DRAFT

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 [REDACTED] FROM THE ALLIED CHEMICAL AND DYE CORPORATION, NORTH CLAYMONT, DELAWARE

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ABBREVIATIONS AND ACRONYMS

ACP	Allied Chemical Plant
Advisory Board	Advisory Board on Radiation and Worker Health
AEC	Atomic Energy Commission
Bq	Becquerel
CADW	Chronic Annual Dose Workbook
CATI	Computer-Assisted Telephone Interview
CF	conversion factor
DCF	dose conversion factor
DOE	(U.S.) Department of Energy
DOL	(U.S.) Department of Labor
DR	dose reconstruction
EE	Energy Employee
EPA	(U.S.) Environmental Protection Agency
FIPR	Florida Institute of Phosphate Research
GM	geometric mean
GSD	geometric standard deviation
hr	hour
IREP	Interactive RadioEpidemiological Program
keV	kiloelectron volts
l	liter
m^3	cubic meter
m/s	meter per second
mrem	millirem
NIOSH	National Institute for Occupational Safety and Health
ORAUT	Oak Ridge Associated Universities Team
pCi	picocuries
POC	probability of causationrem Roentgen equivalent man
SC&A	S. Cohen and Associates (SC&A, Inc.)
sec	second
SRDB	Site Research Database
TBD	technical basis document

TENORM	Technologically Enhanced Naturally Occurring Radioactive Materials
U_3O_8	triuranium octoxide
WLM/yr	working level month per year
yr	year

1.0 STATEMENT OF PURPOSE

Under Contract No. 200-2009-28555, SC&A was tasked by the Advisory Board on Radiation and Worker Health (Advisory Board) to perform six blind dose reconstructions (DRs) at the May 21, 2013, 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 reconstructing doses in behalf of these cases. SC&A used two independent approaches to reconstruct occupational external and internal doses for the cases. Both approaches used the available dosimetry records and current guidance from NIOSH. The first approach, 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.

One of the six draft blind DR reports [*Blind Dose Reconstruction of Case* [**Redacted**] *from the Allied Chemical Plant* (SC&A 2014)], was submitted to the Advisory Board and NIOSH on February 21, 2014. In this report, SC&A presents a comparison between SC&A's and NIOSH's DR methodologies, doses, and resultant probability of causation (POC) values for Case [**Redacted**]. Table 1-1 summarizes the external and internal occupational doses calculated by SC&A (using two independent methods) and the NIOSH-assigned dose for Case [**Redacted**]. A detailed comparison of the three 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 an explanation is provided regarding the differences in doses and why they occurred; however, SC&A does not make any value judgments regarding which are the more correct approaches. It is our position that further discussions are best addressed by the DR Subcommittee.

Table 1-1. Comparison of SC&A's Blind Dose Reconstruction to NIOSH's Dose Reconstruction for Case [Redacted]

	SC&A–Method A	SC&A–Method B	NIOSH
External Dose (Occupational):			
▪ **Operations Dose** (rem)			
- Photons 30–250 keV	0.462	NA	0.209
- Photons >250 keV	0.579	NA	0.172
▪ **Residual Dose** (rem)			
- Photons 30–250 keV	0.086	NA	0.056
- Photons >250 keV	0.108	NA	0.047
▪ **Occupational Medical Dose** (rem)			
- Photons 30–250 keV	1.886	NA	1.592
Internal Dose (rem)**:**			
- Uranium/Thorium (Operational)	93.679	NA	15.106
- Uranium/Thorium (Residual)	24.635	NA	0.088
Total	**121.435**	NA	**17.271**
Total Radon	**0.812 WLM**	**2.115 WLM**	**0.214 WLM**
POC	**85.4%**	**64.1%**	**45.90%**

NA = not applicable

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

Case [**Redacted**] represents an energy employee (EE) who worked at the Allied Chemical and Dye Company in North Claymont, Delaware [referred to in this report as the Allied Chemical Plant (ACP)], from [**redacted**] to [**redacted**], and [**redacted**] to [**redacted**]. This employment period spans the operational period of 1950 through 1969, when the ACP was involved in a small-scale pilot operation recovering uranium from a phosphoric acid plant, as well as the residual contamination period from 1970 through 1977. According to the DOL records and the CATI, the EE worked as a [**redacted**] during both employment periods. No employee monitoring records or site survey records were found. The EE was diagnosed with **oat cell carcinoma of the lung** (ICD-9 Code 162.9) in [**redacted**].

