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 ROCKY FLATS PLANT

Contract No. 200-2009-28555
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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 concerning one case selected by the Advisory Board, which represents a worker from the Rocky Flats Plant (RFP).

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 NIOSH for constructing doses in behalf of this case. SC&A used two independent approaches to reconstruct occupational external and internal doses in behalf of this case. Both approaches used the available dosimetry records and current guidance from the National Institute for Occupational Safety and Health (NIOSH). 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.

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 RFP from [redacted], through [redacted], and again from [redacted], through [redacted]. The EE was diagnosed with **lung cancer** (ICD Code 162.9) in [redacted]. Although this is a covered cancer under the Special Exposure Cohort (SEC), the current RFP SEC would not cover the time period this EE worked at the RFP.

According to the DOE records, the majority of the EE's radiation exposure was received while working as a [redacted], primarily in the plutonium buildings [redacted], [redacted], [redacted], [redacted], and [redacted]. During the course of employment, the EE was monitored for external photon and neutron radiation exposure and internal radiation exposure by urinalyses and lung counts.

PRESENTATION OF RESULTS

The results of both independent DR methods are shown in Table ES-1. DR–Method A derived a total lung dose of **41.914 rem**, with a probability of causation (POC) of **56.71%**; while DR–Method B derived a total lung dose of **71.944 rem**, with a POC of **55.75%**. Although the Method B total dose was almost double the Method A total dose, the POCs were nearly identical. This can be explained by the fact that Method A entered the doses into the NIOSH-Interactive RadioEpidemiological Program (IREP) as a lognormal distribution with a geometric standard deviation (GSD) of 3 and Method B entered the annual doses into IREP as a normal distribution with a 30% uncertainty.

Table ES-1. Derived Dose Estimates

	DR–Method A	DR–Method B
External Dose (Occupational):		
▪ **Recorded Dose**		
- Photons <30 keV	0.019	0.018
- Photons 30–250 keV	1.440	1.551
- Neutrons	1.127	1.107
▪ **Missed Dose**		
- Photons	0.048	0.038
- Neutrons	0.312	0.324
▪ **Unmonitored Dose**		
- Photons	NA	0.677
- Neutrons	NA	0.521
▪ **Occupational Medical Dose**		
- Photons 30–250 keV	0.294	0.294
Internal Dose:		
- Plutonium/Americium (Alpha)	38.676	57.114
- DU (Alpha)	NA	10.300
Total	**41.914**	**71.944**

There were a number of similarities between the two methods for determining both the external doses and the internal doses, with variance in methodology that led to some different dose assignments. These can be summarized as follows:

<u>External Doses</u>

Photon Dose

DR–Method A derived a total photon dose of **1.507 rem** compared to **2.284 rem** derived by DR–Method B. The difference was mainly from DR–Method A using a minimizing approach, which only assigned dose from actual recorded dose and recorded missed dose (zeros); whereas, DR–Method B used a best-estimate approach, which added missed or unmonitored doses when gaps occurred in the dosimetry records. A minor difference in photon dose assignment occurred because DR–Method A assigned 100% 30 keV and 100% 30–250 keV photon doses, and DR–Method B assigned 25% <30 keV and 75% photon doses. Assigning 100% 30 keV and 100% 30–250 keV photon doses is claimant favorable, but assigning 25% <30 keV and 75% photon doses is more realistic for the lung.

Neutron Dose

DR–Method A derived a total neutron dose of **1.439 rem** compared to **1.888 rem** derived by DR–Method B. Again, the difference was mainly from DR–Method A using a minimizing approach, which only assigned dose from actual recorded dose and recorded missed dose (zeros); whereas DR–Method B used a best-estimate approach, which added missed or unmonitored doses when gaps occurred in the dosimetry records. Both methods used the appropriate energy distributions and ICRP conversion factors.

Environmental External Dose
As per *Occupational On-Site Ambient Dose Reconstruction for DOE Sites* (ORAUT-PROC-0060), neither method assigned environmental external dose, because the EE was monitored or assigned missed dose during the employment period.

Occupational Medical Dose
DR–Method A and DR–Method B both derived a total medical x-ray dose of **0.294 rem**.

<u>Internal Doses</u>

For internal dose assignments, the largest differences in assigned dose between DR–Method A and DR–Method B were that the results of DR–Method B included potential depleted uranium (DU) intake/dose, whereas DR–Method A did not assess a dose from DU. Additionally, DR–Method A combined the data from the two bioassay methods (lung counts and urinalyses) when determining the projected intakes, whereas DR–Method B analyzed the bioassay data separately.

DU Dose
DR–Method B assigned potential internal intake from DU, which was very claimant favorable because the EE worked in the plutonium facility. DR–Method A did not consider that the EE was sufficiently exposed to DU to warrant dose assignment, because the bioassay was performed as a precautionary measure as the result of an incident and no uranium was detected by the bioassay. This difference results in an additional **10.300 rem** being assigned by DR–Method B.

Plutonium/Americium
DR–Method A used the lung counts and the urinalyses results in combination to perform a best-fit analysis of the bioassay data, whereas DR–Method B analyzed the lung counts and urinalyses results separately and compared the results, and selected the lung count as being more representative of the intakes. Both DR methods considered the potential different solubility types and used the type resulting in the highest dose. DR–Method A derived a total lung dose of **38.676 rem** and DR–Method B derived a total lung dose of **57.114 rem**.

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 Rocky Flats Plant (RFP) from [redacted], to [redacted], and [redacted], to [redacted]. The EE was diagnosed with **squamous cell lung cancer** (ICD-9 Code 162.9) on [redacted].

According to Department of Labor (DOL) and Department of Energy (DOE) records, the EE worked as a [redacted] primarily in buildings [redacted], [redacted], [redacted], [redacted] and [redacted]. The EE was monitored for external photon and neutron exposures from [redacted] through [redacted]. Internal exposure monitoring was also conducted by means of in-vitro bioassays and chest counts from [redacted] through [redacted]. The DOL records also indicated that the EE was a [redacted].

SC&A reviewed all of the DOL and DOE records provided on behalf of this employee and all of the NIOSH procedures relevant to this case and the site profile for the RFP, which was issued as six separate technical basis documents (TBDs) numbered ORAUT-TKBS-0011-1 through ORAUT-TKBS-0011-6. Using the guidance provided in these documents, along with the employee's dosimetry records, SC&A manually calculated reasonable, claimant-favorable annual organ doses shown in Table I-1. Appendix I-A provides a list of SC&A's annual organ doses and also includes the NIOSH-Interactive RadioEpidemiological Program (IREP) input parameters, such as energy range, distribution type, and uncertainty for each year.

Table I-1. Summary of Method A-Derived External/Internal Dose Estimates

	Appendix I-A Exposure Entry No.	Lung Dose (rem)
External Dose (Occupational):		
▪ **Recorded Dose**		
- Photons < 30 keV	35–40	0.019
- Photons 30–250 keV	1–6	1.440
- Neutrons <10 keV	7–13	0.101
- Neutrons 10–100 keV	14–20	0.021
- Neutrons 0.1–2 MeV	21–27	0.691
- Neutrons 2–20 MeV	28–34	0.313
▪ **Missed Dose**		
- Photons 30–250 keV	41–45	0.048
- Neutrons <10 keV	46–51	0.028
- Neutrons 10–100 keV	52–57	0.006
- Neutrons 0.1–2 MeV	58–63	0.191
- Neutrons 2–20 MeV	64–69	0.087
▪ **Occupational Medical Dose**		
- Photons 30–250 keV	70–76	0.293
Internal Dose:		
- Plutonium/Americium (Alpha)	77–109	38.676
Total		**41.914**

SC&A determined the probability of causation (POC) for this case using these annual doses as input into the IREP program. The IREP program was also run using the [redacted] option, since this was a lung cancer. The total doses shown in Table I-1 produced a POC of **56.71%.**

I.2 EXTERNAL DOSE

The reconstruction of the EE's external doses began with a review of the DOE records. In the sections that follow, a description is provided of how SC&A reconstructed the dose to the lung considering the recorded and missed doses.

I.2.1 Recorded Photon Dose

The DOE records show that this EE received positive recorded photon doses during each year of employment except for [redacted], when the limit of detection (LOD) was 0.020 R. SC&A used the guidance described in ORAUT-TKBS-0011-6 in order to derive the organ dose from this exposure. The organ dose conversion factors (DCFs) shown in Table I-2 were applied in accordance with Table 4.1a and Appendix A of the *External Dose Reconstruction Implementation Guideline*, (OCAS-IG-001).

Table I-2. Effective Dose Conversion Factors and Energy Distributions

Plutonium Facility (Buildings [redacted]) – Exposure ([redacted]–[redacted])						
	Photons		**Neutrons**			
	<30 keV	**30–250 keV**	**<10 keV**	**10–100 keV**	**100 keV–2 MeV**	**2–20 MeV**
Energy Range	100%	100%	—	—	—	—
ICRP 60 CF	—	—	0.0755	0.0309	1.31	0.345
Organ DCF	0.030	0.986	1.523	0.751	0.579	1.004
$DCF_{Effective}$	0.030	0.986	0.115	0.023	0.758	0.346
Plutonium Facility (Buildings [redacted]) – Deep Dose Equivalent ([redacted]–[redacted])						
	Photons		**Neutrons**			
	<30 keV	**30–250 keV**	**<10 keV**	**10–100 keV**	**100 keV–2 MeV**	**2–20 MeV**
Energy Range	100%	100%	—	—	—	—
ICRP 60 CF	—	—	0.0755	0.0309	1.31	0.345
Organ DCF	0.050	0.695	1.332	0.737	0.557	0.950
$DCF_{Effective}$	0.050	0.695	0.101	0.023	0.730	0.328

SC&A calculated the [redacted] photon dose to the lung using assumptions provided in Table I-2 as follows:

- [Redacted]: Records show that for [redacted], the EE received (above the LOD/2 value) a deep dose (D) of 0.447 R and shallow dose (S) of 0.517 R. The photon dose to the lung was assumed to be 100% <30 keV and 100% 30–250 keV. Lung DCFs of 0.030 for <30 keV photons and 0.986 for 30–250 keV shown in Table I-2 were applied.

$$\begin{aligned}\text{Lung Dose (<30 keV)} &= (S - D) \times DCF \times 100\% \\ &= (0.517-0.447) \times 0.030 \times 1.0 \\ &= 0.002 \text{ rem}\end{aligned}$$

$$\begin{aligned}\text{Lung Dose (30–250 keV)} &= D \times DCF \times 100\% \\ &= 0.447 \times 0.986 \times 1.0 \\ &= 0.441 \text{ rem}\end{aligned}$$

SC&A's calculated <30 keV and 30–250 keV lung doses are shown in entries #35 and #1, respectively, of Appendix I-A.

The recorded photon doses were entered into IREP as a constant distribution with no uncertainty. Although uncertainty would normally be factored in, the resulting POC was greater than 50%; therefore, uncertainty factors were not needed. SC&A found that the current DR tool available on the server would not factor in uncertainty for this case.

I.2.2 Missed Photon Dose

The EE was monitored on a monthly dosimeter exchange schedule from the end of [redacted] through the middle of [redacted]. Both OCAS-IG-001 and ORAUT-TKBS-0011-6 suggest assigning missed dose to monitored workers who received doses below the LOD.[1] After correcting for values that were below the LOD, SC&A counted a total of 5 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, along with the DCF.

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

- [Redacted]: Records show that for [redacted], there was one dosimeter reading that was either zero or less than the LOD/2 and marked as zero. The LOD for the time period is 0.020 R, making the LOD/2 equal to 0.010 R.

$$\begin{aligned}\text{Lung Dose (30–250 keV)} &= (\text{\# zeros} \times LOD/2) \times DCF \\ &= (1 \times 0.010 \text{ R}) \times 0.986 \\ &= 0.010 \text{ rem}\end{aligned}$$

SC&A's calculated 30–250 keV missed dose of 0.010 rem is shown in entry #42 of Appendix I-A.

