Olympic Dam

Annual Radiation Protection Report

1 July 2016 to 30 June 2017
OLYMPIC DAM

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1 July 2016 to 30 June 2017

DISTRIBUTION

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1 Introduction

This document is the annual report on radiation protection for BHP Billiton Olympic Dam Corporation Pty Ltd.

In fulfilment of clauses 2.10.1, 3.8.1 and 3.10.1 of the Code of Practice and Safety Guide on Radiation Protection and Radioactive Waste Management in Mining and Processing 2005, employee dose assessments, dose calculation methodologies, dose parameters and dose conversion factors for the period 1 July 2016 to 30 June 2017 (FY2017) are presented. Personal doses and dose components for the same period are also forwarded with this document on electronic media.
2 Employee Dose Assessment Method

2.1 Exposure Calculation Methodology

2.1.1 Exposure Calculation at the Mine

The main exposure pathways for Mine workers are inhalation of Radon Decay Products (RDP), irradiation by gamma radiation and inhalation of Long Lived Radioactive Dust (Dust). Assessment of exposure from dust and RDP are based on employee time sheet information and measurements from the approved monitoring program.

Medgate™ is the data and dose management system, which is used to assess and record individual radiation exposures. The site security database (CARDAX) is used to determine the daily hours for employees working on site. The information in CARDAX is categorised into 3 major areas: surface, underground safe zone and underground blasting zone. Medgate™ records employee name, employee number, occupation, date, work location and hours in location information.

Locations at the Mine End are separated into three main zones: Surface, Safe, and Blast. Surface includes all above ground locations, including the quarry and backfill areas. The Safe Zone includes the 420 Platform and adjacent offices and workshops and is considered a fresh air base. The Blast Zone includes all other underground areas. The RDP concentrations are determined for each zone for each week using measurements from the approved monitoring program, which monitor the most active work areas. Where no samples were taken for the week an overall average of all samples from that zone is used to determine the RDP concentration for that week. This average is calculated from all readings for that particular zone over the quarter.

RDP exposure for certain workgroups is also assessed through the use of Personal Alpha Dosimeters (PADs). PADs are typically allocated to workgroups with higher RDP exposures such as Ventilation and Raise Drilling.

Employee exposure to radioactive dust is calculated using quarterly occupational-based averages. The averages are obtained from monitoring performed under the approved monitoring program.

The occupation-based dust concentration information and location-based RDP concentration information is then combined with the employee time card information to derive individual exposure data. Dust concentration is measured in units of Becquerel-hours per cubic metre (Bq.hr/m³) and RDP concentration is measured in units of micro Joule-hours per cubic metre (µJ.hr/m³). Exposure details are combined to give quarterly personal exposures.

The system is designed such that the Radiation Safety Officer is required to perform checks in each step of the process. This is in addition to a built-in auditing system within the program, as set out in section 8.10 of Olympic Dam’s Radiation Management Plan.

Respiratory protection in the form of airstream helmets is available for high-risk workers. They are typically worn by some workgroups such as Ore Handling Beltrunners and Services Ventilation Crew. Airstream helmets are also mandatory for specific tasks or in certain conditions. Routine and non-routine use of airstream helmets is monitored and logged. Further respiratory protection includes the P2 dust masks, which are now mandatory for all workers that are not located in fresh-air bases or closed cabins. No respiratory protection factors are used in exposure calculations, and therefore actual individual exposures could be lower than reported.

Exposure to gamma radiation is assessed using Optically Stimulated Luminescence Dosimeters (OSLD) badges from the Landauer Personal Radiation Monitoring Service. OSLD badges are worn for a period of three months; non-badge wearers are allocated an occupation-based average exposure.

2.1.2 Exposure calculation in the Metallurgical Plant

The main exposure pathways for Metallurgical Plant workers are inhalation of long lived radioactive dust (LLRD) and fumes, and irradiation by gamma radiation. Assessment of exposure from dust and fumes is based on employee time information and measurements from the approved monitoring program. Dust exposure in the Metallurgical Plant may involve exposure to different types of dust. The dust can differ in particle size and radionuclide composition, which results in different dust Dose Conversion Factors (DCFs). Appendix A provides a table of DCFs used in FY2017.
Information from employee and contractor time cards or employee activity sheets is captured by the radiation management software, Medgate\textsuperscript{TM}, which contains daily time sheet/card information. Medgate\textsuperscript{TM} contains an up-to-date list of all locations and occupations on-site. Occupations and Locations which have similar exposure characteristics are grouped into similar exposure groups (SEGs). A quarterly mean of dust radioactivity concentration is determined for each of the exposure groups based on the results of the monitoring program.

Dust concentration averages are calculated for each SEG on a quarterly basis. These averages are then combined with the previously captured time and location information to produce a dust exposure for each employee.

Exposure to gamma radiation is assessed using OSLD badges provided by Landauer. OSLD badges are worn for a period of three months. They are issued to a randomly selected subset of workers from each SEG. Workers who do not receive an OSLD have a dose calculated based on the average OSLD dose rate for their corresponding SEG and their time sheet/card information.

Although the exposure to RDP within the Metallurgical Plant is much less than other pathways, it is assessed in the same way as for Mine workers. The same time information used for calculation of dust exposure is used for calculating RDP exposure. All surface locations/occupations are grouped into one surface airway. This surface airway has its RDP concentration calculated on the basis of a grab sampling method.

### 2.2 Dose Calculations

Conversion of dust exposure to committed effective dose is achieved by the use of dose conversion factors, which are derived using the methodologies in International Commission on Radiological Protection (ICRP) Publication 68/72. The parameters physically measured to determine the factors are; particle size and radionuclide content. These measurements are undertaken in a number of areas of the Mine and Metallurgical Plant.

Analysis of the samples used to determine the radionuclide content was carried out by the Olympic Dam Analytical Laboratory. These results were used to determine dose conversion factors, which remain unchanged from last year.

Changes to existing conversion factors will only occur in the event of introduction of new processing techniques, major changes to plant or ore type or new recommendations published by the ICRP. Appendix A provides a summary of the dose conversion factors used for FY2017.

To calculate committed dose for airborne dust exposure, the airborne dust exposure is multiplied by the appropriate dose conversion factor. The committed doses for the different dusts are then added to give a total airborne dust dose.

