DRAFT

REPORT TO THE ADVISORY BOARD ON RADIATION AND WORKER HEALTH

National Institute for Occupational Safety and Health

COMPARISON OF SC&A'S BLIND DOSE RECONSTRUCTION TO NIOSH'S DOSE RECONSTRUCTION OF CASE #[REDACT] FROM THE HANFORD SITE AND WELDON SPRING PLANT

Contract No. 211-2014-58081
SCA-TR-DRC2015-CN[Redact]

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S. Cohen & Associates: ***Technical Support for the Advisory Board on Radiation & Worker Health Review of NIOSH Dose Reconstruction Program***	Document No. SCA-TR-DRC2015-CN[Redact] Effective Date: Draft – June 17, 2015
Comparison of SC&A's Blind Dose Reconstruction to NIOSH's Dose Reconstruction of Case #[Redact] from the Hanford Site and Weldon Spring Plant	Page 2 of 23
Task Manager: _____ Date: _____ Rose Gogliotti	Supersedes: N/A
Project Manager: _____ Date: _____ John Stiver, MS, CHP	Reviewer: Kathleen Behling Rose Gogliotti John Stiver

Record of Revisions

Revision Number	Effective Date	Description of Revision
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TABLE OF CONTENTS

LIST OF TABLES

NOTICE: This report has been reviewed for Privacy Act information and has been cleared for distribution. However, this report is pre-decisional and has not been reviewed by the Advisory Board on Radiation and Worker Health for factual accuracy or applicability within the requirements of 42 CFR 82.

ABBREVIATIONS AND ACRONYMS

Advisory Board	Advisory Board on Radiation and Worker Health
Bq	Becquerel
CADW	Chronic Annual Dose Workbook
CATI	Computer-Assisted Telephone Interview
CF	correction factor
CW	coworker
DCF	dose conversion factor
D.D.	deep dose
DOE	(U.S.) Department of Energy
DOL	(U.S.) Department of Labor
DR	dose reconstruction
EE	Energy Employee
EEOICPA	Energy Employees Occupational Illness Compensation Program Act of 2000
FEMP	Fernald Environmental Management Project
GCF	geometric correction factor
ICD	International Classification of Diseases
ICRP	International Commission on Radiological Protection
IMBA	Integrated Modules of Bioassay Analysis
IREP	Interactive RadioEpidemiological Program
keV	kiloelectron volts
LAT	lateral
LOD	limit of detection
µg/L	micrograms per liter
mg/g	milligrams per gram
mg/L	milligrams per liter
MDA	minimum detectable activity
MeV	million electron volts
NIOSH	National Institute for Occupational Safety and Health
np	neutron-to-photon (ratio)
ORAUT	Oak Ridge Associated Universities Team

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PA	posterior/anterior
PFG	photofluorography
pCi	picocuries
pCi/day	picocuries per day
pCi/g	picocuries per gram
pCi/mg	picocuries per milligram
POC	probability of causation
ppb	parts per billion
rem	Roentgen equivalent man
RU	recycled uranium
SC&A	S. Cohen and Associates (SC&A, Inc.)
SD	standard deviation
SEC	Special Exposure Cohort
TBD	technical basis document
Th	thorium
TIB	technical information bulletin
U	uranium
UF	uncertainty factor
WSP	Weldon Spring Plant
yr	year

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1.0 RELEVANT BACKGROUND INFORMATION

Under Contract No. 211-2014-58081, SC&A was tasked by the Advisory Board on Radiation and Worker Health (Advisory Board) to perform six blind dose reconstructions (DRs) at the July 2014, DR Subcommittee meeting. SC&A was provided 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) Reports that were made available to the National Institute for Occupational Safety and Health (NIOSH) for constructing doses in behalf of these cases. SC&A used an independent approach to reconstruct occupational external and internal doses for the cases using the available dosimetry records and current guidance from NIOSH, including the spreadsheets and other tools developed by NIOSH to calculate the doses.

On February 27, 2015, SC&A submitted to the Advisory Board and NIOSH, a memorandum containing the summary results of our blind DR in behalf of Case #[Redact]. The complete DR report titled, *Blind Dose Reconstruction of Case* #[Redact] *from the Hanford and Weldon Spring Sites* (SCA-TR-BDR2015-CN[Redact]), which provides the assumptions and methodologies used to derive occupational radiation doses and resultant probability of causation (POC) values, is included herein as Addendum A. In this report, SC&A presents a comparison between NIOSH's and SC&A's DR methodologies, doses, and resultant POC values for Case #[Redact]. Table 1-1 summarizes the external and internal occupational doses calculated by SC&A and the NIOSH-assigned doses for the liver cancer diagnosed in behalf of Case #[Redact]. A detailed comparison of the two methodologies used to calculate doses in behalf of this case is presented in Section 2. Section 3 of this report provides Summary Conclusions.

It should be noted that where appropriate, an explanation is provided regarding the differences in doses and why they occurred. However, SC&A does not make any value judgments regarding which among them may be the more preferred approach. It is our position that further discussions are best addressed by the DR Subcommittee.

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Table 1-1. Comparison of NIOSH's Assigned Doses to SC&A's Blind DR Doses

	NIOSH Liver Doses (rem)	SC&A Liver Doses (rem)
External Dose (Occupational)		
▪ Recorded/Modeled:		
30–250 keV Photons	2.227	1.750
>250 keV Photons	2.093	1.264
0.1–2 MeV Neutrons	1.839	NA
▪ Missed/Modeled:		
30–250 keV Photons	2.010	2.010
>250 keV Photons	1.890	1.598
0.1–2 MeV Neutrons	1.661	NA
▪ 1957 Coworker Dose:		
30–250 keV Photons	NA	0.198
>250 keV Photons	NA	0.143
▪ 1957 Onsite Ambient Dose:		
30–250 keV Photons	0.043	NA
▪ 1963 Onsite Ambient Dose:		
30–250 keV Photons	0.020	NA
▪ 1948 Onsite Ambient Dose:		
30–250 keV Photons	0.038	0.027
▪ Occupational Medical Dose:		
PFG exam, 1948	NA	0.690
30–250 keV Photons	1.602	1.602
Internal Dose (alpha):		
U, RU, Th	6.623	4.065
Total Dose	**20.046**	**13.347**
POC	**42.49%**	**40.71%**

NA = Not assessed

2.0 COMPARISON OF METHODOLOGY/DOSES USED BY NIOSH AND SC&A FOR CASE #[REDACT]

Case #[Redact] represents an energy employee (EE) who worked as a [redact] at the Hanford Site from [redact], to [redact], and as a [redact] at the Weldon Spring Plant from [redact], to [redact].

The EE was not monitored for external or internal radiation exposure at the Hanford Site. However, the EE was monitored for external photon exposure and internal exposures during most of the employment period at the Weldon Spring Plant. The EE was diagnosed with **bile duct cancer** (cholangiocarcinoma) (ICD-9 Code 155.1) on [redact].

For calculating radiation doses from employment at Hanford and the Weldon Spring Plant, both DR methods primarily relied on guidance in the technical basis document (TBD) for Hanford (issued as six separate documents numbered ORAUT-TKBS-0006-1 through ORAUT-TKBS-0006-6), the TBD for the Weldon Spring Plant (ORAUT-TKBS-0028-1 through ORAUT-

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TKBS-0028-6), and ORAUT-OTIB-0005, *Technical Information Bulletin: Internal Dosimetry Organ, External Dosimetry Organ, and IREP Model Selection by ICD-9 Code.* NIOSH and SC&A used the guidance provided in the relevant technical documents, along with the EE's records to reconstruct the EE's radiation dose. NIOSH used efficiency measures and assumptions related to radiation exposure and intakes resulting in an **overestimate** of the EE's total dose. SC&A employed a **best-estimate approach** for calculating annual organ doses.

