DOE Review 10/12/2017

Division of Compensation Analysis and Support Technical Basis Document for Texas City Chemicals, Inc. Texas City, Texas	Document Number: DCAS-TKBS-0011 Effective Date: 04/27/2020 Revision No.: 01 Page 1 of 24
Subject Expert: Thomas P. Tomes Approval: Signature on file Date: 04/27/2020 Timothy D. Taulbee, Associate Director for Science	Supersedes: Revision 00

TABLE OF CONTENTS

Section Page

1.0 Introduction 5

2.0 Site Description and Operational History 6

3.0 Process Description 7

3.1 Uranium Recovery Plant 7

3.2 Developmental Work 7

4.0 Internal Dose 8

4.1 Intakes from Phosphate Plant Operation 8

4.2 Intakes from Uranium Recovery 10

4.3 Intakes from Residual Contamination 11

4.4 Radon Exposures 13

4.5 Internal Dose Reconstruction Summary 15

5.0 External Dose 17

5.1 Penetrating Dose 18

5.1.1 Penetrating Dose from the Phosphate Plant 18

5.1.2 Penetrating Dose from Uranium Recovery 18

5.2 Non-Penetrating Dose 19

5.2.1 Non-Penetrating Dose from the Phosphate Plant 19

5.2.2 Non-Penetrating Dose from Uranium Recovery 19

5.2.3 Extremity Dose 20

5.3 External Dose from Residual Contamination 21

5.5 External Dose Reconstruction Summary 22

6.0 References 23

LIST OF TABLES

Table Page

Table 1: Radionuclide Ratios for Uranium Recovery 8
Table 2: Bounding Radionuclide Concentrations in Phosphate Plant Materials 9
Table 3: Intakes from Operation of the Phosphate Plant 9
Table 4: Intakes during Period of Uranium Recovery Plant Operation 11
Table 5: Depletion Factors for Residual Contamination 13
Table 6: Residual Radon Exposures 14
Table 7: AWE Operational Period Intakes 15
Table 8: Inhalation Intake Rates from Residual Contamination 16
Table 9: Ingestion Intake Rates from Residual Contamination 17
Table 10: Photon Dose Rates from Yellowcake 19
Table 11: Summary of External Doses for Texas City Chemicals 22

RECORD OF ISSUE/REVISIONS

ISSUE AUTHORIZATION DATE	EFFECTIVE DATE	REV. NO.	DESCRIPTION
DRAFT	09/29/2017	00-A	Draft site profile document for radiation dose reconstructions for the Energy Employees Occupational Illness Compensation Program Act (EEOICPA).
10/26/2017	11/02/2017	00-B	Incorporated review comments.
04/08/2020	04/22/2020	01	Revision to address comments from SC&A on ingestion intakes and interpretation/format of Tables 7, 8 and 9. Revised methods to calculate ingestion intakes from residual contamination. Ingestion intakes in Table 9 increased for years 1955 through 1977. No other dose or intakes values were changed. The updated calculation methods are described in section 4.3. Changes were made in the explanation of calculations in sections 4.1 and 4.2 to better explain the ingestion calculations. Table 7 was revised to include dose for all of 1955 (operational and residual periods). Tables 8 and 9 were changed to include intakes only for years 1956 through 1977. Text was added to section 4.5 to incorporate the changes into the summary section. Reference section updated and in-text callouts were revised to the currently used format. Added an acronyms and abbreviations list. Changes made to the layout of Tables 5, 7, and 11 to facilitate 508 compliance. No additional site information was added. Updated calculation descriptions throughout to present doses in consistent units. Incorporated internal review comments.

ACRONYMS AND ABBREVIATIONS

AEC	U. S. Atomic Energy Commission
AWE	atomic weapons employer facility
DOE	U. S. Department of Energy
DOL	U. S. Department of Labor
EEOICPA	Energy Employees Occupational Illness Compensation Program Act
EPA	U. S. Environmental Protection Agency
ER	SEC evaluation report
FIPR	Florida Institute of Phosphate Research
ICRP	International Commission on Radiological Protection
MCNP	Monte Carlo N-Particle Transport Code
NCRP	National Council on Radiation Protection and Measurements
NIOSH	National Institute for Occupational Safety and Health
ORAUT	Oak Ridge Associated Universities Team
SEC	Special Exposure Cohort
TCC	Texas City Chemicals
USC	United States Code
WLM	working level month

1.0 Introduction

Technical basis documents and site profile documents are not official determinations made by the National Institute for Occupational Safety and Health (NIOSH) but are rather general working documents that provide historical background information and guidance to assist in the preparation of dose reconstructions at particular Department of Energy (DOE) or Atomic Weapons Employer (AWE) facilities or categories of DOE or AWE facilities. They will be revised in the event additional relevant information is obtained about the affected DOE or AWE facility(ies). These documents may be used to assist NIOSH staff in the evaluation of Special Exposure Cohort (SEC) petitions and the completion of the individual work required for each dose reconstruction.

In this document the word "facility" is used to refer to an area, building, or group of buildings that served a specific purpose at a DOE or AWE facility. It does not mean, nor should it be equated to, an "AWE facility" or a "DOE facility." The terms AWE and DOE facility are defined in sections 7384l(5) and (12) of the Energy Employees Occupational Illness Compensation Program Act of 2000 (EEOICPA), respectively. A DOE facility is defined as "any building, structure, or premise, including the grounds upon which such building, structure, or premise is located … in which operations are, or have been, conducted by, or on behalf of, the [DOE] (except for buildings, structures, premises, grounds, or operations … pertaining to the Naval Nuclear Propulsion Program);" and with regard to which the DOE has or had a proprietary interest, or "entered into a contract with an entity to provide management and operation, management and integration, environmental remediation services, construction, or maintenance services." 42 U.S.C. § 7384l(12). On the other hand, an AWE facility means "a facility, owned by an atomic weapons employer, that is or was used to process or produce, for use by the United States, material that emitted radiation and was used in the production of an atomic weapon, excluding uranium mining or milling." 42 U.S.C. § 7384l(5). The DOE determines whether a site meets the statutory definition of an AWE facility and the Department of Labor (DOL) determines if a site is a DOE facility and, if it is, designates it as such.

