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ADVISORY BOARD ON
RADIATION AND WORKER HEALTH

National Institute for Occupational Safety and Health

EVALUATION OF TECHNICAL BASIS DOCUMENT FOR TEXAS CITY CHEMICALS, INC., TEXAS CITY, TEXAS

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ABBREVIATIONS AND ACRONYMS

ABRWH or Advisory Board	Advisory Board on Radiation and Worker Health
AEC	Atomic Energy Commission
AWE	Atomic Weapons Employer
DOE	U.S. Department of Energy
dpm	disintegrations per minute
EPA	U.S. Environmental Protection Agency
ER	evaluation report
FIPR	Florida Institute of Phosphate Research
h	hour
ICRP	International Commission on Radiological Protection
keV	kiloelectron volt
MCNPX	Monte Carlo N-Particle Transport Code eXtended
mrad	millirad
mrem	millirem
NIOSH	National Institute for Occupational Safety and Health
ORAUT	Oak Ridge Associated Universities Team
OTIB	ORAUT technical information bulletin
pCi	picocurie
R	roentgen
SDC	Smith-Douglas Corporation
SEC	Special Exposure Cohort
SRDB	Site Research Database
TBD	technical basis document
TCC	Texas City Chemicals Inc.
U	uranium
WLM	working level month

1 INTRODUCTION AND BACKGROUND

Construction on the Texas City Chemicals Inc. (TCC) plant in Texas City, Texas began in 1952. The plant was designed to produce animal feed and fertilizer from phosphate rock. The plant also had a contract with the Atomic Energy Commission (AEC) to construct a uranium recovery plant to extract uranium as a byproduct of the phosphates. TCC also had a development contract with the AEC to evaluate leach zone material. Preliminary operations began at both the new fertilizer plant and uranium recovery plant on October 5, 1953. The plant encountered a number of problems during startup, and the plant produced only a limited amount of uranium, approximately 300 pounds, for the AEC during the first few months of operation. Due to equipment problems, the plant never reached full-scale uranium production. TCC ceased operations in 1956 and filed for bankruptcy. Following bankruptcy in 1956, the Smith-Douglas Corporation (SDC) acquired TCC. SDC did not pursue uranium work with the AEC. SDC was later acquired by Borden Chemical, who operated the phosphate plant until it closed in 1977.

1.1 Texas City Chemicals SEC

Petitioners filed a Special Exposure Cohort (SEC) petition in March 2007, covering the dates January 1, 1952, through December 31, 1956. On August 17, 2007, Petition SEC-0088 qualified for evaluation. The National Institute for Occupational Safety and Health (NIOSH) issued Revision 0 of the SEC petition evaluation report (ER) for Petition 0088 on January 18, 2008 (NIOSH 2008). During the meeting of the Advisory Board on Radiation and Worker Health (Advisory Board) held on April 7–9, 2008, in Tampa, Florida, the Advisory Board directed SC&A, Inc. to perform a review of the TCC SEC-0088 ER. That report was issued July 18, 2008, and identified nine findings (SC&A 2008).

During the May 8, 2009, Use of Surrogate Data Work Group meeting, NIOSH reported that a series of developments, including the discovery of new information, since the initial issue of the ER led to the need to revise the ER. Because of this, SC&A's findings in the ER review were not addressed in detail in the Use of Surrogate Data Work Group meeting.

NIOSH amended the ER on October 19, 2010 (NIOSH 2010). The amended ER modified the covered period to October 5, 1953, through September 30, 1955, based on newly discovered documentation. The amended ER also recommended granting the SEC based on an inability to bound radon dose with sufficient accuracy. On November 17, 2010, the Advisory Board voted to accept the NIOSH SEC class recommendation. The SEC class includes:

> *All Atomic Weapons Employer employees who worked at Texas City Chemicals, Inc., from October 5, 1953, through September 30, 1955, for a number of work days aggregating at least 250 work days, occurring either solely under this employment or in combination with work days within the parameters established for one or more other classes of employees included in the Special Exposure Cohort.* [NIOSH 2010, page 4]

1.2 Texas City Chemicals TBD

NIOSH issued a technical basis document (TBD) for TCC, DCAS-TKBS-0011, Revision 00, *Technical Basis Document for Texas City Chemicals, Inc. Texas City, Texas* (2017; hereafter "TCC TBD"), to address exposures to workers for all cancers that are not covered by the SEC, and also for the residual period doses. In December 2017, the Advisory Board tasked SC&A with the review of the TCC TBD. This review addresses that tasking.