A summary of the documents, assumptions, and dose parameters used by each DR method is provided in Table 2-1:

Table 2-1. Comparison of Data and Assumptions Used by NIOSH and SC&A

Parameters	NIOSH	SC&A
External Dose		
Recorded/Missed/Unmonitored:		
Records/Guidance Documents	DOE records, ORAUT-TKBS-0028-6	DOE records, ORAUT-TKBS-0028-6
Work Locations	Site wide as [redact]	Site wide as [redact]
Energy Range	Photons: 50% 30 keV–250 keV 50% >250 keV Neutrons: 100% 0.1–2 MeV	Photons: 50% 30 keV–250 keV 50% >250 keV Neutrons: NA
DCF	1.064 (30 keV–250 keV) 1.0 (>250 keV) 1.0 (0.1–2 MeV)	1.064 (30 keV–250 keV) 0.845 (>250 keV) NA (0.1–2 MeV)
Dosimeter Uncertainty Factor	1.4	NA
Dose Distribution	Recorded/CW– Constant Missed – Lognormal	Recorded/CW– Constant Missed – Lognormal
External Medical X-rays:		
Guidance Documents	ORAUT-TKBS-0028-3, OTIB-0079.	ORAUT-TKBS-0028-3
Frequency	PA and LAT chest examinations during most years of employment, with two such examinations in [redact]. (8 exams)	PA and LAT chest examinations during most years of employment, with two such examinations in [redact]. (8 exams)
Dose Data	Table 3-3 of ORAUT-TKBS-0028-3	Table 3-3 of ORAUT-TKBS-0028-3
Dose Distribution	Normal; SD = 30%.	Normal; SD = 30%.
Onsite Ambient Dose:		
Guidance Documents	OCAS-IG-001, ORAUT-TKBS-0006-4, ORAUT-TKBS-0028-4	ORAUT-PROC-0060, ORAUT-TKBS-0006-4
Dose Data	ORAUT-TKBS-0006-4, ORAUT-TKBS-0028-4	Table 4-8 of ORAUT-TKBS-0006-4
Dose Distribution	Constant	Constant
Internal Dose		
Recorded/Missed/unmonitored:		
Records/Guidance Documents	DOE records, ORAUT-OTIB-0014, ORAUT-TKBS-0006-4, ORAUT-TKBS-0028-4	DOE records, ORAUT-TKBS-0006-4, ORAUT-TKBS-0028-4
Dose Determination Approach	Overestimate – chronic through entire employment period	Best Estimate – chronic through most of employment based on fit of bioassay
Solubility Type	Various, see Section 2.1.1	Various, see Section 2.1.1
POC Program:		
NIOSH-IREP POC	Ver. 5.7	Ver. 5.7.1

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2.1 OCCUPATIONAL EXTERNAL DOSE CALCULATIONS

2.1.1 Recorded/Modeled Photon and Neutron External Doses

The DOE records show that the EE was not monitored while employed at the Hanford Site for 3 months in [redact]. Dosimetry records were available for the time period the EE was employed at the Weldon Spring Plant, [redact] to [redact]. Individual dosimeter results or quarterly dosimeter totals are available for [redact]–[redact]. However, no dosimeter results are found for [redact]. Monitoring records for the EE begin in [redact].

Photons
SC&A used the EE's recorded photon dose values that were >LOD/2 of 0.025 rem to assign doses using a photon energy range of 50% 30–250 keV photons and 50% >250 keV photons. A dosimeter correction factor (CF) of 1.1 (for 30–250 keV photons only) and geometric correction factor (GCF) of 2.1 were also included. NIOSH applied the same energy range and GCF, in addition to a 1.4 uncertainty factor (UF), but NIOSH did not apply the dosimeter CF of 1.1 for 30–250 keV photon doses. Also, SC&A applied a 30–250 keV photon dose conversion factor (DCF) of 1.064 and a >250 keV photon DCF of 0.845 from OCAS-IG-001. NIOSH used the 30–250 keV photon DCF of 1.064 and a maximizing DCF of 1.0 for the >250 keV photon doses. The recorded photon doses are shown in Table 2-2.

Table 2-2. Recorded Photon Doses

Year	Photon Energy	SC&A Dose (rem)	NIOSH Dose (rem)
[redact]	E=30–250 keV	0.042	0.053
[redact]	E=30–250 keV	0.091	0.116
[redact]	E=30–250 keV	0.602	0.766
[redact]	E=30–250 keV	0.684	0.871
[redact]	E=30–250 keV	0.244	0.311
[redact]	E=30–250 keV	0.086	0.109
[redact]	E>250 keV	0.030	0.050
[redact]	E>250 keV	0.066	0.109
[redact]	E>250 keV	0.435	0.720
[redact]	E>250 keV	0.494	0.819
[redact]	E>250 keV	0.177	0.293
[redact]	E>250 keV	0.062	0.103

To illustrate the differences between the SC&A and NIOSH calculations, examples of the [redact] recorded photon calculations are shown below.

Records show in [redact], the EE received a deep dose (D.D.) of 0.490 rem. The photon dose was assumed to be 50% 30–250 keV and 50% >250 keV. A GCF of 2.1 was applied.

SC&A's Calculation
DCFs of 1.064 for 30–250 keV photons and 0.845 for >250 keV photons were applied; along with a dosimeter CF of 1.1 for the 30–250 keV photon doses.

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30–250 keV photon dose = D.D. × DCF × Energy f. × CF × GCF
= 0.490 × 1.064 × 0.50 × 1.1 × 2.1
= 0.602 rem

>250 keV photon dose = D.D. × DCF × Energy f. × GCF
= 0.490 × 0.845 × 0.50× 2.1
= 0.435 rem

NIOSH's Calculation

DCFs of 1.064 for 30–250 keV photons and 1.0 for >250 keV photons were applied, along with a UF of 1.4 for both the 30–250 keV and >250 keV photon doses.

30–250 keV photon dose = D.D. × DCF × Energy f. × GCF × UF
= 0.490 × 1.064 × 0.50 × 2.1 × 1.4
= 0.766 rem

>250 keV photon dose = D.D. × DCF × Energy f. × GCF × UF
= 0.490 × 1.0 × 0.50× 2.1× 1.4
= 0.720 rem

SC&A multiplied the 30–250 keV photon doses by a factor of 1.1 to account for low-energy photons emitted by uranium and thorium at the Weldon Spring Plant in accordance with Section 6.3.8 of ORAUT-TKBS-0028-6. According to the NIOSH DR report, "To account for uncertainty in dosimeter response, an uncertainty factor of 1.4 was applied to measured photon doses." While this is consistent with Section 6.3.10 of ORAUT-TKBS-0028-6, it is unclear if this uncertainty would be applied in a best-estimate DR.

Neutrons

The EE did not have any neutron dosimetry data. Based on Section 6.3.4.2 of ORAUT-TKBS-0028-6, SC&A did not assess doses from neutron exposure. It states:

> *Because the WSP processed very small amounts of slightly enriched uranium (<1% ^{235}U and 0.68% of total throughput and no UF_6), the exposure to neutrons was miniscule* [SEC-00143, p. 33]. *The fact that the uranium was in the form of UF_4 and other nonproducing neutron compounds resulted in the total absence of recordable neutron doses even though neutron dosimeters were worn by those employees working with the enriched uranium… The slightly enriched uranium was processed in Buildings 103,105, 201, and 301, so employees assigned to these facilities during the processing of this material received neutron dosimeters. Studies as reported in ORAUT 2010a* [SEC-00143, p. 33 and pp. 59–61] *provide adequate evidence that there is no technical reason to expect any measurable neutron doses and, therefore, no reported results.*

NIOSH assessed unmonitored neutron dose. The NIOSH DR report states:

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> *Site-specific information indicates that* [the EE] *was also likely to have been exposed to neutron radiation, which was not monitored by the site during* [the EE's] *employment* [ORAUT-TKBS-0028-6]. *Therefore, unmonitored neutron dose has been assigned.*

The DR report also states that, "while at the Weldon Spring Plant, [the EE] performed [redact]on machinery throughout the plant, repaired motors and equipment, and worked on [redact]."

SC&A did not find any statements in the EE's records or ORAUT-TKBS-0028-6 indicating the EE was likely exposed to neutrons. It is uncertain if NIOSH would include the unmonitored neutron doses in a best-estimate DR.

An example of NIOSH's [redact] neutron calculation is shown below.

Records show in [redact], the EE received a D.D. of 0.490 rem. The neutron energy was assumed to be 0.1 to 2.0 MeV with an organ DCF of 1.0, GCF of 2.1, an uncertainty of 1.4 and a neutron-to-photon (np) ratio of 0.23. An ICRP-60 CF of 1.91 was also applied. [The liver DCF in OCAS-IG-001 for 0.1–2.0 MeV neutrons is 0.641.]

$$\begin{aligned}\text{0.1 to 2.0 MeV neutron dose} &= \text{D.D.} \times \text{DCF} \times \text{np} \times \text{GCF} \times \text{UF} \times \text{ICRP} \\ &= 0.490 \times 1.0 \times 0.23 \times 2.1 \times 1.4 \times 1.91 \\ &= 0.633 \text{ rem}\end{aligned}$$

Table 2-3. Comparison of Recorded/Modeled Photon and Neutron Doses

	SC&A (rem)	NIOSH (rem)
Total Recorded/Unmonitored Photon Dose	3.014	4.320
Total Recorded Neutron Dose	NA	1.839

Both DR methods entered doses into the Interactive RadioEpidemiological Program (IREP) as a constant distribution with no uncertainty.

2.1.2 Missed/Modeled Photon and Neutron External Doses

SC&A assigned only missed photon doses based on information in ORAUT-TKBS-0028-6. Both missed photon and neutron doses were assigned by NIOSH.

Missed Photon Doses

SC&A analyzed the number of actual zeros and potential zeros based on a biweekly badge exchange cycle and arrived at a total of **72 zeros** (or <LOD/2 values) for photons. SC&A used the annual number of zeros, the LOD/2 value, the DR parameters as listed above, and the applicable DCFs to determine the annual missed photon doses. This resulted in the assignment of 2.010 rem for 30–250 keV photons and 1.598 rem for >250 photons.

