

SEC Petition Evaluation Report

Petition SEC-00088

Report Rev #: 1

Report Submittal Date: October 18, 2010

| | |
|--------------------|-----------------|
| Subject Expert(s): | Thomas P. Tomes |
| Site Expert(s): | N/A |

Petition Administrative Summary

Petition Under Evaluation

| Petition # | Petition Type | Petition B Qualification Date | DOE/AWE Facility Name |
|------------|---------------|-------------------------------|----------------------------------|
| SEC-00088 | 83.13 | August 17, 2007 | Texas City Chemicals, Inc. (TCC) |

Petitioner Class Definition

All laborers who worked in all areas at Texas City Chemical, Inc. from January 1, 1952, through December 31, 1956.

Class Evaluated by NIOSH

All workers who worked in any area at Texas City Chemicals, Inc., from October 5, 1953, through December 31, 1956.

NIOSH-Proposed Class to be Added to the SEC

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 in the Special Exposure Cohort.

Related Petition Summary Information

| SEC Petition Tracking #(s) | Petition Type | DOE/AWE Facility Name | Petition Status |
|----------------------------|---------------|-----------------------|-----------------|
| NONE | | | |

Related Evaluation Report Information

| Report Title | DOE/AWE Facility Name |
|--------------|-----------------------|
| NONE | |

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Evaluation Report Summary: SEC-00088, Texas City Chemicals, Inc.

This is a revised Evaluation Report by the National Institute for Occupational Safety and Health (NIOSH) that addresses a class of employees proposed for addition to the Special Exposure Cohort (SEC) per the *Energy Employees Occupational Illness Compensation Program Act of 2000*, as amended, 42 U.S.C. § 7384 *et seq.* (EEOICPA) and 42 C.F.R. pt. 83, *Procedures for Designating Classes of Employees as Members of the Special Exposure Cohort under the Energy Employees Occupational Illness Compensation Program Act of 2000*.

The revision was made to incorporate a change in the Department of Labor's (DOL) covered period for Texas City Chemicals and to reflect the NIOSH change in its recommendation. Texas City Chemicals, Inc. was previously listed as an Atomic Weapons Employer (AWE) facility from 1952 through 1956, the same period that was specified in the SEC petition. The DOL revised the covered period to start on October 5, 1953, which was the first day of operations at the newly constructed facility. The revised end date of the covered period was changed to September 1955, which was the expiration date of the AEC contract for phosphate leached zone ore development work. The changes were based on reports providing additional details on the Atomic Energy Commission work at Texas City Chemicals; these reports were not available when the previous Evaluation Report was written.

This revision also incorporates the requirements of OCAS-IG-004, *The Use of Data from Other Facilities in the Completion of Dose Reconstructions Under the Energy Employees Occupational Illness Compensation Program Act*, effective August 21, 2008. Some additional documents and publications concerning Texas City Chemicals, Inc., (TCC) and the phosphate industry were also used in this revision.

This revision also considers comments received on the original Evaluation Report from S. Cohen & Associates, under contract to the Advisory Board on Radiation and Worker Health.

Some technical changes were made based on the new information and the comments received on the previous version. The original Evaluation Report provided a large bounding dose estimate from the start of plant operations through the end of the covered period under the assumption of exposure to concentrated uranium. The specified covered period has been reduced as well as the period in which uranium was extracted. This revision reduces the potential exposure to uranium concentrates from extraction operations to the period ending March 1954. Maximum doses during the covered period after March 1954 are now based on exposure to phosphate compounds unrelated to uranium recovery work, which would have been higher than the doses to workers doing development work with leached-zone phosphates. The TCC phosphate plant doses, other than from exposure to radon and its progeny, are based on doses received at other phosphate facilities.

An SEC period is now recommended based on the inability to bound radon exposures with sufficient accuracy during the AWE covered period.

Petitioner-Requested Class Definition

The petitioner(s) for SEC-00088, which qualified on August 17, 2007, requested that NIOSH consider the following class: *All laborers who worked in all areas at Texas City Chemical, Inc. from January 1, 1952, through December 31, 1956.*

Class Evaluated by NIOSH

The petitioner-requested class time period encompassed the years 1952 through 1956, which was the previously defined covered period. TCC is now defined as an Atomic Weapons Employer (AWE) facility from October 5, 1953, through September 1955. It is covered for residual contamination through 1977.

Based on the revised covered period, NIOSH evaluated potential dose to all workers in any area at Texas City Chemicals, Inc., from October 5, 1953, through December 31, 1956. The last fifteen months of this period are in the residual contamination period.

NIOSH-Proposed Class to be Added to the SEC

Based on its full research of the class under evaluation, NIOSH has defined a single class of employees for which NIOSH cannot estimate radiation doses with sufficient accuracy. The NIOSH-proposed class includes all Atomic Weapons Employer employees who worked at Texas City Chemicals 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 in the Special Exposure Cohort. The class under evaluation was accepted (see Section 3.0 below) because internal dose from exposure to radon cannot be bounded for employees in the phosphoric acid plant. Because there is no Texas City Chemicals employment data to associate individuals with specific buildings and work areas, it is not possible to define a class of workers limited to those who worked in the phosphoric acid building; therefore, NIOSH cannot bound internal dose to all employees on the Texas City Chemicals site.