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 Neutron Dose

The DOE records show that this EE was monitored for neutrons and received positive recorded neutron doses during each year of employment from [redacted]–[redacted]. SC&A calculated the neutron doses to the lung using the International Commission on Radiological Protection (ICRP) correction factors (CFs) and organ DCFs shown in Table I-2.

[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.

For example, SC&A calculated the [redacted] neutron doses as follows:

- [Redacted]: Records show that for [redacted], the EE's recorded neutron dose (N), above the LOD/2 value, was 0.247 rem. The calculated neutron dose is simply the recorded dose multiplied by the effective DCF (or organ DCF × ICRP 60 CF).

<10 keV neutrons $= N \times DCF_{eff}$
$= 0.247 \text{ rem} \times 0.115$
$= 0.028 \text{ rem}$

10–100 keV neutrons $= N \times DCF_{eff}$
$= 0.247 \text{ rem} \times 0.023$
$= 0.006 \text{ rem}$

0.1–2 MeV neutrons $= N \times DCF_{eff}$
$= 0.247 \text{ rem} \times 0.758$
$= 0.187 \text{ rem}$

2.0–20 MeV neutrons $= N \times DCF_{eff}$
$= 0.247 \text{ rem} \times 0.346$
$= 0.086 \text{ rem}$

SC&A's calculated neutron doses for [redacted] are shown as IREP entries #8, #15, #22, and #29 of Appendix I-A. The total neutron dose was 1.127 rem. The neutron doses were entered into IREP as a constant distribution with no uncertainty.

I.2.4 Missed Neutron Dose

Missed neutron doses were calculated based on a dosimeter reading that was either zero or less than the LOD/2 and was therefore marked as zero. Like the photon missed doses, a monthly dosimeter exchange frequency was assumed. A total of 20 dosimeter results were less than the LOD/2 and marked as zero. The number of zero readings for a year is multiplied by the appropriate LOD/2 and the DCF_{eff} from Table I-2.

SC&A calculated the [redacted] missed neutron doses to the lung as follows:

- [Redacted]: Records show that for [redacted], there were five dosimeter readings that were either less than the LOD/2 or marked as zero. The LOD for the time period is 0.020 rem, making the LOD/2 equal to 0.010 rem.

<10 keV neutrons $= (\# \text{ zeros} \times LOD/2) \times DCF_{eff}$
$= (5 \times 0.010 \text{ rem}) \times 0.115$
$= 0.006 \text{ rem}$

10–100 keV neutrons $= (\# \text{ zeros} \times LOD/2) \times DCF_{eff}$
$= (5 \times 0.010 \text{ rem}) \times 0.023$
$= 0.001 \text{ rem}$

0.1–2 MeV neutrons = (# zeros × LOD/2) × DCF_{eff}
= (5 × 0.010 rem) × 0.758
= 0.038 rem

2.0–20 MeV neutrons = (# zeros × LOD/2) × DCF_{eff}
= (5 × 0.010 rem) × 0.346
= 0.017 rem

SC&A's calculated neutron doses are shown as IREP entries #46, #52, #58, and #64 of Appendix I-A. The total missed neutron dose is 0.312 rem. The missed neutron doses were entered into IREP as a lognormal distribution with an uncertainty of 1.520.

I.2.5 Occupational Medical Dose

In addition to the estimated dose received from site operations, the doses received from diagnostic x-ray procedures that were required as a condition of employment were also included in the overall dose. The x-ray dose was based on information in the RFP TBD for Occupational Medical Dose, ORAUT-TKBS-0011-3. The DOE records show that the EE received three x-ray exams; two chest exams and one left foot exam. Table 3-1 of ORAUT-TBKS-0011-3 indicates an annual x-ray examination frequency for workers from [redacted]–[redacted]. Therefore, an annual PA chest x-ray was assumed for each year for the EE's employment from [redacted]–[redacted]. The annual x-ray dose to the lung is shown in Table 3-6 of ORAUT-TKBS-0011-3 as 0.042 rem per year. The total occupational medical dose of 0.294 rem is shown in IREP entries #70–#76 of Appendix I-A.

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.2.6 Onsite Ambient Dose

The EE was monitored for ionizing radiation doses during all of the EE's employment at the RFP, and the dosimetry results account for any doses from stack releases or other radiation sources that may have been unmonitored at the site in that era. Therefore, no onsite ambient doses were assigned, in accordance with guidance in the procedure, *Occupational On-Site Ambient Dose Reconstruction for DOE Sites* (ORAUT-PROC-0060).

I.3 INTERNAL DOSE

Internal dose monitoring records for radionuclides were reviewed. The in-vitro bioassay results are shown in Table I-3.

Table I-3. In-Vitro Bioassay Results

Date	Type	Nuclide	Result	Units	MDA
[redacted]	Urine	Am	0.01	dpm/24hr	0.31
[redacted]	Urine	Am	0.01	dpm/24hr	0.31
[redacted]	Urine	Am	0.00	dpm/24hr	0.31
[redacted]	Urine	Pu	0.00	dpm/24hr	0.24
[redacted]	Urine	Pu	0.03	dpm/24hr	0.24
[redacted]	Urine	Pu	0.01	dpm/24hr	0.24
[redacted]	Urine	Pu	0.04	dpm/24hr	0.24
[redacted]	Urine	Pu	0.08	dpm/24hr	0.24
[redacted]	Urine	H-3	795.0	pCi/L	Unknown
[redacted]	Urine	H-3	890.0	pCi/L	Unknown
[redacted]	Urine	H-3	833.0	pCi/L	Unknown

According to the RFP TBD ORAUT-TKBS-0011-5, the actual minimum detectable amount (MDA) for the tritium analyses has not been quantified for the methods in the [redacted] and [redacted]; however, it is likely in the range of several hundred to several thousand picocuries per liter. The current MDA for tritium is 600 pCi/L.

The EE was also monitored for plutonium and americium via chest counts. The EE had eight chest counts from [redacted]–[redacted] with all results less than the MDA.

I.3.1 Dose from Plutonium/Americium

All of the EE's bioassay results were below the MDA of the analyses for plutonium and americium. The plutonium urine and chest count results and the americium urine and chest count results were used to calculate the total plutonium intake.

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 urine and chest count 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 the EE's first employment period, [redacted], to [redacted]. The EE did not have any urinalyses performed during the [redacted] second period of employment during [redacted]. The level of the intake was based on one-half the MDA of the analysis. Using IMBA and a maximum likelihood fitting method, the total plutonium intake rate was determined to be 106.9 dpm/day of Type S plutonium, based on both the urine and chest count data. Following the same method, the americium urine and chest count data were used to determine the Type S americium intake rate of 5.0 dpm/day. The RFP Pu-Am Intake Calculation tool was used to determine the isotopic mixture for weapons-grade plutonium with Pu-241 weight percent of 0.36%. Table I-4 shows the individual plutonium and americium intake rates based on the plutonium urine and chest count data. SC&A noted that the Am-241 intake rate derived using the urine data was consistent with the intake rate derived using the chest count data.

Table I-4. Pu/Am Chronic Intakes – [redacted]–[redacted]

Nuclide	Type	Intake Rate (dpm/day)
Pu-238	S	2.5
Pu-239/240	S	104.5
Pu-241	S	592.5
Am-241	S	5.04

The chronic annual dose workbook (CADW) was used to calculate the annual doses from each of the above chronic intakes. The methods described in ORAUT-OTIB-0049 were used to account for the increased organ doses due to the intake of plutonium that is strongly retained in the lung. This type of plutonium is also known as Type SS plutonium. The methods described in Section 4.0 of ORAUT-OTIB-0049 and Attachment D were used to modify the plutonium and americium doses from CADW based on a 5-year chronic intake. Table I-5 shows the isotopic doses from CADW, the dose adjustment and chest count adjustment factors from Attachment D, yearly fraction to account for partial year exposure in [redacted] and [redacted] (since CADW only calculates whole year doses), and the total adjusted dose. The total dose from intakes of plutonium and americium was 38.676 rem.

Table I-5. OTIB-0049 Adjusted Doses

[**]	Isotopic Dose (rem)				Total Dose (rem)	Dose Adj. Factor	OTIB-49 Adj. Dose	*Chest Count Adj. Factor	Annual Adj. Dose	Frac. of Year	Total Adj. Dose (rem)
	Pu-239	Pu-238	Pu-241	Am-241							
	1.408E+00	3.891E-02	1.918E-03	7.821E-02	1.527	1.6	2.443	2.6	0.9398	0.175	0.165
	1.844E+00	5.045E-02	5.079E-03	1.015E-01	2.001	1.9	3.803	2.6	1.4625	1.000	1.463
	2.055E+00	5.586E-02	9.050E-03	1.124E-01	2.232	2.1	4.688	2.6	1.8031	1.000	1.803
	2.210E+00	5.978E-02	1.329E-02	1.204E-01	2.403	2.4	5.767	2.6	2.2182	1.000	2.218
	2.325E+00	6.269E-02	1.741E-02	1.265E-01	2.532	2.6	6.582	2.6	2.5316	1.000	2.532
	2.417E+00	6.499E-02	2.125E-02	1.312E-01	2.634	3.5	9.219	2.6	3.5458	0.532	1.885
	1.075E+00	2.771E-02	2.284E-02	5.639E-02	1.181	4.5	5.317	2.6	2.0448	0.625	1.277
	6.966E-01	1.761E-02	2.290E-02	3.617E-02	0.773	5.7	4.408	2.6	1.6954	1.000	1.695
	5.286E-01	1.324E-02	2.190E-02	2.740E-02	0.591	6.9	4.079	2.6	1.5688	1.000	1.569
	4.117E-01	1.023E-02	2.040E-02	2.130E-02	0.464	8.2	3.802	2.6	1.4622	1.000	1.462
	3.289E-01	8.109E-03	1.883E-02	1.698E-02	0.373	9.6	3.579	2.6	1.3764	1.000	1.376
	2.697E-01	6.598E-03	1.740E-02	1.391E-02	0.308	11	3.384	2.6	1.3016	1.000	1.302
	2.266E-01	5.494E-03	1.617E-02	1.166E-02	0.260	12	3.119	2.6	1.1995	1.000	1.200
	1.942E-01	4.672E-03	1.511E-02	9.985E-03	0.224	13	2.912	2.6	1.1200	1.000	1.120
	1.693E-01	4.039E-03	1.420E-02	8.692E-03	0.196	15	2.944	2.6	1.1323	1.000	1.132
	1.499E-01	3.546E-03	1.342E-02	7.685E-03	0.175	16	2.792	2.6	1.0739	1.000	1.074
	1.342E-01	3.151E-03	1.274E-02	6.871E-03	0.157	17	2.668	2.6	1.0263	1.000	1.026
	1.212E-01	2.822E-03	1.212E-02	6.199E-03	0.142	18	2.562	2.6	0.9855	1.000	0.986
	1.102E-01	2.546E-03	1.154E-02	5.625E-03	0.130	20	2.598	2.6	0.9991	1.000	0.999
	1.007E-01	2.309E-03	1.101E-02	5.136E-03	0.119	21	2.503	2.6	0.9625	1.000	0.963
	9.248E-02	2.104E-03	1.050E-02	4.710E-03	0.110	23	2.525	2.6	0.9712	1.000	0.971
	8.513E-02	1.921E-03	1.001E-02	4.329E-03	0.101	24	2.434	2.6	0.9360	1.000	0.936
	7.851E-02	1.758E-03	9.535E-03	3.988E-03	0.094	26	2.439	2.6	0.9379	1.000	0.938
	7.257E-02	1.613E-03	9.076E-03	3.681E-03	0.087	27	2.347	2.6	0.9028	1.000	0.903
	6.719E-02	1.481E-03	8.635E-03	3.405E-03	0.081	29	2.341	2.6	0.9002	1.000	0.900
	6.226E-02	1.361E-03	8.203E-03	3.150E-03	0.075	31	2.324	2.6	0.8939	1.000	0.894
	5.770E-02	1.251E-03	7.782E-03	2.917E-03	0.070	33	2.298	2.6	0.8840	1.000	0.884

Table I-5. OTIB-0049 Adjusted Doses

[**]	Isotopic Dose (rem)				Total Dose (rem)	Dose Adj. Factor	OTIB-49 Adj. Dose	*Chest Count Adj. Factor	Annual Adj. Dose	Frac. of Year	Total Adj. Dose (rem)
	Pu-239	Pu-238	Pu-241	Am-241							
	5.355E-02	1.151E-03	7.378E-03	2.705E-03	0.065	35	2.267	2.6	0.8720	1.000	0.872
	4.974E-02	1.061E-03	6.991E-03	2.508E-03	0.060	37	2.231	2.6	0.8581	1.000	0.858
	4.622E-02	9.774E-04	6.617E-03	2.327E-03	0.056	39	2.189	2.6	0.8421	1.000	0.842
	4.294E-02	9.006E-04	6.255E-03	2.161E-03	0.052	41	2.142	2.6	0.8240	1.000	0.824
	3.994E-02	8.312E-04	5.912E-03	2.007E-03	0.049	43	2.094	2.6	0.8052	1.000	0.805
	3.718E-02	7.674E-04	5.586E-03	1.866E-03	0.045	46	2.088	2.6	0.8032	1.000	0.803
											38.676

* The dose is divided by the Chest Count Adjustment Factor.
[**] [**The dates in this column have been redacted.**]

I.3.2 Dose from Tritium

The EE submitted three bioassay samples that were analyzed for tritium. Using those results, a chronic tritium intake was calculated for the time period of **[**redacted**]**– **[**redacted**]**. The tritium intake rate was calculated to be 1,150 pCi/day, and the total dose was <0.001 rem. Therefore, the doses from the tritium intakes were not included in the IREP table.