The RDP dose equivalent is calculated by multiplying the RDP exposure by the default dose conversion factor recommended by ICRP65 of 1.41 mSv.m\textsuperscript{3}/mJ.hr (5 mSv/WLM).
3 Employee Doses

Occupational doses received by all Olympic Dam workers remain well below the internal dose constraint of 10 mSv/y. Olympic Dam remains committed to the principle of “as low as reasonably achievable” (ALARA), social and economic factors taken into account.

3.1 Doses to Mine Workers

3.1.1 Descriptive Statistics

A total of 1968 full-time and 1062 part-time Mine workers’ doses were calculated for the period FY2017. This includes all BHP Billiton Olympic Dam Mine employees and contractors. The distribution of doses for the mine workers is given in Figure 1.

The selection criteria for determining whether workers are categorised as ‘full-time’ or ‘part-time’ is as follows:

A ‘full-time’ employee is an employee whose dose has been assessed for a total of three or more quarters within the financial year. A ‘part-time’ employee therefore has dose assessment for less than three quarters within the financial year.

The mean dose to all Mine workers was 1.34 mSv in FY2017 as compared to 1.40 mSv in FY2016. The mean dose for full-time Mine workers was 1.90 mSv in FY2017, unchanged from FY2016. The mean dose for part-time Mine workers was 0.30 mSv in FY2017 as compared to 0.40 in FY2016.

Table A provides the radiation dose statistics for all mine workers.
No Mine worker received an annual dose greater than 10 mSv. The highest dose was 6.83 mSv for a worker with 3515 working hours in FY2017 (2000 hours per annum corresponds to a full time worker), compared to a maximum value in FY2016 of 6.10 mSv.

3.1.2 Review of Doses by Work Areas

Table B displays the breakdown of doses for all workgroups for Full-Time Mine workers.

Average annual doses for all mine work groups have varied but are still well within historical variations. All workers remain well under the annual occupational dose limit of 20 mSv.

The dose components for work categories are shown graphically in Figure 2.

<table>
<thead>
<tr>
<th>Statistics</th>
<th>Full Time Workers</th>
<th>Part Time Workers</th>
<th>All Workers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Count</td>
<td>1968</td>
<td>1062</td>
<td>3030</td>
</tr>
<tr>
<td>Arithmetic Mean (mSv)</td>
<td>1.90</td>
<td>0.30</td>
<td>1.34</td>
</tr>
<tr>
<td>90th Percentile (mSv)</td>
<td>3.95</td>
<td>0.89</td>
<td>3.57</td>
</tr>
<tr>
<td>Max (mSv)</td>
<td>6.83</td>
<td>2.32</td>
<td>6.83</td>
</tr>
<tr>
<td>Mean % Dose from Dust</td>
<td>23%</td>
<td>25%</td>
<td>23%</td>
</tr>
<tr>
<td>Mean % Dose from RDP</td>
<td>51%</td>
<td>48%</td>
<td>51%</td>
</tr>
<tr>
<td>Mean % Dose from Gamma</td>
<td>26%</td>
<td>27%</td>
<td>26%</td>
</tr>
</tbody>
</table>

Table B – Statistics for Full Time Mine Workers

<table>
<thead>
<tr>
<th>Workgroups</th>
<th>No. of Workers</th>
<th>Mean (mSv)</th>
<th>Minimum (mSv)</th>
<th>Maximum (mSv)</th>
<th>90th Percentile (mSv)</th>
</tr>
</thead>
<tbody>
<tr>
<td>420 Plat Workers</td>
<td>136</td>
<td>1.80</td>
<td>0.07</td>
<td>4.35</td>
<td>2.96</td>
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<tr>
<td>Backfill</td>
<td>165</td>
<td>0.87</td>
<td>0.02</td>
<td>3.94</td>
<td>1.10</td>
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<tr>
<td>Beltrunners</td>
<td>17</td>
<td>1.56</td>
<td>0.26</td>
<td>2.18</td>
<td>2.01</td>
</tr>
<tr>
<td>CC Machine Operators</td>
<td>322</td>
<td>3.65</td>
<td>0.02</td>
<td>6.83</td>
<td>4.71</td>
</tr>
<tr>
<td>Core processing</td>
<td>5</td>
<td>0.64</td>
<td>0.55</td>
<td>0.74</td>
<td>0.73</td>
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<tr>
<td>Development</td>
<td>182</td>
<td>1.90</td>
<td>0.62</td>
<td>4.10</td>
<td>2.49</td>
</tr>
<tr>
<td>Diamond Drilling</td>
<td>61</td>
<td>2.41</td>
<td>0.17</td>
<td>4.13</td>
<td>3.29</td>
</tr>
<tr>
<td>Electricians</td>
<td>59</td>
<td>1.99</td>
<td>0.64</td>
<td>3.43</td>
<td>2.87</td>
</tr>
<tr>
<td>Fitters/Maintenance</td>
<td>121</td>
<td>2.57</td>
<td>0.02</td>
<td>5.47</td>
<td>4.42</td>
</tr>
<tr>
<td>Offices</td>
<td>391</td>
<td>0.65</td>
<td>0.00</td>
<td>3.99</td>
<td>1.56</td>
</tr>
<tr>
<td>Production Charging</td>
<td>34</td>
<td>3.48</td>
<td>0.86</td>
<td>5.18</td>
<td>4.33</td>
</tr>
<tr>
<td>Production Drilling</td>
<td>23</td>
<td>3.55</td>
<td>2.08</td>
<td>5.04</td>
<td>4.45</td>
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<tr>
<td>Raise Drill</td>
<td>24</td>
<td>2.73</td>
<td>0.85</td>
<td>4.66</td>
<td>3.89</td>
</tr>
<tr>
<td>Surface Worker</td>
<td>156</td>
<td>0.72</td>
<td>0.00</td>
<td>3.16</td>
<td>1.24</td>
</tr>
<tr>
<td>UG Part Time</td>
<td>51</td>
<td>1.33</td>
<td>0.03</td>
<td>2.90</td>
<td>2.26</td>
</tr>
<tr>
<td>UG Services</td>
<td>70</td>
<td>2.76</td>
<td>0.01</td>
<td>4.57</td>
<td>4.16</td>
</tr>
<tr>
<td>UG Supervisor</td>
<td>83</td>
<td>1.99</td>
<td>0.06</td>
<td>4.57</td>
<td>3.03</td>
</tr>
<tr>
<td>Ventilation</td>
<td>68</td>
<td>2.51</td>
<td>0.02</td>
<td>4.49</td>
<td>3.38</td>
</tr>
</tbody>
</table>
The annual dose distribution for all workers and dose trends for full time workers are provided in Figures 3 - Figures 39 for all underground Workgroups.
420 Workers

All workers are under the 10 mSv OD radiation dose constraint. Average doses for full time workers have remained below 2 mSv per annum for the last 4 years. The workgroup spends a significant proportion of time at 420 platform underground, therefore, RDP accounts for majority of radiation dose following by gamma radiation. Due to 420 platform being a safe zone, overall doses remain low.

