DRAFT

# REPORT TO THE ADVISORY BOARD ON RADIATION AND WORKER HEALTH

***National Institute for Occupational Safety and Health***

# SC&A'S DOSE RECONSTRUCTION OF CASE #[REDACTED] FROM THE FERNALD ENVIRONMENTAL MANAGEMENT PROJECT

**Contract No. 200-2009-28555**
**SCA-TR-BDR2014-CN[REDACTED]**

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# EXECUTIVE SUMMARY

Under Contract No. 200-2009-28555, SC&A has been tasked by the Advisory Board on Radiation and Worker Health (Advisory Board) to perform eight blind dose reconstructions (DRs). This report presents the methodologies and results of our DR of one of the eight blind cases selected by the Advisory Board.

To perform this blind DR, SC&A was provided with all of the Department of Energy (DOE) dosimetry records; the Department of Labor (DOL) correspondence, forms, and medical records; and the Computer-Assisted Telephone Interview (CATI) Report that were made available to the National Institute for Occupational Safety and Health (NIOSH) for constructing doses in behalf of Case #[redacted]. SC&A used two independent approaches to reconstruct occupational doses associated with this case. Both approaches used the available dosimetry records and current technical guidance documents published by NIOSH and the Oak Ridge Associated Universities Team (ORAUT). The first approach, which is referred to as DR–Method A, used the spreadsheets and other tools developed by NIOSH to calculate the doses, whereas the second approach, referred to as DR–Method B, manually calculated the doses [with the assistance of the internal dosimetry computer program Integrated Modules for Bioassay Analysis (IMBA)].

This Executive Summary provides an overview of the case and a comparison of the results of the two independent DR methods. Section I of this report provides a detailed discussion of the approach used to reconstruct external/internal occupational radiation doses using DR–Method A, and Section II describes the reconstruction of doses using DR–Method B.

## RELEVANT BACKGROUND INFORMATION

According to the DOL records, this case represents an energy employee (EE) who worked at the Feed Materials Production Center [FMPC, later known as the Fernald Environmental Management Project (FEMP)] from [redacted] to [redacted]. The EE was diagnosed with **multiple squamous and basal cell skin cancers**. The primary cancers, diagnosis dates, and ICD-9 codes are shown in Table ES-1.

**Table ES-1. Primary Cancers**

| Diagnosis Date | Description | ICD-9 Code |
|---|---|---|
| [redacted] | SCC [redacted] | [redacted] |
| [redacted] | BCC [redacted] | [redacted] |
| [redacted] | BCC [redacted] | [redacted] |
| [redacted] | SCC [redacted] | [redacted] |
| [redacted] | SCC [redacted] | [redacted] |

According to the DOE records and the CATI Report, the majority of the EE's radiation exposure was received while working as a [redacted], [redacted], [redacted], [redacted], [redacted], [redacted], and [redacted], primarily in Plant [redacted], [redacted]. During the course of employment, the EE was monitored for external photon and electron radiation exposure and internal radiation exposure via in-vitro bioassays and chest counts.

## PRESENTATION OF RESULTS

The results of both independent DR methods are shown in Table ES-2. DR–Method A calculated external and internal doses using the EE's dosimetry records. This method derived a total skin dose to the chest of 15.817 rem and doses ranging from 18.057 rem to 18.092 rem for the skin cancers of the [redacted], [redacted], [redacted], and [redacted]. The Method A skin doses varied depending on cancer location and date of diagnosis.

DR–Method B derived a total skin dose to the chest of 16.510 rem and a dose of 18.818 rem to the skin of the [redacted], [redacted], [redacted], and [redacted]. DR–Method B explicitly evaluated external dose from photon, beta, and neutron dose, and occupational medical dose. Also, special consideration was given to the possible contribution of Tc-99 to the external dose, along with the skin dose that might have resulted from the direct deposition of uranium dust onto skin and clothing. Internal dose to the organs of concern included inhalation of uranium and consideration of the internal dose to the skin from recycled uranium.

**Table ES-2. Derived Dose Estimates**

| | DR–Method A | | | | | DR–Method B | |
|---|---|---|---|---|---|---|---|
| | **#1 SCC [redact] (rem)** | **#2 BCC [redact] (rem)** | **#3 BCC [redact] (rem)** | **#4 SCC [redact] (rem)** | **#5 SCC [redact] (rem)** | **[redact] (rem) (attenuated)** | **[redact], [redact], [redact], [redact] (rem) (unattenuated)** |
| External Dose (Occupational) | | | | | | | |
| ▪ Recorded Photon Dose | | | | | | | |
| <30 keV Photons | 0.190 | 0.190 | 0.190 | 0.190 | 0.190 | 0.175 | 0.175 |
| 30–250 keV Photons | 0.481 | 0.481 | 0.481 | 0.481 | 0.481 | 0.545 | 0.545 |
| >250 keV Photons | 0.764 | 0.764 | 0.764 | 0.764 | 0.764 | 0.877 | 0.877 |
| ▪ Missed Photon Dose < 30 keV Photons | – | – | – | – | – | 0.024 | 0.024 |
| 30–250 keV Photons | 0.980 | 0.980 | 0.980 | 0.980 | 0.980 | 0.403 | 0.403 |
| >250 keV Photons | – | – | – | – | – | 0.479 | 0.479 |
| ▪ Missed Neutron Dose | – | – | – | – | – | 0.288 | 0.288 |
| ▪ Skin Deposition | – | – | – | – | – | 0.0845 | 0.0845 |
| ▪ Recorded Shallow Dose Electrons >15 keV | 13.304 | 15.559 | 15.559 | 15.559 | 15.559 | 13.265 | 15.519 |
| ▪ Occupational Medical Dose | 0.065 | 0.049 | 0.041 | 0.081 | 0.081 | 0.131 | 0.131 |
| Internal Dose | | | | | | | |
| Uranium | 0.030 | 0.031 | 0.034 | 0.034 | 0.034 | 0.238 | 0.293 |
| RU Contaminants | 0.003 | 0.003 | 0.003 | 0.003 | 0.003 | – | – |
| **Total** | 15.817 | 18.057 | 18.052 | 18.092 | 18.092 | 16.510 | 18.818 |

Even though two different DR approaches were used, the total skin doses calculated by DR–Method A and DR–Method B for all skin cancers are nearly identical. Both DR methods assigned the majority of dose to exposure to electrons >15 keV (shallow dose), since the recorded electron dose was by far the dominant contributor to skin dose, and both methods employed similar approaches to reconstruct these doses. However, as noted in Table ES-2, though the two approaches derived similar total doses, there are substantial differences in the approaches to reconstruct other portions of the external dose and internal dose. Only Method B considered neutron dose and dose due to potential skin contamination from deposition of radioactive particles. The disparity in occupational medical doses can be attributed to the fact that the two DR methods used differing guidance documents for assessing the x-ray dose. In addition, the significant difference in internal doses was due to varying approaches taken in fitting the bioassay data to an intake in IMBA.

Both DR methods calculated a POC using NIOSH-Interactive RadioEpidemiological Program (IREP, v.5.7). Method A calculated a probability of causation (POC) value of 38.12%, and Method B derived a POC value of 39.33%, as described in Sections I and II below.

# SECTION I: DR–METHOD A

## I.1 DOSE RECONSTRUCTION OVERVIEW

This report presents the results of an independent blind dose reconstruction (DR) performed by SC&A for an energy employee (EE) who worked at the Feed Materials Production Center (FMPC) [later known as the Fernald Environmental Management Project (FEMP)] from October 13, 1982, to March 31, 1997. The EE was diagnosed with **five skin cancers (basal and squamous cell carcinoma)** on the [redacted], [redacted], [redacted], [redacted], and [redacted], as shown in Table I-1.

**Table I-1. Cancers and Diagnosis Date**

| # | Description | Primary/Secondary | Diagnosis Date | ICD-9 Code |
|---|---|---|---|---|
| 1 | SCC [redacted] | Primary | [redacted] | [redacted] |
| 2 | BCC [redacted] | Primary | [redacted] | [redacted] |
| 3 | BCC [redacted] | Primary | [redacted] | [redacted] |
| 4 | SCC [redacted] | Primary | [redacted] | [redacted] |
| 5 | SCC [redacted] | Primary | [redacted] | [redacted] |

According to the Computer-Assisted Telephone Interview (CATI) report, the EE was a [redacted], [redacted], [redacted], [redacted], [redacted], [redacted], and [redacted], and worked primarily in Plant [redacted], [redacted]. Uranium metal products were heat-treated and were extruded either onsite or sent offsite and returned to be machined into the final products. The EE was monitored for external photon and electron exposures from [redacted] through [redacted]. Internal exposure monitoring was also conducted by means of in-vitro bioassays and chest counts from [redacted] through [redacted].

### I.1.1 SC&A BLIND DR APPROACH

SC&A reviewed all of the DOE records provided on behalf of this EE and all of the NIOSH procedures relevant to this case, which includes the Technical Basis Document (TBD) for the FEMP (issued as six separate TBDs numbered ORAUT-TKBS-0017-1 through ORAUT-TKBS-0017-6) and *Interpretation of Dosimetry Data for Assignment of Shallow Dose* (ORAUT-OTIB-0017). Using the guidance provided in these documents, along with the EE's dosimetry records, SC&A manually calculated reasonable, claimant-favorable annual organ doses for each of the cancers, as shown in Table I-2. Appendices I.A-1 through I.A-5 provide a list of SC&A's annual organ doses and also include IREP input parameters, such as energy range, distribution type, and uncertainty for each year.

**Table I-2. Summary of SC&A-Derived External/Internal Dose Estimates for Method A**

| | #1 SCC [redact] (rem) | #2 BCC [redact] (rem) | #3 BCC [redact] (rem) | #4 SCC [redact] (rem) | #5 SCC [redact] (rem) |
|---|---|---|---|---|---|
| External Dose (Occupational):* | | | | | |
| ▪ Recorded Photon Dose | | | | | |
| - <30 keV Photons: | 0.190 | 0.190 | 0.190 | 0.190 | 0.190 |
| - 30–250 keV Photons: | 0.481 | 0.481 | 0.481 | 0.481 | 0.481 |
| - >250 keV Photons: | 0.764 | 0.764 | 0.764 | 0.764 | 0.764 |
| ▪ Missed Photon Dose - 30–250 keV Photons: | 0.980 | 0.980 | 0.980 | 0.980 | 0.980 |
| ▪ Recorded Shallow Dose- Electrons >15 keV: | 13.304 | 15.559 | 15.559 | 15.559 | 15.559 |
| ▪ Occupational Medical Dose: | 0.065 | 0.049 | 0.041 | 0.081 | 0.081 |
| Internal Dose: | | | | | |
| - Uranium | 0.030 | 0.031 | 0.034 | 0.034 | 0.034 |
| - RU Contaminants | 0.003 | 0.003 | 0.003 | 0.003 | 0.003 |
| **Total** | **15.817** | **18.057** | **18.052** | **18.092** | **18.092** |

* This table is limited to doses reconstructed based on external exposures "at a distance," as measured by film badges, and does not include skin exposures that may have resulted from direct skin contamination.

SC&A determined the probability of causation (POC) for this case using these annual doses as input into the IREP program. Since the EE was diagnosed with five independent cases of skin cancer, these doses were entered five times into the IREP program, one for each instance or cancer. The total doses shown in Table I-2 produced a POC of 38.12%.

## I.2 EXTERNAL DOSES

The reconstruction of the skin dose to the EE began with a review of the EE's film badge exposure records. A summary of the EE's annual dosimetry records is shown in Table I-3. Dosimeter readings that were less than the LOD/2 were set to zero.

**Table I-3. External Dosimetry Records for FEMP Case #[Redacted]**

| Year | Deep/DDE (rem) | Shallow/Skin (rem) |
|---|---|---|
| [redact] | 0.000 | 0.029 |
| [redact] | 0.159 | 2.881 |
| [redact] | 0.289 | 3.627 |
| [redact] | 0.141 | 2.039 |
| [redact] | 0.134 | 2.203 |
| [redact] | 0.402 | 4.512 |
| [redact] | 0.164 | 0.895 |
| [redact] | 0.021 | 0.355 |
| [redact] | 0.000 | 0.000 |
| [redact] | 0.027 | 0.028 |
| [redact] | 0.000 | 0.000 |
| [redact] | 0.037 | 0.301 |
| [redact] | 0.012 | 0.012 |
| [redact] | 0.012 | 0.075 |
| [redact] | 0.000 | 0.000 |
| [redact] | 0.016 | 0.016 |

In the sections that follow, a description is provided of how we reconstructed the dose to the skin considering recorded photon, beta doses, and missed doses.

### I.2.1 RECORDED PHOTON DOSES

The DOE records show that this EE received positive recorded photon doses during each year from **[redact]** to **[redact]** except **[redact]** and **[redact]**, **[redact]**, and **[redact]**. SC&A used the guidance described in ORAUT-TKBS-0017-6 and ORAUT-OTIB-0017 in order to derive the organ dose from this exposure. The organ dose conversion factor (DCF) of 1.00 was applied in accordance with the *External Dose Reconstruction Implementation Guideline* (OCAS-IG-001). Based on guidance in ORAUT-TKBS-0017-6 and assuming the EE worked in Plant 6, an energy distribution of 13% <30 keV photons, 33% 30–250 keV photons, and 54% >250 keV photons was assumed. All electron doses are assumed to be associated with the >15 keV energy range. Table I-4 cites all DCFs used for calculating photon doses.

**Table I-4. Effective Dose Conversion Factors and Energy Distributions for Plant [redact]**

| **Plant 6 – Exposure ([redact]–[redact])** | | | |
|---|---|---|---|
| **Radiation Type** | **Photons** | | |
| **Energy Range** | **<30 keV** | **30–250 keV** | **>250 keV** |
| Energy Fraction | 0.130 | 0.330 | 0.540 |
| ICRP 60 CF | NA | NA | NA |
| Organ DCF | 1.000 | 1.000 | 1.000 |
| Dosimeter CF | 1.1 | 1.1 | 1 |
| Eff. DCF* | 0.143 | 0.363 | 0.540 |
| **Plant 6 – Deep Dose Equivalent ([redact]–[redact])** | | | |
| **Radiation Type** | **Photons** | | |
| **Energy Range** | **<30 keV** | **30–250 keV** | **>250 keV** |
| Energy Fraction | 0.130 | 0.330 | 0.540 |
| ICRP 60 CF | NA | NA | NA |
| Organ DCF | 1.000 | 1.000 | 1.000 |
| Eff. DCF* | 0.130 | 0.330 | 0.540 |

* Effective DCF incorporates all correction factors cited above.

Using the parameters provided in Table I-4 above, SC&A calculated the **[redact]** photon dose to the skin as follows:

**[Redact]**: Records show that for **[redact]**, the EE received a deep dose (D) of 0.159 rem. The photon dose to the skin was assumed to be 13% <30 keV, 33% 30–250 keV and 54% >250 keV. An organ DCF of 1.0 for the skin was applied. A dosimeter correction factor (CF) of 1.1 was applied for <30 keV photon and 30–250 keV photon doses until **[redact]**.

Skin Dose (<30 keV) $= D \times CF \times DCF \times 13\%$
$= 0.159 \times 1.10 \times 1.0 \times 0.13$
$= 0.023$ rem

Skin Dose (30–250 keV) $= D \times CF \times DCF \times 33\%$
$= 0.159 \times 1.10 \times 1.0 \times 0.33$
$= 0.058$ rem

Skin Dose (>250 keV) $= D \times CF \times DCF \times 54\%$

$= 0.159 \times 1 \times 1.0 \times 0.54$

$= 0.086$ rem

SC&A's calculated <30 keV, 30–250 keV, and >250 keV skin doses are shown in entries #1, #13, and #25 of Appendices I.A-1 through I.A-5.

The recorded photon doses were entered into IREP as a constant distribution with no uncertainty.

### I.2.2 MISSED PHOTON DOSES

The EE was monitored on a monthly dosimeter exchange schedule from [redact]–[redact] and quarterly from [redact]–[redact]. Both OCAS-IG-001 and the FEMP TBD suggest assigning missed dose to monitored workers who received doses below the limit of detection (LOD).[1] After correcting for values that were below the LOD, SC&A counted a total of 89 zero photon readings during the EE's employment. In order to calculate missed photon dose, the number of zero readings is multiplied by the appropriate LOD/2 value, along with the DCF. However, the site-specific guidance in ORAUT-OTIB-0017 cites the following for the assignment of missed dose to the skin.

1. *If only the OW (shallow) reading was reported as zero, the missed dose assigned should be the appropriate OW LOD (divided by 2, treated as lognormal) and considered >15 keV electrons.*

2. *If only the S (deep) reading was reported as zero, the missed dose assigned should be the appropriate S LOD (divided by 2, treated as lognormal) and considered 30–250 keV photons.*

3. *If both the OW and S readings were reported as zero, the missed dose assigned should be the appropriate OW LOD (divided by 2, treated as lognormal) and considered 30–250 keV photons.*

SC&A followed the guidance presented in ORAUT-OTIB-0017, and found that there were no instances when the photon (or S) reading was positive and the beta (or OW) reading was zero. Therefore, there are no missed doses listed in the appendices for >15 keV electrons. The only missed doses are for 30–250 keV photons.

For example, SC&A calculated the [redact] missed photon dose to the skin as follows:

[Redact]: Records show that for [redact], there were six dosimeter readings that were either zero or less than the LOD and marked as zero. The LOD for the time period is 0.030 rem, making the LOD/2 equal to 0.015 rem.

[1] On occasion, a worker's records may indicate a dose for a given change-out period that is less than the LOD, but greater than the LOD/2. Under these circumstances, the reported value is assigned, as opposed to LOD/2, in order to be claimant favorable. However, the more typical case is that the reported value is "0," which means less than the LOD. In these instances, the LOD/2 is assigned for a given change-out period.

Skin Dose (30–250 keV) = (# zeros × LOD/2) × DCF
= (6 × 0.015 rem) × 1.0
= 0.090 rem

SC&A's calculated 30–250 keV missed dose of 0.090 rem is shown in entry #49 of Appendices I.A-1 through I.A-5.

The 30–250 keV photon missed doses were entered into IREP as a lognormal distribution with an uncertainty of 1.520.

### I.2.3 RECORDED ELECTRON (SHALLOW) DOSE

The non-penetrating dose was assumed to be the reported beta dose in the site "Occupational Radiation Exposure Report" and was applied as >15 keV electrons. An additional correction for clothing attenuation was applied per guidance in the Technical Information Bulletin (TIB), *Interpretation of Dosimetry Data for Assignment of Shallow Dose* (ORAUT-OTIB-0017). A reduction of the electron dose due to attenuation from clothing was applied to the SCC on the [redact] (#1 from Table I-1), because this cancer is located in an area normally covered with clothing. The calculated electron doses were multiplied by 0.855, which represents the midpoint of the uranium attenuation factors reported for two pairs of coveralls, including the paper liner (0.80) and one Dacron/cotton lab coat (0.91). Because the specific clothing worn by the EE could not be determined, the approach adopted is considered reasonable. The electron doses for the other four cancers were not reduced, because they were in locations where the skin would not normally be covered.

For example, SC&A calculated the [redact] >15 keV dose to the skin of the [redact] as follows:

[Redact]: Records show that for [redact], the EE's recorded deep dose (D) was 0.159 rem and the recorded shallow dose was 2.881 rem. The >15 keV electron dose is the difference between the shallow and deep doses multiplied by the organ DCF and, for this cancer, an attenuation factor of 0.855.

Skin Dose (>15 keV electrons) = (shallow – deep) × DCF × 0.855
= (2.881 rem – 0.159 rem) × 1.0 × 0.855
= 2.327 rem

SC&A's calculated >15 keV electron dose of 2.327 rem is shown in entry #38 of Appendix A-1. The non-attenuated value of 2.722 rem is shown in entry #38 of Appendices A-2 through A-5.

The >15 keV electron doses were entered into IREP as a constant distribution with no uncertainty.

## I.3 OCCUPATIONAL MEDICAL DOSE

The DOE records show that the EE received seven PA exams and one LAT ([redact]) x-ray exam during the employment period. Using the values presented in Table A-9 ORAUT-OTIB-0006, SC&A assigned the total occupational medical doses shown in Table I-5.

**Table I-5. Occupational Medical Doses**

| # | Location | OTIB-0006 Dose (rem) | | | Dose (rem) |
|---|---|---|---|---|---|
| | | PA (<1985) | PA (>1985) | LAT (>1985) | |
| 1 | SCC [redacted] | | 0.0024 | 0.0456 | 0.065 |
| 2 | BCC [redacted] | 0.0032 | 0.0039 | 0.0182 | 0.049 |
| 3 | BCC [redacted] | 0.0032 | 0.0039 | 0.0182 | 0.0029 |
| 4 | SCC [redacted] | 0.0135 | 0.0070 | 0.0182 | 0.081 |
| 5 | SCC [redacted] | 0.0135 | 0.0070 | 0.0182 | 0.081 |

In order to provide the most claimant-favorable results, the annual occupational medical dose values were entered into IREP as a normal distribution with 30% uncertainty and a photon energy range of 30–250 keV.

## I.4 ONSITE AMBIENT DOSE

SC&A chose not to include external onsite ambient dose as part of this DR.

The EE was continuously monitored for ionizing radiation doses during employment at the FMPC. Therefore, all onsite ambient doses were assessed as part of the EE's measured and missed doses.

## I.5 INTERNAL DOSE

Internal dose monitoring records for radionuclides were reviewed. This included baseline thorium fecal bioassay, uranium urine, and chest count measurements. The DOE records show that the EE submitted 217 urine samples from [redacted] to [redacted] that were analyzed for uranium. Table I-6 shows the routine uranium in-vitro bioassay capabilities at the FMPC (ORAUT-TKBS-0017-5). A listing of the samples and results is shown in Table I-7.

**Table I-6. FEMP Uranium Bioassay Capabilities**

| Type of Analysis | Method | Time Period | MDL |
|---|---|---|---|
| Urine-uranium | Fluorophotometry | [redacted] to [redacted] | 14 μg $L^{-1}$ |
| | Chemchek KPA | [redacted] to [redacted] | 0.17 μg $L^{-1}$ (total U) |

## Table I-7. Uranium Bioassay Results

| Sample Date | Sample Number | Result | Result Units | Sample Date | Sample Number | Result | Result Units | Sample Date | Sample Number | Result | Result Units |
|---|---|---|---|---|---|---|---|---|---|---|---|
| [redact] | | 1.00 | µg/L | [redact] | 597 | 3.00 | µg/L | [redact] | 2794 | 9.00 | µg/L |
| [redact] | | 9.00 | µg/L | [redact] | 634 | 4.00 | µg/L | [redact] | 3900 | 8.00 | µg/L |
| [redact] | | 13.00 | µg/L | [redact] | 706 | 3.00 | µg/L | [redact] | 5505 | 7.00 | µg/L |
| [redact] | | 0.00 | µg/L | [redact] | 714 | 3.00 | µg/L | [redact] | 6335 | 7.00 | µg/L |
| [redact] | | 1.00 | µg/L | [redact] | 769 | 3.00 | µg/L | [redact] | 6711 | 7.00 | µg/L |
| [redact] | | 6.00 | µg/L | [redact] | 815 | 3.00 | µg/L | [redact] | 6942 | 8.00 | µg/L |
| [redact] | | 6.00 | µg/L | [redact] | 906 | 3.00 | µg/L | [redact] | 7438 | 8.00 | µg/L |
| [redact] | | 5.00 | µg/L | [redact] | 68 | 3.00 | µg/L | [redact] | 8050 | 9.00 | µg/L |
| [redact] | | 0.00 | µg/L | [redact] | 183 | 3.00 | µg/L | [redact] | 9285 | 8.00 | µg/L |
| [redact] | | 0.00 | µg/L | [redact] | 516 | 3.00 | µg/L | [redact] | 481 | 9.00 | µg/L |
| [redact] | | 3.00 | µg/L | [redact] | | 3.00 | µg/L | [redact] | 1736 | 10.00 | µg/L |
| [redact] | | 3.00 | µg/L | [redact] | 617 | 3.00 | µg/L | [redact] | 3121 | 10.00 | µg/L |
| [redact] | | 2.00 | µg/L | [redact] | 815 | 3.00 | µg/L | [redact] | 5189 | 10.00 | µg/L |
| [redact] | | 2.00 | µg/L | [redact] | 861 | 3.00 | µg/L | [redact] | 7227 | 9.00 | µg/L |
| [redact] | | 18.00 | µg/L | [redact] | 67 | 3.00 | µg/L | [redact] | 8785 | 10.00 | µg/L |
| [redact] | | 3.00 | µg/L | [redact] | 141 | 3.00 | µg/L | [redact] | 1230 | 11.00 | µg/L |
| [redact] | | 3.00 | µg/L | [redact] | 182 | 3.00 | µg/L | [redact] | 1658 | 11.00 | µg/L |
| [redact] | 560 | 1.00 | µg/L | [redact] | 154 | 5.00 | µg/L | [redact] | 3031 | 11.00 | µg/L |
| [redact] | 219 | 3.00 | µg/L | [redact] | 182 | 5.00 | µg/L | [redact] | 4293 | 12.00 | µg/L |
| [redact] | 89 | 3.00 | µg/L | [redact] | 191 | 5.00 | µg/L | [redact] | 4600 | 12.00 | µg/L |
| [redact] | 809 | 3.00 | µg/L | [redact] | 282 | 5.00 | µg/L | [redact] | 6053 | 12.00 | µg/L |
| [redact] | 508 | 3.00 | µg/L | [redact] | 296 | 5.00 | µg/L | [redact] | 7343 | 12.00 | µg/L |
| [redact] | 174 | 3.00 | µg/L | [redact] | 404 | 5.00 | µg/L | [redact] | 9307 | 12.00 | µg/L |
| [redact] | 34 | 3.00 | µg/L | [redact] | 427 | 5.00 | µg/L | [redact] | 1647 | 14.00 | µg/L |
| [redact] | 77 | 3.00 | µg/L | [redact] | 465 | 5.00 | µg/L | [redact] | 1981 | 14.00 | µg/L |
| [redact] | 131 | 3.00 | µg/L | [redact] | 515 | 5.00 | µg/L | [redact] | 3525 | 14.00 | µg/L |
| [redact] | 186 | 3.00 | µg/L | [redact] | 539 | 5.00 | µg/L | [redact] | 5983 | 14.00 | µg/L |
| [redact] | 230 | 4.00 | µg/L | [redact] | 655 | 5.00 | µg/L | [redact] | 6661 | 14.00 | µg/L |
| [redact] | 430 | 3.00 | µg/L | [redact] | 686 | 5.00 | µg/L | [redact] | 8724 | 14.00 | µg/L |
| [redact] | 345 | 3.00 | µg/L | [redact] | 769 | 5.00 | µg/L | [redact] | 32 | 14.00 | µg/L |
| [redact] | 573 | 6.00 | µg/L | [redact] | 831 | 5.00 | µg/L | [redact] | 568 | 14.00 | µg/L |
| [redact] | 607 | 3.00 | µg/L | [redact] | 860 | 5.00 | µg/L | [redact] | 1332 | 14.00 | µg/L |
| [redact] | 417 | 5.00 | µg/L | [redact] | 2 | 5.00 | µg/L | [redact] | 2419 | 14.00 | µg/L |
| [redact] | 858 | 14.00 | µg/L | [redact] | 67 | 5.00 | µg/L | [redact] | 3554 | 14.00 | µg/L |
| [redact] | 988 | 7.00 | µg/L | [redact] | 188 | 5.00 | µg/L | [redact] | 5049 | 14.00 | µg/L |
| [redact] | 606 | 7.00 | µg/L | [redact] | 252 | 5.00 | µg/L | [redact] | 6098 | 14.00 | µg/L |
| [redact] | 266 | 3.00 | µg/L | [redact] | 520 | 5.00 | µg/L | [redact] | 7240 | 14.00 | µg/L |
| [redact] | 346 | 3.00 | µg/L | [redact] | 576 | 5.00 | µg/L | [redact] | 8618 | 14.00 | µg/L |
| [redact] | 742 | 3.00 | µg/L | [redact] | 742 | 5.00 | µg/L | [redact] | | 14.00 | µg/L |
| [redact] | 851 | 3.00 | µg/L | [redact] | 880 | 5.00 | µg/L | [redact] | 9461 | 14.00 | µg/L |
| [redact] | 884 | 3.00 | µg/L | [redact] | 175 | 5.00 | µg/L | [redact] | 1168 | 14.00 | µg/L |
| [redact] | 976 | 5.00 | µg/L | [redact] | 215 | 5.00 | µg/L | [redact] | 1759 | 14.00 | µg/L |
| [redact] | 3 | 3.00 | µg/L | [redact] | 265 | 5.00 | µg/L | [redact] | 3178 | 14.00 | µg/L |
| [redact] | 53 | 3.00 | µg/L | [redact] | 457 | 5.00 | µg/L | [redact] | 6192 | 14.00 | µg/L |
| [redact] | 118 | 6.00 | µg/L | [redact] | 665 | 5.00 | µg/L | [redact] | 4144 | 14.00 | µg/L |
| [redact] | 175 | 3.00 | µg/L | [redact] | 334 | 5.00 | µg/L | [redact] | 4980 | 14.00 | µg/L |
| [redact] | 327 | 4.00 | µg/L | [redact] | 13 | 5.00 | µg/L | [redact] | 7257 | 0.80 | µg/L |
| [redact] | 355 | 3.00 | µg/L | [redact] | 610 | 5.00 | µg/L | [redact] | 8768 | 0.80 | µg/L |
| [redact] | 454 | 3.00 | µg/L | [redact] | 681 | 5.00 | µg/L | [redact] | 218 | 0.80 | µg/L |
| [redact] | 494 | 4.00 | µg/L | [redact] | 899 | 5.00 | µg/L | [redact] | 1865 | 0.8 | µg/L |
| [redact] | 639 | 3.00 | µg/L | [redact] | 904 | 5.00 | µg/L | [redact] | 3445 | 0.8 | µg/L |

**Table I-7. Uranium Bioassay Results**

| Sample Date | Sample Number | Result | Result Units | Sample Date | Sample Number | Result | Result Units | Sample Date | Sample Number | Result | Result Units |
|---|---|---|---|---|---|---|---|---|---|---|---|
| [redact] | 673 | 3.00 | µg/L | [redact] | 51 | 5.00 | µg/L | [redact] | 4165 | 0.8 | µg/L |
| [redact] | 753 | 3.00 | µg/L | [redact] | 304 | 5.00 | µg/L | [redact] | 582 | 0.8 | µg/L |
| [redact] | 792 | 4.00 | µg/L | [redact] | 92 | 5.00 | µg/L | [redact] | 2224 | 0.8 | µg/L |
| [redact] | 814 | 3.00 | µg/L | [redact] | 560 | 5.00 | µg/L | [redact] | 2256 | 0.8 | µg/L |
| [redact] | 951 | 3.00 | µg/L | [redact] | 1906 | 5.00 | µg/L | [redact] | 4386 | 0.8 | µg/L |
| [redact] | 90 | 3.00 | µg/L | [redact] | 3324 | 5.00 | µg/L | [redact] | 5961 | 0.8 | µg/L |
| [redact] | 112 | 3.00 | µg/L | [redact] | 4581 | 5.00 | µg/L | [redact] | 7977 | 0.8 | µg/L |
| [redact] | 210 | 3.00 | µg/L | [redact] | 5873 | 5.00 | µg/L | [redact] | 261 | 0.8 | µg/L |
| [redact] | 237 | 3.00 | µg/L | [redact] | 7137 | 5.00 | µg/L | [redact] | 1755 | 0.8 | µg/L |
| [redact] | 311 | 3.00 | µg/L | [redact] | 8060 | 5.00 | µg/L | [redact] | 2436 | 0.8 | µg/L |
| [redact] | 338 | 3.00 | µg/L | [redact] | 8866 | 5.00 | µg/L | [redact] | 4848 | 0.8 | µg/L |
| [redact] | 468 | 3.00 | µg/L | [redact] | 9562 | 5.00 | µg/L | [redact] | 6821 | 0.8 | µg/L |
| [redact] | 667 | 3.00 | µg/L | [redact] | 1510 | 5.00 | µg/L | [redact] | 9530 | 0.8 | µg/L |
| [redact] | 759 | 3.00 | µg/L | [redact] | 1816 | 5.00 | µg/L | [redact] | 767 | 0.8 | µg/L |
| [redact] | 950 | 3.00 | µg/L | [redact] | 2019 | 5.00 | µg/L | [redact] | 4563 | 0.8 | µg/L |
| [redact] | 988 | 3.00 | µg/L | [redact] | 2088 | 5.00 | µg/L | [redact] | 6132 | 0.8 | µg/L |
| [redact] | 102 | 3.00 | µg/L | [redact] | 3210 | 5.00 | µg/L | [redact] | 7836 | 0.8 | µg/L |
| [redact] | 114 | 3.00 | µg/L | [redact] | 4677 | 5.00 | µg/L | [redact] | 8934 | 0.8 | µg/L |
| [redact] | 221 | 3.00 | µg/L | [redact] | 6297 | 5.00 | µg/L | | | | |
| [redact] | 252 | 3.00 | µg/L | [redact] | 7952 | 8.00 | µg/L | | | | |
| [redact] | 359 | 3.00 | µg/L | [redact] | 9324 | 8.00 | µg/L | | | | |
| [redact] | 390 | 3.00 | µg/L | [redact] | 751 | 9.00 | µg/L | | | | |
| [redact] | 597 | 3.00 | µg/L | [redact] | 1800 | 9.00 | µg/L | | | | |

### I.5.1 DOSE FROM URANIUM

All of the EE's uranium bioassay results except one were below the minimum detection level (MDL) of the analyses. The urine sample submitted on **[redact]**, had a result of 18 $\mu gL^{-1}$ with an MDL of 14 $\mu gL^{-1}$.