NIOSH also used 72 zeros to determine the missed photon dose. However, NIOSH used an organ DCF of 1.0 instead of 0.845 for the >250 keV photon doses. This resulted in NIOSH

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assigning a total missed photon dose of 2.010 rem for 30–250keV photons and 1.890 rem for >250 keV photons.

Missed Neutron Doses

NIOSH used the annual number of zeros, the photon LOD/2, the 95th percentile np ratio of 0.23, the GCF of 2.1, ICRP 60 CF of 1.91, and organ DCF of 1.0 to calculate the missed neutron doses. An example of NIOSH's [redact] missed neutron dose calculation is shown below.

Records show in [redact], the EE's dosimeter results shown 7 zeros with an LOD/2 of 0.025 rem.

$$\text{Missed Neutron Dose (0.1–2.0 MeV)} = (\#\text{ zeros} \times \text{LOD}/2) \times \text{DCF} \times \text{ICRP} \times \text{GCF} \times \text{np}$$
$$= (7 \times 0.025 \text{ rem}) \times 1.0 \times 1.91 \times 2.1 \times 0.23$$
$$= 0.161 \text{ rem}$$

Table 2-4. Comparison of Missed Photon and Neutron Doses

	SC&A (rem)	NIOSH (rem)
Total Missed Photon Dose	3.608	3.900
Total Missed Neutron Dose	NA	1.661

Both DR methods entered missed photon doses into IREP as a lognormal distribution with an uncertainty of 1.520. NIOSH also entered unmonitored neutron doses as a geometric mean value with a geometric standard deviation of 1.520.

2.1.3 Occupational Medical Doses

Both DR methods calculated an occupational medical dose from diagnostic x-ray procedures required as a condition of employment. NIOSH indicated that they followed guidance cited in ORAUT-OTIB-0079 and ORAUT-TKBS-0028-3 in order to calculate their occupational medical doses.

SC&A used guidance provided in ORAUT-TKBS-0028-3 and ORAUT-TKBS-0006-3.

Both NIOSH and SC&A assigned dose for 8 occupational medical x-ray exams during the period [redact]–[redact] while the EE was employed at the Weldon Spring Plant. NIOSH and SC&A both assumed the exams included PA views plus LAT views. SC&A used the recommended exam frequency in Section 3.1.2 and the liver dose values recommended in Table 3-3 of ORAUT-TKBS-0028-3.

In [redact], the EE had a pre-employment photofluorography (PFG) exam at the Hanford Site. Exhibit 2-1 shows the radiographic report form from the Hanford Works. SC&A used the dose values recommended in Table 3-1 of ORAUT-TKBS-0006-3 to assign a dose to the liver from this PFG exam. NIOSH did not assign the Hanford PFG dose, citing guidance in ORAUT-OTIB-0079.

Table 2-5 summarizes NIOSH's and SC&A's dose assignments.

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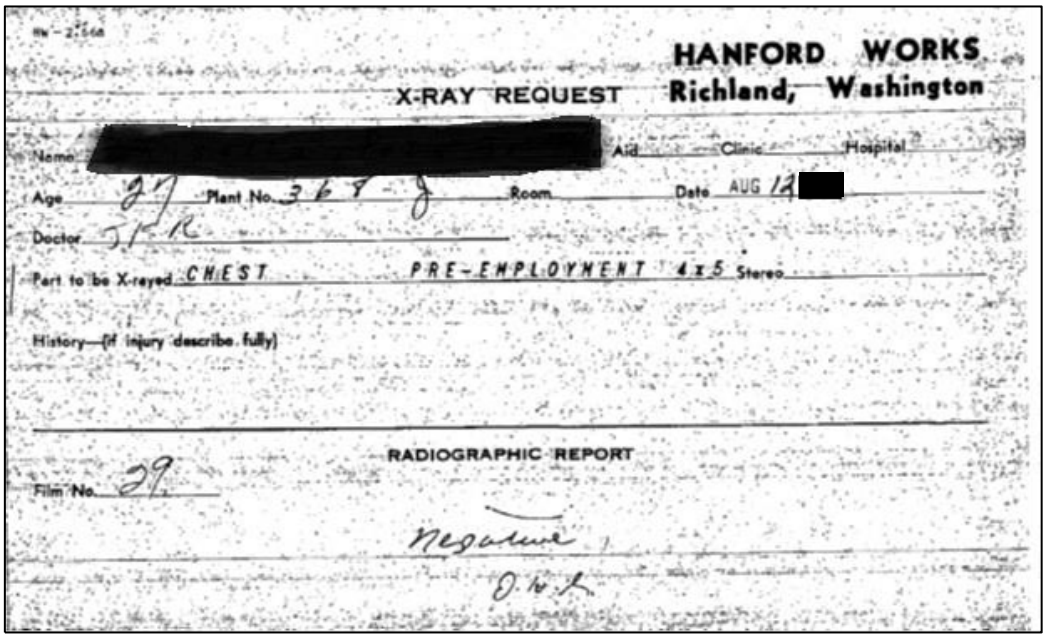
Table 2-5. Comparison of Occupational Medical Doses

Site	NIOSH (rem)	SC&A (rem)
Weldon Spring Plant [redact]– [redact]	1.602	1.602
Hanford Site [redact]	–	0.690
Total	1.602	2.292

Each DR method entered the annual doses into the IREP Input tables with a normal distribution and a standard deviation (SD) of 30%.

Exhibit 2-1. Hanford PFG Exam


HANFORD WORKS
Richland, Washington
X-RAY REQUEST
Name [redacted] Aid Clinic Hospital
Age 27 Plant No. 3 6 7 - 3 Room Date AUG 12 [redacted]
Doctor J.P.R.
Part to be X-rayed CHEST PRE-EMPLOYMENT 4 x 5 Stereo
History—(if injury describe fully)
RADIOGRAPHIC REPORT
Film No. 29
Negative
O.W.L.

2.1.4 Onsite Ambient External Dose

The EE was not monitored for external exposure while at the Hanford Site from [redact], to [redact]. Both NIOSH and SC&A assigned ambient external dose for this Hanford time period.

SC&A determined the Hanford ambient dose as follows. Table 4-8 of ORAUT-TKBS-0006-4 shows 0.115 rem/year as the maximum external gamma dose for [redact]. Using the isotropic DCF for the liver of 0.568, correcting for 2,500 hours/year (50 hours/week and 50 occupational weeks/year), and prorating for the 3-month time period results in an ambient dose of:

SC&A ambient dose = Annual Dose × DCF × 2,500/2,000 × 3/12 months
= 0.115 rem/year × 0.568 × 1.25 × 0.25 year
= 0.020 rem

NIOSH determined the Hanford ambient dose using 0.115 rem/yr as the maximum external gamma dose for [redact], an isotropic DCF of 1.0, correcting for 2,500 hours/yr (50 hours/week and 52 calendar weeks/yr), and prorating for the 3-month time period based on days.

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NIOSH ambient dose = Annual Dose × DCF × 2600/2000 × 93/265 days
= 0.115 rem/year × 1.0× 1.30 × 0.255 year
= 0.038 rem

NIOSH used maximizing assumptions for the DCF (1.0 instead of 0.568) and the working hours per year (2,600 hours instead of 2,500), while SC&A used best-estimate parameters for calculating the Hanford ambient external dose.

NIOSH also assigned ambient dose for employment at the Weldon Spring Plant during [redact] and [redact]. The EE began work in [redact]; however, no dosimeter results were found for that year. In [redact], the EE was monitored every month except September. Using the 50th percentile value of the median external doses from Table 4-3 of ORAUT-TKBS-0028-4, NIOSH calculated onsite ambient doses of 0.043 rem and 0.020 rem for [redact] and [redact], respectively.

1957 Ambient dose = (1957 Table 4-3) × DCF × fraction of year
= 0.161 rem × 1.064 × 0.25
= 0.043 rem

Since the EE submitted a bioassay sample in August (pre-hire) and September of [redact], SC&A assigned coworker (CW) doses instead of ambient doses. The 50th percentile value of the median external doses in [redact] from Table 6-8 of ORAUT-TKBS-0028-6 was used to account for any potential dose from [redact], until [redact]. Table 6-8 contains the same external doses as Table 4-3. SC&A used the same photon energy distribution and geometric factors as were used to assign recorded and missed photon doses.

30–250 keV photon ambient dose = (1957 Table 6-8) × DCF × Energy f. × CF × GCF
= 0.161 rem × 1.064 × 0.50 × 1.1 × 2.1
= 0.198 rem

>250 keV photon ambient dose = (1957 Table 6-8) × DCF × Energy f. × GCF
= 0.161 rem × 0.845 × 0.50× 2.1
= 0.143 rem

SC&A did not assign unmonitored or ambient dose for September of [redact].

Table 2-6. Comparison of Onsite Ambient Doses

Site	NIOSH (rem)	SC&A (rem)
Weldon Spring Plant	0.063	0.341
Hanford Site	0.038	0.027
Total	0.101	0.368

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2.2 OCCUPATIONAL INTERNAL DOSES

The EE was not monitored for internal exposures while at Hanford in [redact]. According to the Special Exposure Cohort (SEC) and the determination by NIOSH, the maximum internal exposure cannot be completely reconstructed for some radionuclides through December 31, 1983. Therefore, the Hanford internal dose was assessed based on reported environmental airborne radionuclide concentrations given in Table A-12 of ORAUT-TKBS-0006-4.