2 SC&A ORIGINAL FINDINGS FROM REVIEW OF 2008 SEC ER

In order to properly evaluate the TCC TBD, SC&A also reevaluated the related SEC findings from SC&A's review (SC&A 2008) of NIOSH's original ER (NIOSH 2008), in view of the revised NIOSH evaluation report (NIOSH 2010) and the recently released TCC TBD. The nine findings associated with the SC&A 2008 ER review have not been resolved and/or formally closed out. The revised ER and newly issued TCC TBD addressed many of the findings; however, the findings remain open or in progress. As part of this review, SC&A makes recommendations on paths forward for each of these original findings.

> *Finding 1: The petitioners' class definition needs to be re-examined to insure that the time period has been properly justified.*

The revised ER adequately addressed this finding. The revised ER changed the covered period to October 5, 1953, through September 1955. SC&A recommends this finding should be closed.

> *Finding 2: The use of mean annual external exposures observed among phosphogypsum workers in Idaho does not appear to be a scientifically sound or claimant-favorable surrogate for pre-operational phosphate ore handlers at TCC. Consideration should be given to using the upper 95th percentile exposures for Florida phosphate rock workers as a more appropriate claimant-favorable surrogate.*

The current Atomic Weapons Employer (AWE) period does not include a pre-operational period. The SEC period, uranium recovery, plant operations, and residual periods have been redefined by the current SEC, the revised ER, and the TCC TBD; therefore, this finding is no longer applicable and SC&A recommends that this finding be closed.

> *Finding 3: An alternative modeling approach based on reasonable assumptions derived from the available information suggests that external doses could be two orders of magnitude lower than those developed by NIOSH. NIOSH should reexamine its modeling approach to insure that its assumptions for calculating external doses are representative of plausible circumstances.*

The use of approximately 400 pounds of uranium oxide for the external dose calculation would be more realistic and still be claimant favorable. NIOSH took this into account in the revised ER and TCC TBD. SC&A recommends that this finding be closed.

> *Finding 4: NIOSH should consider data from FIPR 1998 as an alternative source of data for estimating internal exposures.*

Finding 4 refers to *pre-operational* internal exposures. The current AWE period does not include a pre-operational period. The SEC period, uranium recovery, plant operations, and residual periods have been redefined by the current SEC, the revised ER, and the TCC TBD; therefore, this finding is no longer applicable and SC&A recommends that this finding be closed.

> *Finding 5: The assumption that workers were exposed to yellowcake for 39 months, while claimant favorable, is not consistent with the available data and may overstate the exposure by an order of magnitude.*

The revised ER adequately addressed this finding. Covered exposures from the uranium recovery building ended in March 1954, rather than the 39-month exposure period assumed by NIOSH in the original ER. Exposure to yellowcake dust beyond March 1954 could only have come from residual contamination. This is reflected in the TCC TBD and revised ER. SC&A recommends this finding be closed.

> *Finding 6: NIOSH should consider other data sources in addition to EPA 1978 to estimate internal exposures to workers outside the uranium recovery building, such as FIPR 1998.*

As recommended in SC&A's finding, the revised ER and the TCC TBD included analyses of data from other studies, such as from the Florida Institute of Phosphate Research (FIPR 1998), in evaluating internal exposures to workers outside the uranium recovery building (NIOSH 2010, pages 29–34). SC&A recommends this finding be closed.

> *Finding 7: The approach used in the evaluation report to reconstruct internal exposures to uranium production operations appears to be unrealistically conservative with regard to exposure duration and exposure level.*

The revised ER states that covered exposures from the uranium recovery plant ended in March 1954, rather than the 39-month exposure period assumed by NIOSH in the original ER. Exposure to yellowcake dust beyond March 1954 could only have come from residual contamination. This a more realistic exposure period. Therefore, SC&A recommends this finding be closed.

> *Finding 8. The methodology used to estimate inadvertent ingestion should be revised.*

NIOSH used the procedures recommended in OCAS-TIB-009, Revision 0, *Estimation of Ingestion Intakes* (2004), in the SEC ERs and the TCC TBD. Since this finding by SC&A, the issues concerning ingestion have been addressed and resolved by the OCAS-TIB-009 Work Group and closed on February 5, 2013. Therefore, SC&A recommends this finding be closed.