Accordingly, a Part B claim for benefits must be based on an energy employee's eligible employment and occupational radiation exposure at a DOE or AWE facility during the facility's designated time period and location (i.e., covered employment). After DOL determines that a claim meets the eligibility requirements under EEOICPA, DOL transmits the claim to NIOSH for a dose reconstruction. EEOICPA provides, among other things, guidance on eligible employment and types of radiation exposure to be included in an individual dose reconstruction. Under EEOICPA, eligible employment at an AWE facility is categorized as employment either (1) during "a period when the employer was processing or producing, for the use by the United States, material that emitted radiation and was used in the production of an atomic weapon, excluding uranium mining and milling," (i.e., the operational period); or (2) during a period that NIOSH has determined that "there is a potential for significant residual contamination outside of the period in which weapons-related production occurred," (i.e., the residual contamination period). 42 U.S.C. § 7384l(3).

Based on the abovementioned definition for eligible employment during an AWE facility's operational period, NIOSH includes radiation exposures incurred in the performance of duty, such as medical X-rays received as a condition of employment for participating in DOE projects,

at an AWE facility in dose reconstructions. This may include radiation exposure related to the Naval Nuclear Propulsion Program and any radiation exposure received from the production of commercial radioactive products that were concurrently manufactured by the AWE facility during the operational period. In contrast, only two categories of radiation exposure as defined in 42 U.S.C. § 7384n(c)(4) should be included in dose reconstructions for claims involving employment during the residual contamination period. First, NIOSH must include exposures to radiological contaminants resulting from activities that had a nuclear-weapon nexus or conducted by or on behalf of the DOE (with an exclusion of activities related to, among other things, the Naval Nuclear Propulsion Program) that took place during the operational period. 42 U.S.C. § 7384n(c)(4)(A). Second, radiation doses from sources not included in the first category but which cannot be distinguished through reliable documentation should also be included in dose reconstructions. 42 U.S.C. § 7384n(c)(4)(B). Furthermore, because all DOE-related activities have ceased during the residual contamination period, NIOSH does not include doses from medical X-rays performed during the residual contamination period [NIOSH 2010a] in dose reconstructions.

Likewise, NIOSH does not consider the following types of exposure as those incurred in the performance of duty as a condition of employment for DOE-related activities at an AWE facility. Therefore these exposures are not included in dose reconstructions for either the operational or residual contamination period [NIOSH 2010a]:

- Background radiation, including radiation from naturally occurring radon present in conventional structures.

- Radiation from X-rays received in the diagnosis of injuries or illnesses or for therapeutic reasons

The following information from the Department of Energy's Office of Health, Safety and Security EEOICPA Find Facilities webpage defines the EEOICPA covered periods for Texas City Chemicals.

Site:	Texas City Chemicals, Inc.
Location:	Texas City Chemicals, Inc., Texas City, Texas
Covered Period:	AWE, October 5, 1953 through September 1955
Covered Period:	Residual Contamination, October 1955 through 1977

This document contains a summary description of the site, as well as the Atomic Energy Commission activities performed there, and provides the technical basis to be used to evaluate the occupational radiation doses for EEOICPA claims.

2.0 Site Description and Operational History

In 1952 Texas City Chemicals, Inc. (TCC) started construction of a plant in Texas City, Texas, to produce animal feed and fertilizer from phosphate rock. They contracted with the AEC to simultaneously construct, at TCC's expense, a Uranium Recovery Plant to be used to extract uranium as a byproduct from the phosphates. The contract specified terms for sale of the uranium to the AEC. Shake-down operations of the new fertilizer plant and Uranium Recovery

Plant began on October 5, 1953 [AEC 1952, 1953; Johnson 1953]. TCC also had a development contract with the AEC [DOE 1986].

The TCC plant encountered numerous problems during start-up of the plant, and it produced a small amount of uranium for the AEC in the first few months of operation. Full-scale uranium production was never realized due to equipment problems. TCC was operating at a loss and it ceased operations and filed for bankruptcy in U.S. District Court sometime in 1956. The court allowed the Smith-Douglass Corporation to acquire and reorganize TCC and reopen the plant later that year. Smith-Douglas did not pursue uranium work with the AEC. Smith-Douglass, later acquired by Borden Chemical, operated the phosphate plant until its closure in 1977 [AEC 1953; Greenleaf 1955; Powers 1979; Corporate Profile 1958].

Section 3 provides a summary of the AEC work at TCC. Additional details of the plant and operations are provided in the NIOSH Texas City Chemicals *SEC Petition Evaluation Report, Petition SEC-00088,* Rev. 1 [NIOSH 2010b], referred to as the TCC ER in this document.

3.0 Process Description

TCC was a plant built to process phosphate rock into phosphoric acid by the wet process. The plant had a design capacity to process 100,000 tons of phosphate rock per year. The phosphoric acid was subsequently used to produce animal feed and phosphate fertilizers. The phosphate rock ore was received from sources in Florida and contained small concentrations of natural uranium, nominally 0.012%. The uranium recovery plant was built to recover the uranium as a byproduct from the phosphoric acid.

3.1 Uranium Recovery Plant

The Uranium Recovery Plant was designed to extract uranium from phosphoric acid using a solvent extraction process. Operations began in December 1953, but TCC encountered equipment problems upon startup. They produced a total of 400 pounds of uranium (as U_3O_8) from intermittent operations of the Uranium Recovery Plant from December 1953 through March 1954, at which time the Uranium Recovery Plant was permanently shut down.

3.2 Developmental Work

TCC also had an AEC contract to study methods to process leached zone phosphate ores. The leached zone is a layer of the phosphate ores that has similar uranium concentrations as the phosphate rock layer that was being utilized by industry; however the leached zone layer had characteristics that made it uneconomical for commercial use. The developmental work involved experiments to separate P_2O_5, Al_2O_3, and U. The AEC was involved with the study because the trace amounts of uranium in the leached zone phosphate ores could be recovered as a byproduct if the leached zone phosphates were processed by industry for commercial use.

TCC received a drum of phosphates for the research, followed by receipt of subsequent smaller quantities. All the work was laboratory scale research. The research was intermittent. The AEC concluded their work on leached zone materials in 1955. The TCC contract ended in September 1955.

4.0 Internal Dose

Workers at TCC had the potential to receive internal dose from phosphate plant operations, uranium recovery operations for the AEC, and the developmental work for the AEC. Intakes from the AEC research and development work are presumed lower than from work in the production areas; therefore, intakes from the development work are not assessed.

Workers were potentially exposed to uranium and decay progeny. Natural thorium is also presumed at trace quantities. Favorable assumptions were made to assess intakes of the various radionuclides. The relative ratios of the radionuclides of interest are provided in the Table 1, reproduced from the TCC ER Table 5-3.