Since no monitoring records exist for the EE and there are no technical basis documents (TBDs) or survey information for ACP, both SC&A and NIOSH used surrogate data for reconstructing external doses. Key guidance documents used by SC&A and/or NIOSH include the following:

- ORAUT-OTIB-0043, Rev. 00, *Characterization of Occupational Exposure to Radium and Radon Progeny during Recovery of Uranium from Phosphate Materials* (ORAUT 2006).

- Battelle-TBD-6000, Rev. 1, *Technical Basis Document: Site Profiles for Atomic Weapons Employers that Worked Uranium Metals* (Battelle 2011).

- ORAUT-OTIB-0070, Rev. 01, *Dose Reconstruction during Residual Radioactivity Periods at Atomic Weapons Employer Facilities*, (ORAUT 2012).

- DCAS-TKBS-0002, Rev. 3, *Technical Basis Document for Atomic Energy Operations at Blockson Chemical Company, Joliet, Illinois* (DCAS 2010).

- Florida Institute of Phosphate Research (FIPR), *Evaluation of Exposure to Technologically Enhanced Naturally Occurring Radioactive Materials (TENORM) in the Phosphate Industry*, Publication 05-046-155 (FIPR 1998).

A summary of how these documents were used by each DR method, as well as other assumptions and dose parameters, is provided in Table 2-1:

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

Dose Element	NIOSH	SC&A's DR–Method A	SC&A's DR–Method B
External Dose: Operations	Assumed 22 mrem/yr, which represents **10% of upper-bound external dose** value of 220 mrem/yr from Table 4-1 of ORAUT-OTIB-0043. Lung ***Exposure (R)*** DCF (mode) values from OCAS-IG-001. Photon energy range = 50% 30–250 keV; 50% >250 keV. Dose distribution = **constant**.	Used the **geometric mean external dose** value of 70 mrem/yr from Table 4-1 of ORAUT-OTIB-0043. Lung ***Hp(10)*** DCF (mode) values from OCAS-IG-001. Photon energy range = 50% 30–250 keV; 50% >250 keV. Dose distribution = **lognormal** with GSD of 2.0.	Not considered
Residual Period	Used same photon dose parameters as above for the operations. However, calculated residual contamination based on guidance in **Battelle-TBD-6000** and **ORAUT-OTIB-0043.**	Used same photon dose parameters as above for the operations. However, calculated residual contamination based on data in **ORAUT-OTIB-0070.**	Not considered
Occupational Medical	Assumed an annual x-ray for each year of employment **during operations ([redact]–[redact], ([redact]–[redact])** based on doses in ORAUT-OTIB-0006. Dose distribution = normal with 30% uncertainty.	Assumed annual x-ray for each year of employment (**both operational and residual periods; ([redact]–[redact], ([redact]–[redact])** based on doses in ORAUT-OTIB-0006. Dose distribution = normal with 30% uncertainty.	Not considered
Onsite Ambient	Not considered	Not considered	Not considered
Internal Dose: Inhalation	Although not explicitly stated in the DR, it was determined via personal communications (Allen 2014) and data in EE's file that NIOSH used **10%** of the maximum U-238/Th-232 (and progeny) values from Table 4-3 of ORAUT-OTIB-0043 for the **operations period ([redact]–[redact])**. Intake for the **residual period** (**([redact]**–[redact]) was based on operational data. Assumed contamination settled for one year and was resuspended based on a resuspension factor of 1E-6 m^{-1}.	Used the uranium intake value of 44.0 pCi/day for U-238 and 0.605 pCi/day Th-232 from Table 4-3 of ORAUT-OTIB-0043, plus the ratio values for associated radionuclides from **the Blockson TBD** and ORAUT-OTIB-0043 to derive the potential intakes during the **operational period.** For the **residual period**, these same intake values were adjusted for depletion according to **ORAUT-OTIB-0070**.	Not considered
Ingestion	Ingestion intake based on an inhalation conversion factor of 0.2 from OCAS-TIB-009.	Not considered	Not considered
Radon	Used 10% of **maximum** radon intake value (i.e., 0.0112 WLM/yr) from Table 4-4 of ORAUT-OTIB-0043 for operations period. Calculated intake for residual period using operations data and same assumptions as inhalation, as described above.	Used **best-estimate** radon intake value of 0.036 WLM/yr from Table 4-4 of ORAUT-OTIB-0043 to assign yearly radon intakes for the operational years, and the same value, adjusted for depletion rate according to ORAUT-OTIB-0070, for the residual period.	Assumed radon intake of 4 pCi/l in 50% equilibrium, which corresponds to 0.235 WLM/yr. The value of 4 pCi/l is the EPA guideline for radon as quoted in FIPR 1998, and was considered a minimizing approach.

