broken rocks have a larger surface area. The amount of emanation is also proportional to the uranium grade of the rocks, so that as the grade increases, the concentration of uranium series radionuclides increases, and so does radon emanation.

The Draft EIS utilised a total radon emanation figure of 2.5 $Bq/m^2/s$ for *in situ* ore. For broken ore, it was estimated that the emanation was five times this figure, and this estimate was based on a first principles calculation. The basis of this estimate is further described in Section 26.1.3 of the Supplementary EIS.

Emanation of radon from the pit primarily depends upon the surface area and the emanation rate. For the air quality modelling undertaken for the Draft EIS, a figure of 8.6 MBq/s was estimated and used.

Using the pit dimension assumptions provided in section 26.1.3 of the Supplementary EIS, the calculated radon emanation rate is slightly less than this.

The modelling indicates that the final long-term radon concentration in the pit would be 8.8 Bq/m^3. Assuming equilibrium between radon and its decay products, this corresponds to approximately 48 nJ/m^3. Using the standard dose conversion factor recommended in the Mining Code (ARPANSA 2005) this results in an annual dose of 0.14 mSv/y.

The radon concentrations in the pit would also depend on the atmospheric conditions that existed at any time in the pit. Under specific temperature inversion conditions (a temperature inversion at 100 m from the base of the pit), it was estimated that the radon levels could increase to 1,700 Bq m^3 below this level, corresponding to a radon decay product concentration (assuming equilibrium) of 9.3 $\mu J/m^3$ after 12 hours. From a dose assessment perspective, over a 12-hour period the average is assumed to be half this figure, that is, approximately 4.6 $\mu J/m^3$ (assuming the levels build up linearly to the maximum level over the 12-hour period). Using the Mining Code 2005 dose conversion factor, this equates to a 12-hour dose of 78 μSv. Based on the work roster and the limited number of nights when temperature inversion occurs, the additional annual dose as a result of inversion conditions was estimated to be 1.8 mSv/y.

The method for determining the exposure levels under temperature inversion conditions was outlined in Section S3.1 of Appendix S of the Draft EIS.

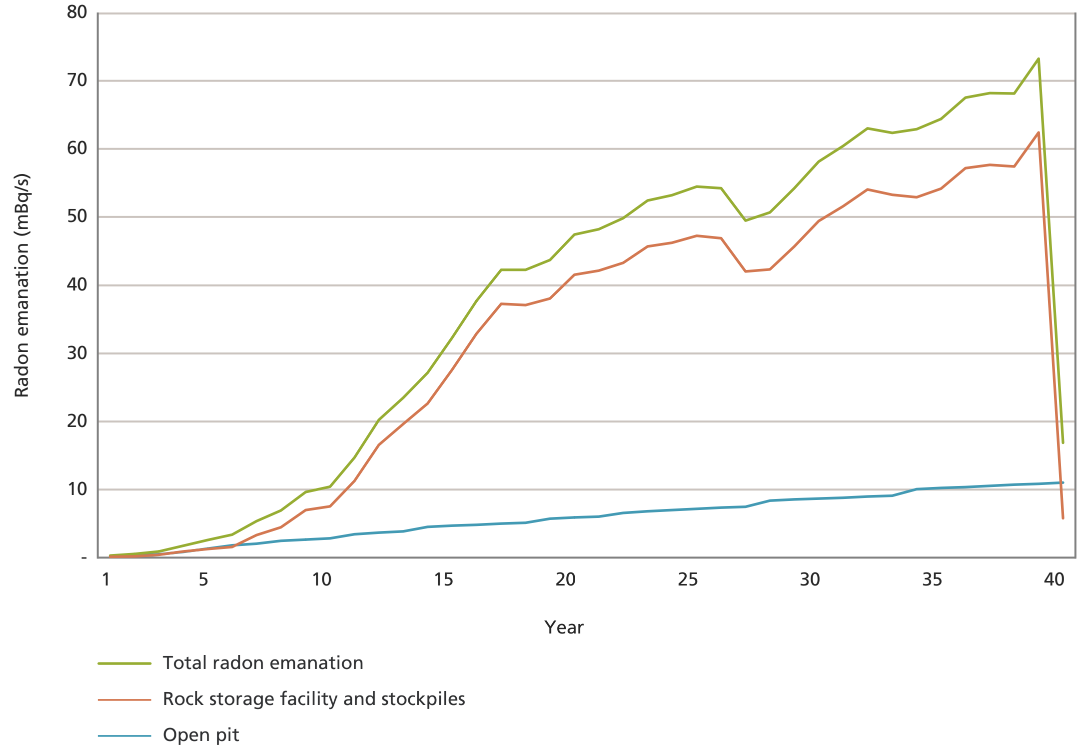

Figure 26.2 Radon emanation from the mine over time

It is noted that the dose estimates do not take into account the fact that most of the workers would be working in air-conditioned equipment, where particulates would be filtered from the air, resulting in lower actual doses.

Issue:

Clarification was sought on the vertical profile of radon levels in the proposed pit due to the effect of temperature inversions, and the associated dose impacts.

Submissions: 1 and 2

Response:

In the Draft EIS, radon in the proposed pit was considered from two perspectives.

Firstly, it was assumed that all radon emanating in the pit would disperse uniformly into the whole volume of the pit, as would be expected under normal conditions. Under these conditions it was assumed that there would be a constant concentration of radon in the whole of the open pit, which would be independent of the depth in the pit.

The second perspective involved consideration of some constraint that would limit the natural dispersion of radon, in particular the presence of temperature inversions. Inversion conditions occur when layers of air become trapped due to differences in the temperature of the air. Inversions, however, break down quickly when the air heats (due to sunlight) and the layers of air mix.

For the Draft EIS, it was assumed that under certain conditions, inversions may form in the open pit. When this occurred, there would be a change in radon concentrations with height in the pit as the radon would accumulate in the inversion layer, resulting in higher than normal radon and radon decay product concentrations.

Therefore, the issue of vertical profiling of radon in the pit primarily depends on understanding whether inversion conditions may occur in the pit.

BHP Billiton undertook investigative work to determine whether or not inversions actually occur in large pits. By determining whether inversions occur, it is possible to make some initial conclusions about the vertical profile of radon in the pit.

In autumn and winter of 2009, CSIRO assisted in a study of atmospheric temperature profiles in two deep open pit mines in Western Australia (Hibberd 2010). The aim of the study was to obtain vertical potential temperature profile measurements in existing, deep open pit mines to indicate the depth in an open pit where temperature changes (and hence inversions) may occur.

Vehicle-mounted data loggers were used to record temperature, relative humidity and atmospheric pressure at 10-second intervals while descending or ascending access roads into the pits.

At Mount Keith, a total height range of approximately 340 m was traversed by the vehicle on 12 nights. There were two nights with potential temperature gradients that indicated inversion conditions, although there was no clear indication of a change that would clearly mark the inversion height.

At Mount Whaleback, a total height range of approximately 300 m was traversed on 13 nights, with inversions identified on five nights, although, again, there was no clear indication of a change in temperature gradient to mark the exact inversion height.

For the entire study, inversions were detected on about 25% of the study nights during autumn and winter (note that a figure of 26% was predicted in the Draft EIS).

The observations suggest that inversions occur at a level at least 200–300 m above the pit floor.

This initial work indicates that the Draft EIS dose assessment work for pit workers (which assumed an inversion height of 100 m from the pit floor) was conservative (that is, the actual doses would be lower than predicted). Ongoing monitoring and management would occur to confirm the estimates.

Issue:

The radiological and health impact of the annual emission of dust from the expanded operation was questioned, as were the activity levels and radionuclide composition of the dust.

Submissions: 1, 10, 46 and 173

Response:

Extensive assessment of dust emissions from the expanded facilities was carried out and presented in Chapters 13 and 22 and Appendices L and S of the Draft EIS. The assessment showed that although emissions would increase, doses to the public and the workforce would remain low. Dose assessments in particular were provided in Sections 22.6.5 and 22.6.6 and Section S2 of Appendix S of the Draft EIS.

Section 25.1.3 of the Supplementary EIS provides further discussion on the broader health impacts of emissions from the proposed expansion

Estimated doses are predicted to be well below the internationally accepted member of the public dose limit and therefore potential health impacts would be negligible. As discussed elsewhere in this chapter, the limits are set at levels that provide an internationally agreed level of protection.

There are different types of dust which have different radionuclide concentrations. The dusts of interest at Olympic Dam are ore dust, tailings dust and smelter emissions. Table 26.10 of the Supplementary EIS shows the approximate concentrations of radionuclides in each of these source terms for the current operation. For the expanded operation, it is expected that the relative ratio of radionuclides in the respective dusts would be the same, and be proportional to the original ore grade of the material feeding the plant.

Table 26.10 Approximate radionuclide composition of dust source

Radionuclide concentration (Bq/g)	^{238}U	^{234}U	^{230}Th	^{226}Ra	^{210}Pb	^{210}Po
Ore dust	8	8	8	8	8	8
Tailings dust	2	2	8	8	8	8
Smelter dust	0	0	0	0	1,000	1,000

Issue:

Clarification was sought on whether radon from the RSF would impact on exposures in the open pit.

Submission: 2

Response:

Radon emanation from the RSF is not expected to have an impact in the open pit.

Approximately 70% of the rock in the rock storage facility (RSF) does not contain uranium above natural background levels and any radon that emanated would disperse naturally. The air quality modelling presented in Chapter 13 of the Draft EIS, and the predicted radon concentration contours presented in Figure S2.7 of Appendix S of the Draft EIS, take this into account.

The exposure estimates for workers in the pit do not take into account radon from the RSF entering the pit, although it is recognised that this could occur. The reason for this is that the quantity of radon entering the pit via natural air movement is expected to be small because of natural convection, air movement and temperature differentials causing the radon to disperse. Even under temperature inversion conditions, which occur during the colder months, natural ventilation around the RSF would act to dilute the radon concentrations quickly.

It needs to be recognised that although radon is heavier than air, the image of radon rolling down the slopes of the RSF into the bottom of the pit is incorrect. Section 26.3.2 of the Supplementary EIS describes the misconceptions around radon seeking the lowest geographical points.

In addition to this, the radiation exposure estimates are conservative (i.e. they more than likely overestimate what would actually be received) and show that mine workers' exposures would be low and well below the annual dose limit (average annual doses are expected to be 3.5 mSv compared to the annual limit of 20 mSv).

Real-time monitoring of mine workers and the pit work environment would be undertaken and would identify any abnormal radon and exposure levels. This information would then be used to make changes to bring exposures back to expected levels. Such changes might include additional personal protective equipment (PPE) or removal of certain personnel from the pit area until levels returned to normal. These management procedures are consistent with those used in the current underground mine and have been shown to be effective in controlling workers' exposures.

In a worst-case situation, where an extreme atmospheric temperature inversion occurred in the pit, or where very stable (non-mixing) air conditions prevailed for an extended period, then both radon (and its decay products) and dust would build up in the pit. In these extreme conditions, appropriate monitoring would identify when the conditions became unacceptable and personnel would be removed from the pit. It is important to note that modelling indicates that under extreme conditions, the lack of visibility due to airborne dust would trigger action before radon (and decay product) levels became a concern.

Control of exposure to radon decay products would focus on controlling individual doses rather than controlling workplace conditions.

Issue:

Clarification was sought on the implications of the expanded operation for the management of underground radon decay product levels.

Submission: 2

Response:

Section S2.2.2 in Appendix S of the Draft EIS estimated that radon from the open pit may lead to an increase in radon decay product levels in the underground mine of 0.5 $\mu J/m^3$, leading to a potential additional dose of up to 1.4 mSv/y for underground miners.

Using the atmospheric modelling, it was estimated that the ambient radon concentration near the existing air intakes for the underground mine would be approximately 100 Bq/m3. Taking a cautious approach and assuming radon decay products were in equilibrium with the radon, this would lead to an increase of 0.5 $\mu J/m^3$ in the mine air. With no changes to the existing controls (i.e. no change to ventilation), this would lead to an additional 1.4 mSv/y for underground miners.

The current underground radiation management procedures for dose control include the requirement for specific action when monitored radon decay product levels exceed 2 μJ/m^3 and an escalated response when levels are monitored to be above 8 μJ/m^3. The 2 and 8 μJ/m^3 triggers are used for operational control and usually involve actions to reduce levels. These are examples of how the ALARA principle is implemented for the Olympic Dam operation.

The impact of the additional radon decay product concentrations from the surface would not be expected to constitute a significant alteration to the existing control mechanisms. There may be more exceedances of the trigger levels, however the management response would be as it is now: take action to reduce levels. As noted, even if no change was made to workplace conditions, doses would rise by a maximum 1.4 mSv/y, with total doses remaining well below the accepted limits.

Issue:

Clarification was sought on the management controls and possible engineering solutions to control dust, radon and radon decay product in the open pit.

Submissions: 1, 2 and 102

Response:

BHP Billiton has successfully demonstrated its ability to manage radiation exposures in the underground mine and metallurgical plant for over 25 years. Management of radiation, including such measures as monitoring programs, training, engineering controls and systems and procedures, is detailed in the existing annual reports to the regulatory authorities on occupational radiation. For the proposed open pit mine, the management systems would be adapted to take into account the different exposure situation.

For example, in the underground mine, exposure to elevated radon decay product levels can be lowered through such controls as removing workers from the area and/or changes to the ventilation system. In the open pit mine, ventilation changes would not be as practical.

Under normal conditions, the assessment has shown that natural ventilation in the pit would dilute and disperse radon and its decay products and it is therefore not expected that any special management systems would be necessary during these conditions (see Section 2.2.2 of Appendix S of the Draft EIS). Standard routine monitoring would be conducted to determine radiation exposures and to identify changes in conditions that may lead to increased exposures. The monitoring would be undertaken according to a plan approved by the regulatory authorities (refer Section 26.2.1 of the Draft EIS for details).

Where periods of low natural ventilation (such as during atmospheric inversion conditions) occurred in the pit, and the potential for increased levels of radon in an area of the pit arose, real-time radon or radon decay product monitoring positioned in these areas would help determine what steps needed to be taken to ensure workers' exposures remained low.

Environmental, atmospheric and meteorological monitoring equipment and software installed as part of the expansion would also provide important information on expected weather conditions before events occurred, which in turn would assist in the planning and notification of these events.

Mechanical ventilation in targeted areas of the pit, and procedures such as ensuring personnel remained inside vehicles while in a low-ventilation area, are among the control mechanisms that may be used.

The opportunity exists to identify additional control mechanisms during the open pit pre-strip period. This is a window of approximately four to five years, in which dust suppression techniques can be optimised to further minimise exposures. Improvements and future opportunities in the control of dust lead to safety and productivity benefits and arise through operational experiences. The information gained is shared both across the company and throughout the industry. For example, BHP Billiton reports improvements through its occupational health, safety and environmental networks.

BHP Billiton is one of the world's largest operators of open pit mines and has extensive experience that is applicable to an expanded Olympic Dam operation. Existing BHP Billiton controls and management measures have been demonstrated to be appropriate to maintain safe workplaces and comply with health and environmental requirements.

The work to date demonstrates that doses and exposures are able to be controlled without additional measures.

26.2.2 Radiological aspects of the rock storage facility

Issue:

BHP Billiton was asked to specify what radiological issues would be associated with the rock storage facility (RSF) (including seepage and dust lift-off), and to provide a review of radiological impacts when acidic pore water (water filling spaces between grains of sediment) may be formed.

Submissions: 1, 2 and 318

Response:

Section 5.4.6 of the Draft EIS described the process for the development of the RSF, which incorporates a number of design features specifically aimed at reducing the impacts from waste rock that might contain low-grade uranium mineralisation.

In summary, the rock storage facility (RSF) would primarily contain material that has no elevated levels of uranium (above natural background levels) and would be designed to minimise any radiological impacts. Given the characteristics of the material, the RSF would have a very low acid-generating capacity.

The potential radiological issues can be summarised as:

- radon emanation
- dust emissions
- seepage of radionuclides
- gamma radiation.

Radon emanation

Table S6 of Appendix S of the Draft EIS provided an estimate of the radon emanation from the various parts of the proposed expanded project. It is estimated that the final RSF facility would contribute about 75% of the total radon emanation from the expanded operation. The Draft EIS estimated emissions, assuming that the various rock types would be stored openly and separately and that there would be no covering with benign rock. This is therefore a worst-case estimate of the potential emissions.

The radon impact modelling was based on the radon source terms provided in Table S6 of Appendix S of the Draft EIS, which is the basis for the modelled radon concentration contours provided in Figure S2.7 of Appendix S of the Draft EIS. This figure showed the impact of the radon emanation from the whole of the operation and also showed the reducing project-sourced concentration at further distances from the RSF.

The impact of the radon from the proposed Olympic Dam expansion should be seen in perspective with the amount of radon that exists naturally in the environment. The conservative modelling of radon from the fully expanded operation, as presented in Appendix S of the Draft EIS in Figure S2.7, showed that for the fully expanded operation, the predicted impact drops off rapidly with distance from the mine. At about 20 km the concentration of radon from the operation is 2.5 Bq/m^3. This would continue to reduce significantly with distance and is negligible beyond 50 km. Figure 26.3 of the Supplementary EIS shows modelled radon concentrations at distances from the operation. In comparison, the naturally occurring concentration of radon in the region is variable, with the average being approximately 20 to 30 Bq/m^3.

Dust emissions

The radiological impacts of dust emissions from the RSF are low. This is mainly because the material on the RSF contains low quantities of uranium and its decay products.

When assessing the radiological impacts, an overestimate of the concentration for uranium has been used (refer Appendix S of the Draft EIS). Dust produced in the operation of the RSF would become a nuisance long before it ever became a radiological issue (due to its low grade of uranium).

Section 13.3.5 of the Draft EIS described the specific controls for dust for the mining operations and included measures such as:

- relocating some or all of the mining activities
- redirecting mine rock haulage activities
- dust suppression measures such as watering roads and saline water sprays
- cessation of operations.

BHP Billiton has committed to a dust management program and an environmental radiation monitoring program, which are described in Section U1.2 of Appendix U of the Draft EIS.