Table 1:Radionuclide Ratios for Uranium Recovery

Radionuclide	Relative Ratio[1]	Notes	Normalized to U-238[1]
U-238	85	Progeny in equilibrium through Th-230	1
U-235	3.87	Progeny in equilibrium	0.0455
Ra-226[2]	4	Progeny in equilibrium	0.047 or 1
Pb-210	85	Equal to U-238	1
Bi-210	85	Equal to U-238	1
Po-210	85	Equal to U-238	1
Th-232	2.8	Progeny in equilibrium	0.033

Notes: The data and information contained in this table are from Table 1 in OCAS-TKBS-0002.
1. Ratios given are for progeny without consideration of branching ratios, where applicable.
2. For Ra-226, 0.047 is assumed for the uranium recovery plant, but a factor of 1 is assumed for the phosphate plant.

The AWE operational period is October 5, 1953, through September 1955. Internal dose from phosphate plant intakes are covered only through September 1955.

Intakes from operation of the Uranium Recovery Plant are only applicable through March 1954, after which it was permanently shut down. Intakes from residual contamination are covered through 1977, the end of the Residual Contamination period.

Radon exposures were possible from the radium in the phosphate ores and in the phosphogypsum waste produced from phosphoric acid production. A class of TCC workers has been added to the SEC. NIOSH has concluded, and the Secretary of Health and Human Services has concurred, that radon exposures cannot be estimated with sufficient accuracy from October 5, 1953, through September 30, 1955 [Sebelius 2011]. Radon exposure estimates are provided below in Section 4.4 for the period of October 1955 through 1977.

4.1 Intakes from Phosphate Plant Operation

There are no monitoring data from TCC for the AEC covered period; therefore, NIOSH considered data from other phosphate plants to assess potential worker intakes. The references

and the assumptions made are summarized below and are discussed in more detail in the TCC ER.

The intakes for phosphate plant workers at TCC will be based on a limiting phosphate dust concentration of 50.4 mg/m^3 (5.04 x 10^{-2} g/m^3). That concentration provides an upper bound average particulate concentration to which a worker would have been exposed. The total dust concentration is converted to individual radionuclide concentrations in the phosphate materials according to Table 2. The Table 2 values are considered bounding for the various phosphate products.

Table 2: Bounding Radionuclide Concentrations in Phosphate Plant Materials

Radionuclides	Concentration (pCi/g)
U-238, Th-230, U-234, Ra-226, Pb-210, Po-210	95
Pa-231,[1] Ac-227[1]	4.3
Th-232, Ra-228, Th-228	3.2

1. U-235 progeny assumed in natural abundance relative to U-238. The U-238 and U-234 concentrations allow for dose from U-235.
2. Note: Short lived progeny not listed in this table are also assumed to be in equilibrium.
3. Reproduced from the TCC ER, Table 5.6.

A 2,500-hour work-year is assumed to bound exposure. Exposure to 5.04 x 10^{-2} g/m^3 at a breathing rate of 1.2 m^3/hour, results in an annual inhalation intake of 151.2 g of dust per year. The annual total dust inhalation intake is multiplied by the 95 pCi/g value for U-238 in Table 2 to determination an annual U-238 intake of 1.44 x 10^{+4} pCi, equivalent to a U-238 air concentration of 4.80 pCi/m^3. Conversion of the 1.44 x 10^{+4} pCi U-238 annual intake into a calendar-day intake results in a 39 pCi/day chronic inhalation of U-238. Intakes of the other radionuclides were calculated similarly.

A chronic ingestion mode of intake is assumed to have occurred as a function of the airborne radioactivity, based on the methods provided in OCAS-TIB-009 [NIOSH 2004].

The bounding intakes for ingestion and inhalation in the phosphate plant are listed in Table 3.

Table 3: Intakes from Operation of the Phosphate Plant

Radionuclides	Inhalation pCi/day[1]	Ingestion pCi/day[1]
U-238, Th-230, U-234, Ra-226, Pb-210, Po-210	39.4	0.73
Pa-231, Ac-227	1.79	0.033
Th-232, Ra-228, Th-228	1.30	0.024

1. Intake rates are normalized to a calendar day basis.
2. U-235 progeny assumed in natural abundance relative to U-238.

The intakes in Table 3 are applicable only to April 1, 1954 through September 30, 1955. See Section 4.5 for dose reconstruction summary instructions.

4.2 Intakes from Uranium Recovery

TCC extracted 400 pounds of uranium for the AEC from December 1953 through March 1954. The methods to estimate intakes for the uranium recovery operation are taken from the TCC ER Section 7.2.2.

For the intake evaluation, a 100-pound per month production is assumed for October 1953 through March 1954. This rate and time span provides a total 600 pounds uranium concentrate produced. Although this is more than the actual production total, it provides a reasonable assurance that the timeframe of production is accounted for and that reconstructed doses from uranium recovery are favorable.

During the wet chemical processes used to concentrate uranium, contamination and dust exposures are minimal. The greatest potential for exposure to radioactive materials associated with the uranium recovery process arises in the final packing areas. Here the essentially-pure uranium compound is dried and barreled for shipping, resulting in a potentially dusty operation. The AEC [1953] contract specified that TCC was to produce uranium concentrates containing at least 50% U_3O_8.

The intake rate is modeled based on one 25-pound batch processed per week from October 5, 1953 through March 1954. Based on a description of how uranium concentrates were handled at Blockson, a batch of material may have been in-process over a two-day period to allow for filtering, drying and packaging, with the latter two steps being significant for potential inhalation. The total uranium alpha air concentration is assumed to be 190 dpm/m^3, or 85.6 pCi/m^3, as discussed in the TCC ER, section 7.2.2. The total uranium alpha is assumed to be 50% U-238 and 50% U-234; U-235 is not explicitly calculated, but this method allows for dose from U-235. The resulting U-238 air concentration is 42.8 pCi/m^3.

Applying a 1.2 m^3/hour inhalation rate, a 10-hour work day to the 42.8 pCi/m^3 concentration results in a U-238 inhalation intake of 513.6 pCi per workday and 1,027 pCi per week for the assumed two days per week in the Uranium Recovery Building.

If workers extracted uranium 2 days per week, they would have been exposed to lower levels of airborne uranium in the Uranium Recovery Building for the remainder of the work week, or they would have been exposed to airborne radioactivity from phosphates in other buildings or areas. The 39 pCi/day U-238 intake rate from phosphate plant operations (see Table 3) is higher than the 6.84 pCi/day U-238 residual intake estimated for the Uranium Recover Plant (see Section 4.3). Therefore, intakes during uranium production periods will be modeled as two 10-hour days in the Uranium Recovery Building and three 10-hour days exposed to phosphate products.

U-238 is used as the basis for intake calculations. The relative ratios of other radionuclides for the uranium recovery work are provided in Table 1, and the relative ratios for the phosphate plant work are provided in Table 2. The only difference is the Ra-226 ratio, which is presumed substantially removed from the phosphoric acid product used to extract uranium.