I.3.2 Environmental Dose

Since the EE's bioassay data were used to assess internal dose for the EE's major employment period, no additional environmental dose was calculated.

I.4 DOSE FROM RADIOLOGICAL INCIDENTS

SC&A reviewed the EE's DOE records to determine if the EE was involved in any radiological incidents that may not have been detected with external and internal radiological monitoring. The EE submitted urine, fecal, and nasal samples in response to a possible **[**redacted**]** incident due to **[**redacted**]** on [redacted]. A urine sample, fecal sample, and chest count were taken on the same date as the nasal smear and analyzed for plutonium. The results of the analyses did not indicate any uptake of plutonium or uranium. No additional dose was assigned from radiological incidents.

I.5 SUMMARY CONCLUSIONS

The EE worked at the RFP facility from [**redacted**] through [**redacted**] and from [**redacted**] through [**redacted**]. During that time, the EE was monitored for exposure to external and internal radiation. The EE was diagnosed with lung cancer in [**redacted**]. The DR derived a total external and internal dose of **41.914 rem** to the lung. The total POC for the primary lung cancer was calculated using the NIOSH-IREP (v.5.7) and determined to be **73.54%**.

I.6 REFERENCES

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APPENDIX I-A: IREP INPUT – LUNG

EXPOSURE INFORMATION							
Number of exposures							
109							
Exposure #	Exposure Year	Exposure Rate	Radiation Type	Dose Distribution Type	Parameter 1	Parameter 2	Parameter 3
1	[redacted]	Acute	photons E=30–250keV	Constant	0.441	0.000	0.000
2	[redacted]	Acute	photons E=30–250keV	Constant	0.233	0.000	0.000
3	[redacted]	Acute	photons E=30–250keV	Constant	0.351	0.000	0.000
4	[redacted]	Acute	photons E=30–250keV	Constant	0.326	0.000	0.000
5	[redacted]	Acute	photons E=30–250keV	Constant	0.059	0.000	0.000
6	[redacted]	Acute	photons E=30–250keV	Constant	0.031	0.000	0.000
7	[redacted]	Chronic	neutrons E<10keV	Constant	0.002	0.000	0.000
8	[redacted]	Chronic	neutrons E<10keV	Constant	0.028	0.000	0.000
9	[redacted]	Chronic	neutrons E<10keV	Constant	0.007	0.000	0.000
10	[redacted]	Chronic	neutrons E<10keV	Constant	0.026	0.000	0.000
11	[redacted]	Chronic	neutrons E<10keV	Constant	0.017	0.000	0.000
12	[redacted]	Chronic	neutrons E<10keV	Constant	0.013	0.000	0.000
13	[redacted]	Chronic	neutrons E<10keV	Constant	0.008	0.000	0.000
14	[redacted]	Chronic	neutrons E=10–100keV	Constant	0.000	0.000	0.000
15	[redacted]	Chronic	neutrons E=10–100keV	Constant	0.006	0.000	0.000
16	[redacted]	Chronic	neutrons E=10–100keV	Constant	0.001	0.000	0.000
17	[redacted]	Chronic	neutrons E=10–100keV	Constant	0.005	0.000	0.000
18	[redacted]	Chronic	neutrons E=10–100keV	Constant	0.004	0.000	0.000
19	[redacted]	Chronic	neutrons E=10–100keV	Constant	0.003	0.000	0.000
20	[redacted]	Chronic	neutrons E=10–100keV	Constant	0.002	0.000	0.000
21	[redacted]	Chronic	neutrons E=100keV–2MeV	Constant	0.012	0.000	0.000
22	[redacted]	Chronic	neutrons E=100keV–2MeV	Constant	0.187	0.000	0.000
23	[redacted]	Chronic	neutrons E=100keV–2MeV	Constant	0.048	0.000	0.000
24	[redacted]	Chronic	neutrons E=100keV–2MeV	Constant	0.171	0.000	0.000
25	[redacted]	Chronic	neutrons E=100keV–2MeV	Constant	0.120	0.000	0.000
26	[redacted]	Chronic	neutrons E=100keV–2MeV	Constant	0.092	0.000	0.000
27	[redacted]	Chronic	neutrons E=100keV–2MeV	Constant	0.061	0.000	0.000
28	[redacted]	Chronic	neutrons E=2–20MeV	Constant	0.006	0.000	0.000
29	[redacted]	Chronic	neutrons E=2–20MeV	Constant	0.086	0.000	0.000
30	[redacted]	Chronic	neutrons E=2–20MeV	Constant	0.022	0.000	0.000
31	[redacted]	Chronic	neutrons E=2–20MeV	Constant	0.078	0.000	0.000
32	[redacted]	Chronic	neutrons E=2–20MeV	Constant	0.054	0.000	0.000
33	[redacted]	Chronic	neutrons E=2–20MeV	Constant	0.041	0.000	0.000
34	[redacted]	Chronic	neutrons E=2–20MeV	Constant	0.027	0.000	0.000
35	[redacted]	Acute	photons E<30keV	Constant	0.002	0.000	0.000
36	[redacted]	Acute	photons E<30keV	Constant	0.002	0.000	0.000
37	[redacted]	Acute	photons E<30keV	Constant	0.005	0.000	0.000
38	[redacted]	Acute	photons E<30keV	Constant	0.003	0.000	0.000
39	[redacted]	Acute	photons E<30keV	Constant	0.005	0.000	0.000
40	[redacted]	Acute	photons E<30keV	Constant	0.002	0.000	0.000
41	[redacted]	Acute	photons E=30–250keV	Lognormal	0.010	1.520	0.000
42	[redacted]	Acute	photons E=30–250keV	Lognormal	0.010	1.520	0.000
43	[redacted]	Acute	photons E=30–250keV	Lognormal	0.010	1.520	0.000

Appendix I-A: IREP Input – Lung (continued)

44	[redacted]	acute	photons E=30–250keV	Lognormal	0.010	1.520	0.000
45	[redacted]	acute	photons E=30–250keV	Lognormal	0.007	1.520	0.000
46	[redacted]	chronic	neutrons E<10keV	Lognormal	0.006	1.520	0.000
47	[redacted]	chronic	neutrons E<10keV	Lognormal	0.008	1.520	0.000
48	[redacted]	chronic	neutrons E<10keV	Lognormal	0.005	1.520	0.000
49	[redacted]	chronic	neutrons E<10keV	Lognormal	0.005	1.520	0.000
50	[redacted]	chronic	neutrons E<10keV	Lognormal	0.003	1.520	0.000
51	[redacted]	chronic	neutrons E<10keV	Lognormal	0.002	1.520	0.000
52	[redacted]	chronic	neutrons E=10–100keV	Lognormal	0.001	1.520	0.000
53	[redacted]	chronic	neutrons E=10–100keV	Lognormal	0.002	1.520	0.000
54	[redacted]	chronic	neutrons E=10–100keV	Lognormal	0.001	1.520	0.000
55	[redacted]	chronic	neutrons E=10–100keV	Lognormal	0.001	1.520	0.000
56	[redacted]	chronic	neutrons E=10–100keV	Lognormal	0.001	1.520	0.000
57	[redacted]	chronic	neutrons E=10–100keV	Lognormal	0.000	1.520	0.000
58	[redacted]	chronic	neutrons E=100keV–2MeV	Lognormal	0.038	1.520	0.000
59	[redacted]	chronic	neutrons E=100keV–2MeV	Lognormal	0.053	1.520	0.000
60	[redacted]	chronic	neutrons E=100keV–2MeV	Lognormal	0.030	1.520	0.000
61	[redacted]	chronic	neutrons E=100keV–2MeV	Lognormal	0.035	1.520	0.000
62	[redacted]	chronic	neutrons E=100keV–2MeV	Lognormal	0.023	1.520	0.000
63	[redacted]	chronic	neutrons E=100keV–2MeV	Lognormal	0.012	1.520	0.000
64	[redacted]	chronic	neutrons E=2–20MeV	Lognormal	0.017	1.520	0.000
65	[redacted]	chronic	neutrons E=2–20MeV	Lognormal	0.024	1.520	0.000
66	[redacted]	chronic	neutrons E=2–20MeV	Lognormal	0.014	1.520	0.000
67	[redacted]	chronic	neutrons E=2–20MeV	Lognormal	0.016	1.520	0.000
68	[redacted]	chronic	neutrons E=2–20MeV	Lognormal	0.010	1.520	0.000
69	[redacted]	chronic	neutrons E=2–20MeV	Lognormal	0.005	1.520	0.000
70	[redacted]	acute	photons E=30–250keV	Normal	0.042	0.013	0.000
71	[redacted]	acute	photons E=30–250keV	Normal	0.042	0.013	0.000
72	[redacted]	acute	photons E=30–250keV	Normal	0.042	0.013	0.000
73	[redacted]	acute	photons E=30–250keV	Normal	0.042	0.013	0.000
74	[redacted]	acute	photons E=30–250keV	Normal	0.042	0.013	0.000
75	[redacted]	acute	photons E=30–250keV	Normal	0.042	0.013	0.000
76	[redacted]	acute	photons E=30–250keV	Normal	0.042	0.013	0.000
77	[redacted]	chronic	alpha	Lognormal	0.165	3.000	0.000
78	[redacted]	chronic	alpha	Lognormal	1.463	3.000	0.000
79	[redacted]	chronic	alpha	Lognormal	1.803	3.000	0.000
80	[redacted]	chronic	alpha	Lognormal	2.218	3.000	0.000
81	[redacted]	chronic	alpha	Lognormal	2.532	3.000	0.000
82	[redacted]	chronic	alpha	Lognormal	1.885	3.000	0.000
83	[redacted]	chronic	alpha	Lognormal	1.277	3.000	0.000
84	[redacted]	chronic	alpha	Lognormal	1.695	3.000	0.000
85	[redacted]	chronic	alpha	Lognormal	1.569	3.000	0.000
86	[redacted]	chronic	alpha	Lognormal	1.462	3.000	0.000
87	[redacted]	chronic	alpha	Lognormal	1.376	3.000	0.000
88	[redacted]	chronic	alpha	Lognormal	1.302	3.000	0.000
89	[redacted]	chronic	alpha	Lognormal	1.200	3.000	0.000
90	[redacted]	chronic	alpha	Lognormal	1.120	3.000	0.000
91	[redacted]	chronic	alpha	Lognormal	1.132	3.000	0.000
92	[redacted]	chronic	alpha	Lognormal	1.074	3.000	0.000
93	[redacted]	chronic	alpha	Lognormal	1.026	3.000	0.000

Appendix I-A: IREP Input – Lung (continued)

94	[redacted]	chronic	alpha	Lognormal	0.986	3.000	0.000
95	[redacted]	chronic	alpha	Lognormal	0.999	3.000	0.000
96	[redacted]	chronic	alpha	Lognormal	0.963	3.000	0.000
97	[redacted]	chronic	alpha	Lognormal	0.971	3.000	0.000
98	[redacted]	chronic	alpha	Lognormal	0.936	3.000	0.000
99	[redacted]	chronic	alpha	Lognormal	0.938	3.000	0.000
100	[redacted]	chronic	alpha	Lognormal	0.903	3.000	0.000
101	[redacted]	chronic	alpha	Lognormal	0.900	3.000	0.000
102	[redacted]	chronic	alpha	Lognormal	0.894	3.000	0.000
103	[redacted]	chronic	alpha	Lognormal	0.884	3.000	0.000
104	[redacted]	chronic	alpha	Lognormal	0.872	3.000	0.000
105	[redacted]	chronic	alpha	Lognormal	0.858	3.000	0.000
106	[redacted]	chronic	alpha	Lognormal	0.842	3.000	0.000
107	[redacted]	chronic	alpha	Lognormal	0.824	3.000	0.000
108	[redacted]	chronic	alpha	Lognormal	0.805	3.000	0.000
109	[redacted]	chronic	alpha	Lognormal	0.803	3.000	0.000

SECTION II: DR–METHOD B

II.1 DOSE RECONSTRUCTION OVERVIEW

This report presents a blind dose reconstruction (DR) for a claimant that worked at the Rocky Flats Plant (RFP) and was later diagnosed with lung cancer. This worker was monitored under an external and internal monitoring program.