A computer code, the Integrated Modules for Bioassay Analysis (IMBA), was used to estimate intakes of radioactive material and the subsequent annual organ doses from the uranium bioassay data. The IMBA Expert ORAU-Edition was used for this DR. The ICRP 66 lung model with default aerosol characteristics was assumed, in conjunction with ICRP 68 metabolic models.

To account for any potential undetected dose, internal dose was assigned based on a chronic intake assumed to have occurred throughout EE's employment period. To account for the single elevated sample, an acute intake was assumed to have occurred on **[redact]**, the midpoint between bioassay samples. The specific activity of uranium was assumed to be 2% enriched uranium (specific activity = 1.616 pCi/µg). In addition, the uranium intake was assessed as 100% uranium-234, a claimant-favorable assumption. Both Types M and S uranium were considered and both resulted in similar overall doses. However, when consideration is given to the uranium intake quantities and recycled uranium (RU) contaminants, Type S uranium resulted in the most claimant-favorable doses. The calculated uranium intakes are shown in Table I-8.

**Table I-8. Uranium Intakes**

| Type of Intake | Date | Quantity |
|---|---|---|
| Chronic | [redacted] to [redacted] | 128.54 pCi/day |
| Acute | [redact] | 228,000 pCi |

Observation #1: For calculating internal doses using the above-cited chronic intake quantity, DR–Method A used both the IMBA software and Chronic Annual Dose Workbook (CADW). A comparison of resultant doses identified a discrepancy between these two calculational methods. As shown in Table I-9, CADW calculated a total alpha dose that is nearly 45% lower than the total dose calculated by IMBA. SC&A could not reconcile why there is difference between the IMBA calculation and the CADW calculation for uranium.

**Table I-9. Comparison of Alpha Dose Using IMBA and CADW**

| Calendar Year | Alpha Dose Using IMBA (rem) | Alpha Dose Using CADW (rem) |
|---|---|---|
| [redacted] | 1.17E-05 | 2.033E-05 |
| [redacted] | 1.32E-04 | 4.431E-05 |
| [redacted] | 2.02E-04 | 6.887E-05 |
| [redacted] | 8.83E-04 | 2.542E-04 |
| [redacted] | 6.74E-04 | 2.377E-04 |
| [redacted] | 7.50E-04 | 2.726E-04 |
| [redacted] | 8.30E-04 | 3.068E-04 |
| [redacted] | 9.04E-04 | 3.408E-04 |
| [redacted] | 9.79E-04 | 3.738E-04 |
| [redacted] | 1.05E-03 | 4.069E-04 |
| [redacted] | 1.13E-03 | 4.399E-04 |
| [redacted] | 1.20E-03 | 4.733E-04 |
| [redacted] | 1.28E-03 | 5.059E-04 |
| [redacted] | 1.35E-03 | 5.388E-04 |
| [redacted] | 1.43E-03 | 5.718E-04 |
| [redacted] | 1.42E-03 | 6.051E-04 |
| [redacted] | 1.40E-03 | 6.172E-04 |
| [redacted] | 1.40E-03 | 6.259E-04 |
| [redacted] | 1.41E-03 | 6.342E-04 |
| [redacted] | 1.41E-03 | 6.416E-04 |
| [redacted] | 1.41E-03 | 6.468E-04 |
| [redacted] | 1.41E-03 | 6.516E-04 |
| [redacted] | 1.41E-03 | 6.556E-04 |
| [redacted] | 1.40E-03 | 6.593E-04 |
| [redacted] | 1.40E-03 | 6.616E-04 |
| [redacted] | 1.40E-03 | 6.639E-04 |
| [redacted] | 1.40E-03 | 6.657E-04 |
| [redacted] | 1.39E-03 | 6.675E-04 |
| [redacted] | 1.39E-03 | 6.681E-04 |
| [redacted] | 1.38E-03 | 6.688E-04 |
| [redacted] | 4.34E-04 | 6.692E-04 |
| Total | 3.43E-02 | 1.526E-02 |

### I.5.2 DOSE FROM RECYCLED URANIUM CONTAMINANTS

Production level quantities of recycled uranium (RU) were first introduced at the FEMP site in 1961. Therefore, all uranium intakes after 1961 are assumed to have associated plutonium-239, neptunium-237, and technetium-99 intakes. According to ORAUT-TKBS-0017-5, the intakes of plutonium-239, neptunium-237, and technetium-99 will be 0.38%, 0.15%, and 9.4%, respectively, of the uranium intake, assuming 2% uranium enrichment. The RU intakes are shown in Table I-10.

**Table I-10. Intakes from RU Contaminants**

| Type of Intake | Date | Pu-239 (S) | Np-237 (M) | Tc-99 (M) |
|---|---|---|---|---|
| Chronic | [redacted] to [redacted] | 5.001E-01 pCi/day | 1.987E-01 pCi/day | 1.227E+01 pCi/day |
| Acute | [redacted] | 8.873E+02 pCi | 3.526E+02 pCi | 2.178E+04 pCi |

The doses from the intakes of RU contaminants were all less than 0.003 rem and are included in the IREP table. SC&A notes that the issue of RU has been a topic of intense discussion in the Fernald Work Group (WG). After a series of white paper exchanges and WG discussions, NIOSH has agreed to change the default levels of plutonium-239, neptunium-237, and technetium-99 in RU over three periods of time that correspond to changing constituent concentration levels in incoming feed stocks. However, at the time that this DR was performed, the TBD has not been updated. Thus, in assigning dose to this EE from RU, SC&A used the intakes from ORAUT-TKBS-0017-5 in Table I-10.

## I.6 ENVIRONMENTAL DOSE

The EE primarily worked in Plant [redacted] during employment at FEMP, and it was assumed that the EE might have been occupationally exposed to environmental levels of radioactive material while working there. According to Figure 4-2 of ORAUT-TKBS-0017-4, Plant [redacted] was located in Exposure Area [redacted]. Tables A-1 and A-2 of the same document list the environmental radionuclide concentration and intake summaries for [redacted] to [redacted] and [redacted] to [redacted]. The CADW version 8.2.4 was used to calculate the EE's environmental doses using intake values for Pu-239, Np-237, Tc-99, and Th-232 for [redacted]. All of the environmental doses calculated for the time period from [redacted], through [redacted], were less than 0.001 rem and were not reported in the IREP table.

## I.7 CATI REPORT AND RADIOLOGICAL INCIDENTS

SC&A reviewed the EE's DOE records and CATI Report to determine if the EE was involved in any radiological incidents that may not have been detected with external and internal radiological monitoring. There are several instances where the EE's thermoluminescent dosimeter (TLD) was either lost or damaged; however, investigations were documented and either a zero or estimated dose assigned. There are three radiological incidents of note. In [redacted], the EE was in the vicinity of [redacted]. Bioassays were collected and the results were less than the detection limit. In [redacted], the EE was in the immediate area when [redacted] resulting in airborne particulates. Again, bioassays were collected and the results were less than the detection limit. Finally, in [redacted], while in a controlled area, the EE noticed [redacted]. An investigation was conducted and the EE was assigned 0.015 rem for the quarter based on coworker information.

SC&A did not find any documentation of radiological incidents that occurred during a time the EE was not monitored for internal or external radiation exposure.

## I.8 SUMMARY CONCLUSIONS

The EE worked at the Fernald facility from [redacted] through [redacted]. During most of the time, the EE was monitored for exposure to external and internal radiation. The EE was diagnosed with multiple skin cancers beginning in [redacted] through [redacted]. The DR derived a total external and internal dose of approximately 18 rem to each bare skin (un-attenuated) cancer location and 15.8 rem to the skin cancer on the [redact]. Approximately 15.5 rem of the [redact] skin dose and 13.3 rem of the [redact] skin cancer doses were attributed to exposure to >15 keV electrons.

The total POC for the five multiple primary cancers was calculated using the IREP (version .5.7) and determined to be 40.92%.

## I.9 REFERENCES


ICRP (International Commission on Radiological Protection) 1991. *1990 Recommendations of the International Commission on Radiological Protection*, Publication 60, Pergamon Press, Oxford, England.

ICRP (International Commission on Radiological Protection) 1994. Human Respiratory Tract Model for Radiological Protection, ICRP Publication 66, Ann. ICRP 24 (1-3), 1994, Pergamon Press, Oxford, England.

ICRP (International Commission on Radiological Protection) 1994. *Dose Coefficients for Intakes of Radionuclides by Workers*, ICRP Publication 68, Ann. ICRP 24 (4), Pergamon Press, Oxford, England.

OCAS-IG-001. 2007. *External Dose Reconstruction Implementation Guideline,* Rev. 3, National Institute for Occupational Safety and Health, Office of Compensation Analysis and Support, Cincinnati, Ohio. November 21, 2007.

ORAUT-OTIB-0006. 2005. *Technical Information Bulletin: Dose Reconstruction from Occupationally Related Diagnostic X-Ray Procedures,* Rev. 04, Oak Ridge Associated Universities Team, Cincinnati, Ohio. June 20, 2011.

ORAUT-OTIB-0017. 2005. *Technical Information Bulletin: Interpretation of Dosimetry Data for Assignment of Shallow Dose,* Rev. 01, Oak Ridge Associated Universities Team, Cincinnati, Ohio. October 11, 2005.

ORAUT-TKBS-0017-4. 2006. *Fernald Environmental Management Project – Occupational Environmental Dose,* Rev. 01, Oak Ridge Associated Universities Team, Cincinnati, Ohio. February 7, 2006.

ORAUT-TKBS-0017-5. 2004. *Technical Basis Document for the Fernald Environmental Management Project (FEMP) – Occupational Internal Dose,* Rev. 00, Oak Ridge Associated Universities Team, Cincinnati, Ohio. May 28, 2004.

ORAUT-TKBS-0017-6. 2004. *Technical Basis Document for the Fernald Environmental Management Project - Occupational External Dose,* Rev. 00, Oak Ridge Associated Universities Team, Cincinnati, Ohio. April 20, 2004.

# APPENDIX I.A-1: IREP INPUT – SCC [REDACTED]

| EXPOSURE INFORMATION | | | | | | | |
|---|---|---|---|---|---|---|---|
| Number of exposures<br>148 | | | | | | | |
| Exposure # | Exposure Year | Exposure Rate | Radiation Type | Dose Distribution Type | Parameter 1 | Parameter 2 | Parameter 3 |
| 1 | [redact] | acute | photons E<30keV | Constant | 0.023 | 0.000 | 0.000 |
| 2 | [redact] | acute | photons E<30keV | Constant | 0.041 | 0.000 | 0.000 |
| 3 | [redact] | acute | photons E<30keV | Constant | 0.018 | 0.000 | 0.000 |
| 4 | [redact] | acute | photons E<30keV | Constant | 0.017 | 0.000 | 0.000 |
| 5 | [redact] | acute | photons E<30keV | Constant | 0.052 | 0.000 | 0.000 |
| 6 | [redact] | acute | photons E<30keV | Constant | 0.021 | 0.000 | 0.000 |
| 7 | [redact] | acute | photons E<30keV | Constant | 0.003 | 0.000 | 0.000 |
| 8 | [redact] | acute | photons E<30keV | Constant | 0.004 | 0.000 | 0.000 |
| 9 | [redact] | acute | photons E<30keV | Constant | 0.005 | 0.000 | 0.000 |
| 10 | [redact] | acute | photons E<30keV | Constant | 0.002 | 0.000 | 0.000 |
| 11 | [redact] | acute | photons E<30keV | Constant | 0.002 | 0.000 | 0.000 |
| 12 | [redact] | acute | photons E<30keV | Constant | 0.002 | 0.000 | 0.000 |
| 13 | [redact] | acute | photons E=30-250keV | Constant | 0.058 | 0.000 | 0.000 |
| 14 | [redact] | acute | photons E=30-250keV | Constant | 0.105 | 0.000 | 0.000 |
| 15 | [redact] | acute | photons E=30-250keV | Constant | 0.047 | 0.000 | 0.000 |
| 16 | [redact] | acute | photons E=30-250keV | Constant | 0.044 | 0.000 | 0.000 |
| 17 | [redact] | acute | photons E=30-250keV | Constant | 0.133 | 0.000 | 0.000 |
| 18 | [redact] | acute | photons E=30-250keV | Constant | 0.054 | 0.000 | 0.000 |
| 19 | [redact] | acute | photons E=30-250keV | Constant | 0.007 | 0.000 | 0.000 |
| 20 | [redact] | acute | photons E=30-250keV | Constant | 0.009 | 0.000 | 0.000 |
| 21 | [redact] | acute | photons E=30-250keV | Constant | 0.012 | 0.000 | 0.000 |
| 22 | [redact] | acute | photons E=30-250keV | Constant | 0.004 | 0.000 | 0.000 |
| 23 | [redact] | acute | photons E=30-250keV | Constant | 0.004 | 0.000 | 0.000 |
| 24 | [redact] | acute | photons E=30-250keV | Constant | 0.005 | 0.000 | 0.000 |
| 25 | [redact] | acute | photons E>250keV | Constant | 0.086 | 0.000 | 0.000 |
| 26 | [redact] | acute | photons E>250keV | Constant | 0.156 | 0.000 | 0.000 |
| 27 | [redact] | acute | photons E>250keV | Constant | 0.076 | 0.000 | 0.000 |
| 28 | [redact] | acute | photons E>250keV | Constant | 0.072 | 0.000 | 0.000 |
| 29 | [redact] | acute | photons E>250keV | Constant | 0.217 | 0.000 | 0.000 |
| 30 | [redact] | acute | photons E>250keV | Constant | 0.089 | 0.000 | 0.000 |
| 31 | [redact] | acute | photons E>250keV | Constant | 0.011 | 0.000 | 0.000 |
| 32 | [redact] | acute | photons E>250keV | Constant | 0.015 | 0.000 | 0.000 |
| 33 | [redact] | acute | photons E>250keV | Constant | 0.020 | 0.000 | 0.000 |
| 34 | [redact] | acute | photons E>250keV | Constant | 0.006 | 0.000 | 0.000 |
| 35 | [redact] | acute | photons E>250keV | Constant | 0.006 | 0.000 | 0.000 |
| 36 | [redact] | acute | photons E>250keV | Constant | 0.009 | 0.000 | 0.000 |
| 37 | [redact] | acute | electrons E>15keV | Constant | 0.029 | 0.000 | 0.000 |
| 38 | [redact] | acute | electrons E>15keV | Constant | 2.722 | 0.000 | 0.000 |
| 39 | [redact] | acute | electrons E>15keV | Constant | 3.338 | 0.000 | 0.000 |
| 40 | [redact] | acute | electrons E>15keV | Constant | 1.898 | 0.000 | 0.000 |
| 41 | [redact] | acute | electrons E>15keV | Constant | 2.069 | 0.000 | 0.000 |
| 42 | [redact] | acute | electrons E>15keV | Constant | 4.110 | 0.000 | 0.000 |

## Appendix I.A-1: IREP Input – SCC [Redacted] (continued)

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 43 | [redact] | acute | electrons E>15keV | Constant | 0.731 | 0.000 | 0.000 |
| 44 | [redact] | acute | electrons E>15keV | Constant | 0.334 | 0.000 | 0.000 |
| 45 | [redact] | acute | electrons E>15keV | Constant | 0.001 | 0.000 | 0.000 |
| 46 | [redact] | acute | electrons E>15keV | Constant | 0.264 | 0.000 | 0.000 |
| 47 | [redact] | acute | electrons E>15keV | Constant | 0.063 | 0.000 | 0.000 |
| 48 | [redact] | acute | photons E=30-250keV | Lognormal | 0.180 | 1.520 | 0.000 |
| 49 | [redact] | acute | photons E=30-250keV | Lognormal | 0.090 | 1.520 | 0.000 |
| 50 | [redact] | acute | photons E=30-250keV | Lognormal | 0.030 | 1.520 | 0.000 |
| 51 | [redact] | acute | photons E=30-250keV | Lognormal | 0.020 | 1.520 | 0.000 |
| 52 | [redact] | acute | photons E=30-250keV | Lognormal | 0.050 | 1.520 | 0.000 |
| 53 | [redact] | acute | photons E=30-250keV | Lognormal | 0.100 | 1.520 | 0.000 |
| 54 | [redact] | acute | photons E=30-250keV | Lognormal | 0.120 | 1.520 | 0.000 |
| 55 | [redact] | acute | photons E=30-250keV | Lognormal | 0.140 | 1.520 | 0.000 |
| 56 | [redact] | acute | photons E=30-250keV | Lognormal | 0.120 | 1.520 | 0.000 |
| 57 | [redact] | acute | photons E=30-250keV | Lognormal | 0.010 | 1.520 | 0.000 |
| 58 | [redact] | acute | photons E=30-250keV | Lognormal | 0.030 | 1.520 | 0.000 |
| 59 | [redact] | acute | photons E=30-250keV | Lognormal | 0.050 | 1.520 | 0.000 |
| 60 | [redact] | acute | photons E=30-250keV | Lognormal | 0.040 | 1.520 | 0.000 |
| 61 | [redact] | acute | photons E=30-250keV | Normal | 0.003 | 0.001 | 0.000 |
| 62 | [redact] | acute | photons E=30-250keV | Normal | 0.002 | 0.001 | 0.000 |
| 63 | [redact] | acute | photons E=30-250keV | Normal | 0.005 | 0.001 | 0.000 |
| 64 | [redact] | acute | photons E=30-250keV | Normal | 0.002 | 0.001 | 0.000 |
| 65 | [redact] | acute | photons E=30-250keV | Normal | 0.005 | 0.001 | 0.000 |
| 66 | [redact] | acute | photons E=30-250keV | Normal | 0.002 | 0.001 | 0.000 |
| 67 | [redact] | acute | photons E=30-250keV | Normal | 0.046 | 0.014 | 0.000 |
| 68 | [redact] | chronic | alpha | Lognormal | 0.000 | 3.000 | 0.000 |
| 69 | [redact] | chronic | alpha | Lognormal | 0.000 | 3.000 | 0.000 |
| 70 | [redact] | chronic | alpha | Lognormal | 0.000 | 3.000 | 0.000 |
| 71 | [redact] | chronic | alpha | Lognormal | 0.001 | 3.000 | 0.000 |
| 72 | [redact] | chronic | alpha | Lognormal | 0.001 | 3.000 | 0.000 |
| 73 | [redact] | chronic | alpha | Lognormal | 0.001 | 3.000 | 0.000 |
| 74 | [redact] | chronic | alpha | Lognormal | 0.001 | 3.000 | 0.000 |
| 75 | [redact] | chronic | alpha | Lognormal | 0.001 | 3.000 | 0.000 |
| 76 | [redact] | chronic | alpha | Lognormal | 0.001 | 3.000 | 0.000 |
| 77 | [redact] | chronic | alpha | Lognormal | 0.001 | 3.000 | 0.000 |
| 78 | [redact] | chronic | alpha | Lognormal | 0.001 | 3.000 | 0.000 |
| 79 | [redact] | chronic | alpha | Lognormal | 0.001 | 3.000 | 0.000 |
| 80 | [redact] | chronic | alpha | Lognormal | 0.001 | 3.000 | 0.000 |
| 81 | [redact] | chronic | alpha | Lognormal | 0.001 | 3.000 | 0.000 |
| 82 | [redact] | chronic | alpha | Lognormal | 0.001 | 3.000 | 0.000 |
| 83 | [redact] | chronic | alpha | Lognormal | 0.001 | 3.000 | 0.000 |
| 84 | [redact] | chronic | alpha | Lognormal | 0.001 | 3.000 | 0.000 |
| 85 | [redact] | chronic | alpha | Lognormal | 0.001 | 3.000 | 0.000 |
| 86 | [redact] | chronic | alpha | Lognormal | 0.001 | 3.000 | 0.000 |
| 87 | [redact] | chronic | alpha | Lognormal | 0.001 | 3.000 | 0.000 |
| 88 | [redact] | chronic | alpha | Lognormal | 0.001 | 3.000 | 0.000 |

## Appendix I.A-1: IREP Input – SCC [Redacted] (continued)

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 89 | [redact] | chronic | alpha | Lognormal | 0.001 | 3.000 | 0.000 |
| 90 | [redact] | chronic | alpha | Lognormal | 0.001 | 3.000 | 0.000 |
| 91 | [redact] | chronic | alpha | Lognormal | 0.001 | 3.000 | 0.000 |
| 92 | [redact] | chronic | alpha | Lognormal | 0.001 | 3.000 | 0.000 |
| 93 | [redact] | chronic | alpha | Lognormal | 0.001 | 3.000 | 0.000 |
| 94 | [redact] | chronic | alpha | Lognormal | 0.001 | 3.000 | 0.000 |
| 95 | [redact] | chronic | alpha | Lognormal | 0.000 | 3.000 | 0.000 |
| 96 | [redact] | chronic | alpha | Lognormal | 0.000 | 3.000 | 0.000 |
| 97 | [redact] | chronic | alpha | Lognormal | 0.000 | 3.000 | 0.000 |
| 98 | [redact] | chronic | alpha | Lognormal | 0.000 | 3.000 | 0.000 |
| 99 | [redact] | chronic | alpha | Lognormal | 0.000 | 3.000 | 0.000 |
| 100 | [redact] | chronic | alpha | Lognormal | 0.000 | 3.000 | 0.000 |
| 101 | [redact] | chronic | alpha | Lognormal | 0.000 | 3.000 | 0.000 |
| 102 | [redact] | chronic | alpha | Lognormal | 0.000 | 3.000 | 0.000 |
| 103 | [redact] | chronic | alpha | Lognormal | 0.000 | 3.000 | 0.000 |
| 104 | [redact] | chronic | alpha | Lognormal | 0.000 | 3.000 | 0.000 |
| 105 | [redact] | chronic | alpha | Lognormal | 0.000 | 3.000 | 0.000 |
| 106 | [redact] | chronic | alpha | Lognormal | 0.000 | 3.000 | 0.000 |
| 107 | [redact] | chronic | alpha | Lognormal | 0.000 | 3.000 | 0.000 |
| 108 | [redact] | chronic | alpha | Lognormal | 0.000 | 3.000 | 0.000 |
| 109 | [redact] | chronic | alpha | Lognormal | 0.000 | 3.000 | 0.000 |
| 110 | [redact] | chronic | alpha | Lognormal | 0.000 | 3.000 | 0.000 |
| 111 | [redact] | chronic | alpha | Lognormal | 0.000 | 3.000 | 0.000 |
| 112 | [redact] | chronic | alpha | Lognormal | 0.000 | 3.000 | 0.000 |
| 113 | [redact] | chronic | alpha | Lognormal | 0.000 | 3.000 | 0.000 |
| 114 | [redact] | chronic | alpha | Lognormal | 0.000 | 3.000 | 0.000 |
| 115 | [redact] | chronic | alpha | Lognormal | 0.000 | 3.000 | 0.000 |
| 116 | [redact] | chronic | alpha | Lognormal | 0.000 | 3.000 | 0.000 |
| 117 | [redact] | chronic | alpha | Lognormal | 0.000 | 3.000 | 0.000 |
| 118 | [redact] | chronic | alpha | Lognormal | 0.000 | 3.000 | 0.000 |
| 119 | [redact] | chronic | alpha | Lognormal | 0.000 | 3.000 | 0.000 |
| 120 | [redact] | chronic | alpha | Lognormal | 0.000 | 3.000 | 0.000 |
| 121 | [redact] | chronic | alpha | Lognormal | 0.000 | 3.000 | 0.000 |
| 122 | [redact] | chronic | electrons E>15keV | Lognormal | 0.000 | 3.000 | 0.000 |
| 123 | [redact] | chronic | electrons E>15keV | Lognormal | 0.000 | 3.000 | 0.000 |
| 124 | [redact] | chronic | electrons E>15keV | Lognormal | 0.000 | 3.000 | 0.000 |
| 125 | [redact] | chronic | electrons E>15keV | Lognormal | 0.000 | 3.000 | 0.000 |
| 126 | [redact] | chronic | electrons E>15keV | Lognormal | 0.000 | 3.000 | 0.000 |
| 127 | [redact] | chronic | electrons E>15keV | Lognormal | 0.000 | 3.000 | 0.000 |
| 128 | [redact] | chronic | electrons E>15keV | Lognormal | 0.000 | 3.000 | 0.000 |
| 129 | [redact] | chronic | electrons E>15keV | Lognormal | 0.000 | 3.000 | 0.000 |
| 130 | [redact] | chronic | electrons E>15keV | Lognormal | 0.000 | 3.000 | 0.000 |
| 131 | [redact] | chronic | electrons E>15keV | Lognormal | 0.000 | 3.000 | 0.000 |
| 132 | [redact] | chronic | electrons E>15keV | Lognormal | 0.000 | 3.000 | 0.000 |
| 133 | [redact] | chronic | electrons E>15keV | Lognormal | 0.000 | 3.000 | 0.000 |
| 134 | [redact] | chronic | electrons E>15keV | Lognormal | 0.000 | 3.000 | 0.000 |

## Appendix I.A-1: IREP Input – SCC [Redacted] (continued)

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 135 | [redact] | chronic | electrons E>15keV | Lognormal | 0.000 | 3.000 | 0.000 |
| 136 | [redact] | chronic | electrons E>15keV | Lognormal | 0.000 | 3.000 | 0.000 |
| 137 | [redact] | chronic | electrons E>15keV | Lognormal | 0.000 | 3.000 | 0.000 |
| 138 | [redact] | chronic | electrons E>15keV | Lognormal | 0.000 | 3.000 | 0.000 |
| 139 | [redact] | chronic | electrons E>15keV | Lognormal | 0.000 | 3.000 | 0.000 |
| 140 | [redact] | chronic | electrons E>15keV | Lognormal | 0.000 | 3.000 | 0.000 |
| 141 | [redact] | chronic | electrons E>15keV | Lognormal | 0.000 | 3.000 | 0.000 |
| 142 | [redact] | chronic | electrons E>15keV | Lognormal | 0.000 | 3.000 | 0.000 |
| 143 | [redact] | chronic | electrons E>15keV | Lognormal | 0.000 | 3.000 | 0.000 |
| 144 | [redact] | chronic | electrons E>15keV | Lognormal | 0.000 | 3.000 | 0.000 |
| 145 | [redact] | chronic | electrons E>15keV | Lognormal | 0.000 | 3.000 | 0.000 |
| 146 | [redact] | chronic | electrons E>15keV | Lognormal | 0.000 | 3.000 | 0.000 |
| 147 | [redact] | chronic | electrons E>15keV | Lognormal | 0.000 | 3.000 | 0.000 |
| 148 | [redact] | chronic | electrons E>15keV | Lognormal | 0.000 | 3.000 | 0.000 |

