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Advisory Board on Radiation and Worker Health  
National Institute for Occupational Safety and Health

## **A Review of NIOSH's Program Evaluation Report DCAS-PER-092, "Weldon Spring Plant"**

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*SC&A, Inc. technical support for the Advisory Board on Radiation and Worker Health’s review of NIOSH dose reconstruction program*

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## Abbreviations and Acronyms

ABRWH, Board	Advisory Board on Radiation and Worker Health
AEC	U.S. Atomic Energy Commission
Bq	becquerel
DCAS	Division of Compensation Analysis and Support
DoD	U.S. Department of Defense
DR	dose reconstruction
EEOICPA	Energy Employees Occupational Illness Compensation Program Act
GSD	geometric standard deviation
IREP	Integrated Modules for Bioassay Analysis
m <sup>3</sup>	cubic meter
mrem	millirem
NIOSH	National Institute for Occupational Safety and Health
NOCTS	NIOSH Claims Tracking System
ORAUT	Oak Ridge Associated Universities Team
PER	program evaluation report
pCi/mg	picocurie per milligram
POC	probability of causation
Ra	radium
Rn	radon
RU	recycled uranium
SEC	Special Exposure Cohort
TBD	technical basis document
Th	thorium
U	uranium
WSP	Weldon Spring Plant
WSRP	Weldon Spring Raffinate Pits
WSQ	Weldon Spring Quarry

## 1 Statement of Purpose

To support dose reconstruction (DR), the National Institute for Occupational Safety and Health (NIOSH) and the Oak Ridge Associated Universities Team (ORAUT) assembled a large body of guidance documents, workbooks, computer codes, and tools. In recognition of the fact that all of these supporting elements in DR may be subject to revisions, provisions exist for evaluating the effect of such programmatic revisions on the outcome of previously completed DRs. Such revisions may be prompted by document revisions due to new information, misinterpretation of guidance, changes in policy, and/or programmatic improvements.

A program evaluation report (PER) provides a critical evaluation of the effects that a given issue or programmatic change may have on previously completed DRs. This includes a qualitative and quantitative assessment of potential impacts. Most important in this assessment is the potential impact on the probability of causation (POC) of previously completed DRs with POCs less than 50 percent.

On February 15, 2022, the Advisory Board on Radiation and Worker Health (Board) tasked SC&A to review DCAS-PER-092, “Weldon Spring Plant” (NIOSH, 2021; “PER-092”). In conducting a PER review, SC&A is committed to perform the following five subtasks, each of which is discussed in this report:

- **Subtask 1:** Assess NIOSH’s evaluation and characterization of the issue addressed in the PER and its potential impacts on DR. Our assessment intends to ensure that the issue was fully understood and characterized in the PER.
- **Subtask 2:** Assess NIOSH’s specific methods for corrective action. When the PER involves a technical issue that is supported by documents (e.g., white papers, technical information bulletins, procedures) that have not yet been subjected to a formal SC&A review, subtask 2 will include a review of the scientific basis and/or sources of information to ensure the credibility of the corrective action and its consistency with current/consensus science. Conversely, if such technical documentation has been formalized and previously subjected to a review by SC&A, subtask 2 will simply provide a brief summary and conclusion of this review process.
- **Subtask 3:** Evaluate the PER’s stated approach for identifying the universe of potentially affected DRs, and assess the criteria by which a subset of potentially affected DRs was selected for reevaluation. The second step may have important implications where the universe of previously denied DRs is very large and, for reasons of practicality, NIOSH’s reevaluation is confined to a subset of DRs that, based on their scientific judgment, have the potential to be significantly affected by the PER. In behalf of subtask 3, SC&A will also evaluate the timeliness of the completion of the PER.
- **Subtask 4:** Conduct audits of DRs affected by the PER under review. The number of DRs selected for audit for a given PER will vary. (It is assumed that the Board will select the DRs and the total number of DR audits for each PER.)
- **Subtask 5:** Prepare a written report that contains the results of DR audits under subtask 4, along with our review conclusions.