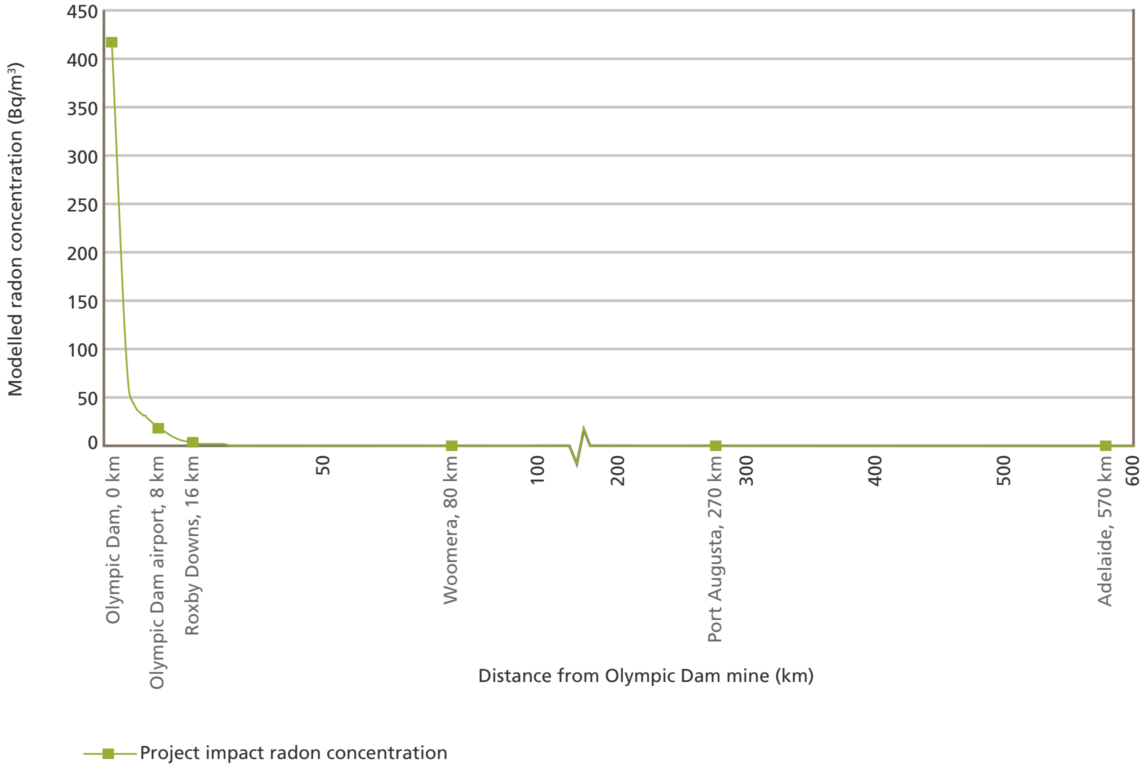

Figure 26.3 Radon concentration with distance from operation

Gamma radiation levels

Due to the low uranium content of the material in RSF, gamma radiation levels are expected to be consistent with existing background levels beyond the outer wall of the RSF.

Seepage of radionuclides

Test work outlined in the Chapter 12 and Appendix K of the Draft EIS and further work reported in Chapter 12 of the Supplementary EIS show that percolate from the RSF would largely infiltrate and report to groundwater. Seepage of water from the base of the RSF could occur in very localised areas (e.g. where the RSF overlies clay plan areas), however the amount of seepage that could be generated would be small. Furthermore, the radiological contaminants would be strongly attenuated in the calcareous clays and limestone beneath the RSF, as discussed for the TSF in the Draft EIS and the supplemental testing program for the TSF (see Section 12.3.2 of the Supplementary EIS).

Water run-off from the RSF has been addressed in Chapter 11 of the Supplementary EIS.

Review of radiological impacts when acidic pore water forms in the RSF

Appendix K5 of the Draft EIS noted that the overburden material that constitutes the majority of the RSF is non-reactive and a net consumer of acid with a limited potential for solute release.

However, given that some 30% of the RSF is made up of basement mine rock (refer Figure 5.17 of the Draft EIS), which could contain low levels of mineralisation, there is the potential for rainwater that infiltrates the rock to react with sulphidic material, which could lead to localised zones of acidic pore water forming.

Any acidic pore water that forms could dissolve and then mobilise metals contained in the basement rocks. During operation of the RSF, BHP Billiton has committed to a program of encapsulating the potentially reactive basement mine rock within the non-reactive material, as was described in detail in Section 5.4.6 and illustrated in Figure 5.16 of the Draft EIS.

It would therefore be expected that if acid pore water formed, it would first react with the surrounding rock in the RSF and be neutralised. If the pore water moved further, it would flow through the foundation layer of overburden materials (which are either benign or acid-neutralising) and to the sediments underlying the RSF, for which extensive work on the TSF has shown that solubilised radionuclides and metals in the acid seepage precipitate out or are attenuated through sorption as the acid solution is neutralised through interaction with the underlying clays and limestone (see Chapter 12 of the Supplementary EIS for details). As such, the pore water would be neutralised and metals would precipitate and be attenuated effectively.

Following closure, the entire outer surface of the RSF would comprise benign or acid-neutralising materials (i.e. class C or D mine rock) and infiltration modelling presented in Chapter 12 of the Supplementary EIS shows that the net rate of percolation from rainfall would be very low (i.e. 1–4% of mean annual precipitation, or up to 6 mm/y). This is considerably lower than the existing TSF, for which test work demonstrates effective neutralisation and significant capacity for ongoing neutralisation in underlying sediments. Therefore, long-term impacts are considered to be low.

Issue:

Information was requested on the control of radioactive emissions from the RSF.

Submissions: 1 and 2

Response:

Previous responses in this section of the Supplementary EIS (Section 26.2.2) describe the radiological impacts of the RSF and show that the impacts are low, mainly because the levels of radioactivity in the material in the RSF is low.

Control of radioactive emissions from the RSF depends on effective and ongoing management of the RSF. Section 5.4.6 of the Draft EIS described the overall approach to management of the RSF, which would be based on classifying all material from the mine into one of four classes and then optimally placing that material in the RSF in order to minimise impacts, including radiological impacts. It is planned that material that contains low levels of radioactivity would be contained within an outer layer of benign material.

Management Plan ID4.2 from Appendix U of the Draft EIS described the specific management measures and control actions that would be implemented to manage the RSF. Management Plan ID3.5, also from Appendix U of the Draft EIS, described the broader radiation safety controls through the control of emissions.

26.2.3 RADIOLOGICAL ASPECTS OF THE TAILINGS STORAGE FACILITY

Issue:

Clarification was sought on several aspects of the tailings in relation to radionuclides, specifically:

- the composition of the tailings (including metals and radionuclides)
- the dose conversion factor for tailings dust and the potential doses from the tailings
- how tailings dust is generated.

Submissions: 1, 27, 52, 88, 125 and 282

Response:

The tailings would be placed in a specially designed and constructed facility (refer Section 5.5.6 and Appendix F1 of the Draft EIS for design details), located entirely in the expanded special mining lease area and designed to securely and safely contain the tailings. At the end of the facility's life, and progressively throughout the operation of the expanded mine, tailings cells would be capped with inert rock and remain permanently secure. Tailings would not come into contact with any other area around the mine.

Composition of tailings

As listed in Tables 5.18 and 5.19 of the Draft EIS, the tailings are made up of a host of different chemicals and minerals. They also contain 85% of the radionuclides (the decay products of the ^{238}U and ^{235}U uranium isotopes) from the mined ore and therefore contain the majority of the radioactivity from the mined ore (as indicated in Tables 5.20 and 5.21 of Draft EIS). The concentration of radionuclides would be up to 7 Bq/g for each of the longer-lived radionuclides in the ^{238}U chain and up to 0.01 Bq/g for the ^{235}U chain radionuclides (for a uranium ore grade of 600 ppm). Radionuclides would predominantly be in the solids phase of the tailings, with the more soluble radionuclides in the liquor phase. However, as tailings consolidated, the soluble radionuclides would also precipitate into the solids phase. This effect is described more fully in Chapter 12 of the Supplementary EIS.

The concentration of radionuclides in the tailings (excluding uranium) would generally be proportional to the concentration in the ore (that is, the uranium ore grade). Therefore, for the expanded operation, as the ore grade decreased, so would the radionuclides in the tailings.

Dose conversion factor (DCF) and doses

While the tailings are contained in the TSF, they are safe and secure. For there to be a potential for exposure, there needs to be a pathway by which a person, a community group or the environment can be exposed. In the case of tailings, the potential pathways are from emissions to air (discussed further below) and seepage to groundwater (discussed further in response to the next issue).

The airborne pathway can include tailings dust or radon emitted from the tailings surface. To determine the impacts of these emissions, the amount of dust and radon being emitted is determined and exposure is estimated. The exposures, usually expressed as a concentration at some receptor position, are converted to dose through the use of dose conversion factors (DCF). A more detailed description of the dose assessment method was outlined in Section 22.4.1 and Section S1.6.3 of Appendix S of the Draft EIS.

Further explanation and details of predicted doses are provided in Sections 26.4 and 26.5 of this chapter.

Dose conversion factors (DCFs) for various dusts can be calculated using the method outlined by the International Commission on Radiological Protection (ICRP 1979). The calculation method is complex and takes into account various factors such as radionuclide composition, particle size (known as the activity median aerodynamic diameter, or AMAD) and radionuclide solubility (which is directly related to the solubility of the host mineral).

Mining Code (ARPANSA 2005) provides default DCFs for uranium tailings as follows:

6.7 µSv/Bq (for an AMAD of one micron)

2.6 µSv/Bq (for an AMAD of five microns).

Note: the Mining Code 2005 (ARPANSA 2005) refers to 'alpha disintegrations per second' rather than Bq – however, when considering long-lived alpha-emitting radionuclides alone, the terms have the same meaning.

BHP Billiton, through its annual occupational radiation reporting to government (BHP Billiton 2006), quotes a DCF for general areas, including tailings areas, as 4.1 µSv.m^3/Bq.h, which has taken into account breathing rate and measured AMAD. This is consistent with the above Mining Code figures.

Generation of dust
From an operational perspective, dusting from the tailings is practically negligible, given that during operations the tailings surface is usually wet or damp during deposition cycles before forming a competent dry crust. This crust consists of iron and other salts and has been shown over 25 years of the existing operation to be wind-resistant and to form a competent surface for the tailings (see Plate 26.1 of the Supplementary EIS).

Routine passive and active monitoring shows that relatively little dust from the existing operation reaches Roxby Downs. These levels are so low that BHP Billiton reports (BHP Billiton 2005–2006) that the radioactive dust levels in Roxby Downs are at the minimum detectable level when compared to the natural radionuclide levels in environmental dusts. It should be recognised that of any radioactive dust that did reach Roxby Downs, only a small percentage would originate from the TSF, with the majority originating from other sources.

Plate 26.1 Crusting of tailings

In terms of doses from tailings dust, for a resident of Roxby Downs to receive their annual dose limit of 1 mSv from tailings dust alone, a dust cloud would have to emanate directly from the tailings and form a concentration of 1,000 $\mu g/m^3$ at the resident's location for a full year. This is not considered to be a credible scenario.

Another way to look at this example is to say that if all the dust currently being produced from the operation came from the TSF (which it does not), then dust levels would need to be 1,000 times higher than predicted levels in Olympic Dam village and 3,000 times higher than predicted levels in Roxby Downs to reach the level required for full-time exposure (for a year) to result in the annual member of the public dose limit of 1 mSv.

Studies undertaken for the two previous environmental impact statements for Olympic Dam support this conclusion. The 1982 EIS (Kinhill Stearns Roger 1982) presented findings from wind tunnel tests on the dried tailings with a range of moisture contents and wind speeds. Sampling showed that even at high wind speeds the driest samples failed to produce measurable dust.

The 1997 Olympic Dam EIS (Kinhill 1997) demonstrated that dust monitoring around the perimeter of the TSF confirmed that this facility was not a major emission source. This is because the smooth, flat, even grain size and moist surface of the tailings limits the processes that could lead to dust lift-off, such as saltation and creep. The tailings also form a crust as they dry.

Potential for dusting is increased during mechanical working of the tailings, particularly when tailings are used in construction of the successive lifts of the walls, but water sprays are effective in limiting the release of dust. Also, with the introduction of the open pit, extracted rock material for storage, rather than the continued use of consolidated tailings, would be used to raise TSF walls.

Issue:

More details on the radioactive emissions from the TSF were requested.

Submissions: 1, 7, 52, 88, 174, 304 and 318

Response:

The main emissions pathways are emission of tailings dust, emissions of radon, gamma radiation and seepage. Dust emissions have been addressed elsewhere in this section, so this response will focus on the other emission pathways of groundwater, gamma irradiation and radon gas.

Groundwater

A potential pathway of exposure is through seepage of tailings liquor into the groundwater. Beneath Olympic Dam, two groundwater aquifers are recognised: one is between 30 and 50 m below the surface and the second between 160 and 200 m below the surface. Therefore, the groundwater in the region is quite inaccessible, it is also of high salinity and there are no third party groundwater bores within 50 km of the operation (refer Chapter 12 of Draft EIS).

Recent analysis (reported in Chapter 12.3.2 of the Supplementary EIS) shows that despite there being seepage from the base of the existing tailings, the contaminants (the radionuclides and the metals in the seepage) are precipitated within a few metres of the base. This is due to the neutralising effect of the acid seepage meeting the alkaline underlying sediments, resulting in dissolved metals and radionuclides precipitating out.

Therefore, the potential doses to members of the public, to workers or to fauna from seepage from the TSF would be negligible.

Gamma irradiation

Although the tailings contain most of the radioactivity of the original ore, the gamma radiation levels would drop to background levels within 50 m of the TSF facility.

Radon

For the fully expanded operation, the TSF would account for approximately 12% of the radon emitted from the operation (refer Section S3.1.1 of Appendix S of the Draft EIS). A broader discussion on radon is provided in Section 26.6.1 of the Supplementary EIS. Post-closure, the tailings would be covered with an inert material, thereby significantly reducing radon emission.

As a result, emissions from the TSF would result in doses well below the accepted limit of 1 mSv/y.

Issue:

Information was requested on the control measures for radioactive emissions from the TSF.

Submissions: 1, 45 and 206

Response:

In general, the controls would include (refer Section 5.5.6 of the Draft EIS):

- best practice design of the TSF
- best practice placement of tailings in thin layers, providing time to dry
- operation of a central decant system to minimise seepage
- monitoring systems for airborne dust and radon.

Potential sources of radioactive emissions from the TSF and the specific management strategies that would be employed are discussed below.

Airborne emissions

Airborne emissions from the TSF were described in Section 13.3 of the Draft EIS. The impacts of the emissions from a radiological perspective are included in the discussion on radiation protection that was provided in Chapter 22 and Appendix S of the Draft EIS.

Section S2.5 of Appendix S of the Draft EIS showed that the radiological impact of emissions of radon and dust from the expanded project would be low, resulting in radiation doses to the nearest critical groups being less than 20% of the member of the public limit.

The low anticipated exposures from dust and radon are primarily due to design features of the tailings itself. During deposition and settling, the tailings dry into a hard, competent mass that does not produce dust. Plate 26.1 of the Supplementary EIS shows the surface once dried. Wind tunnel testing has shown that the dried tailings have low dustability (Kinhill-Stearns Roger 1982).

Radon emissions from the TSF are anticipated to be relatively low at 0.5 $Bq/m^2/s$, based on measured emissions from the existing tailings. This low emission level is due to the low radium content of the tailings (which is the source of the radon) and the characteristics of the tailings themselves, which solidify and compact and act to limit radon diffusing through them.

During closure, the TSF would be covered with inert waste rock to provide containment in perpetuity for both tailings and radon. The depth of cover would be determined through on-site trials and test work, with the aim of ensuring that post-closure radiation levels did not produce doses of more than 1 mSv/y. More details are provided in Section 26.5.2 of the Supplementary EIS.

Gamma irradiation

Gamma levels drop off quickly with distance from tailings cell walls, with no increase in gamma levels noted beyond 50 m of the wall.

Seepage

Seepage test work shows (see Chapter 12 of the Supplementary EIS and later in Section 26.2.3) that the base of the TSF (consisting of clays and limestone) provides a very effective barrier to dissolved metals and radionuclides in seepage water. As the seepage is neutralised through interaction with the underlying material, the metals and radionuclides precipitate out of solution and deposit in a layer directly beneath the TSF.

Post-closure

Following closure, the control of radiation from the tailings is through the initial design, which aims for containment of the tailings in perpetuity. More details are provided in Section 26.5.2 of the Supplementary EIS.

Issue:

Further information was sought on radionuclide behaviour in tailings, tailings liquor and seepage from the base of the TSF.

Submissions: 1 and 2

Response:

Section 12.6.2 and Appendix F1 of the Draft EIS provided the assumptions and results of detailed assessments, including numerical modelling, of seepage from the base of the TSF.

Further work was undertaken for the Supplementary EIS and this has confirmed the conservative nature and conclusions presented in the Draft EIS. Chapter 12 of the Supplementary EIS describes the additional work.

This response provides more detail on the behaviour of radionuclides in tailings and seepage from the TSF and draws from the assessments provided in the Draft EIS, the additional geochemistry work for the Supplementary EIS and the operational radionuclide analysis data routinely collected for the current metallurgical plant.

Overview of the TSF seepage

The current seepage situation in the tailings systems can be described as follows:

- a slurry of tailings (approximately 50% solids and 50% liquids) is pumped to the TSF
- the tailings are acidic (pH of 1 to 2) and radionuclides are present in the solids and to a lesser extent also dissolved in the liquor
- most of the liquor evaporates and dissolved metals and radionuclides concentrate in the remaining liquor or precipitate out as solids
- remnant liquor is recycled back to the metallurgical plant, but some permeates downwards through the tailings and then through the underlying sediments (containing sands and clays), and into the underlying limestone
- as the liquor seeps it is neutralised by contact with the underlaying clays and limestone, and metals (including radionuclides) precipitate
- the underlying sediments and deeper limestone provide an effective barrier for inhibiting radionuclide and metal migration.