# APPENDIX I.A-2: IREP INPUT – BCC [REDACTED]

| EXPOSURE INFORMATION | | | | | | | |
|---|---|---|---|---|---|---|---|
| Number of exposures<br>151 | | | | | | | |
| Exposure # | Exposure Year | Exposure Rate | Radiation Type | Dose Distribution Type | Parameter 1 | Parameter 2 | Parameter 3 |
| 1 | [redact] | acute | photons E<30keV | Constant | 0.023 | 0.000 | 0.000 |
| 2 | [redact] | acute | photons E<30keV | Constant | 0.041 | 0.000 | 0.000 |
| 3 | [redact] | acute | photons E<30keV | Constant | 0.018 | 0.000 | 0.000 |
| 4 | [redact] | acute | photons E<30keV | Constant | 0.017 | 0.000 | 0.000 |
| 5 | [redact] | acute | photons E<30keV | Constant | 0.052 | 0.000 | 0.000 |
| 6 | [redact] | acute | photons E<30keV | Constant | 0.021 | 0.000 | 0.000 |
| 7 | [redact] | acute | photons E<30keV | Constant | 0.003 | 0.000 | 0.000 |
| 8 | [redact] | acute | photons E<30keV | Constant | 0.004 | 0.000 | 0.000 |
| 9 | [redact] | acute | photons E<30keV | Constant | 0.005 | 0.000 | 0.000 |
| 10 | [redact] | acute | photons E<30keV | Constant | 0.002 | 0.000 | 0.000 |
| 11 | [redact] | acute | photons E<30keV | Constant | 0.002 | 0.000 | 0.000 |
| 12 | [redact] | acute | photons E<30keV | Constant | 0.002 | 0.000 | 0.000 |
| 13 | [redact] | acute | photons E=30-250keV | Constant | 0.058 | 0.000 | 0.000 |
| 14 | [redact] | acute | photons E=30-250keV | Constant | 0.105 | 0.000 | 0.000 |
| 15 | [redact] | acute | photons E=30-250keV | Constant | 0.047 | 0.000 | 0.000 |
| 16 | [redact] | acute | photons E=30-250keV | Constant | 0.044 | 0.000 | 0.000 |
| 17 | [redact] | acute | photons E=30-250keV | Constant | 0.133 | 0.000 | 0.000 |
| 18 | [redact] | acute | photons E=30-250keV | Constant | 0.054 | 0.000 | 0.000 |
| 19 | [redact] | acute | photons E=30-250keV | Constant | 0.007 | 0.000 | 0.000 |
| 20 | [redact] | acute | photons E=30-250keV | Constant | 0.009 | 0.000 | 0.000 |
| 21 | [redact] | acute | photons E=30-250keV | Constant | 0.012 | 0.000 | 0.000 |
| 22 | [redact] | acute | photons E=30-250keV | Constant | 0.004 | 0.000 | 0.000 |
| 23 | [redact] | acute | photons E=30-250keV | Constant | 0.004 | 0.000 | 0.000 |
| 24 | [redact] | acute | photons E=30-250keV | Constant | 0.005 | 0.000 | 0.000 |
| 25 | [redact] | acute | photons E>250keV | Constant | 0.086 | 0.000 | 0.000 |
| 26 | [redact] | acute | photons E>250keV | Constant | 0.156 | 0.000 | 0.000 |
| 27 | [redact] | acute | photons E>250keV | Constant | 0.076 | 0.000 | 0.000 |
| 28 | [redact] | acute | photons E>250keV | Constant | 0.072 | 0.000 | 0.000 |
| 29 | [redact] | acute | photons E>250keV | Constant | 0.217 | 0.000 | 0.000 |
| 30 | [redact] | acute | photons E>250keV | Constant | 0.089 | 0.000 | 0.000 |
| 31 | [redact] | acute | photons E>250keV | Constant | 0.011 | 0.000 | 0.000 |
| 32 | [redact] | acute | photons E>250keV | Constant | 0.015 | 0.000 | 0.000 |
| 33 | [redact] | acute | photons E>250keV | Constant | 0.020 | 0.000 | 0.000 |
| 34 | [redact] | acute | photons E>250keV | Constant | 0.006 | 0.000 | 0.000 |
| 35 | [redact] | acute | photons E>250keV | Constant | 0.006 | 0.000 | 0.000 |
| 36 | [redact] | acute | photons E>250keV | Constant | 0.009 | 0.000 | 0.000 |
| 37 | [redact] | acute | electrons E>15keV | Constant | 0.029 | 0.000 | 0.000 |
| 38 | [redact] | acute | electrons E>15keV | Constant | 2.722 | 0.000 | 0.000 |
| 39 | [redact] | acute | electrons E>15keV | Constant | 3.338 | 0.000 | 0.000 |
| 40 | [redact] | acute | electrons E>15keV | Constant | 1.898 | 0.000 | 0.000 |
| 41 | [redact] | acute | electrons E>15keV | Constant | 2.069 | 0.000 | 0.000 |

## Appendix I.A-2: IREP Input –BCC [Redacted] (continued)

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 42 | [redact] | acute | electrons E>15keV | Constant | 4.110 | 0.000 | 0.000 |
| 43 | [redact] | acute | electrons E>15keV | Constant | 0.731 | 0.000 | 0.000 |
| 44 | [redact] | acute | electrons E>15keV | Constant | 0.334 | 0.000 | 0.000 |
| 45 | [redact] | acute | electrons E>15keV | Constant | 0.001 | 0.000 | 0.000 |
| 46 | [redact] | acute | electrons E>15keV | Constant | 0.264 | 0.000 | 0.000 |
| 47 | [redact] | acute | electrons E>15keV | Constant | 0.063 | 0.000 | 0.000 |
| 48 | [redact] | acute | photons E=30-250keV | Lognormal | 0.180 | 1.520 | 0.000 |
| 49 | [redact] | acute | photons E=30-250keV | Lognormal | 0.090 | 1.520 | 0.000 |
| 50 | [redact] | acute | photons E=30-250keV | Lognormal | 0.030 | 1.520 | 0.000 |
| 51 | [redact] | acute | photons E=30-250keV | Lognormal | 0.020 | 1.520 | 0.000 |
| 52 | [redact] | acute | photons E=30-250keV | Lognormal | 0.050 | 1.520 | 0.000 |
| 53 | [redact] | acute | photons E=30-250keV | Lognormal | 0.100 | 1.520 | 0.000 |
| 54 | [redact] | acute | photons E=30-250keV | Lognormal | 0.120 | 1.520 | 0.000 |
| 55 | [redact] | acute | photons E=30-250keV | Lognormal | 0.140 | 1.520 | 0.000 |
| 56 | [redact] | acute | photons E=30-250keV | Lognormal | 0.120 | 1.520 | 0.000 |
| 57 | [redact] | acute | photons E=30-250keV | Lognormal | 0.010 | 1.520 | 0.000 |
| 58 | [redact] | acute | photons E=30-250keV | Lognormal | 0.030 | 1.520 | 0.000 |
| 59 | [redact] | acute | photons E=30-250keV | Lognormal | 0.050 | 1.520 | 0.000 |
| 60 | [redact] | acute | photons E=30-250keV | Lognormal | 0.040 | 1.520 | 0.000 |
| 61 | [redact] | acute | photons E=30-250keV | Normal | 0.003 | 0.001 | 0.000 |
| 62 | [redact] | acute | photons E=30-250keV | Normal | 0.004 | 0.001 | 0.000 |
| 63 | [redact] | acute | photons E=30-250keV | Normal | 0.008 | 0.002 | 0.000 |
| 64 | [redact] | acute | photons E=30-250keV | Normal | 0.004 | 0.001 | 0.000 |
| 65 | [redact] | acute | photons E=30-250keV | Normal | 0.008 | 0.002 | 0.000 |
| 66 | [redact] | acute | photons E=30-250keV | Normal | 0.004 | 0.001 | 0.000 |
| 67 | [redact] | acute | photons E=30-250keV | Normal | 0.018 | 0.005 | 0.000 |
| 68 | [redact] | chronic | alpha | Lognormal | 0.000 | 3.000 | 0.000 |
| 69 | [redact] | chronic | alpha | Lognormal | 0.000 | 3.000 | 0.000 |
| 70 | [redact] | chronic | alpha | Lognormal | 0.000 | 3.000 | 0.000 |
| 71 | [redact] | chronic | alpha | Lognormal | 0.001 | 3.000 | 0.000 |
| 72 | [redact] | chronic | alpha | Lognormal | 0.001 | 3.000 | 0.000 |
| 73 | [redact] | chronic | alpha | Lognormal | 0.001 | 3.000 | 0.000 |
| 74 | [redact] | chronic | alpha | Lognormal | 0.001 | 3.000 | 0.000 |
| 75 | [redact] | chronic | alpha | Lognormal | 0.001 | 3.000 | 0.000 |
| 76 | [redact] | chronic | alpha | Lognormal | 0.001 | 3.000 | 0.000 |
| 77 | [redact] | chronic | alpha | Lognormal | 0.001 | 3.000 | 0.000 |
| 78 | [redact] | chronic | alpha | Lognormal | 0.001 | 3.000 | 0.000 |
| 79 | [redact] | chronic | alpha | Lognormal | 0.001 | 3.000 | 0.000 |
| 80 | [redact] | chronic | alpha | Lognormal | 0.001 | 3.000 | 0.000 |
| 81 | [redact] | chronic | alpha | Lognormal | 0.001 | 3.000 | 0.000 |
| 82 | [redact] | chronic | alpha | Lognormal | 0.001 | 3.000 | 0.000 |
| 83 | [redact] | chronic | alpha | Lognormal | 0.001 | 3.000 | 0.000 |
| 84 | [redact] | chronic | alpha | Lognormal | 0.001 | 3.000 | 0.000 |
| 85 | [redact] | chronic | alpha | Lognormal | 0.001 | 3.000 | 0.000 |
| 86 | [redact] | chronic | alpha | Lognormal | 0.001 | 3.000 | 0.000 |
| 87 | [redact] | chronic | alpha | Lognormal | 0.001 | 3.000 | 0.000 |

## Appendix I.A-2: IREP Input –BCC [Redacted] (continued)

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 88 | [redact] | chronic | alpha | Lognormal | 0.001 | 3.000 | 0.000 |
| 89 | [redact] | chronic | alpha | Lognormal | 0.001 | 3.000 | 0.000 |
| 90 | [redact] | chronic | alpha | Lognormal | 0.001 | 3.000 | 0.000 |
| 91 | [redact] | chronic | alpha | Lognormal | 0.001 | 3.000 | 0.000 |
| 92 | [redact] | chronic | alpha | Lognormal | 0.001 | 3.000 | 0.000 |
| 93 | [redact] | chronic | alpha | Lognormal | 0.001 | 3.000 | 0.000 |
| 94 | [redact] | chronic | alpha | Lognormal | 0.001 | 3.000 | 0.000 |
| 95 | [redact] | chronic | alpha | Lognormal | 0.001 | 3.000 | 0.000 |
| 96 | [redact] | chronic | alpha | Lognormal | 0.000 | 3.000 | 0.000 |
| 97 | [redact] | chronic | alpha | Lognormal | 0.000 | 3.000 | 0.000 |
| 98 | [redact] | chronic | alpha | Lognormal | 0.000 | 3.000 | 0.000 |
| 99 | [redact] | chronic | alpha | Lognormal | 0.000 | 3.000 | 0.000 |
| 100 | [redact] | chronic | alpha | Lognormal | 0.000 | 3.000 | 0.000 |
| 101 | [redact] | chronic | alpha | Lognormal | 0.000 | 3.000 | 0.000 |
| 102 | [redact] | chronic | alpha | Lognormal | 0.000 | 3.000 | 0.000 |
| 103 | [redact] | chronic | alpha | Lognormal | 0.000 | 3.000 | 0.000 |
| 104 | [redact] | chronic | alpha | Lognormal | 0.000 | 3.000 | 0.000 |
| 105 | [redact] | chronic | alpha | Lognormal | 0.000 | 3.000 | 0.000 |
| 106 | [redact] | chronic | alpha | Lognormal | 0.000 | 3.000 | 0.000 |
| 107 | [redact] | chronic | alpha | Lognormal | 0.000 | 3.000 | 0.000 |
| 108 | [redact] | chronic | alpha | Lognormal | 0.000 | 3.000 | 0.000 |
| 109 | [redact] | chronic | alpha | Lognormal | 0.000 | 3.000 | 0.000 |
| 110 | [redact] | chronic | alpha | Lognormal | 0.000 | 3.000 | 0.000 |
| 111 | [redact] | chronic | alpha | Lognormal | 0.000 | 3.000 | 0.000 |
| 112 | [redact] | chronic | alpha | Lognormal | 0.000 | 3.000 | 0.000 |
| 113 | [redact] | chronic | alpha | Lognormal | 0.000 | 3.000 | 0.000 |
| 114 | [redact] | chronic | alpha | Lognormal | 0.000 | 3.000 | 0.000 |
| 115 | [redact] | chronic | alpha | Lognormal | 0.000 | 3.000 | 0.000 |
| 116 | [redact] | chronic | alpha | Lognormal | 0.000 | 3.000 | 0.000 |
| 117 | [redact] | chronic | alpha | Lognormal | 0.000 | 3.000 | 0.000 |
| 118 | [redact] | chronic | alpha | Lognormal | 0.000 | 3.000 | 0.000 |
| 119 | [redact] | chronic | alpha | Lognormal | 0.000 | 3.000 | 0.000 |
| 120 | [redact] | chronic | alpha | Lognormal | 0.000 | 3.000 | 0.000 |
| 121 | [redact] | chronic | alpha | Lognormal | 0.000 | 3.000 | 0.000 |
| 122 | [redact] | chronic | alpha | Lognormal | 0.000 | 3.000 | 0.000 |
| 123 | [redact] | chronic | alpha | Lognormal | 0.000 | 3.000 | 0.000 |
| 124 | [redact] | chronic | electrons E>15keV | Lognormal | 0.000 | 3.000 | 0.000 |
| 125 | [redact] | chronic | electrons E>15keV | Lognormal | 0.000 | 3.000 | 0.000 |
| 126 | [redact] | chronic | electrons E>15keV | Lognormal | 0.000 | 3.000 | 0.000 |
| 127 | [redact] | chronic | electrons E>15keV | Lognormal | 0.000 | 3.000 | 0.000 |
| 128 | [redact] | chronic | electrons E>15keV | Lognormal | 0.000 | 3.000 | 0.000 |
| 129 | [redact] | chronic | electrons E>15keV | Lognormal | 0.000 | 3.000 | 0.000 |
| 130 | [redact] | chronic | electrons E>15keV | Lognormal | 0.000 | 3.000 | 0.000 |
| 131 | [redact] | chronic | electrons E>15keV | Lognormal | 0.000 | 3.000 | 0.000 |
| 132 | [redact] | chronic | electrons E>15keV | Lognormal | 0.000 | 3.000 | 0.000 |
| 133 | [redact] | chronic | electrons E>15keV | Lognormal | 0.000 | 3.000 | 0.000 |

## Appendix I.A-2: IREP Input –BCC [Redacted] (continued)

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 134 | [redact] | chronic | electrons E>15keV | Lognormal | 0.000 | 3.000 | 0.000 |
| 135 | [redact] | chronic | electrons E>15keV | Lognormal | 0.000 | 3.000 | 0.000 |
| 136 | [redact] | chronic | electrons E>15keV | Lognormal | 0.000 | 3.000 | 0.000 |
| 137 | [redact] | chronic | electrons E>15keV | Lognormal | 0.000 | 3.000 | 0.000 |
| 138 | [redact] | chronic | electrons E>15keV | Lognormal | 0.000 | 3.000 | 0.000 |
| 139 | [redact] | chronic | electrons E>15keV | Lognormal | 0.000 | 3.000 | 0.000 |
| 140 | [redact] | chronic | electrons E>15keV | Lognormal | 0.000 | 3.000 | 0.000 |
| 141 | [redact] | chronic | electrons E>15keV | Lognormal | 0.000 | 3.000 | 0.000 |
| 142 | [redact] | chronic | electrons E>15keV | Lognormal | 0.000 | 3.000 | 0.000 |
| 143 | [redact] | chronic | electrons E>15keV | Lognormal | 0.000 | 3.000 | 0.000 |
| 144 | [redact] | chronic | electrons E>15keV | Lognormal | 0.000 | 3.000 | 0.000 |
| 145 | [redact] | chronic | electrons E>15keV | Lognormal | 0.000 | 3.000 | 0.000 |
| 146 | [redact] | chronic | electrons E>15keV | Lognormal | 0.000 | 3.000 | 0.000 |
| 147 | [redact] | chronic | electrons E>15keV | Lognormal | 0.000 | 3.000 | 0.000 |
| 148 | [redact] | chronic | electrons E>15keV | Lognormal | 0.000 | 3.000 | 0.000 |
| 149 | [redact] | chronic | electrons E>15keV | Lognormal | 0.000 | 3.000 | 0.000 |
| 150 | [redact] | chronic | electrons E>15keV | Lognormal | 0.000 | 3.000 | 0.000 |
| 151 | [redact] | chronic | electrons E>15keV | Lognormal | 0.000 | 3.000 | 0.000 |

# APPENDIX I.A-3: IREP INPUT – BCC [REDACTED]

| EXPOSURE INFORMATION | | | | | | | |
|---|---|---|---|---|---|---|---|
| Number of exposures<br>160 | | | | | | | |
| Exposure # | Exposure Year | Exposure Rate | Radiation Type | Dose Distribution Type | Parameter 1 | Parameter 2 | Parameter 3 |
| 1 | [redact] | acute | photons E<30keV | Constant | 0.023 | 0.000 | 0.000 |
| 2 | [redact] | acute | photons E<30keV | Constant | 0.041 | 0.000 | 0.000 |
| 3 | [redact] | acute | photons E<30keV | Constant | 0.018 | 0.000 | 0.000 |
| 4 | [redact] | acute | photons E<30keV | Constant | 0.017 | 0.000 | 0.000 |
| 5 | [redact] | acute | photons E<30keV | Constant | 0.052 | 0.000 | 0.000 |
| 6 | [redact] | acute | photons E<30keV | Constant | 0.021 | 0.000 | 0.000 |
| 7 | [redact] | acute | photons E<30keV | Constant | 0.003 | 0.000 | 0.000 |
| 8 | [redact] | acute | photons E<30keV | Constant | 0.004 | 0.000 | 0.000 |
| 9 | [redact] | acute | photons E<30keV | Constant | 0.005 | 0.000 | 0.000 |
| 10 | [redact] | acute | photons E<30keV | Constant | 0.002 | 0.000 | 0.000 |
| 11 | [redact] | acute | photons E<30keV | Constant | 0.002 | 0.000 | 0.000 |
| 12 | [redact] | acute | photons E<30keV | Constant | 0.002 | 0.000 | 0.000 |
| 13 | [redact] | acute | photons E=30-250keV | Constant | 0.058 | 0.000 | 0.000 |
| 14 | [redact] | acute | photons E=30-250keV | Constant | 0.105 | 0.000 | 0.000 |
| 15 | [redact] | acute | photons E=30-250keV | Constant | 0.047 | 0.000 | 0.000 |
| 16 | [redact] | acute | photons E=30-250keV | Constant | 0.044 | 0.000 | 0.000 |
| 17 | [redact] | acute | photons E=30-250keV | Constant | 0.133 | 0.000 | 0.000 |
| 18 | [redact] | acute | photons E=30-250keV | Constant | 0.054 | 0.000 | 0.000 |
| 19 | [redact] | acute | photons E=30-250keV | Constant | 0.007 | 0.000 | 0.000 |
| 20 | [redact] | acute | photons E=30-250keV | Constant | 0.009 | 0.000 | 0.000 |
| 21 | [redact] | acute | photons E=30-250keV | Constant | 0.012 | 0.000 | 0.000 |
| 22 | [redact] | acute | photons E=30-250keV | Constant | 0.004 | 0.000 | 0.000 |
| 23 | [redact] | acute | photons E=30-250keV | Constant | 0.004 | 0.000 | 0.000 |
| 24 | [redact] | acute | photons E=30-250keV | Constant | 0.005 | 0.000 | 0.000 |
| 25 | [redact] | acute | photons E>250keV | Constant | 0.086 | 0.000 | 0.000 |
| 26 | [redact] | acute | photons E>250keV | Constant | 0.156 | 0.000 | 0.000 |
| 27 | [redact] | acute | photons E>250keV | Constant | 0.076 | 0.000 | 0.000 |
| 28 | [redact] | acute | photons E>250keV | Constant | 0.072 | 0.000 | 0.000 |
| 29 | [redact] | acute | photons E>250keV | Constant | 0.217 | 0.000 | 0.000 |
| 30 | [redact] | acute | photons E>250keV | Constant | 0.089 | 0.000 | 0.000 |
| 31 | [redact] | acute | photons E>250keV | Constant | 0.011 | 0.000 | 0.000 |
| 32 | [redact] | acute | photons E>250keV | Constant | 0.015 | 0.000 | 0.000 |
| 33 | [redact] | acute | photons E>250keV | Constant | 0.020 | 0.000 | 0.000 |
| 34 | [redact] | acute | photons E>250keV | Constant | 0.006 | 0.000 | 0.000 |
| 35 | [redact] | acute | photons E>250keV | Constant | 0.006 | 0.000 | 0.000 |
| 36 | [redact] | acute | photons E>250keV | Constant | 0.009 | 0.000 | 0.000 |
| 37 | [redact] | acute | electrons E>15keV | Constant | 0.029 | 0.000 | 0.000 |
| 38 | [redact] | acute | electrons E>15keV | Constant | 2.722 | 0.000 | 0.000 |
| 39 | [redact] | acute | electrons E>15keV | Constant | 3.338 | 0.000 | 0.000 |
| 40 | [redact] | acute | electrons E>15keV | Constant | 1.898 | 0.000 | 0.000 |
| 41 | [redact] | acute | electrons E>15keV | Constant | 2.069 | 0.000 | 0.000 |

## Appendix I.A-3: IREP Input – BCC [Redacted] (continued)

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 42 | [redact] | acute | electrons E>15keV | Constant | 4.110 | 0.000 | 0.000 |
| 43 | [redact] | acute | electrons E>15keV | Constant | 0.731 | 0.000 | 0.000 |
| 44 | [redact] | acute | electrons E>15keV | Constant | 0.334 | 0.000 | 0.000 |
| 45 | [redact] | acute | electrons E>15keV | Constant | 0.001 | 0.000 | 0.000 |
| 46 | [redact] | acute | electrons E>15keV | Constant | 0.264 | 0.000 | 0.000 |
| 47 | [redact] | acute | electrons E>15keV | Constant | 0.063 | 0.000 | 0.000 |
| 48 | [redact] | acute | photons E=30-250keV | Lognormal | 0.180 | 1.520 | 0.000 |
| 49 | [redact] | acute | photons E=30-250keV | Lognormal | 0.090 | 1.520 | 0.000 |
| 50 | [redact] | acute | photons E=30-250keV | Lognormal | 0.030 | 1.520 | 0.000 |
| 51 | [redact] | acute | photons E=30-250keV | Lognormal | 0.020 | 1.520 | 0.000 |
| 52 | [redact] | acute | photons E=30-250keV | Lognormal | 0.050 | 1.520 | 0.000 |
| 53 | [redact] | acute | photons E=30-250keV | Lognormal | 0.100 | 1.520 | 0.000 |
| 54 | [redact] | acute | photons E=30-250keV | Lognormal | 0.120 | 1.520 | 0.000 |
| 55 | [redact] | acute | photons E=30-250keV | Lognormal | 0.140 | 1.520 | 0.000 |
| 56 | [redact] | acute | photons E=30-250keV | Lognormal | 0.120 | 1.520 | 0.000 |
| 57 | [redact] | acute | photons E=30-250keV | Lognormal | 0.010 | 1.520 | 0.000 |
| 58 | [redact] | acute | photons E=30-250keV | Lognormal | 0.030 | 1.520 | 0.000 |
| 59 | [redact] | acute | photons E=30-250keV | Lognormal | 0.050 | 1.520 | 0.000 |
| 60 | [redact] | acute | photons E=30-250keV | Lognormal | 0.040 | 1.520 | 0.000 |
| 61 | [redact] | acute | photons E=30-250keV | Normal | 0.003 | 0.001 | 0.000 |
| 62 | [redact] | acute | photons E=30-250keV | Normal | 0.004 | 0.001 | 0.000 |
| 63 | [redact] | acute | photons E=30-250keV | Normal | 0.004 | 0.001 | 0.000 |
| 64 | [redact] | acute | photons E=30-250keV | Normal | 0.004 | 0.001 | 0.000 |
| 65 | [redact] | acute | photons E=30-250keV | Normal | 0.004 | 0.001 | 0.000 |
| 66 | [redact] | acute | photons E=30-250keV | Normal | 0.004 | 0.001 | 0.000 |
| 67 | [redact] | acute | photons E=30-250keV | Normal | 0.018 | 0.005 | 0.000 |
| 68 | [redact] | chronic | alpha | Lognormal | 0.000 | 3.000 | 0.000 |
| 69 | [redact] | chronic | alpha | Lognormal | 0.000 | 3.000 | 0.000 |
| 70 | [redact] | chronic | alpha | Lognormal | 0.000 | 3.000 | 0.000 |
| 71 | [redact] | chronic | alpha | Lognormal | 0.001 | 3.000 | 0.000 |
| 72 | [redact] | chronic | alpha | Lognormal | 0.001 | 3.000 | 0.000 |
| 73 | [redact] | chronic | alpha | Lognormal | 0.001 | 3.000 | 0.000 |
| 74 | [redact] | chronic | alpha | Lognormal | 0.001 | 3.000 | 0.000 |
| 75 | [redact] | chronic | alpha | Lognormal | 0.001 | 3.000 | 0.000 |
| 76 | [redact] | chronic | alpha | Lognormal | 0.001 | 3.000 | 0.000 |
| 77 | [redact] | chronic | alpha | Lognormal | 0.001 | 3.000 | 0.000 |
| 78 | [redact] | chronic | alpha | Lognormal | 0.001 | 3.000 | 0.000 |
| 79 | [redact] | chronic | alpha | Lognormal | 0.001 | 3.000 | 0.000 |
| 80 | [redact] | chronic | alpha | Lognormal | 0.001 | 3.000 | 0.000 |
| 81 | [redact] | chronic | alpha | Lognormal | 0.001 | 3.000 | 0.000 |
| 82 | [redact] | chronic | alpha | Lognormal | 0.001 | 3.000 | 0.000 |
| 83 | [redact] | chronic | alpha | Lognormal | 0.001 | 3.000 | 0.000 |
| 84 | [redact] | chronic | alpha | Lognormal | 0.001 | 3.000 | 0.000 |
| 85 | [redact] | chronic | alpha | Lognormal | 0.001 | 3.000 | 0.000 |
| 86 | [redact] | chronic | alpha | Lognormal | 0.001 | 3.000 | 0.000 |
| 87 | [redact] | chronic | alpha | Lognormal | 0.001 | 3.000 | 0.000 |

## Appendix I.A-3: IREP Input – BCC [Redacted] (continued)

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 88 | [redact] | chronic | alpha | Lognormal | 0.001 | 3.000 | 0.000 |
| 89 | [redact] | chronic | alpha | Lognormal | 0.001 | 3.000 | 0.000 |
| 90 | [redact] | chronic | alpha | Lognormal | 0.001 | 3.000 | 0.000 |
| 91 | [redact] | chronic | alpha | Lognormal | 0.001 | 3.000 | 0.000 |
| 92 | [redact] | chronic | alpha | Lognormal | 0.001 | 3.000 | 0.000 |
| 93 | [redact] | chronic | alpha | Lognormal | 0.001 | 3.000 | 0.000 |
| 94 | [redact] | chronic | alpha | Lognormal | 0.001 | 3.000 | 0.000 |
| 95 | [redact] | chronic | alpha | Lognormal | 0.001 | 3.000 | 0.000 |
| 96 | [redact] | chronic | alpha | Lognormal | 0.001 | 3.000 | 0.000 |
| 97 | [redact] | chronic | alpha | Lognormal | 0.001 | 3.000 | 0.000 |
| 98 | [redact] | chronic | alpha | Lognormal | 0.000 | 3.000 | 0.000 |
| 99 | [redact] | chronic | alpha | Lognormal | 0.000 | 3.000 | 0.000 |
| 100 | [redact] | chronic | alpha | Lognormal | 0.000 | 3.000 | 0.000 |
| 101 | [redact] | chronic | alpha | Lognormal | 0.000 | 3.000 | 0.000 |
| 102 | [redact] | chronic | alpha | Lognormal | 0.000 | 3.000 | 0.000 |
| 103 | [redact] | chronic | alpha | Lognormal | 0.000 | 3.000 | 0.000 |
| 104 | [redact] | chronic | alpha | Lognormal | 0.000 | 3.000 | 0.000 |
| 105 | [redact] | chronic | alpha | Lognormal | 0.000 | 3.000 | 0.000 |
| 106 | [redact] | chronic | alpha | Lognormal | 0.000 | 3.000 | 0.000 |
| 107 | [redact] | chronic | alpha | Lognormal | 0.000 | 3.000 | 0.000 |
| 108 | [redact] | chronic | alpha | Lognormal | 0.000 | 3.000 | 0.000 |
| 109 | [redact] | chronic | alpha | Lognormal | 0.000 | 3.000 | 0.000 |
| 110 | [redact] | chronic | alpha | Lognormal | 0.000 | 3.000 | 0.000 |
| 111 | [redact] | chronic | alpha | Lognormal | 0.000 | 3.000 | 0.000 |
| 112 | [redact] | chronic | alpha | Lognormal | 0.000 | 3.000 | 0.000 |
| 113 | [redact] | chronic | alpha | Lognormal | 0.000 | 3.000 | 0.000 |
| 114 | [redact] | chronic | alpha | Lognormal | 0.000 | 3.000 | 0.000 |
| 115 | [redact] | chronic | alpha | Lognormal | 0.000 | 3.000 | 0.000 |
| 116 | [redact] | chronic | alpha | Lognormal | 0.000 | 3.000 | 0.000 |
| 117 | [redact] | chronic | alpha | Lognormal | 0.000 | 3.000 | 0.000 |
| 118 | [redact] | chronic | alpha | Lognormal | 0.000 | 3.000 | 0.000 |
| 119 | [redact] | chronic | alpha | Lognormal | 0.000 | 3.000 | 0.000 |
| 120 | [redact] | chronic | alpha | Lognormal | 0.000 | 3.000 | 0.000 |
| 121 | [redact] | chronic | alpha | Lognormal | 0.000 | 3.000 | 0.000 |
| 122 | [redact] | chronic | alpha | Lognormal | 0.000 | 3.000 | 0.000 |
| 123 | [redact] | chronic | alpha | Lognormal | 0.000 | 3.000 | 0.000 |
| 124 | [redact] | chronic | alpha | Lognormal | 0.000 | 3.000 | 0.000 |
| 125 | [redact] | chronic | alpha | Lognormal | 0.000 | 3.000 | 0.000 |
| 126 | [redact] | chronic | alpha | Lognormal | 0.000 | 3.000 | 0.000 |
| 127 | [redact] | chronic | alpha | Lognormal | 0.000 | 3.000 | 0.000 |
| 128 | [redact] | chronic | alpha | Lognormal | 0.000 | 3.000 | 0.000 |
| 129 | [redact] | chronic | alpha | Lognormal | 0.000 | 3.000 | 0.000 |
| 130 | [redact] | chronic | electrons E>15keV | Lognormal | 0.000 | 3.000 | 0.000 |
| 131 | [redact] | chronic | electrons E>15keV | Lognormal | 0.000 | 3.000 | 0.000 |
| 132 | [redact] | chronic | electrons E>15keV | Lognormal | 0.000 | 3.000 | 0.000 |
| 133 | [redact] | chronic | electrons E>15keV | Lognormal | 0.000 | 3.000 | 0.000 |