> *Finding 9: NIOSH should consider adjustments to the dataset used to calculate radon doses to fully reflect the available information. This would increase the dose from 0.112 WLM/year* [working level month per year] *to 0.56 WLM/year. Should NIOSH determine that the value they selected is, in fact, appropriate for the reasons discussed in the main body of this report, the rationale for this conclusion should be provided in the evaluation report.*

The Advisory Board, based on the inability to reconstruct radon doses during the operational period, granted the SEC class; therefore, this finding is no longer relevant. SC&A recommends this finding be closed.

3 TCC INTERNAL DOSE RECONSTRUCTION

There are no internal monitoring data available for employees during any time at TCC. The TCC TBD assumed there were four possible internal dose pathways: development work for the AEC, phosphate plant operations, uranium recovery operations for the AEC, and the residual period.

3.1 Intakes from Development Work for the AEC

Due to the nature of the research and development work performed by TCC, intakes from these activities were assumed lower than those from work in the production activities; therefore, research and development work was not assessed by NIOSH. After evaluating the available documentation, SC&A concurs that these activities would not result in intakes greater than either the phosphate operations or the uranium recovery operations.

3.2 Intakes from Uranium Recovery Operations

During its short time of operations, TCC extracted approximately 400 pounds of uranium. This mass of uranium would fill less than half of a 55-gallon drum. To evaluate possible intake, NIOSH assumed 100 pounds per month production of material from October 1953 through March 1954. Although this assumption over predicts the material produced, NIOSH argues that, "*it provides a reasonable assurance that the timeframe of production is accounted for and that reconstructed doses from uranium recovery are favorable*" (TCC TBD, page 9). SC&A finds this argument acceptable, given the unknown production timetables at the site. This further breaks down to an estimated 25-pound batch per week.

3.2.1 Inhalation from Uranium Recovery Operations

In the SEC ER (NIOSH 2010) and the TCC TBD, NIOSH assumed that the production process at TCC was similar to that at the Blockson Chemical Company, as described in OCAS-TKBS-0002, Revision 04, *Technical Basis Document for Atomic Energy Operations at Blockson Chemical Company, Joliet, Illinois* (2014). Each batch would have been in process for 2 days, which allowed time for filtering, drying, and packaging the materials. Drying and packaging are known to create a significant inhalation risk. NIOSH cites a Christofano and Harris 1960 study on industrial hygiene at uranium processing facilities as the basis for using an air concentration of 190 disintegration per minute per meter cubed (dpm/m^3). This value comes from Table 2 of that reference and represents the maximum of the daily average exposures, which ranged from 90 to 190 dpm/m^3, with an average value of 140 dpm/m^3. NIOSH chose the upper limit (190 dpm/m^3) of these daily average exposures and converted this to a uranium-238 (U-238) exposure of 1,027 picocuries (pCi) per week, based on a breathing rate of 1.2 m^3/h and 2,500 hours per year (190 gross alpha dpm/m^3 × 1.2 m^3/h × 10 hours/workday × 1 pCi/2.22 dpm × 2 workdays/week × 0.5 U-238 dpm/gross alpha dpm = 1,027 U-238 pCi/week). The relative ratios of the other radionuclides for the uranium recovery work are provided in Table 1 of the TCC TBD.

SC&A found that the TCC TBD and revised ER presented lower intake values per calendar day than the original ER. Although the revised intake values still appear large for the relatively small volume of material processed at TCC compared to the other facilities used in the Christofano and

Harris 1960 study, the few workers who did perform the uranium recovery operations at TCC were potentially exposed to comparable inhalation intakes at the time.

3.2.2 Ingestion from Uranium Recovery Operations

NIOSH used the procedures recommended in OCAS-TIB-009 in the ERs and the TCC TBD to derive intake by ingestion during the uranium recovery period. Intake by ingestion issues have been addressed by the OCAS-TIB-009 Work Group and resolved. A summary of the recommended inhalation and ingestion intakes for the uranium recovery period (October 5, 1953, through March 31, 1954) is provided in Table 7 of the TCC TBD. SC&A has verified the values in this table.