Table 3 provides a bounding U-238 inhalation intake of 39.4 pCi/calendar day from phosphate plant work, which is based on a U-238 air concentration of 4.80 pCi/m^3 (derived from the dust

concentration presented in Section 4.1). Applying a 1.2 m^3/hour inhalation rate, a 10-hour work day, and a 3-day exposure to the 4.80 pCi/m^3 dpm/m^3 U-238 concentration, results in an inhalation intake of 173 pCi for the three days.

The weekly total U-238 inhalation intake is 1,200 pCi (1,027 pCi from uranium recovery and 173 pCi from phosphates).

Ingestion intakes are estimated as a function of the inhalation intakes using methods in OCAS-TIB-009 [NIOSH 2004]. That method applies a factor of 0.2 to the air concentration to estimate work-day ingestion rates; it is based on an 8-hour workday. Adjustments to the methods to allow for a 10-hour workday result in a factor of 0.223 applied to the air concentration. Applying that factor to U-238 air concentrations for uranium recovery (42.8 pCi/m^3) and fertilizer plant (4.80 pCi/m^3) results in ingestion intake rates of 9.543 pCi/work-day and 1.070 pCi/work-day for uranium recovery and fertilizer plant, respectively.

Intakes were normalized to calendar day intake rates, and the results are presented in Table 4. These intakes are similar to those in the TCC ER Table 7-4; however, adjustments were made to more accurately account for the assumed 2,500 hours worked per year.

Table 4: Intakes during Period of Uranium Recovery Plant Operation

Radionuclides	Uranium Plant Inhalation (pCi/week)	Fertilizer Plant Inhalation (pCi/week)	Combined Inhalation (pCi/cal-day)[1]	Combined Ingestion (pCi/cal-day)[1]
U-238, Th-230, U-234, Pb-210, Po-210	1,027	173	171	3.19
Pa-231, Ac-227	46.7	7.86	7.80	0.14
Ra-226	48.3	173	31.6	0.59
Th-232, Ra-228, Th-228	33.9	5.70	5.66	0.11

1. The calendar day intake rates in Table 4 are applicable from October 5, 1953, through March 31, 1954.

4.3 Intakes from Residual Contamination

The calculations presented in this section have been updated from the residual contamination estimates provided in the TCC ER. Updated depletion factors have been applied based on the most recent revision to ORAUT-0TIB-070 [ORAUT 2012]. Also, the resuspension factor was changed from 1 x 10^{-6}/m to 1 x 10^{-5}/m. This Revision No. 1 updates the methods used to calculate ingestion intakes from residual contamination.

The Uranium Recovery Building operated intermittently for a few months and never reached full operational status. The potential contamination levels would have been low initially and increased as more uranium concentrates were produced.

Inhalation intakes from residual contamination are based on settling and resuspension of particulates and depletion of source term as described in TBD-6000 [NIOSH 2011] and ORAUT-TKBS-070 [ORAUT 2012]. An estimate was made of the surface contamination resulting from the settling of 85.6 pCi/m^3 airborne total uranium (section 4.2), the bounding concentration assumed for uranium recovery. The suspended particulates are assumed to have settled out of the air for 30 days with a settling velocity of 7.5 x 10^{-4} m/s. Assuming 85.6 pCi/m^3

for 30 days results in a total uranium contamination of 1.66×10^5 pCi/m^2. A resuspension factor of 1×10^{-5}/m was applied to the contamination level to determine a *total uranium* airborne concentration of 1.66 pCi/m^3. Half of the uranium intake is assigned to U-238. A 2,500 hour work-year and a 1.2 m^3/hour breathing rate is assumed.

The resulting U-238 inhalation intake rate is 6.84 pCi per calendar day starting April 1, 1954; however, during the AWE Operational Period (through September 1955) intakes provided for phosphate plant work are higher. Thus residual intakes from uranium recovery work are assigned starting at the beginning of the Residual Contamination Period, October 1, 1955, with application of depletion factors.

Depletion factors from ORAUT-OTIB-070 are provided at one year intervals based on a given rate of source depletion, starting with an initial factor of 1.0 for the first year. For this TCC calculation, the 1.0 factor is applied for April 1, 1954 through the end of 1955. The factors applicable to each year are provided in Table 5.

Inhalation intake rates from residual contamination were calculated for each year (1955 – 1977) by applying the depletion factors to the 6.84 pCi/calendar day U-238 initial inhalation intake rate and multiplying by the number of calendar days. The results for the various radionuclides are included in the intakes are listed in Tables 7 (1955) and 8 (1956-1977).

A chronic ingestion intake from residual contamination from uranium recovery operations is also assumed to have occurred starting April 1, 1954. The initial U-238 ingestion intake rate from residual contamination on April 1, 1954, is assumed to be equal to the operational U-238 ingestion rate of 9.543 pCi/ workday, or 6.536 pCi/workday (section 4.2). Ingestion intake rates from residual contamination were calculated for each year (1955 – 1977) by applying the depletion factors to the 6.536 pCi/calendar day U-238 initial ingestion intake rate and multiplying by the number of calendar days. The results for the various radionuclides are included in the intakes listed in Tables 7 and 9.

Section 4.5 provides dose reconstruction instructions and summary tables of intakes to be used for dose reconstructions. Intake rates from residual contamination for inhalation and ingestion are provided in Tables 8 and 9, respectively.

Table 5: Depletion Factors for Residual Contamination

Year	Depletion Factor
1955	1.00E+00
1956	7.83E-01
1957	6.13E-01
1958	4.80E-01
1959	3.76E-01
1960	2.94E-01
1961	2.31E-01
1962	1.81E-01
1963	1.41E-01
1964	1.11E-01
1965	8.67E-02
1966	6.79E-02
1967	5.32E-02
1968	4.16E-02
1969	3.26E-02
1970	2.55E-02
1971	2.00E-02
1972	1.56E-02
1973	1.23E-02
1974	9.60E-03
1975	7.51E-03
1976	5.88E-03
1977	4.61E-03

4.4 Radon Exposures

A class of TCC workers has been added to the SEC. NIOSH has concluded, and the Secretary of Health and Human Services has concurred, that radon exposures cannot be estimated with sufficient accuracy from October 5, 1953, through September 30, 1955 [Sebelius 2011]. Radon exposure estimates are assessed for the period of October 1955 through 1977. Estimates of radon exposure from residual contamination after October 1955 are provided below.