At the Weldon Spring Plant, the EE was monitored for potential internal exposure via urine sampling from [redact]–[redact].

2.2.1 Internal Doses from Uranium

Both SC&A and NIOSH used the EE's uranium bioassay data to determine the uranium intake. The EE was monitored for potential uranium exposure from [redact], through [redact]. Several of the urine samples were reported with total uranium concentrations above the minimum detectable activity (MDA), of 0.008 micrograms per liter (µg/L).

SC&A's Best-Estimate Method

Prior to [redact], all of the EE's bioassay results were less than the detection limit. SC&A performed a visual fit of the bioassay data using Integrated Modules of Bioassay Analysis (IMBA) and an assumed chronic intake period from [redact], until the EE's sample date of [redact]. The IMBA-generated uranium-234 intake activity associated with absorption Type M was calculated to be 225 pCi/day.

NIOSH's Overestimating Method

NIOSH used overestimating assumptions to determine the EE's uranium intake. A chronic intake was calculated throughout the EE's employment that would have led to the EE's highest bioassay result during employment, which was 0.025 mg/L in a [redact], sample. Intakes of lead-210, polonium-210, radium-226, radium-228, thorium-228, thorium-230, and thorium-232 were calculated as bounding intakes based on the ratios to uranium provided in Table 5-21 of ORAUT-TKBS-0028-5, "Intakes of uranium decay products and other impurities based on raffinate pit measurements."

Table 2-7. NIOSH Uranium and Decay Product Intakes

Radionuclide	Type	Start	End	Intake	Unit/Rate
Uranium-234	S	[redact]	[redact]	5,780	pCi/day
Lead-210	F	[redact]	[redact]	1,058	pCi/day
Polonium-210	M	[redact]	[redact]	1,058	pCi/day
Radium-226	M	[redact]	[redact]	1,058	pCi/day
Radium-228	S	[redact]	[redact]	42.3	pCi/day
Thorium-228	S	[redact]	[redact]	33.9	pCi/day
Thorium-230	S	[redact]	[redact]	2,877	pCi/day
Thorium-232	S	[redact]	[redact]	50.8	pCi/day

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2.2.2 Internal Doses from Recycled Uranium Contaminants

Both SC&A and NIOSH assigned dose from recycled uranium (RU) contaminants. Recycled uranium (RU) was first introduced at the Weldon Spring Plant in 1961. Therefore, all uranium intakes after 1960 are assumed to have associated plutonium-239, neptunium-237, and technetium-99 intakes. The RU components were added as 100 ppb plutonium-239, 3,500 ppb neptunium-237, and 9,000 ppb technetium-99 (ppb = parts per billion) (ORAUT-TKBS-0028-5). These are the same RU ratios to uranium listed in Section 5.2.2 of the TBD for the Fernald Environmental Management Project (FEMP) – Occupational Internal Dose (ORAUT-TKBS-0017-5).

SC&A's Best-Estimate Method

SC&A used the previously determined uranium intake of 225 pCi/day and the FEMP Recycled Uranium Mix Intake Rate Calculator 2.00 to determine the RU contaminants intake rates assuming natural uranium with RU components in [redact] and [redact], and 1% enriched uranium with RU components for [redact] and [redact]. Table 2-8 lists each of the intake periods, intake rates and RU:U ratios.

Table 2-8. SC&A Uranium and RU Contaminant Intakes

Radionuclide	Type	Intake Period	Intake Rate (pCi/day)	Uranium Type	RU:U Ratio
U-234	M	[redact]– [redact]	225		–
Pu-239	M	[redact]– [redact]	2.072	natural	9.21E-03
Np-237	M	[redact]– [redact]	0.823		3.66E-03
Tc-99	M	[redact]– [redact]	50.850		2.26E-01
Pu-239	M	[redact]– [redact]	1.454	1% enriched	6.46E-03
Np-239	M	[redact]– [redact]	0.578		2.57E-03
Tc-99	M	[redact]– [redact]	35.390		1.57E-01

The Chronic Annual Dose Workbook (CADW), version 8.2.4, and above-cited intake rates were used to calculate the doses. The EE's dose to the liver from uranium and RU processing from [redact] through [redact], assuming a full year of exposure for each year, was calculated to be 2.331 rem.

NIOSH's Overestimating Method

NIOSH used the previously determined uranium intake of 5,780 pCi/day and the RU contaminant conversion factors from Table 5-11 of ORAUT-TKBS-0017-5 to determine the RU contaminant intake rates. As an overestimate of the RU contaminant intakes, NIOSH assumed a uranium intake of natural uranium for the entire time period. Table 2-9 lists each of the intake periods, intake rates, and RU:U ratios.

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Table 2-9. NIOSH Uranium and RU Contaminant Intakes

Radionuclide	Type	Start	End	Intake Rate (pCi/day)	Uranium Type	RU:U Ratio
U-234	S	[redact]	[redact]	5,780		–
Pu-239	S	[redact]	[redact]	0.532	natural	9.20E-04
Np-237	M	[redact]	[redact]	0.006		1.04E-06
Tc-99	M	[redact]	[redact]	0.145		2.51E-05

NIOSH used the CADW, version 8.2.4, and intake rates above to calculate the uranium and RU doses. NIOSH calculated the EE's gallbladder dose from uranium and RU processing from [redact] through [redact], assuming a full year of exposure for each year, to be 3.215 rem.

Comparison of the Methods and Results

Besides the obvious differences in the best-estimate versus overestimate approaches, SC&A found two key distinctions.

1. The RU:U ratios in Tables 2-8 and 2-9 for natural uranium are different for SC&A and NIOSH. SC&A used the FEMP Recycled Uranium Mix Intake Rate Calculator 2.00 to determine the RU contaminant intake rates shown in Table 2-10. The RU:U ratio is simply the RU specific activity divided by the U mixture specific activity.

Table 2-10. SC&A RU:U Determination

Radionuclide	Specific Activity (pCi/mg)	RU:U Ratio
U-234 (natural)	683	–
Pu-239	6.289	9.21E-03
Np-237	2.499	3.66E-03
Tc-99	154.35	2.26E-01

It appears the NIOSH dose reconstructor developed a spreadsheet to calculate the RU:U ratios in which the ppb conversion factors from Table 5-11 of ORAUT-TKBS-0017-5 were applied as the specific activities for Pu-239, Np-237, and Tc-99. For example, the RU:U ratio for Np-237 was incorrectly calculated as:

$$\text{RU:U(Np-237)} = 0.714 \text{ pCi/g} \div 683 \text{ pCi/mg} \div 1{,}000 \text{ mg/g}$$
$$= 1.04\text{E-}06$$

The correct RU:U ratio for Np-237 would be:

$$\text{RU:U(Np-237)} = 2.499 \text{ pCi/mg} \div 683 \text{ pCi/mg}$$
$$= 3.66\text{E-}03$$

When applied to NIOSH's U-234 intake of 5,780 pCi/day gives an Np-237 intake rate of 21.2 pCi/day instead of 0.006 pCi/day assigned by NIOSH.

Table 2-11 shows a comparison of the SC&A- and NIOSH-calculated RU-to-U ratios.

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Table 2-11. RU:U Comparison

Radionuclide	SC&A RU:U Ratio	NIOSH RU:U Ratio	SC&A/NIOSH
Pu-239	9.21E-03	9.20E-04	10
Np-237	3.66E-03	1.04E-06	3519
Tc-99	2.26E-01	2.51E-05	9003

2. SC&A assigned the dose to the liver, while NIOSH assigned the dose to the gallbladder. According to the EE's DOL initial case file, the EE's cancer is listed as cholangiocarcinoma – bile ducts, ICD-9 Code 155.1. ORAUT-OTIB-0005 states:

> *For ICD-9 code 155.1, for cancers that are described as cancer of the intrahepatic ducts, select liver as the internal organ. For those that are described as gallbladder carcinoma, select gallbladder as the internal organ. If the description is unclear, a medical review should be conducted to determine the appropriate internal organ of interest.*

2.2.3 Internal Doses from Thorium Processing

Both SC&A and NIOSH assigned dose from thorium processing at the Weldon Spring Plant from [redact] through [redact].

SC&A's Best-Estimate Method

Inhalation and ingestion intakes of thorium-228, thorium-232, and radium-228 were assigned per the guidance of ORAUT-TKBS-0028-5. The Th-232 intake rates were taken from Table 5-22 of ORAUT-TKBS-0028-5. Based on Table 5-23 of ORAUT-TKBS-0028-5, the Th-228 activity is equal to the Th-232 activity, and the Ra-228 activity is equal to two times the Th-232 activity. Intake activities in the table below are in Bq/year. Since the EE terminated in June of [redact], SC&A applied one-half the annual intakes for that year. SC&A calculated the EE's dose to the liver from thorium processing in [redact] through [redact] to be 1.734 rem. Table 2-12 shows the intakes and doses used by SC&A.