Feasibility of Dose Reconstruction

Per EEOICPA and 42 C.F.R. § 83.13(c)(1), NIOSH has established that it does not have access to sufficient information to: (1) estimate the maximum radiation dose for every type of cancer for which radiation doses are reconstructed, that could have been incurred in plausible circumstances by any member of the class; or (2) estimate radiation doses of members of the class more precisely than an estimate of maximum dose. Information available from resources is not sufficient to document or estimate the maximum internal dose to members of the evaluated class under plausible circumstances during the specified period.

The NIOSH dose reconstruction feasibility findings are based on the following:

- Principal sources of internal and external radiation dose for members of the proposed class included exposures to technologically enhanced concentrations of naturally-occurring uranium and decay products and naturally-occurring thorium and decay products present in phosphate rock.
- NIOSH finds there are insufficient data to estimate dose with sufficient accuracy from workers exposed to radon in the phosphoric acid plant at Texas City Chemicals. NIOSH has found no radon monitoring for the facility neither during the AEC period nor of the plant when it was in operation. Radon data is available from surveys of the site in the 1980s after the phosphate plant

was shut down. NIOSH also determined that it lacks needed information to model radon exposures from processing phosphate rock; dose from processing phosphate rock is only applicable to EEOICPA dose reconstructions through September 1955. Although the source term is known, available information on the building size, layout, and process activities are insufficient to model maximum radon exposures with sufficient accuracy.

- NIOSH finds that it is feasible to bound occupational external dose from uranium extraction operations at Texas City Chemicals using source term and process information.
- NIOSH finds that it is feasible to bound occupational internal dose from uranium extraction operations based on data from uranium ore concentrate processing at other facilities.
- NIOSH finds that it is feasible to bound occupational external and internal dose, other than radon, for phosphate workers exposed to technologically enhanced naturally occurring radioactive material using data from other phosphate facilities.

Health Endangerment Determination

Per EEOICPA and 42 C.F.R. § 83.13(c)(3), a health endangerment determination is required because NIOSH has determined that it does not have sufficient information to estimate dose for the members of the evaluated class.

NIOSH did not identify any evidence supplied by the petitioners or from other resources that would establish that the proposed class was exposed to radiation during a discrete incident likely to have involved exceptionally high-level exposures. However, evidence indicates that some workers in the proposed class may have accumulated substantial chronic exposures through episodic intakes of radionuclides, combined with external exposures to gamma and beta radiation. Consequently, NIOSH has determined that health was endangered for those workers covered by this evaluation who were employed for at least 250 aggregated work days either solely under their employment at Texas City Chemicals or in combination with work days within the parameters established for other SEC classes (excluding aggregate work day requirements).

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SEC Petition Evaluation Report for SEC-00088

ATTRIBUTION AND ANNOTATION: This is a single-author document. All conclusions drawn from the data presented in this evaluation were made by the DCAS Health Physicist: Tom Tomes. The conclusions were peer-reviewed by the individuals listed on the cover page. The rationales for all conclusions in this document are explained in the associated text.

1.0 Purpose and Scope

This report evaluates the feasibility of reconstructing doses for all Atomic Weapon Employer employees who worked in any areas at Texas City Chemicals, Inc., from October 5, 1953, through December 31, 1956. It provides information and analyses germane to considering a petition for adding a class of employees to the congressionally-created SEC.

This report does not make any determinations concerning the feasibility of dose reconstruction that necessarily apply to any individual energy employee who might require a dose reconstruction from NIOSH. This report also does not contain the final determination as to whether the proposed class will be added to the SEC (see Section 2.0).

This evaluation was conducted in accordance with the requirements of EEOICPA, 42 C.F.R. pt. 83, and the guidance contained in the NIOSH Division of Compensation Analysis and Support's (DCAS) *Internal Procedures for the Evaluation of Special Exposure Cohort Petitions*, OCAS-PR-004.¹

2.0 Introduction

Both EEOICPA and 42 C.F.R. pt. 83 require NIOSH to evaluate qualified petitions requesting that the Department of Health and Human Services (HHS) add a class of employees to the SEC. The evaluation is intended to provide a fair, science-based determination of whether it is feasible to estimate with sufficient accuracy the radiation doses of the class of employees through NIOSH dose reconstructions.²

42 C.F.R. § 83.13(c)(1) states: *Radiation doses can be estimated with sufficient accuracy if NIOSH has established that it has access to sufficient information to estimate the maximum radiation dose, for every type of cancer for which radiation doses are reconstructed, that could have been incurred in plausible circumstances by any member of the class, or if NIOSH has established that it has access to sufficient information to estimate the radiation doses of members of the class more precisely than an estimate of the maximum radiation dose.*

Under 42 C.F.R. § 83.13(c)(3), if it is not feasible to estimate radiation doses with sufficient accuracy for members of the class, then NIOSH must determine that there is a reasonable likelihood that such

¹ DCAS was formerly known as the Office of Compensation Analysis and Support (OCAS).

² NIOSH dose reconstructions under EEOICPA are performed using the methods promulgated under 42 C.F.R. pt. 82 and the detailed implementation guidelines available at <http://www.cdc.gov/niosh/ocas>.

radiation doses may have endangered the health of members of the class. The regulation requires NIOSH to assume that any duration of unprotected exposure may have endangered the health of members of a class when it has been established that the class may have been exposed to radiation during a discrete incident likely to have involved levels of exposure similarly high to those occurring during nuclear criticality incidents. If the occurrence of such an exceptionally high-level exposure has not been established, then NIOSH is required to specify that health was endangered for those workers who were employed for at least 250 aggregated work days within the parameters established for the class or in combination with work days within the parameters established for other SEC classes (excluding aggregate work day requirements).