Figure 3 – Annual Dose Distribution for the 420 Workers Workgroup

Figure 4 – Annual Dose Trends for the 420 Workers Workgroup
**Backfill**

All workers are under the 10 mSv OD radiation dose constraint. Average doses for full time workers have remained within historical variations and have fluctuated around 1 mSv per annum for the last 5 years.

Figure 5 – Annual Dose Distribution for the Backfill Workgroup

Figure 6 – Annual Dose Trends for the Backfill Workgroup
Beltrunners

All workers are under the 10 mSv OD radiation dose constraint. Average doses for full time workers have remained below 2 mSv per annum for the last 4 years. The workgroup spends a significant proportion of time underground, therefore, RDP and Gamma account for majority of radiation dose. PADs continue to provide an accurate RDP dose assessment for the workgroup.

Figure 7 – Annual Dose Distribution for the Beltrunners Workgroup

Figure 8 – Annual Dose Trends for the Beltrunners Workgroup
CC Machine Operators

All workers are under the 10 mSv OD radiation dose constraint. Average doses for full time workers have remained below 4 mSv per annum for the last 5 years. The workgroup spends a significant proportion of time in the blast zone underground, therefore, RDP and Gamma accounts for majority of radiation dose. The introduction of PADs from 1st July 2017 for LLRD and RDP dose assessment is expected to provide improved dose assessment in future.

Figure 9 – Annual Dose Distribution for the CC Machine Operators Workgroup

Figure 10 – Annual Dose Trends for the CC Machine Operators Workgroup
Core Processing

All workers are under the 10 mSv OD radiation dose constraint and full time worker average dose remains under 1 mSv for the last 5 years.
Development

All workers are under the 10 mSv OD radiation dose constraint. Average doses for full time workers have remained below 5 mSv per annum for the last 5 years with the full time worker average dose under 2 mSv in FY2017. The workgroup spends a significant proportion of time in the underground blast zone, therefore, RDP and Gamma accounts for majority of radiation dose. PADs continue to provide an accurate RDP dose assessment for the workgroup.

Figure 13 – Annual Dose Distribution for the Development Workgroup

Figure 14 – Annual Dose Trends for the Development Workgroup
Diamond Drilling

All workers are under the 10 mSv OD radiation dose constraint. Average doses for full time workers have remained below 5 mSv per annum for the last 5 years. The workgroup spends a significant proportion of time in the blast zone underground, therefore, RDP and Gamma accounts for majority of radiation dose. The introduction of personal dosimetry in the form of PADs from 2015 Q4 has resulted in a more accurate RDP dose assessment and significantly reduced RDP dose for FY2016 and FY2017 compared to the previous years. PADs continue to provide an accurate RDP dose assessment for the workgroup.

Figure 15 – Annual Dose Distribution for the Diamond Drillers Workgroup

Figure 16 – Annual Dose Trends for the Diamond Drillers Workgroup
Electricians

All workers are under the 10 mSv OD radiation dose constraint. Average doses for full time workers have remained below 4 mSv per annum for the last 5 years with a general down trend in the observed maximum dose. The workgroup spends a significant proportion of time underground, therefore, RDP and Gamma account for the majority of radiation dose. PADs continue to provide an accurate RDP dose assessment for the workgroup. The introduction of personal dosimetry in the form of PADs from 2015 Q4 has resulted in a more accurate RDP dose assessment and significantly reduced RDP dose for FY2016 and FY2017 compared to the previous years. PADs continue to provide an accurate RDP dose assessment for the workgroup.
Fitters/Maintenance

All workers are under the 10 mSv OD radiation dose constraint. Average doses for full time workers have remained below 3 mSv per annum for the last 5 years with a general down trend in the observed maximum dose. The workgroup spends a significant proportion of time underground, therefore, RDP and Gamma accounts for the majority of radiation dose. The introduction of PADs from 1st July 2017 for LLRD and RDP dose assessment is expected to provide improved dose assessment in future.

Figure 19 – Annual Dose Distribution for the Fitters/Maintenance Workgroup

Figure 20 – Annual Dose Trends for the Fitters/Maintenance Workgroup
Mine Offices

All workers are under the 10 mSv OD radiation dose constraint. Average doses for full time workers have remained below 4 mSv per annum for the last 5 years with a general down trend in the observed maximum dose. The workgroup spends a significant proportion of time in an office environment, therefore the full time worker average dose remains below 1 mSv. Due to significant mobility between the Mine Offices workgroups and other underground workgroups with higher average doses, the maximum observed dose in Mine Offices workgroup is in line with the doses observed in other underground workgroups.
Production Charging

All workers are under the 10 mSv OD radiation dose constraint. Average doses for full time workers have remained below 5 mSv per annum for the last 5 years with a general down trend in the observed maximum dose. The workgroup spends a significant proportion of time in underground blast zone, therefore, RDP and Gamma account for the majority of radiation dose. PADs continue to provide an accurate RDP dose assessment for the workgroup.

Figure 23 – Annual Dose Distribution for the Production Charging Workgroup

Figure 24 – Annual Dose Trends for the Production Charging Workgroup
Production Drilling

All workers are under the 10 mSv OD radiation dose constraint. Average doses for full time workers have remained below 4 mSv per annum for the last 4 years. The workgroup comprises mostly of full time workers and spends a significant proportion of time in the blast zone underground, therefore, RDP and Gamma account for the majority of radiation dose. PADs continue to provide an accurate RDP dose assessment for the workgroup.