Our investigation evaluated recorded and unmonitored external photon dose, potential external neutron exposures, occupational medical dose, and missed internal dose from exposures to plutonium, americium, and depleted uranium (DU). The following table summarizes our estimate of the worker's lung dose from the annual doses presented in Appendix II-A, which is used as input to the NIOSH-Interactive RadioEpidemiological Program (IREP) to derive the probability of causation (POC).

Table II-1. Assigned Dose for Case #[redacted]

Radiation Type	Appendix II-A Exposure No.	Lung Dose (rem)
Recorded photon	1–12	1.569
Missed photon	13–17	0.038
Unmonitored photon	18–27	0.677
Recorded neutron	28–51	1.107
Unmonitored neutron	52–71	0.521
Missed neutron	72–97	0.324
Occupational medical	98–104	0.294
Missed plutonium	105–136	55.650
Missed americium	137–169	1.464
Missed depleted uranium	170–202	10.300
Total		**71.944**

We calculated a dose of 71.944 rem to the lung and derived a POC of 55.75%.

II.1.1 Introduction

The approach used by SC&A to perform this blind DR began with developing an understanding of the work history of this worker, vis-à-vis the types of activities that were ongoing in different buildings and time periods at RFP. This was accomplished by reviewing the totality of the worker'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 worker might have experienced each year of employment at RFP. Once we were able to develop a rich understanding of this worker's occupational/radiological exposure history, we compiled all the information available that would help us reconstruct the worker's exposure for each year of employment at RFP. This information included the EE's personnel dosimetry and bioassay records (including urine samples and chest counts) and air sampling and other data that might help to characterize the internal and external radiation exposures this worker might have experienced. An attempt was then made to develop the input sheets to IREP that we believe places a plausible but realistic upper bound on the annual exposures that the worker might have experienced to the organ of concern up to the time of cancer diagnosis. The IREP input was then used to derive the POC for this worker.

II.1.2 Relevant Background Information

According to the DOL records, this case involves an EE who worked at the RFP as a [redacted] from [redacted], to [redacted], and then again from [redacted], through [redacted]. On [redacted], the EE was diagnosed with lung cancer (squamous cell, ICD Code 162.9). The worker describes the EE as a [redacted].

According to the DOL forms filed by this worker, the EE was a [redacted]. The EE states the following regarding the EE's job responsibilities:

> [**This section redacted in full.**]

The DOL forms indicate the following:

- The EE occasionally wore self-contained breathing apparatus (SCBA) when [redacted]
- The EE always carried a face mask with filter cartridges and wore it when necessary
- The EE often wore a disposable mask
- The EE wore a full protective suit, radiation monitoring badge, and pocket dosimeter every day
- The EE worked with cesium, californium, cobalt machine, plutonium, polonium, tritium, uranium, and x-ray machines
- The EE was never involved in a major accident
- The EE had numerous urine samples collected

The administrative record for this worker indicates that DOE provided internal and external dosimetry records, diagnostic x-ray records, and incident investigation reports for this worker, which included cuts and bruises. The DOE records also provided a tabulation of the type of work activities that this worker might have been involved in as a [redacted] and worked in Building [redacted]. Many of these activities are relevant to exposures to non-radioactive toxic and hazardous chemicals, but also include exposure to plutonium, weapons component packing, and radiography.

II.1.3 Radiation Incidents

The worker's DOE records indicate that the EE may have been involved in an incident on [redacted]. The EE experienced a [redacted]. This incident is well documented in the DOE records. Immediately following the incident, the EE was given a nasal smear and had a urinalysis bioassay, a fecal bioassay, and a lung count. ORAUT-TKBS-0011-5 discusses how individuals were monitored at RFP following an incident.

> *Nasal smear (later called swab) and fecal sample data were occasionally obtained throughout RFP operations as supplemental data for workers with actual or suspected significant inhalation intakes. Through the 1980s, they were used subjectively to verify that an intake did occur and to estimate the possible magnitude of the intake. The data have also been used to determine or confirm the ppm ^{241}Am in the inhaled plutonium mixture.*

The EE was given follow-up body counts on [redacted]; [redacted]; and [redacted]. The lung counts tested for exposure to plutonium/americium as well as uranium/thorium. An incident report dated [redacted], stated the following:

> *This letter is to inform you of the results of the bioassay studies carried out by Radiation Dosimetry following the incident* [redacted].
>
> *The urine sample received following the incident indicated no significant increase in your plutonium systemic burden.*
>
> *The nasal sample contained 45.7 dpm of plutonium and 0.481 dpm of americium. These values are of little significance and do not indicate that a significant amount of plutonium was* [redacted].
>
> *Our primary method to assess the deposition of plutonium in your lungs is the body counter. Your initial body count and the recounts on* [redacted], [redacted], *and* [redacted] *were background, indicating no detectable activity in your lungs.*
>
> *Our conclusion is that no increase in your systemic or lung burden occurred as a result of this incident.*

All of the test results following the incident were below the limit of detection (LOD). The internal dose assessment using these results is discussed below in the internal dose section.

II.2 EXTERNAL DOSE

II.2.1 Completeness and Reliability of External Dosimetry Records

The administrative record for this worker indicates that the EE was monitored for external exposures under what appears to be a monthly external dosimetry program for the EE's entire employment at RFP. Exhibit II-1 presents the external dosimetry data provided by DOE for this worker.

Dosimetry History by Individual — Date: [redacted]

Plant ID: [redacted] Name: [redacted] SSN: [redacted] Page 1 of 2

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	7	23		23	16	
		CALCULATED				OFFICIAL	53	144		493	73	
		CALCULATED				OFFICIAL	62	95		305	31	
		CALCULATED				OFFICIAL	19	50		379	12	
		CALCULATED				OFFICIAL	57	122		603	65	
		CALCULATED				OFFICIAL	68	81		801	12	
		CALCULATED				OFFICIAL	56	71		371	10	
		CALCULATED				OFFICIAL	19	67		558	44	
		CALCULATED				OFFICIAL	43	52		486	9	
		CALCULATED				OFFICIAL	12	21		21	5	
		CALCULATED				OFFICIAL	26	35		35	4	
		CALCULATED				OFFICIAL	9	15		15	3	
		CALCULATED				OFFICIAL	32	37		37	5	
		CALCULATED				OFFICIAL	27	79		79	10	
		CALCULATED				OFFICIAL	4	8		8	4	
		CALCULATED				OFFICIAL	25	65		65	40	
		CALCULATED				OFFICIAL	55	68		68	13	
		CALCULATED				OFFICIAL	28	32		32	4	
		CALCULATED				OFFICIAL	28	36		159	8	
		CALCULATED				OFFICIAL	16	38		318	7	
		CALCULATED				OFFICIAL	21	27		183	6	
		CALCULATED				OFFICIAL	11	15		287	4	
		CALCULATED				OFFICIAL	25	30		542	5	
		CALCULATED				OFFICIAL	43	169		324	12	
		CALCULATED				OFFICIAL	20	34		94	4	
		CALCULATED				OFFICIAL	27	37		135	10	
		CALCULATED				OFFICIAL	36	38		38	2	
		CALCULATED				OFFICIAL	9	14		156	5	
		CALCULATED				OFFICIAL	32	114		114	62	
		CALCULATED				OFFICIAL	50	88		88	18	
		CALCULATED				OFFICIAL	20	23		23	2	
		CALCULATED				OFFICIAL	33	61		61	28	
		CALCULATED				OFFICIAL	22	32		32	10	
		CALCULATED				OFFICIAL	62	144		144	72	
		CALCULATED				OFFICIAL	11	24		24	13	
		CALCULATED				OFFICIAL	24	42		42	16	
		CALCULATED				OFFICIAL	26	136		225	47	
		CALCULATED				OFFICIAL	17	41		41	24	
		CALCULATED				OFFICIAL	20	27		27	7	

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

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	12	19		19	7	
		CALCULATED				OFFICIAL	198	217		217	19	
		CALCULATED				OFFICIAL	95	105		105	10	
		CALCULATED				OFFICIAL	78	137		137	59	
		CALCULATED				OFFICIAL	12	64		64	52	
		CALCULATED				OFFICIAL	24	26		26	0	
		CALCULATED				OFFICIAL	14	153		3445	50	
		CALCULATED				OFFICIAL	35	35		35	0	
		CALCULATED				OFFICIAL	3	27		27	24	
		CALCULATED				OFFICIAL	27	152		152	83	
		CALCULATED				OFFICIAL	17	31		31	14	
		ROUTINE				No Records						
						Total Official Dose - Routine	1670	3201		11694	1040	

II.2.2 Reliability of Methods Used to Reconstruct Neutron Exposures

The RFP TBD for external dosimetry (ORAUT-TKBS-0011-6) describes the neutron monitoring program. Prior to 1971, NTA film was used to monitor for neutron exposure, but that method was problematic. Section 6.7.3.3 of the TBD describes the Neutron Dose Reconstruction Project (NDRP) that was started at RFP to determine neutron exposures to workers prior to 1971.

For this case, it is not necessary for us to address the NDRP data, since the EE began work at RFP in [[redacted]]. Therefore, we refer to Section 6.7.3.1 of the TBD, which describes the neutron dosimetry used at RFP beginning in 1971.

> *In 1971, RFP started using an albedo neutron TLD. Documentation of the research performed to develop this dosimeter (Falk 1971) indicates a practical lower neutron dose limit of 10 to 20 mrem in the presence of a photon dose as*

high as 100 mrem. The upper limit of this estimate was selected as the LOD for this dosimeter.

In 1983, the Panasonic UD-809 dosimeter was introduced at RFP to measure neutrons. Data are not available on the LOD for this dosimeter system. Because the hardware is the same as that used in 1990, it was assumed to be similar to performance of the system at that time. The assumed LOD is 32 mrem.

In 1990, an algorithm update was incorporated in the Panasonic dosimetry system (Stanford 1990). The documentation cites a minimum detectable neutron dose of 15 to 32 mrem for a moderated ^{252}*Cf source.*

SC&A's method for calculating neutron dose is described in detail below.

The RFP TBD provides an extensive discussion of the recommended International Commission on Radiological Protection (ICRP) weighting factors for assignment of neutron dose. Table 6-17 of ORAUT-TKBS-0011-6 is reproduced here as Table II-2.