NIOSH is required to document its evaluation in a report, and to do so, relies upon both its own dose reconstruction expertise as well as technical support from its contractor, Oak Ridge Associated Universities (ORAU). Once completed, NIOSH provides the report to both the petitioner(s) and to the Advisory Board on Radiation and Worker Health (Board). The Board will consider the NIOSH evaluation report, together with the petition, petitioner(s) comments, and other information the Board considers appropriate, in order to make recommendations to the Secretary of HHS on whether or not to add one or more classes of employees to the SEC. Once NIOSH has received and considered the advice of the Board, the Director of NIOSH will propose a decision on behalf of HHS. The Secretary of HHS will make the final decision, taking into account the NIOSH evaluation, the advice of the Board, and the proposed decision issued by NIOSH. As part of this decision process, petitioners may seek a review of certain types of final decisions issued by the Secretary of HHS.³

3.0 SEC-00088 Texas City Chemicals Class Definitions

3.1 Petitioner-Requested Class Definition and Basis

The petitioner(s) for SEC-00088, which was qualified on August 17, 2007, requested that NIOSH consider the following class for addition to the SEC: *All laborers who worked in all areas at Texas City Chemical, Inc. from January 1, 1952 – December 31, 1956.*

The petitioner provided information and affidavit statements in support of the petitioner's belief that it is not feasible to estimate, with sufficient accuracy, the radiation doses received by workers at TCC. NIOSH deemed the information and affidavit statements provided by the petitioner to be sufficient to qualify SEC-00088 for evaluation. This information may be summarized as follows:

Radiation monitoring records for members of the proposed class may have been lost, falsified, or destroyed.

Information regarding monitoring from TCC is unavailable.

The information and statements provided by the petitioner qualified the petition for further consideration by NIOSH, the Board, and HHS. The details of the petition basis are addressed in Section 7.4.

³ See 42 C.F.R. pt. 83 for a full description of the procedures summarized here. Additional internal procedures are available at <http://www.cdc.gov/niosh/ocas>.

3.2 Class Evaluated by NIOSH

Based on its preliminary research, NIOSH expanded the petitioner-proposed class to include all workers at TCC. NIOSH recognized from the research that there was insufficient information about the differences in exposure potential among the various categories of workers at Texas City Chemicals to estimate doses for a particular job description. Therefore, NIOSH evaluated maximum potential doses received by any worker at the site. The starting date of the time period under evaluation was changed to October 5, 1953, because TCC is now considered an Atomic Weapons Employer (AWE) facility starting October 5, 1953.

3.3 NIOSH-Proposed Class to be Added to the SEC

Based on its full research of the class under evaluation, NIOSH has defined a single class of employees for which NIOSH cannot estimate radiation doses with sufficient accuracy. The NIOSH-proposed class includes all Atomic Weapons Employer employees who worked at Texas City Chemicals 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 in the Special Exposure Cohort. The class under evaluation was accepted (see Section 3.0 below) because internal dose from exposure to radon cannot be bounded for employees in the phosphoric acid plant. Because there is no Texas City Chemicals employment data to associate individuals with specific buildings and work areas, it is not possible to define a class of workers who did not work in the phosphoric acid building; therefore, NIOSH cannot bound internal dose to all employees on the Texas City Chemicals site.

4.0 Data Sources Reviewed by NIOSH

NIOSH identified and reviewed numerous data sources to locate information relevant to determining the feasibility of dose reconstruction for the class of employees proposed for the SEC petition. This included determining the availability of information on personal monitoring, area monitoring, industrial processes, and radiation source materials.

For this revision NIOSH incorporated information received from the DOE and performed additional searches for information on Texas City Chemicals and on the phosphate industry in the 1950s; a few additional industry publications on TCC in the 1950s were found during internet searches and were incorporated into this revision.

In June 2008 NIOSH also received copies of court records from *Amoco Oil Company vs. Borden, Inc* (Court records, 1989). The records from that court case between the previous and current owners of the former Texas City Chemicals property have been reviewed for any information that may be applicable to estimating radiation doses to workers from AEC sponsored work.

The following subsections summarize data sources identified and reviewed by NIOSH.

4.1 Site Profile Technical Basis Documents

A Site Profile provides specific information concerning the documentation of historical practices at the specified site. Dose reconstructors can use the Site Profile to evaluate internal and external dosimetry data for monitored and unmonitored workers, and to supplement, or substitute for, individual monitoring data. A Site Profile consists of an Introduction and five Technical Basis Documents (TBDs) that provide process history information, information on personal and area monitoring, radiation source descriptions, and references to primary documents relevant to the radiological operations at the site. The Site Profile for a small site may consist of a single document. NIOSH has not developed a Site Profile for TCC; however, as part of NIOSH's evaluation detailed herein, it examined the following TBDs for insights into TCC operations or related topics/operations at other sites:

- *Technical Basis Document for Atomic Energy Operations at Blockson Chemical, Joliet, Illinois; OCAS-TKBS-0002, Rev. 02; November 21, 2007; SRDB Ref ID: 36611.*
- *Basis for Development of an Exposure Matrix for Blockson Chemical Company, Joliet, Illinois; Period of Operation: March 1, 1951 through March 31, 1962, ORAUT-TKBS-0002, Rev. 01; June 29, 2004; SRDB Ref ID: 19480.*
- *Site Profiles for Atomic Weapons Employers that Refined Uranium and Thorium, Battelle-TBD-6001, Rev. F0; December 13, 2006; SRDB Ref ID: 30673.*
- *Site Profiles for Atomic Weapons Employers that Refined Uranium and Thorium, Appendix BH – International Minerals and Chemical Corporation, Battelle-TBD-6001, App. BH, Rev. 0; July 16, 2007; SRDB Ref ID: 35365.*

4.2 Technical Information Bulletins and Procedures

A Technical Information Bulletin (TIB) is a general working document that provides guidance for preparing dose reconstructions at particular sites or categories of sites. A procedure provides specific requirements and guidance regarding EEOICPA project-level activities, including preparation of dose reconstructions at particular sites or categories of sites. NIOSH reviewed the following TIBs and procedures as part of its evaluation:

- *OCAS-PR-004, Internal Procedures for the Evaluation of Special Exposure Cohort Petitions, Rev. 0, September 23, 2004; SRDB Ref ID 32022.*
- *OCAS-TIB-009, Estimation of Ingestion Intakes, Rev. 0, April 13, 2004; SRDB Ref ID: 22397.*
- *ORAUT-OTIB-0006, Dose Reconstruction from Occupationally Related Diagnostic X-ray Procedures, Rev. 3 PC-1; December 21, 2005; SRDB Ref ID: 20220.*
- *ORAUT-OTIB-0024, Estimation of Neutron Dose Rates from Alpha-Neutron Reactions in Uranium and Thorium Compounds, Rev. 00; April 7, 2005; SRDB Ref ID: 19445.*

- ORAUT-OTIB-0043, *Characterization of Occupational Exposure to Radium and Radon Progeny During Recovery of Uranium from Phosphate Materials*, Rev. 00; January 6, 2006; SRDB Ref ID: 22596.
- ORAUT-OTIB-0070, *Dose Reconstruction During Residual Radioactivity Periods at Atomic Weapons Employer Facilities*, Rev. 00, March 10, 2008; SRDB Ref ID 41603.

4.3 Facility Employees and Experts

Telephone interviews were conducted with one former TCC employee and a TCC petitioner whose spouse worked at the TCC site. The purpose of these interviews was to gain additional information and insight into TCC operations during the applicable time period. The questions and responses have been documented in the Site Research Database (SRDB). Worker Outreach meetings were also held.

- Personal Communication, 2007a, *Personal Communication with Former TCC Employee*; Telephone Interview by ORAU Team; October 2, 2007; SRDB Ref ID: 35466
- Personal Communication, 2007b, *Personal Communication with Survivor of Former TCC Employee*; Telephone Interview by ORAU Team; October 2, 2007; SRDB Ref ID: 35465
- NIOSH Worker Outreach Meetings; 2:00 PM and 7:00 PM CDT; October 18, 2007; International Union of Operating Engineers Union Hall; 2800 Texas Avenue; Texas City, Texas. Meeting minutes are available on the OCAS website (<http://www.cdc.gov/niosh/ocas>).

4.4 Previous Dose Reconstructions

NIOSH reviewed its NIOSH OCAS Claims Tracking System (NOCTS) to locate EEOICPA-related dose reconstructions that might provide information relevant to the petition evaluation. Table 4-1 summarizes the results of this review for NOCTS data available as of September 28, 2010.

| Table 4-1: Number of TCC Claims Submitted Under the Dose Reconstruction Rule | |
|--|---------------|
| Description | Totals |
| Total number of claims submitted for dose reconstruction | 15 |
| Total number of claims submitted for energy employees who meet the proposed class definition criteria (employment during the period October 5, 1953, through September 30, 1955) | 10 |
| Number of dose reconstructions completed for energy employees who meet the proposed class definition criteria | 2 |
| Number of claims for which internal dosimetry records were obtained for the identified years in the proposed class definition | 0 |
| Number of claims for which external dosimetry records were obtained for the identified years in the proposed class definition | 0 |

NIOSH reviewed each claim to determine whether internal and/or external personal monitoring records could be obtained for the employee. No internal or external dose monitoring records were found.

4.5 NIOSH Site Research Database

NIOSH data capture efforts have included internet searches and contacts with the existing site (Amoco BP), a DOE representative for exception facilities, Texas State Radiation Group, U.S. Environmental Protection Agency (USEPA) Region 6, and the Texas Commission for Environmental Quality. Data have also been sought from the Federal Records Center in Fort Worth, Texas. NIOSH has reviewed the pertinent data collected by these combined efforts.

NIOSH has also reviewed its Site Research Database to locate documents supporting the evaluation of the proposed class. A number of documents in this database were identified as pertaining to TCC several of which were added since the previous version of the report. These documents were evaluated for their relevance to this petition. The documents include historical background on the process materials, the industrial process, and Formerly Utilized Sites Remedial Action Program (FUSRAP)-related residual contamination surveys.