Although the revised ingestion values may appears large for the relatively small volume of material processed at TCC compared to the other facilities used in the Christofano and Harris 1960 study, the few workers who did perform the uranium recovery operations at TCC were potentially exposed to comparable ingestion intakes at the time.

3.2.3 Radon Exposure from Uranium Recovery Operations

Radon exposures were possible during the uranium recovery operations. However, 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. Therefore, a class of TCC workers has been added to the TCC SEC for that period.

3.3 Intakes from Phosphate Plant Operations

The intakes for phosphate plant workers at TCC is based on a limiting phosphate dust concentration of 50.4 mg/m^3. This value is the maximum measured dust concentration at the Idaho plant from a survey by the U.S. Environmental Protection Agency (EPA). The EPA performed a thorough study of dust-loading and radionuclide concentrations in air throughout the phosphate ore process at an Idaho phosphate facility (EPA 1978). The facility used the wet-process method to process phosphate rock, a process comparable to that used at TCC. Various air samples were taken at locations throughout the Idaho plant. The samples were analyzed for total dust-loading, and airborne radioactivity concentrations were reported. To obtain this dust loading (50.4 mg/m^3), NIOSH used the mass of dust collected (0.2742 gram from Table 12) during the flow of 5.44 m^3 of air through a particulate sampler (EPA 1978). According to NIOSH, that concentration provides an upper bound average particulate concentration to which an employee would have been exposed.

During its SEC ER review, SC&A suggested NIOSH consider other data, such as FIPR 1998 (SC&A's Finding 6). The revised ER did consider this, as well as FIPR 1995. NIOSH concluded that those studies are less applicable because of modern engineering techniques that reduced the dust generation at the plant.

SC&A has examined another approach to the issue of developing a claimant-favorable approach to air concentrations and intakes that would complement the use of the distribution developed by NIOSH. A paper by Wesley R. Van Pelt Associates (Van Pelt 2005) was commissioned by

SC&A in 2005. That paper performed an evaluation of air dust concentrations in industrial settings. Its conclusion was as follows:

> *While it is impossible to predict the maximum likely dust concentration to which a worker would be exposed in an industrial setting, it is possible to construct some likely bounds on the largest dust concentration likely to occur. …it is my opinion that the maximum likely dust concentration in the breathing zone of a worker without a respirator would be about 30 mg/m^3 for exposures lasting many hours per day and about 300 mg/m^3 for exposures lasting only 5 or 10 minutes or less.* [pages 3–4]

NIOSH's model assumes a dust loading of 50.4 mg/m^3, whereas the Wesley R. Van Pelt Associates study concluded 30 mg/m^3 as being reasonably bounding, which is similar to the second highest values of 33.9 mg/m^3 derived from Table 14 (0.3998 g ÷ 11.8 m^3 × 1,000 mg/g = 33.9 mg/m^3) of the EPA study (EPA 1978). Based on this information, it would appear that NIOSH selected the more conservative upper value of 50.4 mg/m^3.

SC&A finds this approach reasonable and claimant favorable.

3.3.1 Inhalation from Phosphate Plant Operations

NIOSH assumed that, with a bounding air dust loading of 50.4 mg/m^3, a 2,500-hour work year and a breathing rate of 1.2 m^3/h

$$50.4 \text{ mg/m}^3 \times 1.2 \text{ m}^3\text{/h} \times 2{,}500 \text{ hours/year} = 151{,}200 \text{ mg/year} = 151.2 \text{ g/year inhaled.}$$

This is converted to activity based on the bounding radionuclide concentrations presented in Table 5-6 of the SEC ER (NIOSH 2010). SC&A verified the concentrations recommended in Table 5-6. Although it is possible that some radionuclides could temporarily be present in higher concentrations than presented, continuous exposure to the concentrations used provides a bounding source term for internal exposure.

3.3.2 Ingestion from Phosphate Plant Operations

NIOSH used the procedures recommended in OCAS-TIB-009 in the SEC ERs and the TCC TBD to derive intake by ingestion during the phosphate operational period. A summary of the recommended inhalation and ingestion intakes for the phosphate operational period (April 1, 1954, through September 30, 1955) is provided in Table 7 of the TCC TBD. SC&A has verified the values in this table.