The doses and fractions discussed above are based on quality factors published in NCRP (1971). NIOSH (2007) [OCAS-IG-001] *indicates the use of radiation weighting factors from ICRP Publication 60 (ICRP 1991). To perform this correction, the neutron energy deposition values in rad for each energy were multiplied by the ICRP radiation weighting factor to determine the corrected dose equivalent. These values were totaled for each neutron energy interval used in this dose reconstruction and compared with the value determined previously using quality factors from NCRP (1971). Column 3 of Table 6-17 lists the multipliers that were determined for each neutron energy interval. The fraction of the dose using NCRP (1971) quality factors and the dose multiplier using ICRP (1991) radiation weighting factors were combined to determine a dose multiplier (column 4 of Table 6-17). The neutron dose reported in the worker's dose record should be multiplied by these factors to determine the ICRP (1991) neutron dose for each neutron energy interval.*

Table II-2. Default Neutron Energy Distribution for RFP

Neutron energy intervals	Fraction of dose (NCRP 38)	Dose multiplier (ICRP 60)	Dose multiplier (a)
<10 keV	0.035	2.13	0.0755
10–100 keV	0.017	1.86	0.0309
0.1–2 MeV	0.687	1.91	1.31
2–20 MeV	0.261	1.32	0.345
>20 MeV	0	none	None

(a) Multiply the reported dose by these factors to determine the ICRP 60 neutron dose for each neutron energy interval.

Source: ORAUT-TKBS-0011-6, Table 6-17

II.2.3 Reconstruction of External Doses

SC&A thoroughly reviewed the dosimetry records for Case #[redacted] and found that this EE was monitored for external photon and neutron exposures through most of the EE's employment. These records, along with the RFP external dose TBD (ORAUT-TKBS-0011-6) and the *External Dose Reconstruction Implementation Guideline* (OCAS-IG-001), were used to reconstruct the external doses for this case. The DR includes an assessment of recorded and missed photon dose, recorded and missed neutron dose, unmonitored photon and neutron dose, and occupational medical dose. Table II-3 is a summary of the assigned doses and Appendix II-A presents the IREP input values used to determine the POC. The assigned external doses totaled 4.529 rem to the lung for this case.

Table II-3. Assigned External Doses for Case #[redacted]

Radiation Type	Appendix II-A Exposure No.	Lung Dose (rem)
Recorded photon	1–12	1.569
Missed photon	13–17	0.038
Unmonitored photon	18–27	0.677
Recorded neutron	28–51	1.107
Unmonitored neutron	52–71	0.521
Missed neutron	72–97	0.324
Occupational medical	98–04	0.293
Total		**4.529**

Table II-4 lists the external dose parameters used to calculate doses. The default photon energy distributions at RFP are listed in Table 6-10 of ORAUT-TKBS-0011-6, and the default neutron energy distributions and ICRP CFs are listed in Table 6-17. These parameters are discussed in detail below.

Table II-4. External DR Parameters for Case #[redacted]

	Photons		Neutrons			
	<30 keV	**30–250 keV**	**<10 keV**	**10–100 keV**	**0.1–2 MeV**	**2–20 MeV**
Energy fraction	25%	75%	3.5%	1.7%	68.7 %	26.1%
Organ DCFs 1979–1982 (R to Organ dose)	0.03	1.13	1.523	0.751	0.579	1.004
Organ DCFs 1983–1985 (Hp10 to Organ dose)	0.05	0.8	1.332	0.737	0.557	0.95
ICRP correction factor	NA	NA	2.13	1.86	1.91	1.32

II.2.3.1 Recorded Photon Dose

The EE was monitored on a monthly and quarterly basis for external exposure to photons with thermoluminescent dosimeters (TLDs). If the EE had positive readings above the LOD for each exchange period, it is not necessary to assign missed photon dose. The recorded photon doses were calculated using the energy fractions and DCFs listed in Table II-4, along with dosimeter uncertainty factors discussed below. The assignment of claimant-favorable DCFs is complicated. Table 6-11 of ORAUT-TKBS-0011-6 indicates that for the time [redacted] through [redacted], the Exposure (R) to organ DCF should be used based on the types of dosimeters used at the time. For the period [redacted] to [redacted], the Hp(10) to organ DCFs should be used based on the use of specific TLDs at RFP. For low-energy photons (<30 keV photons), NIOSH recommends using the plutonium-specific DCFs listed in Table 4.1a of OCAS-IG-001 for plutonium exposures at RFP. For the lung, those DCFs are 0.030 for the exposure (R) to organ dose and 0.050 for the Hp(10) to organ dose.

For the 30–250 keV photon DCFs, the procedures in OCAS-IG-001 recommend that the rotational or isometric DCFs be used for the lung, as opposed to the anterior-posterior (AP) DCFs. Page 39 of OCAS-IG-001 states the following:

> *The AP DCF values in Appendix A are not the most claimant favorable for bone (surface), bone (red marrow), esophagus, and lung when the dosimeter is worn on the chest. For these organs, if the dosimeter is worn on the chest, multiply the Appendix A values of ROT* [rotational] *and ISO* [idometric] *by the factors in Table 4.1a instead of using the AP value. In these cases, the ROT or ISO geometries are more claimant favorable than the AP value in Appendix A. However, the correction factors need not be applied if it is determined that the most representative geometry is 100% AP or other compensating claimant*[-]*favorable determinations have been made in dose reconstruction.*

In order to calculate the recorded photon doses, the measured values were multiplied by the rotational DCFs from Appendix A of OCAS-IG-001, along with the CFs for those DCFs in Table 4.1a of OCAS-IG-001. It should be noted that there are two tables labeled Table 4.1a on pages 38 and 39 of OCAS-IG-001. The first one pertains to plutonium-specific DCFs and the second table lists CFs for ROT and ISO DCFs. Table II-5 lists the lung DCFs derived from those values. SC&A used the ROT DCFs of 1.13 and 0.800 in this case, because this would be the EE's most likely geometry relative to the radiation sources.

Table II-5. Lung Dose Conversion Factors (30–250 keV)

	AP	ROT (Exp)	ROT (Hp 10)	ISO (Exp)	ISO (Hp 10)
Lung DCF (OCAS-IG-001)	0.695	0.779	0.552	0.625	0.441
Correction factor	NA	1.45	1.45	1.58	1.58
Adjusted lung DCF	0.695	**1.13**	**0.800**	0.988	0.697

In addition, the TBD provides dosimeter uncertainty factors. Table II-6 below summarizes those uncertainty factors from pages 42 and 43 of ORAUT-TKBS-0011-6.

Table II-6. Photon Dosimeter Uncertainty Factors for RFP

Dates	Photon Dosimeter Uncertainty Factor
1969–1982 (Readings under 100 mrem)	2
1969–1982 (Readings over 100 mrem)	1.26
1983–1998	1.23

These factors were used to calculate the photon doses for this DR. An example of SC&A's calculations is given below for the year [redacted].

For [redacted], the EE had recorded readings (above LOD/2) for shallow dose of 0.790 rem, deep dose of 0.447 rem, and neutron dose of 0.247 rem.

Calculated photon dose to the lung = 0.447 rem * energy fraction * DCF * UF
Calculated <30 keV photon dose to the lung = 0.447 * 0.25 * 0.030 * 1.26 = 0.004 rem
Calculated 30–250 keV photon dose to the lung = 0.447 *0.75* 1.13 * 1.26 = 0.477 rem

SC&A calculated 1.569 rem to the lung for the years [redacted] through [redacted], as cited in entries #1–#12 of Appendix II-A. These values are entered with a constant distribution with no uncertainty because of the use of the uncertainty factor in deriving the dose.

II.2.3.2 Missed Photon Dose

The EE had photon readings that were below the LOD/2 value. For each of those instances, SC&A assigned missed photon dose. The missed photon doses are calculated by multiplying the number of zero readings by the LOD/2 value for the dosimeter, the energy fraction, and organ DCFs.

An example of SC&A missed dose calculation is provided below for [redacted].

For [redacted], there is 1 zero reading for photons:

Missed photon dose = # of zeroes * LOD/2 * energy fraction * DCF
Calculated <30 keV missed photon dose = 1 zero * 0.010 rem * 0.25* 0.030 = 0.0001 rem
Calculated 30–250 keV missed photon dose = 1 zero *0.010 rem * 0.75* 1.13 = 0.008 rem

SC&A calculated 0.038 rem to the lung for the years [redacted] through [redacted], as cited in entries #13–#17 of Appendix II-A. These values are entered as the geometric mean of a lognormal distribution with a geometric standard deviation (GSD) of 1.52. The total <30 keV missed dose was <0.001 rem, and as such, was not entered into the IREP Input tables.

II.2.3.3 Recorded/Assigned Neutron Dose

DR–Method B determined that the EE had neutron readings from [redacted] through [redacted]. It is not clear from the procedures if the neutron doses measured by the TLDs in the 1980s and 1990s at RFP are considered accurate measurements. At other DOE facilities, the TLD neutron readings are used to assign neutron doses in DRs. However, Table 6-22 of the RFP TBD (ORAUT-TKBS-0011-6) lists neutron-to-photon dose ratios. SC&A's Method B decided to calculate the neutron doses using two methods and compare the results. First, the recorded TLD neutron readings were used to determine the neutron doses. The recorded neutron values are multiplied by the neutron energy fractions, which include the associated ICRP CFs, and the neutron DCFs for the lung. These parameters are listed here in Table II-4. Additional details regarding the ICRP weighting factors are discussed below. An example of SC&A's recorded neutron dose calculation is given below for [redacted].

In [redacted], the EE had a recorded neutron reading of 0.247 rem, which was ≥LOD/2.

> Calculated neutron dose = 0.247 rem * ICRP CF * DCF
> <10 keV neutron dose = 0.247 rem * 0.0755 * 1.523 = 0.028 rem
> 10–100 keV neutron dose = 0.247 rem * 0.0309 * 0.751 = 0.006 rem
> 0.1–2 MeV neutron dose = 0.247 rem * 1.31 * 0.579 = 0.187 rem
> 2–20 MeV neutron dose = 0.247 rem * 0.345 * 1.004 = 0.086 rem

Using the recorded neutron values, SC&A calculated a total dose of 1.107 rem to the lung.

Our second method of determining the neutron doses involved the neutron-to-photo dose ratios. These ratios were applied to the recorded photon doses, along with the energy fractions (which include the ICRP CFs) and organ DCFs. An example of SC&A's derived neutron dose calculations is given below for [redacted].

In [redacted], the EE had a recorded photo dose of 0.447 rem:

> Assigned neutron dose = 0.447 rem * ratio * ICRP CF * DCF
> <10 keV neutron dose = 0.447 rem * 0.43 * 0.0755 * 1.332 = 0.019 rem
> 10–100 keV neutron dose = 0.447 rem * 0.43 * 0.0309 * 0.737 = 0.004 rem
> 0.1–2 MeV neutron dose = 0.447 rem * 0.43 * 1.31 * 0.557 = 0.140 rem
> 2–20 MeV neutron dose = 0.447 rem * 0.43 * 0.345 * 0.95 = 0.063 rem

Using the neutron-to-photon dose ratios and the recorded photon values, SC&A calculated a total dose of 0.840 rem to the lung. The neutron doses calculated using the recorded values are slightly higher than those calculated using the neutron-to-photon dose ratio; therefore, the recorded neutron doses were included in the calculation of the POC. These values are entered as the mean of a normal distribution with a standard deviation of 30%.

II.2.3.4 Missed Neutron Dose

The EE did have some zero neutron readings during employment; therefore, SC&A decided it would be appropriate for a best-estimate DR to assign missed neutron dose. The missed neutron doses are calculated by multiplying the number of zero readings by the LOD/2 value for the dosimeter, along with the energy fractions, ICRP CFs, and organ DCFs.