Figure 25 – Annual Dose Distribution for the Production Drilling Workgroup

Figure 26 – Annual Dose Trends for the Production Drilling Workgroup
Raise Drilling

All workers are under the 10 mSv OD radiation dose constraint. Average doses for full time workers have remained below 4 mSv per annum for the last 5 years. The workgroup spends a significant proportion of time in the blast zone underground, therefore, RDP and Gamma account for majority of radiation dose. PADs continue to provide an accurate RDP dose assessment for the workgroup.

![Figure 27 – Annual Dose Distribution for the Raise Drilling Workgroup](image)

![Figure 28 – Annual Dose Trends for the Raise Drilling Workgroup](image)
Surface Worker

All workers are under the 10 mSv OD radiation dose constraint. Average doses for full time workers have remained below 5 mSv per annum for the last 5 years. The workgroup spends most of the time on surface but there is mobility between this workgroup and underground workgroups resulting in maximum dose trends in line with underground workgroups.

Figure 29 – Annual Dose Distribution for the Mine Surface Worker Workgroup

Figure 30 – Annual Dose Trends for the Mine Surface Worker Workgroup
Underground Part Time

All workers are under the 10 mSv OD radiation dose constraint. Average doses for full time workers have remained below 3 mSv per annum for the last 5 years. The workgroup spends a significant proportion of time in the underground, therefore, RDP and Gamma account for the majority of radiation dose. The introduction of PADs from 1st July 2017 for LLRD and RDP dose assessment is expected to provide improved dose assessment in future.

Figure 31 – Annual Dose Distribution for the Underground Part Time Workgroup

Figure 32 – Annual Dose Trends for the Underground Part Time Workgroup
Underground Services

All workers are under the 10 mSv OD radiation dose constraint. Average doses for full time workers have remained below 5 mSv per annum for the last 5 years. The workgroup spends a significant proportion of time in the blast zone underground, therefore, RDP and Gamma account for the majority of radiation dose. The introduction of PADs from 1st July 2017 for LLRD and RDP dose assessment is expected to provide improved dose assessment in future.

Figure 33 – Annual Dose Distribution for the Underground Services Workgroup

Figure 34 – Annual Dose Trends for the Underground Services Workgroup
Underground Supervisor

All workers are under the 10 mSv OD radiation dose constraint. Average doses for full time workers have remained below 3 mSv per annum for the last 5 years. The workgroup spends a significant proportion of time underground, therefore, RDP and Gamma account for the majority of radiation dose. The introduction of PADs from 1st July 2017 for LLRD and RDP dose assessment is expected to provide improved dose assessment in future.

Figure 35 – Annual Dose Distribution for the Underground Supervisor Workgroup

Figure 36 – Annual Dose Trends for the Underground Supervisor Workgroup
Ventilation

All workers are under the 10 mSv OD radiation dose constraint. Average doses for full time workers have remained below 4 mSv per annum for the last 5 years. The workgroup spends a significant proportion of time in the blast zone underground, therefore, RDP and Gamma account for the majority of radiation dose. PADs continue to provide an accurate RDP dose assessment for the workgroup.
3.1.3 Strategies for Dose Reduction

Ventilation Improvements

- The Mine Ventilation department has continued to focus on ensuring that exposure to RDP is kept low through continued extensions and improvements of the mine ventilation systems.
- All primary fans have been fitted with new telemetry systems that can automatically alert the control room in case any primary fan malfunctions or stops working.
- Radon and RDP simulation has been incorporated into the VentSim® simulation software used by ventilation department to model airflow through the ventilation network.

Improvements in Dose Assessment

Starting 1st July 2017, PAD coverage was extended to the following underground workgroups:

- 420 Plat Workers
- CC Machine Operators
- Fitters/Maintenance
- UG Part Time
- UG Services
- UG Supervisor

Regulatory approval was obtained from SA EPA (July 2017) to commence administration of LLRD dosimetry using PADs for all underground workgroups.

Therefore, commencing 1st July 2017, the administration of RDP and LLRD dosimetry for all underground workgroups has been switched to PADs. The first set of dose results will be provided as part of FY18Q1 Quarterly Radiation Dose Report.

It is expected that a more accurate assessment of radiation doses will be obtained and specifically, RDP doses for workgroups spending significant amount of time in underground blast zones are expected to come down. This is due to the fact that personal dosimetry in the form of PADs will take into account the protection provided by closed cabin vehicles for all underground workers.

Moreover, LLRD dosimetry using PADs will provide a more accurate assessment of LLRD doses as a PADs is worn by the worker at all times while underground for a 3 month period. This can be compared to the current sampling method where a LLRD sample consists of a dust pump being worn by a worker for the duration of the shift and 3 such samples are conducted for each underground exposure group per month.

Workforce Changes

The 4 radiation technician positions in the department were upgraded to specialist positions (radiation and occupational hygiene) resulting in the hiring of 4 degree qualified professionals with multiple years of professional experience at other BHP assets in Australia.

3.1.4 Cumulative Five Year Dose

As outlined in ICRP 103, the total dose of any individual radiation worker should not exceed 100 mSv in any five-year period. To this end, a five-year total dose has been determined for all full-time Mine workers who were employed at Olympic Dam over the previous five years.

There were a total of 3428 mine workers who worked at OD during the period FY2013 to FY2017. The maximum dose for a Mine worker was 26.35 mSv for the five-year period ending 30 June 2017, as compared with 27.2 mSv for the five-year dose period ending 30 June 2016. The arithmetic mean for the group was 5.42 mSv, a decrease from 7.9 mSv for the five-year dose period FY2012 to FY2016.

The cumulative five-year dose distribution is shown in Figure 39.
A summary of the cumulative five-year dose is given in Table C.