2.1 OCCUPATIONAL EXTERNAL DOSE CALCULATIONS

2.1.1 Photon Doses during the Operational Period

The EE was employed for all of the operational years (i.e., 1950–1969) at ACP except for [redacted]. As indicated above, there were no dosimetry records or ACP-specific radiological survey data available for estimating the EE's dose. Therefore, both NIOSH and SC&A's Method A used generic guidance provided in ORAUT-OTIB-0043, Rev. 00, *Characterization of Occupational Exposure to Radium and Radon Progeny During Recovery of Uranium from Phosphate Materials* (ORAUT 2006). Table 4-1 of ORAUT-OTIB-0043 provides DRs with the option of assuming (1) an upper-bound exposure for plant workers of 220 mrem/yr entered into the Interactive RadioEpidemiological Program (IREP) as a constant value, or (2) the geometric mean (GM) exposure rate of 70 mrem/yr with a geometric standard deviation (GSD) of 2.0.

NIOSH's Method

For calculating photon doses during the operational period, NIOSH assumed 10% of upper-bound external dose value of 220 mrem/yr from Table 4-1 of ORAUT-OTIB-0043, or 22 mrem/yr. This value was multiplied by an Exposure (R) to Organ (H_T) dose conversion factor (DCF) for the lung of 0.986 for photon energies 30–250 keV and 0.842 for energies >250 keV from Appendix A of OCAS-IG-001, *External Dose Reconstruction Implementation Guideline* (OCAS 2007). External dose values were assigned assuming 50% 30–250 keV photon energies and 50% >250 keV energies, as specified in Table 4-1 of ORAUT-OTIB-0043, and entered into IREP as a constant.

This resulted in the calculation of photon doses for each of the operational years (1950–1969), as shown below:

Photon 30–250 keV = Annual dose (10% upper-bound) × DCF × Percent of Energy Range
= 0.022 rem × 0.986 × 0.5
= 0.011 rem

Photon >250 keV = Annual dose (10% upper-bound) × DCF × Percent of Energy Range
= 0.022 rem × 0.842 × 0.5
= 0.009 rem

SC&A's 'Method A'

Note: Only SC&A's 'Method A' calculated photon doses; SC&A's 'Method B' did a partial dose assessment considering only the radon exposure and did not estimate any external doses.

SC&A's 'Method A' also used values cited in Table 4-1 of ORAUT-OTIB-0043 for estimating photon doses. However, this method selected the GM value of 0.070 rem/yr, which was entered into IREP as a lognormal distribution with a GSD of 2.00. The Hp10 organ DCFs from Appendix A of OCAS-IG-001 were used to convert dose to the lung. As specified in ORAUT-OTIB-0043, SC&A also used an energy distribution of 50% 30–250 keV and 50% >250% keV.