Table 2-12. SC&A Thorium Processing Intakes

Radionuclide	Type	Year	Intake Rate (Bq/yr)	Pathway	Dose (rem)
Ra-228	M	[redact]	92	Inhalation	7.911E-04
Th-228	M	[redact]	46	Inhalation	5.369E-02
Th-232	M	[redact]	46	Inhalation	8.794E-02
Ra-228	M	[redact]	1,040	Inhalation	8.943E-03
Th-228	M	[redact]	520	Inhalation	6.069E-01
Th-232	M	[redact]	520	Inhalation	9.750E-01
Ra-228	0.2	[redact]	2	Ingestion	1.748E-05
Th-228	MAX(0.0005)	[redact]	1	Ingestion	1.040E-05
Th-232	MAX(0.0005)	[redact]	1	Ingestion	1.555E-05
Ra-228	0.2	[redact]	21	Ingestion	1.835E-04
Th-228	MAX(0.0005)	[redact]	10.5	Ingestion	1.092E-04
Th-232	MAX(0.0005)	[redact]	10.5	Ingestion	1.602E-04

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NIOSH's Method

The DR report states that NIOSH also assigned inhalation and ingestion intakes of thorium-228, thorium-232, and radium-228 using the guidance of ORAUT-TKBS-0028-5. NIOSH calculated the EE's dose to the gallbladder from thorium processing as 0.254 rem. Table 2-13 shows the intakes and doses used by NIOSH.

Table 2-13. NIOSH Thorium Processing Intakes

Radionuclide	Type	Year	Intake Rate (Bq/yr)	Pathway	Dose (rem)
Ra-228	S	[redact]	92	Inhalation	9.538E-04
Th-228	MAX(M)	[redact]	46	Inhalation	3.555E-03
Th-230	MAX(M)	[redact]	46	Inhalation	6.370E-03
Ra-228	S	[redact]	2,080	Inhalation	2.156E-02
Th-228	MAX(M)	[redact]	1,040	Inhalation	8.037E-02
Th-230	MAX(M)	[redact]	1,040	Inhalation	1.404E-01
Ra-228	0.2	[redact]	2	Ingestion	1.877E-05
Th-228	MAX(0.0005)	[redact]	1	Ingestion	7.148E-07
Th-230	MAX(0.0005)	[redact]	1	Ingestion	1.130E-06
Ra-228	0.2	[redact]	42	Ingestion	3.943E-04
Th-228	MAX(0.0005)	[redact]	21	Ingestion	1.501E-05
Th-230	MAX(0.0005)	[redact]	21	Ingestion	2.314E-05

Comparison of the Methods and Results

Considering SC&A applied one-half the annual intake rates for [redact], both SC&A's and NIOSH's intake rates are similar. However, the doses differ by a factor of 7. The two key differences are:

1. SC&A assigned the dose to the liver; NIOSH assigned the dose to the gallbladder.
2. NIOSH assigned dose from Th-230 instead of Th-232. Row four, column six, of each table shows the difference in dose; Th-232/Th-230 = 8.794E-02/6.370E-03 = 13.8.

2.2.4 Internal Environmental Dose

Both SC&A and NIOSH assessed internal environmental dose for [redact] while the EE was employed at Hanford. In both calculations, the dose from environmental intakes in [redact] was determined to be less than 0.001 rem.

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3.0 SUMMARY CONCLUSIONS

Total external and internal doses and resultant POCs calculated by NIOSH and SC&A in behalf of Case #[Redact] are presented in Table 3-1 for comparison.

Table 3-1. Comparison of Total External and Internal Doses

Total Dose	NIOSH (rem)	SC&A (rem)
External Dose:	13.423	9.282
Internal Dose:	6.623	4.065
Total Dose	**20.046**	**13.347**
POC	**42.49%**	**40.71%**

As shown in Table 3-1, NIOSH's and SC&A's methods resulted in individual cancer POCs, and a combined total POC, that were nearly identical; NIOSH derived a total combined POC of **42.49%** compared to **40.71%** for SC&A.

The following summarizes/compares the methods used by NIOSH and SC&A to assign doses in this case:

- Dose Reconstruction Methodology
  – NIOSH used an overestimating approach and SC&A employed a best-estimate approach to the dose reconstruction.

- Assignment of External Dose
  – NIOSH applied overestimating factors, such as a DCF equal to 1.0 for photons greater than 250 keV. SC&A used the photon DCF values in OCAS-IG-001. NIOSH assigned neutron doses; SC&A did not.

.

- Assignment of Occupational Medical Dose
  – NIOSH and SC&A used the same methodology in assigning medical doses for the Weldon Spring Plant. NIOSH did not assign a dose for Hanford, while SC&A did assign medical dose for the Hanford employment.

- Assignment of Internal Doses
  – SC&A employed a best-estimate approach to assigning internal doses. NIOSH used an overestimating approach. NIOSH assigned the internal doses to the gallbladder. SC&A assigned the internal doses to the liver.

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ORAUT-TKBS-0028-5. 2013. *Weldon Spring Plant – Occupational Internal Dose*, Rev. 02, Oak Ridge Associated Universities Team, Cincinnati, Ohio. May 21, 2013.

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ADDENDUM A: SC&A'S BLIND DOSE RECONSTRUCTION REPORT OF CASE #[REDACT]

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DRAFT

REPORT TO THE ADVISORY BOARD ON RADIATION AND WORKER HEALTH

National Institute of Occupational Safety and Health

BLIND DOSE RECONSTRUCTION OF CASE #[REDACT] FROM THE HANFORD AND WELDON SPRING SITES

Contract No. 211-2014-58081
SCA-TR-BDR2015-CN[Redact]

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February 2015

Disclaimer

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S. Cohen & Associates: ***Technical Support for the Advisory Board on Radiation & Worker Health Review of NIOSH Dose Reconstruction Program***	Document No. SCA-TR-BDR2015-CN[Redact] Effective Date: Draft – February 27, 2015 Revision No. 0 (Draft)
BLIND DOSE RECONSTRUCTION OF CASE #[REDACT] FROM THE HANFORD AND WELDON SPRING SITES	Page 2 of 19
Task Manager: _____ Date: Douglas Farver, CHP	Supersedes: N/A
Project Manager: _____ Date: John Stiver, MS, CHP	Reviewers: Kathleen Behling Rose Gogliotti John Stiver

Record of Revisions

Revision Number	Effective Date	Description of Revision
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TABLE OF CONTENTS

LIST OF TABLES

NOTICE: This report has been reviewed for Privacy Act information and has been cleared for distribution. However, this report is pre-decisional and has not been reviewed by the Advisory Board on Radiation and Worker Health for factual accuracy or applicability within the requirements of 42 CFR 82.

ABBREVIATIONS AND ACRONYMS

AP	anterior-posterior
Bq	Becquerel
CADW	chronic annual dose workbook
CATI	Computer-Assisted Telephone Interview
CF	correction factor
CW	coworker
D.D.	deep dose
DCF	dose conversion factors
DOE	(U.S.) Department of Energy
DOL	(U.S.) Department of Labor
dpm	disintegrations per minute
DR	dose reconstruction
EE	energy employee
GF	geometric correction factor
ICD	International Classification of Diseases
ICRP	International Commission on Radiological Protection
IMBA	Integrated Modules for Bioassay Analysis
IREP	Interactive RadioEpidemiological Program
keV	kilo electron volt; 1,000 electron volts
LAT	lateral
LOD	limit of detection
L/day	liters per day
MDA	minimum detectable activity
mg/L	milligrams per liter
µg/L	micrograms per liter
NIOSH	National Institute for Occupational Safety and Health
OCAS	Office of Compensation Analysis and Support
ORAUT	Oak Ridge Associated Universities Team
PA	posterior-anterior
PFG	photofluorography
pC/d	picocuries per day

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pCi/mg	picocuries per milligram
POC	probability of causation
ppb	parts per billion
rem	Roentgen equivalent man
RU	recycled uranium
SC&A	S. Cohen and Associates (SC&A, Inc.)
SpA	specific activities
TBD	technical basis document
U	uranium
yr	year

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1.0 SUMMARY BACKGROUND INFORMATION

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 Hanford Site from [**redact**], to [**redact**], and at the Weldon Spring Plant from [**redact**], to [**redact**]. The EE was diagnosed with **bile duct cancer** (cholangiocarcinoma) (ICD-9 Code 155.1) on [**redact**].

According to Department of Labor (DOL) files and the Computer-Assisted Telephone Interview (CATI) report, the EE was a [**redact**] at the Hanford Plant and a [**redact**] at the Weldon Spring Plant. The EE was not monitored for external or internal radiation exposure at the Hanford Site. However, the EE was monitored for external photon exposure and internal exposures during most of the employment period at the Weldon Spring Plant.