The additional geochemical studies as presented in Chapter 12 of the Supplementary EIS confirm this situation.

Overview of geochemical study

The geochemical study involved drilling through the tailings and into the underlying material and analysing samples from different depths. Five 'zones' were analysed for the purpose of answering this question, as follows:

- tailings – samples from the consolidated tailings
- contact zone – directly at the interface between tailings and underlying material (tailings to 50 cm below tailings interface)
- underlying material (1–5 m below contact zone)
- Andamooka Limestone (~50m below contact zone)

Arcoona Quartzite (>80m below contact zone).

The geochemical study also considered surface samples in the area of the proposed RSF, which provide an indication of the naturally occurring concentrations of heavy metals and radionuclides of the surface sediments.

Results

Results for both solid and liquid samples are described.

Table 26.11 of the Supplementary EIS is a summary of the average concentrations of key radionuclides and metals in solids in the various zones. The elemental forms of the main radionuclides have also been included as these provide additional information on the attenuation of the radionuclides in the zones. This is because the chemical characteristics of the radionuclides are identical to the respective chemical (for example; ^{230}Th behaves identically in a chemical sense to elemental thorium).

Table 26.11 Summary of concentrations in zones (note all results are from samples taken during the geochemical study)

		Average levels in each zone					
		Tailings	Contact zone	Underlying material	Limestone	Quartzite	RSF footprint surface sediments
Paste pH		3.8	4.8	6.6	7.7	n/a	n/a
Pb	mg/kg	84.6	8.3	15.2	9.8	6.3	7.0
Th	mg/kg	34.9	9.8	5.0	3.0	3.2	4.9
U	mg/kg	168	268	46.1	2.7	2.0	1.8
^{234}Th (^{238}U)	Bq/g	1.45	3.13	0.43	0.04	0.02	n/a
^{230}Th	Bq/g	7.31	2.47	<MDL	<MDL	<MDL	n/a
^{226}Ra	Bq/g	6.91	0.14	0.05	0.02	0.01	n/a
^{210}Pb	Bq/g	5.11	0.17	0.03	0.03	0.01	n/a
^{227}Ac	Bq/g	0.32	0.02	<MDL	<MDL	<MDL	n/a

Note: <MDL is less than minimum detectable level.

Table 26.12 of the Supplementary EIS provides a summary of the concentrations of radionuclides in liquor and water samples associated with the existing TSF at Olympic Dam. Elemental concentrations of the key radionuclides were also assessed to provide further information on their attenuation behaviour. The four sample locations listed in Table 26.12 are:

- Draft EIS Chapter 5 – (refer figure 5.19 in the Draft EIS)
- measured levels in the evaporation pond return liquor (EPRL) – that is, the free liquor that has been removed from the tailings cell (as sampled at the end of 2007)
- pore water – water contained in the tailings and obtained during the above-mentioned tailings study
- groundwater – water extracted from the Andamooka Limestone aquifer and provided as a background measurement for context.

Table 26.12 Radionuclide and metal concentration in key TSF materials

		Concentrations in liquors			
	Units	Reported in Draft EIS (range)	EPRL	Pore water	Groundwater
Th	mg/L	17	14.3	2.9	0.05
^{230}Th	Bq/L	1,200 to 2,400	4,800	n.a.	0.85
Pb	mg/L	6	3	0.09	0.07
^{210}Pb	Bq/l	150 to 250	440	n.a.	0.24
^{226}Ra	Bq/l	3 to 10	3	n.a.	0.8
U	mg/L	130	132	210	0.21
^{238}U	Bq/L	250 to 1,200	1,600	n.a.	2.53
^{210}Po	Bq/L	30 to 100	540	n.a.	0.24
^{227}Ac	Bq/L	n.a.	50	n.a.	0.05

A discussion of the results follows and a graphical representation of the results is provided in Figure 26.4 of the Supplementary EIS.

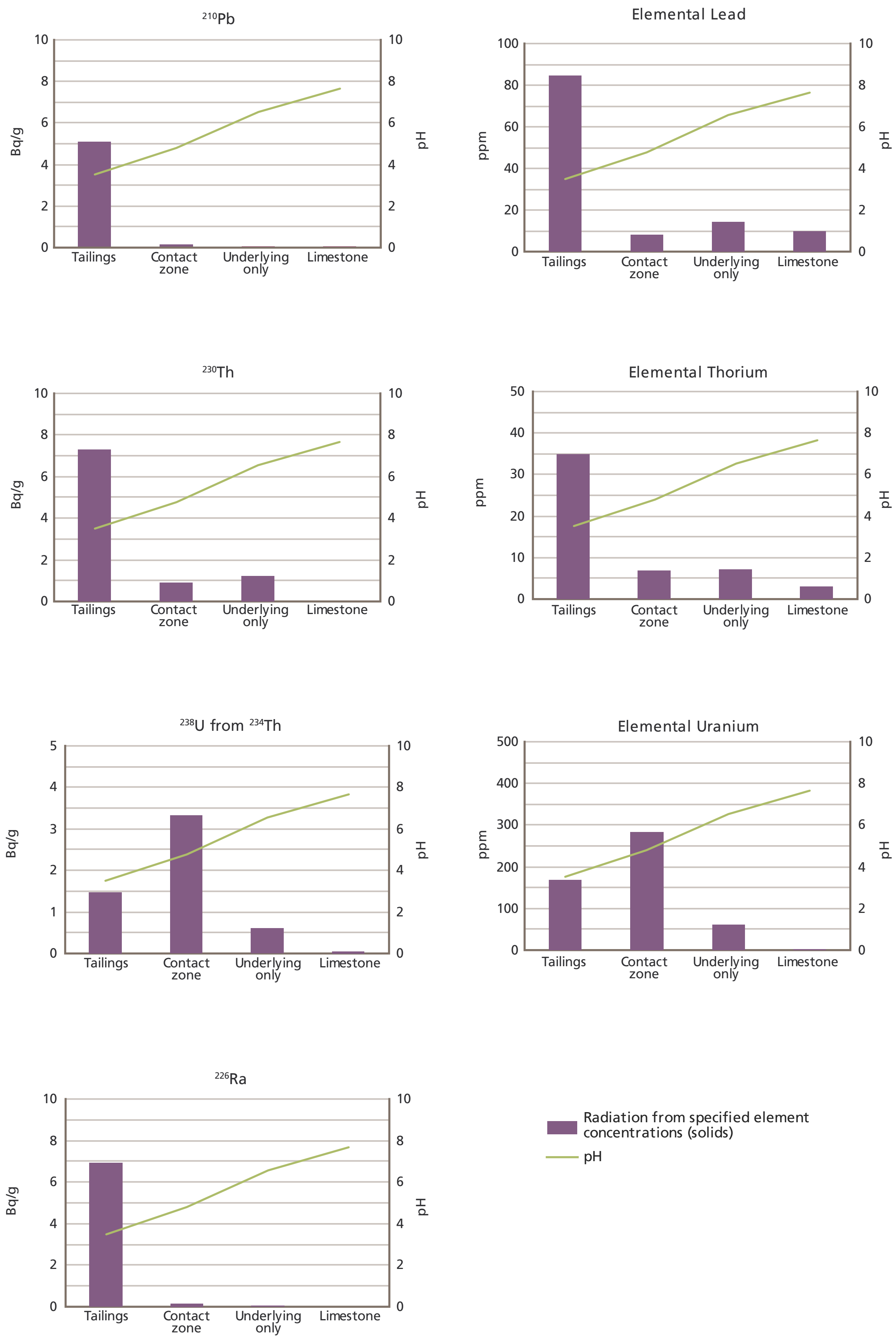

Figure 26.4 Radiation in the existing tailings storage facility

Thorium

Concentrations of elemental thorium in solids in all zones below the tailings and in the RSF surface sediments are generally consistent, indicating that there is no apparent migration of elemental thorium from the tailings (i.e. it principally remains in the tailings). Thorium is present at low concentrations in the tailings liquor and lower concentrations in pore water. Concentrations in groundwater are approximately 300 times lower than tailings liquor levels, indicating that thorium is relatively immobile in the tailings.

^{230}Th

Chemically, ^{230}Th behaves identically to elemental thorium, and therefore is not expected to migrate from the tailings. The sampling results confirm this and show that apart from the contact zone, ^{230}Th in solids is not above minimum detectable concentrations and therefore is not transferring into the underlying sediments.

The ^{230}Th concentration is more than three orders of magnitude (1,000 times) lower in the groundwater than in the tailings liquor.

Lead

Concentrations of elemental lead in solids in all zones below the tailings and at the RSF surface sediments are generally consistent, indicating that there is minimal movement of lead from the tailings. There is a significant reduction of lead in tailings liquor (i.e. EPRL) compared to lead in tailings pore water, indicating that the lead is relatively immobile in the tailings.

^{210}Pb

There are elevated ^{210}Pb concentrations in the contact zone. Beyond this there is no evidence of accumulation, demonstrating the effectiveness of the sediments immediately underlying the TSF in attenuating ^{210}Pb.

^{226}Ra

^{226}Ra is relatively insoluble and primarily present in the tailings solids. As with ^{210}Pb, there are elevated ^{226}Ra concentrations in the contact zone and beyond this there is no evidence of accumulation, demonstrating the effectiveness of the sediments immediately underlying the TSF in filtering ^{226}Ra.

^{226}Ra is present in low concentrations in the tailings liquor and at even lower levels in the tailings pore water. The data indicate that it predominantly remains bound in the tailings system.

Uranium

The chemical characteristics of uranium and its isotopes (^{234}U, ^{238}U and ^{235}U) are identical and the elemental analysis of U (via mass spectrometry) provides a reliable indication of the fate of uranium in the tailings systems.

As the seepage liquor neutralises, uranium precipitates and is removed from the solute. The data show an increase in uranium concentrations in solids at the tailings/substrate interface (i.e. the contact zone), confirming that the uranium is precipitating out of solution.

The results show that concentrations of uranium in the limestone and beyond are almost 100 times lower than concentrations in the tailings, again demonstrating the attenuating effect of the underlying sediments.

Mechanisms of radionuclide control in the tailings system

The main reason why the overall TSF system is so effective in controlling heavy metal and radionuclide movement is because the acidity of the liquor reduces (i.e. the liquor becomes less acidic and more neutral) through contact with the neutralising material like the underlying sediments and limestone. As the liquor becomes less acidic, heavy metals and radionuclides in it precipitate (become solid) and stop moving with the liquor. Heavy metals and radionuclides are incorporated into secondary minerals due to neutralisation of the liquor and the resulting increase in pH.

The acidic nature of the tailings means that ^{226}Ra, the most mobile of the uranium series radionuclides in neutral waters, has very low concentrations in the acidic free and pore water and hence reduces the potential source term for this radionuclide (in comparison with neutralised tailings).

A secondary means of radionuclide control is sorption through ion exchange. However, due to limitations in this process, over the long term uranium concentrations may be elevated in the neutral solution just below the neutralised front. For example, it can be observed that increased levels of uranium in solids (above background levels) extend to up to 5 m below the current tailings system.

The data show that radium and thorium are the least mobile radionuclides, followed by lead and then uranium.

Polonium-210 was not measured in solids. It has been assumed that the ^{210}Po would be in equilibrium with the ^{210}Pb, given the long timeframes, throughout the tailings.

Findings of the TSF seepage studies

The current TSF system is effective in controlling radionuclide and metal movement from the TSF facility. The design of the proposed TSF is based on the current TSF facility and would therefore be equally effective.

Issue:

Actinium-227 (^{227}Ac) is present in the Olympic Dam ore and further details were requested on its concentration and ultimate fate in the tailings.

Submission: 1

Response:

^{227}Ac exists in very low concentrations in the tailings. Studies of the existing TSF demonstrate that ^{227}Ac is ultimately contained in the solid tailings.

There are three naturally occurring radioactive decay chains, being uranium-238 (^{238}U), uranium-235 (^{235}U) and thorium-232 (^{232}Th). ^{227}Ac is a naturally occurring radionuclide in the ^{235}U decay chain, with a half-life of approximately 22 years. ^{227}Ac is the decay product of protactinium-231 (^{231}Pa) and decays to ^{227}Th through emission of a beta particle (see Table 26.13 of the Supplementary EIS). ^{227}Ac is primarily a beta emitter, but does also emit an alpha particle with an abundance of about 1%.

Table 26.13 ^{235}U decay chain

Radionuclide	Half-life	Decay
Uranium-235	7.1 x 10^8 y	α,γ
Thorium-231	25.5 h	β, γ
Protactinium-231	3.25 x 10^4 y	α, γ
Actinium-227	21.77 y	β
Thorium-227	18.72 d	α, γ
Radium-223	11.43 d	α, γ
Radon-219	3.96 s	α, γ
Polonium-215	1.78 ms	α
Lead-211	36.1 m	β, γ
Bismuth-211	2.14 m	α, γ
Thallium-207	4.77 m	β
Lead-207	stable	

Characteristics of ^{227}Ac

The relative radiotoxicity (and therefore radiological hazard) of a radionuclide is reflected in its 'dose coefficient'. This is a measure of the radiological risk of a radionuclide and takes into account a range of factors, such as exposure characteristics, toxicity, solubility, biological half-life, type of radiation and exposure pathway (ICRP 1996). The dose coefficient is represented in the units of Sv/Bq.

Testing of the Olympic Dam tailings shows that the ^{227}Ac is relatively insoluble, with the majority remaining in the tailings solids. The ^{227}Ac has about the same solubility level as ^{210}Pb, which is 10 times lower than uranium.

^{227}Ac is assigned a solubility classification of 'S' ('S' for slow – i.e. relatively insoluble and slow to be removed from the body).

^{230}Th has the highest dose coefficient for inhalation from the ^{238}U chain and ^{227}Ac is about 20% of the dose coefficient for ^{230}Th for inhalation. However, the main hazard from ^{227}Ac comes from ingestion, where its ingestion dose coefficient is 20 times higher than for ^{230}Th.

Measurement of ^{227}Ac can be difficult and usually ^{227}Th can be used as an indirect measure of ^{227}Ac. The reason for this is that ^{227}Th is the decay product of ^{227}Ac and has a half-life of 18.72 days. ^{227}Th will 'grow into' radioactive equilibrium with its parent (^{227}Ac) with its own half-life. Therefore after three half-lives (about two months), the activity concentration of the ^{227}Th will be similar to the ^{227}Ac levels, thereby providing an indication of the ^{227}Ac concentration. While not a direct measure of ^{227}Ac, this method provides an effective means of determining its concentration.

Results from monitoring at Olympic Dam

A routine survey of radionuclides (including ^{227}Th) in various circuits of the Olympic Dam metallurgical processing plant was conducted in 2007. Groundwater was monitored at the same time.

The recent TSF study that examined drill cores through the tailings also included ^{227}Ac analysis.

A summary of the results is provided below.

^{227}Ac levels in groundwater samples were reported as less than the minimum detectable level (which varied, depending on sample mass). This was <0.12 Bq/L in 12 of the 13 samples and <0.18 Bq/L in one sample.

Indirect ^{227}Ac levels (measurements of ^{227}Th) in tailings is provided in Table 26.14 of the Supplementary EIS. For comparison purposes, other radionuclides are included.

Table 26.14 Concentration of ^{227}Ac in tailings

	Average concentration in solids in tailings (Bq/g)	Average concentration in liquids in tailings (Bq/mL)	Average concentration in ore (Bq/g)
^{227}Th (^{227}Ac)	0.25	0.04	0.34
^{238}U	1.3	1.2	7.4
^{230}Th	5.1	4.8	7.5

Tailings drill core sampling provided an indication of the mobility of ^{227}Ac within the tailings and into the substrate below. As can be seen in Figures 26.5 of the Supplementary EIS, the ^{227}Ac is relatively immobile, remaining predominantly within the tailings solids fraction.

The analytical work shows that ^{227}Ac is relatively immobile and accumulates in the solids fraction of the Olympic Dam tailings. The results of both the metallurgical plant sampling and the analysis of drill cores confirm this conclusion.

The concentrations of ^{227}Ac in the tailings are consistent with the levels in the ore, showing that containment in the solid tailings is the ultimate fate for ^{227}Ac.

Issue:

It was suggested that a Features, Events and Processes (FEP) study should be conducted on the Olympic Dam TSF.

Submission: 1

Response:

BHP Billiton was asked to conduct a more detailed radiological risk assessment of the proposed TSF in the form of a Features, Events and Processes (FEP) study.

A FEP study (IAEA 2008) is a part of a structured risk assessment process for radioactive waste disposal facilities that focuses on the radiological implications of various radiation release scenarios. It forms part of a broader safety assessment and uses standard lists of features, events and processes against which the design, operational aspects and closure plan are assessed.

The assessment was originally developed for dedicated geological and near-surface radioactive waste repositories and has not yet been applied to uranium tailings storage facilities.

Since the methods and tools for conducting a FEP on a TSF system have not been developed, it would be unwise to conduct a study with an inappropriate set of FEPs. The construction of the proposed TSF is scheduled to occur a number of years after project approval and consequently there is time for an appropriate set of tailings facility-specific FEPs to be developed. BHP Billiton recognises the value of conducting such a study and would help develop the FEPs and the FEP process in consultation with appropriate experts and the relevant authorities.

In any case, as part of the Draft EIS risk assessment (refer Chapter 26 of the Draft EIS), a comprehensive risk assessment of the proposed TSF was undertaken.