## Appendix I.A-3: IREP Input – BCC [Redacted] (continued)

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 134 | [redact] | chronic | electrons E>15keV | Lognormal | 0.000 | 3.000 | 0.000 |
| 135 | [redact] | chronic | electrons E>15keV | Lognormal | 0.000 | 3.000 | 0.000 |
| 136 | [redact] | chronic | electrons E>15keV | Lognormal | 0.000 | 3.000 | 0.000 |
| 137 | [redact] | chronic | electrons E>15keV | Lognormal | 0.000 | 3.000 | 0.000 |
| 138 | [redact] | chronic | electrons E>15keV | Lognormal | 0.000 | 3.000 | 0.000 |
| 139 | [redact] | chronic | electrons E>15keV | Lognormal | 0.000 | 3.000 | 0.000 |
| 140 | [redact] | chronic | electrons E>15keV | Lognormal | 0.000 | 3.000 | 0.000 |
| 141 | [redact] | chronic | electrons E>15keV | Lognormal | 0.000 | 3.000 | 0.000 |
| 142 | [redact] | chronic | electrons E>15keV | Lognormal | 0.000 | 3.000 | 0.000 |
| 143 | [redact] | chronic | electrons E>15keV | Lognormal | 0.000 | 3.000 | 0.000 |
| 144 | [redact] | chronic | electrons E>15keV | Lognormal | 0.000 | 3.000 | 0.000 |
| 145 | [redact] | chronic | electrons E>15keV | Lognormal | 0.000 | 3.000 | 0.000 |
| 146 | [redact] | chronic | electrons E>15keV | Lognormal | 0.000 | 3.000 | 0.000 |
| 147 | [redact] | chronic | electrons E>15keV | Lognormal | 0.000 | 3.000 | 0.000 |
| 148 | [redact] | chronic | electrons E>15keV | Lognormal | 0.000 | 3.000 | 0.000 |
| 149 | [redact] | chronic | electrons E>15keV | Lognormal | 0.000 | 3.000 | 0.000 |
| 150 | [redact] | chronic | electrons E>15keV | Lognormal | 0.000 | 3.000 | 0.000 |
| 151 | [redact] | chronic | electrons E>15keV | Lognormal | 0.000 | 3.000 | 0.000 |
| 152 | [redact] | chronic | electrons E>15keV | Lognormal | 0.000 | 3.000 | 0.000 |
| 153 | [redact] | chronic | electrons E>15keV | Lognormal | 0.000 | 3.000 | 0.000 |
| 154 | [redact] | chronic | electrons E>15keV | Lognormal | 0.000 | 3.000 | 0.000 |
| 155 | [redact] | chronic | electrons E>15keV | Lognormal | 0.000 | 3.000 | 0.000 |
| 156 | [redact] | chronic | electrons E>15keV | Lognormal | 0.000 | 3.000 | 0.000 |
| 157 | [redact] | chronic | electrons E>15keV | Lognormal | 0.000 | 3.000 | 0.000 |
| 158 | [redact] | chronic | electrons E>15keV | Lognormal | 0.000 | 3.000 | 0.000 |
| 159 | [redact] | chronic | electrons E>15keV | Lognormal | 0.000 | 3.000 | 0.000 |
| 160 | [redact] | chronic | electrons E>15keV | Lognormal | 0.000 | 3.000 | 0.000 |
| 161 | [redact] | chronic | electrons E<15keV | Lognormal | 2.000 | 2.000 | 0.000 |

# APPENDIX I.A-4: IREP INPUT – SCC [REDACTED]

| EXPOSURE INFORMATION | | | | | | | |
|---|---|---|---|---|---|---|---|
| Number of exposures<br>160 | | | | | | | |
| Exposure # | Exposure Year | Exposure Rate | Radiation Type | Dose Distribution Type | Parameter 1 | Parameter 2 | Parameter 3 |
| 1 | [redact] | acute | photons E<30keV | Constant | 0.023 | 0.000 | 0.000 |
| 2 | [redact] | acute | photons E<30keV | Constant | 0.041 | 0.000 | 0.000 |
| 3 | [redact] | acute | photons E<30keV | Constant | 0.018 | 0.000 | 0.000 |
| 4 | [redact] | acute | photons E<30keV | Constant | 0.017 | 0.000 | 0.000 |
| 5 | [redact] | acute | photons E<30keV | Constant | 0.052 | 0.000 | 0.000 |
| 6 | [redact] | acute | photons E<30keV | Constant | 0.021 | 0.000 | 0.000 |
| 7 | [redact] | acute | photons E<30keV | Constant | 0.003 | 0.000 | 0.000 |
| 8 | [redact] | acute | photons E<30keV | Constant | 0.004 | 0.000 | 0.000 |
| 9 | [redact] | acute | photons E<30keV | Constant | 0.005 | 0.000 | 0.000 |
| 10 | [redact] | acute | photons E<30keV | Constant | 0.002 | 0.000 | 0.000 |
| 11 | [redact] | acute | photons E<30keV | Constant | 0.002 | 0.000 | 0.000 |
| 12 | [redact] | acute | photons E<30keV | Constant | 0.002 | 0.000 | 0.000 |
| 13 | [redact] | acute | photons E=30-250keV | Constant | 0.058 | 0.000 | 0.000 |
| 14 | [redact] | acute | photons E=30-250keV | Constant | 0.105 | 0.000 | 0.000 |
| 15 | [redact] | acute | photons E=30-250keV | Constant | 0.047 | 0.000 | 0.000 |
| 16 | [redact] | acute | photons E=30-250keV | Constant | 0.044 | 0.000 | 0.000 |
| 17 | [redact] | acute | photons E=30-250keV | Constant | 0.133 | 0.000 | 0.000 |
| 18 | [redact] | acute | photons E=30-250keV | Constant | 0.054 | 0.000 | 0.000 |
| 19 | [redact] | acute | photons E=30-250keV | Constant | 0.007 | 0.000 | 0.000 |
| 20 | [redact] | acute | photons E=30-250keV | Constant | 0.009 | 0.000 | 0.000 |
| 21 | [redact] | acute | photons E=30-250keV | Constant | 0.012 | 0.000 | 0.000 |
| 22 | [redact] | acute | photons E=30-250keV | Constant | 0.004 | 0.000 | 0.000 |
| 23 | [redact] | acute | photons E=30-250keV | Constant | 0.004 | 0.000 | 0.000 |
| 24 | [redact] | acute | photons E=30-250keV | Constant | 0.005 | 0.000 | 0.000 |
| 25 | [redact] | acute | photons E>250keV | Constant | 0.086 | 0.000 | 0.000 |
| 26 | [redact] | acute | photons E>250keV | Constant | 0.156 | 0.000 | 0.000 |
| 27 | [redact] | acute | photons E>250keV | Constant | 0.076 | 0.000 | 0.000 |
| 28 | [redact] | acute | photons E>250keV | Constant | 0.072 | 0.000 | 0.000 |
| 29 | [redact] | acute | photons E>250keV | Constant | 0.217 | 0.000 | 0.000 |
| 30 | [redact] | acute | photons E>250keV | Constant | 0.089 | 0.000 | 0.000 |
| 31 | [redact] | acute | photons E>250keV | Constant | 0.011 | 0.000 | 0.000 |
| 32 | [redact] | acute | photons E>250keV | Constant | 0.015 | 0.000 | 0.000 |
| 33 | [redact] | acute | photons E>250keV | Constant | 0.020 | 0.000 | 0.000 |
| 34 | [redact] | acute | photons E>250keV | Constant | 0.006 | 0.000 | 0.000 |
| 35 | [redact] | acute | photons E>250keV | Constant | 0.006 | 0.000 | 0.000 |
| 36 | [redact] | acute | photons E>250keV | Constant | 0.009 | 0.000 | 0.000 |
| 37 | [redact] | acute | electrons E>15keV | Constant | 0.029 | 0.000 | 0.000 |
| 38 | [redact] | acute | electrons E>15keV | Constant | 2.722 | 0.000 | 0.000 |
| 39 | [redact] | acute | electrons E>15keV | Constant | 3.338 | 0.000 | 0.000 |
| 40 | [redact] | acute | electrons E>15keV | Constant | 1.898 | 0.000 | 0.000 |
| 41 | [redact] | acute | electrons E>15keV | Constant | 2.069 | 0.000 | 0.000 |

## Appendix I.A-4: IREP Input – SCC [Redacted] (continued)

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 42 | [redact] | acute | electrons E>15keV | Constant | 4.110 | 0.000 | 0.000 |
| 43 | [redact] | acute | electrons E>15keV | Constant | 0.731 | 0.000 | 0.000 |
| 44 | [redact] | acute | electrons E>15keV | Constant | 0.334 | 0.000 | 0.000 |
| 45 | [redact] | acute | electrons E>15keV | Constant | 0.001 | 0.000 | 0.000 |
| 46 | [redact] | acute | electrons E>15keV | Constant | 0.264 | 0.000 | 0.000 |
| 47 | [redact] | acute | electrons E>15keV | Constant | 0.063 | 0.000 | 0.000 |
| 48 | [redact] | acute | photons E=30-250keV | Lognormal | 0.180 | 1.520 | 0.000 |
| 49 | [redact] | acute | photons E=30-250keV | Lognormal | 0.090 | 1.520 | 0.000 |
| 50 | [redact] | acute | photons E=30-250keV | Lognormal | 0.030 | 1.520 | 0.000 |
| 51 | [redact] | acute | photons E=30-250keV | Lognormal | 0.020 | 1.520 | 0.000 |
| 52 | [redact] | acute | photons E=30-250keV | Lognormal | 0.050 | 1.520 | 0.000 |
| 53 | [redact] | acute | photons E=30-250keV | Lognormal | 0.100 | 1.520 | 0.000 |
| 54 | [redact] | acute | photons E=30-250keV | Lognormal | 0.120 | 1.520 | 0.000 |
| 55 | [redact] | acute | photons E=30-250keV | Lognormal | 0.140 | 1.520 | 0.000 |
| 56 | [redact] | acute | photons E=30-250keV | Lognormal | 0.120 | 1.520 | 0.000 |
| 57 | [redact] | acute | photons E=30-250keV | Lognormal | 0.010 | 1.520 | 0.000 |
| 58 | [redact] | acute | photons E=30-250keV | Lognormal | 0.030 | 1.520 | 0.000 |
| 59 | [redact] | acute | photons E=30-250keV | Lognormal | 0.050 | 1.520 | 0.000 |
| 60 | [redact] | acute | photons E=30-250keV | Lognormal | 0.040 | 1.520 | 0.000 |
| 61 | [redact] | acute | photons E=30-250keV | Normal | 0.014 | 0.004 | 0.000 |
| 62 | [redact] | acute | photons E=30-250keV | Normal | 0.007 | 0.002 | 0.000 |
| 63 | [redact] | acute | photons E=30-250keV | Normal | 0.014 | 0.004 | 0.000 |
| 64 | [redact] | acute | photons E=30-250keV | Normal | 0.007 | 0.002 | 0.000 |
| 65 | [redact] | acute | photons E=30-250keV | Normal | 0.014 | 0.004 | 0.000 |
| 66 | [redact] | acute | photons E=30-250keV | Normal | 0.007 | 0.002 | 0.000 |
| 67 | [redact] | acute | photons E=30-250keV | Normal | 0.018 | 0.005 | 0.000 |
| 68 | [redact] | chronic | alpha | Lognormal | 0.000 | 3.000 | 0.000 |
| 69 | [redact] | chronic | alpha | Lognormal | 0.000 | 3.000 | 0.000 |
| 70 | [redact] | chronic | alpha | Lognormal | 0.000 | 3.000 | 0.000 |
| 71 | [redact] | chronic | alpha | Lognormal | 0.001 | 3.000 | 0.000 |
| 72 | [redact] | chronic | alpha | Lognormal | 0.001 | 3.000 | 0.000 |
| 73 | [redact] | chronic | alpha | Lognormal | 0.001 | 3.000 | 0.000 |
| 74 | [redact] | chronic | alpha | Lognormal | 0.001 | 3.000 | 0.000 |
| 75 | [redact] | chronic | alpha | Lognormal | 0.001 | 3.000 | 0.000 |
| 76 | [redact] | chronic | alpha | Lognormal | 0.001 | 3.000 | 0.000 |
| 77 | [redact] | chronic | alpha | Lognormal | 0.001 | 3.000 | 0.000 |
| 78 | [redact] | chronic | alpha | Lognormal | 0.001 | 3.000 | 0.000 |
| 79 | [redact] | chronic | alpha | Lognormal | 0.001 | 3.000 | 0.000 |
| 80 | [redact] | chronic | alpha | Lognormal | 0.001 | 3.000 | 0.000 |
| 81 | [redact] | chronic | alpha | Lognormal | 0.001 | 3.000 | 0.000 |
| 82 | [redact] | chronic | alpha | Lognormal | 0.001 | 3.000 | 0.000 |
| 83 | [redact] | chronic | alpha | Lognormal | 0.001 | 3.000 | 0.000 |
| 84 | [redact] | chronic | alpha | Lognormal | 0.001 | 3.000 | 0.000 |
| 85 | [redact] | chronic | alpha | Lognormal | 0.001 | 3.000 | 0.000 |
| 86 | [redact] | chronic | alpha | Lognormal | 0.001 | 3.000 | 0.000 |
| 87 | [redact] | chronic | alpha | Lognormal | 0.001 | 3.000 | 0.000 |

## Appendix I.A-4: IREP Input – SCC [Redacted] (continued)

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 88 | [redact] | chronic | alpha | Lognormal | 0.001 | 3.000 | 0.000 |
| 89 | [redact] | chronic | alpha | Lognormal | 0.001 | 3.000 | 0.000 |
| 90 | [redact] | chronic | alpha | Lognormal | 0.001 | 3.000 | 0.000 |
| 91 | [redact] | chronic | alpha | Lognormal | 0.001 | 3.000 | 0.000 |
| 92 | [redact] | chronic | alpha | Lognormal | 0.001 | 3.000 | 0.000 |
| 93 | [redact] | chronic | alpha | Lognormal | 0.001 | 3.000 | 0.000 |
| 94 | [redact] | chronic | alpha | Lognormal | 0.001 | 3.000 | 0.000 |
| 95 | [redact] | chronic | alpha | Lognormal | 0.001 | 3.000 | 0.000 |
| 96 | [redact] | chronic | alpha | Lognormal | 0.001 | 3.000 | 0.000 |
| 97 | [redact] | chronic | alpha | Lognormal | 0.001 | 3.000 | 0.000 |
| 98 | [redact] | chronic | alpha | Lognormal | 0.000 | 3.000 | 0.000 |
| 99 | [redact] | chronic | alpha | Lognormal | 0.000 | 3.000 | 0.000 |
| 100 | [redact] | chronic | alpha | Lognormal | 0.000 | 3.000 | 0.000 |
| 101 | [redact] | chronic | alpha | Lognormal | 0.000 | 3.000 | 0.000 |
| 102 | [redact] | chronic | alpha | Lognormal | 0.000 | 3.000 | 0.000 |
| 103 | [redact] | chronic | alpha | Lognormal | 0.000 | 3.000 | 0.000 |
| 104 | [redact] | chronic | alpha | Lognormal | 0.000 | 3.000 | 0.000 |
| 105 | [redact] | chronic | alpha | Lognormal | 0.000 | 3.000 | 0.000 |
| 106 | [redact] | chronic | alpha | Lognormal | 0.000 | 3.000 | 0.000 |
| 107 | [redact] | chronic | alpha | Lognormal | 0.000 | 3.000 | 0.000 |
| 108 | [redact] | chronic | alpha | Lognormal | 0.000 | 3.000 | 0.000 |
| 109 | [redact] | chronic | alpha | Lognormal | 0.000 | 3.000 | 0.000 |
| 110 | [redact] | chronic | alpha | Lognormal | 0.000 | 3.000 | 0.000 |
| 111 | [redact] | chronic | alpha | Lognormal | 0.000 | 3.000 | 0.000 |
| 112 | [redact] | chronic | alpha | Lognormal | 0.000 | 3.000 | 0.000 |
| 113 | [redact] | chronic | alpha | Lognormal | 0.000 | 3.000 | 0.000 |
| 114 | [redact] | chronic | alpha | Lognormal | 0.000 | 3.000 | 0.000 |
| 115 | [redact] | chronic | alpha | Lognormal | 0.000 | 3.000 | 0.000 |
| 116 | [redact] | chronic | alpha | Lognormal | 0.000 | 3.000 | 0.000 |
| 117 | [redact] | chronic | alpha | Lognormal | 0.000 | 3.000 | 0.000 |
| 118 | [redact] | chronic | alpha | Lognormal | 0.000 | 3.000 | 0.000 |
| 119 | [redact] | chronic | alpha | Lognormal | 0.000 | 3.000 | 0.000 |
| 120 | [redact] | chronic | alpha | Lognormal | 0.000 | 3.000 | 0.000 |
| 121 | [redact] | chronic | alpha | Lognormal | 0.000 | 3.000 | 0.000 |
| 122 | [redact] | chronic | alpha | Lognormal | 0.000 | 3.000 | 0.000 |
| 123 | [redact] | chronic | alpha | Lognormal | 0.000 | 3.000 | 0.000 |
| 124 | [redact] | chronic | alpha | Lognormal | 0.000 | 3.000 | 0.000 |
| 125 | [redact] | chronic | alpha | Lognormal | 0.000 | 3.000 | 0.000 |
| 126 | [redact] | chronic | alpha | Lognormal | 0.000 | 3.000 | 0.000 |
| 127 | [redact] | chronic | alpha | Lognormal | 0.000 | 3.000 | 0.000 |
| 128 | [redact] | chronic | alpha | Lognormal | 0.000 | 3.000 | 0.000 |
| 129 | [redact] | chronic | alpha | Lognormal | 0.000 | 3.000 | 0.000 |
| 130 | [redact] | chronic | electrons E>15keV | Lognormal | 0.000 | 3.000 | 0.000 |
| 131 | [redact] | chronic | electrons E>15keV | Lognormal | 0.000 | 3.000 | 0.000 |
| 132 | [redact] | chronic | electrons E>15keV | Lognormal | 0.000 | 3.000 | 0.000 |
| 133 | [redact] | chronic | electrons E>15keV | Lognormal | 0.000 | 3.000 | 0.000 |

## Appendix I.A-4: IREP Input – SCC [Redacted] (continued)

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 134 | [redact] | chronic | electrons E>15keV | Lognormal | 0.000 | 3.000 | 0.000 |
| 135 | [redact] | chronic | electrons E>15keV | Lognormal | 0.000 | 3.000 | 0.000 |
| 136 | [redact] | chronic | electrons E>15keV | Lognormal | 0.000 | 3.000 | 0.000 |
| 137 | [redact] | chronic | electrons E>15keV | Lognormal | 0.000 | 3.000 | 0.000 |
| 138 | [redact] | chronic | electrons E>15keV | Lognormal | 0.000 | 3.000 | 0.000 |
| 139 | [redact] | chronic | electrons E>15keV | Lognormal | 0.000 | 3.000 | 0.000 |
| 140 | [redact] | chronic | electrons E>15keV | Lognormal | 0.000 | 3.000 | 0.000 |
| 141 | [redact] | chronic | electrons E>15keV | Lognormal | 0.000 | 3.000 | 0.000 |
| 142 | [redact] | chronic | electrons E>15keV | Lognormal | 0.000 | 3.000 | 0.000 |
| 143 | [redact] | chronic | electrons E>15keV | Lognormal | 0.000 | 3.000 | 0.000 |
| 144 | [redact] | chronic | electrons E>15keV | Lognormal | 0.000 | 3.000 | 0.000 |
| 145 | [redact] | chronic | electrons E>15keV | Lognormal | 0.000 | 3.000 | 0.000 |
| 146 | [redact] | chronic | electrons E>15keV | Lognormal | 0.000 | 3.000 | 0.000 |
| 147 | [redact] | chronic | electrons E>15keV | Lognormal | 0.000 | 3.000 | 0.000 |
| 148 | [redact] | chronic | electrons E>15keV | Lognormal | 0.000 | 3.000 | 0.000 |
| 149 | [redact] | chronic | electrons E>15keV | Lognormal | 0.000 | 3.000 | 0.000 |
| 150 | [redact] | chronic | electrons E>15keV | Lognormal | 0.000 | 3.000 | 0.000 |
| 151 | [redact] | chronic | electrons E>15keV | Lognormal | 0.000 | 3.000 | 0.000 |
| 152 | [redact] | chronic | electrons E>15keV | Lognormal | 0.000 | 3.000 | 0.000 |
| 153 | [redact] | chronic | electrons E>15keV | Lognormal | 0.000 | 3.000 | 0.000 |
| 154 | [redact] | chronic | electrons E>15keV | Lognormal | 0.000 | 3.000 | 0.000 |
| 155 | [redact] | chronic | electrons E>15keV | Lognormal | 0.000 | 3.000 | 0.000 |
| 156 | [redact] | chronic | electrons E>15keV | Lognormal | 0.000 | 3.000 | 0.000 |
| 157 | [redact] | chronic | electrons E>15keV | Lognormal | 0.000 | 3.000 | 0.000 |
| 158 | [redact] | chronic | electrons E>15keV | Lognormal | 0.000 | 3.000 | 0.000 |
| 159 | [redact] | chronic | electrons E>15keV | Lognormal | 0.000 | 3.000 | 0.000 |
| 160 | [redact] | chronic | electrons E>15keV | Lognormal | 0.000 | 3.000 | 0.000 |

# APPENDIX I.A-5: IREP INPUT – SCC [REDACTED]

| EXPOSURE INFORMATION | | | | | | | |
|---|---|---|---|---|---|---|---|
| Number of exposures<br>160 | | | | | | | |
| Exposure # | Exposure Year | Exposure Rate | Radiation Type | Dose Distribution Type | Parameter 1 | Parameter 2 | Parameter 3 |
| 1 | [redact] | acute | photons E<30keV | Constant | 0.023 | 0.000 | 0.000 |
| 2 | [redact] | acute | photons E<30keV | Constant | 0.041 | 0.000 | 0.000 |
| 3 | [redact] | acute | photons E<30keV | Constant | 0.018 | 0.000 | 0.000 |
| 4 | [redact] | acute | photons E<30keV | Constant | 0.017 | 0.000 | 0.000 |
| 5 | [redact] | acute | photons E<30keV | Constant | 0.052 | 0.000 | 0.000 |
| 6 | [redact] | acute | photons E<30keV | Constant | 0.021 | 0.000 | 0.000 |
| 7 | [redact] | acute | photons E<30keV | Constant | 0.003 | 0.000 | 0.000 |
| 8 | [redact] | acute | photons E<30keV | Constant | 0.004 | 0.000 | 0.000 |
| 9 | [redact] | acute | photons E<30keV | Constant | 0.005 | 0.000 | 0.000 |
| 10 | [redact] | acute | photons E<30keV | Constant | 0.002 | 0.000 | 0.000 |
| 11 | [redact] | acute | photons E<30keV | Constant | 0.002 | 0.000 | 0.000 |
| 12 | [redact] | acute | photons E<30keV | Constant | 0.002 | 0.000 | 0.000 |
| 13 | [redact] | acute | photons E=30-250keV | Constant | 0.058 | 0.000 | 0.000 |
| 14 | [redact] | acute | photons E=30-250keV | Constant | 0.105 | 0.000 | 0.000 |
| 15 | [redact] | acute | photons E=30-250keV | Constant | 0.047 | 0.000 | 0.000 |
| 16 | [redact] | acute | photons E=30-250keV | Constant | 0.044 | 0.000 | 0.000 |
| 17 | [redact] | acute | photons E=30-250keV | Constant | 0.133 | 0.000 | 0.000 |
| 18 | [redact] | acute | photons E=30-250keV | Constant | 0.054 | 0.000 | 0.000 |
| 19 | [redact] | acute | photons E=30-250keV | Constant | 0.007 | 0.000 | 0.000 |
| 20 | [redact] | acute | photons E=30-250keV | Constant | 0.009 | 0.000 | 0.000 |
| 21 | [redact] | acute | photons E=30-250keV | Constant | 0.012 | 0.000 | 0.000 |
| 22 | [redact] | acute | photons E=30-250keV | Constant | 0.004 | 0.000 | 0.000 |
| 23 | [redact] | acute | photons E=30-250keV | Constant | 0.004 | 0.000 | 0.000 |
| 24 | [redact] | acute | photons E=30-250keV | Constant | 0.005 | 0.000 | 0.000 |
| 25 | [redact] | acute | photons E>250keV | Constant | 0.086 | 0.000 | 0.000 |
| 26 | [redact] | acute | photons E>250keV | Constant | 0.156 | 0.000 | 0.000 |
| 27 | [redact] | acute | photons E>250keV | Constant | 0.076 | 0.000 | 0.000 |
| 28 | [redact] | acute | photons E>250keV | Constant | 0.072 | 0.000 | 0.000 |
| 29 | [redact] | acute | photons E>250keV | Constant | 0.217 | 0.000 | 0.000 |
| 30 | [redact] | acute | photons E>250keV | Constant | 0.089 | 0.000 | 0.000 |
| 31 | [redact] | acute | photons E>250keV | Constant | 0.011 | 0.000 | 0.000 |
| 32 | [redact] | acute | photons E>250keV | Constant | 0.015 | 0.000 | 0.000 |
| 33 | [redact] | acute | photons E>250keV | Constant | 0.020 | 0.000 | 0.000 |
| 34 | [redact] | acute | photons E>250keV | Constant | 0.006 | 0.000 | 0.000 |
| 35 | [redact] | acute | photons E>250keV | Constant | 0.006 | 0.000 | 0.000 |
| 36 | [redact] | acute | photons E>250keV | Constant | 0.009 | 0.000 | 0.000 |
| 37 | [redact] | acute | electrons E>15keV | Constant | 0.029 | 0.000 | 0.000 |
| 38 | [redact] | acute | electrons E>15keV | Constant | 2.722 | 0.000 | 0.000 |
| 39 | [redact] | acute | electrons E>15keV | Constant | 3.338 | 0.000 | 0.000 |
| 40 | [redact] | acute | electrons E>15keV | Constant | 1.898 | 0.000 | 0.000 |
| 41 | [redact] | acute | electrons E>15keV | Constant | 2.069 | 0.000 | 0.000 |

## Appendix I.A-5: IREP Input – SCC [Redacted] (continued)

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 42 | [redact] | acute | electrons E>15keV | Constant | 4.110 | 0.000 | 0.000 |
| 43 | [redact] | acute | electrons E>15keV | Constant | 0.731 | 0.000 | 0.000 |
| 44 | [redact] | acute | electrons E>15keV | Constant | 0.334 | 0.000 | 0.000 |
| 45 | [redact] | acute | electrons E>15keV | Constant | 0.001 | 0.000 | 0.000 |
| 46 | [redact] | acute | electrons E>15keV | Constant | 0.264 | 0.000 | 0.000 |
| 47 | [redact] | acute | electrons E>15keV | Constant | 0.063 | 0.000 | 0.000 |
| 48 | [redact] | acute | photons E=30-250keV | Lognormal | 0.180 | 1.520 | 0.000 |
| 49 | [redact] | acute | photons E=30-250keV | Lognormal | 0.090 | 1.520 | 0.000 |
| 50 | [redact] | acute | photons E=30-250keV | Lognormal | 0.030 | 1.520 | 0.000 |
| 51 | [redact] | acute | photons E=30-250keV | Lognormal | 0.020 | 1.520 | 0.000 |
| 52 | [redact] | acute | photons E=30-250keV | Lognormal | 0.050 | 1.520 | 0.000 |
| 53 | [redact] | acute | photons E=30-250keV | Lognormal | 0.100 | 1.520 | 0.000 |
| 54 | [redact] | acute | photons E=30-250keV | Lognormal | 0.120 | 1.520 | 0.000 |
| 55 | [redact] | acute | photons E=30-250keV | Lognormal | 0.140 | 1.520 | 0.000 |
| 56 | [redact] | acute | photons E=30-250keV | Lognormal | 0.120 | 1.520 | 0.000 |
| 57 | [redact] | acute | photons E=30-250keV | Lognormal | 0.010 | 1.520 | 0.000 |
| 58 | [redact] | acute | photons E=30-250keV | Lognormal | 0.030 | 1.520 | 0.000 |
| 59 | [redact] | acute | photons E=30-250keV | Lognormal | 0.050 | 1.520 | 0.000 |
| 60 | [redact] | acute | photons E=30-250keV | Lognormal | 0.040 | 1.520 | 0.000 |
| 61 | [redact] | acute | photons E=30-250keV | Normal | 0.014 | 0.004 | 0.000 |
| 62 | [redact] | acute | photons E=30-250keV | Normal | 0.007 | 0.002 | 0.000 |
| 63 | [redact] | acute | photons E=30-250keV | Normal | 0.014 | 0.004 | 0.000 |
| 64 | [redact] | acute | photons E=30-250keV | Normal | 0.007 | 0.002 | 0.000 |
| 65 | [redact] | acute | photons E=30-250keV | Normal | 0.014 | 0.004 | 0.000 |
| 66 | [redact] | acute | photons E=30-250keV | Normal | 0.007 | 0.002 | 0.000 |
| 67 | [redact] | acute | photons E=30-250keV | Normal | 0.018 | 0.005 | 0.000 |
| 68 | [redact] | chronic | alpha | Lognormal | 0.000 | 3.000 | 0.000 |
| 69 | [redact] | chronic | alpha | Lognormal | 0.000 | 3.000 | 0.000 |
| 70 | [redact] | chronic | alpha | Lognormal | 0.000 | 3.000 | 0.000 |
| 71 | [redact] | chronic | alpha | Lognormal | 0.001 | 3.000 | 0.000 |
| 72 | [redact] | chronic | alpha | Lognormal | 0.001 | 3.000 | 0.000 |
| 73 | [redact] | chronic | alpha | Lognormal | 0.001 | 3.000 | 0.000 |
| 74 | [redact] | chronic | alpha | Lognormal | 0.001 | 3.000 | 0.000 |
| 75 | [redact] | chronic | alpha | Lognormal | 0.001 | 3.000 | 0.000 |
| 76 | [redact] | chronic | alpha | Lognormal | 0.001 | 3.000 | 0.000 |
| 77 | [redact] | chronic | alpha | Lognormal | 0.001 | 3.000 | 0.000 |
| 78 | [redact] | chronic | alpha | Lognormal | 0.001 | 3.000 | 0.000 |
| 79 | [redact] | chronic | alpha | Lognormal | 0.001 | 3.000 | 0.000 |
| 80 | [redact] | chronic | alpha | Lognormal | 0.001 | 3.000 | 0.000 |
| 81 | [redact] | chronic | alpha | Lognormal | 0.001 | 3.000 | 0.000 |
| 82 | [redact] | chronic | alpha | Lognormal | 0.001 | 3.000 | 0.000 |
| 83 | [redact] | chronic | alpha | Lognormal | 0.001 | 3.000 | 0.000 |
| 84 | [redact] | chronic | alpha | Lognormal | 0.001 | 3.000 | 0.000 |
| 85 | [redact] | chronic | alpha | Lognormal | 0.001 | 3.000 | 0.000 |
| 86 | [redact] | chronic | alpha | Lognormal | 0.001 | 3.000 | 0.000 |
| 87 | [redact] | chronic | alpha | Lognormal | 0.001 | 3.000 | 0.000 |