3.3.3 Radon Exposure from Phosphate Plant Operations

Radon exposures were possible from the radium in the phosphate ores and in the phosphogypsum waste. However, 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. Therefore, a class of TCC workers has been added to the TCC SEC for that period.

3.4 COMBINED URANIUM RECOVERY AND PLANT OPERATIONS INTAKES

The TCC TBD provides 1953 through 1977 recommended annual intakes in Table 8 for inhalation and in Table 9 for ingestion.

Observation 1 – Combined Intakes

As written, SC&A finds that TCC TBD Tables 8 and 9 have the potential to be incorrectly interpreted, leading to unintentional underestimates of dose during the operational years. Calendar-day intakes are intended to be applied over an entire year, even when employment does not cover the entire calendar year. For example, the 1953 U-238 pCi/calendar day intake in Table 8 is presented as 41.3 pCi/day, and the covered period at the site begins October 5, 1953. Intuitively, this would result in an intake of 41.3 pCi for 87 days, or 3,593 pCi of U-238; however, this is incorrect. Instead, the table intends for the dose reconstructor to multiply 41.3 pCi by 365 days, despite the covered period beginning on October 5. The table notes seem to suggest the proper way to calculate annual dose; however, they have ambiguities, and note 1 references a nonexistent note 3. SC&A would suggest intake per calendar day be converted to true annual intakes or further clarification added to the table to prevent misinterpretation.

3.5 INTAKES DURING THE RESIDUAL PERIOD

The residual contamination period was October 1, 1955, through December 31. 1977. The following outlines NIOSH's recommended procedure to derive the associated inhalation and ingestion intakes during this period.

3.5.1 Inhalation from Residual Period

For the residual period (as outlined on pages 10 and 11 of the TCC TBD), NIOSH used the average source term depletion rate from ORAUT-OTIB-0070, Revision 01, *Dose Reconstruction during Residual Radioactivity Periods at Atomic Weapons Employer Facilities* (2012), and a resuspension factor of 1×10^{-5} per meter. NIOSH used a 2,500-hour work-year and a 1.2 m^3/h breathing rate to estimate the surface contamination resulting from the settling of 190 dpm/m^3 airborne uranium, the bounding concentration assumed for uranium recovery. Suspended particulates were assumed to have settled out of the air for 30 days with a settling velocity of 7.5×10^{-4} m/s. NIOSH assumed 190 dpm/m^3 for 30 days, resulting in a total uranium contamination of 3.69×10^5 dpm/m^2. NIOSH applied a resuspension factor of 1×10^{-5}/m to the contamination level to determine a *total uranium* airborne concentration of 3.69 dpm/m^3; half of the uranium intake was assigned to U-238. NIOSH assumed a 2,500 hour work-year and a 1.2 m^3/h breathing rate. The resulting U-238 intake rate was 6.84 pCi per calendar day starting April 1, 1954. The depletion factors for the residual period are listed in TBD Table 5. These depletion factors were based on a deletion rate of 0.00067/d as recommend in ORAUT-OTIB-0070.

However, during the AWE operational period (through September 1955), intakes estimates for phosphate plant work were higher. Therefore, residual intakes from uranium recovery work were not assigned until the beginning of the residual contamination period, October 1, 1955.

NIOSH used depletion factors, which are based on a given rate of source depletion at 1-year intervals, from ORAUT-OTIB-070, starting with an initial factor of 1.0 for the first year (1955). For the TCC TBD calculations, the 1.0 depletion factor was applied for April 1, 1954, through the end of 1955.

The factors applicable to each year are provided in Table 5 for the period 1955 through 1977. The resulting U-238 intake values in TBD Tables 8 (inhalation) and 9 (ingestion) for 1955 through 1977 were derived from multiplying the annual intake value of 6.84 pCi per calendar day by the depletion factor in Table 5. The 1955 intake values in Tables 8 and 9 are a combination of phosphate plant operations and the residual period intakes, as stated in the footnotes to the tables.

3.5.2 Ingestion from Residual Period

NIOSH used the procedures recommended in OCAS-TIB-009, the TCC SEC ERs, and the TCC TBD to derive intake by ingestion during the residual period. According to the TCC TBD, pages 10 and 11, this consisted of applying a factor of 0.2 to the air concentration as a function of time to estimate daily ingestion. A summary of the recommended ingestion intakes for the residual period (1955 through 1977) is provided in Table 9 of the TCC TBD. SC&A has verified the values in Table 9.