Using these data, annual photon doses during the operational years were calculated as follows:

Photon 30–250 keV = Annual dose (GM value) × DCF × Percent of Energy Range
= 0.070 rem × 0.695 × 0.5
= 0.024 rem

Photon >250 keV = Annual dose (GM value) × DCF × Percent of Energy Range
= 0.070 rem × 0.870 × 0.5
= 0.030 rem

2.1.2 Photon Doses during the Residual Period

The residual period begins in 1970, after the completion of operations, and is assumed to last until 1977. The EE was employed during the residual period from [redacted] through [redacted]. Photon doses were calculated by NIOSH and SC&A's 'Method A' as described below.

NIOSH's Method
For the residual period, NIOSH used the same assumptions for calculating photon doses that were used during the operational period. Therefore, for the residual years [redacted] through [redacted], the annual doses are identical to those calculated above during operations. For the year [redacted], the EE only worked [redacted] and the dose was prorated accordingly.

SC&A's 'Method A'
SC&A's 'Method A' calculated the EE's exposure to residual contamination using the guidance found in ORAUT-OTIB-0070, *Dose Reconstruction during Residual Radioactivity Periods at Atomic Weapons Employer Facilities* (ORAUT 2012), from 1970 until the EE's last year of employment in [redacted].

ORAUT-OTIB-0070 provides guidance and adjustment factors to account for depletion of the source term during the residual period based on an average depletion rate of 0.00067 per day. This resulted in the estimate of photon doses as shown in Table 2-2. These values were entered into IREP as a GM with a GSD of 2.0.

Table 2-2. SC&A's 'Method A' Residual Photon Doses

Year	Adjustment Factor	Photon Dose (rem)	
		30–250 keV photons	>250 keV photons
[redacted]	1.000	0.024	0.030
[redacted]	0.783	0.019	0.024
[redacted]	0.613	0.015	0.019
[redacted]	0.480	0.012	0.015
[redacted]	0.376	0.009	0.011
[redacted]	0.294	0.007	0.009

A summary of modeled photon doses derived by NIOSH and SC&A for the operational and residual periods is presented in Table 2-3.

Table 2-3. Comparison of Modeled External Photon Doses

Modeled External Doses	SC&A-Method A (rem)	SC&A-Method B (rem)	NIOSH (rem)
Lung Dose during Operational Period	0.462 (30–250 keV) 0.579 (>250 keV) 1.041 Total	Not considered	0.209 (30–250 keV) 0.172 (>250 keV) 0.381 Total
Lung Dose during Residual Period	0.086 (30–250 keV) 0.108 (>250 keV) 0.194 Total	Not considered	0.056 (30–250 keV) 0.047 (>250 keV) 0.103 Total

The operational period photon dose calculated by SC&A's 'Method A' is 2.7 times higher than the NIOSH-assigned photon dose. Although both methods used dose data cited in Table 4-1 of ORAUT-OTIB-0043, SC&A's 'Method A' assumed the EE's exposure rate was more likely represented by the GM of 70 mrem/yr to workers located at gypsum stacks, while NIOSH assumed a lower exposure represented by 10% of the upper-bound value of 0.220 rem/yr.

Although two different approaches were used to calculate doses during the residual period, the NIOSH-assigned and SC&A total doses differed by less than a factor of 2.

2.1.3 Occupational Medical Doses

NIOSH and SC&A's 'Method A' calculated an occupational medical dose from diagnostic x-ray procedures required as a condition of employment, even though DOE records contained no diagnostic x-ray records from ACP. In the absence of records, both methods used guidance provided in the *Technical Information Bulletin: Dose Reconstruction from Occupationally Related Diagnostic X-Ray Procedures*, Rev. 04 (ORAUT 2011). NIOSH assumed an annual medical x-ray procedure for each year of employment during the Atomic Energy Commission (AEC) contract period. SC&A assumed the EE received an annual x-ray exam for all years of employment, which included the operational and residual periods.

A comparison of medical doses derived by the SC&A and NIOSH methods is presented in Table 2-4.