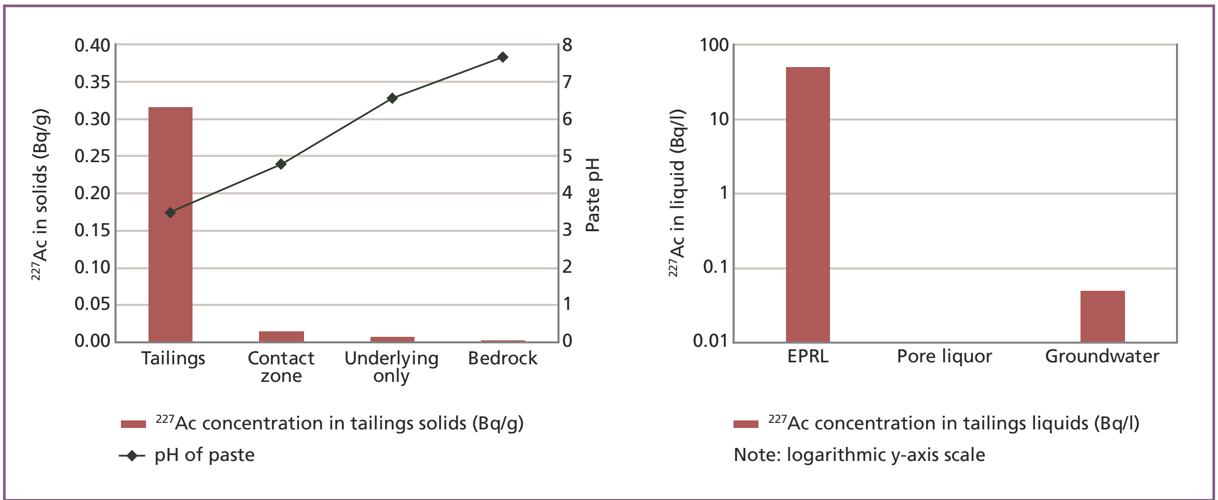

Figure 26.5 Mobility of actinium-227 (^{227}Ac) in tailings (solids and liquids)

26.2.4 Post-closure radiation emissions

Issue:

Further information was requested on the water quality in the pit following closure and the quality of the water flowing from the abandoned mine workings, particularly in relation to radionuclides.

Submissions: 1 and 2

Response:

It is expected that the concentrations of radionuclides in the precipitate within the pit would be higher than that of normal average soil concentrations, but the expected concentrations would not present a significant risk to people or the environment.

Section 11.5.4 of the Draft EIS and Section 11.4.3 of the Supplementary EIS discuss more fully the water quality predicted for the pit lake post-closure.

The water quality in the pit will depend on the quality of the water that flows into it. The analysis documented in Section 11.4.3 of the Supplementary EIS shows that most of the water flowing into the pit in the first 100 years would be rainwater. After this time, the natural groundwater inflow would increase as groundwater levels returned to their pre-mining levels. Water would evaporate from the pit lake, leaving behind precipitated solids.

Table 11.3 of the Draft EIS showed the modelled build-up of various elements (including uranium) in pit lake water. An assessment for other radionuclides in the uranium decay chain was not undertaken as uranium was considered to be the most soluble radionuclide in the series and therefore the best indicator for radionuclide build-up in the pit lake water.

The proportion of radionuclides in the precipitated solids should not be more than the proportion of radionuclides in the dissolved solids in the inflow water.

The possible sources of inflow into the pit lake (apart from rainwater) are:

- seepage from the TSF
- seepage from the RSF
- the current natural groundwater
- other water that has been in contact with unmined ore in either the current underground workings or the open pit.

Seepage from the TSF and RSF

Radionuclide and metal levels in water seepage from the TSF and RSF have been shown to be low (see Sections 26.2.2 and 26.2.3 of the Supplementary EIS). The TSF and RSF are therefore not anticipated to be significant sources of radionuclides and metals. Uranium concentrations in the water mound directly beneath the existing TSF have been used in this radiological assessment and present a conservative (worst-case) assessment.

Current groundwater

The radionuclide levels in the existing groundwater from routine monitoring at Olympic Dam are provided in Table 26.15.

Table 26.15 Groundwater radionuclide results

	^{238}U range (Bq/L)	^{226}Ra range (Bq/L)
2008 monitoring	1.6–4.8 (av. 2.5)	0.04–1.32 (av. 0.7)

Other water

The radionuclide levels in water flowing from the abandoned mine workings can be determined by considering results from existing mine water measurements, shown in Table 26.16. Compared to the existing groundwater, mine water uranium levels are elevated. However, the volume of water entering the pit from the existing mine workings should be small compared to the inflow from the natural groundwater system.

Table 26.16 Radionuclide concentration in mine evaporation pond water

	^{238}U range (Bq/L)	^{226}Ra range (Bq/L)
2006 monitoring	0.5–14	0.3–0.8

The concentration of radionuclides in the precipitate in the pit is determined by assuming that the total dissolved solids in the water eventually form the precipitate. If the groundwater were to evaporate completely, the resulting solid deposit would contain the radionuclides present in the water.

The natural salinity of groundwater surrounding the pit is of the order of 20,000–100,000 ppm (refer Section 12.3.2 of the Draft EIS). Assuming an average of 50,000 ppm and a density of 1 g/mL, this would form a solid with a weight of 50 g for every litre of groundwater. The total uranium and radium levels in the solid can be determined by assuming that the radionuclides precipitate with the other solids (note that this would be the worst case).

As shown in Tables 26.15 and 26.16, the uranium concentration in mine water is up to five times higher than in groundwater, but the mine water would enter the pit in relatively low volumes. If it were assumed that, in the worst case, 25% of the water entering the pit was via the mine workings and 75% via groundwater, then the average uranium concentration of this water would be 5 Bq/L and the radium concentration approximately 0.7 Bq/L.

This equates to a uranium (^{238}U) concentration of about 100 to 200 Bq/kg and a radium concentration of approximately 20 Bq/kg.

The uranium level is equivalent to a uranium grade of about 10 ppm. This concentration is higher than the average for soils (about 40 Bq/kg or 3 ppm (UNSCEAR 2000)) but is well within the range found in 'normal soil' and compares with an average grade of 600 ppm in the Olympic Dam ore body.

These concentrations would not present a significant risk to people or the environment.

26.2.5 OTHER RADIATION SOURCES

Issue:

More information was requested on the radionuclide concentrations in processing streams and in the copper concentrate.

Submission: 2

Response:

Routine analysis of radionuclide levels in materials of various process streams is conducted by BHP Billiton. Figure 26.6 of the Supplementary EIS shows the levels in the key streams from the most recent samples.

The ^{235}U and ^{232}Th chains have not been considered due to their relatively low radionuclide concentrations (refer to response in this section of the Supplementary EIS above for details).

The copper concentrate is quoted in the Draft EIS as containing between 1,000 and 2,000 ppm of uranium (refer Section 5.5.4 and Appendix E4 (Section E4.2.3) of the Supplementary EIS for detailed description of copper concentrate). The exact quantity of radionuclides in the copper concentrate depends on the uranium grade of the mined ore and is not expected to exceed this range. The copper concentrate is a product that would not undergo acid leaching in the Olympic Dam concentrator, so it is assumed that the concentrate contains uranium in secular equilibrium with its decay products. This means that the activity concentrations of the radionuclides are equal. This is a conservative assumption, as the mining and grinding would liberate some of the radon, resulting in activity concentrations of some radionuclides being less.

The specific activity of uranium-238 (^{238}U – the radioisotope at the head of the uranium decay chain) is 12,400 Bq/g. Therefore, in concentrate with 1,000 ppm uranium, there would be 12.4 Bq of ^{238}U for every gram of concentrate. If all the decay products are in equilibrium, then the total activity of all radionuclides in one gram of concentrate is 174 Bq (for the purposes of the radiation assessment, this is an overestimate because it will be less due to the loss of some radon and its decay products).

26.3 RADIATION RISKS

26.3.1 RADIATION RISK FACTORS

Issue:

It was suggested that descriptions of the biological, health and long-term effects of radiation were not provided in the Draft EIS.

Submissions: 21, 44, 45, 85, 244, 257 and 318

Response:

Appendix S of the Draft EIS provided an overview of radiation relevant to the Olympic Dam expansion, with details of the health effects of radiation being provided in Section S1.3.6 of Appendix S of the Draft EIS. General information about radiation is generally widely available from a number of public sources and can be obtained from standard texts and published information. Useful and reputable references to pursue include:

- Recommendations and publications of the ICRP and the IAEA
- Olympic Dam EIS 1997 – chapter 10 (Kinhill 1997)
- Documents produced by UNSCEAR (<http://www.unscear.org/>)
- Publications of the Health Physics Society (<www.hps.org>)
- Publications of ARPANSA (<http://www.arpansa.gov.au/>), particularly the radiation and health fact sheets (<http://www.arpansa.gov.au/radiationprotection/factsheets/index.cfm>) and radiation basics (<http://www.arpansa.gov.au/radiationprotection/Basics/index.cfm>).

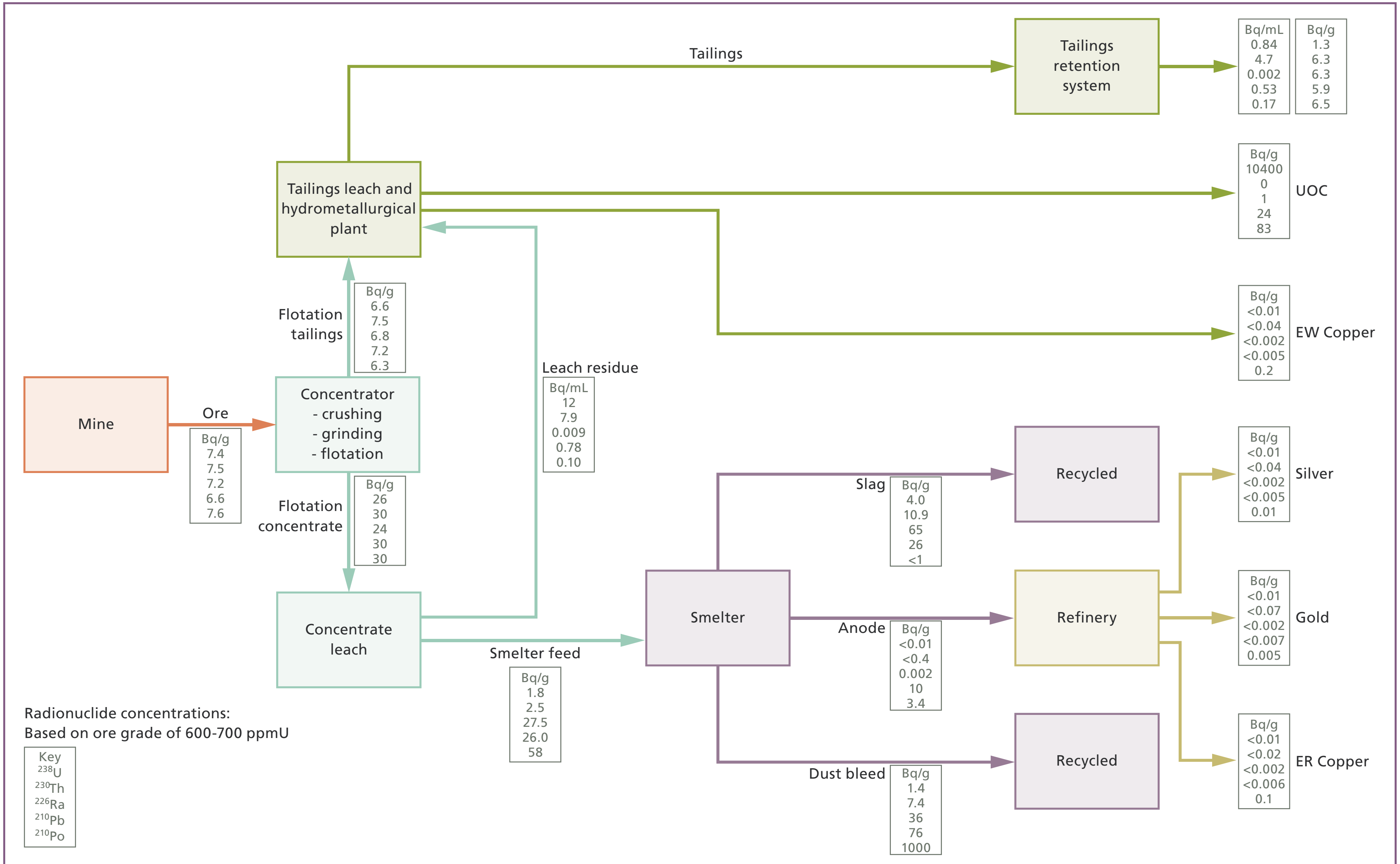

Figure 26.6 Radionuclide concentrations in existing processing plant materials

Issue:

It was suggested that communities living close to uranium mines are exposed to dangerously high levels of radiation.

Submission: 65

Response:

The submission asserts that 'others in communities near uranium mines can be exposed to dangerously high radiation levels'.

The evidence does not support this assertion. In 1997, a Senate Inquiry into Uranium Mining and Milling in Australia (Commonwealth of Australia 1997) reported that radiation exposure levels in communities near the Ranger and Olympic Dam mines were less than 10% and 2% respectively of the established international member of the public radiation dose limit. More recent results show that annual public doses in communities near the Ranger uranium mine are less than 5% of the dose limit (Australian Uranium Association 2009) and Roxby Downs levels remain at less than 2% of the dose limit (refer chapter 22 of Draft EIS).

A recent report (Uranium Mining, Processing and Nuclear Energy – Opportunities for Australia, Report to the Prime Minister by the Uranium Mining, Processing and Nuclear Energy Review Taskforce, Canberra, ACT, (UMPNE (2006)) noted that, 'Uranium mining does not discernibly increase background levels of radiation for members of the public, including communities living near uranium mines'.

For the expanded Olympic Dam operation, the estimated doses are higher than previous levels but still well below the member of the public limit, as presented in Chapters 13 and 22 and Appendices L and S of the Draft EIS.

The member of the public dose limit is 1 mSv/y above natural background radiation levels. This limit is established at an international level by the ICRP and is considered to be an acceptable level of exposure.

The level of radiation from natural background is highly variable across the world. UNSCEAR (UNSCEAR 2000) describes the range of natural radiation levels around the world and shows the variability between countries. Even using the conservative estimates of expansion-related radiation dose and adding it to the natural background radiation at Roxby Downs, the total dose is still less than the worldwide average. It is also far lower than that received from nature in many countries, including most northern European countries. Although all measures would be taken to minimise the operational component of radiation dose to members of the public, the total dose is still low in comparison with natural levels and would not be considered 'dangerous' in any way.

Issue:

One submission noted that statements in the Health Protection Agency (UK) report entitled 'Assessment of Doses from Measurements of Polonium-210 in Urine', dated 11 January 2007, contrasts with the Draft EIS statement that 'studies have not shown any increase in cancer incidence for exposure below 50 mSv/y' (Draft EIS statement from Appendix S, Section 1.3.6).

Submission: 13

Response:

The UK Health Protection Agency (HPA) report referred to in the submission has its genesis in the fatal poisoning by polonium-210 of Alexander Litvinenko – and it refers specifically to monitoring undertaken by the HPA to determine the extent of any contamination and to assess the possible doses to bystanders (Health Protection Agency 2006 and 2007).

At the time, there was significant public concern about the radiation levels, particularly in people who may have been exposed. The HPA undertook testing to address these concerns and provide estimates of probable doses.

The theoretical estimated risk to the highest exposed group (based on the linear non-threshold dose model as outlined in ICRP 1990) showed a slightly increased risk of cancer (0.03%). However, it was noted that there have been no studies that show any increase in cancer at low doses, below about 50 mSv/y (BEIR VII).

The additional monitoring undertaken by the HPA was to provide reassurance that the ^{210}Po levels were decreasing and to make a more accurate dose assessment.

Once the context of the statement on ^{210}Po from the HPA is understood, it can be seen that it is not applicable and therefore not in contrast to the statement provided in the Draft EIS.

Common misconceptions about radiation

Issue:

It was suggested that uranium is the most toxic and most lethal of all materials.

Submissions: 85, 206 and 321

Response:

The assertion that uranium is the most toxic and most lethal of all materials is scientifically incorrect.

Uranium is a naturally occurring, radioactive heavy metal and it is generally recognised that the risks from the heavy metal properties of uranium exceed the risks from its radiological properties (ASTD Registry 2009).

BHP Billiton recognises that uranium is a hazardous substance that must be managed properly, and that safeguards must be in place for its use.

The following discussion provides information on uranium in relation to other substances.

Chemical toxicity

The chemical properties of all uranium isotopes are identical, therefore this discussion applies equally to the isotopes of uranium, ^{238}U, ^{235}U and ^{234}U (the major components of natural uranium), as well as to depleted uranium. Studies in humans and animals indicate that the chemical toxicities of natural, depleted and enriched uranium do not differ.

The toxicity of an element depends on a variety of factors, including its chemical form, its solubility in water, the route of exposure (ingestion, inhalation, dermal (skin absorption)), the amount that is absorbed and the rate of excretion from the body.

Kathren and Burklin (2008) comment that 'there has never been a death attributable to uranium poisoning in humans, and humans seem to be less sensitive to both acute and chronic toxic effects of uranium than other mammalian species studied'. This was reflected in estimates of the LD_{50} for uranium in humans. (LD_{50} is an abbreviation of Lethal Dose, 50%, or median lethal dose. It gives the amount of the substance required (usually per kilogram body weight) to kill 50% of the test population, usually rats or mice).

Uranium is a common heavy metal, found in rocks, soil and water. Uranium may be present in the environment from sources including natural deposits, combustion of coal and other fuels, and the use of phosphate fertilisers. In Australia, the National Health and Medical Research Council, together with the National Resource Management Ministerial Council, sets limits for the maximum acceptable concentrations of a large number of potential substances in drinking water. These include metals, pesticides and other organic substances. The guideline set for uranium in drinking water in the most recent revision is 15 micrograms per litre (µg/L). Table 26.17 provides a comparison of the guideline for uranium with those for other heavy metals, some pesticides and other organic compounds.

These guidelines indicate that uranium is not the most toxic substance known.