The wet process used to make phosphoric acid removes most Ra-226 from the phosphate stream in the plant. The radium resides in the phosphogypsum waste stack (pile) on the TCC property. The amount of phosphates used in the AEC uranium recovery work was small in comparison to the many tons TCC processed in subsequent years producing fertilizer. Although the waste piles are not typically occupied, it is assumed a worker worked routinely in the vicinity of the piles, which should provide a bounding radon exposure estimate during the residual period for radon exposures attributable to materials used for the AEC uranium recovery work.

Annual exposure to radon are provided in Table 6. The values were reproduced from the TCC ER, Table 7-6. Section 7.2.5.2 of the ER provides a detailed explanation of the derivation of the radon values.

Table 6: Residual Radon Exposures

Year	AEC radon, pCi/L	AEC WLM
1955	0.38	*0.0056
1956	0.38	0.022
1957	0.38	0.022
1958	0.091	0.0054
1959	0.052	0.0031
1960	0.036	0.0021
1961	0.028	0.0016
1962	0.023	0.0013
1963	0.019	0.0011
1964	0.016	0.0010
1965	0.014	0.0009
1966	0.013	0.0008
1967	0.012	0.00069
1968	0.011	0.00063
1969	0.010	0.00057
1970	0.0090	0.00053
1971-1977	0.0084	0.00049

*WLM values for 1955 only include exposures from October 1, 1955, through December 31, 1955. For other years, WLM calculations assume a 2,500 hour exposure for a full work year at the given concentration and a 0.4 equilibrium factor.

4.5 Internal Dose Reconstruction Summary

The intakes and radon exposure values provided are based on bounding assumptions. The dose distributions are to be applied as constant values.

Table 7 lists the intake rates for the various radionuclides for the AWE operational period. Table 7 also includes intakes for the last three months of 1955, which are in the residual contamination period, i.e., Table 7 has all intake rates from the startup of the plant through December 31, 1955.

Table 8 has inhalation intake rates for the residual period from 1956 through 1977.

Table 9 has ingestion intake rates for the residual period from 1956 through 1977.

Table 6 has annual radon exposure rates for the residual period, October 1955 through 1977. Radon exposures cannot be estimated prior to October 1955.

Table 7: AWE Operational Period Intakes

Area/Time Period	Radionuclides	Inhalation (pCi/d)	Ingestion (pCi/d)
Uranium recovery/phosphates October 5 , 1953, through March 31, 1954	U-238, Th-230, U-234, Pb-210, Po-210	171	3.19
Uranium recovery/phosphates October 5 , 1953 through March 31, 1954	Pa-231, Ac-227	7.80	0.14
Uranium recovery/phosphates October 5 , 1953, through March 31, 1954	Ra-226	31.6	0.59
Uranium recovery/phosphates October 5 , 1953, through March 31, 1954	Th-232, Ra-228, Th-228	5.66	0.11
Phosphates April 1, 1954, through September 30, 1955	U-238, Th-230, U-234, Ra-226, Pb-210, Po-210	39.4	0.73
Phosphates April 1, 1954, through September 30, 1955	Pa-231, Ac-227	1.79	0.033
Phosphates April 1, 1954, through September 30, 1955	Th-232, Ra-228, Th-228	1.30	0.021
(Residual contamination period) October 1, 1955, through December 31, 1955	U-238, Th-230, U-234, Pb-210, Po-210	6.84	6.54
(Residual contamination period) October 1, 1955, through December 31, 1955	Pa-231, Ac-227	0.311	0.297
(Residual contamination period) October 1, 1955, through December 31, 1955	Ra-226	0.321	0.307
(Residual contamination period) October 1, 1955, through December 31, 1955	Th-232, Ra-228, Th-228	0.226	0.216

1. All intake rates are normalized to calendar day intake rates.

Table 8: Inhalation Intake Rates from Residual Contamination

Year	U-238, Th-230, U-234, Pb-210, Po-210 (pCi/cal. day)[1]	Pa-231, Ac-227 (pCi/cal. day)[1]	Ra-226 (pCi/cal. day)[1]	Th-232, Ra-228, Th-228 (pCi/cal. day)[1]
1956	5.35E+00	2.44E-01	2.52E-01	1.77E-01
1957	4.19E+00	1.91E-01	1.97E-01	1.38E-01
1958	3.28E+00	1.49E-01	1.54E-01	1.08E-01
1959	2.57E+00	1.17E-01	1.21E-01	8.48E-02
1960	2.01E+00	9.15E-02	9.45E-02	6.63E-02
1961	1.58E+00	7.19E-02	7.42E-02	5.21E-02
1962	1.24E+00	5.63E-02	5.82E-02	4.08E-02
1963	9.64E-01	4.39E-02	4.53E-02	3.18E-02
1964	7.59E-01	3.45E-02	3.57E-02	2.50E-02
1965	5.93E-01	2.70E-02	2.79E-02	1.96E-02
1966	4.64E-01	2.11E-02	2.18E-02	1.53E-02
1967	3.64E-01	1.66E-02	1.71E-02	1.20E-02
1968	2.84E-01	1.29E-02	1.34E-02	9.39E-03
1969	2.23E-01	1.01E-02	1.05E-02	7.36E-03
1970	1.74E-01	7.94E-03	8.20E-03	5.76E-03
1971	1.37E-01	6.22E-03	6.42E-03	4.51E-03
1972	1.07E-01	4.87E-03	5.03E-03	3.53E-03
1973	8.38E-02	3.81E-03	3.94E-03	2.76E-03
1974	6.56E-02	2.99E-03	3.08E-03	2.17E-03
1975	5.14E-02	2.34E-03	2.41E-03	1.70E-03
1976	4.02E-02	1.83E-03	1.89E-03	1.33E-03
1977	3.15E-02	1.43E-03	1.48E-03	1.04E-03

1. All intake rates are normalized to calendar day intake rates of continuous exposure from January 1 through December 31 of each year.