4.6 Documentation and/or Affidavits Provided by Petitioners

In qualifying and evaluating the petition, NIOSH reviewed the following documents submitted by the petitioners:

- *Form B with attachment*, petition and miscellaneous information from survivor of former TCC employee; received March 13, 2007; OSA document id: 102669
- *Affidavit*, site and medical information from survivor of former TCC employee; received April 4, 2007; OSA document id: 103975
- *Proof of Relationship*, affidavit of marriage and employment from survivor of former TCC employee; April 17, 2007; OSA document id: 102839

5.0 Radiological Operations Relevant to the Evaluated Class

This section summarizes operations at TCC and the information available to NIOSH to characterize particular processes and radioactive source materials.

TCC processed phosphate rock that contained naturally occurring radioactive materials (NORM). Radionuclides of concern are those that are found in the natural uranium decay series and, to a lesser degree, the natural thorium decay series. Chemical operations at the plant resulted in potential worker exposures to technologically enhanced naturally occurring radioactive materials (TENORM). NIOSH has gathered the source term and process information needed to provide an estimate of the likely maximum doses received by workers.

5.1 TCC Plant and Process Descriptions

In 1952 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; AEC, 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 fertilizer 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 problems with the fertilizer plant. 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-Douglas Corporation to acquire and reorganize TCC and reopen the plant later that year. Smith-Douglas did not pursue uranium work with the AEC (AEC, 1953; Greenleaf, 1955; Powers, 1979; Corporate Profile, 1958). Smith-Douglas, later acquired by Borden Chemical, operated the phosphate plant until its closure in 1977.

Table 5-1 lists the AEC contracts with TCC as identified in the records of the DOE FUSRAP Program (Formerly Utilized Sites Remedial Action Program) (DOE, 1986).

| AEC Contract Number | Dates | Description |
|----------------------------|--|---|
| AT(49-1)-616 | Dated February 14, 1952 | Letter contract for uranium plant construction |
| AT(49-1)-647 | Dated May 12, 1953, lasting 5 years from start-up or no longer than September 30, 1958 | Formal contract to construct plant and extract uranium from phosphate |
| AT(49-6)-910 | through September 10, 1955 | Process development studies |
| AT(05-1)-481 | Unknown | Unknown |

Copies of the first two contracts, AT(49-1)-616 and AT(49-1)-647, are available (AEC, 1952; AEC, 1953). Work conducted under those contracts is discussed in more detail in Section 5.1.1.

A copy of contract AT(49-6)-910 for process development studies is not available. The FUSRAP documentation indicated that the scope of the work under that contract was unknown; however, NIOSH received three reports that describe the development work that was performed under the contract (Kopf, 1954; Cutter et al., 1954; Greenleaf, 1955). Section 5.1.2 discusses those activities.

The FUSRAP report also listed contract AT(05-1)-481. There are no details of this contract and reports that summarize AEC work at the plant did not include any reference to it. This is discussed further in Section 5.1.3.

5.1.1 Uranium Recovery Operations

In February 1952 the AEC signed a letter contract with Texas City Chemicals, Inc. The letter contract, which later was superseded by a formal contract, was an agreement between the two parties for TCC to construct a uranium recovery unit, at its expense, simultaneous with construction of its fertilizer plant, and for the AEC to purchase uranium that was to be produced as a byproduct of the fertilizer plant. The contract specified that construction of the plant was to be completed no later than October 1, 1953.

The TCC phosphate plant was designed to have the capacity to process 100,000 tons of Florida phosphate rock per year. TCC was to sell all recovered uranium to the AEC. Contract terms limited the obligations of both the AEC and TCC to not more than 50,000 pounds of U_3O_8 annually, specified as a concentrate containing at least 50% U_3O_8 (AEC, 1952; AEC, 1953). The term " U_3O_8 " was used by the AEC for inventory purposes to include many uranium feed compounds, not necessarily only U_3O_8 . The nominal uranium production capacity based on uranium concentration in the phosphate rock source term was about 12 tons per year (Johnson, 1953). Based on concentration of uranium in the phosphate rock and the plant capacity, 12 tons could be realized at full plant capacity if complete (100%) recovery of uranium was achieved.

According to an internal AEC memorandum (Johnson, 1953), "shake down" operations began at the TCC plant on October 5, 1953. "Full-scale" operations were scheduled to begin December 4, 1953, at which time the company had planned a ceremony with state and local dignitaries. Subsequent documentation indicates that TCC never achieved full-scale uranium production. An AEC Monthly Report on Activities of Domestic Production Phosphates (AEC, 1955a), states that TCC operations were shut down from January 1954 to the date of the report (December 1955) for "modifications in base plant" and that TCC had only produced an "estimated" 303 pounds of U_3O_8 from "intermittent shake-down operations" through December 1953.

Another AEC report (AEC, c1963) lists details of AEC receipts from all phosphate plants from fiscal years 1953 through 1962. For TCC, the report lists a total of 400 pounds of U_3O_8 produced in fiscal year 1954 at a cost to the AEC of \$25.00 per pound, which was the maximum price allowed per contract terms (AEC, 1952). The report identifies the production period as March 1954. Production is listed as zero pounds for fiscal years 1955 and 1956. An adjusting entry of -2 (negative two) pounds (and negative \$52) is listed for fiscal year 1957. The entry appears to be an accounting adjustment and is the final entry for TCC in the report. All subsequent years are listed as "Unsuccessful Operation" with no data provided. Final figures for TCC production was 398 pounds of U_3O_8 produced.