An example of SC&A missed dose calculation is provided below for [redacted].
For [redacted], there are 5 zero readings for neutrons:

> Missed neutron dose = # of zeroes * LOD/2 * ICRP CF * DCF
> <10 keV neutron dose = 5 zeroes * 0.010 rem * 0.0755 * 1.523 = 0.006 rem
> 10–100 keV neutron dose = 5 zeroes * 0.010 rem* 0.0309 * 0.751 = 0.001 rem
> 0.1–2 MeV neutron dose = 5 zeroes * 0.010 rem* 1.31 * 0.579 = 0.038 rem
> 2–20 MeV neutron dose = 5 zeroes * 0.010 rem* 0.345 * 1.004 = 0.017 rem

SC&A calculated a total dose of 0.324 rem to the lung for missed neutron dose, as cited in entries #72–#97 of Appendix II-A. These values are entered as a lognormal distribution with a GSD of 1.52.

II.2.3.5 Unmonitored Dose

SC&A assigned unmonitored doses for the years the EE was employed onsite at RFP, but did not have monitoring records. For some of these years, the EE was only employed for a few months of the year; therefore, the doses were prorated based on the number of working months. SC&A assigned unmonitored doses using the values from the plutonium coworker model in Table C-4 of ORAUT-TKBS-0011-6. There were some months in the years [redacted], [redacted], [redacted], [redacted], and [redacted] where no dosimetry readings were recorded. Given this EE's job duties and the amount of recorded dose the EE received, SC&A decided it would be claimant favorable to assign the 95th percentile values of the coworker model for the month the EE was not monitored. Table II-7 shows the calculations for unmonitored photon and neutron doses. The photon and neutron doses were then divided into the appropriate energy fractions listed in Table II-4 above. The assigned unmonitored photon dose totaled 0.677 rem, and the assigned unmonitored neutron dose totaled 0.521 rem. These values are entered as the mean of a normal distribution with a standard deviation of 30%.

Table II-7. Unmonitored Doses

Year	# Months not monitored	Unmonitored CW Dose (rem)		Unmonitored Doses Prorated for Time (rem)	
		Photon	Neutron	Photon	Neutron
[redacted]	1.1	0.638	0.268	0.058	0.025
[redacted]	2	0.600	0.252	0.100	0.042
[redacted]	4	0.854	0.359	0.285	0.120
[redacted]	2	0.848	0.356	0.141	0.059
[redacted]	6	0.917	0.385	0.459	0.193
Total:	**15.1**			**1.043**	**0.438**

The example calculation for the year [redacted] is given below:

Unmonitored photon dose = 0.917 rem * energy fraction * DCF * Time fraction
<30 keV photon dose to the lung = 0.917 * 0.25 * 0.050 * (6/12) = 0.006 rem
30–250 keV photon dose to the lung = 0.917 *0.75* 0.80 * (6/12) = 0.275 rem

Unmonitored neutron dose = 0.385 rem * ICRP CF * DCF * Time fraction
<10 keV neutron dose = 0.385 rem * 0.0755 * 1.332 * (6/12) = 0.019 rem
10–100 keV neutron dose = 0.385 rem * 0.0309 * 0.737 * (6/12) = 0.004 rem
0.1–2 MeV neutron dose = 0.385 rem * 1.31 * 0.557 * (6/12) = 0.140 rem
2–20 MeV neutron dose = 0.385 rem * 0.345 * 0.95 * (6/12) = 0.063 rem

SC&A calculated 0.677 rem to the lung from unmonitored photon dose, as cited in entries #18–#27 of Appendix II-A. SC&A calculated 0.521 rem to the lung from unmonitored neutron dose, as cited in entries #52–#71 of Appendix II-A. These values are entered as the mean of a normal distribution with a standard deviation of 30%.

II.2.3.6 Occupational Medical Dose

The EE had two documented x-ray exams in [redacted] and [redacted], both of which were conventional chest x-rays. The procedures in Attachment A of ORAUT-PROC-0061 recommend that occupational medical dose be assigned for every year of employment at RFP. The procedures state that the x-ray doses should be assigned with the "Frequency per TBD Table 3-1, or actual records if records indicate more procedures than Table 3-1." SC&A assigned occupational medical dose from these exams using the values in Table 3-6 of ORAUT-TKBS-0011-3. The doses are assigned as acute 30–250 keV photons as the mean of a normal distribution with 30% standard deviation. The occupational medical doses totaled 0.294 rem as cited in entries #98–#104 of Appendix II-A.

II.3 INTERNAL DOSE

The EE was monitored for plutonium and americium via urinalysis bioassays during employment. As was previously mentioned, the EE was involved in an [redacted] incident on [redacted]. Immediately following the incident, the EE was given a nasal smear and had a urinalysis bioassay, a fecal bioassay, and a lung count. The EE was given follow-up body counts on [redacted]; [redacted]; and [redacted]. In addition, the EE was given lung counts, which were assessed for exposure to plutonium/americium as well as uranium/thorium. All of the bioassays and lung count results were below the minimum detectable activity (MDA) and considered normal. The internal doses from [redacted] plutonium are particularly important in this case, since the EE was diagnosed with lung cancer. Internal dose from inhalation of plutonium represents the majority of the assigned dose for this case. SC&A's Method B performed internal dose assessments using results from each of these internal monitoring methods. A comparison of these results was made, and the doses that were considered the most scientifically sound and claimant favorable were used to determine the POC for this case, as described in Sections II.3.1 through II.3.5 below.

II.3.1 Missed Plutonium Dose using the In-Vitro Urinalysis Bioassay Data

The EE had several urinalysis bioassays for plutonium during employment, all of which were below the MDA. Those results are reproduced here as Table II-8.

Table II-8. Plutonium/Americium Bioassay Results for Case #[redacted]

Date of bioassay	Type	Radionuclide	Result (dpm/24hr)	
[redacted]	urinalysis	P	0	<MDA
[redacted]	urinalysis	P	0	<MDA
[redacted]	urinalysis	A	0.01	<MDA
		P	0.03	<MDA
[redacted]	urinalysis	P	0.01	<MDA
[redacted]	urinalysis	A	0.01	<MDA
		P	0	<MDA
[redacted]	urinalysis	P	0.04	<MDA
[redacted]	urinalysis	A	0	<MDA

Table 5-5 of ORAUT-TKBS-0011-5 lists the MDA as 0.24 dpm/24 hour. The urinalysis bioassays measured the combination of Pu-239+240, but the IMBA program separates these isotopes. We used the isotopic fractions of alpha activity in weapons-grade plutonium listed in Table 5-1 of ORAUT-TKBS-0011-5 and applied them to the ½ MDA value. These values were used as input into the IMBA program in order to derive the intakes and doses from chronically inhaled plutonium. We used the last plutonium bioassay result from [redacted], and assumed Type S absorption, since this would be claimant favorable in cases involving the lung. IMBA was used to calculate the chronic intakes from the first to the last day of employment. Those calculated intakes are listed below in Table II-9. Those intakes were then used to calculate the doses to the lung for each year until the date of diagnosis. According to the procedures in ORAUT-OTIB-0049, *Estimating Doses for Plutonium Strongly Retained in the Lung*, this employee had the potential for exposure to highly insoluble Super S plutonium. The doses from bioassay results are multiplied by 4 to estimate the dose from Super S plutonium. The dose to the lung from missed plutonium totaled 298 rem. However, this dose was not entered into the IREP Input table because the lung count data (which represents a more direct bioassay method) was used as described in a later section.

Table II-9. Plutonium Intakes and Doses Calculated from Bioassay Results

Isotope	Absorption Type	Fraction of Weapons Grade Pu (WGP)	Excreted bioassay rate (dpm/24 hr)	Intake (dpm/d)	Dose (rem)
Pu-238	Type S	0.023	0.0028	10.72	2.24
Pu-239	Type SS	0.8	0.098	369	280
Pu-240	Type S	0.18	0.022	82.88	15.8

II.3.2 Missed Americium Dose using the In-Vitro Urinalysis Bioassay Data

The EE had several urinalysis bioassays for americium during the RFP employment period, all of which were below the MDA of 0.31 dpm/24hour (ORAUT-TKBS-0011-5, Table 5-6). The ½ MDA value was used as input in the IMBA program in order to derive the doses from chronically inhaled americium. Method B used the last americium bioassay result from [redacted], and assumed Type S absorption, since this would be claimant favorable in cases involving the lung. IMBA was used to calculate the chronic intakes from the first day of employment to the last date of employment. The calculated intake is 12.87 dpm/d, which results in 2.730 rem to the lung. However, this dose was not entered into the IREP Input table, because the lung count data (which represents a more direct bioassay method) was used as described in a later section.

II.3.3 Missed Plutonium Dose using Lung Count Results

SC&A also calculated missed plutonium dose using the lung count results. All of the results were below the MDA. SC&A's Method B chose to assign missed dose using the lung count taken on [redacted]. It is usually claimant favorable to calculate missed intake using the MDA value from the last test result and then assuming a chronic intake throughout employment. In this case, the last lung count was performed in [redacted] and represents a screening lung count performed with a Phoswich detector with a high americium MDA. Since the EE did receive lung counts following the inhalation incident using detectors that were much more sensitive, we decided to use the results from the second to last lung count on [redacted].

The lung counts measure exposure to Am-24; therefore, conversion is needed in order to determine the associated intake of plutonium. The EE's lung count was considered a "full-time" test at 2,000 seconds and a "standard system" test, since it included both the right and left sides. Table B-11 of ORAUT-TKBS-0011-5 lists the MDA values for Am-241 given the type of detector and the conditions in which the test was performed. The concentration of americium in units of parts per million (ppm) is used to determine the associated MDA of plutonium for the lung counts. Section B.1 of ORAUT-TKBS-0011-5 discusses the detection of americium as a surrogate for plutonium in lung counts.

> *Plutonium was not detected directly because of the low abundance of gamma photons and because of the severe attenuation of the more abundant, low-energy L X-rays. Instead, the 59.5-keV gamma photon from* ^{241}*Am was used as a surrogate. The isotope* ^{241}*Am was present to some extent in all WG* [weapons-grade] *plutonium at RFP. The activity of plutonium was then calculated from the detected* ^{241}*Am by measuring, calculating, or assuming the fraction of the* ^{241}*Am in the plutonium mixture on the date of the lung count. At RFP, the fraction of the* ^{241}*Am in the plutonium mixture has historically been characterized in terms of parts per million by weight. Direct in vivo measurement of plutonium in the lungs, although investigated, was never implemented at RFP. The RFP lung counter detected* ^{241}*Am. The assessment of the MDA, therefore, is focused on the MDA for* ^{241}*Am. The MDA for plutonium can then be derived from the* ^{241}*Am MDA based on the value of the ppm 241Am for the plutonium mixture.*

The lung count records in this EE's files indicate that the EE was potentially exposed to plutonium with a concentration of americium at 740 ppm. Using the conversion method in Attachment B of ORAUT-TKBS-0011-5, Table B-9, the americium MDAs should be multiplied by 20.7 in order to get the MDA for plutonium. Table II-10 below presents the MDA values for Pu/Am used in our analysis.

Table II-10. Americium and Plutonium Lung Count MDA

Test Date	Detector Type	Am-241 MDA (nCi)	Pu MDA (nCi)
07/13/1984	PGT-1	0.21	4.347

The plutonium MDA represents Pu-239+240. The ½ MDA value for plutonium is 2,174 pCi. Method B used the isotopic fractions of alpha activity in weapons-grade plutonium listed in Table 5-1 of ORAUT-TKBS-0011-5 and applied them to the ½ MDA value. These values were used as input into the IMBA program in order to derive the intakes and doses.