Table 2-4. Comparison of Occupational Medical Doses

Occupational Medical Doses	SC&A-Method A (rem)	SC&A-Method B (rem)	NIOSH (rem)
Lung Dose	1.886	Not considered	1.592

SC&A's 'Method A' doses are slightly higher than those calculated by NIOSH, strictly because NIOSH did not assign medical doses during the residual period (i.e., [redacted]– [redacted]).

2.2 OCCUPATIONAL INTERNAL DOSES

No records of bioassay monitoring results were found for the EE's employment at ACP. However, both NIOSH and SC&A's 'Method A' assumed that the EE was chronically exposed to material during the operational period of uranium recovery and from residual contamination, as discussed below.

2.2.1 Inhalation Doses during Operational Period

NIOSH's Operational Inhalation Dose

For calculating inhalation doses during the operational period, a professional judgment was made by NIOSH, which assumed 10% of the maximizing intake value of 8.17 pCi/hr for U-238 in equilibrium with its daughters, and 0.112 pCi/hr for Th-232 and daughters from Table 4-3 of ORAUT-OTIB-0043. The basis for this assumption was provided by David Allen (Allen 2014):

> *. . . The primary issue is that we assumed 10% of the exposure associated with OTIB-43 rather than 100%. This is due to the fact that this was a bench scale operations (produced a few pounds of U) and OTIB-43 was based on large scale production. This bench scale operation tried to extract uranium from phosphoric acid but there is no indication the phosphoric acid was made there. SRDB #99079 (pg 4 of 4) indicates the No. Claymont plant was part of the General Chemical division while the Nitrogen Division is the one that produced a wide line of fertilizers so it is very possible the phosphoric acid was brought into the lab rather than created there.*

Using the 10% assumption, NIOSH calculated inhalation from U-238 and Th-232 during recovery operations as detailed below:

U-238:

8.17 pCi/hr × 2,000 hr/yr × 0.1 (factor for bench scale vs. production scale)/365 d/yr = 4.478 pCi per calendar day

Th-232:

0.112 pCi/hr × 2,000 hr/yr × 0.1 (factor for bench scale vs. production scale)/365 d/yr = 0.0613 pCi per calendar day

All U-238 and daughter radionuclides, with the exception of Ra-226, and Th-232 and daughter radionuclides were assumed to be Type S solubility. The most claimant-favorable solubility type for Ra-226 was Type M. The above-cited intakes were entered into the Chronic Annual Dose Workbook (CADW) and resulted in a dose due to inhalation of 15.105 rem.

SC&A's 'Method A' Operational Inhalation Dose

Since there are no ACP survey records or EE dosimeter records, SC&A determined that the wet chemical phosphoric acid treatment process used at ACP is similar to the process used in Building 55 at the Blockson Chemical Company site. Therefore, using the Blockson Site Profile (DCAS 2010) and ORAUT-OTIB-0043 (ORAUT 2006), the following assumptions were used to calculate an inhalation dose during the operational period.

(1) 85% of U reports to phosphoric acid (DCAS 2010); ORAUT 2006 cites "approximately 86%."

(2) 4% of Ra-226 reports to acid (DCAS 2010).

(3) Thorium reports to the acid in same proportion as uranium (DCAS 2010, ORAUT 2006).

(4) U-238:Th-232 radioactivity ratio in Blockson's rock was 30:1. However, ORAUT 2006 uses a U-238/Th-232 ratio of 72:1 based on material averages from several facilities. Since the exact composition of the Allied material is unknown, the U-238/Th-232 ratio of 72:1 was used. Th-232 progeny are assumed to be in equilibrium. Although most of the Ra-228 would have been separated and removed with the phosphogypsum, it is assumed to be in equilibrium with Th-232 for dose modeling to allow for ingrowth over the operational and residual contamination period (DCAS 2010).

(5) Pb-210 and Po-210 assumed to report to the acid the same as U-238 (DCAS 2010, ORAUT 2006).