**Table C – Five-Year Dose Statistics**

<table>
<thead>
<tr>
<th>Statistics</th>
<th>Cumulative 5 Year Doses</th>
<th>Equivalent Average Yearly Dose</th>
</tr>
</thead>
<tbody>
<tr>
<td>Count</td>
<td>3428</td>
<td></td>
</tr>
<tr>
<td>Arithmetic Mean (mSv)</td>
<td>5.42</td>
<td>1.08</td>
</tr>
<tr>
<td>90th Percentile (mSv)</td>
<td>15.85</td>
<td>3.17</td>
</tr>
<tr>
<td>Max (mSv)</td>
<td>26.35</td>
<td>5.27</td>
</tr>
<tr>
<td>Mean % Dose from Dust</td>
<td>13%</td>
<td></td>
</tr>
<tr>
<td>Mean % Dose from RDP</td>
<td>55%</td>
<td></td>
</tr>
<tr>
<td>Mean % Dose from Gamma</td>
<td>32%</td>
<td></td>
</tr>
</tbody>
</table>
3.2 Doses to Metallurgical Plant Workers

3.2.1 Descriptive Statistics

A total of 1797 full-time and 2122 part-time Metallurgical Plant workers’ doses were calculated for the period FY2017. This included both BHP Billiton Olympic Dam Metallurgical Plant workers and associated contractors. The dose distribution for all workers is shown in Figure 40.

Detailed dose statistics are given in Table D. The mean dose to all workers decreased from 0.50 mSv in FY2016 to 0.38 in FY2017. The mean dose to full time workers decreased from 0.90 mSv to 0.73 mSv. The mean dose to part time workers remained unchanged.

Table D – Statistics for Metallurgical Plant Workers

<table>
<thead>
<tr>
<th>Statistics</th>
<th>Full Time Workers</th>
<th>Part Time Workers</th>
<th>All Workers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Count</td>
<td>1797</td>
<td>2122</td>
<td>3919</td>
</tr>
<tr>
<td>Arithmetic Mean (mSv)</td>
<td>0.73</td>
<td>0.09</td>
<td>0.38</td>
</tr>
<tr>
<td>90th Percentile (mSv)</td>
<td>1.44</td>
<td>0.18</td>
<td>0.85</td>
</tr>
<tr>
<td>Max (mSv)</td>
<td>5.37</td>
<td>2.88</td>
<td>5.37</td>
</tr>
<tr>
<td>Mean % Dose from Dust</td>
<td>66%</td>
<td>68%</td>
<td>66%</td>
</tr>
<tr>
<td>Mean % Dose from RDP</td>
<td>18%</td>
<td>18%</td>
<td>18%</td>
</tr>
<tr>
<td>Mean % Dose from Gamma</td>
<td>16%</td>
<td>14%</td>
<td>16%</td>
</tr>
</tbody>
</table>

No Plant worker received an annual dose greater than 10 mSv. The highest dose was 5.37 mSv for a smelter worker with 2430 working hours in FY2017 (2000 hours per annum corresponds to a full time worker), compared to a maximum value of 4.7 mSv in FY2016. These results are in line with observed historical variations in smelter worker doses.
3.2.2 Review of Doses by Work Areas

Table E shows the dose statistics for all metallurgical plant workgroups and the dose components for each work area can be seen in Figure 41. Dose trends remain in line with historical variations.