Observation 2 – Apparent Inconsistence in Ingestion Method Used During Residual Period

While NIOSH followed the procedure in OCAS-TIB-009 for deriving ingestion intakes during the TCC residual period, a different procedure was used in NIOSH's SEC-00236 ER during the residual period for the Metals and Control Corporation (NIOSH 2017). According the SEC-00236 ER, page 29, the ingestion intake (in units of dpm/hour) was derived by applying a factor of 1×10^{-4} m^2/hour to the surface contamination levels (in units of dpm/m^2) as a function of time. The TCC and the Metals and Control Corporation residual situations appear to be similar; therefore, it is not apparent why different methods were used to derive ingestion intake values during the residual period.

3.5.3 Radon Exposure from Residual Period

There were radon flux monitoring results available for the phosphogypsum stacks at TCC taken from February 1983 through September 1984. The highest reading was 0.42 pCi/l. NIOSH assumed that the radon flux was five times greater during the residual period due to lack of crust on the piles. The highest radon reading would have been 2.1 pCi/l and was assumed to the bounding exposure during the residual period. As outlined on pages 41 and 42 of the revised SEC ER (NIOSH 2010), the percentage of AEC-related radon exposure was estimated to be approximately 18% of the total in 1955 (the beginning of the AEC residual period) and remained at 18% through the phosphate plant dormant period of 1956 and 1957. Then, during the phosphate plant's activity operational period of 1958 through 1971, the relative amount from AEC-related work decreased each year of phosphate plant operations to 0.4% in 1971. Multiplying the appropriate AEC-related fraction by 2.1 pCi/l resulted in the AEC radon exposure as listed in Column 2 of Table 6 of the TCC TBD. Assuming a 0.4 equilibrium factor, 100 pCi/l per working level, and 2,500 hours worked per year, resulted in the AEC-related radon WLM values as listed in Column 3 of Table 6.

Although it is possible that the uranium recovery operations may not have added any additional materials to the piles, it appears that NIOSH has considered phosphate ore that was processed to recover uranium as additional material in the piles concerning radon intake during the residual period. SC&A would like NIOSH to confirm that this was their intent in the TCC TBD.

3.6 SC&A's Evaluation of TCC Internal Dose Assessments

SC&A evaluated NIOSH's recommendations for internal dose assessment in the TCC TBD. Because there were no radiological measurements performed during the operations of the facility, surrogate data from other similar facilities must be relied upon. There is a wide range and variety of such facilities. SC&A found that, for the most part, NIOSH selected parameters to provide plausible but upper-bound intake values, which are claimant favorable.

4 TCC EXTERNAL DOSE RECONTRUCTION

4.1 EXTERNAL DOSIMETRY

There are no dosimetry data or radiation measurements available for TCC. Therefore, NIOSH considered worker external doses using source-term information and measured doses of phosphate plant workers according to OCAS-IG-004, Revision 0, *The Use of Data from Other Facilities in the Completion of Dose Reconstructions Under the Energy Employees Occupational Illness Compensation Program Act* (2008). The values NIOSH used provided an upper bound and are therefore to be assigned as constants in the dose reconstruction process.

4.2 EXTERNAL EXPOSURE FROM DEVELOPMENT WORK FOR THE AEC

NIOSH found that doses from the AEC research with small quantities of phosphate ores were presumed lower than from work in the uranium recovery or production areas; therefore, dose from the development work was not assessed. After evaluating the available documentation, SC&A concurs that these activities would not result in exposures greater than either the uranium recovery operations or the phosphate operations.

4.3 EXTERNAL EXPOSURES FROM URANIUM RECOVERY OPERATIONS

The applicable dates that these external doses are to be applied are October 5, 1953, through March 31, 1954.

4.3.1 Penetrating Dose from Uranium Recovery Operations

NIOSH used the Monte Carlo N-Particle Transport Code eXtended (MCNPX) (version 2.7b) to determine the dose rate per curie of U-238 in a drum. A density of 2 g/cm^3 was chosen to provide a claimant-favorable geometry. 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. Factors from ICRP Publication 74 (1996) were used to convert the photon flux to units of air kerma. Results are provided in Table 10 of the TCC TBD.