As noted above, the references have some differences in total U_3O_8 produced by TCC and in the months in which it was produced. The AEC 1955 report listed an "estimated" 303 pounds produced in December 1953 from intermittent shake-down operations. The more complete report (AEC c1963) listed 400 pounds produced in fiscal year 1954, which would include the third quarter of calendar year 1953. That report separately lists March 1954 as the production period.

Although the references discussed above have some differences in the exact dates in which uranium was produced, they all indicate that TCC produced a relatively small amount of uranium during initial

start-up of the plant. For purposes of this evaluation, 400 pounds of uranium is assumed to have been produced intermittently between October 1953 and March 1954.

The TCC plant was one of four Uranium Recovery Plants built in the early to mid-1950s that was designed to recover uranium from phosphoric acid using a solvent extraction process developed by Dow Chemical Company. The other three plants were Virginia-Carolina Chemical Corporation, International Minerals & Chemicals Corporation (IMCC), and U.S. Phosphoric Products. The TCC and Virginia-Carolina uranium extraction plants were never successfully placed into production (Wilkinson 1976).

The production problems encountered by TCC were reported in an AEC memorandum after a visit to the TCC plant in January 1955 (Greenleaf 1955). The main subject of the report was the development contract work by TCC, but the report also provided information on the uranium recovery contract. The report stated that TCC's fertilizer plant did not function as designed and that the Uranium Recovery Plant was not in operation and would not be in operation until the fertilizer plant could maintain a reasonably normal level of production. The fertilizer plant had several equipment design and performance problems that were so significant that operation of the uranium plant was considered hopeless at that time. Before TCC could achieve full fertilizer production it had to order replacement equipment. In January 1955 Greenleaf estimated it would be at least three to six months before the fertilizer plant would be able to produce enough product to start up the Uranium Recovery Plant. There are no additional details on the replacement equipment to get the fertilizer facility fully operational, although, as discussed above, AEC production reports indicate the uranium plant was never fully operational.

5.1.2 Development Work

The AEC had contract AT(49-6)-910 with TCC for development work. That contract expired September 10, 1955 (ERDA, 1976; DOE, 1986). TCC submitted reports to the AEC summarizing all work performed under contract AT(49-6)-910 (Kopf, 1954; Cutter, et al., 1954). The reports state that research was being performed with leached-zone material. The objective was to "develop a cheap method of recovering P_2O_5 , Al_2O_3 and U from this material."

Barr described the AEC interest in the leached-zone layer; he also published photographs of four plants that were involved in AEC phosphate work at the time, one of which was an aerial photograph of Texas City Chemicals. The leached-zone is a layer of earth that overlies the Florida phosphate rock "matrix" layer. The matrix layer and leached-zone layer have similar uranium concentrations, but the matrix layer has higher phosphate content. Industry utilized the matrix layer as a phosphate (P_2O_5) source while the overlying leached-zone was discarded as waste during mining due to its lower economic value. Uranium extraction from phosphate was economically feasible only when it could be recovered as byproduct material. Thus, the AEC had contracts with the phosphate industry to find an economical method for the chemical industry to utilize leached-zone material so the uranium could be recovered as byproduct. Barr identified three approaches being researched. One of the three approaches was the separation of P_2O_5 , Al_2O_3 and U, which was similar to the description of TCC development work (Barr, et al., 1955b; Kopf, 1954).

TCC received a drum of calcined leached-zone material from the Tennessee Valley Authority (TVA) laboratory for its initial work. The reports indicate receipts of additional small quantities of leached-

zone material as research progressed. As of the May 1954 report (Cutter, et al., 1954), the experiments had not yet started on uranium extraction from the leached-zone material, but TCC laboratory analyses indicated that the uranium stayed with the phosphate when it was separated from alumina. Uranium recovery experiments were planned for the future.

An AEC official visited TCC on January 12-13, 1955, and wrote a report on the status of uranium recovery operations and the leached-zone research activities (Greenleaf, 1955). Greenleaf's report indicates that the leached-zone studies had been suspended sometime prior to his visit and no charges were being made to the AEC development contract at that time. TCC was devoting its laboratory efforts to more pressing needs concerning trouble with the fertilizer plant, which was not fully functional. Up to that point the leached-zone studies had been concentrating on the separation of alumina from the phosphate, and estimated that an additional six to eight months of research was needed by TCC on alumina phosphate separation. TCC suggested the AEC get another company to study some phases of the process due to TCC's limitations in available resources. Greenleaf's report also mentions that TCC was going to receive some additional 25-pound samples of leached-zone material from the TVA facility.

An AEC Semiannual Report issued in July 1955, for January through June 1955, stated that the AEC had completed its studies on recovering uranium from leached-zone materials and concluded it was not economically feasible at that time (AEC, 1955b).

The available reports all indicate that the leached-zone development involved only laboratory-scale studies of leached-zone material. A drum of material was initially received and all other quantities referenced in the reports identify source material as samples or small quantities.

5.1.3 TCC Operations Summary

Sections 5.1.1 and 5.1.2 discuss work under three contracts with the AEC. A fourth contract, AT(05-1)-481, was identified by the DOE FUSRAP program, but no information on the scope of that contract is available. The only references to that contract are reports prepared for the FUSRAP project (ERDA, 1976; ORNL, 1980). However, based on production data and other published reports, no additional AEC work is known to have occurred. The development contract AT(49-6)-910 had a September 10, 1955, expiration date and the AEC had abandoned research on leached-zone materials by July 1955.