Table II-11. Type S Plutonium Intakes and Doses from Lung Counts

Isotope	Absorption Type	Fraction of WGP	Lung Count Measurement of ½ MDA (pCi)	Intake (pCi/d)	Dose (rem)
Pu-238	Type S	0.023	51	1.528	0.709
Pu-239	Type S	0.8	1774	52.44	22.1
Pu-240	Type S	0.18	399	11.77	4.98

It is possible that this EE was exposed to highly insoluble Super S plutonium. We followed the guidance in ORAUT-OTIB-0049, which is the technical information bulletin (TIB) that pertains to exposure to highly insoluble plutonium. In order to account for exposure to Super S highly insoluble plutonium, the annual doses from lung counts are multiplied by adjustment factors. These factors are dependent upon the number of years that the individual was exposed. The exposure is determined by the number of absolute years, not by calendar years. For this case, year 1 would be from the first day of employment, [redacted], to [redacted]. Therefore, this EE was chronically exposed for [redacted] years. The procedures recommend that the exposure period be rounded down. Page 10 of ORAUT-OTIB-0049 states the following:

> *Because the dose adjustment factors decrease as the chronic exposure period increases, for chronic intakes for partial years, dose reconstructors should truncate the partial year and use the dose adjustment factor table for the full year; for instance, if the intake period is 4.5 years, use the dose adjustment factors for a 4-year chronic intake.*

The procedures in ORAUT-OTIB-0049 recommend that the doses from each of the plutonium isotopes be adjusted for Super S absorption. Page 17 of this TIB describes the following:

> *Adjustment factors apply only to doses resulting from intakes of plutonium for which the activity isotopic ratio of $^{239+240}$Pu to ^{238}Pu is greater than 1. This restriction is based on the observed behavior of relatively pure ^{238}Pu, which tends to be more soluble than ^{239}Pu. When this condition is met, SS behavior applies to all isotopes in the plutonium mixture.*

The annual Type S lung doses for each isotope are multiplied by the adjustment factors from Table D-1, page 46 of ORAUT-OTIB-0049, from the chronic 6 years column. In order to correct the doses for the year in which the test was performed, the results are then divided by the adjustment factor from that year. In this case, it is the factor of 2.6 from year 5. This additional adjustment is performed so that the Type SS dose for the year the lung count was taken is equal to the Type S dose. Page 11 of ORAUT-OTIB-0049 describes this procedure:

> *To calculate Type SS lung doses from chest count measurements, the dose to the lung is first calculated assuming that Type S material was inhaled. This dose is then adjusted upward with the factors given in Appendix D. However, the application of the adjustment factor will result in an implied Type SS lung content that is inconsistent with the original chest count. To make the observed and predicted chest counts agree, the Type SS lung dose must be adjusted downward by applying the adjustment factor for the year of the chest count used to determine the intake.*

The Type SS lung dose from the chest count data totaled 55.650 rem.

II.3.4 Missed Americium Dose using Lung Count Results

SC&A also calculated missed americium dose using the lung count results. All of the results were below the MDA. As with the plutonium dose, we chose to assign missed dose using the lung count taken on July 13, 1984. The lung count MDA for americium is 0.21 nCi (ORAUT-TKBS-0011-5, Table 5-11). A chronic intake of 3.11 pCi/d was calculated by the IMBA program using the ½ MDA value. Using this intake, the total lung dose from exposure to americium from the beginning of employment to the date of diagnosis is 1.464 rem.

II.3.5 Depleted Uranium Dose

Given this EE's work duties, it is possible that the EE was exposed to DU while at RFP. In addition, the EE was monitored for uranium/thorium exposure with lung counts following the radiological incident in [redacted]. All of the results were below the MDA. SC&A's Method B decided to assign missed dose from exposure to DU. It was determined that this EE would not have had exposure to thorium. Our review of the site profile revealed that the time periods and locations where the EE worked were such that thorium exposures were not plausible, but exposures to DU were plausible.

II.3.5.1 Lung Count MDAs

SC&A calculated the missed dose from exposure to DU using the MDA of the lung counts. Section 5.3.2.2.2 of ORAUT-TKBS-0011-5 states the following regarding the uranium MDA for lung counts:

> *U-238 worker-specific MDA can be obtained by multiplying the Am-241 worker-specific MDA by 9.4. That result is divided by 0.89 to obtain the worker-specific MDA for DU.*

The Am-241 MDA of 0.21 nCi was used in our assessment based on the count performed on July 13, 1984. One-half this MDA value is multiplied by the alpha activity fractions for DU listed on Table 5-4 of ORAUT-TKBS-0011-5. The DU daily intake rates derived using these MDA values in the IMBA program were as follows: 3.25 pCi/d of U-234, 0.44 pCi/d of U-235, and 29.26 pCi/d of U-238. Using these intakes in the IMBA program and assuming a chronic intake from the beginning to the end of employment produced a total missed dose to the lung from DU of 10.300 rem.

II.3.5.2 Missed Tritium Dose

This EE was monitored for tritium in [redacted] and [redacted]. Table II-12 lists the urinalysis results.

Table II-12. Tritium Bioassay Results for Case #[redacted]

Date of Bioassay	Type	Radionuclide	Result (pCi/L)
[redacted]	urinalysis	tritium	795
[redacted]	urinalysis	tritium	890
[redacted]	urinalysis	tritium	833

Section 5.3.1.6 of ORAUT-TKBS-0011-5 describes the MDAs for tritium:

> *Although the actual MDA has not been quantified for the methods in the 1970s and 1980s, it likely is in the range of several hundred to several thousand*

> *picocuries per liter. The current MDA for tritium is 600 pCi/L (RFETS 1998c, p. 7-3).*

We determined that it was not necessary to assign doses due to exposure to tritium, because the concentrations of tritium in urine, as described above in Table 12, are associated with whole body doses well below 1 mrem/yr.

II.5 SUMMARY CONCLUSIONS

SC&A performed dose assessments using all of the monitoring data available in the DOE records for this EE. In the records, the EE is described as [redacted], and this information was included in the POC calculation. For the internal dose, SC&A decided to use the lung count results for plutonium, americium, and DU in the IREP calculation for determining the POC. In comparison to the lung count results, which directly measured the radionuclide exposure for this EE, the urinalysis bioassay results may be a gross overestimate of the EE's actual exposure. SC&A's DR–Method B concluded that the doses derived from the lung count data represent a realistic and scientifically sound dose assessment, while still being favorable to the claimant. The IREP input values of Appendix II-A were imported into the IREP program available on the DCAS website. The POC was determined to be **55.75%,** which would make this claim eligible for compensation.

II.6 REFERENCES

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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.

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APPENDIX II-A: IREP INPUT – LUNG

EXPOSURE INFORMATION							
Number of exposures							
202							
Exposure #	Exposure Year	Exposure Rate	Radiation Type	Dose Distribution Type	Parameter 1	Parameter 2	Parameter 3
1	[redacted]	acute	photons E<30keV	Constant	0.004	0	0.000
2	[redacted]	acute	photons E<30keV	Constant	0.002	0	0.000
3	[redacted]	acute	photons E<30keV	Constant	0.003	0	0.000
4	[redacted]	acute	photons E<30keV	Constant	0.007	0	0.000
5	[redacted]	acute	photons E<30keV	Constant	0.001	0	0.000
6	[redacted]	acute	photons E<30keV	Constant	0.001	0	0.000
7	[redacted]	acute	photons E=30–250keV	Constant	0.477	0	0.000
8	[redacted]	acute	photons E=30–250keV	Constant	0.252	0	0.000
9	[redacted]	acute	photons E=30–250keV	Constant	0.38	0	0.000
10	[redacted]	acute	photons E=30–250keV	Constant	0.347	0	0.000
11	[redacted]	acute	photons E=30–250keV	Constant	0.063	0	0.000
12	[redacted]	acute	photons E=30–250keV	constant	0.032	0	0.000
13	[redacted]	acute	photons E=30–250keV	lognormal	0.008	1.52	0.000
14	[redacted]	acute	photons E=30–250keV	lognormal	0.008	1.52	0.000
15	[redacted]	acute	photons E=30–250keV	lognormal	0.008	1.52	0.000
16	[redacted]	acute	photons E=30–250keV	lognormal	0.008	1.52	0.000
17	[redacted]	acute	photons E=30–250keV	lognormal	0.006	1.52	0.000
18	[redacted]	acute	photons E<30keV	normal	0.0004	0.004	0.000
19	[redacted]	acute	photons E<30keV	normal	0.0008	0.008	0.000
20	[redacted]	acute	photons E<30keV	normal	0.0036	0.021	0.000
21	[redacted]	acute	photons E<30keV	normal	0.0018	0.011	0.000
22	[redacted]	acute	photons E<30keV	normal	0.0057	0.023	0.000
23	[redacted]	acute	photons E=30–250keV	normal	0.050	0.012	0.000
24	[redacted]	acute	photons E=30–250keV	normal	0.085	0.023	0.000
25	[redacted]	acute	photons E=30–250keV	normal	0.171	0.064	0.000
26	[redacted]	acute	photons E=30–250keV	normal	0.085	0.032	0.000
27	[redacted]	acute	photons E=30–250keV	normal	0.275	0.069	0.000
28	[redacted]	chronic	neutrons E<10keV	normal	0.028	0.009	0.000
29	[redacted]	chronic	neutrons E<10keV	normal	0.007	0.002	0.000
30	[redacted]	chronic	neutrons E<10keV	normal	0.026	0.008	0.000
31	[redacted]	chronic	neutrons E<10keV	normal	0.017	0.005	0.000
32	[redacted]	chronic	neutrons E<10keV	normal	0.013	0.004	0.000
33	[redacted]	chronic	neutrons E<10keV	normal	0.008	0.003	0.000
34	[redacted]	chronic	neutrons E=10-100keV	normal	0.006	0.002	0.000
35	[redacted]	chronic	neutrons E=10-100keV	normal	0.001	0	0.000
36	[redacted]	chronic	neutrons E=10-100keV	normal	0.005	0.002	0.000
37	[redacted]	chronic	neutrons E=10-100keV	normal	0.004	0.001	0.000
38	[redacted]	chronic	neutrons E=10-100keV	normal	0.003	0.001	0.000
39	[redacted]	chronic	neutrons E=10-100keV	normal	0.002	0.001	0.000
40	[redacted]	chronic	neutrons E=100keV-2MeV	normal	0.187	0.056	0.000
41	[redacted]	chronic	neutrons E=100keV-2MeV	normal	0.048	0.014	0.000

Appendix II-A: IREP Input – Lung (continued)