Table 26.17 Maximum acceptable concentrations in drinking water (micrograms per L)

Metals		Pesticides		Other organics	
Uranium	15.0	DDT	9.0	Benzene	1.0
Selenium	10.0	Diquat	7.0	Hexachlorobutadiene	0.7
Lead	10.0	Chlordane	1.5	Vinyl chloride	0.3
Antimony	3.0	Methyl bromide	1.4	Acrylamide	0.2
Cadmium	2.0	Aldrin + dieldrin	0.3	Benzo-(a)-pyrene	0.01
Lanthanum	2.0				
Mercury	1.0				

Radiological toxicity

^{238}U is the major component of natural uranium (more than 99%). It decays through a number of steps (and other radioisotopes) to finally form stable lead (^{206}Pb). Stable isotopes do not emit radiation, and do not decay into other isotopes. They could therefore be said to have infinite half-lives.

Various organisations produce periodic lists of known and suspected carcinogens. These include the National Toxicology Program (NTP) and the International Agency for Research in Cancer (IARC). The NTP's Report on Carcinogens 11th edition does not list uranium in any form in either of its two categories: 'known to be a human carcinogen' or 'reasonably anticipated to be a human carcinogen'.

The US EPA has withdrawn its carcinogenicity classification for natural uranium. In terms of occupational exposure, the US National Institute of Occupational Safety and Health (NIOSH) (NIOSH 2009) refers to soluble and insoluble salts of uranium as 'potential occupational carcinogens', not as confirmed carcinogens.

The US Agency for Toxic Substances and Disease Registry states that: 'No human cancer of any type has ever been seen as a result of exposure to natural or depleted uranium' (ATSD Registry 2009).

Hence, natural and depleted uranium are not particularly toxic substances.

Issue:

It was claimed that the Draft EIS did not mention that uranium has an affinity to DNA and therefore can irradiate DNA, causing cancers.

Submission: 318

Response:

It has been known for many years that heavy metals, including uranium, will bind to DNA (Zobel and Beer 1961; Stoeckenius 1961).

Heavy metal toxicity has been well studied and uranium behaves in a similar manner to many other heavy metals (Liu et al. 2008). The specific activity (the amount of radioactivity per gram of the material) of pure uranium is very low, and pathological effects are generally attributed to chemical toxicity rather than to radiological effects. Laboratory experiments have suggested that the detrimental effects of uranium in isolated cell cultures may be due to oxidative stress (Kalinich et al. 2002; Miller et al. 2002; Periyakaruppan et al. 2007) or to inhibition of binding of certain proteins to the DNA which disrupts normal function (Hartsock et al. 2007).

There is little evidence of genotoxic or carcinogenic activity for uranium. The US Agency for Toxic Substances and Disease Registry states that, 'No human cancer of any type has ever been seen as a result of exposure to natural or depleted uranium' (ATSD Registry 2009).

Issue:

It was noted that the US National Academy of Sciences states that there are 'no safe levels of radiation'.

Submissions: 44, 45, 77 and 85

Response:

The National Academies, (which include the US National Academy of Sciences) through the Biological Effects of Ionising Radiation (BEIR VII) report, noted that, 'At doses of 100 mSv or less, statistical limitations make it difficult to evaluate cancer risks in humans. A comprehensive review of available biological and biophysical data led the committee to conclude that the risk would continue in a linear fashion at lower doses without a threshold and that the smallest dose has the potential to cause a small increase in risk to humans.' (BEIR VII Committee on Biological Effects of Ionizing Radiation 2006).

All human activities involve some risk, and the question of what level of risk is acceptable in particular circumstances is very complex (Sjoberg 2000). It is not unique to situations involving radiation exposure. A great deal of consideration has been given to this question in the setting of radiation dose limits by the ICRP and national bodies. Some matters considered include the natural level of risk, and risks resulting from everyday activities that are considered 'acceptable'. From these considerations, the ICRP has recommended the system of dose limitation, and considers that provided this system is properly implemented (including application of the ALARA principle and compliance with the appropriate dose limits) then the resulting risks from radiation exposure can be regarded as acceptable.

BHP Billiton abides by the advice of the ICRP and the appropriate regulatory authorities and implements the systems of dose limitation with a focus on the ALARA principle.

In terms of radiation effects, there has been a gradual refining of the dose limits. For example, in 1990, ICRP issued a revision, saying that the annual occupational dose limit had reduced from 50 to 20 mSv per year, with a maximum of 50 mSv in any one year. The most recent publication of the ICRP did not reduce the limits.

The question, 'What is a safe level of radiation?' has been addressed in Section 1.3.6 of Appendix S of the Draft EIS and is reproduced here.

In standard setting, the International Commission on Radiological Protection (ICRP) states, 'It must be presumed that even small radiation doses may produce some deleterious effects' (ICRP 1990). This is not to be confused with the often stated, 'There is no safe level of radiation', which equates 'safety' with 'no risk at all'. This is not the normal use of the word 'safe'. For example, most people recognise that there is some risk involved in commercial air travel, but still regard it as 'safe', because they consider that the level of risk is so low that it is acceptable. Similarly, exposure to radiation can be considered 'safe' if the resulting risks are low enough to be considered acceptable.

Issue:

It was stated that radon is heavier than air and accumulates along the ground, and also can attach to water, and that this should have been considered in the dose assessment presented in the Draft EIS.

Submissions: 1, 12, 77 and 318

Response:

The belief that radon, being heavier than air, will 'pool' in depressions is widespread and incorrect. Even large amounts of radon make no significant difference to air density, which is increased by less than one part in a billion even for extremely high radon concentrations of 1 MBq/m^3. This corresponds to the change in density resulting from a change of temperature of less than 0.001 degree, and local variations in air temperature are generally many orders of magnitude greater than this. The flow of air containing radon is thus driven not by any density change arising from the presence of radon, but by winds and the normal temperature gradients found in the atmosphere. These were discussed in some detail in S2.2.2 of Appendix S of the Draft EIS.

Radon in its pure form is a very dense gas, and for this reason it is commonly believed that it will 'settle out' of the atmosphere, flow downhill and accumulate in surface depressions, where it can build up to high concentrations. This is incorrect for the following reasons:

Pure radon has a density approximately 7.7 times that of air at the same temperature and pressure. However, 'pure' radon never occurs in the atmosphere. Radon diffusing out of soil or from uranium ore or other material will quickly mix with air by diffusion and air movement. The result will be a mixture of air and radon.

The mass of air in 1 cubic metre of air at 20°C is 1.2 kg (Ierardi 2010). The specific activity of radon is 5.7 x 10^{15} Bq/g; thus, 1 Bq of radon (^{222}Rn) weighs approximately 1.8 x 10^{-16} g.

If we take the extreme radon concentration of 1 MBq/m^3 (where 1 MBq equals 1,000,000 Bq and noting that the recommended 'action level' for radon in homes is 200 Bq/m^3 and in workplaces 1,000 Bq/m^3), the mass of radon in one cubic metre of air would thus be approximately 0.18 ng (Note: a nanogram (ng) is one billionth of a gram). The relative increase in the mass of one cubic metre (i.e. the relative increase in density) will thus be 0.18 ng/1.2 kg, a factor of less than one part in a trillion.

Clearly this is an extremely small change in density. For comparison, the change in air density when the temperature changes by just one millionth of a degree is less than five parts in a billion. A millionth of a degree is, in turn, less than the change in temperature that you expect when going one millimetre higher up a mountain.

Thus, the changes in air density resulting from extremely high concentrations of radon are completely insignificant compared with those arising from normal variations in air temperature. Movement of air containing radon will be dominated by winds and convection resulting from temperature differentials, with the presence of radon having no effect.

To use another example, air contains approximately 380 ppm of carbon dioxide, which is about 50% denser than air. If the CO_2 were to settle out because of its higher density (as is claimed to happen for radon), it would form a suffocating layer more than a metre thick over Earth's surface, which does not happen The carbon dioxide concentration on mountain tops (e.g. Mauna Loa in Hawaii at 3,400 m) is virtually the same as that near sea level (e.g. Cape Grim) (Tans 2010, Tasmanian Planning Commission 2009).

Radon is an inert gas and therefore does not readily interact with its environment. However, its decay products are charged solid particles and actively seek particles in the air to which to attach themselves. The particles may also include airborne water droplets. When the particles settle, or the droplets fall to the ground, the radionuclides transfer to soils, watercourses or vegetation. However, this is occurring naturally all the time. The increase due to radon that would originate from the proposed expansion is negligible.

Issue:
It was suggested that the actual risks of alpha radiation were not properly presented in the Draft EIS.

Submissions: 45 and 318

Response:

The dose assessments presented in the Draft EIS used the recommendations of the ICRP, which incorporates the actual risks of the different types of radiation (being alpha, beta and gamma radiation) emitted from various radionuclides.

The actual risks of the different types of radiation are covered by a term called the 'relative biological effectiveness' (RBE), which is included in dose assessment calculations to take into account the biological effects of differing types of radiation.

The RBE for the main types of radiation is provided in Table 26.18 of the Supplementary EIS, which has been summarised from ICRP (1990). As can be seen in the table, alpha radiation has 20 times more effect than gamma or beta radiation. However, this factor is taken into account when calculating doses.

Table 26.18 Type and energy range radiation weighting factors

Type of radiation	Relative biological effectiveness (RBE)
X and gamma rays	1
Electrons/beta particles	1
Neutrons (energy-dependent)	5–20
Protons	5
Alpha particles	20

Issue:
It was noted that the 'hot particle' theory had not been considered in the Draft EIS.

Submission: 237

Response:

The 'hot particle theory' asserts that particles of highly radioactive material, such as plutonium, would concentrate their radiation on a small group of cells, thereby increasing the risk to those cells.

There is very little credible evidence that radiation exposure from hot particles (small, highly active particles) would more likely result in cancer than the same exposure evenly distributed through an organ. The main reason for this is that, while the cells immediately adjacent to a hot particle may receive a high dose, those at a greater distance will receive much less, or none.
Thus the overall average dose to that organ would not be different to that from the same amount of radioactive material uniformly distributed throughout the organ.

For uranium production, the chance of a hot particle forming is minimal. This is due to the combination of the low specific activity of uranium and the low concentration of the material being handled.

26.3.2 NUCLEAR INDUSTRY HEALTH STUDIES

Issue:

Information on the cancer rates in the Roxby Downs region was requested.

Submission: 21

Response:

Cancer rates by region in South Australia are available at the Cancer SA website <http://www.cancersa.org.au>. Data is available for the main regions of South Australia, and Roxby Downs is included in the Far North category. Annualised incidence data is provided for 40 different types of cancer for the period 1977 to 2001.

A review of the data shows that, in all cases, cancer rates in the Northern Region are consistent with or below the South Australian averages. However, the Northern Region is a very large area and this review should be considered as indicative only.

Cancer develops slowly, and even if cancers were initiated by radiation exposure at Olympic Dam or Roxby Downs, the high turnover of the workforce and residents means that people are likely to have moved away before such cancers were diagnosed. In addition, cancer is mainly a disease of old age, whereas Roxby Downs residents are a relatively young group (there are very few over 65: refer Figure 19.4 of the Draft EIS).

BHP Billiton is not aware of any specific studies on the number of cancers observed in either Olympic Dam workers or Roxby Downs residents. However, the Australian Government is currently establishing a national radiation dose registry of uranium industry workers. This will enable better compilation of dose statistics, particularly in cases where uranium industry workers move between states, and would assist in future epidemiological studies should they ever be considered practicable.

Issue:

It was suggested that research in the UK has shown there is an increase in childhood leukaemia in populations living close to nuclear power stations. On this basis, it was then asked what the increase in childhood leukaemia is at Roxby Downs and Andamooka.

Submission: 44

Response:

It is incorrect to say that an increase in childhood leukaemia has been demonstrated near UK nuclear power stations, and that this increase is due to exposure to radiation.

Initial concern about this possibility arose in the 1980s, when an increased rate of childhood leukaemia was found near the Sellafield nuclear reprocessing plant in Cumbria, and further studies have generally confirmed this finding. However, this matter has been reviewed by the Committee on the Medical Aspects of Radiation Exposure (COMARE), an independent expert committee that does not include members from the nuclear industry.

The COMARE study (Elliot 2006) confirmed the known childhood cancer clusters near Sellafield and the nuclear research site of Dounreay in the Scottish Highlands, but the overall pattern was not consistent. There was no evidence of increased childhood leukaemia around nuclear power stations. The total number of cases of childhood leukaemia observed in the vicinity of the nuclear installations studied (including Sellafield and Dounreay) was almost exactly the same as expected.

There is no established cause for the excess childhood cancers seen at some sites, and any releases of radiation from the sites were too small to account for any increase in childhood cancer rates. COMARE has noted that the distribution of childhood leukaemia across the general population is not uniform, and that there is some degree of 'clustering' of cases. The causes of this clustering are not known, but may be related to population mixing or infectious agents.

Given the small numbers and transient nature of the population at Olympic Dam, it is difficult to assess childhood leukaemia rates, however, there is no evidence of any increase at Roxby Downs.

The actual number of cases of leukaemia occurring in Olympic Dam and Andamooka is difficult to ascertain. In 2007 (the last year for which full statewide statistics are available), there was a total of 14 cases of leukaemia in children under 14 years in the whole state. Determining which of these were from the Olympic Dam area is difficult as a number of variables need to be considered: for instance, children born in the area and being diagnosed with leukaemia there; children born elsewhere but being diagnosed with leukaemia after moving to the area; children born in the area but being diagnosed after moving elsewhere. Many children of parents living in the area are actually born in hospitals in the city or elsewhere, and their registered 'place of birth' is thus not Olympic Dam or Andamooka. Tracking down all these different categories in light of privacy concerns would be difficult.

Issue:

The results of health studies on Australian veterans of British nuclear weapons tests were requested.

Submissions: 44 and 206

Response:

This question is beyond the scope of the Olympic Dam EIS as it does not relate to the impact or risk assessment of the proposed expansion, although there is some recently published information on the radiation doses received by the servicemen and others who were exposed during the atomic testing in Australia and the radiation-related health effects (see Crouch et al. 2010; Gun et al. 2008).

26.3.3 RADIOACTIVE CONTAMINATION

Issue:

Information was sought on contamination of the food chain through nuclear waste disposal.

Submissions: 44 and 206

Response:

The mining and processing at Olympic Dam does not produce nuclear waste (see section 27.6.2 of the Supplementary EIS). Nuclear waste disposal is outside the scope of the EIS, however information is provided here on the potential for radioactive material entering the food chain from the uranium mining and processing industry.

Uranium is a naturally occurring, radioactive material (NORM), and together with other NORMs such as ^{232}Th and ^{40}K is widely distributed in Earth's crust, including in water, soil, minerals and rocks (ARPANSA 2005). The radionuclides with the greatest potential of contributing to human exposure through food are those that are analogues of essential elements and those that have high solubility in water. These include ^{134}Cs and ^{137}Cs, ^{90}Sr, ^{131}I, ^{3}H, ^{35}S and ^{40}K (Ould-Dada 2007). None of these radionuclides is derived from the uranium decay chain.

Earth's crust contains materials that are naturally radioactive, including uranium, radium and thorium (UNSCEAR 2000). These can enter the food chain by a variety of routes, including uptake through the plant root system (in the case of water-soluble radioisotopes) and deposition on the surfaces of the food (Ould-Dada 2007). It is important to remember that this 'contamination' of the food chain is normal and natural (UNSCEAR 2000).

Uptake of NORM from soil is generally low, and the radionuclide concentration at each transfer point (soil to plant, plant to animal etc) is generally reduced. Hanlon (2004) provides an example in the soil, grass, cow, milk chain. Of the radionuclides present in soil, only 0.04% appears in the milk of cows grazing on pasture grown on that soil. In addition, the human stomach excludes 80% or more of ingested radionuclides which exit the body with the faeces (Hanlon 2004).

Humans and all other life forms have evolved in a naturally radioactive environment (Ould-Dada 2007) and the proposed expansion would be subject to stringent environmental controls that would minimise the likelihood of harm to human health.

26.4 OCCUPATIONAL RADIATION EXPOSURE

26.4.1 DOSE TO SMELTER WORKERS

Issue:

Justification for the predicted doses to smelter workers was requested. Details of radiation protection systems for the expanded smelter and details of the real-time monitoring, including monitoring of ^{210}Po, were also requested.

Submissions: 1 and 13

Response:

The proposed expanded smelter was described in Section 5.5.4 of the Draft EIS, which noted that additional ventilation on tap holes would be required to increase the current smelter throughput. Estimates of doses to smelter workers were presented in Section 22.6.5 and Appendix S of the Draft EIS, and were based primarily on historical trends.

A maximum probable dose of 9 mSv/y was estimated, based on the smelter performance to date and incorporating proposed ventilation improvements. It is noted that the Draft EIS dose assessment (which is consistent with the way BHP Billiton currently calculates radiation doses) has not taken into account any protection afforded by respirators. Hence, dose estimates are considered to be overestimates.

Table 27.1 of the Draft EIS outlines BHP Billiton's commitment to the installation of a real-time sulphur dioxide monitoring system in the smelter, which would assess the effectiveness and adequacy of the ventilation systems. Sulphur dioxide was chosen as it can be measured very effectively in real time, enabling a rapid response to emerging situations. Operational experience indicates that sulphur dioxide is a good indicator or surrogate of polonium-210 (^{210}Po) because both are produced under similar conditions from similar operations. A real-time ^{210}Po monitor is currently not available, so the sulphur dioxide monitoring provides a practical solution. BHP Billiton will install a real-time ^{210}Po monitoring system when this becomes available.

In the current Olympic Dam smelter, the primary radiation exposure pathway is through the inhalation of airborne radionuclides, specifically ^{210}Po, which is released during the smelting of copper concentrate. Additional airborne exposure comes from the inhalation of copper concentrate dusts, which contain lower concentrations of radionuclides (refer figure 26.6 of the Supplementary EIS). Therefore the focus of the radiation control system is on minimising exposure to airborne fumes and dusts, and this is achieved through a hierarchy of controls.

Design controls include:

- extraction ventilation systems with large-volume hoods placed over the smelter tapping holes and the molten metal launders to capture dusts and fumes
- keeping the smelter building open for a high level of natural ventilation
- covering and enclosing materials handling systems
- designing workplaces for ease of clean-up.

Administrative system controls include:

- operator and supervisor training
- radiation training
- safe work permits (including radiation work permits) for specified non-routine work
- reporting and management control
- regulatory review and approvals.