## 2 Relevant Background Information Pertaining to Facility Operations, Potential Source Terms, and Worker Monitoring Protocols

### 2.1 Facility operations

The facilities covered under the Energy Employees Occupational Illness Compensation Program Act (EEOICPA) are the Weldon Spring Plant (WSP), Weldon Spring Quarry (WSQ), and the Weldon Spring Raffinate Pits (WSRP). In this document, the term “WSP site” is used where it is unnecessary to distinguish between the plant, the quarry, and the raffinate pits. The WSP site was operated for the U.S. Atomic Energy Commission (AEC) as a feed materials plant to process uranium and thorium ore by the Uranium Division of Mallinckrodt Chemical Works.

There were four periods for the WSP site:

1. Site acquisition and development, 1954–1957
2. Operational, 1957–1966
3. The U.S. Department of Energy (DOE) did not control WSP during the period 1967–1985 and WSRP and WSQ during the period 1967–1974. The U.S. Department of Defense (DoD) had control of those Weldon Spring facilities during these periods.
4. Remediation, 1985–2002

WSP employment is covered under EEOICPA only during the operational (1957–1966) and remediation (1985–2002) periods when the AEC, U.S. Energy Research and Development Administration, and DOE had contractors and radioactive materials at WSP.

WSQ and WSRP employment is covered during the operational period (1957–1966), the period 1975–1984, and remediation period (1985–2002).

### 2.2 Source terms

The radionuclides of concern are those that make up 95 percent of the potential internal dose. According to the technical basis document (TBD) for internal dose, ORAUT-TKBS-0028-5, revision 04 (NIOSH, 2017a), the radionuclides of concern at the WSP site for DR are the naturally occurring isotopes of uranium (U-234, U-235, and U-238), their decay products (primarily thorium (Th)-230 and radium (Ra)-226), isotopes of natural thorium (Th-228 and Th-232) and their decay products, and recycled uranium (RU).

#### 2.2.1 Uranium

ORAUT-TKBS-0028-5 (NIOSH, 2017a) recommends that for the purposes of DR, the assumption be made that all uranium processed at the WSP site was natural uranium from 1957 through 1962, with a specific activity of 683 picocuries per milligram (pCi/mg). After 1962, all uranium is assumed to be enriched to 1 percent, with a specific activity of 973 pCi/mg.

#### 2.2.2 Radon

The three radon isotopes that are generated during the decay of U-235, U-238, and Th-232 are radon (Rn)-219, Rn-222, and Rn-220, respectively. Due to the limited amount of enriched

uranium (which contains U-235) processed at WSP site, there was no large source of Ra-223 and in turn Rn-219. The risks associated with Rn-219 were insignificant due to its extremely short half-life (4 seconds) and small source term. Therefore, ORAUT-TKBS-0028-5 (NIOSH, 2017a) considers only the inhalation intakes for Rn-222 and Rn-220 to be potentially significant.

### **2.2.3 Recycled uranium**

It should be assumed that all of the uranium that the WSP site processed beginning in 1961 was RU. For the periods that include RU (i.e., after 1960), RU contaminant mass concentrations are provided in section 5.6.1.3.3 of ORAUT-TKBS-0028-5 (NIOSH, 2017a).

## **2.3 Internal monitoring**

The following summarizes the internal intake monitoring at the WSP site. SC&A obtained this information from ORAUT-TKBS-0028-4, revision 04 (NIOSH, 2020; “TBD-4”) and ORAUT-TKBS-0028-5 (NIOSH, 2017a).

### **2.3.1 Operational period, 1957–1966**

Urine bioassay was the primary method of determining uranium intakes during the production phase. There has been no indication so far that a routine urine sampling program was implemented for thorium. No urine bioassay data for thorium have been found in the worker files.

### **2.3.2 DoD period, 1967–1985**

There did not appear to be DOE contractor personnel present during the DoD period, and no bioassay monitoring records have been located for this period.

### **2.3.3 Remediation period, 1985–2002**

An extensive bioassay monitoring program was conducted from 1991 to 2001 to detect intakes greater than 100 millirem (mrem) committed effective dose equivalent.