The exposure time for external dose during uranium recovery was based on the assumptions of intermittent work. During the period of operation of the uranium recovery plant, it is assumed the intermittent uranium extraction work was a 2-day-per-week process and that a worker spent 20% of the time over those 2 days at a distance of 30 cm (1 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 allowed 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. Assuming a 50-hour work week, 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 was modeled by assuming a general area dose rate that is equivalent to the dose rate at 100 cm (3 feet) 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 of the TCC TBD 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 to be applied as 50% 30–250 kiloelectron volt (keV) photons and 50% >250 keV photons. The derivation of this dose is outlined on pages 16 and 17 and summarized in Table 11 of the TCC TBD.

4.3.2 Shallow Dose from Uranium Recovery Operations

For nonpenetrating beta dose from the recovered uranium concentrates at TCC, NIOSH used the estimated dose rates at 30 cm from the surface of yellowcake, adjusted for additional radionuclides at TCC. The resulting dose rate was 3.6 millirem (mrem)/h. Dose was modeled based on a 50-hour work week. It was assumed workers were exposed to uranium concentrates for 20 hours per week at 3.6 mrem/h during the period of intermittent uranium recovery work, resulting in 72 mrem/week. For the remaining 30 hours per week, beta exposure from phosphates was assumed at a rate of 0.028 mrem per hour, resulting in an additional 0.84 mrem. This resulted in a weekly beta dose of 0.073 rem, or **0.010 rem/calendar day**. Doses are to be applied as electrons >15 keV. The derivation of this dose is outlined on page 18 and summarized in Table 11 of the TCC TBD.

4.3.3 Shallow Dose from Contaminated Clothing from Uranium Recovery Operations

NIOSH used the average shallow dose rates from contaminated clothing at Mallinckrodt of 1.5 mrem/h (AEC 1958). The Mallinckrodt dose rate was 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. NIOSH assumed that, during uranium recovery at TCC, 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, or **0.0021 rem/calendar day**. Doses are to be applied as electrons > 15keV. The derivation of this dose is outlined on page 18 and summarized in Table 11 of the TCC TBD.

4.3.4 Hand and Forearm Dose from Uranium Recovery Operations

Extremity dose was considered for operators and maintenance workers who may have had direct contact with the uranium concentrates during uranium recovery. NIOSH made an estimate of shallow dose to the hands and forearms based on direct contact with yellowcake. Surface dose rates on yellowcake have been reported to be approximately 203 millirad (mrad) per hour (DOE 2000). The reported dose rates were modified to reflect exposure conditions at the TCC during uranium recovery. A factor of 1.8 was applied to the 203 mrad/h 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 365 mrad/h. Extremity dose modeling during the period of intermittent operation of the uranium recovery plant was based on 1 hour of contact with the recovered uranium concentrate per week (1 hour × 365 mrad/h), and an additional 5 hours per week of contact with phosphates in other buildings (5 hours × 2.8 mrad/h = 14 mrad). This results in a weekly extremity dose of 379 mrad, or **0.054 mrem/calendar day**. This dose is to be applied to the hands and forearms of operators and maintenance worker as electrons >15 keV. The derivation of this dose is outlined on page 19 and summarized in Table 11 of the TCC TBD.

4.4 External Exposures from Phosphate Plant Operations

The applicable dates that these external doses are to be applied are April 1, 1954, through September 30, 1955.

4.4.1 Penetrating Dose from Plant Operations

NIOSH used the highest annual dose value of 210 mrem from the FIPR 1998 study of phosphate processing plants. This equates to **0.00060 rem per calendar day** and is to be assigned as 50% 30–250 keV and 50% >250 keV photons. The derivation of this dose is outlined on page 16 and summarized in Table 11 of the TCC TBD.

4.4.2 Shallow Dose from Plant Operations

NIOSH used the estimated nonpenetrating beta dose at 30 cm from the surface of yellowcake for phosphate materials, adjusted for additional radionuclides and uranium concentration, as specified in the TCC ER, Section 7.3.4.1 (NIOSH 2010). The resulting dose rate was 0.028 mrem/h. For a 2,500 hour work year, this results in an annual beta dose of 0.070 rem, or a dose of **0.00020 rem per calendar day**. This dose is to be assigned as >15 keV electrons. The derivation of this dose is outlined on page 18 and summarized in Table 11 of the TCC TBD.