As a back-up, personal protective equipment (PPE), including respiratory protection appropriate for the tasks, is also available.

Issue:

One submission noted that page 649 of the Draft EIS discussed exceedences, and requested a list of the exceedences of smelter control that resulted in overexposure in the smelter.

Submission: 1

Response:

Page 668 of the Draft EIS noted that 'the monitoring results have also identified some situations where control limits have been exceeded within the metallurgical plant and the underground mine'. The text then goes on to describe the management response to these situations.

Control limits are a way of ensuring that long-term concentrations and exposures remain controlled. When control levels are exceeded, such as airborne dust concentrations exceeding a predefined level, this initiates a management response which involves making a change to reduce levels to below the control level.

For example, in the smelter in the past, control levels have been exceeded in the following situations:

- temperature fluctuations in the tapped blister or slag copper releasing sulphur dioxide and fumes
- incorrect setting of the tapping hole exhaust system
- ineffective or damaged ventilation systems.

This has resulted in engineering and workplace changes to reduce levels to below the control levels.

Exceeding control limits does not constitute an overexposure. Control limits are management measures established to alert management and workers to a change that has occurred which needs to be rectified or investigated. Control limits refer to short-term changes that, if allowed to continue, could lead to higher exposure levels.

26.4.2 DOSES TO MINE WORKERS

Issue:

Further details were sought on the dose assessment for the pit workers, specifically the average radon decay product dose for miners.

Submission: 1

Response:

The radon decay product dose for miners is not expected to exceed the maximum probable dose of 2.3 mSv/y. This was noted in Table S2 of Appendix S2 of the Draft EIS, which showed the estimated average total dose to mine workers being 3.5 mSv/y.

Table S2 of Appendix S2 did not provide a figure for the average radon decay product component of the total average dose. However, a conservative figure of approximately 2.0 mSv was used to calculate the average total dose per year. This was not provided in the text of the Draft EIS.

A detailed description of the method of estimating the doses to mine workers was, however, provided in Section 22.6 of the Draft EIS and Section S2.2.2 of Appendix S. In addition, verification and justification for the dose estimates for open pit miners has been provided in Section 26.1.3 of the Supplementary EIS.

Sensitivity assessment of RDP doses for pit workers

In the Draft EIS, estimates of RDP doses to pit workers were provided and these took into account two exposure situations, being ventilation conditions induced by surface winds and atmospheric inversion conditions causing very still ventilation conditions in the pit.

Modelling of the conditions resulted in radon concentrations of 8.8 Bq/m^3 in the pit based on pit ventilation caused by surface wind speeds. The average surface wind speeds at Olympic Dam were 3.6 m/s and a conservative wind speed of 2 m/s was used to calculate radon concentrations in the pit. This provided an estimated radon concentration of 8.8 Bq/m^3.

Under very stable atmospheric conditions (i.e. inversions), when there is no air movement in the pit, the modelling showed that radon concentrations could reach 1,700 Bq/m^3 over a full 12-hour shift. The average of 850 Bq/m^3 was used to assess doses under these conditions.

In a sensitivity analysis, an important variable is wind speed and its impacts on dilution of radon concentrations in the pit. Other variables tend to be fixed (i.e. the radon emanation rate is fixed as this was estimated from both measurements and theoretical considerations, and the proportion of time when inversions occur is relatively constant).

Assuming a very-worst-case situation, where the average pit ventilation rate is 10 times lower than expected, (corresponding to a surface wind speed of less than 0.5 m/s), then the doses to mine workers would be 1.4 mSv/y, giving a total RDP dose of 3.2 mSv/y.

In addition, if the dose conversion factor for RDP were to double, doses would be approximately 6.4 mSv/y for RDP and, when combined with doses from gamma and dust, the total dose would be approximately 10 mSv/y. Therefore, even in a conservative worst-case, the predicted doses are half of the occupational dose limit of 20 mvS/y.

26.4.3 MEDICAL SURVEILLANCE

Issue:
It was questioned whether any records on workers' doses are kept for the purposes of epidemiology.

Submission: 44

Response:

Workers' dose records are computerised and kept for an indefinite period.

BHP Billiton has noted that it supports the development of the national dose register (ANRDR) (ARPANSA 2008–2009), which will provide a central repository for radiation workers' dose information.

No long-term health studies have been conducted to date. Given the relatively low doses from Olympic Dam, it is not expected that there would be any observable increases in health impacts due to the Olympic Dam operation.

Issue:
It was questioned whether routine bioassays are conducted.

Submissions: 1 and 240

Response:

BHP Billiton does not conduct routine bioassays for uranium. The main reason for this is that there are strict rules and procedures in place to minimise the potential for ingestion of radioactive materials. These include:

- requirement for workers to change into work clothes at the commencement of shift and then shower and change at the end of shift
- focus on washing hands and face before breaks
- dedicated clean lunchrooms
- regular cleaning of workplaces, offices and lunchrooms.

Uranium oxide is largely insoluble and the majority of ingested uranium is eliminated from the body in faeces. Urine analysis indicates the amount of uranium a person has absorbed either from the ingestion or inhalation of uranium (Karpas et al. 1998).

Urine analysis has not routinely been conducted at Olympic Dam because the exposure levels are very low.

Issue:

It was questioned whether there was regular medical surveillance of workers.

Submission: 13

Response:

All radiation workers undergo routine medical surveillance as part of a broader health program. Pre-employment medical checks are conducted to ensure that employees are fit for work. They are then checked every second year and again when they finish their employment at Olympic Dam.

26.4.4 EXPOSURE TO OTHER WORK GROUPS

Issue:

Information was requested on monitoring of non-routine exposures.

Submission: 1

Response:

Currently at Olympic Dam, all non-routine and clean-up work situations are assessed using the standard site safety risk assessment process (called a task hazard analysis). When radioactive material is involved in the non-routine work, the potential for exposure is determined. Based on the predicted results, protective measures such as ventilation, personal protective equipment or other precautions are required for the work to commence. In addition, appropriate monitoring is conducted to determine actual radiation levels when the work is occurring.

This safety system would be implemented in the expanded operation.

Issue:

Radiation dose estimates for employees, workers at the heavy industrial area, construction workers and workers at the administration area were requested. It was also asked whether there were special considerations for students and pregnant workers.

Submissions: 2, 302 and 318

Response:

Doses for employees were provided in Appendix S, Section 2 of the Draft EIS. Further information on worker doses is also provided in Section 26.1.3 of the Supplementary EIS.

Information on doses to administrative workers was provided in Section 2.3.2 of Appendix S of the Draft EIS. For the expansion, as is the case for the current operation, the administration area would also be monitored to determine the doses to these workers.

The existing Heavy Industrial Area (HIA) would be relocated to a new area approximately 3 km south of the existing Charlton Road estate. This is due to the existing area being within the eventual RSF footprint.

Modelling has indicated that radon decay product concentrations drop with increasing distance from the operation, approximately halving every 4 km (refer to figure S2.7 of Appendix S of the Draft EIS). Hence, doses at the relocated HIA as a result of the proposed expansion would be expected to be approximately 0.5 to 0.6 mSv/y.

Construction workers are not expected to receive doses exceeding the member of the public limit of 1 mSv per year. Routine monitoring would be conducted to confirm this. In the unlikely event that doses were elevated, the construction workers would be classified as radiation workers, undergo further induction and training and be required to comply with the site radiation safety rules.

All construction workers' time on-site would be recorded in a database for future reference so dose estimates could be made if necessary.

As part of the current site operating standards, which would be used in the expanded operation, all workers receive a radiation induction and are informed of risks from exposure to radiation. Workers are asked to reveal pregnancies at the earliest opportunity to ensure that management measures are implemented to ensure their doses for the remainder of the pregnancy are less than 1 mSv. For work experience students under 18, doses would be monitored and maintained below the member of the public limit of 1 mSv.

26.4.5 OPERATIONAL CONTROLS

Issue:

More details were requested on spillage management and control.

Submission: 240

Response:

The current Olympic Dam operation has developed a procedure for reporting spillages, including spills into contained and uncontained areas. The procedure ensures that all spills are adequately investigated and cleaned up.

It is noted that of the spills that occur for the existing operation, the majority are process materials spills within the defined processing plant area. Process material spillages are unplanned events and, despite designs and systems to minimise them, there is a chance that they will occur. When they do, the procedures require an investigation to be undertaken and measures implemented to prevent recurrences.

Spillage of material at Olympic Dam is treated extremely seriously. Spills above certain criteria must be reported internally for remediation and those above a certain quantity must be reported externally to the regulatory authorities (i.e. SA EPA). For process materials, the external reporting requirements are:

- any volume of material into undisturbed environment
- volume >50 m^3 outside a bunded area (unplanned)
- volume >50 m^3 into the TSF pipeline corridor.

For concentrated uranium-bearing material (such as uranium oxide or pregnant liquor), the external reporting requirements are:

- any volume of material outside a bunded area
- >2 m^3 inside a bunded area (unplanned).

Note that 'planned spillages' may occur where material may be deliberately released in a controlled manner under very specific circumstances.

Spills are considered to be reportable incidents, much like an accident, and therefore must be investigated and actions taken to prevent recurrences.

BHP Billiton has established mandatory design criteria for the project development phase. Design standards have been established to prevent spillages where possible and provide for ease of clean-up elsewhere. For example, tanks containing process material are required to be bunded and have sumps for ease of clean-up. Government design standards require that bunds be able to contain at least 120% of the maximum volume of the material contained in the tank, and 133% for certain materials.

As noted in Section 22.4.5, it could be expected that the number and size of spills may increase, simply due to the expanded size of the operation. The method applied for predicting the number of spills that may occur in the expanded operation was by simple scaling.

Material reclaimed during clean-up is either reprocessed or disposed of. For example, a spill from a tailings disposal line would be allowed to dry within a contained area and then be reclaimed with a bobcat or front-end loader and transferred to the tailings storage facility.

If a spill occurred outside the Special Mining Lease, emergency response personnel would secure and make safe the area, then the material would be salvaged safely. For a spill of radioactive material, personnel from Olympic Dam would be directly involved in material security and recovery.

Operations personnel receive the training necessary for the safe handling and reclamation of spilt materials and the appropriate notification procedures.

Transport personnel review instructions on what to do in the event of an accident involving materials spill.

Issue:
Clarification was sought on whether radiation work permits are used at Olympic Dam.

Submission: 1

Response:

Radiation work permits (RWP) are an important part of the systems of radiation control at Olympic Dam. Just like safe work permits, RWPs are used for specific tasks as defined in the safe work procedure for those tasks.

The safe work permit system identifies when a RWP is required. For non-routine work, the task hazard analysis is used to identify the need for a RWP.

The main uses of a RWP are for:

- any work on or near a radiation density gauge
- any maintenance work on the uranium calciner or in the product packing booth.

A copy of the Olympic Dam RWP is provided as Figure 26.7 of the Supplementary EIS.

Issue:
Clarification was sought on how radioactively contaminated metals (and materials) are treated and what controls exist.

Submission: 2

Response:

BHP Billiton at Olympic Dam has specific procedures in place to deal with all material leaving the operational area. The overall objective is that no material leaves site until it is clean; the purpose of this is to ensure there is no spread of radioactive contamination from the operation. Procedures exist to ensure that contaminated material on-site is segregated and stored or disposed of in a safe manner.

To achieve this, all material must receive a 'radiation clearance', which involves a visual and physical check of the material by a trained officer. The material is inspected and then a surface contamination check is performed using a surface alpha contamination probe. All surfaces are inspected and any internal cavities (such as inside a pump) are also checked. If surface contamination is identified (either through the material being visible or the surface contamination levels being elevated), then the material is sent to be re-cleaned. The limits for surface contamination are defined in the Transport Code (ARPANSA 2008) and are 0.4 Bq/m^2 for beta and gamma emitters and low-toxicity alpha emitters and 0.04 Bq/m^2 for all other alpha emitters.

The procedure is controlled by the operation's statutory radiation safety office, which ensures that all procedures are being followed and that officers are appropriately trained. The South Australian regulatory authorities audit the system.

Material that cannot be cleaned is disposed of on-site in designated areas.

26.5 PUBLIC RADIATION EXPOSURE

26.5.1 MEMBER OF THE PUBLIC EXPOSURE LEVELS

Issue:
More detail was requested on the assessment of member of the public doses in Roxby Downs, Olympic Village and Andamooka.

Submissions: 10, 163 and 318

Response:

Section S2.5 of Appendix S of the Draft EIS provided significant details on the assessment of doses to the public in Roxby Downs. It is estimated that the total dose for a resident of the Roxby Downs municipality or Hiltaba Village would be 130 μSv/y (0.13 mSv/y), above natural background levels, mainly from radon decay product exposure.

Doses at Olympic Village are expected to reach 1 mSv/y during full production. However, it is expected that no people would be living at Olympic Village after production commenced.

In the Draft EIS, doses to residents of Andamooka were not provided as the modelling did not extend that far. Estimates are provided here.

As noted in Section 2.5 of Appendix S of the Draft EIS, the only significant pathways for exposure in the environment outside the operation are from inhalation of radioactive dusts and radon decay products. The modelling was used to estimate the concentrations of dust and radon in the environment, and even though these calculations did not extend to Andamooka (about 25 km east of the operation) doses were estimated for the proposed Hiltaba Village (about 10 km east of the pit). Doses at Hiltaba Village were estimated to be approximately 130 µSv/y, predominantly from inhalation of radon decay products. The radon decay products concentrations and resulting dose levels drop with increasing distance from the operation, approximately halving every 4 km (refer to figure S2.7 of Appendix S of the Draft EIS). Therefore the dose at Andamooka above natural background levels would be expected to be around 15 µSv/y. This is compared to the annual member of the public dose limit of 1,000 µSv/y (1 mSv/y).

Issue:

Information on the expected doses to workers at Arid Recovery was requested.

Submission: 301

Response:

Arid Recovery consists of two main areas, being the laboratory and visitor centre in Olympic Village and the recovery area itself, which is north of the project area.

Section S2.5.2 of Appendix S of the Draft EIS provided an assessment of the potential doses to members of the public in Olympic Village. For a person living full-time in Olympic Village, it is calculated that their annual dose would be 1 mSv. Workers in Olympic Village would be exposed to lower levels of radiation as they would not be exposed for a full 24 hours a day (because they would not necessarily be living in Olympic Village).

BHP Billiton has committed to relocating the facilities at Olympic Village to the new heavy industrial area, or to the Roxby Downs industrial area.

Arid Recovery workers in the recovery area itself are further away from the mine site and annual doses are expected to be not more than 1 mSv for full-time occupancy.

The member of the public limit is 1 mSv/y per year.

Issue:

A submission asked whether radioactive dust from Olympic Dam would reach the east coast of Australia and, if so, what the impact would be.

Submission: 77

Response:

Dust from Olympic Dam is highly unlikely to reach the eastern seaboard of Australia under everyday atmospheric conditions and, even if it did, estimates show that the radiation doses would be so low as to be negligible.

As a first approximation, the standard method of determining the spread of radioactive material, or any other material, in air is through Gaussian plume modelling (UNSCEAR 2000). This method calculates the air concentration at some point at a distance based on the emission rates at the source and a set of standard atmospheric conditions. Using this method, levels on the eastern seaboard are about one million times lower than levels closer to the source.

Table 13.22 of Chapter 13 of the Draft EIS provided an estimate of the particulate emission rates in kg/d for each activity of the proposed mining operation. If it is assumed that the average uranium grade of the dust is 100 ppm of uranium, the radiological impact of these conditions can be determined.

An amount of 100 ppm of uranium in dust is equivalent to 1.24 Bq/g of ^{238}U. Using the dilution factors provided in Table 5 of UNSCEAR (2000) and the predicted emission rates, it is possible to estimate a theoretical project impact dust concentration 1,000 km away from Olympic Dam. Applying the factors gives a theoretical uranium activity in air which is 1/100th of the UNSCEAR reference figures (which are indicative global averages). The potential most conservative dose for a resident of the eastern seaboard as a result of this concentration is less than 1 μSv for a full year (compared to the annual member of the public dose limit of 1,000 μSv/y).

It is noted that this calculation has been undertaken purely to demonstrate how low the potential doses would be. From a radiological perspective, the potential doses would be so low as to be negligible.

Severe dusts storms in the Australian Outback also provide a mechanism for dusts to potentially travel long distances.

In the 2009 outback desert storms, approximately 75,000 tonnes of topsoil dust was being deposited over Sydney every hour (Macey & Wallace 2009). The report notes that the dust originated from an area of approximately 500 km^2, therefore implying that 3 mm of topsoil was removed.

Simple calculations show that this dust cloud could have contained up to 1.5 million tonnes of dust. Assuming the natural average uranium content of topsoil, this equates to 4.5 tonnes per day of uranium falling on Sydney from natural sources.

If a worst case was assumed, in which the dust emissions were increased by a factor of 10 during a dust storm for a full day and all the dust generated was transferred by the storm in one homogeneous cloud to the eastern seaboard, without any fallout, then the increase in uranium levels over the levels due to natural uranium in dust would be less than 2%, and would still be well below applicable limits.

26.5.2 POST-CLOSURE RADIATION EXPOSURE

Issue:

Details of the post-operational radiation hazard and possible future radiation exposure scenarios were requested.

Submissions: 1 and 318

Response:

The radiation levels into the future, following closure, are expected to be very low and consistent with current background levels. This is due to the proposed closure design standards that aim to contain radioactive material.

Radiation control through design

The two major facilities that require appropriate closure management in terms of radiation control are the rock storage facility (RSF) and the tailings storage facility (TSF). All other constructed facilities would be removed and appropriately disposed of, with the exception of the open pit that would remain.

The overriding closure design objective of both the RSF and TSF is to ensure that the final landforms remain stable over the long term.

The long-term stability of the RSF involves ensuring that the reactive material and the low-grade mineralised rock remain permanently encapsulated within the benign outer layer (refer Section 5.4.6 and Section 23.8 of the Draft EIS for details of the measures proposed to maintain stability). This would ensure that radiation levels outside the facility were negligible.