## **2.4 External and ambient monitoring**

The following summarizes external monitoring methods at the WSP site. SC&A obtained this information from TBD-4 and ORAUT-TKBS-0028-6, revision 01 (NIOSH, 2013).

### **2.4.1 Operational period, 1957–1966**

Employees who worked in radiological areas were monitored, and their exposures should be accounted for in their normal dosimetry results. Documents obtained to date do not contain monitoring data that describe the ambient exposure rate at the WSP site during the operational period.

### **2.4.2 DoD period, 1967–1985**

There did not appear to be DOE contractor personnel present during the DoD period, and no external monitoring records have been located for this period. There are no records of site surveys being conducted until 1982, except for a 1975 aerial radiological survey.

### **2.4.3 Remediation period, 1985–2002**

Personnel external monitoring was provided as needed during the remediation period. Site external ambient exposure monitoring began in 1982.

### 3 Subtask 1: Identify the Circumstances that Necessitated DCAS-PER-092

#### 3.1 Chronology of events

##### 3.1.1 Previous versions of ORAUT-TKBS-0028-4

NIOSH issued revision 02 of the Weldon Spring occupational environmental dose TBD on March 29, 2017 (NIOSH, 2017b).

Revision 03 was issued on September 8, 2017 (NIOSH, 2017c).

##### 3.1.2 DCAS-PER-083

On January 7, 2019, NIOSH issued DCAS-PER-083 (NIOSH, 2019a) for the WSP site, which addressed changes in DR procedures using ORAUT-TKBS-0028-4, revision 03 (NIOSH, 2017c).

##### 3.1.3 Environmental internal intakes in ORAUT-TKBS-0028-4, revision 04

NIOSH issued revision 04 of ORAUT-TKBS-0028-4 on March 27, 2020 (NIOSH, 2020). Notable changes incorporated in revision 04 compared to revision 03 that could affect internal intakes and assigned dose include the following:

- **Daily intake values:** Intake values based on a daily intake instead of an annual intake (NIOSH, 2020, pp. 12, 21, and 22). This involved dividing the previous intake values by 365.25 days/year.
- **Lognormal distribution:** Airborne radioactivity concentrations that were reported as an arithmetic mean were converted to a median of a lognormal distribution using the equations in table 2.2 of Battelle-TIB-5000 (NIOSH, 2007), and a geometric standard deviation (GSD) of 3 (NIOSH, 2020, pp. 12, 21, and 22). This involved dividing the previous intake values by 1.828, when applicable, as stated on page 3 of TBD-4, revision 04.
- **Added table 4-1:** NIOSH added table 4-1, “Median airborne radioactivity concentrations (WSP, WSRP, WSQ) and sitewide maximums (U and Rn)” (p. 13), with the WSQ U-234 values for the years 1990, 1991, 1993–1996, and 1998–2001 changed from the previous revision 03. Revision 03 had set these values equal to zero as the airborne concentrations were considered to be insignificant. However, the nonzero airborne U-234 concentrations were included in revision 04. The airborne concentration values for 1992 and 1997 were equal to zero and, therefore, were not changed. The intake values, in becquerels per cubic meter ( $\text{Bq}/\text{m}^3$ ), in table 4-1 were multiplied by  $9.6 \text{ m}^3/\text{day}$  air intake rate and ( $250 \text{ days}/365.25 \text{ days}$ ) to derive the intake values in  $\text{Bq}/\text{day}$  in tables 4-3 and 4-4.
- **Outline of derivation of values in tables:** The following is a brief outline of the data and methods used to derive the intakes values in tables 4-1, 4-3, and 4-4.
  - **Table 4-1:** The data used to derive airborne radioactivity concentration in table 4-1 (in units of  $\text{Bq}/\text{m}^3$ ) for 1957–2002 for WSRP, WSP, and WSQ were obtained from perimeter and area monitoring records, which are summarized in a

2019 NIOSH spreadsheet (NIOSH, 2019b), and the use of equations and methods as outlined on pages 12–24 of TBD-4. The air concentration values in table 4-1 reflect the Battelle-TIB-5000 adjustment factor of 1.828 as applicable.