(6) The daily 8-hour U-238 intake (in equilibrium with progeny) and Th-232 intake (in equilibrium with progeny) are 44.0 pCi/day (1.63 Bq/day) and 0.605 pCi/day (0.0224 Bq/day), respectively (using best-estimate hourly intake values from Table 4-3 of ORAUT 2006).

(7) The U_3O_8 product produced from wet phosphoric acid by filtering the precipitated uranium most closely corresponds to the clearance rate associated with Type M uranium material (DCAS 2010).

(8) Thorium could have been Type M or Type S, and polonium could have been F or M. Therefore, the thorium and polonium solubility types were selected based on the types that deliver the largest dose to the target organ (DCAS 2010). For this case, the solubility types of thorium and polonium are S and M, respectively. Pb-210 is Type F.

These assumptions result in the following ratios and intakes:

Table 2-5. SC&A's 'Method A' Relative Radionuclide Concentrations and Intakes

Radionuclide	Ratio to U-238	Daily Intake		Solubility Type
		pCi/day	Bq/day	
U-238	1	44.0	1.628	M
U-234	1	44.0	1.628	M
Th-230	1	44.0	1.628	S
Po-210	1	44.0	1.628	M
Pb-210	1	44.0	1.628	F
Ra-226	4% = 0.040	1.76	0.0765	M
Th-232	1/72 = 0.014	0.605	0.0224	S
Th-228	1/72 = 0.014	0.605	0.0224	S
Ra-228	1/72 = 0.014	0.605	0.0224	M

Using the CADW and the daily intake values and solubility types cited in Table 2-5, SC&A calculated an inhalation dose of 93.68 rem for the operational period. Annual internal doses were entered as lognormal distributions with an uncertainty of 1.270.

2.2.2 Inhalation Doses during the Residual Period

NIOSH's Residual Inhalation Dose

Residual period inhalation doses were based on operational period intake values. Calculations for inhalation of U-238 are shown below.

$$4.478 \text{ pCi/calendar day} \times 365 \text{ days}/1.2 \text{ m}^3 \text{ per hr}/2{,}000 \text{ hrs} = 0.681 \text{ pCi/m}^3$$

The 0.681 pCi/m^3 was assumed to settle for a full year at a rate of 0.00075 m/s to produce 16,107.7 pCi/m^2 of contamination (0.681 pCi/m^3 × 0.00075 m/s × 365 days × 24 hrs × 3,600 sec.). It was assumed that the contamination was resuspended using a resuspension factor of 1E-6 m^{-1} to get 0.0161 pCi/m^3. This resulted in the following inhalation rate for U-238 and daughters:

$$0.0161 \text{ pCi/m}^3 \times 1.2 \text{ m}^3/\text{hr} \times 2{,}000 \text{ hrs}/365 \text{ days} = 0.106 \text{ pCi/calendar day}$$

Using the Th-232 operational intake of 0.0613 pCi/calendar day and the above-cited settling and resuspension factors, NIOSH calculated a residual period inhalation rate of 1.45E-03 pCi/calendar day for Th-232 and daughters.

The NIOSH-calculated uranium and thorium intake values were entered into the CADW with the solubility Type S for all radionuclides except Ra-226, which was entered with solubility Type M. This resulted in an inhalation dose of 0.088 rem.

SC&A's 'Method A' Residual Inhalation Dose

SC&A's 'Method A' calculated the EE's internal exposure to residual contamination using the guidance found in ORAUT-OTIB-0070, *Dose Reconstruction during Residual Radioactivity Periods at Atomic Weapons Employer Facilities* (ORAUT 2012), from 1970 until the EE's last year of employment in [redacted]. ORAUT-OTIB-0070 provides adjustment factors based on an average depletion rate of 0.00067 per day. Table 2-6 shows how the factors were applied to the U-238 and Th-232 intakes; these adjustment factors were also applied to the daughter radionuclides.