## Appendix I.A-5: IREP Input – SCC [Redacted] (continued)

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 88 | [redact] | chronic | alpha | Lognormal | 0.001 | 3.000 | 0.000 |
| 89 | [redact] | chronic | alpha | Lognormal | 0.001 | 3.000 | 0.000 |
| 90 | [redact] | chronic | alpha | Lognormal | 0.001 | 3.000 | 0.000 |
| 91 | [redact] | chronic | alpha | Lognormal | 0.001 | 3.000 | 0.000 |
| 92 | [redact] | chronic | alpha | Lognormal | 0.001 | 3.000 | 0.000 |
| 93 | [redact] | chronic | alpha | Lognormal | 0.001 | 3.000 | 0.000 |
| 94 | [redact] | chronic | alpha | Lognormal | 0.001 | 3.000 | 0.000 |
| 95 | [redact] | chronic | alpha | Lognormal | 0.001 | 3.000 | 0.000 |
| 96 | [redact] | chronic | alpha | Lognormal | 0.001 | 3.000 | 0.000 |
| 97 | [redact] | chronic | alpha | Lognormal | 0.001 | 3.000 | 0.000 |
| 98 | [redact] | chronic | alpha | Lognormal | 0.000 | 3.000 | 0.000 |
| 99 | [redact] | chronic | alpha | Lognormal | 0.000 | 3.000 | 0.000 |
| 100 | [redact] | chronic | alpha | Lognormal | 0.000 | 3.000 | 0.000 |
| 101 | [redact] | chronic | alpha | Lognormal | 0.000 | 3.000 | 0.000 |
| 102 | [redact] | chronic | alpha | Lognormal | 0.000 | 3.000 | 0.000 |
| 103 | [redact] | chronic | alpha | Lognormal | 0.000 | 3.000 | 0.000 |
| 104 | [redact] | chronic | alpha | Lognormal | 0.000 | 3.000 | 0.000 |
| 105 | [redact] | chronic | alpha | Lognormal | 0.000 | 3.000 | 0.000 |
| 106 | [redact] | chronic | alpha | Lognormal | 0.000 | 3.000 | 0.000 |
| 107 | [redact] | chronic | alpha | Lognormal | 0.000 | 3.000 | 0.000 |
| 108 | [redact] | chronic | alpha | Lognormal | 0.000 | 3.000 | 0.000 |
| 109 | [redact] | chronic | alpha | Lognormal | 0.000 | 3.000 | 0.000 |
| 110 | [redact] | chronic | alpha | Lognormal | 0.000 | 3.000 | 0.000 |
| 111 | [redact] | chronic | alpha | Lognormal | 0.000 | 3.000 | 0.000 |
| 112 | [redact] | chronic | alpha | Lognormal | 0.000 | 3.000 | 0.000 |
| 113 | [redact] | chronic | alpha | Lognormal | 0.000 | 3.000 | 0.000 |
| 114 | [redact] | chronic | alpha | Lognormal | 0.000 | 3.000 | 0.000 |
| 115 | [redact] | chronic | alpha | Lognormal | 0.000 | 3.000 | 0.000 |
| 116 | [redact] | chronic | alpha | Lognormal | 0.000 | 3.000 | 0.000 |
| 117 | [redact] | chronic | alpha | Lognormal | 0.000 | 3.000 | 0.000 |
| 118 | [redact] | chronic | alpha | Lognormal | 0.000 | 3.000 | 0.000 |
| 119 | [redact] | chronic | alpha | Lognormal | 0.000 | 3.000 | 0.000 |
| 120 | [redact] | chronic | alpha | Lognormal | 0.000 | 3.000 | 0.000 |
| 121 | [redact] | chronic | alpha | Lognormal | 0.000 | 3.000 | 0.000 |
| 122 | [redact] | chronic | alpha | Lognormal | 0.000 | 3.000 | 0.000 |
| 123 | [redact] | chronic | alpha | Lognormal | 0.000 | 3.000 | 0.000 |
| 124 | [redact] | chronic | alpha | Lognormal | 0.000 | 3.000 | 0.000 |
| 125 | [redact] | chronic | alpha | Lognormal | 0.000 | 3.000 | 0.000 |
| 126 | [redact] | chronic | alpha | Lognormal | 0.000 | 3.000 | 0.000 |
| 127 | [redact] | chronic | alpha | Lognormal | 0.000 | 3.000 | 0.000 |
| 128 | [redact] | chronic | alpha | Lognormal | 0.000 | 3.000 | 0.000 |
| 129 | [redact] | chronic | alpha | Lognormal | 0.000 | 3.000 | 0.000 |
| 130 | [redact] | chronic | electrons E>15keV | Lognormal | 0.000 | 3.000 | 0.000 |
| 131 | [redact] | chronic | electrons E>15keV | Lognormal | 0.000 | 3.000 | 0.000 |
| 132 | [redact] | chronic | electrons E>15keV | Lognormal | 0.000 | 3.000 | 0.000 |
| 133 | [redact] | chronic | electrons E>15keV | Lognormal | 0.000 | 3.000 | 0.000 |

## Appendix I.A-5: IREP Input – SCC [Redacted] (continued)

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 134 | [redact] | chronic | electrons E>15keV | Lognormal | 0.000 | 3.000 | 0.000 |
| 135 | [redact] | chronic | electrons E>15keV | Lognormal | 0.000 | 3.000 | 0.000 |
| 136 | [redact] | chronic | electrons E>15keV | Lognormal | 0.000 | 3.000 | 0.000 |
| 137 | [redact] | chronic | electrons E>15keV | Lognormal | 0.000 | 3.000 | 0.000 |
| 138 | [redact] | chronic | electrons E>15keV | Lognormal | 0.000 | 3.000 | 0.000 |
| 139 | [redact] | chronic | electrons E>15keV | Lognormal | 0.000 | 3.000 | 0.000 |
| 140 | [redact] | chronic | electrons E>15keV | Lognormal | 0.000 | 3.000 | 0.000 |
| 141 | [redact] | chronic | electrons E>15keV | Lognormal | 0.000 | 3.000 | 0.000 |
| 142 | [redact] | chronic | electrons E>15keV | Lognormal | 0.000 | 3.000 | 0.000 |
| 143 | [redact] | chronic | electrons E>15keV | Lognormal | 0.000 | 3.000 | 0.000 |
| 144 | [redact] | chronic | electrons E>15keV | Lognormal | 0.000 | 3.000 | 0.000 |
| 145 | [redact] | chronic | electrons E>15keV | Lognormal | 0.000 | 3.000 | 0.000 |
| 146 | [redact] | chronic | electrons E>15keV | Lognormal | 0.000 | 3.000 | 0.000 |
| 147 | [redact] | chronic | electrons E>15keV | Lognormal | 0.000 | 3.000 | 0.000 |
| 148 | [redact] | chronic | electrons E>15keV | Lognormal | 0.000 | 3.000 | 0.000 |
| 149 | [redact] | chronic | electrons E>15keV | Lognormal | 0.000 | 3.000 | 0.000 |
| 150 | [redact] | chronic | electrons E>15keV | Lognormal | 0.000 | 3.000 | 0.000 |
| 151 | [redact] | chronic | electrons E>15keV | Lognormal | 0.000 | 3.000 | 0.000 |
| 152 | [redact] | chronic | electrons E>15keV | Lognormal | 0.000 | 3.000 | 0.000 |
| 153 | [redact] | chronic | electrons E>15keV | Lognormal | 0.000 | 3.000 | 0.000 |
| 154 | [redact] | chronic | electrons E>15keV | Lognormal | 0.000 | 3.000 | 0.000 |
| 155 | [redact] | chronic | electrons E>15keV | Lognormal | 0.000 | 3.000 | 0.000 |
| 156 | [redact] | chronic | electrons E>15keV | Lognormal | 0.000 | 3.000 | 0.000 |
| 157 | [redact] | chronic | electrons E>15keV | Lognormal | 0.000 | 3.000 | 0.000 |
| 158 | [redact] | chronic | electrons E>15keV | Lognormal | 0.000 | 3.000 | 0.000 |
| 159 | [redact] | chronic | electrons E>15keV | Lognormal | 0.000 | 3.000 | 0.000 |
| 160 | [redact] | chronic | electrons E>15keV | Lognormal | 0.000 | 3.000 | 0.000 |

# SECTION II: DR–METHOD B

## II.1 DOSE RECONSTRUCTION OVERVIEW

Section II of this report presents a blind DR for a claimant that worked at Fernald and contracted five skin cancers. This worker was monitored under an external and internal radiation monitoring program, which included recorded photon and beta exposure and uranium bioassay data.

Our investigation evaluated recorded and missed doses to penetrating and non-penetrating radiation based on film badge and TLD data, potential neutron exposures, exposures associated with the direct deposition of uranium dust on bare skin and clothing, and internal dose from uranium inhalation. The following table summarizes our estimate of the worker's skin dose. Based on these results, we derived a POC of 39.33%.

**Table II-1. Summary of SC&A-Derived Dose Estimates for Method B**

| | Dose for [redact] BCC (Unattenuated) (rem) | Dose for [redact] BCC & SCCs (rem) | Dose [redact] SCC (Attenuated) (rem) |
|---|---|---|---|
| Recorded photon dose | 1.6 | 1.6 | 1.6 |
| Recorded shallow dose | 15.5 | 15.5 | 13.3 |
| Missed photon dose | 0.9 | 0.9 | 0.9 |
| Occupational x-ray | 0.13 | 0.13 | 0.13 |
| Missed neutron dose | 0.288 | 0.288 | 0.288 |
| Skin deposition | 0.201 | 0.201 | 0.201 |
| Internal dose | 0.254 | 0.293 | 0.238 |
| **Total** | **18.9** | **18.9** | **16.6** |

### II.1.1 DOSE RECONSTRUCTION APPROACH

The approach used by SC&A to perform this blind DR began with developing an understanding of the work history of this EE vis-à-vis the types of activities that were ongoing in different buildings and time periods at Fernald. This was accomplished by reviewing the totality of the EE's records, and also reviewing the site profile and other documents in the Site Research Database (SRDB) that would help us understand the types of activities and exposures this EE might have experienced each year of employment at Fernald. Once we were able to develop an understanding of this EE's occupational/radiological exposure history, we compiled all the information available that would help us reconstruct the EE's exposure for each year of employment at Fernald. This information included the EE's personnel dosimetry and bioassay records (including urine samples and chest counts) and air sampling, as well as other data that might help to characterize the internal and external radiation exposures this EE might have experienced. We reconstructed the doses as needed for the IREP input sheets, which were used to derive a POC for this worker.

## II.2 RELEVANT CASE INFORMATION

According to the DOL records, this case represents a [redacted] EE born in [redacted] who worked at Fernald from [redacted] to [redacted] as a [redacted], [redacted], [redacted], [redacted], and [redacted]. Beginning in [redacted] through [redacted], the EE was diagnosed with several non-melanoma skin cancers on the [redacted], [redacted], [redacted], and [redacted].

The DR for the case relied heavily on the detailed information provided by the EE in the CATI Report. For this reason, we provide excerpts of the interview. The following are <u>verbatim</u> statements cited in the CATI Report for Case #[redacted].

<u>Job Locations and Responsibilities</u>

> *Locations*
> [redacted]*: Laboratory*
> [redacted]*: Plant* [redacted]
> [redacted]*: Plant* [redacted]
> [redacted]*: Plant* [redacted]
> [redacted]*: Numerous Plants:* [EE] *said they went anywhere the work was; this involved moving throughout the facility.*
> [redacted]*:* [EE] *said they went anywhere the work was;* [the EE] *said they were in about 80% of the buildings on-site.*
> [redacted]*:* [redacted]
> [redacted]*: Plant* [redacted]*, Plant* [redacted] *and miscellaneous jobs throughout the site*
>
> *Duties*
> [Redacted in full.]

The CATI Report also provides the following information regarding the EE:

- The EE was exposed to lead, radon, thorium, natural and enriched uranium, and plutonium
- The EE always wore coveralls, safety glasses, a head cover, and goggles at all times, and showered before going to lunch and at quitting time
- The EE wore gloves and shoe covers for certain jobs
- The EE wore a film badge on the EE's chest or collar and always on the outside of the EE's clothing
- In the early years they did not frisk, but did so in later years
- The EE worked under a radiation work permit when working as a [redacted]
- The EE was required to received x-ray examinations as a requirement for employment (an initial and annual x-rays)

- The EE was involved in incidents
- The EE names several coworkers

In the interview, the EE also described the following incidents:

*Incident One:* [Redacted in full.]

*Incident Two:* [Redacted in full.]

### II.2.1 INTERPRETATION OF CATI AND OTHER BACKGROUND INFORMATION AS APPLICABLE TO THE DR

The worker was employed at FMPC, also known as Fernald, from [redacted], to [redacted]. During that period, management of the Fernald operating contract changed several times. [Redacted in full.]. Dates of employment for the worker with each contractor were as follows (DOE Response_[Redacted]_D103.pdf, p. 21):

[Redacted in full.]

During the EE's employment at Fernald, the EE's work breakdown and work locations were as follows (CATI Summary Draft_[Redacted]_P12241_v1.pdf, p. 10):

- [Redacted], Laboratory
- [Redacted], Plant [Redacted]
- [Redacted], Plant [Redacted]
- [Redacted], Plant [Redacted]
- [Redacted], Numerous Plants
- [Redacted], About 80% of on-site buildings
- [Redacted], [Redacted], [Redacted]
- [Redacted], Plant [Redacted] and Plant [Redacted]

In all of the jobs, except that of [redacted], the worker was exposed to radioactive materials for 40+ hours per week. As a [redacted], exposure to radiation was about 10 hours per week.

The worker received x-rays at the time of employment and at each annual physical. The EE had at least one additional x-ray relating to a [redacted] (DOE Response_[redacted]_D103.pdf, p. 92).

A considerable portion of the EE's employment ([redacted]–[redacted] and [redacted]–[redacted]) was spent in Plant [redacted]. Operations in Plant [redacted] included (ORAUT-TKBS-0017-2):

[Redacted in full.]

In Plant [redacted], the EE's exposure was to depleted and/or enriched uranium. The EE was also exposed to thorium while working with the [redacted] in [redacted]–[redacted]. Elsewhere, the EE cites exposure to lead, radon, radium, thorium, plutonium, natural uranium, enriched uranium and uranium dust (CATI Summary Draft _[redacted]_v2.pdf, [redact]). The EE states in the CATI Report that the EE was exposed to "plutonium (green salt)" in Plant [redacted]. This appears to be in error. Plant [redacted] did indeed produce green salt (uranium tetrafluoride or $UF_4$), but did not handle plutonium except as a contaminant introduced with RU.

### II.2.2 RADIATION INCIDENTS

As discussed in Section II.2 above, the CATI describes two incidents where non-routine radiation exposures could have occurred. <u>Incident 1</u> occurred in Plant [redacted] when the worker was [redacted]. The EE was wearing coveralls, a hard hat, gloves and a face shield.

According to the incident report, <u>Incident 2</u> occurred in Plant [redacted] while the worker was [redacted]. [redacted]. During the [redacted]. After the EE felt better, the EE donned a chemical respirator instead of a particulate respirator and completed the test. In the CATI, the EE said that the test was not completed, and the EE only used a particulate respirator. On [redacted], a special request was made for a whole-body scan of the worker, who at the time was doing decontamination in Building [redacted]. The scan did not detect any significant exposure.

On [redacted], the EE was involved in an incident not mentioned in the CATI. At that time, the EE was [redacted]. Consequently, the next day the EE's urine was tested, and the EE received a whole-body count, which showed negligible contamination from Pb-212, Ac-228, U-235 and U-238 (DOE Response_[redacted]_D103.pdf, p. 77).

### II.2.3 RADIATION MONITORING AND CONTROL MEASURES

Based on the CATI, the EE's radiation monitoring and radiological control measures included the following:

- Wore a head cover, coveralls and safety glasses at all times
- Wore cotton gloves in the work area and sometimes shoe covers
- Took a shower when leaving the work area for lunch and at the end of the day as well as anytime the EE left the contaminated side of the work area for the clean side
- Wore radiation monitoring badge at all times either on the EE's chest pocket or just below the collar of the EE's coveralls
- Used a whole-body frisker, after [redacted], to assess contamination when passing from the contaminated side to the clean side of the work area
- Radiation surveys were performed while the EE was employed as an [redacted] if a work permit was required to enter a particular area

- Urinalysis monitoring performed routinely for uranium intake from [redacted] through [redacted]
- Additional urine samples were taken if an incident occurred
- Limited fecal samples were analyzed for thorium in [redacted]
- Received about seven in-vivo lung scans between [redacted] and [redacted] with all results reported as less than the limit of detection (DOE Response_[redacted]_ D103.pdf, p. 40).

### II.2.4 PRIMARY RADIONUCLIDES OF CONCERN

On a generic basis, workers at FMPC were exposed to uranium and progeny (including enriched, depleted, natural and recycled), thorium and progeny, thoron and progeny, and radon and progeny. Specific activities and activity fractions are summarized in Table II-2 (from ORAUT-TKBS-0017-2, Table 2-49). It should be noted that as part of discussions in the Fernald WG, NIOSH has agreed to change the default levels of plutonium-239, neptunium-237, and technetium-99 in RU over three periods of time that correspond to changing constituent concentration levels in incoming feed stocks. However, at the time that this DR was performed, the TBD has not been updated. Thus, in assigning dose to this EE from RU, SC&A used the values cited in Table II-2 below.

**Table II-2. Specific Activities and Activity Fractions***

| Uranium Enrichment | U+Cont. (Bq/mg) | U | | Pu - 80ppb | | Np – 300 ppb | | Tc- 5000 ppb | |
|---|---|---|---|---|---|---|---|---|---|
| | | Bq/mg | *f act.* | Bq/mg | *f act.* | Bq/mg | *f act.* | Bq/mg | *f act.* |
| Depleted | 4.53E+01 | 1.38E+01 | 0.305 | 1.83E-01 | 0.004 | 7.77E-03 | 1.72E-04 | 3.13E+00 | 0.69 |
| Natural | 5.76E+01 | 2.61E+01 | 0.453 | 1.83E-01 | 0.003 | 7.77E-03 | 1.35E-04 | 3.13E+00 | 0.54 |
| 2% Enrich | 9.14E+01 | 6.03E+01 | 0.66 | 1.83E-01 | 0.002 | 7.77E-03 | 8.50E-05 | 3.13E+00 | 0.34 |

**Specific Activities for Enriched Uranium:**

| Uranium Enrichment | Isotopes | Mass % | *f* activities |
|---|---|---|---|
| Depleted | U-234<br>U-235<br>U-238 | 0.05<br>0.25<br>99.75 | 0.083<br>0.014<br>0.903 |
| Natural | U-234<br>U-235<br>U-238 | 0.0057<br>0.7204<br>99.273 | 0.504<br>0.023<br>0.473 |
| 2% Enrich | U-234<br>U-235<br>U-238 | 0.02<br>2.0<br>97.98 | 0.770<br>0.026<br>0.204 |

**Specific Activities for Thorium:**

Thorium-232 would be the default isotope. The degree of equilibrium is impossible to estimate, due to the variation in times since chemical separation of the feed stock. The specific activity value for $^{232}$Th and daughters is 1.11E-07 Ci/gm or 4.11 Bq/mg.

**Working Level (WL) Conversion Factor for Rn daughters:**

1 WL = 100 pCi/L for 100% Rn daughter equilibrium

1 WLM (100% equilibrium) = 1.70E+04 pCi

$$WLM = \frac{Equalibrium\ Faction \times Exposure\ Time}{1.0\ WLM_{100}} \times Rn\ Concentration = \frac{f_{eq} \times 2000}{17000} \times Concentration\ \frac{pCi}{L}$$

WLM = 0.118 (*feq* )(Rn concentration in pCi/L), equilibrium factor *feq* = 0.4(for indoor), 0.7(for outdoor) and 2,000 hrs exposure time.

*Recycled uranium (RU) is uranium which was recovered from spent fuel processing plants at Hanford, Savannah River, ICPP, and West Valley. Between 1958 and 1988, 17,966 MT of RU was shipped to FMPC. Information above can be used to estimate the exposures to lead, plutonium, and technetium, as well as the uranium isotopes.

## II.3 RECONSTRUCTION OF EXTERNAL DOSE

Since the worker was diagnosed with several non-melanoma skin cancers on the [redacted], [redacted], [redacted], and [redacted], it is deemed likely that the reconstruction of external gamma and beta doses were likely the major sources of skin exposure. However, the DR also considered assigning doses to skin from neutron exposures and from direct deposition of fine particles of uranium and uranium flakes on the exposed and covered portions of this worker's body. In assessing skin dose from potential direct deposition of uranium particles/flakes, consideration was given to the fact that the EE worked at Fernald from [redacted] to [redacted], when contamination control measures were in place, such as wearing protective clothing and showering at least daily after completing a work day or a particular task. As will be noted throughout this blind DR, it was necessary to perform an in-depth review of many of the issues associated with external exposures of skin, which can be quite complex. We believe that we have uncovered a number of site profile issues that, though they do not affect this blind DR, should be considered by the Fernald DR WG as part of the site profile issues resolution process.

### II.3.1 RELIABILITY OF SKIN DOSES AS RECONSTRUCTED USING EXTERNAL BETA DOSIMETRY DATA

The administrative record for this worker indicates that the EE was monitored for external exposures under a monthly external dosimetry program for most of the EE's employment at Fernald, and the program monitored deep dose equivalent and non-penetrating exposures. Table II-3 presents an example of the types of external dosimetry data that were provided by DOE for this worker. The administrative record also includes annual roll-up doses and doses in handwritten form. In addition, there appears to be a limited amount of data on external exposures to hands and forearms.

**Table II-3. Example of External Dosimetry Data Recorded in Behalf of Case #[redacted]**

| Begin Date | End Date | Dosimeter Category | Process ID | Dosimeter Type | Wear Location | Record Type | DDE* | SDE SK | LDE | SDE EX | Neut. | PSE |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| [redacted] | [redacted] | CALCULATED | | | | OFFICIAL | 26 | 434 | | | | |
| [redacted] | [redacted] | CALCULATED | | | | OFFICIAL | 35 | 350 | | | | |
| [redacted] | [redacted] | CALCULATED | | | | OFFICIAL | 23 | 299 | | | | |
| [redacted] | [redacted] | CALCULATED | | | | OFFICIAL | 0 | 99 | | | | |
| [redacted] | [redacted] | CALCULATED | | | | OFFICIAL | 14 | 107 | | | | |
| [redacted] | [redacted] | CALCULATED | | | | OFFICIAL | 8 | 8 | | | | |
| [redacted] | [redacted] | CALCULATED | | | | OFFICIAL | 0 | 0 | | | | |
| [redacted] | [redacted] | CALCULATED | | | | OFFICIAL | 0 | 0 | | | | |
| [redacted] | [redacted] | CALCULATED | | | | OFFICIAL | 0 | 0 | | | | |
| [redacted] | [redacted] | CALCULATED | | | | OFFICIAL | 0 | 0 | | | | |
| [redacted] | [redacted] | CALCULATED | | | | OFFICIAL | 15 | 15 | 15 | | | |
| [redacted] | [redacted] | CALCULATED | | | | OFFICIAL | 9 | 9 | 9 | | | |
| [redacted] | [redacted] | CALCULATED | | | | OFFICIAL | 0 | 0 | | | | |
| [redacted] | [redacted] | ROUTINE | UN23675 | WHOLE BODY | CHEST | OFFICIAL | 0 | 0 | | | | |
| [redacted] | [redacted] | ROUTINE | UN23676 | WHOLE BODY | CHEST | OFFICIAL | 0 | 0 | | | | |
| [redacted] | [redacted] | ROUTINE | UN23677 | WHOLE BODY | CHEST | OFFICIAL | 0 | 0 | | | | |
| [redacted] | [redacted] | ROUTINE | UN23678 | WHOLE BODY | CHEST | OFFICIAL | 0 | 0 | | | | |
| [redacted] | [redacted] | ROUTINE | UN23679 | WHOLE BODY | CHEST | OFFICIAL | 0 | 0 | | | | |
| [redacted] | [redacted] | ROUTINE | UN23680 | WHOLE BODY | CHEST | OFFICIAL | 0 | 0 | | | | |
| [redacted] | [redacted] | ROUTINE | UN23681 | WHOLE BODY | CHEST | OFFICIAL | 0 | 0 | | | | |
| [redacted] | [redacted] | ROUTINE | UN23682 | WHOLE BODY | CHEST | OFFICIAL | 0 | 0 | | | | |
| [redacted] | [redacted] | ROUTINE | UN23683 | WHOLE BODY | CHEST | OFFICIAL | 0 | 0 | | | | |
| [redacted] | [redacted] | ROUTINE | UN23684 | WHOLE BODY | CHEST | OFFICIAL | 0 | 10 | | | | |
| [redacted] | [redacted] | ROUTINE | UN23685 | WHOLE BODY | CHEST | OFFICIAL | 0 | 13 | | | | |
| [redacted] | [redacted] | ROUTINE | UN23686 | WHOLE BODY | CHEST | OFFICIAL | 5 | 29 | | | | |
| [redacted] | [redacted] | ROUTINE | UN23687 | WHOLE BODY | CHEST | OFFICIAL | 0 | 0 | | | | |
| [redacted] | [redacted] | ROUTINE | UN23688 | WHOLE BODY | CHEST | OFFICIAL | 0 | 0 | | | | |
| [redacted] | [redacted] | ROUTINE | UN23689 | WHOLE BODY | CHEST | OFFICIAL | 5 | 5 | | | | |
| [redacted] | [redacted] | ROUTINE | UN23690 | WHOLE BODY | CHEST | OFFICIAL | 0 | 0 | | | | |
| [redacted] | [redacted] | ROUTINE | UN23691 | WHOLE BODY | CHEST | OFFICIAL | 0 | 0 | | | | |
| [redacted] | [redacted] | ROUTINE | UN23692 | WHOLE BODY | CHEST | OFFICIAL | 9 | 310 | | | | |
| [redacted] | [redacted] | ROUTINE | UN23693 | WHOLE BODY | CHEST | OFFICIAL | 21 | 379 | | | | |
| [redacted] | [redacted] | ROUTINE | UN23694 | WHOLE BODY | CHEST | OFFICIAL | 38 | 465 | | | | |
| [redacted] | [redacted] | ROUTINE | UN23695 | WHOLE BODY | CHEST | OFFICIAL | 33 | 598 | | | | |
| [redacted] | [redacted] | ROUTINE | UN23696 | WHOLE BODY | CHEST | OFFICIAL | 21 | 394 | | | | |
| [redacted] | [redacted] | ROUTINE | UN23697 | WHOLE BODY | CHEST | OFFICIAL | 23 | 471 | | | | |
| [redacted] | [redacted] | ROUTINE | UN23698 | WHOLE BODY | CHEST | OFFICIAL | 23 | 264 | | | | |
| [redacted] | [redacted] | ROUTINE | UN23700 | WHOLE BODY | CHEST | OFFICIAL | 27 | 326 | | | | |

All dose equivalents are expressed in millirem
* - indicates deep dose equivalent only. Neutron dose is not added

Given that the EE was monitored for deep and shallow doses and the cancers of concern are skin cancers, we attempted to determine whether the data are complete, adequate, and accurate with respect to reconstructing doses to skin for the broad range of jobs that this worker performed. These job assignments included working with uranium metal, uranium salts, enriched and RU, and thorium. In addition, the EE was also involved in incidents where the EE's skin could have been contaminated with uranium.

Section 6.0 of the site profile (ORAUT-TKBS-0017-6) is helpful in understanding the complexity of the external exposures that the EE might have experienced. Noteworthy are exposure to Tc-99 (0.292 MeV beta), and the strong beta emitters associated with the progeny of U-238 (e.g., Pa-234m with its 2.29 MeV beta). Also, Section 6.3.1 of the site profile, *Site Historic Administrative Practices,* provides an understanding of the types of external dosimetry practices employed at the facility from [redacted] through [redacted].

As indicated in Table 6-3 of ORAUT-TKBS-0017-6, workers were badged with the Oak Ridge National Laboratory (ORNL) beta/gamma dosimeters from [redacted] to [redacted]. According to the ORNL site profile (ORAUT-TKBS-0012-6), a number of different types of film badges and TLDs were issued at ORNL beginning in 1975. It appears that a type of hybrid Class 2 or Class 3 dosimeter was likely employed for this Fernald worker from [redacted] to [redacted]. According to the ORNL site profile, Class 2 dosimeters were issued for whole-body and skin dose, and for indicating neutron exposure, but not to quantifiably measure neutron exposure. The Class 2 dosimeter contained a TLD-100 chip under an aluminum filter, and two thin TLD-700 chips, one under an open window (OW) and the other under plastic. The Type 3 (and red dot issued [redacted]–[redacted]) dosimeter was a four-element design with a TLD-600 and a TLD-700 under a cadmium filter, a TLD-600 and a TLD-700 under an aluminum filter, and two thin (0.015-inch) TLD-700 chips under the OW and plastic filters. A vapor-sealed NTA film monitored fast neutrons. The Type 3 and red dot dosimeters were issued to radiation workers for whom neutron monitoring was appropriate. It does not appear that the EE was issued red dot dosimeters.