42	[redacted]	chronic	neutrons E=100keV-2MeV	normal	0.171	0.051	0.000
43	[redacted]	chronic	neutrons E=100keV-2MeV	normal	0.12	0.036	0.000
44	[redacted]	chronic	neutrons E=100keV-2MeV	normal	0.092	0.028	0.000
45	[redacted]	chronic	neutrons E=100keV-2MeV	normal	0.061	0.018	0.000
46	[redacted]	chronic	neutrons E=2-20MeV	normal	0.086	0.026	0.000
47	[redacted]	chronic	neutrons E=2-20MeV	normal	0.022	0.007	0.000
48	[redacted]	chronic	neutrons E=2-20MeV	normal	0.078	0.023	0.000
49	[redacted]	chronic	neutrons E=2-20MeV	normal	0.054	0.016	0.000
50	[redacted]	chronic	neutrons E=2-20MeV	normal	0.041	0.012	0.000
51	[redacted]	chronic	neutrons E=2-20MeV	normal	0.027	0.008	0.000
52	[redacted]	chronic	neutrons E<10keV	normal	0.003	0.001	0.000
53	[redacted]	chronic	neutrons E<10keV	normal	0.005	0.001	0.000
54	[redacted]	chronic	neutrons E<10keV	normal	0.012	0.004	0.000
55	[redacted]	chronic	neutrons E<10keV	normal	0.006	0.002	0.000
56	[redacted]	chronic	neutrons E<10keV	normal	0.019	0.006	0.000
57	[redacted]	chronic	neutrons E=10-100keV	normal	0.001	0	0.000
58	[redacted]	chronic	neutrons E=10-100keV	normal	0.001	0	0.000
59	[redacted]	chronic	neutrons E=10-100keV	normal	0.003	0.001	0.000
60	[redacted]	chronic	neutrons E=10-100keV	normal	0.001	0	0.000
61	[redacted]	chronic	neutrons E=10-100keV	normal	0.004	0.001	0.000
62	[redacted]	chronic	neutrons E=100keV-2MeV	normal	0.017	0.005	0.000
63	[redacted]	chronic	neutrons E=100keV-2MeV	normal	0.032	0.01	0.000
64	[redacted]	chronic	neutrons E=100keV-2MeV	normal	0.087	0.026	0.000
65	[redacted]	chronic	neutrons E=100keV-2MeV	normal	0.043	0.014	0.000
66	[redacted]	chronic	neutrons E=100keV-2MeV	normal	0.140	0.042	0.000
67	[redacted]	chronic	neutrons E=2-20MeV	normal	0.008	0.002	0.000
68	[redacted]	chronic	neutrons E=2-20MeV	normal	0.015	0.004	0.000
69	[redacted]	chronic	neutrons E=2-20MeV	normal	0.041	0.012	0.000
70	[redacted]	chronic	neutrons E=2-20MeV	normal	0.021	0.006	0.000
71	[redacted]	chronic	neutrons E=2-20MeV	normal	0.063	0.019	0.000
72	[redacted]	chronic	neutrons E<10keV	lognormal	0.001	1.52	0.000
73	[redacted]	chronic	neutrons E<10keV	lognormal	0.006	1.52	0.000
74	[redacted]	chronic	neutrons E<10keV	lognormal	0.008	1.52	0.000
75	[redacted]	chronic	neutrons E<10keV	lognormal	0.005	1.52	0.000
76	[redacted]	chronic	neutrons E<10keV	lognormal	0.005	1.52	0.000
77	[redacted]	chronic	neutrons E<10keV	lognormal	0.003	1.52	0.000
78	[redacted]	chronic	neutrons E<10keV	lognormal	0.002	1.52	0.000
79	[redacted]	chronic	neutrons E=10-100keV	lognormal	0.001	1.52	0.000
80	[redacted]	chronic	neutrons E=10-100keV	lognormal	0.002	1.52	0.000
81	[redacted]	chronic	neutrons E=10-100keV	lognormal	0.001	1.52	0.000
82	[redacted]	chronic	neutrons E=10-100keV	lognormal	0.001	1.52	0.000
83	[redacted]	chronic	neutrons E=10-100keV	lognormal	0.001	1.52	0.000
84	[redacted]	chronic	neutrons E=100keV-2MeV	lognormal	0.008	1.52	0.000
85	[redacted]	chronic	neutrons E=100keV-2MeV	lognormal	0.038	1.52	0.000
86	[redacted]	chronic	neutrons E=100keV-2MeV	lognormal	0.053	1.52	0.000
87	[redacted]	chronic	neutrons E=100keV-2MeV	lognormal	0.03	1.52	0.000
88	[redacted]	chronic	neutrons E=100keV-2MeV	lognormal	0.035	1.52	0.000
89	[redacted]	chronic	neutrons E=100keV-2MeV	lognormal	0.023	1.52	0.000
90	[redacted]	chronic	neutrons E=100keV-2MeV	lognormal	0.012	1.52	0.000

Appendix II-A: IREP Input – Lung (continued)

91	[redacted]	chronic	neutrons E=2-20MeV	lognormal	0.003	1.52	0.000
92	[redacted]	chronic	neutrons E=2-20MeV	lognormal	0.017	1.52	0.000
93	[redacted]	chronic	neutrons E=2-20MeV	lognormal	0.024	1.52	0.000
94	[redacted]	chronic	neutrons E=2-20MeV	lognormal	0.014	1.52	0.000
95	[redacted]	chronic	neutrons E=2-20MeV	lognormal	0.016	1.52	0.000
96	[redacted]	chronic	neutrons E=2-20MeV	lognormal	0.01	1.52	0.000
97	[redacted]	chronic	neutrons E=2-20MeV	lognormal	0.005	1.52	0.000
98	[redacted]	acute	photons E=30–250keV	normal	0.042	0.013	0.000
99	[redacted]	acute	photons E=30–250keV	normal	0.042	0.013	0.000
100	[redacted]	acute	photons E=30–250keV	normal	0.042	0.013	0.000
101	[redacted]	acute	photons E=30–250keV	normal	0.042	0.013	0.000
102	[redacted]	acute	photons E=30–250keV	normal	0.042	0.013	0.000
103	[redacted]	acute	photons E=30–250keV	normal	0.042	0.013	0.000
104	[redacted]	acute	photons E=30–250keV	normal	0.042	0.013	0.000
105	[redacted]	chronic	alpha	normal	1.20E+00	0.36	0.000
106	[redacted]	chronic	alpha	normal	1.86E+00	0.558	0.000
107	[redacted]	chronic	alpha	normal	2.30E+00	0.689	0.000
108	[redacted]	chronic	alpha	normal	2.82E+00	0.847	0.000
109	[redacted]	chronic	alpha	normal	3.21E+00	0.963	0.000
110	[redacted]	chronic	alpha	normal	3.72E+00	1.116	0.000
111	[redacted]	chronic	alpha	normal	4.73E+00	1.418	0.000
112	[redacted]	chronic	alpha	normal	2.49E+00	0.746	0.000
113	[redacted]	chronic	alpha	normal	2.25E+00	0.675	0.000
114	[redacted]	chronic	alpha	normal	2.09E+00	0.628	0.000
115	[redacted]	chronic	alpha	normal	1.94E+00	0.581	0.000
116	[redacted]	chronic	alpha	normal	1.80E+00	0.539	0.000
117	[redacted]	chronic	alpha	normal	1.64E+00	0.491	0.000
118	[redacted]	chronic	alpha	normal	1.64E+00	0.491	0.000
119	[redacted]	chronic	alpha	normal	1.52E+00	0.456	0.000
120	[redacted]	chronic	alpha	normal	1.43E+00	0.43	0.000
121	[redacted]	chronic	alpha	normal	1.36E+00	0.407	0.000
122	[redacted]	chronic	alpha	normal	1.37E+00	0.412	0.000
123	[redacted]	chronic	alpha	normal	1.31E+00	0.393	0.000
124	[redacted]	chronic	alpha	normal	1.26E+00	0.379	0.000
125	[redacted]	chronic	alpha	normal	1.27E+00	0.381	0.000
126	[redacted]	chronic	alpha	normal	1.22E+00	0.366	0.000
127	[redacted]	chronic	alpha	normal	1.22E+00	0.365	0.000
128	[redacted]	chronic	alpha	normal	1.17E+00	0.352	0.000
129	[redacted]	chronic	alpha	normal	1.17E+00	0.35	0.000
130	[redacted]	chronic	alpha	normal	1.16E+00	0.347	0.000
131	[redacted]	chronic	alpha	normal	1.14E+00	0.343	0.000
132	[redacted]	chronic	alpha	normal	1.09E+00	0.328	0.000
133	[redacted]	chronic	alpha	normal	1.08E+00	0.323	0.000
134	[redacted]	chronic	alpha	normal	1.09E+00	0.326	0.000
135	[redacted]	chronic	alpha	Normal	1.06E+00	0.318	0.000
136	[redacted]	chronic	alpha	Normal	1.04E+00	0.311	0.000
137	[redacted]	chronic	alpha	Normal	0.01	0.003	0.000
138	[redacted]	chronic	alpha	Normal	0.12	0.036	0.000
139	[redacted]	chronic	alpha	Normal	0.142	0.043	0.000

Appendix II-A: IREP Input – Lung (continued)

140	[redacted]	chronic	alpha	Normal	0.156	0.047	0.000
141	[redacted]	chronic	alpha	Normal	0.167	0.05	0.000
142	[redacted]	chronic	alpha	Normal	0.175	0.052	0.000
143	[redacted]	chronic	alpha	Normal	0.18	0.054	0.000
144	[redacted]	chronic	alpha	Normal	0.156	0.047	0.000
145	[redacted]	chronic	alpha	Normal	0.064	0.019	0.000
146	[redacted]	chronic	alpha	Normal	0.047	0.014	0.000
147	[redacted]	chronic	alpha	Normal	0.036	0.011	0.000
148	[redacted]	chronic	alpha	Normal	0.029	0.009	0.000
149	[redacted]	chronic	alpha	Normal	0.023	0.007	0.000
150	[redacted]	chronic	alpha	Normal	0.019	0.006	0.000
151	[redacted]	chronic	alpha	Normal	0.016	0.005	0.000
152	[redacted]	chronic	alpha	Normal	0.014	0.004	0.000
153	[redacted]	chronic	alpha	Normal	0.012	0.004	0.000
154	[redacted]	chronic	alpha	Normal	0.011	0.003	0.000
155	[redacted]	chronic	alpha	Normal	0.01	0.003	0.000
156	[redacted]	chronic	alpha	Normal	0.009	0.003	0.000
157	[redacted]	chronic	alpha	Normal	0.008	0.002	0.000
158	[redacted]	chronic	alpha	Normal	0.008	0.002	0.000
159	[redacted]	chronic	alpha	Normal	0.007	0.002	0.000
160	[redacted]	chronic	alpha	Normal	0.006	0.002	0.000
161	[redacted]	chronic	alpha	Normal	0.006	0.002	0.000
162	[redacted]	chronic	alpha	Normal	0.005	0.002	0.000
163	[redacted]	chronic	alpha	Normal	0.005	0.002	0.000
164	[redacted]	chronic	alpha	Normal	0.005	0.001	0.000
165	[redacted]	chronic	alpha	Normal	0.004	0.001	0.000
166	[redacted]	chronic	alpha	Normal	0.004	0.001	0.000
167	[redacted]	chronic	alpha	Normal	0.004	0.001	0.000
168	[redacted]	chronic	alpha	Normal	0.003	0.001	0.000
169	[redacted]	chronic	alpha	Normal	0.003	0.001	0.000
170	[redacted]	chronic	alpha	Normal	0.063	0.019	0.000
171	[redacted]	chronic	alpha	Normal	0.753	0.226	0.000
172	[redacted]	chronic	alpha	Normal	0.923	0.277	0.000
173	[redacted]	chronic	alpha	Normal	1.038	0.311	0.000
174	[redacted]	chronic	alpha	Normal	1.122	0.336	0.000
175	[redacted]	chronic	alpha	Normal	1.188	0.356	0.000
176	[redacted]	chronic	alpha	Normal	1.232	0.37	0.000
177	[redacted]	chronic	alpha	Normal	1.091	0.327	0.000
178	[redacted]	chronic	alpha	Normal	0.506	0.152	0.000
179	[redacted]	chronic	alpha	Normal	0.379	0.114	0.000
180	[redacted]	chronic	alpha	Normal	0.291	0.087	0.000
181	[redacted]	chronic	alpha	Normal	0.23	0.069	0.000
182	[redacted]	chronic	alpha	Normal	0.187	0.056	0.000
183	[redacted]	chronic	alpha	Normal	0.155	0.047	0.000
184	[redacted]	chronic	alpha	Normal	0.132	0.04	0.000
185	[redacted]	chronic	alpha	Normal	0.114	0.034	0.000
186	[redacted]	chronic	alpha	Normal	0.1	0.03	0.000
187	[redacted]	chronic	alpha	Normal	0.09	0.027	0.000
188	[redacted]	chronic	alpha	Normal	0.08	0.024	0.000

Appendix II-A: IREP Input – Lung (continued)

189	[redacted]	chronic	alpha	Normal	0.073	0.022	0.000
190	[redacted]	chronic	alpha	Normal	0.066	0.02	0.000
191	[redacted]	chronic	alpha	Normal	0.061	0.018	0.000
192	[redacted]	chronic	alpha	Normal	0.056	0.017	0.000
193	[redacted]	chronic	alpha	Normal	0.052	0.015	0.000
194	[redacted]	chronic	alpha	Normal	0.048	0.014	0.000
195	[redacted]	chronic	alpha	Normal	0.044	0.013	0.000
196	[redacted]	chronic	alpha	Normal	0.041	0.012	0.000
197	[redacted]	chronic	alpha	Normal	0.038	0.011	0.000
198	[redacted]	chronic	alpha	Normal	0.035	0.01	0.000
199	[redacted]	chronic	alpha	Normal	0.032	0.01	0.000
200	[redacted]	chronic	alpha	Normal	0.03	0.009	0.000
201	[redacted]	chronic	alpha	Normal	0.028	0.008	0.000
202	[redacted]	chronic	alpha	Normal	0.022	0.007	0.000