- **Table 4-3:** The intake values in table 4-3 for 1957–2002 for WSRP, WSP, and WSQ were derived from the air concentration values in table 4-1, using a breathing rate of 1.2 m<sup>3</sup>/hour, 2,000 hours worked per year (as originally used in revision 03, page 11) and adjusted for 365.25 calendar days per year, to convert to daily intakes values in units of Bq/day.
- **Table 4-4:** The maximum sitewide daily intake values for U-234, Th-230, Rn-220, and Rn-222 in table 4-4 were derived from the maximum intake values listed in table 4-3 for each year 1957–2002. The maximum RU component intake values were obtained by multiplying the maximum U-234 intake value by the uranium-to-RU component ratios from table 4-2, which were recommended in ORAUT-TKBS-0028-5 (NIOSH, 2017a).
- Rn-220 was added to the intake values for the period 1963–1966 as described in the last paragraph on page 16 of TBD-4 and added to table 4-3 and table 4-4 as appropriate.
- **Uncertainties:** Uncertainties and distribution functions when assigning internal doses were clarified in section 4.4, page 27.

#### **3.1.4 External ambient dose in ORAUT-TKBS-0028-4, revision 04**

This section outlines notable changes incorporated in revision 04 compared to revision 03 of TBD-4 that could affect assigned external dose.

External ambient dose is based on a worker's exposure of 2,500 hours per year, as described in section 4.3, page 24, and is used to determine the exposure values in table 4-6 (page 28), and table 4-7 (page 30) of revision 04. This is a change from a continuous exposure of 8,760 hours per year used in revision 03. The following is a brief outline of the data and methods NIOSH used to derive the ambient external dose values in tables 4-5, 4-6, and 4-7.

- **Table 4-5:** TBD-4 recommends using the 50th percentile co-exposure dose for workers who were unmonitored for the operational period of 1957–1966 instead of an external ambient dose. The annual dose values (rem/year) in table 4-5 were obtained from NIOSH's analysis of the workers' recorded external doses for 1957–1966 (NIOSH, 2019c). The GSD values were added to table 4-5 for use in lognormal distribution dose assignments.
- **Table 4-6:** For the operational period, 1957–1966, the annual co-exposure dose values in table 4-5 are recommended for WSRP and WSP; WSQ did not have significant exposure levels during this period. There were no DOE personnel involved at WSRP, WSP, or WSQ during the 1967–1974 period, and no external ambient doses are recommended. For the period 1975–2002, table 4-6 lists the recommended external ambient annual doses (mrem/year) based on 2,500 hour per year for WSRP, WSP, and WSQ. There were occasional site surveys conducted and annual perimeter doses recorded during the period 1982–2000. The recommended ambient doses during the period 1975–2002 were derived as follows.

- **WSRP:**
  - For the period 1975–1981, it was assumed the pits conditions were similar to the conditions in the 1980s; therefore, the average ambient recorded dose (57 mrem/year) during 1982 and 1983 was applied to the period 1975–1981.
  - Ambient dose measurements were made during 1982 and 1983.
  - For the period 1984–2000, twice the recorded annual WSRP parameter measured dose rates were used, as this was consistent with onsite measurements (NIOSH, 2020, p. 26).
  - For the year 2001, the dose rate from 2000 was applied.
  - For the year 2002, remediation was complete and it was assumed that the additional ambient dose above background was zero (NIOSH, 2020, p. 9).
- **WSP:**
  - During the period 1975–1984, there were no DOE personnel involved at the plant and no external ambient doses are recommended.
  - For the period 1985–2000, twice the recorded annual WSP parameter measured dose rates were used, as this was consistent with onsite measurements (NIOISH, 2020, p. 26).
  - For the year 2001, the dose rate from 2000 was applied.
  - For the year 2002, remediation was complete and it was assumed that the additional ambient dose was zero (NIOSH, 2020, p. 9).
- **WSQ:**
  - For the period 1975–1981, it was assumed the quarry conditions were similar to the conditions in the 1980s; therefore, the average ambient recorded dose (28 mrem/year) during the period 1982 through 1989 was applied to the period 1975–1981.
  - For the period 1982–2000, the recorded annual WSQ parameter measured dose rates were used, as this was consistent with onsite measurements (NIOISH, 2020, p. 27).
  - For the year 2001, the dose rate from 2000 was applied.
  - For the year 2002, remediation was complete and it was assumed that the additional ambient dose above background was zero (NIOSH, 2020, p. 9).
- **Table 4-7:** This table gives the maximum annual external ambient dose (in units of mrem/year) for WSRP, WSP, or WSQ from table 4-6. SC&A noted that the maximum sitewide ambient dose of 35 mrem per year (based on 2,500 hours per year) at the WSP site for 1994 was entered correctly in table 4-7, page 30, of revision 04, correcting an error in the 1994 dose entry in revision 03, where 172 mrem was entered instead of the correct value of 122 mrem (based on 8,760 hour per year) in table 4-6 (NIOSH, 2017c, p. 26).