TCC closed the phosphate plant and filed for bankruptcy in 1956. Shortly thereafter, the Smith-Douglas company petitioned the U. S. District Court to allow them to reorganize the company and reopen the phosphate plant (Corporate Profile 1958). Smith-Douglas was later acquired by Borden Chemical. Uranium recovery was not pursued by Smith-Douglas, which operated the plant solely for fertilizer and feed production (Powers 1979).

The Uranium Recovery Plant was torn down (on an unknown date) prior to a FUSRAP program site visit in November 1977. Fertilizer production ended at the site in September 1977, and the property was sold to the American Oil Company (Amoco) on December 15, 1977 (DOE, 1986; ORNL, 1980).

5.2 Exposure Periods

The TCC AWE covered period for EEOICPA is defined as October 5, 1953, through September 1955, with a residual contamination period ending in 1977. All occupationally-derived radiation exposures during the covered period must be included in dose reconstructions regardless of whether or not the dose was related to AEC atomic weapons-related contract work. After September 1955, only dose received from residual contamination that was a result of AEC contract work is considered in dose reconstructions (OCAS-IG-003).

Based on the available information, NIOSH has evaluated the TCC activities and timeframes, and designated evaluation periods for dose assessments, as shown in Table 5-2. The periods differ in the source terms and potential for exposure, as discussed below.

| Table 5-2: Relevant TCC Chronology and NIOSH-Designated Evaluation Periods | | |
|---|--------------------------------------|---|
| NIOSH-Designated Evaluation Period | Dates | Dose |
| Phosphate Plant Operation | Oct. 5, 1953, through Sept. 30, 1955 | Industrial dose from exposure to TENORM during phosphate rock processing. Dose applicable only during the AEC covered period. |
| Uranium Production Period | Oct. 5, 1953, through Mar. 31, 1954 | Dose from production of 400 pounds of uranium. |
| Development Period | Dec. 1, 1953, through Sept. 30, 1955 | Dose from research and development with phosphate materials. |
| Residual Contamination Period | Oct. 1, 1955 through Dec. 31, 1977 | Dose from residual contamination from production of 400 pounds of uranium |

5.2.1 Phosphate Plant Operation

Records indicate TCC started shake-down operation of the plant on October 5, 1953, and full-scale operations were planned for December 1953. After start-up of the plant, workers were potentially exposed to TENORM from chemical processing of phosphate rock. Dose from processing phosphate rock is considered applicable throughout the covered period for TCC ending September 1955. Dose to workers from operation of the fertilizer and animal feed plant will be evaluated using data from other phosphate fertilizer plants.

5.2.2 Uranium Production Period

The October 5, 1953, start-up date of the phosphate plant is presumed to be the start date of potential worker exposure to concentrated uranium and associated radionuclides from operation of the Uranium Recovery Plant. AEC records indicate that 400 pounds of uranium concentrates were produced intermittently between October 1953 and March 1954. For this evaluation a 100-pound per month

production rate is assumed for October 5, 1953 through March 1954, to provide a bounding rate of production during this period.

5.2.3 Development Period

For the purpose of this evaluation, a nominal start date of development work is assumed to be December 1, 1953, and work on the contract is presumed to have ended by the September 30, 1955, expiration date of the contract; the AEC reported it had completed all its research on leached-zone phosphates by the end of June 1955.

Doses to TCC workers engaged in small-scale phosphate research are presumed to be lower than doses to workers who worked in production areas of the animal feed and fertilizer plant discussed in Section 5.2.1 because the small scale and limited scope of the development work would not have exposed affected workers to the larger source terms associated with production activities. Therefore, dose received by the chemists and others involved in research are presumed to be bounded by assignment of dose from fertilizer plant operations.

5.2.4 Residual Contamination Period

The Residual Contamination Period starts October 1, 1955, and continues through 1977. The only doses applicable to EEOICPA dose reconstructions at TCC after October 1, 1955, are the doses attributable to residual contamination from AEC work. Uranium extraction operations are assumed to have ended not later than March 31, 1954, which is the start date assumed in residual dose calculations for the Uranium Recovery Plant, although for dose reconstruction purposes the maximum doses from all sources is considered applicable through September 1955.

5.3 TCC Source Term

TCC operations began with phosphate rock from central Florida, which was reacted with sulfuric acid by the wet process to produce phosphoric acid from which uranium was recovered (Barr, et al., 1955). The rock contained naturally occurring radioactive material (NORM), primarily uranium and associated decay products, and to a much lesser degree thorium and its associated progeny. An AEC memo in 1953 (Johnson, 1953) stated that the phosphate rock used by TCC contained about 0.2 pounds U_3O_8 per ton, which is equivalent to about 0.01% U_3O_8 . Blockson reported the average uranium content of the central Florida phosphate rock it used in the 1950s was between 0.01% and 0.014% U_3O_8 (Lopker, 1951; Stoltz, 1958). Mills, et al. (1977) reported that the marketable rock from central Florida had 41 pCi/gm of U-238, which is equivalent to about 0.012% uranium. These values are all similar and the differences likely represent the variation that is seen in various batches of phosphate rock. A total uranium concentration of 0.014% will be used to bound the average concentration in phosphate rock at TCC.