Table 6-3 of the FEMP site profile indicates that from 1959 to 1985, the "ORNL dosimeter" was used with a Cu, Cd, plastic, lead and filter, and also an OW portion, and Table 6-4 indicates that calibration of the dosimeters used radium and uranium until 1985 with results expressed in units of air exposure (i.e., Roentgens). The combination of different types of filters allows the readout to account for the over-response of film or TLDs[2] to low-energy photons, to reliably measure beta and low-energy non-penetrating photons to determine skin exposures, and to determine if neutron exposures were occurring. These features appear to be adequate to obtain a reliable estimate of skin exposures if (1) the dosimeter was worn outside of clothing (which, according to the CATI, they were), (2) consideration was given to any special packaging, and (3) calibration of the dosimeters employed photon and electron energy spectra that were comparable to the spectra experienced by the workers.

From 1985 to the present, Fernald used commercial Panasonic TLDs with multiple filters, and according to Table 6-4 of the site profile, these dosimeters were calibrated using a phantom to derive dose in units of rem, as required for radiation protection reporting requirements. In all cases, natural background was subtracted from the reported exposures. Sections 6.3.2.2 and 6.3.3.2 of the ORAUT-TKBS-0017-6 explain that Cs-137 was used for gamma calibration, and it appears that a uranium slab was used for beta calibration. Also, algorithms were developed and tested to convert the readout under each element of the TLD to deep dose equivalent and skin

[2] There appears to be some ambiguity regarding whether film or TLD multi-element dosimetry was employed into the 1980s, as discussed in Section 6.3.2.1. However, the discussion that follows is applicable to each type of dosimeter.

dose. The section also describes problems encountered in beta calibration. Issues related to calibration of beta/photon dosimeters are discussed in Section 6.3.3 of the site profile, which emphasizes the importance of using appropriate calibration sources when calibrating dosimeters for beta exposures.

In light of the many complexities and uncertainties regarding the types of dosimeters that might have been used at Fernald, Table 6-4 of the site profile recommends that, from 1954 to 1985, when film was used, the skin dose should be estimated using the OW plus deep dose results. For 1985 to the present, when TLDs were used, the skin dose should be determined by summing the non-penetrating (Npen) plus deep dose readouts. In addition, Section 6.5 of the site profile addresses the need for conversion factors (CFs) to the dosimeter results; i.e., add 10% dose to the <250 MeV fractions given in Table 6-8. However, these recommended adjustment factors are limited to film (i.e., pre-1985) and only to the deep dose results, and no CFs are recommended for non-penetrating dose.

Section 6.6.1 of the site profile addresses missed dose, and recommends that ½ the MDL for missed beta/photon dose be used. For 1959–1984, the recommended MDL is 30 mrem/change out (which was monthly at that time), and from 1984 to the present, the recommended MDL is 20 mrem/change out (which was quarterly during that time period).

#### II.3.1.1 Issues Related to Tc-99

Based on our review, the external dosimetry program for photon and beta exposures appears comprehensive and reliable. However, one issue arose during our investigations that required further investigation; namely, exposures to Tc-99.

Section 6.3.2 of ORAUT-TKBS-0017-6 acknowledges that many of the facilities and activities at Fernald involved the generation of considerable dust, and that dosimeters were placed in plastic bags for protection against dust contamination. Such plastic bags would shield the sensitive elements (whether film or TLD) resulting in an underestimate of the beta exposure. The site profile further explains that the dosimeters were calibrated with plastic bags in place, and, as such, should provide reliable estimates of both penetrating and non-penetrating exposures, because calibration takes into consideration the presence of the plastic bags. However, it must be acknowledged that even a small change in the energy distribution of beta emitters in the working environment, as compared to that used for calibration purposes, could affect the accuracy of the calibration factors, especially in the presence of additional shielding, such as the use of plastic bags to protect the dosimeters from dust. Variability in the energy distribution of beta emitters at Fernald could be of concern because of the presence of Tc-99 at the facility. Since the dosimeters were calibrated with uranium, the question that needs to be addressed is to what degree the presence of Tc-99 could substantively affect calibration factors based on uranium and the recorded beta doses.

The maximum beta energy for Tc-99 is 0.29 MeV, while the maximum energy of the principal beta emitters associated with U-238 are its short-lived progeny; i.e., Pa-234m (max beta = 2.26 MeV) and Th-238 (max beta = 0.199 MeV). The implications are that a dosimeter calibrated for beta exposure using U-238 (with baggie) will be virtually useless for monitoring beta exposures to Tc-99, because most of the Tc-99 betas would be shielded by the baggie. However, since the amount of Tc-99 present in RU is minute,[3] the issue of the presence of the baggie affecting the calibration factor is of marginal significance. On this basis, we conclude that the film badge and/or TLD results for non-penetrating exposure can be used to reconstruct skin exposures at Fernald, as long as the Tc-99 was not separated from the RU and had a specific activity in RU that was on the order of 1,346 ppb.[4] Table 5-9 in the site profile (ORAUT-TKBS-00175-5, 5/28/204) indicates that the RU subgroup with the highest level of Tc-99 was subgroup 6B with a relative concentration of 8,934 ppb ("bootstrap" mean).[5] Though higher than the overall average of 1,346 ppb, such a relative concentration of Tc-99 in RU would still not contribute significantly to the external beta dose as compared to U-238 and its short-lived progeny, primarily Pa-234m.

Though we found that none of the RU groups could represent an important source of beta exposure from Tc-99 as compared to that from U-238 and its short-lived progeny, we investigated whether there might be some processes that enriched various waste streams in Tc-99 relative to U-238. As stated in SC&A 2011, hydrofluorination (which occurred in Plant 4) could increase the airborne technetium concentration:

> *[Hydrofluorination] reacted uranium dioxide powder with HF to produce a $UF_4$ powder. The process is not believed to have permitted separation of constituents because, regardless of chemical reaction, the powders were mechanically or pneumatically moved through the solid-gas reaction processes from start to finish. The exception to this presumption is the situational data that suggest that* ***the Tc-99 constituent tended to volatilize in high temperature processes, such as hydrofluorination, and would tend to collect on dust collector residues and media*** (DOE 2000, page D.1-72 and D.1-73, emphasis added).

However, the Plant 4 dust collector samples reported in Fernald 1987 (Tables 58 through 65; see Table II-4) show that none of these samples has a Tc-99 specific activity greater than the 8,934 ppb in RU subgroup 6B. Hence, this source of waste material enriched in Tc-99 is not an important contributor to external beta dose as compared to that of U-238 and its progeny.

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[3] Section 5.2.2 (Table 5-10) of ORAUT-TKBS-00175-5 states that typical RU contained 1,346 ppb of Tc-99. Since the half-life of Tc-99 is 2.1E5 years and that of U-238 is 4.4E9 years, the contribution of Tc-99 external beta exposures relative to that of Pa-234m is small; i.e. on a per unit mass basis for RU, the beta flux from Pa-234m is about 15 times greater than that from Tc-99 in RU, and the energy of the Pa-234m beta distribution is about 10 times greater than that of the Tc-99 beta distribution based on Emax.

[4] During the ongoing Fernald WG discussions, the agreed upon default 95th percentile levels of RU post-1970 are 20,000 ppb. However, at the time this DR was performed, the TBD had not been changed to reflect the increased value.

[5] The values reported in Table 5-9 of the site profile are referred to (by DOE) as "bootstrap means" of the 19 subgroup data distributions. The bootstrap mean is similar to a standard arithmetic mean (AM), but the technique is designed to minimize the influence of "outliers" in a dataset.

**Table II-4. Tc-99 Content in Dust Samples**

| Sample | Tc-99 µCi/kg-U | Tc-99/U-238 | Tc-99 ppb |
|---|---|---|---|
| G4-2 | 82 | 24.6% | 4,791 |
| G4-4 | 52 | 15.6% | 3,038 |
| G4-5 | 97 | 29.1% | 5,668 |
| G4-7 | 110 | 33.0% | 6,427 |
| G4-12 | 2.1 | 0.6% | 123 |
| G4-13 | 93 | 27.9% | 5,434 |
| G4-14 | 0.046 | 0.0% | 2.7 |
| G4-15 | 53 | 15.9% | 3,097 |

Given the importance of external beta exposure to this particular worker's DR, we investigated this issue further and found that purifying the uranium will result in some products and waste streams that have a lower concentration (relative to uranium) of impurities (including technetium) than the feed material, and some that have a higher concentration of impurities. Thus, depending on the type of material being handled (either feed material, product, or waste), a worker could be exposed to technetium concentrations that were consistent with, lower than, or higher than the concentration in RU.

Uranium purification occurred in Plant 2/3, according to ORAUT-TKBS-0017-2, Section 2.2.3, and DOE 2000, Figure D-1 and Attachment D.1, Section 2.0. The raffinate from Plant 2/3 (depleted of uranium, but enhanced in technetium) was transferred to Waste Pits 3 or 5. Table II-5 shows the increase in the Tc-99 to U-238 ratio in Waste Pits 3 and 5 materials compared to enriched RU. As shown, there is about twice as much Tc-99 in Waste Pit 9 and 8 times higher concentrations in Waste Pit 5 as compared to enriched uranium.

**Table II-5. Tc-99 Content in Waste Streams**

| FEMP Area | TBD Source | U-238 | Tc-99 | Units | Tc-99/ U-238 | Const. | Closed | Waste Type |
|---|---|---|---|---|---|---|---|---|
| Waste Pit 1 | Table 2-26 | 1,950.6 | 3.6 | (pCi/g) | 0.2% | 1952 | 1959 | Dry |
| Waste Pit 6 | Table 2-40 | 16,975. | 127. | (pCi/g) | 0.7% | 1979 | 1985 | Solids |
| Waste Pit 4 | Table 2-34 | 4,644. | 80.45 | (pCi/g) | 1.7% | 1960 | 1985 | Solids |
| Waste Pit 2 | Table 2-28 | 4,725.4 | 128.9 | (pCi/g) | 2.7% | 1957 | 1964 | Dry |
| Clearwell | Table 2-42 | 621.5 | 98.85 | (pCi/g) | 15.9% | 1959 | 1970 | Runoff |
| Burn Pit | Table 2-43 | 175.33 | 29.21 | (pCi/g) | 16.7% | 1957 | 1984 | Combust. |
| Depleted Uranium | Table 2-49 | 12.46 | 3.13 | (Bq/mg) | 25.1% | N.A. | N.A. | N.A. |
| Natural Uranium | Table 2-49 | 12.35 | 3.13 | (Bq/mg) | 25.3% | N.A. | N.A. | N.A. |
| 2% Enrich Uranium | Table 2-49 | 12.3 | 3.13 | (Bq/mg) | 25.4% | N.A. | N.A. | N.A. |
| Waste Pit 3 | Table 2-31 | 442. | 233.4 | (pCi/g) | 52.8% | 1958 | 1969 | Slurries |
| Waste Pit 5 | Table 2-37 | 641.17 | 1,274.5 | (pCi/g) | 198.8% | 1968 | 1987 | Slurries |

The waste stream with the highest concentration of Tc-99 relative to U-238 is that in Waste Pit 5, where the activity ratio of Tc-99 to U-238 is a factor of 2, which would appear to be important. However, from Federal Guidance Report (FGR) 13 (EPA 1999), the mortality (and morbidity) risk factor to the skin from submersion in Tc-99 (2.01E-19, 2.01E-19 $Bq^{-1}$) is only about 5% of the submersion risk factor for Pa-234m (4.03E-18, 4.03E-18 $Bq^{-1}$). Thus, for enriched uranium (with a Tc-99 to U-238 ratio of 25.4%), the Tc-99 contribution to the skin risk is about 1.25% of the Pa-234m risk. For Plant 4 (with a maximum Tc-99 to U-238 ratio of 33.0%), the Tc-99 contribution to the skin risk is about 1.67% of the Pa-234m risk. For Waste Pit 5 (with a Tc-99 to U-238 ratio of 198.8%), the Tc-99 contribution to the skin risk is about 10% of the Pa-234m risk. We conclude that external exposure of skin to Tc-99 relative to that of U-238 is not very significant (i.e., about 10%), even under worst-case conditions. Based on this EE's work history, most of the EE's time was spent in Plant [redacted], Plant [redacted], and the [redacted]. The EE does <u>not</u> appear to have spent significant time in areas with a higher technetium-to-uranium ratio (i.e., Plant [redacted] or Plant [redacted], or around Waste Pits [redacted]), although the EE may have been in these areas while the EE was working as a [redacted] (in Numerous Plants) or as an [redacted] (in about 80% of the buildings onsite) or in the [redacted] (throughout the site). Thus, it is expected that Tc-99 would contribute less than 10% (and maybe only about 1.25%) to the EE's skin cancer risk.

### II.3.2 RELIABILITY OF METHODS USED TO RECONSTRUCT NEUTRON EXPOSURES

As indicated in Table II-3 above, no values are reported for neutron exposures for this worker. The reason might be because measurements were made but no exposures were detected, or measurements were not made. It is difficult to judge whether we are dealing with a missed dose or a situation where no attempt was made to measure neutron exposures. As best we can determine from reading the site profile, it appears that some attempt was made to at least detect the presence of neutron exposures. A discussion of this matter is provided in Section 6.3.5 of the site profile (ORAUT-TKBS-0017-6), where it states the following:

> *The documentation for FEMP did not include any reference to neutron dosimetry with the exception of high-range, gamma-sensitive 1290 film. This film was packaged with the sensitive 508 film and exchanged on an annual basis. There was some concern expressed in AEC audit letters (Johnson and Heacker 1963) that mention "the badge also contains components to evaluate personnel exposure from criticality accidents" (an event that never occurred at Fernald). There was no established need for neutron dosimetry at FEMP even though there were large quantities of $UF_4$ and $UF_6$. Enrichments were low enough (typically <2% $^{235}U$) that alpha neutron reactions were limited. The limitations of NTA film were well documented including an MDL of approximately 40 mrem for fast neutrons. Based on studies and calculations it was concluded that fast neutron exposures at FEMP would be less than the MDL (Robinson 2001*). The purpose of the following section is to discuss and develop a neutron to photon ratio for estimating neutron doses at Fernald. A possible source of low level neutron exposure at Fernald is the alpha,n reaction from the uranium alpha particle interactions with fluorine atoms. This reaction primarily occurs with the production and storage of $UF_4$ (green salt). The areas at Fernald which produced and/or stored green salt include the Pilot Plant, Plant 4, Warehouse 4B and any other warehouse at Fernald for which the material stored is unknown. The neutron to photon ratio described below should only be applied to workers*

*who were exposed to Uranium – Fluorine materials (i.e. $UF_4$, $UF_6$) at Fernald.*
* A reference for Robinson 2001 could not be found in ORAUT-TKBS-0017-6.

Beginning in Section 6.3.5.1, the site profile presents an approach to reconstructing neutron exposures using neutron-to-photon ratios. As explained in the site profile, neutron dose rates from $UF_4$ canisters containing different levels of enrichment were measured using bubble dosimeters, and, in a separate set of measurements of different canisters, photon dose rates were determined. Bubble dosimeters consist of a small clear plastic cylindrical vial containing a clear polymer in which are dispersed tiny droplets of superheated liquid. When a neutron strikes a droplet, the droplet immediately vaporizes, forming a visible gas bubble trapped in the gel. The number of droplets provides a direct measurement of the tissue-equivalent neutron dose. It is useful because of its sensitivity and its nearly linear response over a wide range of neutron energies (see Reilly 1989).

Adjustments were made to the dataset to account for differences in geometry between the two sets of measurements for depleted and enriched uranium, and distributions of neutron-to-photon ratios were derived from the dataset, one for depleted uranium and one for enriched uranium. The results of the analysis are provided in Table II-6 as follows (from Table 6-10 of the site profile):

**Table II-6. Statistical Parameters of Neutron-to-Photon Ratios**

| Enrichment | Geometric Mean | GSD | Upper 95th% |
|---|---|---|---|
| Depleted Uranium | 0.07 | 1.74 | 0.17 |
| Low Enriched Uranium | 0.10 | 1.71 | 0.23 |

Source: ORAUT-TKBS-0017-6, Table 6-10

In addition to these neutron-to-photon ratios, Table 6-9 of the site profile presents the measured neutron dose rates adjacent to canisters containing $UF_4$ enriched at 1.25% to 2%. Neutron exposure rates of 0.1069 mrem/hr were obtained using bubble dosimeters.

The site profile explains that, though most uranium handled at Fernald was not enriched, it is difficult to determine what level of enriched uranium might have been handled by a given worker over a given time period, and recommends employing the low-enriched uranium ratio for employees who worked in the Pilot Plant, Plant 4, any warehouse or other area known to store $UF_4$, or any of the onsite warehouses for which the stored material is not known. The site profile further recommends that the neutron energy distribution should be assumed to range from 0.1 to 2.0 MeV.

Given some of the limitations associated with the neutron-to-photon ratios, it might be prudent to evaluate doses to neutrons using both the neutron-to-photon ratio approach and also the direct measurements of the neutron dose rates in mrem/hr for slightly enriched uranium, and make assumptions regarding exposure duration for this worker.

Neutron-to-Photon Ratio Approach

As discussed above, the recorded photon doses for this worker were primarily below the MDL, and from [redacted]–[redacted], the recommended MDL is 30 mrem/change out (which was monthly during that time). From [redacted] to the present, the recommended MDL is 20 mrem/change out (which was quarterly during that time period). Using a neutron-to-photon ratio of 0.1 and a photon dose rate of 15 mrem/month, the annual neutron dose to the skin for this worker using the neutron-to-photon ratio approach is 15 mrem/month × 0.1 × 12 months = 18 mrem/yr. Missed neutron doses are included in entries #84–#99 in Appendices II.A-1, II.A-2, II.A-3.

Direct Neuron Measurements

As described above, the measured neutron dose rate adjacent to canisters containing $UF_4$ enriched at 1.25% to 2% was 0.1069 mrem/hr, as estimated using bubble dosimeters. Assuming a worker spent full time adjacent to such a source, the annual neutron exposure would be about 200 mrem/yr. We consider this neutron dose to be an unrealistic upper bound value because it is unreasonable to assume that a worker spent all their time adjacent to such a neutron source. Hence, we believe that 18 mrem/yr calculated by the neutron-to-photon ratio approach, as described above, represents a reasonable, if not conservative, estimate of neutron exposure rate for this worker.

### II.3.3 SKIN EXPOSURES ASSOCIATED WITH DEPOSITION OF URANIUM DIRECTLY ON SKIN AND CLOTHING

A skin exposure scenario that is of concern at Fernald is the direct deposition of airborne uranium dust on bare skin and clothing. This exposure scenario is not addressed in the Fernald site profile, but was raised as a generic issue at the May 21, 2013, meeting of the Dose Reconstruction Subcommittee. At that meeting, NIOSH introduced a strategy for reconstructing skin doses from this scenario for the Bridgeport Brass facility, as follows:

> *An assessment was made to determine the skin dose from routine skin contamination associated with uranium operations. Based on the Technical Basis Document: An Exposure Matrix for Bridgeport Brass: Havens Laboratory and Adrian Plant (ORAUT-TKBS-0030 Rev. 01), the geometric mean of the Table 3-5 individual daily weighted-average air concentration is 250 dpm/m$^3$ with a geometric standard deviation of 2.2. This results in a 95$^{th}$ percentile air concentration of 915 dpm/m$^3$. Assuming a terminal settling velocity of 0.00075 m/s and 8 hours of operations, a constant air concentration of 915 dpm/m$^3$ would result in a surface contamination level of 1.98 dpm/cm$^2$. One could assume that the skin of the head, neck, and hands were re-contaminated at the same level of general surfaces every workday (250 workdays) of the year. The skin on the head, neck, and hands represent about 14% of the total body skin area. A maximizing skin dose rate of 40 mrem per 10,000 dpm/cm$^2$ per hour can be applied to determine the skin dose to the affected area (Technical Basis for Beta Skin Dose Calculations at the Y12 Plant, SRDB 19821)* [Thomas and Bogard 1994]. *This would result in a dose to the affected skin of about 16 mrem. Per*

*guidance in Interpretation of Dosimetry Data For Assignment of Shallow Dose (ORAUT-OTIB-0017 Rev. 01), the 16 mrem to the affected skin could be converted to the dose to the skin based on the described approach for non-uniform exposures, resulting in a geometric mean annual skin dose of about 2 mrem with a geometric standard deviation of 8. As a note, this is a bounding estimate using a maximizing skin dose rate and contamination levels. A more realistic skin dose rate and the use of the geometric mean air concentration would result in an exposure of less than 1 mrem.*

We agree with the basic strategy described by NIOSH, except that substantial skin exposure to beta emitters associated with uranium can also contribute significant exposure through clothing. NIOSH's assumption that only bare skin (representing 14% of total skin in the above example) is subject to contamination/radiation exposure from the deposition of airborne activity is unrealistic. This is particularly true for work environments involving heavy physical activity, worker perspiration, and damp clothing. Thus, any deposition of airborne contaminants (as well as contact with existing contaminated surfaces in the workplace) by clothing worn by a worker must reasonably be assumed to become contaminated, and that, at a **minimum, the level of contamination is comparable to that of bare skin**. In Section 6.3.4.2 of Feed Materials Production Center site profile (ORAUT-TKBS-0017-6), NIOSH provides the following guidance for determining the skin dose under clothing from exposure to uranium:

*Results of tests of FEMP dosimeters used during the 1960s (Heatherton 1960) included the conclusion that the half-value thickness of absorption of UX-2 ($^{234}$Pa) beta energy was approximately 110 mg/cm$^2$. It was determined that "the combined dose rate from the surface of uranium metal in equilibrium with its two daughters, UX-1 ($^{234}$Th) and UX-2 ($^{234}$Pa), is about 240 mrad/hr." It was also determined that approximately 95% of the surface dose rate, or approximately 228 mrad/hr, originated from the UX-2 in the metal . . .* ***It was also determined that coveralls worn by workers (about 30 mg/cm$^2$) reduced uranium beta exposure to the skin by approximately 20%****. Figure 6-6, at the end of this TBD, summarizes these data.* [Emphasis added.]

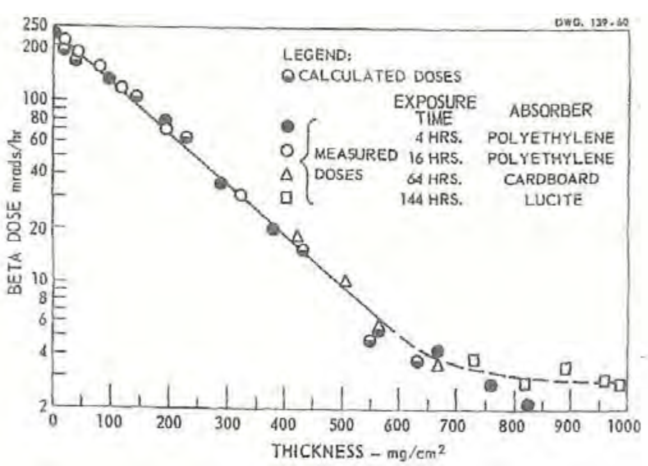


**Figure II-1. Beta Dose vs. Skin Depth**
(Source: ORAUT-TKBS-0017-6, Figure 6-6)

On this basis and given that the worker spent extended periods of time in Plant [redacted], where [redacted], it is reasonable to assume that the EE experienced some degree of skin exposure due to the direct deposition of uranium oxide dust on skin and clothing. As such, we consider it appropriate to assign a skin dose from this exposure scenario using appropriate airborne uranium dust loadings as our starting point.

SC&A explored two strategies for estimating the typical airborne dust loading this worker might have experienced while working in Plant [redacted]. The first was to review the information in Section 5.3.2 of the site profile (ORAUT-TKBS-0017-5) titled, "Air Monitoring Program." The other is to back-calculate the airborne dust loadings that this worker might have experienced based on the EE's bioassay data.

Inspection of the bioassay data for this worker, as provided by the DOE, reveals that urine samples were collected quarterly throughout employment at Fernald, and more often when elevated levels of uranium were observed. All the data are reported in units of microgram/L and range from below the MDL (which appears to be as high as 14 micrograms/L) to a high of 18 microgram/L. The vast majority of the results were below the MDL. We elected to perform a plausible but perhaps overestimate of the airborne dust loading by assuming an average urine concentration of 7 µg/L (i.e., ½ the MDL) and used this value to estimate the chronic intake rate of Type S uranium that would result in this concentration of uranium in urine. Assuming the uranium is 2% enriched, we converted the mass concentration to activity concentration using a unit conversion factor of 1.616 pCi/microgram of uranium, yielding an average uranium concentration in urine of 11.3 pCi/L and an excretion rate of 15.82 pCi/day.

Using this chronic uranium excretion rate, IMBA was run to derive the uranium intake rate that would yield this excretion rate assuming Type S uranium and that the excretion rate followed a normal distribution with a 30% standard deviation. The result of this calculation is a uranium inhalation rate of 3,173 pCi/day, which assumes the intake was 2% enriched uranium. The average airborne concentration of uranium that is associated with this intake rate is about 330 pCi/m$^3$.

The annual skin dose associated with the direct deposition of airborne uranium onto skin and clothing is estimated as follows:

> Daily Skin Contamination = (330 pCi/m$^3$)(0.00075 m/s)(3,600 sec/hr)(8 hr/day) = 7,095 pCi/m$^2$ after 8 hours of exposure
>
> Unit Conversion = (7,095 pCi/m$^2$)(1 GA/27 pCi) (1dis/sec-Bq))(60 sec/min) = 16,765 dpm/m$^2$ = 1.57 dpm/cm
>
> Skin Dose Rate = (1.57 dpm/cm$^2$)(40 mrem/hr cm$^2$/10,000 dpm)[6] = 6.28E-3 mrem/hr
>
> Yearly Skin Dose = (6.28E-3 mrem/h)(8 h/d)(250 d/yr) = 12.57 mrem/yr

[6] SC&A independently checked this DCF and confirmed that it is reasonable. See Attachment 1.

This annual exposure rate is directly proportional to the assumed average uranium concentration in urine. It is also important to acknowledge that this model assumes all the uranium deposited on skin and clothing during the course of a work day is completely removed at the end of the day after showering, and any uranium on clothing is removed during daily laundering. Both these assumptions would tend to reduce the annual exposure. Hence, we believe this annual dose is a plausible estimate of the exposures, and could be 10 times higher. The skin deposition dose of 12.57 mrem is assigned for each year of employment, as cited in entries #100–#115 of Appendices II.A-1, II.A-2, and II.A-3.

It is also possible that the worker experienced exposures to large flakes of uranium falling directly onto the EE's skin and clothing. This topic was discussed at length during the July 18, 2013, meeting of the Procedures Review Subcommittee. There appears to be general agreement that a skin exposure scenario involving the deposition of fine dust particles onto skin is plausible, but not large flakes; at least they would not be present for extended periods of time if they occurred. Hence, we ruled out this scenario. However, if such a scenario were to occur, the exposure rate to the skin directly under the flake would approach 240 mrem/hr.

## II.4 INTERNAL DOSE

Based on a review of the EE's bioassay data, it appears that the EE was on a quarterly uranium bioassay program from [redacted] to [redacted]. The urinalyses results ranged from 0 to 18 µg/L, with most of the results being close to or below the MDL of 14 µg/L. Therefore, it was assumed that the EE's chronic uranium intake rate during employment resulted in a urine concentration of 7 µg/L or an excretion rate of 9.8 µg/day. Assuming that all the uranium was 2% enriched (i.e., 1.616 pCi/µg), the EE's chronic uranium excretion rate can be assumed to be 15.82 pCi/day. Based on this excretion rate, which was entered into IMBA as an annual value with a data type of 'real,' the chronic uranium intake rate would be 267 pCi/day Type M or 3,173 pCi/day Type S uranium.

SC&A's DR–Method B acknowledges that, by assuming a chronic annual intake at the level of ½ MDA for [redacted] years, one should see a buildup of uranium in the body. Therefore, we generated a plot showing the uranium concentration in urine (µg/L) as a function of time for a worker that chronically inhaled 3,173 pCi/day of 2% enriched Type S uranium from [redacted] to [redacted], as shown in Figure II-2 below.

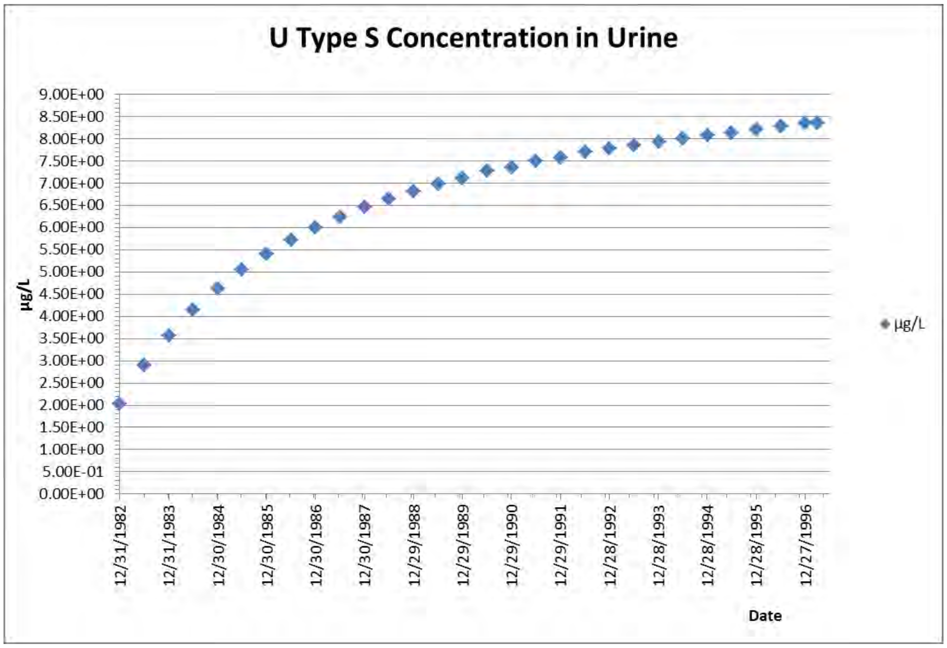


**Figure II-2. Concentration in Urine (µg/L) for Chronic Inhalation of 3,173 pCi/day of 2% enriched Type S Uranium**

For an additional comparison, Method B ran IMBA assuming 15.82 pCi/day with a data type of 'real' on the last day of the EE's employment and back calculated an intake of 2,656 pCi/d. Although this approach resulted in a lower intake value, this comparison indicated that our initial assumptions were reasonable. Therefore, Method B calculated internal doses assuming the claimant-favorable inhalation intake of 3,173 pCi/d of Type S uranium. This resulted in a total internal dose of approximately 300 mrem from the time of employment to the date of diagnosis. The annual internal doses to the skin are cited in entries #116–#142 of Appendix II.A-1, entries #116–#143 of Appendix II.A-2, and entries #116–#146 of Appendix II.A-3.