Table 2-6. SC&A's 'Method A' Adjusted Intakes for Uranium and Thorium during the Residual Period

Year	Adjustment Factor	Adjusted Intake (pCi/d)	
		U-238	Th-232
[redacted]	1.000	44.0	0.014
[redacted]	0.783	34.4	0.011
[redacted]	0.613	27.0	0.009
[redacted]	0.480	21.1	0.007
[redacted]	0.376	16.5	0.005
[redacted]	0.294	12.9	0.004

Using the CADW and the daily intake values cited in Table 2-6, along with solubility types cited in Table 2-5, SC&A calculated an inhalation dose of 24.634 rem for the residual period. Annual internal doses were entered as lognormal distributions with an uncertainty of 1.270.

2.2.3 Ingestion Doses

Only NIOSH calculated doses associated with the ingestion pathway. Their calculation method used guidance in OCAS-TIB-009, *Estimation of Ingestion Intakes*, which states that daily ingestion dose should be calculated by assuming 0.2 times the activity per cubic meter of air and 10% of the maximum intake values cited in Table 4-3 of ORAUT-OTIB-0043. Shown below are the calculations used for deriving U-238 and Th-232 intakes during the operational and residual periods.

$U\text{-}238_{Operations}$ = 8.17 pCi/hr/1.2 m^3/hr × 0.2 (TID-9 CF) × 0.1 (frac. process mat'l)
= 0.136 pCi/calendar day

$Th\text{-}232_{Operations}$ = 0.112 pCi/hr/1.2 m^3/hr × 0.2 (TID-9 CF) × 0.1 (frac. process mat'l)
= 0.0019 pCi/calendar day

$U\text{-}238_{Residual}$ = 1.61E-02 pCi/m^3 × 0.2 (TID-9 CF) = 3.22E-03 pCi/ calendar day

$Th\text{-}232_{Residual}$ = 2.21E-04 pCi/m^3 × 0.2 (TID-9 CF) = 4.42E-05 pCi/ calendar day

Using the CADW, the above-cited intakes, and the same solubility types as for the inhalation pathway, NIOSH calculated an ingestion dose that was less than 0.001 rem. Therefore, this dose was not included in the IREP input sheet.

2.2.4 Radon Doses

All DR methods (i.e., NIOSH, SC&A's 'Method A' and SC&A's 'Method B') calculated dose from exposure to radon and daughters. Their calculation methods are summarized below.

NIOSH's Radon Exposure Estimates
NIOSH assumed the EE was exposed to radon during the operational and residual periods. Doses were calculated based on 10% of maximizing WLM/yr values cited in Table 4-4 of ORAUT-OTIB-0043. This resulted in the assignment of 0.0112 WLM/yr for operational years of 1950 through 1969. The WLM/yr values for the residual period years of 1970 through [**redacted**] were derived by applying settling and source term adjustment factors and resulted in 2.65E-04 WLM/yr. A total of 0.214 WLM of lung exposure to radon progeny was assigned for the operational and residual periods.

SC&A's 'Method A' Radon Exposure Estimate
Radon exposure was also assessed by SC&A's 'Method A' using guidance from ORAUT-OTIB-0043, Section 4.2. The best-estimate value of 0.036 WLM/yr cited in Table 4-4 was selected for assigning exposure during the operational period. In the absence of any residual radon information, the adjustment factors shown in Table 2-6 were applied to the annual radon exposure of 0.036 WLM/yr for years [**redacted**]– [**redacted**]. The EE's total radon exposure is 0.812 WLM.

SC&A's 'Method B' Radon Exposure Estimates

SC&A's 'Method B' elected to derive a minimized dose to the lung by only considering radon exposures at a very low level, i.e., 4 pCi/L, which translates to 0.235 WLM/yr at 50% equilibrium. 'Method B' based this approach on a 1998 report by the FIPR on dose at Florida phosphate plants that processed phosphate rock, and a 1978 U.S. Environmental Protection Agency (EPA) report of exposure to workers at an Idaho phosphate plant (FIPR 1998; EPA 1978). The annual 0.235 WLM value was entered into IREP for only 9 years of employment (i.e., [redacted]– [redacted], [redacted]– [redacted]). Without considering other internal and external exposures, this radon exposure was sufficient to result in a POC of greater than 50%.