Table E – Statistics for Full Time Metallurgical Plant Workers

<table>
<thead>
<tr>
<th>Workgroups</th>
<th>No. of Workers</th>
<th>Mean (mSv)</th>
<th>Minimum (mSv)</th>
<th>Maximum (mSv)</th>
<th>90th Percentile (mSv)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acid Plant</td>
<td>24</td>
<td>1.33</td>
<td>0.06</td>
<td>2.00</td>
<td>1.89</td>
</tr>
<tr>
<td>Casting</td>
<td>38</td>
<td>1.37</td>
<td>0.01</td>
<td>2.10</td>
<td>1.61</td>
</tr>
<tr>
<td>Concentrator Maintenance</td>
<td>54</td>
<td>0.72</td>
<td>0.02</td>
<td>1.05</td>
<td>0.93</td>
</tr>
<tr>
<td>Concentrator Production</td>
<td>35</td>
<td>1.16</td>
<td>0.66</td>
<td>1.61</td>
<td>1.40</td>
</tr>
<tr>
<td>Electrefining</td>
<td>69</td>
<td>0.60</td>
<td>0.01</td>
<td>1.91</td>
<td>0.68</td>
</tr>
<tr>
<td>Electrowinning</td>
<td>7</td>
<td>0.50</td>
<td>0.02</td>
<td>0.88</td>
<td>0.69</td>
</tr>
<tr>
<td>Feed Prep</td>
<td>10</td>
<td>2.03</td>
<td>0.84</td>
<td>2.66</td>
<td>2.63</td>
</tr>
<tr>
<td>Goldroom</td>
<td>18</td>
<td>0.77</td>
<td>0.51</td>
<td>0.92</td>
<td>0.90</td>
</tr>
<tr>
<td>Hydro Maintenance</td>
<td>77</td>
<td>0.68</td>
<td>0.01</td>
<td>1.45</td>
<td>1.01</td>
</tr>
<tr>
<td>Hydro Production</td>
<td>23</td>
<td>0.98</td>
<td>0.02</td>
<td>1.41</td>
<td>1.26</td>
</tr>
<tr>
<td>Plant Maintenance</td>
<td>241</td>
<td>0.51</td>
<td>0.00</td>
<td>2.57</td>
<td>0.87</td>
</tr>
<tr>
<td>Plant Offices</td>
<td>908</td>
<td>0.47</td>
<td>0.00</td>
<td>4.55</td>
<td>0.83</td>
</tr>
<tr>
<td>Refinery Maintenance</td>
<td>64</td>
<td>0.72</td>
<td>0.02</td>
<td>2.10</td>
<td>1.19</td>
</tr>
<tr>
<td>Slag Handling</td>
<td>19</td>
<td>2.52</td>
<td>1.24</td>
<td>3.73</td>
<td>3.28</td>
</tr>
<tr>
<td>Slag Pot Welding</td>
<td>2</td>
<td>2.66</td>
<td>2.57</td>
<td>2.76</td>
<td>2.74</td>
</tr>
<tr>
<td>Smelting</td>
<td>51</td>
<td>3.25</td>
<td>0.03</td>
<td>5.37</td>
<td>4.10</td>
</tr>
<tr>
<td>SX Maintenance</td>
<td>24</td>
<td>0.97</td>
<td>0.02</td>
<td>2.12</td>
<td>1.36</td>
</tr>
<tr>
<td>SX Production</td>
<td>15</td>
<td>1.83</td>
<td>0.15</td>
<td>4.39</td>
<td>2.17</td>
</tr>
<tr>
<td>TRS Operations</td>
<td>29</td>
<td>0.51</td>
<td>0.02</td>
<td>0.84</td>
<td>0.76</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Workgroups</th>
<th>Dust Average (mSv)</th>
<th>Dust % of Total Dose</th>
<th>RDP Average (mSv)</th>
<th>RDP % of Total Dose</th>
<th>Gamma Average (mSv)</th>
<th>Gamma % of Total Dose</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acid Plant</td>
<td>1.02</td>
<td>76%</td>
<td>0.13</td>
<td>10%</td>
<td>0.18</td>
<td>14%</td>
</tr>
<tr>
<td>Casting</td>
<td>1.02</td>
<td>75%</td>
<td>0.12</td>
<td>9%</td>
<td>0.22</td>
<td>16%</td>
</tr>
<tr>
<td>Concentrator Maintenance</td>
<td>0.47</td>
<td>65%</td>
<td>0.13</td>
<td>18%</td>
<td>0.12</td>
<td>16%</td>
</tr>
<tr>
<td>Concentrator Production</td>
<td>0.63</td>
<td>54%</td>
<td>0.13</td>
<td>11%</td>
<td>0.41</td>
<td>35%</td>
</tr>
<tr>
<td>Electrefining</td>
<td>0.37</td>
<td>61%</td>
<td>0.14</td>
<td>23%</td>
<td>0.10</td>
<td>16%</td>
</tr>
<tr>
<td>Electrowinning</td>
<td>0.36</td>
<td>71%</td>
<td>0.11</td>
<td>22%</td>
<td>0.03</td>
<td>7%</td>
</tr>
<tr>
<td>Feed Prep</td>
<td>1.72</td>
<td>85%</td>
<td>0.11</td>
<td>5%</td>
<td>0.19</td>
<td>10%</td>
</tr>
<tr>
<td>Goldroom</td>
<td>0.60</td>
<td>78%</td>
<td>0.12</td>
<td>16%</td>
<td>0.04</td>
<td>8%</td>
</tr>
<tr>
<td>Hydro Maintenance</td>
<td>0.50</td>
<td>73%</td>
<td>0.12</td>
<td>18%</td>
<td>0.06</td>
<td>10%</td>
</tr>
<tr>
<td>Hydro Production</td>
<td>0.48</td>
<td>49%</td>
<td>0.11</td>
<td>11%</td>
<td>0.39</td>
<td>39%</td>
</tr>
<tr>
<td>Plant Maintenance</td>
<td>0.23</td>
<td>46%</td>
<td>0.16</td>
<td>31%</td>
<td>0.12</td>
<td>23%</td>
</tr>
<tr>
<td>Plant Offices</td>
<td>0.30</td>
<td>62%</td>
<td>0.12</td>
<td>25%</td>
<td>0.06</td>
<td>12%</td>
</tr>
<tr>
<td>Refinery Maintenance</td>
<td>0.55</td>
<td>75%</td>
<td>0.12</td>
<td>16%</td>
<td>0.06</td>
<td>8%</td>
</tr>
<tr>
<td>Slag Handling</td>
<td>0.98</td>
<td>39%</td>
<td>0.16</td>
<td>6%</td>
<td>1.38</td>
<td>55%</td>
</tr>
<tr>
<td>Slag Pot Welding</td>
<td>2.48</td>
<td>93%</td>
<td>0.15</td>
<td>6%</td>
<td>0.03</td>
<td>1%</td>
</tr>
<tr>
<td>Smelting</td>
<td>1.03</td>
<td>84%</td>
<td>0.12</td>
<td>9%</td>
<td>0.08</td>
<td>6%</td>
</tr>
<tr>
<td>Smelting</td>
<td>2.79</td>
<td>86%</td>
<td>0.15</td>
<td>4%</td>
<td>0.32</td>
<td>10%</td>
</tr>
<tr>
<td>SX Maintenance</td>
<td>0.48</td>
<td>50%</td>
<td>0.13</td>
<td>13%</td>
<td>0.36</td>
<td>37%</td>
</tr>
<tr>
<td>SX Production</td>
<td>1.10</td>
<td>60%</td>
<td>0.11</td>
<td>6%</td>
<td>0.62</td>
<td>34%</td>
</tr>
<tr>
<td>TRS Operations</td>
<td>0.35</td>
<td>68%</td>
<td>0.12</td>
<td>23%</td>
<td>0.04</td>
<td>8%</td>
</tr>
</tbody>
</table>
Annual total dose distribution and dose trends for each workgroup are provided in Figure 42 to Figure 82.
Acid Plant

All workers are under the 10 mSv OD radiation dose constraint. Average doses for full time workers have remained below 2 mSv per annum for the last 5 years.

Figure 42 – Annual Dose Distribution for the Acid Plant Workgroup

Figure 43 – Annual Dose Trends for the Acid Plant Workgroup
Casting

All workers are under the 10 mSv OD radiation dose constraint. Average doses for full time workers have remained below 2 mSv per annum for the last 5 years.

Figure 44 – Annual Dose Distribution for the Casting Workgroup

Figure 45 – Annual Dose Trends for the Casting Workgroup
Concentrator Maintenance

All workers are under the 10 mSv OD radiation dose constraint. Average doses for full time workers have remained below 1 mSv per annum for the last 5 years.

Figure 46 – Annual Dose Distribution for the Concentrator Maintenance Workgroup

Figure 47 – Annual Dose Trends for the Concentrator Maintenance Workgroup
Concentrator Production

All workers are under the 10 mSv OD radiation dose constraint. Average doses for full time workers have remained below 2 mSv per annum for the last 5 years.

Figure 48 – Annual Dose Distribution for the Concentrator Production Workgroup

Figure 49 – Annual Dose Trends for the Concentrator Production Workgroup
Electrorefining

All workers are under the 10 mSv OD radiation dose constraint. Average doses for full time workers have remained below 1 mSv per annum for the last 5 years.
Electrowinning

All workers are under the 10 mSv OD radiation dose constraint. Average doses for full time workers have remained below 2 mSv per annum for the last 5 years.

Figure 52 – Annual Dose Distribution for the Electrowinning Workgroup

Figure 53 – Annual Dose Trends for the Electrowinning Workgroup
Feed Prep

All workers are under the 10 mSv OD radiation dose constraint. Average doses for full time workers have remained below 3 mSv per annum for the last 5 years.