DR–Method B also investigated the potential exposures to skin from inadvertent ingestion and the intake of RU and found the exposures to be negligible.

### II.4.1 DR ASSUMPTIONS

Table II-7 below presents the external DR parameters used in our assessment for each year and work location.

**Table II-7. External DR Parameters for Case #[redacted]**

| Facility wide, D&D ([redacted], [redacted]–[redacted]) | | | |
|---|---|---|---|
| | Photons | | Electrons |
| | 30–250 keV | >250 keV | >15 keV |
| Energy fraction | 40% | 60% | 100% |
| DCF | 1 | 1 | 1 |
| Attenuation factor (for SCC on chest only) | NA | NA | 0.855 |

**Table II-7. External DR Parameters for Case #[redacted]**

| Plant 6 ([redacted]–[redacted]) | | | | |
|---|---|---|---|---|
| | Photons | | | Electrons |
| | <30 keV | 30–250 keV | >250 keV | >15 keV |
| Energy fraction | 13% | 33% | 54% | |
| DCF | 1 | 1 | 1 | 1 |
| Attenuation factor (for SCC on chest only) | NA | NA | NA | 0.855 |

Table II-8 presents details on each skin cancer documented in the DOL files and the associated dose assigned by SC&A in the DR. Table II-9 presents a breakdown of each type of assigned dose for each skin cancer location. Appendices II.A-1 and II.A-2 list the IREP input values used to calculate the POC for this DR. Note the majority of the assigned dose is attributed to recorded shallow dose.

**Table II-8. Skin Cancers and Total Assigned Doses**

| Cancer Type | Location | Diagnosis Date | ICD Code | Calculated dose to the skin (rem) | |
|---|---|---|---|---|---|
| | | | | Unattenuated | Attenuated |
| Squamous cell carcinoma | [redacted] | [redacted] | [redacted] | NA | 16.6 |
| Basal cell carcinoma | [redacted] | [redacted] | [redacted] | 18.9 | NA |
| Basal cell carcinoma | [redacted] | [redacted] | [redacted] | 18.9 | NA |
| Squamous cell carcinoma | [redacted] | [redacted] | [redacted] | 18.9 | NA |
| Squamous cell carcinoma | [redacted] | [redacted] | [redacted] | 18.9 | NA |

**Table II-9. External Doses Calculated by SC&A (rem)**

| | Appendix II.A-2 and II.A-3 Skin Dose Bare Skin (rem) | Appendix II.A-1 Skin Dose Attenuated due to Clothing (rem) |
|---|---|---|
| Recorded photon dose | 1.6 | 1.6 |
| Recorded shallow dose | 15.5 | 13.3 |
| Missed photon dose | 0.9 | 0.9 |
| X-ray | 0.13 | 0.13 |
| Missed neutron dose | 0.288 | 0.288 |
| Skin deposition | 0.201 | 0.201 |
| **Total** | **18.64** | **16.40** |

### II.4.1.1 Recorded Photon Doses

The values in the deep dose equivalent (DDE) column are the deep dose values recorded by the personnel dosimeter. The recorded photon doses are divided into the energy fractions appropriate for each plant location described in Table 6-8 of ORAUT-TKBS-0017-6. In cases involving skin cancers, the claimant-favorable assumption is a DCF of 1.0 for all recorded and missed external doses, as per the procedures in ORAUT-OTIB-0017. An example of SC&A's calculation of recorded photon dose for [redacted] is provided below.

In [redacted], the EE received a recorded DDE dose of 0.173 rem. Since the EE was working in Plant [redacted] at the time, the recorded photon dose is divided into photon energy fractions of

<30 keV, 30–250 keV, and >250 keV. As was previously mentioned, a DCF of 1.0 is used for cancers involving the skin.

> Calculated skin dose (<30 keV) = 0.173*1*0.13 = 0.022 rem
> Calculated skin dose (30–250 keV) = 0.173*1*0.33 = 0.057 rem
> Calculated skin dose (>250 keV) = 0.173*1*0.54 = 0.093 rem

Using the procedures in OCAS-IG-001, these doses are assumed to have a normal distribution with a 30% standard deviation. The recorded photon doses are listed in entries #1 through #36 of Appendices II.A-1 and II.A-2 and a total 1.6 rem for each of the cancer sites.

#### II.4.1.2 Recorded Shallow Dose

The values in the shallow dose equivalent (SDE) column are all of the doses recorded by the OW, which includes both penetrating and non-penetrating (gamma plus beta) doses. The shallow beta dose is separated out by subtracting the DDE from the SDE values. All of the recorded shallow doses are assumed to be >15 keV electrons, as per the procedures in Table 6-8 of ORAUT-TKBS-0017-6, and a DCF is 1.0 is used. An example of SC&A's calculation of recorded photon dose for [redacted] is provided below.

In [redacted], the EE received a recorded non-penetrating dose of 2.7 rem. Since the DCF is 1.0 and there are no other multipliers for the cancers located on the [redacted] and [redacted], the assigned dose for that year is 2.7 rem. For the cancer located on the [redacted], the beta dose is assumed to be attenuated by clothing and coveralls. The clothing attenuation procedures for shallow dose are described on page 7 of ORAUT-OTIB-0017:

> *For likely non-compensable cases, an acceptable claimant-favorable approach is to assume 100% transmission (i.e., ignore attenuation). For likely compensable cases, an acceptable minimizing approach is to assume a transmission of 0.6 (unless there is evidence a face shield was used and the skin cancer was on the face, in which case 0.41 would be appropriate). For cases in which a best estimate is applied and the specific type of protective clothing is unknown, a factor of 0.855 for uranium is appropriate (equal to the average of the 0.80 and 0.91 factors listed above).*

SC&A chose the best-estimate attenuation factor of 0.855 and applied it to the recorded shallow dose. For [redacted], the assigned shallow dose to the skin of the [redacted] is 2.32 rem. Using the procedures in OCAS-IG-001, the shallow doses are assumed to have a normal distribution with a 30% standard deviation. The recorded photon doses are listed in entries #37 through #47 of Appendices II.A-1 and II.A-2 and a total 15.5 rem to the skin on the [redacted] and [redacted] and 13.3 rem to the skin on the [redacted]. The recorded shallow dose represents the majority of the total assigned dose.

### II.4.1.3 Missed Photon Dose

SC&A assigned missed dose to the skin by multiplying the number of zero readings per year by one-half the limit of detection (LOD). SC&A reviewed the external dosimetry data in detail and assessed each monthly recorded value. Each reading that is below the LOD/2 is considered a zero reading. The procedures on page 21 of ORAUT-OTIB-0017 are used to assess the missed dose. These procedures are specific for Savannah River and Hanford, but they seemed appropriate and claimant favorable for Fernald as well.

> *For any badge cycle with a zero result in either the OW or S reading, or both, assign a single missed dose as explained in Items 7-9 below.*
>
> *If only the OW reading was reported as zero, the missed dose assigned should be the appropriate OW LOD for that era (divided by 2, treated as lognormal) and considered electrons (corrected for attenuation, if applicable) or low-energy photons (multiplied by 0.6 in the film badge era, if applicable) consistent with the approach taken in Step 2.*
>
> *If only the S reading was reported as zero, the missed dose assigned should be the appropriate S LOD for that era (divided by 2, treated as lognormal) and considered 30-250 keV photons.*
>
> *If both the OW and S readings were reported as zero, the missed dose assigned should be the appropriate OW LOD for that era (divided by 2, treated as lognormal) and considered 30-250 keV photons.*

After reviewing the monthly exchange data, SC&A found that all of the zero and below the LOD/2 readings were penetrating deep dose values. Therefore, all of the missed dose is assigned as photons. An example of SC&A's calculation of recorded photon dose for [redacted] is provided below.

In [redacted], the EE received 6 zero readings and the LOD/2 is 15 mrem. Since the EE was working in Plant [redacted] at the time, the recorded photon dose is divided into photon energy fractions of <30 keV, 30–250 keV, and >250 keV. As was previously mentioned, the DCF of 1.0 is used for cancers involving the skin.

> Calculated missed skin dose (<30 keV) = 6 zeroes*0.015*1*0.13 = 0.012 rem
> Calculated missed skin dose (30–250 keV) = 6 zeroes*0.015*1*0.33 = 0.030 rem
> Calculated missed skin dose (>250 keV) = 6 zeroes*0.015*1*0.54 = 0.049 rem

Using the procedures in OCAS-IG-001, these doses are assumed to have a lognormal distribution with a geometric standard deviation of 1.52. The missed photon doses are listed in entries #48 through #77 of Appendices II.A-1 and II.A-2, and a total 0.904 rem for each of the cancer sites.

#### II.4.1.4 Occupational Medical Dose

SC&A assigned occupational medical dose for each documented x-ray examination in the DOE records. The EE had conventional chest x-rays performed in [redacted], [redacted], [redacted], [redacted], [redacted] and [redacted]. The x-ray doses to the skin were assigned using the values in Tables 3-14 through 3-16 of ORAUT-TKBS-0017-3. Using the procedures in ORAUT-TKBS-0017-3, these doses are assumed to be 30–250 keV photons and have a normal distribution with a 30% standard deviation. The occupational medical doses are listed in entries #78 through #83 of Appendices II.A-1 and II.A-2 and a total 0.131 rem for each of the cancer sites.

#### II.4.1.5 Calculation of POC

The IREP input values of Appendix II.A-1 and Appendix II.A-2 were imported into the IREP program available on the DCAS website. Since there are multiple primary cancer sites for this case, the multiple case site portion of the IREP program was used in order to determine the total POC for this DR. The POC is determined to be 39.33%, which would not make this claim eligible for compensation. Table II-10 presents the calculated POC for each skin cancer site.

**Table II-10. Calculated POC for Skin Cancers for Case #[redacted]**

| Skin Cancer | POC |
|---|---|
| SCC [redacted] | 4.58% |
| BCC [redacted] | 16.51% |
| BCC [redacted] | 15.73% |
| SCC [redacted] | 4.94% |
| SCC [redacted] | 4.94% |
| **Total** | **39.33%** |

## II.5 REFERENCES


DOE (U.S. Department of Energy), 2000. *Recycled Uranium Project Report*, Final Report, Ohio Field Office, Fernald Environmental Management Project, Fernald Ohio.

EPA 1999. U.S. Environmental Protection Agency, "Cancer Risk Coefficients for Environmental Exposure to Radionuclides," 402-R-99-001, September 1999.

Fernald 1987. *History of FMPC Radionuclide Discharges*, FMPC-2082, M.W. Boback, T.A., Dugan, D.A., Fleming, R.B., Grant, and R.W. Keys, May 1987.

Heatherton, R.C., 1960. *Estimation of Depth Dose from UX2 Beta Rays.*

Johnson, W.A. and H.V. Heacker, 1963. *Health Protection Review of National Lead Co. of Ohio Letter Report*, Atomic Energy Commission, Bethesda, Maryland.

OCAS-IG-001. 2007. *External Dose Reconstruction Implementation Guideline,* Rev. 3, National Institute for Occupational Safety and Health, Office of Compensation Analysis and Support, Cincinnati, Ohio. November 21, 2007.

ORAUT-TKBS-0012-6. 2007. *Oak Ridge National Laboratory – Occupational External Dose*, Rev. 1, Oak Ridge Associated Universities Team, Cincinnati, Ohio. September 10, 2007.

ORAUT-OTIB-0017. 2005. *Technical Information Bulletin: Interpretation of Dosimetry Data for Assignment of Shallow Dose,* Rev. 01, Oak Ridge Associated Universities Team, Cincinnati, Ohio. October 11, 2005.

ORAUT-TKBS-0017-2, 2004. *Technical Basis Document for the Fernald Environmental Management Project (FEMP) – Site Description*, Rev. 00, Oak Ridge Associated Universities Team, Cincinnati, Ohio. May 20, 2004.

ORAUT-TKBS-0017-3, 2004. *Technical Basis Document for the Fernald Environmental Management Project (FEMP) – Occupational Medical Dose*, Rev. 00, Oak Ridge Associated Universities Team, Cincinnati, Ohio. February 11, 2004.

ORAUT-TKBS-0017-5. 2004. *Technical Basis Document for the Fernald Environmental Management Project (FEMP) – Occupational Internal Dose,* Rev. 00, Oak Ridge Associated Universities Team, Cincinnati, Ohio. May 28, 2004.

ORAUT-TKBS-0017-6, 2004. *Technical Basis Document for the Fernald Environmental Management Project (FEMP) – Occupational External Dose*, Rev. 00, Oak Ridge Associated Universities Team, Cincinnati, Ohio. April 20, 2004.

ORAUT-TKBS-0030. 2013. *An Exposure Matrix for Bridgeport Brass: Havens Laboratory and Adrian Plant*, Rev. 01. Oak Ridge Associated Universities Team, Cincinnati, Ohio. January 24, 2013.

Reilly, E.J., 1989. "A Trident Scholar Project Report No. 159, Evaluation of Bubble Dosimeter Response to Neutron Radiation," United States Naval Academy, USNA-TSPR; No. 150.

SC&A 2011. "SC&A Review of Issues Related to Reconstruction of Doses for Workers Exposed to Recycled Uranium at Fernald – A Second White Paper, Sanford Cohen and Associates, Inc., April 2011.

Thomas, J.M., and R.S. Bogard, 1994. *Technical Basis for Beta Skin Dose Calculations at the Y-12 Plant, Oak Ridge Y-12 Plant*, Oak Ridge, Tennessee. March 1994. (SRDB 19821)

# APPENDIX II.A-1: IREP INPUT – [REDACTED] SCC ON THE [REDACTED]

| | Exposure year | Radiation Type | Exposure rate | Distribution | Parameter 1 | Parameter 2 |
|---|---|---|---|---|---|---|
| 1 | [redact] | <30 keV photons | acute | normal | 0.022 | 0.007 |
| 2 | [redact] | <30 keV photons | acute | normal | 0.038 | 0.011 |
| 3 | [redact] | <30 keV photons | acute | normal | 0.021 | 0.006 |
| 4 | [redact] | <30 keV photons | acute | normal | 0.018 | 0.005 |
| 5 | [redact] | <30 keV photons | acute | normal | 0.052 | 0.016 |
| 6 | [redact] | <30 keV photons | acute | normal | 0.024 | 0.007 |
| 7 | [redact] | 30–250 keV photons | acute | normal | 0.002 | 0.001 |
| 8 | [redact] | 30–250 keV photons | acute | normal | 0.057 | 0.017 |
| 9 | [redact] | 30–250 keV photons | acute | normal | 0.095 | 0.029 |
| 10 | [redact] | 30–250 keV photons | acute | normal | 0.054 | 0.016 |
| 11 | [redact] | 30–250 keV photons | acute | normal | 0.047 | 0.014 |
| 12 | [redact] | 30–250 keV photons | acute | normal | 0.133 | 0.040 |
| 13 | [redact] | 30–250 keV photons | acute | normal | 0.060 | 0.018 |
| 14 | [redact] | 30–250 keV photons | acute | normal | 0.020 | 0.006 |
| 15 | [redact] | 30–250 keV photons | acute | normal | 0.011 | 0.003 |
| 16 | [redact] | 30–250 keV photons | acute | normal | 0.016 | 0.005 |
| 17 | [redact] | 30–250 keV photons | acute | normal | 0.015 | 0.004 |
| 18 | [redact] | 30–250 keV photons | acute | normal | 0.014 | 0.004 |
| 19 | [redact] | 30–250 keV photons | acute | normal | 0.011 | 0.003 |
| 20 | [redact] | 30–250 keV photons | acute | normal | 0.004 | 0.001 |
| 21 | [redact] | 30–250 keV photons | acute | normal | 0.006 | 0.002 |
| 22 | [redact] | >250 keV photons | acute | normal | 0.003 | 0.001 |
| 23 | [redact] | >250 keV photons | acute | normal | 0.093 | 0.028 |
| 24 | [redact] | >250 keV photons | acute | normal | 0.156 | 0.047 |
| 25 | [redact] | >250 keV photons | acute | normal | 0.088 | 0.026 |
| 26 | [redact] | >250 keV photons | acute | normal | 0.076 | 0.023 |
| 27 | [redact] | >250 keV photons | acute | normal | 0.217 | 0.065 |
| 28 | [redact] | >250 keV photons | acute | normal | 0.098 | 0.029 |
| 29 | [redact] | >250 keV photons | acute | normal | 0.030 | 0.009 |
| 30 | [redact] | >250 keV photons | acute | normal | 0.016 | 0.005 |
| 31 | [redact] | >250 keV photons | acute | normal | 0.023 | 0.007 |
| 32 | [redact] | >250 keV photons | acute | normal | 0.022 | 0.007 |
| 33 | [redact] | >250 keV photons | acute | normal | 0.022 | 0.006 |
| 34 | [redact] | >250 keV photons | acute | normal | 0.016 | 0.005 |
| 35 | [redact] | >250 keV photons | acute | normal | 0.007 | 0.002 |
| 36 | [redact] | >250 keV photons | acute | normal | 0.010 | 0.003 |
| 37 | [redact] | <15 keV electrons | acute | normal | 0.04 | 0.012 |
| 38 | [redact] | <15 keV electrons | acute | normal | 2.32 | 0.696 |
| 39 | [redact] | <15 keV electrons | acute | normal | 2.85 | 0.856 |
| 40 | [redact] | <15 keV electrons | acute | normal | 1.60 | 0.481 |
| 41 | [redact] | >15 keV electrons | acute | normal | 1.76 | 0.529 |
| 42 | [redact] | >15 keV electrons | acute | normal | 3.51 | 1.054 |
| 43 | [redact] | >15 keV electrons | acute | normal | 0.62 | 0.185 |
| 44 | [redact] | >15 keV electrons | acute | normal | 0.28 | 0.084 |

## Appendix II.A-1: IREP Input – [Redacted] SCC on the [Redacted] (continued)

| | | | | | | |
|---|---|---|---|---|---|---|
| 45 | [redact] | >15 keV electrons | acute | normal | 0.009 | 0.003 |
| 46 | [redact] | >15 keV electrons | acute | normal | 0.230 | 0.069 |
| 47 | [redact] | >15 keV electrons | acute | normal | 0.046 | 0.014 |
| 48 | [redact] | <30 keV photons | acute | lognormal | 0.012 | 1.52 |
| 49 | [redact] | <30 keV photons | acute | lognormal | 0.004 | 1.52 |
| 50 | [redact] | <30 keV photons | acute | lognormal | 0.003 | 1.52 |
| 51 | [redact] | <30 keV photons | acute | lognormal | 0.005 | 1.52 |
| 52 | [redact] | 30–250 keV photons | acute | lognormal | 0.018 | 1.52 |
| 53 | [redact] | 30–250 keV photons | acute | lognormal | 0.030 | 1.52 |
| 54 | [redact] | 30–250 keV photons | acute | lognormal | 0.099 | 1.52 |
| 55 | [redact] | 30–250 keV photons | acute | lognormal | 0.007 | 1.52 |
| 56 | [redact] | 30–250 keV photons | acute | lognormal | 0.013 | 1.52 |
| 57 | [redact] | 30–250 keV photons | acute | lognormal | 0.040 | 1.52 |
| 58 | [redact] | 30–250 keV photons | acute | lognormal | 0.044 | 1.52 |
| 59 | [redact] | 30–250 keV photons | acute | lognormal | 0.048 | 1.52 |
| 60 | [redact] | 30–250 keV photons | acute | lognormal | 0.008 | 1.52 |
| 61 | [redact] | 30–250 keV photons | acute | lognormal | 0.008 | 1.52 |
| 62 | [redact] | 30–250 keV photons | acute | lognormal | 0.008 | 1.52 |
| 63 | [redact] | 30–250 keV photons | acute | lognormal | 0.016 | 1.52 |
| 64 | [redact] | 30–250 keV photons | acute | lognormal | 0.064 | 1.52 |
| 65 | [redact] | >250 keV photons | acute | lognormal | 0.027 | 1.52 |
| 66 | [redact] | >250 keV photons | acute | lognormal | 0.049 | 1.52 |
| 67 | [redact] | >250 keV photons | acute | lognormal | 0.016 | 1.52 |
| 68 | [redact] | >250 keV photons | acute | lognormal | 0.011 | 1.52 |
| 69 | [redact] | >250 keV photons | acute | lognormal | 0.022 | 1.52 |
| 70 | [redact] | >250 keV photons | acute | lognormal | 0.060 | 1.52 |
| 71 | [redact] | >250 keV photons | acute | lognormal | 0.066 | 1.52 |
| 72 | [redact] | >250 keV photons | acute | lognormal | 0.072 | 1.52 |
| 73 | [redact] | >250 keV photons | acute | lognormal | 0.012 | 1.52 |
| 74 | [redact] | >250 keV photons | acute | lognormal | 0.012 | 1.52 |
| 75 | [redact] | >250 keV photons | acute | lognormal | 0.012 | 1.52 |
| 76 | [redact] | >250 keV photons | acute | lognormal | 0.024 | 1.52 |
| 77 | [redact] | >250 keV photons | acute | lognormal | 0.096 | 1.52 |
| 78 | [redact] | 30–250 keV photons | acute | normal | 0.024 | 0.0071 |
| 79 | [redact] | 30–250 keV photons | acute | normal | 0.024 | 0.0071 |
| 80 | [redact] | 30–250 keV photons | acute | normal | 0.024 | 0.0071 |
| 81 | [redact] | 30–250 keV photons | acute | normal | 0.017 | 0.0051 |
| 82 | [redact] | 30–250 keV photons | acute | normal | 0.021 | 0.0064 |
| 83 | [redact] | 30–250 keV photons | acute | normal | 0.021 | 0.0064 |
| 84 | [redact] | 0.1–2 MeV neutrons | chronic | normal | 0.018 | 0.0054 |
| 85 | [redact] | 0.1–2 MeV neutrons | chronic | normal | 0.018 | 0.0054 |
| 86 | [redact] | 0.1–2 MeV neutrons | chronic | normal | 0.018 | 0.0054 |
| 87 | [redact] | 0.1–2 MeV neutrons | chronic | normal | 0.018 | 0.0054 |
| 88 | [redact] | 0.1–2 MeV neutrons | chronic | normal | 0.018 | 0.0054 |
| 89 | [redact] | 0.1–2 MeV neutrons | chronic | normal | 0.018 | 0.0054 |

## Appendix II.A-1: IREP Input – [Redacted] SCC on the [Redacted] (continued)

| | | | | | | |
|---|---|---|---|---|---|---|
| 90 | [redact] | 0.1–2 MeV neutrons | chronic | normal | 0.018 | 0.0054 |
| 91 | [redact] | 0.1–2 MeV neutrons | chronic | normal | 0.018 | 0.0054 |
| 92 | [redact] | 0.1–2 MeV neutrons | chronic | normal | 0.018 | 0.0054 |
| 93 | [redact] | 0.1–2 MeV neutrons | chronic | normal | 0.018 | 0.0054 |
| 94 | [redact] | 0.1–2 MeV neutrons | chronic | normal | 0.018 | 0.0054 |
| 95 | [redact] | 0.1–2 MeV neutrons | chronic | normal | 0.018 | 0.0054 |
| 96 | [redact] | 0.1–2 MeV neutrons | chronic | normal | 0.018 | 0.0054 |
| 97 | [redact] | 0.1–2 MeV neutrons | chronic | normal | 0.018 | 0.0054 |
| 98 | [redact] | 0.1–2 MeV neutrons | chronic | normal | 0.018 | 0.0054 |
| 99 | [redact] | 0.1–2 MeV neutrons | chronic | normal | 0.018 | 0.0054 |
| 100 | [redact] | >15 keV electrons | acute | normal | 0.013 | 0.0038 |
| 101 | [redact] | >15 keV electrons | acute | normal | 0.013 | 0.0038 |
| 102 | [redact] | >15 keV electrons | acute | normal | 0.013 | 0.0038 |
| 103 | [redact] | >15 keV electrons | acute | normal | 0.013 | 0.0038 |
| 104 | [redact] | >15 keV electrons | acute | normal | 0.013 | 0.0038 |
| 105 | [redact] | >15 keV electrons | acute | normal | 0.013 | 0.0038 |
| 106 | [redact] | >15 keV electrons | acute | normal | 0.013 | 0.0038 |
| 107 | [redact] | >15 keV electrons | acute | normal | 0.013 | 0.0038 |
| 108 | [redact] | >15 keV electrons | acute | normal | 0.013 | 0.0038 |
| 109 | [redact] | >15 keV electrons | acute | normal | 0.013 | 0.0038 |
| 110 | [redact] | >15 keV electrons | acute | normal | 0.013 | 0.0038 |
| 111 | [redact] | >15 keV electrons | acute | normal | 0.013 | 0.0038 |
| 112 | [redact] | >15 keV electrons | acute | normal | 0.013 | 0.0038 |
| 113 | [redact] | >15 keV electrons | acute | normal | 0.013 | 0.0038 |
| 114 | [redact] | >15 keV electrons | acute | normal | 0.013 | 0.0038 |
| 115 | [redact] | >15 keV electrons | acute | normal | 0.013 | 0.0038 |
| 116 | [redact] | alpha | chronic | normal | 5.69E-05 | 0.0000 |
| 117 | [redact] | alpha | chronic | normal | 7.95E-04 | 0.0002 |
| 118 | [redact] | alpha | chronic | normal | 1.51E-03 | 0.0005 |
| 119 | [redact] | alpha | chronic | normal | 2.26E-03 | 0.0007 |
| 120 | [redact] | alpha | chronic | normal | 3.05E-03 | 0.0009 |
| 121 | [redact] | alpha | chronic | normal | 3.87E-03 | 0.0012 |
| 122 | [redact] | alpha | chronic | normal | 4.73E-03 | 0.0014 |
| 123 | [redact] | alpha | chronic | normal | 5.58E-03 | 0.0017 |
| 124 | [redact] | alpha | chronic | normal | 6.46E-03 | 0.0019 |
| 125 | [redact] | alpha | chronic | normal | 7.36E-03 | 0.0022 |
| 126 | [redact] | alpha | chronic | normal | 8.29E-03 | 0.0025 |
| 127 | [redact] | alpha | chronic | normal | 9.19E-03 | 0.0028 |
| 128 | [redact] | alpha | chronic | normal | 1.01E-02 | 0.0030 |
| 129 | [redact] | alpha | chronic | normal | 1.11E-02 | 0.0033 |
| 130 | [redact] | alpha | chronic | normal | 1.20E-02 | 0.0036 |
| 131 | [redact] | alpha | chronic | normal | 1.26E-02 | 0.0038 |
| 132 | [redact] | alpha | chronic | normal | 1.27E-02 | 0.0038 |
| 133 | [redact] | alpha | chronic | normal | 1.30E-02 | 0.0039 |
| 134 | [redact] | alpha | chronic | normal | 1.32E-02 | 0.0040 |

## Appendix II.A-1: IREP Input – [Redacted] SCC on the [Redacted] (continued)

| | | | | | | |
|---|---|---|---|---|---|---|
| 135 | [redact] | alpha | chronic | normal | 1.33E-02 | 0.0040 |
| 136 | [redact] | alpha | chronic | normal | 1.34E-02 | 0.0040 |
| 137 | [redact] | alpha | chronic | normal | 1.35E-02 | 0.0041 |
| 138 | [redact] | alpha | chronic | normal | 1.37E-02 | 0.0041 |
| 139 | [redact] | alpha | chronic | normal | 1.37E-02 | 0.0041 |
| 140 | [redact] | alpha | chronic | normal | 1.38E-02 | 0.0041 |
| 141 | [redact] | alpha | chronic | normal | 1.39E-02 | 0.0042 |
| 142 | [redact] | alpha | chronic | normal | 5.44E-03 | 0.0016 |