1.1 SC&A BLIND DR APPROACH

SC&A reviewed all of the Department of Energy (DOE) records provided on behalf of this employee and the National Institute for Occupational Safety and Health (NIOSH) procedures relevant to this case, which included the Technical Basis Document (TBD) for the Hanford Site (issued as six separate documents numbered ORAUT-TKBS-0006-1 through ORAUT-TKBS-0006-6), the TBD for the Weldon Spring Plant (issued as six separate documents numbered ORAUT-TKBS-0028-1 through ORAUT-TKBS-0028-6), ORAUT-OTIB-0005 for surrogate organs, OCAS-IG-001 for dose conversion factors (DCFs), and ORAUT-TBKS-0006-3 and ORAUT-TKBS-0028-3 for occupational x-ray doses. Using the guidance provided in these documents, along with the employee's dosimetry records, SC&A calculated reasonable, claimant-favorable annual organ doses for the liver. Table 1 provides a summary of the total doses assigned for the cancer site. Appendix A provides a list of SC&A's assigned annual organ doses and also includes the Interactive RadioEpidemiological Program (IREP) input parameters, such as energy range, distribution type, and uncertainty for each year.

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Table 1. Summary of SC&A-Derived External/Internal Dose Estimates

	IREP Entry Number	Dose (rem)
External Dose (Occupational)		
▪ Recorded/CW:		
30–250 keV Photons	1–6	1.750
>250 keV Photons	7–12	1.264
▪ Missed Dose:		
30–250 keV Photons	13–19	2.010
>250 keV Photons	20–26	1.598
▪ 1957 Coworker Dose:		
30–250 keV Photons	41	0.198
>250 keV Photons	42	0.143
▪ 1948 Onsite Ambient Dose:		
30–250 keV Photons	43	0.027
▪ Occupational Medical Dose:		
PFG exam, 1948	44	0.690
30–250 keV Photons	27–40	1.602
Internal Dose (alpha):		
U, RU, Th	45–86	4.065
Total		**13.347**

SC&A determined the probability of causation (POC) for this case using the annual doses as input into the NIOSH POC program. The total doses shown in Table 1 produced a POC of **40.71%**.

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2.0 EXTERNAL DOSES

To perform the external DR, SC&A analyzed the EE's DOE files containing the dosimeter readings and x-ray examinations. Although the EE was employed at the Hanford Site for 3 months in [redact], no dosimeter or x-ray examination records were found. Dosimetry and x-ray exam records were available for the time the EE was employed at the Weldon Spring Plant, [redact], to [redact]. Individual dosimeter results or quarterly dosimeter totals are available for [redact]– [redact]; however, no dosimeter results were found for [redact].

SC&A used the DR parameters as recommended in ORAUT-TKBS-0028-6, which consisted of an energy range of 50% 30–250 keV photons, 50% >250 keV photons (Table 6-10), and a limit of detection (LOD) value of 0.050 rem for photons (Table 6-13, page 27). Exposure (as opposed to deep dose) conversion factors (DCFs) from OCAS-IG-001 were used to calculate the external dose to the liver. For anterior-posterior (AP) geometry, a 30–250 keV photon DCF of 1.064 and a >250 keV photon DCF of 0.845 were used.

2.1 RECORDED PHOTON DOSES

No dosimetry data were available for the EE's employment at the Hanford Site in [redact]. The EE was employed at the Weldon Spring Plant from [redact], to [redact]. Monitoring records for the EE begin in [redact]. SC&A used the recorded photon dose values that were ≥LOD/2 of 0.025 rem to assign photon doses using the parameters previously described. A dosimeter correction factor (CF) of 1.1 (for 30–250 keV photons only) and geometric correction factor of 2.1 were also included. ORAUT-TKBS-0028-6 states:

> *6.3.11 Geometric Correction Factor*
> *Consideration should be given to geometry when performing dose reconstruction for uranium facility workers who worked with uranium metals, powders, or residues or for workers who worked on equipment contaminated with uranium. An underestimation of the measured and missed photon doses could occur if the energy employee wore their dosimeter on the upper chest or lapel and not in the central area of the chest or on the waist. The organs located in the lower torso region are most affected. These include, but are not limited to, the stomach, liver, kidney, ureter, gall bladder, pancreas, small intestine, large intestine, rectum, ovaries, uterus, urinary bladder, and prostate.*

Example of [redact] recorded photon dose calculations – SC&A calculated the recorded [redact] photon dose to the liver as follows:

Records show in [redact] the EE received a deep dose of 0.490 rem. The photon dose was assumed to be 50% 30–250 keV and 50% >250 keV. DCFs of 1.064 for 30–250 keV photons and 0.845 for >250 keV photons were applied. Dosimeter and geometric correction factors were also applied.

$$\begin{aligned} \text{30–250 keV photon dose} &= \text{D.D.} \times \text{DCF} \times \text{Energy f.} \times \text{CF} \times \text{GF} \\ &= 0.490 \times 1.064 \times 0.50 \times 1.1 \times 2.1 \\ &= 0.602 \text{ rem} \end{aligned}$$

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>250 keV photon dose = D.D. × DCF × Energy f. × GF
= 0.490 × 0.845 × 0.50 × 2.1
= 0.435 rem

SC&A's calculated [redact] 30–250 keV, and >250 keV doses are shown as IREP entries #3 and #9, respectively, in Appendix A. SC&A assigned a total of 3.013 rem recorded dose, as shown in IREP entries #1–#12 of Appendix A.

2.2 COWORKER DOSE

The EE was not monitored for external radiation in [redact]. The 50th percentile value of the median external doses in [redact] from Table 6-8 of ORAUT-TKBS-0028-6 was used to account for any potential dose from [redact], until [redact].

Example of [redact] coworker dose calculations – SC&A calculated the [redact] coworker dose to the liver as follows:

The [redact] 50th percentile photon dose is 0.161 rem. The photon dose was assumed to be 50% 30–250 keV and 50% >250 keV. DCFs of 1.064 for 30–250 keV photons and 0.845 for >250 keV photons were applied. Dosimeter and geometric correction factors were also applied.

30–250 keV photon dose = D.D. × DCF × Energy f. × CF × GF
= 0.161 × 1.064 × 0.50 × 1.1 × 2.1
= 0.198 rem

>250 keV photon dose = D.D. × DCF × Energy f. × GF
= 0.161 × 0.845 × 0.50 × 2.1
= 0.143 rem

SC&A's calculated [redact] 30–250 keV and >250 keV doses are shown as IREP entries #41 and #42, respectively, in Appendix A. SC&A assigned a total of 0.341 rem coworker photon dose.

2.3 MISSED PHOTON DOSES

SC&A analyzed the number of physical zeros and potential zeros based on a monthly badge exchange cycle using the guidance in OCAS-IG-001and a best-estimate reasonable approach to arrive at a total 72 zeros, or <LOD/2 values, for photons. SC&A used the annual number of zeros, the LOD/2 value, the DR parameters as listed above, and the applicable DCF to determine the annual missed photon dose.

Example of [redact] missed photon dose calculations – SC&A calculated the missed [redact] photon dose to the liver as follows:

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In [redact], the EE's dosimeter results showed 10 zeros. The photon dose was assumed to be 50% 30–250 keV and 50% >250 keV. DCFs of 1.064 for 30–250 keV photons and 0.845 for >250 keV photons were applied. A geometric correction factor was also applied.

Missed Photon Dose (30–250 keV) = (# zeros × LOD/2) × DCF × Energy f × GF
= (10 × 0.025 rem) × 1.064 × 0.50 × 2.1
= 0.279 rem

Missed Photon Dose (>250 keV) = (# zeros × LOD/2) × DCF × Energy f. × GF
= (10 × 0.025 rem) × 0.845 × 0.50 × 2.1
= 0.222 rem

SC&A's calculated 30–250 keV missed photon dose of 0.279 rem is shown in entry #14 and the >250 keV missed photon dose of 0.222 is shown in entry #21 of Appendix A. SC&A assigned a total of 3.608 rem missed dose, as shown in IREP entries #13–#26 of Appendix A.

2.4 OCCUPATIONAL MEDICAL DOSE

The DOE records show that the EE received one photofluorography (PFG) x-ray exam in [redact] at the Hanford Site and eight occupational medical x-ray exams (which were not for injuries, etc.) during the period [redact]– [redact]. Posterior-anterior (PA) views plus lateral (LAT) views were assumed for all eight exams, per Section 3.1.2 of ORAUT-TKBS-0028-3.

Using the liver organ dose values recommended in Table 3-1 of ORAUT-TKBS-0006-3 and Table 3-3 of ORAUT-TKBS-0028-3 as a function of the year the exam was performed, SC&A assigned a dose of 0.690 rem for the PFG exam in entry #44 of the IREP Input table, a total dose of 0.722 rem for the PA views (entries #27–#33), and 0.880 rem for the LAT views (entries #34–#40), for a total occupational medical x-ray dose of 2.292 rem. These doses are summarized in Table 1 above, and detailed in Appendix A.