- **Uncertainties:** Uncertainties and distribution functions when assigning external doses were clarified in section 4.4, page 27.

### 3.1.5 DCAS-PER-092

On March 29, 2021, NIOSH issued a PER for the WSP site, which addressed changes in DR procedures for WSP, WSRP, and WSQ as a result of the issuance of ORAUT-TKBS-0028-4, revision 04 (NIOSH, 2020). Some of the information that was modified or added during this TBD-4 revision, as outlined in the preceding sections, resulted in an increase in the site environmental assigned dose. PER-0092 addressed these changes, and NIOSH reevaluated claims impacted by the revised TBD. The following is a summary of NIOSH's PER-092 evaluation of the revisions in TBD-4 that could increase assigned doses:

- Environmental intakes of Rn-220 and Ra-228 were added for 1963 through 1966.
- U-234 intakes were added for WSQ for the years 1990, 1991, 1993–1996, and 1998–2001.
- Onsite ambient gamma doses from 1957 to 1966 were previously used as a constant value, but revision 04 included GSD values and the gamma dose values are used as a lognormal distribution.

## 3.2 SC&A's comments

SC&A reviewed ORAUT-TKBS-0028-4, revision 04 (NIOSH, 2020) and PER-092. SC&A found that PER-092 addressed the changes in revision 04 that could potentially result in increases in internal and external dose assignments. These changes include (1) addition of Rn-220 and Ra-228 for 1963–1966, (2) U-234 intakes added for WSQ for certain years during 1990–2001, and (3) use of lognormal distribution for external ambient doses for 1957–1966. Although there were other changes and additions in revision 04, they were for clarification or other purposes and did not result in a potential increase in assigned dose. SC&A had no findings or observations pertaining to subtask 1.

## 4 Subtask 2: Assess NIOSH's Specific Methods for Corrective Action

### 4.1 NIOSH revised ORAUT-TKBS-0028-4

NIOSH revised TKBS-0028-4 from revision 03 to revision 04 as outlined on page 3 of TBD-4. The revision was performed to modify the DR methodology in TBD-4 to reflect best estimate DR methods and to update radionuclide intake values and intake years.

### 4.2 SC&A's review of revision 04 of ORAUT-TKBS-0028-4

SC&A reviewed ORAUT-TKBS-0028-4, revision 04 (NIOSH, 2020), to determine if it contained technically correct methodology and information. Since the Weldon Spring site profile and Special Exposure Cohort (SEC) issues have previously been addressed, resolved, and closed (ABRWH, 2018, p. 38), SC&A focused on changes in revision 04 compared to revision 03. SC&A found that the methodology used was appropriate and applied correctly. Some examples are as follows:

- adding table 4-1 as a summary source for derivation of intake values in table 4-3 and table 4-4
- adjustment of intake values per Battelle-TIB-5000 by dividing by 1.828 when appropriate for lognormal distribution
- adding Rn-220 and Ra-228 associated with thorium operations for 1963–1966
- adding U-234 WSQ intakes that were previously considered insignificant
- adjustment of intakes from annual to daily values
- assigning 1957–1966 external doses as a lognormal distribution with a GSD value for a best estimate approach
- including uncertainty recommendations

SC&A randomly sampled the conversions from values listed in table 4-1 (Bq/m<sup>3</sup>) to those listed in tables 4-3 and 4-4 (Bq/day) using the appropriate conversion factors when applicable. SC&A found the radionuclide intake values to be correct and appropriate as a function of the years listed in tables 4-3 and 4-4.