The closure standards for the TSF were described in Section 10 of Appendix F1 of the Draft EIS and incorporate a range of factors, including radiation control, seepage management, erosion control and overall stability. The long-term stability of the TSF is achieved through an engineered cover system utilising large quantities of available non-radioactive mine rock. Once constructed, the covered TSF would require minimal and, ideally, no ongoing monitoring and supervision.

The stability of the TSF is based on its construction using the centre line raised embankment method in which the rock walls are progressively strengthened as the height increases (refer Figure 5.22 of the Draft EIS). This creates a high level of facility strength that protects against future events such as wall failures.

Final containment of the tailings would involve capping the facilities with waste rock. Ongoing testwork is occurring to determine the optimum depth of material to minimise radon emanation, minimise water ingress and maintain maximum stability. There would be more than a sufficient supply of material from the open pit development to cap to a depth that met regulatory approval.
The performance requirements of the TSF cover would be defined by the regulatory authority, with the overall aim of ensuring that emissions were consistent with background levels.

Additionally, the final capping depths should not necessarily be determined at this stage because, as time progresses, new standards and techniques may develop which would improve the outcomes.

Radiation levels post-closure
Based on the proposed closure design objectives, radiation levels are expected to be low – consistent with background levels. A closure design objective is to maintain doses at less than the member of the public dose limit of 1 mSv/y above natural background (refer Table 23.1 of the Draft EIS). Expected radiation levels are as follows:

- Radon concentrations would be expected to be around 5 to 40 Bq/m^3, which are similar to current concentrations. There may be slightly elevated levels close to the TSF and RSF, but these levels dilute so quickly that they would not be detectable.
- Gamma radiation would be expected to be approximately 0.1 μSv/h, which is consistent with background gamma radiation levels in the Olympic Dam region. Immediately above the RSF, the gamma levels may be elevated and may be up to 0.5 μSv/h.
- Significant dusting of the TSF and RSF outer cover is not expected to occur. However, even if the surface did dust, it would consist of benign material and would therefore have radionuclide concentrations similar to naturally occurring levels.

Impacts on flora and fauna are expected to be negligible following closure as tailings and low-grade mineralised material would be encapsulated.

Radiation doses post-closure
Assessing the radiation doses for risks of potential future failures is somewhat speculative. The RSF and TSF are designed not to fail, therefore the assessment of risks is qualitative and essentially forms part of a more detailed risk assessment (see below).

However, there are some exposure situations that may arise following closure and the potential doses for these situations have been calculated.

The three potential exposure scenarios assessed are as follows:

- long-term resident of Roxby Downs and Andamooka
- casual visitor to the mine area following closure
- long-term resident at base of RSF (approximately in the Olympic Village location).

In undertaking this assessment, it has been assumed that the mine and associated areas have been rehabilitated to the standards outlined in the Draft EIS and the Supplementary EIS. The assumptions in undertaking the dose assessments are as follows:

- the main exposure pathway is through inhalation of radon decay products from rehabilitated TSF
- airborne dust is assumed to be inert as any dust would originate from the inert material used to cover the TSF and RSF
- there will be no exposure from gamma radiation, due to attenuation in the cover material.

Doses from inhalation of radon decay products have been based on the assumption that there will be a cover of 3 m of inert rock across the TSF and RSF, resulting in attenuation of radon emissions by a factor of 6 (based on diffusion equations).

Based on the original radon contours and the estimated radon concentrations at the key locations (see Figure S2.7 and Table S3.1.3 of the Draft EIS) the calculated doses for the potential exposure scenarios are as follows:

- long-term resident of Roxby Downs/Andamooka – 0.020 mSv/y
- visitor to pit area (one day visit to area and assumed concentrations are 10 times higher than Olympic Village concentrations) – <0.001 mSv/y for each visit.

For a person residing at the base of the RSF (which is not considered to be credible and provided for comparison only), the annual dose would be approximately 0.2 mSv/y.

It should also be noted that these estimated doses are in addition to the natural background doses which are approximately 2 mSv/y.

Draft EIS closure risk assessment
Preliminary post-closure risk scenarios were considered as part of the Draft EIS risk assessment process (refer Chapter 26 and Appendix C of the Draft EIS). Broad failure mechanisms, which could result in environmental risk, were considered, including radiation exposure in the future. The closure risk assessments for the TSF and RSF are summarised below.

For the TSF, potential risks associated with the failure to successfully rehabilitate the TSF were identified. These were:

- slope failure, which was rated as low for each of the consequence dimensions (OHS, social, flora/fauna, physical, water and air)
- slope erosion, which was rated as low for each of the consequence dimensions apart from the water dimension, which was rated as medium
- complete erosion of the TSF cover, which was rated as low
- water infiltration, which was rated as medium for all dimensions apart from the water dimension, where it was rated as high and therefore requiring control through the management plans.

For the RSF, potential risks associated with the failure to successfully rehabilitate the RSF were identified. These were:

- slope failure, which was rated as low for each of the consequence dimensions (OHS, social, flora/fauna, physical, water and air)
- slope erosion, which was rated as low for each of the consequence dimensions apart from the water dimension, which was rated as medium
- complete erosion of the TSF cover, which was rated as low
- water infiltration, which was rated medium for all dimensions apart from the water dimension, where it was rated as high and therefore requires control through the management plans
- wind scour leading to excessive dust generation was rated as low in all consequence dimensions apart from flora, physical and air, where it was rated as medium.

While not a preferred post-closure land use, living on top of the final rehabilitated RSF was rated as a low risk from a health and safety perspective.

BHP Billiton has committed to undertaking a formal radiation risk assessment (called a FEP study) for the TSF even though there is no requirement to do this. A FEP is a structured radiation risk assessment usually reserved for radioactive waste repositories. However, in conjunction with the relevant agencies, including the IAEA, ARPANSA and the SA EPA, BHP Billiton intends to develop the process for use with large uranium mining tailings systems.

26.6 ENVIRONMENTAL RADIATION

26.6.1 ENVIRONMENTAL RADIATION LEVELS

Issue:
It was requested that BHP Billiton describe the natural radiation levels in the region and the impact that the expanded operation would have on these levels (including soils, air and groundwater).

Submissions: 1, 2, 10, 21, 71 and 273

Response:
A significant quantity of data and information on environmental radiation has been collected and reported for the Olympic Dam operation to date.

Baseline environmental radiation surveys of the Olympic Dam region were conducted before operations began in the early 1980s and were reported in Kinhill Stearns Roger 1982 and WMC 1988. After operations commenced, the company reported annually on the results of environmental radiation monitoring. In 1996, after demonstrating that the project was having minimal radiological impact on the environment, WMC obtained approval from the State Government to reduce the amount of environmental radiation monitoring.

An overview of the radiological impacts of the Olympic Dam operation on the surrounding environment was also published in the 1997 expansion EIS (Kinhill 1997). Annual reports continued to be produced for government which outlined the results of monitoring (including the radiological monitoring) that had been undertaken during the year. Such documents include the BHP Billiton Environmental Management and Monitoring report 1 July 2007–30 June 2008 (BHP Billiton 2007–2008).

This section of the Supplementary EIS provides additional information in the following areas:

- radon in air
- radionuclides in dust in air
- radionuclides in flora
- radionuclides in fauna
- radionuclides in soils
- radionuclides in groundwater.

The additional information has been collated from existing annual reports and internal BHP Billiton reports.

RADIATION CLEARANCE CERTIFICATE No:

Safe Work Permit No.	Location description:
Detailed description of work to be carried out:	Category:

RADIATION CLEARANCE CERTIFICATE CATEGORIES

A	**Industrial Radiography** The S.A. Radiation Protection and Control Act regulations require the following: 1. The contractor to provide a written plan detailing safety precautions to be followed to limit doses (reg 177). 2. The site to be barricaded off with vivid bunting and sign-posted "DANGER RADIATION KEEP OUT" (reg 179). 3. The client to nominate a site contact to be responsible for compliance with the dose limitation plan (reg 177).	Written plan attached **Y / N**............................. Bunting and signs placed **Y / N** .... ODC contact name .... Contract company name................................. Address... .... Radiation Source .... Energy .... Activity ....
B	**Fixed Sources** (Install, relocate, removal, maintenance and storage.) A Radiation Information Sheet **MUST** be displayed at the location of the work. Personnel working on Radiation Density Gauges under this Clearance Certificate **MUST** wear a Personal Dosimeter. Radiation Density Gauges not installed by the end of shift **MUST** be returned to the Radioisotope store. Keys held by Radiation Department.	Radiation Source .... Radiation Activity .... Serial Number.. Shutters Locked **ON / OFF** .... Dosimeter Wearer... .... Dosimeter Start... Finish...
C	**Process Maintenance and Clean Up** Tools **MUST** be cleared upon completion of work.	Airborne Contamination Tests **Y / N**................................. Ventilation/Respiratory Protection **Y / N** .... Change of Clothing Required **Y / N** .... Bunting Required **Y / N**...

Supervisor:	....
Workers Names:..	....
....	....
....	....

Radiation Department Issuing Officer Authorisation

Name	*Signature*	*Date*	*Time*

Specific Work Precautions/Requirements:	Clearance Valid Until:

Figure 26.7 Radiation clearance certificate

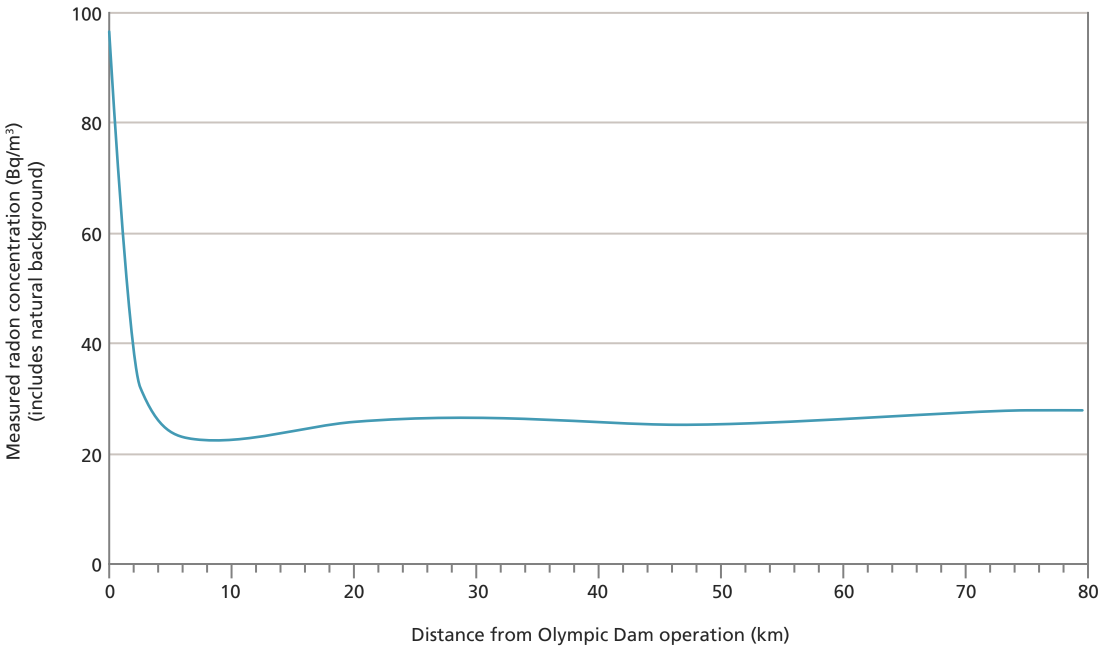

Figure 26.8 Radon concentration with distance from current operation (2010)

To bring information as up to date as possible, some additional fieldwork was conducted, as follows:

- survey of radionuclides in vegetation and fauna
- broad survey of airborne radon concentrations
- regional soil sampling.

In general, over the 25-year life of the operation to date, the radiological impact on the surrounding environment has been low, representing a measurable effect but well within compliance limits (as per the impact assessment criteria provided in Section 1.6.2 of the Draft EIS).

Radon in air

Radon concentrations in air have been monitored since operations began. The pre-operational levels were reported in Kinhill Stearns Roger 1982 to be 20 Bq/m^3. Later, in WMC 1988, seasonal average levels ranging between 4 and 23 Bq/m^3 are reported. WMC (1996) reports three-month average radon concentrations from October 1987 to April 1995 of between 5 and 55 Bq/m^3 for passive monitors at Roxby Downs and from 5 to 30 Bq/m^3 for active radon monitors.

A regional survey of ambient radon levels was conducted during 2009–2010. Average radon concentrations were monitored for the summer of 2009 and autumn of 2010 using passive track etch devices that were placed at locations in the region for a period of three months. Results show that radon concentrations very close to the current operations are elevated, with concentrations falling to background levels at distances beyond 4 km from the operations. Figure 26.8 of the Supplementary EIS shows the rapid fall-off to natural background levels with distance from the operations.

Figure S2.7 of Appendix S of the Draft EIS provided a diagram of the modelled additional radon concentration as a result of the expansion. It shows that the main radon impact of the expanded operation is confined to the immediate vicinity of the expanded operation, with levels reducing with distance to levels similar to natural background levels at Roxby Downs.

The impact (and therefore doses) from the radon decay products (RDP) from the expanded operation are calculated from the radon concentrations that have been determined through air quality modelling. The RDP levels and radon concentrations are generally proportional (as shown in Figure 26.9 of the Supplementary EIS). Modelled radon impacts provide the means for determining the potential doses from RDP.

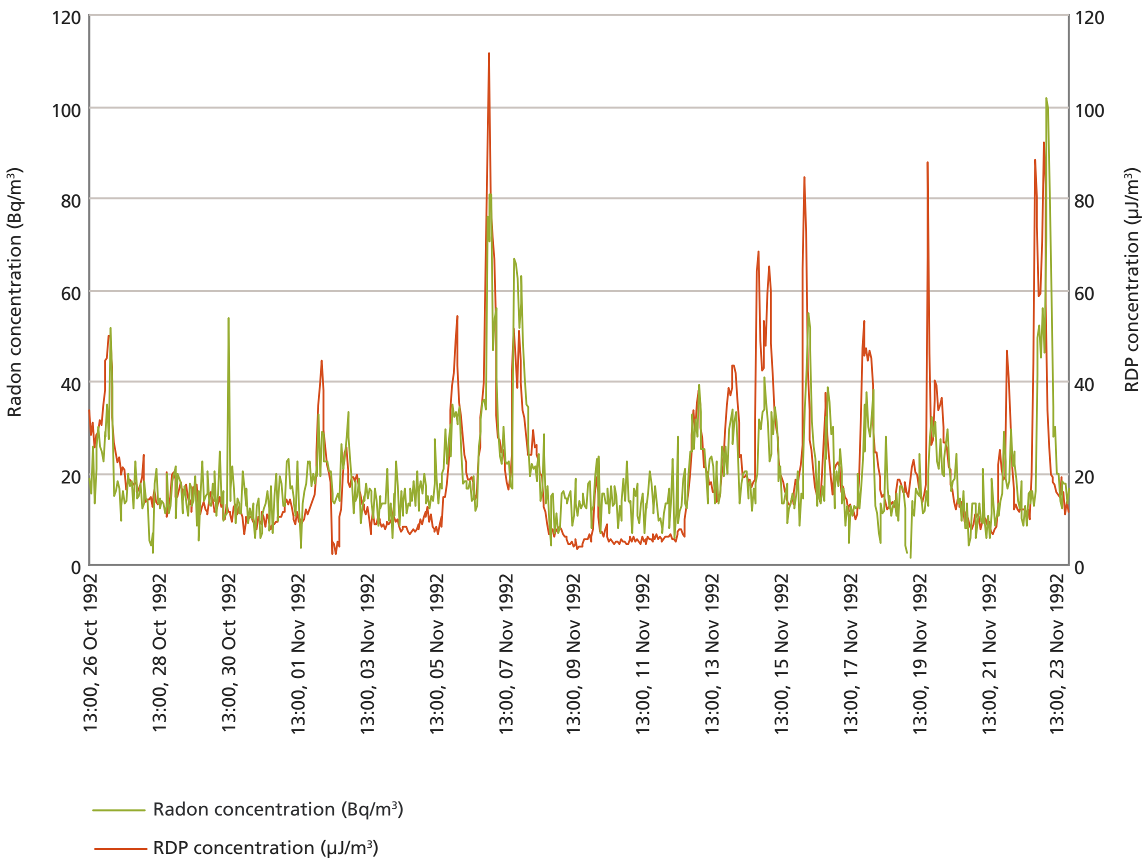

Figure 26.9 Correlation between radon concentrations and radon decay product (RDP) concentrations (1992)

Radionuclides in airborne dust

Dust sampling for the current operation is undertaken using two methods:

- active air sampling using high-volume samplers
- passive sampling via dust deposition gauges.

High-volume air sampling provides information on airborne concentrations of dusts, and deposition gauges provide information on dust that settles on soils or plants.

A summary of the high-volume results is presented here.

High-volume dust sampling results

Early high-volume dust sampler results are available in WMC 1988, which reports annual dust mass concentrations (in µg/m^3) and ^{238}U and ^{226}Ra concentrations (in µBq/m^3) for the years 1982 through to 1986 at a location close to the original Whenan Shaft. The figures from 1982 and 1983, which are before significant mining activities began, provide the most representative results of pre-existing background levels and can be used to indicate the background levels at the time.

More recent high-volume samples from Roxby Downs and Olympic Village are available in the annual environmental reports (BHP Billiton 2007–2008). The report shows that the concentration of dust and the radionuclide concentrations have remained relatively constant for the period 2003 to 2007.

For comparison, the earlier and recent dust levels are presented in Table 26.19 of the Supplementary EIS.

Table 26.19 Comparison of earlier and more recent airborne dust concentrations

	Dust concentration (µg/m^3)	^{238}U concentration (µBq/m^3)	^{226}Ra concentration (µBq/m^3)
Early data background (1982–1983)	40–51	1.7–3.2	4.3–5.6
Recent data (Roxby Downs (2006–2007)	25–70	1–4	1–7.5

The comparison shows that there has been no significant change in the radionuclides in airborne dust since operations began.