2.5 ONSITE AMBIENT DOSE

The EE was not monitored while at the Hanford Site from [redact], to [redact]. Since the EE was monitored at the Weldon Spring Plant, external ambient dose should not be applied, in accordance with ORAUT-PROC-0060. Therefore, external ambient dose was assigned for the time period at the Hanford Site and not assigned while employed at the Weldon Spring Plant. The Hanford ambient dose was determined as follows.

Table 4-8 of ORAUT-TKBS-0006-4 shows the 0.115 rem/yr as the maximum external gamma dose for [redact]. Using the isotropic DCF for the liver of 0.568, correcting for 2,500 hours/yr, and prorating for the 4-month time period, an ambient dose was calculated as follows:

Ambient dose = Annual Dose × DCF × 2,500/2,000 × 4/12 months
= 0.115 rem/yr × 0.568 × 1.25 × 0.333 yr
= 0.027 rem

This value is shown as IREP entry #43 of Appendix A.

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3.0 INTERNAL DOSES

The EE's internal dose monitoring records were reviewed and showed the EE was not monitored for internal exposures while at Hanford in [redact]. At the Weldon Spring Plant, the EE was monitored for potential uranium exposure via urine samples. In addition to uranium exposure, exposures to thorium and radon were considered.

3.1 URANIUM INTAKE

While employed at Weldon Spring, the EE was monitored for potential uranium exposure via urine samples that were submitted from [redact], through [redact]. Several of the urine samples were reported with total uranium concentrations above the minimum detectable activity (MDA) of 0.008 micrograms per liter (µg/L). As specified in the Weldon Spring TBD (ORAUT-TKBS-0028-5), the assumed specific activities (SpA) used in this assessment were natural uranium (specific activity = 683 pCi/mg) for the years [redact] through [redact], natural uranium with recycled uranium (RU) components in [redact] and [redact], and 1% enriched uranium (0.973 pCi/mg) from Table 5-3 of the Fernald Environmental Management Project TBD (ORAUT-TKBS-0017-5) with RU components for [redact]. The uranium activities were normalized to a daily urine excretion rate of 1.4 L/day, and the uranium intakes were assessed as 100% uranium-234. Table 2 shows the EE's bioassay results.

Table 2. Uranium Bioassay Results

Date	Result (mg/L)	pCi/d*	MDA pCi/d*		Date	Result (mg/L)	pCi/d*	MDA pCi/d*
[redact]	0.04+	34.42+	7.87		[redact]	0.02	17.70	7.87
[redact]	0.00	0.98	7.87		[redact]	0.01	13.77	7.87
[redact]	0.00	0.00	7.87		[redact]	0.01	4.92	7.87
[redact]	0.00	1.97	7.87		[redact]	0.01	8.85	7.87
[redact]	0.00	3.93	7.87		[redact]	0.01	7.87	7.87
[redact]	0.00	3.93	7.87		[redact]	0.02	19.67	7.87
[redact]	0.00	1.97	7.87		[redact]	0.02	20.30	9.02
[redact]	0.00	2.95	7.87		[redact]	0.01	15.79	9.02
[redact]	0.01	9.84	7.87		[redact]	0.02	21.42	9.02
[redact]	0.01	4.92	7.87		[redact]	0.01	15.79	9.02
[redact]	0.00	3.93	7.87		[redact]	0.01	7.89	9.02
[redact]	0.01	11.80	7.87		[redact]	0.00	0.00	9.02
[redact]	0.02	19.67	7.87		[redact]	0.02	20.30	9.02
[redact]	0.00	1.97	7.87		[redact]	0.00	4.51	9.02
[redact]	0.02	18.69	7.87		[redact]	0.03	28.19	9.02
[redact]	0.00	2.95	7.87		[redact]	0.02	24.81	9.02
[redact]	0.01	10.82	7.87		[redact]	0.01	9.02	9.02
[redact]	0.02	21.64	7.87		[redact]	0.01	9.02	9.02
[redact]	0.02	16.72	7.87		[redact]	0.01	7.89	9.02

+ Sample is prior to employment date and not included in the intake assessment

* Daily intake based on SpA for natural uranium of 683 pCi/mg through [redact] and SpA of 1% enriched uranium of 783 pCi/mg for [redact] and later

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Prior to [redact], all of the EE's bioassay results were less than the detection limit. A visual fit of the bioassay results was performed using the Integrated Modules for Bioassay Analysis (IMBA) program and an assumed chronic intake period from [redact], until the EE's sample date of [redact]. The IMBA-generated uranium-234 intake activity associated with absorption Type M was calculated to be 225 pCi/d.

3.2 RECYCLED URANIUM CONTAMINANT INTAKES

Recycled uranium (RU) was first introduced at the Weldon Spring Plant in 1961. Therefore, all uranium intakes after 1960 are assumed to have associated plutonium-239, neptunium-237, and technetium-99 intakes. The RU components were added as 100 ppb plutonium-239, 3,500 ppb neptunium-237, and 9,000 ppb technetium-99 (ORAUT-TKBS-0028-5). The ratios of RU contaminants to uranium (dpm/dpm U) were calculated and are shown in Table 3.

Table 3. Recycled Uranium Components at WSP

Contaminant:Uranium Ratio		
RU Contaminant	**Natural U**	**1% Enriched U**
Plutonium-239	9.21E-03	6.46E-03
Neptunium-237	3.66E-03	2.57E-03
Technetium-99	2.26E-01	1.57E-01

The previously determined uranium intake, 225 pCi/d, and the ratios above were used to calculate daily intakes for each of the contaminants based on natural uranium in [redact] and 1% enriched uranium in [redact] and [redact]. Table 4 lists each of the intake periods and intake rates.

Table 4. Uranium and RU Contaminant Intakes

Radionuclide	Intake Period	Intake Rate (pCi/d)
U-234 M	[redact]–[redact]	225
Pu-239 M	[redact]–[redact]	2.072
Np-237 M	[redact]–[redact]	0.823
Tc-99 M	[redact]–[redact]	50.850
Pu-239 M	[redact]–[redact]	1.454
Np-239 M	[redact]–[redact]	0.578
Tc-99 M	[redact]–[redact]	35.390

The Chronic Annual Dose Workbook (CADW), version 8.2.4, and intake rates were used to calculate the doses. The EE's dose to the liver from U and RU processing from [redact] through [redact], assuming a full year of exposure for each year, was calculated to be 2.331 rem.

3.2.1 Insoluble Plutonium

Some forms of plutonium exhibit longer lung clearance times than those used in the International Commission on Radiological Protection Publication 66 (ICRP 1994) model for insoluble (Type S) plutonium. This can result in higher doses to some organs, so dose modification factors were developed, as described in ORAUT-OTIB-0049, *Technical Information Bulletin: Estimating Doses for Plutonium Strongly Retained in the Lung.* The EE's dose is estimated to

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the liver, a systemic organ (portions of the body not included in the respiratory or gastrointestinal tracts), using air concentrations. The dose to a systemic organ from an inhalation of plutonium is the result of plutonium that is absorbed into the bloodstream. Because Type Super S plutonium is retained in the lungs for a longer time than more soluble forms of plutonium (Types M and S), less is transferred to the blood, and hence the dose is lower than for an equal intake of Type M or Type S plutonium. Therefore, dose adjustments for plutonium (plutonium-239 and its mixtures) strongly retained in the lung (Type Super S) are not required for the dose to the liver.

3.3 THORIUM INTAKES

To account for the EE's potential internal dose due to thorium processing at the Weldon Spring Plant from [redact] through [redact], inhalation and ingestion intakes of thorium-228, thorium-232, and radium-228 were also assigned, per the guidance of the ORAUT-TKBS-0028-5. The solubility was selected to maximize the dose to the liver. The Th-232 intake rates shown in Table 5 were taken from Table 5-22 of ORAUT-TKBS-0028-5. Based on Table 5-23 of ORAUT-TKBS-0028-5, the Th-228 activity is equal to Th-232 activity and Ra-228 activity is equal to two times Th-232 activity, when more than one type may have been present. Intake activities in Table 5 are in Bq/year.

Table 5. Intakes from Thorium Processing (Bq/year)

Year	Th-228 M	Th-228	Th-232 M	Th-232	Ra-228 M	Ra-228
	Inhalation	Ingestion	Inhalation	Ingestion	Inhalation	Ingestion
[redact]	46	1	46	1	92	2
[redact]	1040	21	1040	21	2080	42

The CADW tool was used to calculate the thorium doses, assuming a full year of exposure in [redact] and partial year of exposure in [redact]. The dose to the liver from thorium processing from [redact] through [redact], assuming a half year of exposure in [redact], was calculated to be 1.734 rem.

3.4 RADON AND THORON

Because of the nature of the EE's cancer, exposure from radon and thoron was assessed, but not assigned in the DR, as it would not result in a significant dose to the liver.

3.5 ENVIRONMENTAL DOSE

While employed at Hanford during [redact], the EE was potentially exposed to environmental internal exposures. SC&A used the CADW tool and intake information from Table A-12 of ORAUT-TKBS-0006-4 to derive the environmental intakes and resulting doses. The annual dose for [redact] from environmental intakes was less than 0.001 rem and not included in the final IREP Input table.