# APPENDIX II.A-2: IREP INPUT – [REDACTED] BCC ON THE [REDACTED]

| | Exposure year | Radiation Type | Exposure rate | Distribution | Parameter 1 | Parameter 2 |
|---|---|---|---|---|---|---|
| 1 | [redact] | <30 keV photons | acute | normal | 0.0225 | 0.007 |
| 2 | [redact] | <30 keV photons | acute | normal | 0.0376 | 0.011 |
| 3 | [redact] | <30 keV photons | acute | normal | 0.0212 | 0.006 |
| 4 | [redact] | <30 keV photons | acute | normal | 0.0183 | 0.005 |
| 5 | [redact] | <30 keV photons | acute | normal | 0.0523 | 0.016 |
| 6 | [redact] | <30 keV photons | acute | normal | 0.0235 | 0.007 |
| 7 | [redact] | 30–250 keV photons | acute | normal | 0.0020 | 0.001 |
| 8 | [redact] | 30–250 keV photons | acute | normal | 0.0571 | 0.017 |
| 9 | [redact] | 30–250 keV photons | acute | normal | 0.0954 | 0.029 |
| 10 | [redact] | 30–250 keV photons | acute | normal | 0.0538 | 0.016 |
| 11 | [redact] | 30–250 keV photons | acute | normal | 0.0465 | 0.014 |
| 12 | [redact] | 30–250 keV photons | acute | normal | 0.1327 | 0.040 |
| 13 | [redact] | 30–250 keV photons | acute | normal | 0.0597 | 0.018 |
| 14 | [redact] | 30–250 keV photons | acute | normal | 0.0200 | 0.006 |
| 15 | [redact] | 30–250 keV photons | acute | normal | 0.0108 | 0.003 |
| 16 | [redact] | 30–250 keV photons | acute | normal | 0.0156 | 0.005 |
| 17 | [redact] | 30–250 keV photons | acute | normal | 0.0148 | 0.004 |
| 18 | [redact] | 30–250 keV photons | acute | normal | 0.0144 | 0.004 |
| 19 | [redact] | 30–250 keV photons | acute | normal | 0.0108 | 0.003 |
| 20 | [redact] | 30–250 keV photons | acute | normal | 0.0044 | 0.001 |
| 21 | [redact] | 30–250 keV photons | acute | normal | 0.0064 | 0.002 |
| 22 | [redact] | >250 keV photons | acute | normal | 0.0030 | 0.001 |
| 23 | [redact] | >250 keV photons | acute | normal | 0.0934 | 0.028 |
| 24 | [redact] | >250 keV photons | acute | normal | 0.1561 | 0.047 |
| 25 | [redact] | >250 keV photons | acute | normal | 0.0880 | 0.026 |
| 26 | [redact] | >250 keV photons | acute | normal | 0.0761 | 0.023 |
| 27 | [redact] | >250 keV photons | acute | normal | 0.2171 | 0.065 |
| 28 | [redact] | >250 keV photons | acute | normal | 0.0977 | 0.029 |
| 29 | [redact] | >250 keV photons | acute | normal | 0.0300 | 0.009 |
| 30 | [redact] | >250 keV photons | acute | normal | 0.0162 | 0.005 |
| 31 | [redact] | >250 keV photons | acute | normal | 0.0234 | 0.007 |
| 32 | [redact] | >250 keV photons | acute | normal | 0.0222 | 0.007 |
| 33 | [redact] | >250 keV photons | acute | normal | 0.0216 | 0.006 |
| 34 | [redact] | >250 keV photons | acute | normal | 0.0162 | 0.005 |
| 35 | [redact] | >250 keV photons | acute | normal | 0.0066 | 0.002 |
| 36 | [redact] | >250 keV photons | acute | normal | 0.0096 | 0.003 |
| 37 | [redact] | <15 keV electrons | acute | normal | 0.0470 | 0.014 |
| 38 | [redact] | <15 keV electrons | acute | normal | 2.7130 | 0.814 |
| 39 | [redact] | <15 keV electrons | acute | normal | 3.3380 | 1.001 |
| 40 | [redact] | <15 keV electrons | acute | normal | 1.8760 | 0.563 |
| 41 | [redact] | <15 keV electrons | acute | normal | 2.0620 | 0.619 |
| 42 | [redact] | <15 keV electrons | acute | normal | 4.1100 | 1.233 |
| 43 | [redact] | <15 keV electrons | acute | normal | 0.7220 | 0.217 |
| 44 | [redact] | <15 keV electrons | acute | normal | 0.3270 | 0.098 |
| 45 | [redact] | <15 keV electrons | acute | normal | 0.0010 | 0.000 |

## Appendix II.A-2: IREP Input – [Redacted] BCC on the [Redacted] (continued)

| | | | | | | |
|---|---|---|---|---|---|---|
| 46 | [redact] | <15 keV electrons | acute | normal | 0.2690 | 0.081 |
| 47 | [redact] | <15 keV electrons | acute | normal | 0.0540 | 0.016 |
| 48 | [redact] | <30 keV photons | acute | lognormal | 0.0117 | 1.52 |
| 49 | [redact] | <30 keV photons | acute | lognormal | 0.0039 | 1.52 |
| 50 | [redact] | <30 keV photons | acute | lognormal | 0.0026 | 1.52 |
| 51 | [redact] | <30 keV photons | acute | lognormal | 0.0052 | 1.52 |
| 52 | [redact] | 30–250 keV photons | acute | lognormal | 0.0180 | 1.52 |
| 53 | [redact] | 30–250 keV photons | acute | lognormal | 0.0297 | 1.52 |
| 54 | [redact] | 30–250 keV photons | acute | lognormal | 0.0990 | 1.52 |
| 55 | [redact] | 30–250 keV photons | acute | lognormal | 0.0066 | 1.52 |
| 56 | [redact] | 30–250 keV photons | acute | lognormal | 0.0132 | 1.52 |
| 57 | [redact] | 30–250 keV photons | acute | lognormal | 0.0400 | 1.52 |
| 58 | [redact] | 30–250 keV photons | acute | lognormal | 0.0440 | 1.52 |
| 59 | [redact] | 30–250 keV photons | acute | lognormal | 0.0480 | 1.52 |
| 60 | [redact] | 30–250 keV photons | acute | lognormal | 0.0080 | 1.52 |
| 61 | [redact] | 30–250 keV photons | acute | lognormal | 0.0080 | 1.52 |
| 62 | [redact] | 30–250 keV photons | acute | lognormal | 0.0080 | 1.52 |
| 63 | [redact] | 30–250 keV photons | acute | lognormal | 0.0160 | 1.52 |
| 64 | [redact] | 30–250 keV photons | acute | lognormal | 0.0640 | 1.52 |
| 65 | [redact] | >250 keV photons | acute | lognormal | 0.0270 | 1.52 |
| 66 | [redact] | >250 keV photons | acute | lognormal | 0.0486 | 1.52 |
| 67 | [redact] | >250 keV photons | acute | lognormal | 0.0162 | 1.52 |
| 68 | [redact] | >250 keV photons | acute | lognormal | 0.0108 | 1.52 |
| 69 | [redact] | >250 keV photons | acute | lognormal | 0.0216 | 1.52 |
| 70 | [redact] | >250 keV photons | acute | lognormal | 0.0600 | 1.52 |
| 71 | [redact] | >250 keV photons | acute | lognormal | 0.0660 | 1.52 |
| 72 | [redact] | >250 keV photons | acute | lognormal | 0.0720 | 1.52 |
| 73 | [redact] | >250 keV photons | acute | lognormal | 0.0120 | 1.52 |
| 74 | [redact] | >250 keV photons | acute | lognormal | 0.0120 | 1.52 |
| 75 | [redact] | >250 keV photons | acute | lognormal | 0.0120 | 1.52 |
| 76 | [redact] | >250 keV photons | acute | lognormal | 0.0240 | 1.52 |
| 77 | [redact] | >250 keV photons | acute | lognormal | 0.0960 | 1.52 |
| 78 | [redact] | 30–250 keV photons | acute | normal | 0.0237 | 0.00711 |
| 79 | [redact] | 30–250 keV photons | acute | normal | 0.0237 | 0.00711 |
| 80 | [redact] | 30–250 keV photons | acute | normal | 0.0237 | 0.00711 |
| 81 | [redact] | 30–250 keV photons | acute | normal | 0.0171 | 0.00513 |
| 82 | [redact] | 30–250 keV photons | acute | normal | 0.0214 | 0.00642 |
| 83 | [redact] | 30–250 keV photons | acute | normal | 0.0214 | 0.00642 |
| 84 | [redact] | 0.1–2 MeV neutrons | chronic | normal | 0.018 | 0.0054 |
| 85 | [redact] | 0.1–2 MeV neutrons | chronic | normal | 0.018 | 0.0054 |
| 86 | [redact] | 0.1–2 MeV neutrons | chronic | normal | 0.018 | 0.0054 |
| 87 | [redact] | 0.1–2 MeV neutrons | chronic | normal | 0.018 | 0.0054 |
| 88 | [redact] | 0.1–2 MeV neutrons | chronic | normal | 0.018 | 0.0054 |
| 89 | [redact] | 0.1–2 MeV neutrons | chronic | normal | 0.018 | 0.0054 |
| 90 | [redact] | 0.1–2 MeV neutrons | chronic | normal | 0.018 | 0.0054 |
| 91 | [redact] | 0.1–2 MeV neutrons | chronic | normal | 0.018 | 0.0054 |
| 92 | [redact] | 0.1–2 MeV neutrons | chronic | normal | 0.018 | 0.0054 |

## Appendix II.A-2: IREP Input – [Redacted] BCC on the [Redacted] (continued)

| | | | | | | |
|---|---|---|---|---|---|---|
| 93 | [redact] | 0.1–2 MeV neutrons | chronic | normal | 0.018 | 0.0054 |
| 94 | [redact] | 0.1–2 MeV neutrons | chronic | normal | 0.018 | 0.0054 |
| 95 | [redact] | 0.1–2 MeV neutrons | chronic | normal | 0.018 | 0.0054 |
| 96 | [redact] | 0.1–2 MeV neutrons | chronic | normal | 0.018 | 0.0054 |
| 97 | [redact] | 0.1–2 MeV neutrons | chronic | normal | 0.018 | 0.0054 |
| 98 | [redact] | 0.1–2 MeV neutrons | chronic | normal | 0.018 | 0.0054 |
| 99 | [redact] | 0.1–2 MeV neutrons | chronic | normal | 0.018 | 0.0054 |
| 100 | [redact] | >15 keV electrons | acute | normal | 0.013 | 0.0038 |
| 101 | [redact] | >15 keV electrons | acute | normal | 0.013 | 0.0038 |
| 102 | [redact] | >15 keV electrons | acute | normal | 0.013 | 0.0038 |
| 103 | [redact] | >15 keV electrons | acute | normal | 0.013 | 0.0038 |
| 104 | [redact] | >15 keV electrons | acute | normal | 0.013 | 0.0038 |
| 105 | [redact] | >15 keV electrons | acute | normal | 0.013 | 0.0038 |
| 106 | [redact] | >15 keV electrons | acute | normal | 0.013 | 0.0038 |
| 107 | [redact] | >15 keV electrons | acute | normal | 0.013 | 0.0038 |
| 108 | [redact] | >15 keV electrons | acute | normal | 0.013 | 0.0038 |
| 109 | [redact] | >15 keV electrons | acute | normal | 0.013 | 0.0038 |
| 110 | [redact] | >15 keV electrons | acute | normal | 0.013 | 0.0038 |
| 111 | [redact] | >15 keV electrons | acute | normal | 0.013 | 0.0038 |
| 112 | [redact] | >15 keV electrons | acute | normal | 0.013 | 0.0038 |
| 113 | [redact] | >15 keV electrons | acute | normal | 0.013 | 0.0038 |
| 114 | [redact] | >15 keV electrons | acute | normal | 0.013 | 0.0038 |
| 115 | [redact] | >15 keV electrons | acute | normal | 0.013 | 0.0038 |
| 116 | [redact] | alpha | chronic | normal | 5.69E-05 | 0.0000 |
| 117 | [redact] | alpha | chronic | normal | 7.95E-04 | 0.0002 |
| 118 | [redact] | alpha | chronic | normal | 1.51E-03 | 0.0005 |
| 119 | [redact] | alpha | chronic | normal | 2.26E-03 | 0.0007 |
| 120 | [redact] | alpha | chronic | normal | 3.05E-03 | 0.0009 |
| 121 | [redact] | alpha | chronic | normal | 3.87E-03 | 0.0012 |
| 122 | [redact] | alpha | chronic | normal | 4.73E-03 | 0.0014 |
| 123 | [redact] | alpha | chronic | normal | 5.58E-03 | 0.0017 |
| 124 | [redact] | alpha | chronic | normal | 6.46E-03 | 0.0019 |
| 125 | [redact] | alpha | chronic | normal | 7.36E-03 | 0.0022 |
| 126 | [redact] | alpha | chronic | normal | 8.29E-03 | 0.0025 |
| 127 | [redact] | alpha | chronic | normal | 9.19E-03 | 0.0028 |
| 128 | [redact] | alpha | chronic | normal | 1.01E-02 | 0.0030 |
| 129 | [redact] | alpha | chronic | normal | 1.11E-02 | 0.0033 |
| 130 | [redact] | alpha | chronic | normal | 1.20E-02 | 0.0036 |
| 131 | [redact] | alpha | chronic | normal | 1.26E-02 | 0.0038 |
| 132 | [redact] | alpha | chronic | normal | 1.27E-02 | 0.0038 |
| 133 | [redact] | alpha | chronic | normal | 1.30E-02 | 0.0039 |
| 134 | [redact] | alpha | chronic | normal | 1.32E-02 | 0.0040 |
| 135 | [redact] | alpha | chronic | normal | 1.33E-02 | 0.0040 |
| 136 | [redact] | alpha | chronic | normal | 1.34E-02 | 0.0040 |
| 137 | [redact] | alpha | chronic | normal | 1.35E-02 | 0.0041 |
| 138 | [redact] | alpha | chronic | normal | 1.37E-02 | 0.0041 |
| 139 | [redact] | alpha | chronic | normal | 1.37E-02 | 0.0041 |

## Appendix II.A-2: IREP Input – [Redacted] BCC on the [Redacted] (continued)

| | | | | | | |
|---|---|---|---|---|---|---|
| 140 | [redact] | alpha | chronic | normal | 1.38E-02 | 0.0041 |
| 141 | [redact] | alpha | chronic | normal | 1.39E-02 | 0.0042 |
| 142 | [redact] | alpha | chronic | normal | 1.39E-02 | 0.0042 |
| 143 | [redact] | alpha | chronic | normal | 7.41E-03 | 0.0022 |

# APPENDIX II.A-3: IREP INPUT – [REDACTED] SCCS AND BCC

| | Exposure year | Radiation Type | Exposure rate | Distribution | Parameter 1 | Parameter 2 |
|---|---|---|---|---|---|---|
| 1 | [redact] | <30 keV photons | acute | normal | 0.0225 | 0.007 |
| 2 | [redact] | <30 keV photons | acute | normal | 0.0376 | 0.011 |
| 3 | [redact] | <30 keV photons | acute | normal | 0.0212 | 0.006 |
| 4 | [redact] | <30 keV photons | acute | normal | 0.0183 | 0.005 |
| 5 | [redact] | <30 keV photons | acute | normal | 0.0523 | 0.016 |
| 6 | [redact] | <30 keV photons | acute | normal | 0.0235 | 0.007 |
| 7 | [redact] | 30–250 keV photons | acute | normal | 0.0020 | 0.001 |
| 8 | [redact] | 30–250 keV photons | acute | normal | 0.0571 | 0.017 |
| 9 | [redact] | 30–250 keV photons | acute | normal | 0.0954 | 0.029 |
| 10 | [redact] | 30–250 keV photons | acute | normal | 0.0538 | 0.016 |
| 11 | [redact] | 30–250 keV photons | acute | normal | 0.0465 | 0.014 |
| 12 | [redact] | 30–250 keV photons | acute | normal | 0.1327 | 0.040 |
| 13 | [redact] | 30–250 keV photons | acute | normal | 0.0597 | 0.018 |
| 14 | [redact] | 30–250 keV photons | acute | normal | 0.0200 | 0.006 |
| 15 | [redact] | 30–250 keV photons | acute | normal | 0.0108 | 0.003 |
| 16 | [redact] | 30–250 keV photons | acute | normal | 0.0156 | 0.005 |
| 17 | [redact] | 30–250 keV photons | acute | normal | 0.0148 | 0.004 |
| 18 | [redact] | 30–250 keV photons | acute | normal | 0.0144 | 0.004 |
| 19 | [redact] | 30–250 keV photons | acute | normal | 0.0108 | 0.003 |
| 20 | [redact] | 30–250 keV photons | acute | normal | 0.0044 | 0.001 |
| 21 | [redact] | 30–250 keV photons | acute | normal | 0.0064 | 0.002 |
| 22 | [redact] | >250 keV photons | acute | normal | 0.0030 | 0.001 |
| 23 | [redact] | >250 keV photons | acute | normal | 0.0934 | 0.028 |
| 24 | [redact] | >250 keV photons | acute | normal | 0.1561 | 0.047 |
| 25 | [redact] | >250 keV photons | acute | normal | 0.0880 | 0.026 |
| 26 | [redact] | >250 keV photons | acute | normal | 0.0761 | 0.023 |
| 27 | [redact] | >250 keV photons | acute | normal | 0.2171 | 0.065 |
| 28 | [redact] | >250 keV photons | acute | normal | 0.0977 | 0.029 |
| 29 | [redact] | >250 keV photons | acute | normal | 0.0300 | 0.009 |
| 30 | [redact] | >250 keV photons | acute | normal | 0.0162 | 0.005 |
| 31 | [redact] | >250 keV photons | acute | normal | 0.0234 | 0.007 |
| 32 | [redact] | >250 keV photons | acute | normal | 0.0222 | 0.007 |
| 33 | [redact] | >250 keV photons | acute | normal | 0.0216 | 0.006 |
| 34 | [redact] | >250 keV photons | acute | normal | 0.0162 | 0.005 |
| 35 | [redact] | >250 keV photons | acute | normal | 0.0066 | 0.002 |
| 36 | [redact] | >250 keV photons | acute | normal | 0.0096 | 0.003 |
| 37 | [redact] | <15 keV electrons | acute | normal | 0.0470 | 0.014 |
| 38 | [redact] | <15 keV electrons | acute | normal | 2.7130 | 0.814 |
| 39 | [redact] | <15 keV electrons | acute | normal | 3.3380 | 1.001 |
| 40 | [redact] | <15 keV electrons | acute | normal | 1.8760 | 0.563 |
| 41 | [redact] | <15 keV electrons | acute | normal | 2.0620 | 0.619 |
| 42 | [redact] | <15 keV electrons | acute | normal | 4.1100 | 1.233 |
| 43 | [redact] | <15 keV electrons | acute | normal | 0.7220 | 0.217 |
| 44 | [redact] | <15 keV electrons | acute | normal | 0.3270 | 0.098 |

## Appendix II.A-3: IREP Input – [Redacted] SCCs and BCC (continued)

| | | | | | | |
|---|---|---|---|---|---|---|
| 45 | [redact] | <15 keV electrons | acute | normal | 0.0010 | 0.000 |
| 46 | [redact] | <15 keV electrons | acute | normal | 0.2690 | 0.081 |
| 47 | [redact] | <15 keV electrons | acute | normal | 0.0540 | 0.016 |
| 48 | [redact] | <30 keV photons | acute | lognormal | 0.0117 | 1.52 |
| 49 | [redact] | <30 keV photons | acute | lognormal | 0.0039 | 1.52 |
| 50 | [redact] | <30 keV photons | acute | lognormal | 0.0026 | 1.52 |
| 51 | [redact] | <30 keV photons | acute | lognormal | 0.0052 | 1.52 |
| 52 | [redact] | 30–250 keV photons | acute | lognormal | 0.0180 | 1.52 |
| 53 | [redact] | 30–250 keV photons | acute | lognormal | 0.0297 | 1.52 |
| 54 | [redact] | 30–250 keV photons | acute | lognormal | 0.0990 | 1.52 |
| 55 | [redact] | 30–250 keV photons | acute | lognormal | 0.0066 | 1.52 |
| 56 | [redact] | 30–250 keV photons | acute | lognormal | 0.0132 | 1.52 |
| 57 | [redact] | 30–250 keV photons | acute | lognormal | 0.0400 | 1.52 |
| 58 | [redact] | 30–250 keV photons | acute | lognormal | 0.0440 | 1.52 |
| 59 | [redact] | 30–250 keV photons | acute | lognormal | 0.0480 | 1.52 |
| 60 | [redact] | 30–250 keV photons | acute | lognormal | 0.0080 | 1.52 |
| 61 | [redact] | 30–250 keV photons | acute | lognormal | 0.0080 | 1.52 |
| 62 | [redact] | 30–250 keV photons | acute | lognormal | 0.0080 | 1.52 |
| 63 | [redact] | 30–250 keV photons | acute | lognormal | 0.0160 | 1.52 |
| 64 | [redact] | 30–250 keV photons | acute | lognormal | 0.0640 | 1.52 |
| 65 | [redact] | >250 keV photons | acute | lognormal | 0.0270 | 1.52 |
| 66 | [redact] | >250 keV photons | acute | lognormal | 0.0486 | 1.52 |
| 67 | [redact] | >250 keV photons | acute | lognormal | 0.0162 | 1.52 |
| 68 | [redact] | >250 keV photons | acute | lognormal | 0.0108 | 1.52 |
| 69 | [redact] | >250 keV photons | acute | lognormal | 0.0216 | 1.52 |
| 70 | [redact] | >250 keV photons | acute | lognormal | 0.0600 | 1.52 |
| 71 | [redact] | >250 keV photons | acute | lognormal | 0.0660 | 1.52 |
| 72 | [redact] | >250 keV photons | acute | lognormal | 0.0720 | 1.52 |
| 73 | [redact] | >250 keV photons | acute | lognormal | 0.0120 | 1.52 |
| 74 | [redact] | >250 keV photons | acute | lognormal | 0.0120 | 1.52 |
| 75 | [redact] | >250 keV photons | acute | lognormal | 0.0120 | 1.52 |
| 76 | [redact] | >250 keV photons | acute | lognormal | 0.0240 | 1.52 |
| 77 | [redact] | >250 keV photons | acute | lognormal | 0.0960 | 1.52 |
| 78 | [redact] | 30–250 keV photons | acute | normal | 0.0237 | 0.00711 |
| 79 | [redact] | 30–250 keV photons | acute | normal | 0.0237 | 0.00711 |
| 80 | [redact] | 30–250 keV photons | acute | normal | 0.0237 | 0.00711 |
| 81 | [redact] | 30–250 keV photons | acute | normal | 0.0171 | 0.00513 |
| 82 | [redact] | 30–250 keV photons | acute | normal | 0.0214 | 0.00642 |
| 83 | [redact] | 30–250 keV photons | acute | normal | 0.0214 | 0.00642 |
| 84 | [redact] | 0.1–2 MeV neutrons | chronic | normal | 0.018 | 0.0054 |
| 85 | [redact] | 0.1–2 MeV neutrons | chronic | normal | 0.018 | 0.0054 |
| 86 | [redact] | 0.1–2 MeV neutrons | chronic | normal | 0.018 | 0.0054 |
| 87 | [redact] | 0.1–2 MeV neutrons | chronic | normal | 0.018 | 0.0054 |
| 88 | [redact] | 0.1–2 MeV neutrons | chronic | normal | 0.018 | 0.0054 |
| 89 | [redact] | 0.1–2 MeV neutrons | chronic | normal | 0.018 | 0.0054 |

## Appendix II.A-3: IREP Input – [Redacted] SCCs and BCC (continued)

| | | | | | | |
|---|---|---|---|---|---|---|
| 90 | [redact] | 0.1–2 MeV neutrons | chronic | normal | 0.018 | 0.0054 |
| 91 | [redact] | 0.1–2 MeV neutrons | chronic | normal | 0.018 | 0.0054 |
| 92 | [redact] | 0.1–2 MeV neutrons | chronic | normal | 0.018 | 0.0054 |
| 93 | [redact] | 0.1–2 MeV neutrons | chronic | normal | 0.018 | 0.0054 |
| 94 | [redact] | 0.1–2 MeV neutrons | chronic | normal | 0.018 | 0.0054 |
| 95 | [redact] | 0.1–2 MeV neutrons | chronic | normal | 0.018 | 0.0054 |
| 96 | [redact] | 0.1– 2 MeV neutrons | chronic | normal | 0.018 | 0.0054 |
| 97 | [redact] | 0.1–2 MeV neutrons | chronic | normal | 0.018 | 0.0054 |
| 98 | [redact] | 0.1–2 MeV neutrons | chronic | normal | 0.018 | 0.0054 |
| 99 | [redact] | 0.1–2 MeV neutrons | chronic | normal | 0.018 | 0.0054 |
| 100 | [redact] | >15 keV electrons | acute | normal | 0.013 | 0.0038 |
| 101 | [redact] | >15 keV electrons | acute | normal | 0.013 | 0.0038 |
| 102 | [redact] | >15 keV electrons | acute | normal | 0.013 | 0.0038 |
| 103 | [redact] | >15 keV electrons | acute | normal | 0.013 | 0.0038 |
| 104 | [redact] | >15 keV electrons | acute | normal | 0.013 | 0.0038 |
| 105 | [redact] | >15 keV electrons | acute | normal | 0.013 | 0.0038 |
| 106 | [redact] | >15 keV electrons | acute | normal | 0.013 | 0.0038 |
| 107 | [redact] | >15 keV electrons | acute | normal | 0.013 | 0.0038 |
| 108 | [redact] | >15 keV electrons | acute | normal | 0.013 | 0.0038 |
| 109 | [redact] | >15 keV electrons | acute | normal | 0.013 | 0.0038 |
| 110 | [redact] | >15 keV electrons | acute | normal | 0.013 | 0.0038 |
| 111 | [redact] | >15 keV electrons | acute | normal | 0.013 | 0.0038 |
| 112 | [redact] | >15 keV electrons | acute | normal | 0.013 | 0.0038 |
| 113 | [redact] | >15 keV electrons | acute | normal | 0.013 | 0.0038 |
| 114 | [redact] | >15 keV electrons | acute | normal | 0.013 | 0.0038 |
| 115 | [redact] | >15 keV electrons | acute | normal | 0.013 | 0.0038 |
| 116 | [redact] | alpha | chronic | normal | 5.69E-05 | 0.0000 |
| 117 | [redact] | alpha | chronic | normal | 7.95E-04 | 0.0002 |
| 118 | [redact] | alpha | chronic | normal | 1.51E-03 | 0.0005 |
| 119 | [redact] | alpha | chronic | normal | 2.26E-03 | 0.0007 |
| 120 | [redact] | alpha | chronic | normal | 3.05E-03 | 0.0009 |
| 121 | [redact] | alpha | chronic | normal | 3.87E-03 | 0.0012 |
| 122 | [redact] | alpha | chronic | normal | 4.73E-03 | 0.0014 |
| 123 | [redact] | alpha | chronic | normal | 5.58E-03 | 0.0017 |
| 124 | [redact] | alpha | chronic | normal | 6.46E-03 | 0.0019 |
| 125 | [redact] | alpha | chronic | normal | 7.36E-03 | 0.0022 |
| 126 | [redact] | alpha | chronic | normal | 8.29E-03 | 0.0025 |
| 127 | [redact] | alpha | chronic | normal | 9.19E-03 | 0.0028 |
| 128 | [redact] | alpha | chronic | normal | 1.01E-02 | 0.0030 |
| 129 | [redact] | alpha | chronic | normal | 1.11E-02 | 0.0033 |
| 130 | [redact] | alpha | chronic | normal | 1.20E-02 | 0.0036 |
| 131 | [redact] | alpha | chronic | normal | 1.26E-02 | 0.0038 |
| 132 | [redact] | alpha | chronic | normal | 1.27E-02 | 0.0038 |
| 133 | [redact] | alpha | chronic | normal | 1.30E-02 | 0.0039 |
| 134 | [redact] | alpha | chronic | normal | 1.32E-02 | 0.0040 |

## Appendix II.A-3: IREP Input – [Redacted] SCCs and BCC (continued)

| | | | | | | |
|---|---|---|---|---|---|---|
| 135 | [redact] | alpha | chronic | normal | 1.33E-02 | 0.0040 |
| 136 | [redact] | alpha | chronic | normal | 1.34E-02 | 0.0040 |
| 137 | [redact] | alpha | chronic | normal | 1.35E-02 | 0.0041 |
| 138 | [redact] | alpha | chronic | normal | 1.37E-02 | 0.0041 |
| 139 | [redact] | alpha | chronic | normal | 1.37E-02 | 0.0041 |
| 140 | [redact] | alpha | chronic | normal | 1.38E-02 | 0.0041 |
| 141 | [redact] | alpha | chronic | normal | 1.39E-02 | 0.0042 |
| 142 | [redact] | alpha | chronic | normal | 1.39E-02 | 0.0042 |
| 143 | [redact] | alpha | chronic | normal | 1.39E-02 | 0.0042 |
| 144 | [redact] | alpha | chronic | normal | 1.40E-02 | 0.0042 |
| 145 | [redact] | alpha | chronic | normal | 1.40E-02 | 0.0042 |
| 146 | [redact] | alpha | chronic | normal | 4.41E-03 | 0.0013 |

# ATTACHMENT 1: INDEPENDENT VERIFICATION OF DOSE CONVERSION FACTOR FOR URANIUM DUST SETTLING ON SKIN

**Prepared by Michael Mallett**
**8/11/2013**

VARSKIN V.4 calculates the calibration factor as 0.21 mrad/hr per Bq/cm$^2$. The ORNL value is 0.24 mrem/hr per Bq/cm$^2$. In other words, the 40 mrem/hr dose conversion factor ORNL reported is now calculated as 35 mrem/hr—slightly different beta spectra in the data tables. The current result includes the photon contribution, which was not a capability of VARSKIN 1.

## Varskin 4

Date: 8/11/2013 Time: 8:50:36 PM

**U-238**

Disk Source Geometry

Source Diameter: 1.13E+01 cm
Source Area: 1.00E+02 cm$^2$
Irradiation Time: 6.00E+01 min
Irradiation Area: 1.00E+02 cm$^2$
Skin density thickness: 7.00E+00 mg/cm$^2$
Air Gap Thickness: 0.00E+00 mm

**RESULTS FROM ALL SOURCES**

| | Initial Dose Rate | Dose (No Decay) | Decay-Corrected Dose |
|---|---|---|---|
| Beta | 2.10E-06 rad/h | 2.10E-06 rad | 3.67E-07 rad |
| Photon | 2.47E-09 rad/h | 2.47E-09 rad | 2.47E-09 rad |
| Total | 2.10E-06 rad/h | 2.10E-06 rad | 3.69E-07 rad |

**RESULTS FROM INDIVIDUAL SOURCES**

Nuclide: U-238
Half Life: 39166486000000 h
Average Beta Energy: 0.0099691134 MeV
X-99 Distance: 0.00060138991 cm
Source Strength: 1.00E+00 Bq

| | Initial Dose Rate | Dose (No Decay) | Decay-Corrected Dose |
|---|---|---|---|
| Beta | 0.00E+00 rad/h | 0.00E+00 rad | 0.00E+00 rad |
| Photon | 1.17E-09 rad/h | 1.17E-09 rad | 1.17E-09 rad |
| Total | 1.17E-09 rad/h | 1.17E-09 rad | 1.17E-09 rad |

Nuclide: Th-234
Half Life: 578.4 h
Average Beta Energy: 0.035404235 MeV
X-99 Distance: 0.0099562155 cm
Source Strength: 1.00E+00 Bq

| | Initial Dose Rate | Dose (No Decay) | Decay-Corrected Dose |
|---|---|---|---|
| Beta | 3.15E-07 rad/h | 3.15E-07 rad | 3.15E-07 rad |
| Photon | 1.30E-09 rad/h | 1.30E-09 rad | 1.30E-09 rad |
| Total | 3.16E-07 rad/h | 3.16E-07 rad | 3.16E-07 rad |

Nuclide: Pa-234m
Half Life: 0.0195 h
Average Beta Energy: 0.7936723 MeV
X-99 Distance: 0.4719527 cm
Source Strength: 1.00E+00 Bq

| | Initial Dose Rate | Dose (No Decay) | Decay-Corrected Dose |
|---|---|---|---|
| Beta | 1.78E-06 rad/h | 1.78E-06 rad | 5.19E-08 rad |
| Photon | 0.00E+00 rad/h | 0.00E+00 rad | 0.00E+00 rad |
| Total | 1.78E-06 rad/h | 1.78E-06 rad | 5.19E-08 rad |