SC&A reviewed the external onsite ambient dose values recommended in tables 4-6 and 4-7 and found that they were correctly converted from a continuous exposure of 8,760 hour/year (revision 03) to 2,500 hours per year (revision 04).

SC&A had no findings or observations about revision 04 of ORAUT-TKBS-0028-4. Additionally, SC&A found that PER-092 addressed the changes in revision 04 that could potentially result in increases in internal and external dose assignments. However, SC&A did identify two documentation errors in revision 04 of ORAUT-TKBS-0028-4.

**Observation 1: Figure and table reference issues in ORAUT-TKBS-0028-4, rev. 04**

- **Figure 4-2:** This figure is referred to in the next to the last paragraph on page 14, but it appears that it was omitted in revision 04 of ORAUT-TKBS-0028-4.
- **Table 4-7:** Footnote a of this table refers to “Table 4-5” when it should read “Table 4-6.”

## 5 Subtask 3: Evaluate the PER's Stated Approach for Identifying the Number of DRs Requiring Reevaluation of Dose

### 5.1 NIOSH's selection criteria

Section 3.0 of PER-092 described the following criteria NIOSH used to identify previously completed cases requiring reevaluation using guidance in revision 04 of ORAUT-TKBS-0028-4 (NIOSH, 2020) and mandated by PER-092 (NIOSH, 2021):

- A search of the NIOSH Claims Tracking System (NOCTS) database was combined with a text search of the DR reports of previously completed cases. The NOCTS search queried employment at any of the three Weldon Spring facilities, while the text search queried the keyword "Weldon Spring" so that mention of any of the three facilities would be found. The combined search resulted in identifying a total of 338 cases.
- NIOSH then removed 284 cases from this list for the following reasons:
  - A total of 51 cases were removed because they had been "pulled" from DR primarily due to inclusion in the SEC.
  - A total of 135 cases were removed because the previous evaluation of the claims yielded POC values  $\geq 50$  percent.
  - One case was removed because it was returned for other reasons and would be processed using revision 04 of TBD-4.
  - Seven cases were removed because they had no Weldon Spring employment or visits during the covered period.
  - An additional 90 cases were removed because they were not affected by the changes in the revised TBD; primarily, those were monitored individuals for which no environmental dose was assigned.
  - Dose for the remaining 54 cases was recalculated using revision 04 of TBD-4 and all other applicable procedures. The resulting POCs for all 54 claims were less than 45 percent. Therefore, none required additional Integrated Modules for Bioassay Analysis (IREP) runs per NIOSH procedures.

NIOSH will provide the U. S. Department of Labor with the list of all the cases evaluated under this PER. Since none of the cases resulted in a POC greater than 50 percent, NIOSH will not request that the U. S. Department of Labor return any claims for a new DR.

### 5.2 SC&A's comments

The selection criteria used by NIOSH for previously completed DRs that required reevaluation under PER-092 are valid. SC&A had no findings or observations associated with subtask 3.

## **6 Subtask 4: Conduct Audits of a Sample Set of Reevaluated DRs Mandated by DCAS-PER-092**

Previous sections of this report described changes introduced in revision 04 of ORAUT-TKBS-0028-4 (NIOSH, 2020) that could increase the dose assigned for the periods covered for the WSP site.

For SC&A to satisfy its commitment under subtask 4, SC&A suggests that three DR cases be selected for review from the WSP site during the covered period. The combination of selected DRs needs to include the following criteria:

1. environmental intakes of Rn-220 and Ra-228 assigned during all or part of 1963–1966
2. environmental intake of U-234 at the WSQ assigned during all or part of 1990, 1991, 1993–1996, and/or 1998–2001
3. onsite external ambient gamma dose assigned during all or part of 1957–1966

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