Table 9: Ingestion Intake Rates from Residual Contamination

Year	U-238, Th-230, U-234, Pb-210, Po-210 (pCi/cal. day)[1]	Pa-231, Ac-227 (pCi/cal. day)[1]	Ra-226 (pCi/cal. day)[1]	Th-232, Ra-228, Th-228 (pCi/cal. day)[1]
1956	5.12E+00	2.33E-01	2.41E-01	1.69E-01
1957	4.01E+00	1.82E-01	1.88E-01	1.32E-01
1958	3.14E+00	1.43E-01	1.47E-01	1.04E-01
1959	2.46E+00	1.12E-01	1.16E-01	8.11E-02
1960	1.92E+00	8.74E-02	9.03E-02	6.34E-02
1961	1.51E+00	6.87E-02	7.10E-02	4.98E-02
1962	1.18E+00	5.38E-02	5.56E-02	3.90E-02
1963	9.22E-01	4.19E-02	4.33E-02	3.04E-02
1964	7.26E-01	3.30E-02	3.41E-02	2.39E-02
1965	5.67E-01	2.58E-02	2.66E-02	1.87E-02
1966	4.44E-01	2.02E-02	2.09E-02	1.46E-02
1967	3.48E-01	1.58E-02	1.63E-02	1.15E-02
1968	2.72E-01	1.24E-02	1.28E-02	8.97E-03
1969	2.13E-01	9.70E-03	1.00E-02	7.03E-03
1970	1.67E-01	7.59E-03	7.84E-03	5.50E-03
1971	1.31E-01	5.94E-03	6.14E-03	4.31E-03
1972	1.02E-01	4.65E-03	4.81E-03	3.38E-03
1973	8.01E-02	3.64E-03	3.76E-03	2.64E-03
1974	6.27E-02	2.85E-03	2.95E-03	2.07E-03
1975	4.91E-02	2.23E-03	2.31E-03	1.62E-03
1976	3.85E-02	1.75E-03	1.81E-03	1.27E-03
1977	3.01E-02	1.37E-03	1.42E-03	9.94E-04

1. All intake rates are normalized to calendar day intake rates of continuous exposure from January 1 through December 31 of each year.

5.0 External Dose

Workers at TCC had the potential to receive external dose from phosphate plant operations, uranium recovery operations for the AEC, and the developmental work for the AEC. Doses from the AEC research with small quantities of phosphate ores are presumed lower than from work in the production areas; therefore, dose from the development work is not assessed.

There are no dosimetry data or radiation measurements available for TCC. Therefore, NIOSH considered worker doses using source-term information and measured doses of phosphate plant workers according to OCAS-IG-004 [NIOSH 2008].

5.1 Penetrating Dose

5.1.1 Penetrating Dose from the Phosphate Plant

There have been numerous reports and studies on doses received by workers at phosphate plants. The most extensively published works are reports from the Florida Institute of Phosphate Research (FIPR), although the U. S. Environmental Protection Agency (EPA), the National Council on Radiation Protection and Measurements (NCRP), and others have also published data on worker doses. A FIPR [1998] report contains a summary of some of the data that had been previously reported in various publications. Published data indicate average annual external doses received by workers at phosphoric acid and fertilizer plants are relatively low. The data considered were from various phosphate plants that used similar phosphate rock to produce phosphoric acid by the wet process.

Section 7.3.1 of the TCC ER discusses various data on external dose to phosphate plant workers. As recommended in the ER, a 220 mrem/year (0.220 rem/year) bounding external whole-body photon dose rate is assumed for work in the TCC phosphate plant. The annualized dose is equivalent to a dose of 0.00060 rem/calendar day, which is applicable during the AWE Operational Period; however, dose estimates for workers in the uranium recovery area are higher and are applied through March 1954. The 0.00060 rem/calendar day is applicable from April 1, 1954, through September 30, 1955.

5.1.2 Penetrating Dose from Uranium Recovery

The external doses were modeled based on the assumption that the uranium concentrates had the isotopic ratios listed in Table 1, which assumes dose contribution from natural uranium and progeny and contaminants in the natural thorium decay series.

MCNPX (version 2.7b) was used to determine the dose rate per curie of ^{238}U regardless of the actual activity in the drum. This was later adjusted for actual source activity, and all radionuclides were considered as a ratio with respect to ^{238}U to determine the number of photons and electrons per decay of ^{238}U.

The number and energy of photons emitted per unit decay of ^{238}U and the number of beta particle emissions per unit decay of ^{238}U were compiled from Evaluated Nuclear Structure Data Files (NSDF) from the National Nuclear Data Center. The emissions were binned by emission probability. The resulting total photon emission probability per decay of ^{238}U was 1.0434 for the energy range of 0.001 to 3.1 MeV. The resulting total beta emission probability per decay of ^{238}U was 4.19 [DCAS 2009].

A density of 2 g/cm^3 was chosen to provide a claimant-favorable geometry. Based on previous evaluations for Blockson Chemical Company [NIOSH 2014], the density is nominally a self-correcting factor for uranium in that it adds more shielding as it adds more activity. Since the total quantity was fixed at 400 lbs., the exposure geometry was allowed to be higher in the drum by using a lower density. The drum was assumed to have the same physical specifications as listed in ORNL No. 100-1A2-0006. This model results in a drum approximately 75% full.

Photon flux was evaluated at 30 cm and 100 cm from the edge of the drum at a height of 77.9 cm above the floor, the approximate height of the testes. Factors from ICRP [1996] were used to convert the photon flux to units of air kerma. Results are provided in Table 10.

Table 10: Photon Dose Rates from Yellowcake

Distance from drum	Activity of ^{238}U in drum (Ci)	Photon emission dose (rad/hr)	Bremsstrahlung dose (rad/hr)	Total dose rate (rad/hr)
30 cm	0.05134	1.89E-3	2.02E-4	2.09E-3
100 cm	0.05134	6.16E-4	6.64E-5	6.82E-4

The exposure time for external dose is based on the assumptions of intermittent work as described in Section 4.2. During the period of operation of the Uranium Recovery Plant, it is assumed the intermittent uranium extraction work was a two-day-per-week process and that a worker spent 20% of the time over those two days at a distance of 30 cm (one foot) from a drum of product. For an assumed 10-hour work day, a worker would spend 4 hours per week at a distance of 30 cm from the drum. This exposure scenario also allows for work in close proximity to uranium concentrates in other locations in the building, such as working with filter presses or manually transferring the material. If a 50 hour work-week is assumed, a worker could have been working in the building for an additional 46 hours at a lower exposure rate doing tasks that did not involve direct handling of uranium concentrate. Exposure during that time is modeled by assuming a general area dose rate that is equivalent to the dose rate at 100 cm from the drum of material. Thus the weekly external whole-body photon dose is calculated by assuming 4 hours exposure at 30 cm and 46 hours exposure at 100 cm from the drum of material.

Applying the dose rates from Table 10 to the assumed hours, results in a weekly dose of 0.0397 rad (air kerma), or 0.0057 rad per calendar day. The dose is applied as 50% 30-250 keV photons and 50% >250 keV photons. The dose is considered bounding and applied as a constant distribution. The applicable dates are October 5, 1953, through March 31, 1954.