Figure 54 – Annual Dose Distribution for the Feed Prep Workgroup

Figure 55 – Annual Dose Trends for the Feed Prep Workgroup
Goldroom

All workers are under the 10 mSv OD radiation dose constraint. Average doses for full time workers have remained below 1 mSv per annum for the last 5 years.

Figure 56 – Annual Dose Distribution for the Goldroom Workgroup

Figure 57 – Annual Dose Trends for the Goldroom Workgroup
Hydro Maintenance

All workers are under the 10 mSv OD radiation dose constraint. Average doses for full time workers have remained below 1 mSv per annum for the last 5 years.

Figure 58 – Annual Dose Distribution for the Hydro Maintenance Workgroup

Figure 59 – Annual Dose Trends for the Hydro Maintenance Workgroup
Hydro Production

All workers are under the 10 mSv OD radiation dose constraint. Average doses for full time workers have remained below 2 mSv per annum for the last 5 years.
Plant Maintenance

All workers are under the 10 mSv OD radiation dose constraint. Average doses for full time workers have remained below 1 mSv per annum for the last 5 years.

![Annual Dose Distribution for the Plant Maintenance Workgroup](image1)

**Figure 62 – Annual Dose Distribution for the Plant Maintenance Workgroup**

![Annual Dose Trends for the Plant Maintenance Workgroup](image2)

**Figure 63 – Annual Dose Trends for the Plant Maintenance Workgroup**
Plant Offices

All workers are under the 10 mSv OD radiation dose constraint. Average doses for full time workers have remained below 1 mSv per annum for the last 5 years. Due to significant mobility between the plant offices workgroup and other plant workgroups, the maximum observed dose for plant offices workgroup is in line with other workgroups.

Figure 64 – Annual Dose Distribution for the Plant Offices Workgroup

Figure 65 – Annual Dose Trends for the Plant Offices Workgroup
Refinery Maintenance

All workers are under the 10 mSv OD radiation dose constraint. Average doses for full time workers have remained below 1 mSv per annum for the last 5 years.

Figure 66 – Annual Dose Distribution for the Refinery Maintenance Workgroup

Figure 67 – Annual Dose Trends for the Refinery Maintenance Workgroup
Slag Handling

All workers are under the 10 mSv OD radiation dose constraint. Average doses for full time workers have remained below 1 mSv per annum for the last 5 years. Gamma and LLRD remains the main source of exposure for this workgroup.
Slag Pot Welding

All workers are under the 10 mSv OD radiation dose constraint. Average doses for full time workers have remained below 3 mSv per annum for the last 5 years. LLRD remains the main source of exposure for this workgroup.

Figure 70 – Annual Dose Distribution for the Slag Pot Welding Workgroup

Figure 71 – Annual Dose Trends for the Slag Pot Welding Workgroup
Smelter Maintenance

All workers are under the 10 mSv OD radiation dose constraint. Average doses for full time workers have remained below 2 mSv per annum for the last 5 years.

Figure 72 – Annual Dose Distribution for the Smelter Maintenance Workgroup

Figure 73 – Annual Dose Trends for the Smelter Maintenance Workgroup
Smelting

All workers are under the 10 mSv OD radiation dose constraint. Average doses for full time workers have remained below 5 mSv per annum for the last 5 years. LLRD remains the main source of exposure for this workgroup. Improvements in general smelter operating conditions, an improved understanding of exposure profiles and better dust recycle rate and revert management has ensured that doses for full time workers remained under 4 mSv for the last 2 years.

Figure 74 – Annual Dose Distribution for the Smelting Workgroup

Figure 75 – Annual Dose Trends for the Smelting Workgroup
SX Maintenance

All workers are under the 10 mSv OD radiation dose constraint. Average doses for full time workers have remained below 3 mSv per annum.

Figure 76 – Annual Dose Distribution for the SX Maintenance Workgroup

Figure 77 – Annual Dose Trends for the SX Maintenance Workgroup
SX Production

All workers are under the 10 mSv OD radiation dose constraint. Average doses for full time workers have remained below 3 mSv per annum. Automation and use of effective engineering controls in the packing booth has ensured that LLRD and Gamma exposures for this workgroup remain low.

Figure 78 – Annual Dose Distribution for the SX Production Workgroup

Figure 79 – Annual Dose Trends for SX Production Workgroup
TRS Operations

All workers are under the 10 mSv OD radiation dose constraint. Average doses for full time workers have remained below 1 mSv per annum.
3.2.3 Strategies for Dose Reduction

- The high assay frequency of process streams such as Dust Leach, Concentrate Leach and Furnace inputs and outputs remains unchanged as this information is a key control for maintaining Po-210 levels throughout the system.

- Limiting the smelter revert charge rate to 50 MBq/hour has ensured that radiation doses remain low.

- Qualitative risk assessments for key areas/workgroups were conducted in FY2017 to ensure that the monitoring program is aligned with the workgroup risk profile. A revised monitoring program was submitted by BHP and approved by the SA EPA.

3.2.4 Smelter Campaign Maintenance (SCM) 2017 Upgrades

A major (planned) maintenance campaign for Smelter 2 commenced in August 2017 which once completed, will result in a number of smelter infrastructure upgrades that are expected to provide longer term reductions in radiation doses for smelter workers.

Major upgrades will be performed to the smelter hygiene system which minimises employee exposure to sulphur dioxide, radioactive dust and copper fume within the smelter area, by drawing these emissions into ventilation hoods, and exhausting the fume to the main smelter stack.

General Process Plant Unit (PPU) Infrastructure Upgrades

Table F provides a list of key infrastructure upgrades relevant for radiation protection purposes to be performed to the process plant (smelter). These upgrades are expected to provide significant improvements in smelter working atmosphere and are expected to lower radioactive dust exposures for all smelter workers.