Passive dust sampling results

Chapter 13 of the Draft EIS provided estimates of the impact of airborne dust emissions from the expanded operation (refer Table 13.23 of the Draft EIS), noting that potential concentrations of total solid particulates in Roxby Downs would be on average 5.7 µg/m^3, with dust fallout being up to 2.4 g/m^2 per year. Section S2.5.3 of the Draft EIS described potential impact of dust on public doses and estimates that the dose would be no more than 3 µSv/y. This is compared to the annual member of the public limit of 1,000 µSv/y (or 1 mSv/y).

Assuming that the dust contains 100 ppm of uranium in equilibrium with its decay products (as was assumed for the dose assessment in Chapter 22 and Appendix S2 of the Draft EIS), this would lead to an airborne ^{238}U and ^{226}Ra concentration of approximately 6 µBq/m^3 for each radionuclide.

Radionuclides in flora

Results from pre-operational monitoring of radionuclides in local species of flora are presented in WMC 1988. It was noted that while the difference in radionuclide concentrations between the species was low, there was a measurable difference between the radionuclide concentrations in species growing in sand compared to those growing on swales. A summary of the pre-operational results is provided in Table 26.20.

Table 26.20 Background radionuclide concentrations in vegetation

	Radionuclide concentration (Bq/kg)			
	^{238}U	^{230}Th	^{226}Ra	^{210}Pb
Sand dune species	0.38	0.20	0.53	75
Swale species	0.90	0.60	1.67	55

In WMC 1996, WMC reviewed radionuclide in vegetation data for the period 1987 to 1993 at a number of locations at various distances from the operations. It was noted that data collected during this period showed there were some elevated levels of radionuclides in samples close to the operation and no elevated levels beyond the mine lease. The report also noted that any impact as a result of the elevated levels was below detectable levels.

During 2005 and 2006, a survey was conducted that examined radionuclide levels in vegetation close to the operation (<3 km) and vegetation at distance (25 km from the operation). BHP Billiton collected and radiometrically analysed the samples and the results were reviewed externally (Griffin and Dunlop 2008). The review concluded that all radionuclide levels were elevated for the samples close to the operation, while, apart from ^{210}Po and ^{210}Pb, radionuclides in samples at distance were consistent with natural background levels. The elevated levels of ^{210}Po and ^{210}Pb at distance were identified in one particular species, Mulga *Acacia aneura*.

In 2009, an additional, more detailed, study was undertaken to better determine whether there was an impact from the current operation by investigating radionuclide levels in a particular species of plant. The radionuclide survey focused on Mulga *Acacia aneura* because the previous study had identified elevated levels of ^{210}Po and ^{210}Pb in this species out to a distance of up to 25 km (see Appendix M3 of Supplementary EIS).

The radionuclide review concluded that there were no significant differences in the ^{210}Pb distribution in Mulga with direction from Olympic Dam. This indicated that the impact of the Olympic Dam operation on radionuclide levels in vegetation is not significant, other than within 5 km of the operation. The report noted that the mechanism for build-up of radionuclides in vegetation is through uptake of radionuclides in soils.

The increased dust emissions from the expanded operation would lead to a slight increase in the amount of deposited dust, which in turn could lead to increased levels of radionuclides in soils. This additional load of radionuclides in soils would be available for uptake by vegetation. However, as noted later in the soils section of this response, it is predicted that this would be small and within the normal range of soil concentrations (UNSCEAR 2000).

Radionuclides in fauna

BHP Billiton has undertaken fauna monitoring since the operation began. The WMC (1996) review says fauna monitoring was originally undertaken for the purposes of assessing potential member of the public doses from consumption of animals that may have enhanced levels of radionuclides. The review noted that this human exposure pathway was negligible and therefore monitoring was discontinued.

In 2006, BHP Billiton undertook additional fauna sampling, specifically examining radionuclide concentrations in kangaroos from within the mine lease area and at a distance from the operation. The aim of the study was to see whether there were any differences between the samples from close to the mine and those at distance. Overall, the study showed no statistical difference between the two groups of animals tested and that consumption of the fauna would have no effect on human health.

To determine the impact of radiation from the expansion on fauna, BHP Billiton has adopted the approach proposed by the ICRP 2008 and prescribed by the ERICA system (ERICA Program 2007) which does not involve the taking of animals. See Section S1.4.3 of Appendix S of the Draft EIS for assessment.

BHP Billiton does not support the taking of animals for scientific assessment when other means for determining the answers are available.

Radionuclides in soils

Regular soil sampling has been conducted at Olympic Dam since before the operation began and can provide an indication of changes that have occurred over time as a result of the existing operation. The primary pathway by which radionuclide concentrations in soil can change is through deposition of airborne radioactive dusts from the operation. It is also possible for ^{210}Pb and ^{210}Po concentrations to increase due to the decay of radon that emanates from the operation. However, monitoring indicates that the project impact is very small compared to the natural levels that exist (see earlier in this section).

The major soil sampling campaigns were conducted during the following periods:

- prior to operations and reported in Kinhill Stearns Roger (1982) and WMC (1988)
- between 1987 and 1995, when intensive environmental monitoring was undertaken, with information reported in annual environmental reports
- between 1996 and 1999, when environmental sampling focused on the region of the existing TSF, with information reported in the annual environmental reports

during 2006, when a sampling campaign was conducted which focused on soils close to the operation (< 3 km from the operating areas) and at distance (>25 km) from the operating areas, and reported in the Draft EIS and annual environmental reports

- in 2010, when as part of the Supplementary EIS studies, a broad regional soils survey was conducted.

Earlier, pre-operational radionuclide in soil levels were determined from two sources. WMC (1988) reported on baseline data and a table of results that was presented in Kinhill Stearns Roger (1982). ^{210}Po was not included in the earlier radionuclide analysis studies, although it can be reasonably assumed that ^{210}Po would be approximately in equilibrium with ^{210}Pb.

The initial results reported radionuclide concentrations for different soil types which showed that radionuclide levels were generally higher in clayey materials (such as in swales and claypans). The results are also provided for surface and sub-surface soils which do not show any significant difference.

The results are summarised in Table 26.21 of the Supplementary EIS, together with standard radionuclide in soil information from UNSCEAR (UNSCEAR 2000).

Table 26.21 Background average radionuclide concentrations for soils in the Olympic Dam region (various sources)

Soil material	^{238}U (Bq/kg)	^{230}Th (Bq/kg)	^{226}Ra (Bq/kg)	^{210}Pb (Bq/kg)
Surface – clay	3.9	5.2	19.2	41.5
Surface – swale	6.8	8.6	6.9	25.6
Surface – sand	1.6	4	2.8	17.1
Sub-surface – clay	8.3	11.8	5.2	14.8
Sub-surface – swale	6.9	10	8.9	14.4
Sub-surface – sand	1.3	4	2	10
UNSCEAR 2000 (averages)	40	N/A	40	N/A
UNSCEAR 2000 (ranges)	20–110	N/A	20–60	N/A

The results from the latter studies have been summarised by grouping the data into broad categories of inside the mine lease boundary and outside the mine lease boundary, and are provided in Table 26.22 of the Supplementary EIS.

Table 26.22 Average radionuclide concentrations in soils (various sources)

Year	Average radionuclide concentration in soils (Bq/kg)									
	^{238}U		^{230}Th		^{226}Ra		^{210}Pb		^{210}Po	
	Mine	Outside	Mine	Outside	Mine	Outside	Mine	Outside	Mine	Outside
1982	5.0	5.0	6.8	6.8	7.1	7.1	25.0	25.0	n/a	n/a
1987	4.2	9.4	21.8	14.7	7.9	25.8	18.8	18.5	17	20
1989	4.0	6.8	7.4	12.5	n/a	n/a	n/a	n/a	33	58
1992	3.9	2.2	6.1	5.7	4.0	6.4	16.4	14.6	24	24
1995	5.3	4.3	9.6	9.8	7.6	23.3	23.0	24.5	85	90
2006	13.3	3.0	21.6	3.7	19.1	3.4	0.3	7.6	45	8
2010	7.2	5.3	8.6	7.1	9.4	7.4	17.3	21.9	18	25

The results show there is wide variation in the recorded results. The results also show that over time, radionuclide levels in soils have not changed markedly. Generally, radionuclide levels in soils close to the operation (i.e. within the special mine lease) are higher than the levels outside the mine lease, and the increases are not uniform and in some cases the levels are higher in samples from outside the mine lease. Additionally, there does not appear to be a trend of increasing concentration levels over time, so any impact would be negligible.

These low results would be expected due to the relatively low levels of radionuclides in any operational emissions (due to the low grade of the ore being mined) and indicate that there has been minimal impact from the existing operation.

The mechanism by which the dust from the existing operation is produced will be different from that for the expanded operation. The open pit and operation of the RSF are expected to produce dust in greater quantities than the existing operation and Chapter 13 of the Draft EIS provided estimates of the dust deposition.

As noted earlier, Chapter 13 of the Draft EIS and Section S2.5.4 of Appendix S to the Draft EIS refer to dust deposition levels as determined by the air quality model and provide an assessment of the potential changes in uranium in soil concentrations due to the predicted dust fallout. The assessment indicated that even in the highest deposition areas (within the mine lease boundary), after 40 years of the expanded operation the uranium concentrations in soil could increase to 6 ppm. It is noted that the world average uranium concentration in soils is about 3 ppm, with concentrations up to three times higher found in normal soils (UNSCEAR 2000).

Radionuclides in groundwater

The impacts of the expanded operation on radionuclide concentrations in groundwater in relation to seepage from the RSF and the TSF are described in Sections 26.2.3 and 26.2.4 of the Supplementary EIS.

Results from routine groundwater sampling of 12 boreholes within the mining lease in 2006 are provided in Table 26.23. It is noted that the groundwater in the vicinity of Olympic Dam is highly saline and is not used for human or stock consumption.

Table 26.23 Average and range of radionuclide levels in groundwater, 2006

Radionuclide	Average (Bq/l)	Range (Bq/l)
^{238}U	2.53	1.6–4.8
^{234}Th	0.26	0.11–1.0
^{230}Th	0.85	0.35–2.0
^{226}Ra	0.80	0.02–1.32
^{210}Pb	0.24	0.10–1.13
^{210}Po	0.24	<0.01–1.20

Overall

The radiological impact of the expanded operation is expected to be low, with increases being measurable but within compliance limits.

Issue:
Information was requested on radiation levels and doses in or due to rainwater, kangaroos and livestock.

Submissions: 63, 71 and 72

Response:

Radiation levels in water and doses from drinking water

In the Roxby Downs region, water for human consumption is currently obtained from three main sources:

- water from the GAB borefield that is desalinated for use in Roxby Downs, the mining and processing facilities and in Andamooka
- water used in Woomera, which comes from the River Murray via a pipeline
- rainwater that is captured as run-off from roofs during storm events and stored in tanks.

Drinking water in Roxby Downs is routinely monitored by BHP Billiton for radionuclides. The most recent results from sampling conducted in June 2009 are summarised in Tables 26.24 and 26.25 of the Supplementary EIS.

Table 26.24 Results from River Murray (Woomera) and GAB water (Roxby Downs) (Bq/L)

	^{238}U	^{230}Th	^{226}Ra	^{210}Pb	^{210}Po
Woomera	<0.007	0.01	0.05	<0.05	0.015
Roxby Downs tap water	0.02	0.01	0.003	<0.05	0.04

Table 26.25 Results from rainwater tanks (Bq/L)

	^{238}U	^{230}Th	^{226}Ra	^{210}Pb	^{210}Po
Arid Recovery	<0.007	0.007	0.03	<0.05	0.18
Olympic Dam Village	0.02	0.01	0.007	<0.05	0.08
Roxby Downs Station	<0.007	0.01	0.004	<0.05	0.03
Roxby Downs township	<0.007	0.01	0.04	<0.05	0.04
Andamooka	<0.007	0.01	0.08	0.05	0.08

ARPANSA (2008) reports radionuclide levels in a broad range of ground and surface water samples across Australia. Uranium-238, radium-226 and lead-210 radionuclides were individually measured. Gross alpha radiation levels were analysed, and the measured levels were up to 0.1 Bq/L.

Guidelines for radionuclides in water are primarily based on assessment of the potential doses from ingestion of the water. The NHMRC National Water Quality Management Strategy Australian Drinking Water Guidelines 6 (2004) (the Guidelines) recommend that a guidance dose of 1 mSv/y from radioactivity in water should be applied. The Guidelines also provide a set of recommended dose conversion factors that can be used to determine a potential dose from the consumption of radionuclides in water and a standardised annual consumption of 780 litres per year.

Using the method outlined in the Guidelines (see Section 7.6.2 of the Guidelines), the potential dose from the GAB and River Murray water is similar at approximately 50 μSv/y from natural background levels of radionuclides, well below the recommended guideline of 1 mSv.

There are elevated ^{210}Po levels recorded in the Arid Recovery, Andamooka and Olympic Dam Village rainwater tank samples, leading to potential annual doses of up to 200 μSv at Arid Recovery, 120 μSv at Andamooka and 90 μSv at Olympic Dam Village. Roxby Downs and Roxby Downs Station samples are consistent with the levels from the GAB and River Murray water. These levels remain well below the Guidelines level.

As noted, the dose estimates are based on a total annual consumption from a single source, which does not occur in practice. The dose assessment also includes the natural background levels, which would be expected to make up a significant component of the radionuclide content.

Radiation levels in kangaroos and potential doses from consumption of kangaroo meat

BHP Billiton recently conducted sampling of kangaroos from the mine lease area and the wider region for radionuclide levels. The analysis provided no evidence that the presence of the Olympic Dam operation had contributed to radionuclide levels in kangaroo tissues (refer Appendix M4 of Supplementary EIS).

Tissue (muscles, liver and bone) samples from seven kangaroos taken near the Olympic Dam mine (mine animals) and from seven kangaroos taken more than 30 km from the mine (control animals) were analysed for radionuclide activities (^{238}U, ^{230}Th, ^{226}Ra, ^{210}Pb and ^{210}Po). The average concentrations of radionuclides are provided in Table 26.26.

Table 26.26 Median radionuclide concentrations in control and mine kangaroo tissue

		Radionuclide concentration (mBq/g)				
		^{238}U	^{230}Th	^{226}Ra	^{210}Pb	^{210}Po
Mine	**Muscle**	**	**	0.2	0.6	0.3
Control	**Muscle**	**	**	0.2	2.0	0.5
Mine	**Liver**	**	**	0.8	21	23
Control	**Liver**	**	**	0.6	6.0	10
Mine	**Bone**	0.5	0.7	23	34	42
Control	**Bone**	0.4	0.6	7	73	63

Note: ** indicates insufficient values for analysis.

Concentrations of ^{238}U and ^{230}Th in all tissues were very low, as were ^{226}Ra in muscle and liver and ^{210}Pb and ^{210}Po in muscle. There were no significant differences between mine and control animals for ^{238}U, ^{230}Th or ^{226}Ra in any tissues or for ^{210}Pb and ^{210}Po in muscle or ^{210}Po in bone. It should be noted that the radionuclides are predominantly naturally occurring.

Calculated potential dose assessments have been made based on these measured radionuclide levels (which are predominantly naturally occurring background levels) and ICRP dose conversion factors. The calculations show that an adult would need to consume more than 600 kg of kangaroo muscle in a year to reach the member of public maximum dose of 1 mSv per annum. Average annual red meat consumption in Australia per person is 37 kg of beef and 0.25 kg of kangaroo.

Doses from the consumption of livestock taken in the region

Earlier in this section it was noted that there were slightly elevated radionuclide levels in vegetation close to the operation (<5 km). There is the potential for cattle to graze on this vegetation and ingest radionuclides contained in it. The consumed radionuclides may then be deposited in the edible tissue.

The potential dose from consumption of the beef can be modelled using appropriate uptake factors. For the purposes of the Supplementary EIS, this assessment was undertaken using the 2009 radionuclides in vegetation data.

The assessment showed that to receive the member of the public dose of 1 mSv/y, the quantities of meat shown in Table 26.27 would need to be consumed.

Table 26.27 Quantities of locally grown beef that would need to be consumed to reach the member of the public dose limit of 1 mSv/y

Age	kg of meat per year
Three months old	80
Five years old	450
Adult	4,600

As noted earlier, the average annual consumption of beef in Australia is well below this level (i.e. 37 kg per annum for an adult). Since these levels of beef consumption are far in excess of what actually occurs, particularly from cattle that have been grazed close to Olympic Dam, it is considered that radionuclide levels in cattle would not reach levels that would be unsafe for human consumption.

Issue:

It was questioned what steps BHP Billiton would take to ensure that kangaroos harvested in the Olympic Dam region for commercial or Indigenous consumption did not pose unsatisfactory health risks.

Submissions: 2 and 301

Response:

Human consumption of kangaroos harvested from the Olympic Dam region would not lead to radiation doses above normal background levels. Monitoring has shown that radionuclide levels in kangaroos within the mine lease are similar to levels in kangaroos at distance from the mine (>30 km from the mine lease – see previous response in Section 26.6.1 of the Supplementary EIS).

During 2005 and 2006, the Olympic Dam Environmental Department conducted radionuclide surveys on kangaroos in the region of the Olympic Dam mine and processing plant (refer Appendix M4 of Supplementary EIS).

The survey has shown that there are no elevated levels of radionuclides in kangaroos that inhabit the mine lease area when compared to kangaroos outside the mine lease area.

Purely as a precautionary measure, BHP Billiton would ensure that no kangaroos were harvested from within the expanded mine lease and made available for human consumption.

Issue:

More detail was requested on non-human dose assessment, particularly in relation to ICRP 103.

Submission: 1

Response:

The internationally recognised ERICA method was used to undertake the assessment.

Detriment to non-human biota was assessed and presented in Section S2.5.4 of Appendix S of the Draft EIS, including details on the method and results of the non-human dose impact assessment. A technical note (Olympic Dam Expansion EIS – Technical Note – Radiation exposure to non-human biota) was used and this can be seen in Appendix M5 of the Supplementary EIS.