5.2 Non-Penetrating Dose

5.2.1 Non-Penetrating Dose from the Phosphate Plant

Non-penetrating beta dose from phosphate materials was estimated from available dose rates at 30 cm from the surface of yellowcake, adjusted for additional radionuclides and uranium concentration, as specified in the TCC ER, Section 7.3.4.1. The resulting dose rate is 0.028 mrem/hour (0.000028 rem/hour). A 2,500 hour work-year is assumed, resulting in an annual beta dose of 0.070 rem, or a dose of 0.00020 rem per calendar day, which is applicable from April 1, 1954, through September 30, 1955. Dose is applied as electrons >15 keV as a constant distribution. See Section 5.2.2 for dose rates prior to April 1, 1954.

5.2.2 Non-Penetrating Dose from Uranium Recovery

Non-penetrating beta dose from the recovered uranium concentrates at TCC was estimated from available dose rates at 30 cm from the surface of yellowcake, adjusted for additional radionuclides, as specified in the TCC ER, Section 7.3.4.2. The resulting dose rate is s 3.6 mrem/hour (0.0036 rem/hour).

Dose is modeled based on a 50 hour work-week. It is assumed workers were exposed to uranium concentrates for 20 hours per week at 3.6 mrem/hour (0.0036 rem/hour) during the period of intermittent uranium recovery work, resulting in 72 mrem/week. For the remaining 30 hours per week, beta exposure from phosphates is assumed at a rate of 0.028 mrem per hour (0.000028 rem per hour is assumed (see Section 5.2.1), resulting in an additional 0.00084 rem. This results in a weekly beta dose of 0.073 rem, or 0.010 rem/calendar day, applicable from October 5, 1953, through March 31, 1954. Doses are applied as electrons >15 keV with a constant distribution.

Beta Dose from Contaminated Clothing

Skin dose from contamination of the skin, and from contact with contaminated work clothing was estimated from Mallinckrodt Chemical Company data of contaminated clothing. Average dose rates from contaminated clothing at Mallinckrodt indicate a level of 1.5 mrem/hour (0.0015 rem/hr) [AEC 1958]. The Mallinckrodt dose rate is used as a bounding condition for TCC because Mallinckrodt handled materials of similar radiological constituents, but in larger quantities and with a higher radioactive material content. During operation of the Uranium Recovery Plant at TCC it is assumed that the workers were exposed to that level for 10 hours per week, which is considered an upper-bound condition. This results in a dose to the skin of 15 mrem/week (0.015 rem/week), or 0.0021 rem/calendar day. Doses are applied as electrons > 15keV and a constant distribution. This dose is applicable for October 5, 1953, through March 31, 1954.

Electron dose from work clothing in the phosphate plant is considered insignificant due to the relatively low concentration of radionuclides.

5.2.3 Extremity Dose

Extremity dose is considered for operators and maintenance workers who may have had direct contact with the uranium concentrates in the Uranium Recovery Plant and direct contact with phosphate materials in other buildings.

Surface dose rates on yellowcake have been reported to be about 203 mrad per hour (0.203 rad per hour [DOE, 2000]. The reported dose rates were modified for TCC uranium recovery and phosphate plant operations as described in the TCC ER section 7.3.4.3. The results are summarized below.

For the Uranium Recovery Plant, an estimate was made of shallow dose to the hands and forearms based on direct contact with yellowcake. A factor of 1.8 was applied to the 0.203 rad/hour dose rate from yellowcake to allow for additional radionuclides assumed to be present in the uranium concentrates at TCC, resulting in a beta dose rate of 0.365 rad/hour.

For the phosphate plant, the 0.203 rad/hour dose rate was multiplied by a factor of 4.3 to allow for radionuclides associated with the uranium at TCC, then divided by 312 to adjust for the much lower concentration of uranium. The resulting dose rate is 0.0028 rad/hour.

Extremity dose modeling during the period of intermittent operation of the Uranium Recovery Plant is based on one hour of contact with the recovered uranium concentrate per week

(1 hour*0.365 rad/hour), and an additional five hours per week of contact with phosphates in other buildings (5 hours*0.0028 rad/hour=0.014 rad). This results in a weekly extremity dose of 0.379 rad, or 0.054 rad/calendar day. This dose will be applied to the hands and forearms of operators and maintenance worker as electrons >15 keV for work from October 5, 1953, through March 31, 1954. Doses are applied as constant distributions.

Extremity dose is estimated for the period of April 1, 1954, through September 30, 1955, for exposure to phosphates. Six hours per week of direct contact at the rate of 0.0028 rad/hour is assumed, resulting in a weekly dose of 0.017 rad, or 0.0024 rad/calendar day. This dose will be applied to the hands and forearms (operators and maintenance workers) as electrons >15 keV from April 1, 1954 through September 30, 1955. Doses are applied as constant distributions.

5.3 External Dose from Residual Contamination

External dose from residual contamination in the Uranium Recovery Building is considered. Measured dose rates from contamination in the Blockson Chemical Company uranium recovery facility are used to bound dose from residual contamination at TCC. Blockson's uranium recovery plant was in production for over seven years with essentially the same source term. Dose rates on surfaces in that facility should provide a bounding estimate for TCC during the residual period. Based on information in Section 5.0 of the Blockson Technical Basis Document [NIOSH 2014], the dose from residual contamination at TCC will be assumed to be 0.06 R/year, or 0.00016 R/calendar day.

For TCC dose reconstructions, the dose from residual contamination will be applied as a constant because the TCC uranium plant produced less than 1% of the total uranium produced at Blockson. The dose estimates from residual contamination in the Uranium Recovery Plant will be assigned starting September 1, 1955.

Beta dose from residual contamination is not considered separately because the 0.060 R/year dose rate estimates provided for Blockson was based on dose rate measurements taken with an instrument that was sensitive to both photon and beta radiation [DOE 1983].

5.4 External Dose from X-ray Examinations

There is no specific information available on required medical X-rays during the AWE Operational Period. The contract between the AEC and TCC had a provision requiring TCC "to conform to all minimum health and safety regulations and requirements of the Commission" [AEC 1953]. An annual chest X-ray examination is presumed to have been required during the AEC covered period of 1953 through 1955. Doses should be assigned according to the recommendations in ORAU-OTIB-006 [ORAUT 2019].

5.5 External Dose Reconstruction Summary

Table 11 provides a summary of the dose estimates for dose reconstruction purposes.