<table>
<thead>
<tr>
<th>Equipment</th>
<th>Existing Equipment</th>
<th>Upgraded Equipment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electric Furnace Offgas Fan</td>
<td>600W fan</td>
<td>1100kW fan controlled by a Variable State Drive (VSD) – sized for increased volume</td>
</tr>
<tr>
<td>Purge Air Fan</td>
<td>5.5kW fan</td>
<td>18.5kW fan controlled by a VSD – sized for increased volume</td>
</tr>
<tr>
<td>Purge Air Ducting</td>
<td>200mm ducting. No air flow control</td>
<td>Increased ducting size to 400mm allowing for increased air volume to revert chutes – will minimize fugitive dust from revert addition to furnace. Gate valves will provided greater control for air distribution</td>
</tr>
<tr>
<td>Particulate Cooler Fan</td>
<td>50kW fan</td>
<td>150kW fan controlled by a VSD – sized for increased volume</td>
</tr>
<tr>
<td>Quench Tower Pumps (X 3)</td>
<td>22kW drives</td>
<td>30kW drives with new larger impellers and couplings – allows greater flow rates to be achieved.</td>
</tr>
<tr>
<td>Droplet Separator</td>
<td>-</td>
<td>New design is larger than existing allowing for increased handling volumes.</td>
</tr>
<tr>
<td>Quench Tower Lid</td>
<td>-</td>
<td>New QT lid providing greater quenching ability (more nozzles with more throughput of water to handle greater offgas volume)</td>
</tr>
<tr>
<td>Offgas ductwork</td>
<td>-</td>
<td>Upgraded ductwork to handle increased offgas air volume, seal pots to drain water from fan housing and ductwork</td>
</tr>
</tbody>
</table>
Upgrades to the Electric Furnace Slag Hygiene System

The slag taphole hoods have been redesigned (Figure 82) to improve the characteristics of the airflow into the hood and enhance the capture of fume, particularly during tapping operations.

Some of the improvements include:

- Seals off back and side of area around the taphole. This reduces the potential for emissions to escape past the back and sides of the hood.
- Extends sides and rear of hood to a lower height to reduce the spread of emissions prior to entry into the hood
- Extends forwards over the start of the launder to decrease the amount of emissions that may escape past the front edge of the hood
- Capture velocities at the front of the hood are improved by reducing the amount of air drawn from the rear and sides of the hood

![Figure 82 – Electric Furnace Slag Tap Hole Hood Redesign](image)

3.2.5 Cumulative Five Year Dose

As recommended in ICRP 103, the total dose of any individual radiation worker should not exceed 100 mSv in any five-year period. To this end, the five-year total dose has been calculated for Full-Time Metallurgical Plant workers who have been employed at Olympic Dam in the previous five years.

There were a total of 4906 full time Metallurgical Plant workers who worked at Olympic Dam during the period FY2012 to FY2017.

The maximum dose for the five-year period was 23.39 mSv, compared to 27.10 mSv in FY2016. The arithmetic mean for the five-year dose period for the Metallurgical Plant has decreased to 1.71 mSv from 4.80 mSv. This is mainly due to the influx of a large number of full time workers into the Plant Offices workgroup.

The distribution of doses for the cumulative five-year dose is shown in Figure 83.
A summary of the cumulative five-year dose is given in Table G.

### Table G – Five-Year Dose Statistics

<table>
<thead>
<tr>
<th>Statistics</th>
<th>Cumulative 5 Year</th>
<th>Equivalent Average Yearly Dose</th>
</tr>
</thead>
<tbody>
<tr>
<td>Count</td>
<td>4906</td>
<td>-</td>
</tr>
<tr>
<td>Arithmetic Mean (mSv)</td>
<td>1.71</td>
<td>0.34</td>
</tr>
<tr>
<td>90th Percentile (mSv)</td>
<td>4.15</td>
<td>0.83</td>
</tr>
<tr>
<td>Max (mSv)</td>
<td>23.39</td>
<td>4.68</td>
</tr>
<tr>
<td>Mean % Dose from Dust</td>
<td>67%</td>
<td></td>
</tr>
<tr>
<td>Mean % Dose from RDP</td>
<td>11%</td>
<td></td>
</tr>
<tr>
<td>Mean % Dose from Gamma</td>
<td>22%</td>
<td></td>
</tr>
</tbody>
</table>

### 3.3 Annual Dose Trends

The average total effective dose to all workers at the Mine and Metallurgical Plant since FY2013 are shown in Figure 84 and Figure 85 respectively. As can be seen, dose remain low and well under the annual occupational dose limit of 20 mSv. RDP remains the key source of radiation exposure for Mine and LLRD remains the key source of exposure for Metallurgical Plant.
Annual Radiation Protection Report

1 July 2016 – 30 June 2017

Figure 84 – Annual Dose Trend for Mine

Figure 85 – Annual Dose Trend for Metallurgical Plant
3.4 Doses to Members of the Public

The full assessment of doses to members of the public has been presented separately in the Environmental Management and Monitoring Report.

For all members of the public, the effective dose from the operation, for the period FY2017 was well below the statutory limit of 1.0 mSv per annum. The estimated dose contribution from the operation are provided in Table H.

Table H – Public Doses

<table>
<thead>
<tr>
<th>FY2016 Dose to Members of the Public Living</th>
<th>Dose (mSv)</th>
<th>Dose Limit (mSv)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Roxby Downs</td>
<td>0.033</td>
<td>1</td>
</tr>
<tr>
<td>Olympic Dam Village</td>
<td>0.022</td>
<td>1</td>
</tr>
</tbody>
</table>

Figure 86 shows the public dose trends for Olympic Dam Village and Roxby Downs since 2006. The FY2016 dose to the members of the public has continued to remain below the minimum detection limit of 0.048 mSv.
Appendix A

Dose Conversion Factors FY2017

A summary of the airborne dust dose conversion factors for specific work areas can be viewed in the following table.

Table I – Dust Dose Conversion Factors

<table>
<thead>
<tr>
<th>Location</th>
<th>DCF (µSv.m⁻³/Bq.hr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Smelter</td>
<td>7.5</td>
</tr>
<tr>
<td>Refinery / STP</td>
<td>5.4</td>
</tr>
<tr>
<td>SX / Precipitation / Cacliners</td>
<td>4.5</td>
</tr>
<tr>
<td>Other*</td>
<td>4.1</td>
</tr>
</tbody>
</table>

*All other areas of Mine, Concentrator, Slag Concentrator, Hydromet and Services (Laboratories and Metallurgical Workshop)

The default RDP dose conversion factor used was 1.41 mSv.m⁻³/mJ.hr (5 mSv/WLM).