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4.0 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. SCA& did not find any documentation of radiological incidents that would impact the radiation doses assigned in this case.

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5.0 SUMMARY CONCLUSIONS

This DR used best-estimate methods to obtain reasonable external and internal dose assignments. The derived total doses provided for a POC <50%.

The total POC for the bile duct cancer was calculated using the NIOSH-Interactive RadioEpidemiological Program (v.5.7.1) and determined to be **45.63%**.

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APPENDIX A: IREP INPUT – LIVER

CLAIMANT CANCER DIAGNOSES						
	Primary Cancer #1	Primary Cancer #2	Primary Cancer #3	Secondary Cancer #1	Secondary Cancer #2	Secondary Cancer #3
Cancer Type	Intrahepatic Bile Ducts	N/A	N/A	N/A	N/A	N/A
Date of Diagnosis	[redact]	N/A	N/A	N/A	N/A	N/A

EXPOSURE INFORMATION							
Number of exposures							
87							
Exposure #	**Exposure Year**	**Exposure Rate**	**Radiation Type**	**Dose Distribution Type**	**Parameter 1**	**Parameter 2**	**Parameter 3**
1	[redact]	acute	photons E=30–250 keV	Constant	0.042	0.000	0.000
2	[redact]	acute	photons E=30–250 keV	Constant	0.091	0.000	0.000
3	[redact]	acute	photons E=30–250 keV	Constant	0.602	0.000	0.000
4	[redact]	acute	photons E=30–250 keV	Constant	0.684	0.000	0.000
5	[redact]	acute	photons E=30–250 keV	Constant	0.244	0.000	0.000
6	[redact]	acute	photons E=30–250 keV	Constant	0.086	0.000	0.000
7	[redact]	acute	photons E>250 keV	Constant	0.030	0.000	0.000
8	[redact]	acute	photons E>250 keV	Constant	0.066	0.000	0.000
9	[redact]	acute	photons E>250 keV	Constant	0.435	0.000	0.000
10	[redact]	acute	photons E>250 keV	Constant	0.494	0.000	0.000
11	[redact]	acute	photons E>250 keV	Constant	0.177	0.000	0.000
12	[redact]	acute	photons E>250 keV	Constant	0.062	0.000	0.000
13	[redact]	acute	photons E=30–250 keV	Lognormal	0.698	1.520	0.000
14	[redact]	acute	photons E=30–250 keV	Lognormal	0.279	1.520	0.000
15	[redact]	acute	photons E=30–250 keV	Lognormal	0.335	1.520	0.000
16	[redact]	acute	photons E=30–250 keV	Lognormal	0.195	1.520	0.000
17	[redact]	acute	photons E=30–250 keV	Lognormal	0.223	1.520	0.000
18	[redact]	acute	photons E=30–250 keV	Lognormal	0.168	1.520	0.000
19	[redact]	acute	photons E=30–250 keV	Lognormal	0.112	1.520	0.000
20	[redact]	acute	photons E>250 keV	Lognormal	0.555	1.520	0.000
21	[redact]	acute	photons E>250 keV	Lognormal	0.222	1.520	0.000
22	[redact]	acute	photons E>250 keV	Lognormal	0.266	1.520	0.000
23	[redact]	acute	photons E>250 keV	Lognormal	0.155	1.520	0.000
24	[redact]	acute	photons E>250 keV	Lognormal	0.178	1.520	0.000
25	[redact]	acute	photons E>250 keV	Lognormal	0.133	1.520	0.000
26	[redact]	acute	photons E>250 keV	Lognormal	0.089	1.520	0.000
27	[redact]	acute	photons E=30–250 keV	Normal	0.090	0.027	0.000
28	[redact]	acute	photons E=30–250 keV	Normal	0.090	0.027	0.000
29	[redact]	acute	photons E=30–250 keV	Normal	0.090	0.027	0.000
30	[redact]	acute	photons E=30–250 keV	Normal	0.090	0.027	0.000
31	[redact]	acute	photons E=30–250 keV	Normal	0.090	0.027	0.000
32	[redact]	acute	photons E=30–250 keV	Normal	0.090	0.027	0.000
33	[redact]	acute	photons E=30–250 keV	Normal	0.180	0.054	0.000

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Appendix A: IREP Input – Liver (continued)

Exposure #	Exposure Year	Exposure Rate	Radiation Type	Dose Distribution Type	Parameter 1	Parameter 2	Parameter 3
34	[redact]	acute	photons E=30–250 keV	Normal	0.110	0.033	0.000
35	[redact]	acute	photons E=30–250 keV	Normal	0.110	0.033	0.000
36	[redact]	acute	photons E=30–250 keV	Normal	0.110	0.033	0.000
37	[redact]	acute	photons E=30–250 keV	Normal	0.110	0.033	0.000
38	[redact]	acute	photons E=30–250 keV	Normal	0.110	0.033	0.000
39	[redact]	acute	photons E=30–250 keV	Normal	0.110	0.033	0.000
40	[redact]	acute	photons E=30–250 keV	Normal	0.220	0.066	0.000
41	[redact]	acute	photons E=30–250 keV	Constant	0.198	0.000	0.000
42	[redact]	acute	photons E>250 keV	Constant	0.143	0.000	0.000
43	[redact]	chronic	photons E=30–250 keV	Constant	0.027	0.000	0.000
44	[redact]	acute	photons E=30–250 keV	Normal	0.690	0.207	0.000
45	[redact]	chronic	alpha	Lognormal	0.005	3.000	0.000
46	[redact]	chronic	alpha	Lognormal	0.018	3.000	0.000
47	[redact]	chronic	alpha	Lognormal	0.041	3.000	0.000
48	[redact]	chronic	alpha	Lognormal	0.072	3.000	0.000
49	[redact]	chronic	alpha	Lognormal	0.202	3.000	0.000
50	[redact]	chronic	alpha	Lognormal	0.302	3.000	0.000
51	[redact]	chronic	alpha	Lognormal	0.243	3.000	0.000
52	[redact]	chronic	alpha	Lognormal	0.198	3.000	0.000
53	[redact]	chronic	alpha	Lognormal	0.168	3.000	0.000
54	[redact]	chronic	alpha	Lognormal	0.148	3.000	0.000
55	[redact]	chronic	alpha	Lognormal	0.134	3.000	0.000
56	[redact]	chronic	alpha	Lognormal	0.124	3.000	0.000
57	[redact]	chronic	alpha	Lognormal	0.116	3.000	0.000
58	[redact]	chronic	alpha	Lognormal	0.111	3.000	0.000
59	[redact]	chronic	alpha	Lognormal	0.106	3.000	0.000
60	[redact]	chronic	alpha	Lognormal	0.102	3.000	0.000
61	[redact]	chronic	alpha	Lognormal	0.099	3.000	0.000
62	[redact]	chronic	alpha	Lognormal	0.096	3.000	0.000
63	[redact]	chronic	alpha	Lognormal	0.093	3.000	0.000
64	[redact]	chronic	alpha	Lognormal	0.090	3.000	0.000
65	[redact]	chronic	alpha	Lognormal	0.088	3.000	0.000
66	[redact]	chronic	alpha	Lognormal	0.086	3.000	0.000
67	[redact]	chronic	alpha	Lognormal	0.084	3.000	0.000
68	[redact]	chronic	alpha	Lognormal	0.082	3.000	0.000
69	[redact]	chronic	alpha	Lognormal	0.080	3.000	0.000
70	[redact]	chronic	alpha	Lognormal	0.078	3.000	0.000
71	[redact]	chronic	alpha	Lognormal	0.076	3.000	0.000
72	[redact]	chronic	alpha	Lognormal	0.074	3.000	0.000
73	[redact]	chronic	alpha	Lognormal	0.073	3.000	0.000
74	[redact]	chronic	alpha	Lognormal	0.071	3.000	0.000
75	[redact]	chronic	alpha	Lognormal	0.069	3.000	0.000
76	[redact]	chronic	alpha	Lognormal	0.068	3.000	0.000

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Appendix A: IREP Input – Liver (continued)

Exposure #	Exposure Year	Exposure Rate	Radiation Type	Dose Distribution Type	Parameter 1	Parameter 2	Parameter 3
77	[redact]	chronic	alpha	Lognormal	0.067	3.000	0.000
78	[redact]	chronic	alpha	Lognormal	0.065	3.000	0.000
79	[redact]	chronic	alpha	Lognormal	0.064	3.000	0.000
80	[redact]	chronic	alpha	Lognormal	0.063	3.000	0.000
81	[redact]	chronic	alpha	Lognormal	0.061	3.000	0.000
82	[redact]	chronic	alpha	Lognormal	0.060	3.000	0.000
83	[redact]	chronic	alpha	Lognormal	0.059	3.000	0.000
84	[redact]	chronic	alpha	Lognormal	0.058	3.000	0.000
85	[redact]	chronic	alpha	Lognormal	0.057	3.000	0.000
86	[redact]	chronic	alpha	Lognormal	0.056	3.000	0.000
87	[redact]	chronic	alpha	Lognormal	0.055	3.000	0.000

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