4.4.3 Shallow Dose from Contaminated Clothing from Plant Operations

According to page 18 of the TCC TBD, electron dose from work clothing in the phosphate plant was considered insignificant due to the relatively low concentration of radionuclides.

4.4.4 Hand and Forearm Dose from Plant Operations

NIOSH considered extremity dose for operators and maintenance workers who may have had direct contact with phosphate materials in the plant. Surface dose rates on yellowcake have been reported to be about 203 mrad per hour (DOE 2000). For the phosphate plant, the 203 mrad/h 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 2.8 mrad/h. NIOSH assumed 6 hours per week of direct contact at the rate of 2.8 mrad/h, resulting in a weekly dose of 17 mrad, or **0.0024 rem/calendar day**. This dose is to be applied to the hands and forearms (operators and maintenance workers) as electrons >15 keV. The derivation of this dose is outlined on page 19 and summarized in Table 11 of the TCC TBD.

4.5 External Exposures during the Residual Period

The applicable dates that these external doses are to be applied are October 1, 1955, through December 31, 1977.

4.5.1 Penetrating Dose during the Residual Period

NIOSH considered external dose from residual contamination in the uranium recovery building. Measured dose rates from contamination in the Blockson Chemical Company uranium recovery facility were used to bound dose from residual contamination at TCC. Blockson's uranium recovery plant was in production for over 7 years with essentially the same source term. Dose rates on surfaces in that facility provided a bounding estimate for TCC during the residual period. Based on information in Section 5.0 of the Blockson TBD, OCAS-TKBS-0002, the dose from residual contamination at TCC was assumed to be 0.06 roentgen (R)/year, or **0.00016 R/calendar day**. The derivation of this dose is outlined on page 19 and summarized in Table 11 of the TCC TBD.

4.5.2 Nonpenetrating Dose during the Residual Period

NIOSH did not consider nonpenetrating (beta) dose from residual contamination 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).

4.6 Occupational Medical X-ray Examinations

Neither SC&A nor NIOSH located any specific information 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). NIOSH instructs dose reconstructors to assume an annual chest X-ray examination to have been required during the AEC covered period of 1953 through 1955 and instructs dose reconstructors to follow the guidance in ORAUT-OTIB-0006, Revision 04, *Dose Reconstruction from Occupational Medical X-ray Procedures* (2011).

4.7 SC&A's Evaluation of TCC External Dose Assessments

SC&A evaluated NIOSH's recommendations for external dose assessment in the TCC TBD. Because there were no exposure measurements performed during the operation of the facility, surrogate data from other similar facilities must be relied upon. There is a wide range and variety of such facilities. SC&A found that, for the most part, NIOSH selected parameters to provide plausible but upper-bound exposure values, which are claimant favorable. The doses are to be assigned as constants because the doses are considered to be upper bounds.

SC&A had no findings or observations concerning occupation external exposures.

5 SUMMARY AND CONCLUSIONS

5.1 ORIGINAL SEC ER FINDINGS

SC&A analyzed the original findings from SC&A's 2008 review of the 2008 SEC ER in view of NIOSH's revised 2010 SEC ER and the recent TCC TBD. SC&A found that the original findings from SC&A's evaluation of the 2008 SEC ER have all been addressed and resolved by the revised 2010 SEC ER and the TCC TBD. SC&A recommends closure of the original SEC findings.

5.2 EVALUATION OF TCC TBD

SC&A evaluated the TCC TBD and did not identify any findings associated with the methods and procedures NIOSH used in the TCC TBD to reconstruct dose for TCC claimants. SC&A found NIOSH's recommendations were generally based on claimant-favorable assumptions, and SC&A did not identify any technical errors in the TCC TBD. SC&A did have two observations concerning the TCC TBD:

- **Observation 1 – Combined Intakes:** As written, SC&A finds that the TCC TBD Tables 8 and 9 have the potential to be incorrectly interpreted, leading to unintentional underestimates of dose during the operational years.

- **Observation 2 – Apparent Inconsistence in Ingestion Method Used during Residual Period:** While NIOSH followed the procedure in OCAS-TIB-009 for deriving ingestion intakes during the TCC residual period, a different procedure was used in NIOSH's SEC-00236 ER during the residual period for the Metals and Control Corporation (NIOSH 2017).

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