Table 11: Summary of External Doses for Texas City Chemicals

Time Period	Dose[1]	Radiation Type	Dose quantity
October 5, 1953, through March 31, 1954	0.0057 rad/day	Photons 50% 30 - 250 keV 50% > 250 keV	Air kerma
October 5, 1953, through March 31, 1954	0.010 rem/day	Electrons >15 keV	Shallow dose from yellowcake
October 5, 1953, through March 31, 1954	0.0021 rem/day	Electrons >15 keV	Shallow dose from contaminated clothing
October 5, 1953, through March 31, 1954	0.054 rem/day (operators and maintenance workers)	Electrons >15 keV	Shallow dose to skin of hands and forearms
April 1, 1954, through September 30, 1955	0.00060 rem/day	Photons 50% 30 - 250 keV 50% > 250 keV	Deep dose equivalent
April 1, 1954, through September 30, 1955	0.00020 rem/day	Electrons >15 keV	Shallow dose from phosphates
April 1, 1954, through September 30, 1955	0.0024 rem/day (operators and maintenance workers)	Electrons >15 keV	Shallow dose to skin of hands and forearms
October 1, 1955, through the end of covered employment	0.00016 R/day	Photons 50% 30 - 250 keV 50% > 250 keV	Roentgen

[1] External doses are normalized to dose per calendar day. All values are considered constants.

Medical X-ray dose is assigned as described in Section 5.4.

6.0 References

AEC [1952]. Letter contract no. AT(49-1)-616. Washington, D.C.: U.S. Atomic Energy Commission. February 14. [SRDB Ref ID: 16646, pp. 37-48]

AEC [1953]. Contract no. AT(49-1)-647. Washington, D.C.: U.S. Atomic Energy Commission. May 12. [SRDB Ref ID: 16646, pp. 49-67]

AEC [1958]. Symposium on occupational health experience and practices in the uranium industry, U.S. Atomic Energy Commission, October 15-17. [SRDB Ref ID 7886]

Corporate Profile [1958]. Corporate profile…aggressive management, close attention to trends, and emphasis on research keep Smith-Douglas a front runner, Journal of Agricultural and Food Chemistry, 1958: 6(11), pp. 866-867, November 1958. [SRDB Ref ID: 179525]

DCAS [2009]. Supporting documentation for DCAS-TKBS-0011. Cincinnati, OH: U.S. Department of Health and Human Services, Centers for Disease Control and Prevention. National Institute of Occupational Safety and Health, Division of Compensation Analysis and Support. [SRDB Ref ID: 179526]

DOE [1983]. Radiological survey of chemicals group, Olin Corporation, Joliet, Illinois, March 27-November 28, 1978, DOE/EV-0005/35. Argonne, IL: Argonne National Laboratory. May. [SRDB Ref ID 23615]

DOE [1986]. Elimination report, Amoco Chemical Company (the Former Texas City Chemicals, Inc.), Texas City, Texas, U.S. Department of Energy, Formerly Utilized Sites Remedial Action Program (FUSRAP), 1986. [SRDB Ref ID 16646, pp. 8 – 13]

FIPR [1998]. Evaluation of exposure to technologically enhanced naturally occurring radioactive materials (TENORM) in the phosphate industry, Publication No. 05-046-155. Bartow, FL: Florida Institute of Phosphate Research. July. [SRDB Ref ID 18076]

Johnson JC [1953]. Memorandum from J. Johnson, Director, AEC Division of Raw Materials, to L.L. Strauss, AEC Chairman, November 18. [SRDB Ref ID 16646 pp. 24-25]

Greenleaf EF [1955]. Memorandum from EF Greenleaf, Division of Raw Materials, to George G. Marvin, Assistant Director, Process Development, Division of Raw Materials, U.S. Atomic Energy Commission Office. Visit to Texas City Chemical Company on January 12-13, 1955. [SRDB Ref ID 40644]

ICRP [1996]. Conversion coefficients for use in radiological protection against external radiation. International Commission on Radiological Protection, Publication No. 74, Annals of ICRP 26 (3/4). [SRDB Ref ID: 7979]

NIOSH [2004]. Estimation of Ingestion Intakes, OCAS-TIB-009, Rev. 0. Cincinnati, OH: U.S. Department of Health and Human Services, Centers for Disease Control and Prevention, National Institute of Occupational Safety and Health. April 13. [SRDB Ref ID: 22397]

NIOSH [2008]. The use of data from other facilities in the completion of dose reconstructions under the energy employees occupational illness compensation program act, Rev 0. Cincinnati, OH: U.S. Department of Health and Human Services, Centers for Disease Control and Prevention, National Institute of Occupational Safety and Health, NIOSH, Office of Compensation Analysis and Support. August 21. [SRDB Ref ID 49029]

NIOSH [2010a]. Radiation exposures covered for dose reconstruction under Part B of the Energy Employees Occupational Illness Compensation Program Act. DCAS-IG-003 Rev. 1. Cincinnati, OH: U.S. Department of Health and Human Services, Centers for Disease Control and Prevention, National Institute of Occupational Safety and Health. October 5. [SRBD Ref ID 88929]

NIOSH [2010b]. SEC petition evaluation report, petition SEC-00088, Rev. 1. Cincinnati, OH: U.S. Department of Health and Human Services, Centers for Disease Control and Prevention, National Institute of Occupational Safety and Health. October 19. [SRDB Ref ID 175297]

NIOSH [2011]. Site profiles for atomic weapons employers that worked uranium metals. Battelle-TBD-6000, Rev. 1. Cincinnati, OH: U.S. Department of Health and Human Services, Centers for Disease Control and Prevention, National Institute of Occupational Safety and Health. June 17. [SRDB Ref ID 101251]

NIOSH [2014]. Technical basis document for atomic energy operations at Blockson Chemical Company, Joliet, Illinois, DCAS-TKBS-0002, Rev. 4. Cincinnati, OH: U.S. Department of Health and Human Services, Centers for Disease Control and Prevention, National Institute of Occupational Safety and Health. May 19. [SRDB Ref ID 143289]

ORAUT [2012]. Dose reconstruction during residual radioactivity periods at atomic weapons employer facilities, ORAUT-OTIB-0070 Rev. 01, Oak Ridge, TN: Oak Ridge Associated Universities Team. March 5. [SRDB Ref ID 108851]

ORAUT [2019]. Dose reconstruction from occupational medical x-ray procedures, ORAUT-OTIB-0006 Rev. 06. Oak Ridge, TN: Oak Ridge Associated Universities Team. June 6. [SRDB Ref ID 178310]

Powers HG [1979]. Letter from H.G. Powers, Production Manager, Fertilizer Section, Smith-Douglass, to W.E. Mott, Acting Director, Environmental Control Technology Division. U.S. Department of Energy, March 22. [SRDB Ref ID 16646, p. 126]

Sebelius K [2011]. HHS designation of additional members of the special exposure cohort under the energy employees occupational illness compensation program act of 2000, designating a class of employees from Texas City Chemicals, Inc., Texas City, Texas. Washington, DC.: U.S. Department of Health and Human Services. January 6. [SRDB Ref ID 179523]