A summary of the internal doses calculated by NIOSH and SC&A's 'Method A' and 'Method B' is shown in Table 2-7.

Table 2-7. Comparison of Internal Doses

Internal Doses	SC&A 'Method A' (rem)	SC&A 'Method B' (rem)	NIOSH (rem)
Total Uranium/Thorium for Operational and Residual Periods	118.314	NA	15.194
Radon Exposure	0.812 WLM	2.115 WLM	0.214 WLM

A comparison of total internal dose values for uranium and thorium derived by NIOSH and SC&A's 'Method A' varies significantly, with SC&A's 'Method A' doses more than 7.7 times higher than the NIOSH-assigned values. As described above, both DR methods used guidance in ORAUT-OTIB-0043; however, NIOSH assumed 10% of the maximum internal intakes, while SC&A used the best-estimate values provided in Table 4-3.

In addition, radon exposures estimated by all three DR methods resulted in significantly different WLM values. Although both NIOSH and SC&A's 'Method A' used guidance in ORAUT-OTIB-0043, 'Method A' calculated a total WLM value that is 3.8 times higher than the NIOSH value. This variance in exposure estimates can once again be explained by the difference in professional judgment used by the two approaches. Namely, NIOSH assumed 10% of the maximum radon exposure values cited in Table 4-4 of ORAUT-OTIB-0043, and SC&A assumed best-estimate values were appropriate. Using radon exposure data provided by FIPR and EPA, SC&A's 'Method B' derived a total WLM value that was nearly 10 times higher than the value assigned by NIOSH.

3.0 SUMMARY CONCLUSIONS

A comparison of the total external and internal doses and resultant POCs calculated by SC&A's 'Method A' and 'Method B,' and NIOSH in behalf of Case [**Redacted**] is presented in Table 3-1.

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

Total Doses	SC&A-Method A (rem)	SC&A-Method B (rem)	NIOSH (rem)
External Lung Doses:			
- Operational Period	1.041	NA	0.381
- Residual Period	0.194	NA	0.103
- Occupational Medical	1.886	NA	1.592
Internal Lung Doses:			
- Operational Period	93.679	NA	15.106
- Residual Period	24.635	NA	0.088
Total Lung Dose	121.435	NA	17.271
Total Radon	0.812 WLM	2.115 WLM	0.214 WLM
POC	85.4%	64.1%	45.90%

NA = Not applicable.

As shown in Table 3-1, the three DR methods resulted in doses and radon exposure values that are substantially different and, for the two SC&A methods, produced POC values great than 50%. Primary differences in the doses involve dose reconstructor decisions associated with the following selection of model parameters and assumptions:

- Assumptions regarding external dose values cited in Table 4-1 of ORAUT-OTIB-0043
  - NIOSH used **10%** of the **"**upper bound for exposures to plant workers"
  - SC&A's 'Method A' selected the **GM** dose associated with "exposure from work located at gypsum stacks"

- Selection of organ DCF values cited in *External Dose Reconstruction Implementation Guideline* (OCAS-IG-001)
  - NIOSH used DCF values associated with the lung **Exposure (R)**
  - SC&A's 'Method A' used the **Hp(10)** to Organ DCF for the lung

- Assignment of occupational medical doses
  - NIOSH assigned an annual x-ray exam for operational years only
  - SC&A's 'Method A' assigned an annual x-ray exam for all years of employment

- Assumptions regarding internal dose values cited in Table 4-3 of ORAUT-OTIB-0043
  - NIOSH used **10%** of the **maximizing** DR approach intake values for U-238/Th-232
  - SC&A's 'Method A' used the intake values associated with the **best-estimate** DR approach

- Assumptions regarding radon exposure values cited in Table 4-4 of ORAUT-OTIB-0043
  – NIOSH used **10%** of the **maximizing** DR approach WL values
  – SC&A's 'Method A' used the best-estimate WL values

4.0 REFERENCES

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