Chemical processing of phosphate rock at TCC exposed workers to TENORM. The processes involved with both phosphate chemicals production and with uranium extraction would have altered the radioactivity ratios of the various radionuclides. Discussion of the fate of the significant radionuclides is provided below.

5.3.1 Source Term for Uranium Recovery

U-238 and associated decay products, including Ra-226, are essentially in radioactive equilibrium in phosphate rock that has not been chemically processed (Roessler, 1979; FIPR, 1995). During production of phosphoric acid by the wet process, phosphate rock is pulverized, mixed with excess sulfuric acid, and separated into phosphogypsum and phosphoric acid streams. Uranium and radium are chemically separated in such a manner that the radium is concentrated in the phosphogypsum while the uranium is concentrated in the phosphoric acid (OCAS-TKBS-0002; Guimond, 1975; FIPR 1995).

The phosphoric acid produced by TCC occurred in a plant that was built for animal feed and fertilizer production. Uranium was extracted as a byproduct from the acid in a separate plant (AEC, 1953). Radionuclides in the phosphate rock would be a source term for both the phosphate production areas and the Uranium Recovery Plant.

The distributions of specific uranium and thorium decay chain radionuclides within phosphate source materials, and within the various products and waste streams produced by the phosphate ore processing industry, have been the subject of numerous studies. While the distributions of radionuclides are, in some respects, a function of the specific process, the following generalizations can be made for the production of phosphoric acid by the wet process:

- Radiological equilibrium in the uranium chain appears to be maintained in rock that has not been chemically processed (Roessler, 1979; FIPR, 1995).
- Ra-226 and Po-210 are retained in the phosphogypsum; they do not enter the phosphoric acid stream to a significant degree (OCAS-TKBS-0002; Guimond, 1975, page 15; FIPR, 1995, pages 1-16).
- Uranium and thorium tend to favor the phosphoric acid phase (OCAS-TKBS-0002; Guimond, 1975; FIPR, 1995).
- Since Th-230 is present in the matrix with U-238, it is expected to go into solution along with the uranium when leached in sulfuric acid. Th-232, if occupying a different matrix in the mined rock, may not be as readily dissolved in sulfuric acid (Coppinger, 1959, page 20).
- Pb-210 is reported by some references as being retained in the phosphogypsum and by other authors as reporting to the phosphoric acid (OCAS-TKBS-0002).

Uranium and other elements would be present at various stages in concentrations correlated with their chemical properties. There are uncertainties with chemical recoveries and potential losses of some elements in some of the chemical steps. In lieu of this uncertainty, NIOSH employed the following assumptions for isotopic ratios in the production of phosphoric acid from phosphate rock:

- Eighty-five percent of uranium resides in the phosphoric acid (Lopker, 1951; OCAS-TKBS-0002; Stoltz 1958). The remainder reports to the phosphogypsum. A higher recovery is considered unlikely based on the studies done at Blockson Chemical Company (Blockson).

- Four percent of Ra-226 resides in the acid phase while the remainder reports to the phosphogypsum (Hull and Burnett 1996).
- Although several references indicate the percentage of thorium reporting to the acid is likely to be somewhat lower than uranium, this evaluation assumes thorium partitions to acid in the same proportion as uranium. The assumption of equal recovery of thorium to uranium in the acid results in a higher source term for internal and external dose modeling during uranium recovery (OCAS-TKBS-0002). If there were more thorium losses to the phosphogypsum stream, the worker doses would be lower.
- The radioactivity ratio of U-238 to Th-232 in the TCC phosphate rock is assumed to be 30:1, the same as for Blockson (OCAS-TKBS-0002). This ratio is considered to be a bounding ratio to allow for natural thorium and progeny based on reported U-238 and Th-232 concentrations in phosphate rock and phosphate products (Mills, et al., 1977; ORAUT-OTIB-0043). Th-232 progeny are assumed to be in equilibrium. Although most of the Ra-228 likely would have been separated and removed with the phosphogypsum, it is assumed to be in equilibrium with Th-232 for dose-modeling purposes.
- Pb-210 is assumed to reside in the acid solution in equilibrium with U-238. Various references cite data indicating that lead follows the phosphogypsum, while other references report high percentages following to the phosphoric acid (OCAS-TKBS-0002). For dose modeling purposes and to bound concentrations carrying over to the acid and from ingrowth, Bi-210 and Po-210 are assumed to be in equilibrium with Pb-210.
- All isotopes reporting to the acid are carried through to the drum of dried uranium concentrate in the same relative concentration as present in the acid (the uranium concentrate being the highest potential source for internal and external dose) (OCAS-TKBS-0002).

The principal radioactive source term in the Uranium Recovery Plant consisted of dried uranium concentrate. The uranium concentration of this material was likely similar to the product produced at Blockson, 40% to 60% uranium by mass, although no data are available on the actual concentration achieved at TCC. The relative ratios of other radioactive constituents assumed to be present in the product are given in Table 5-3. Elevated airborne concentrations of this product material are assumed to be present in the Uranium Recovery Plant at the given ratios.

| Table 5-3: Uranium Recovery Plant Radionuclide Ratios | | | |
|--|-----------------------------------|---------------------------------------|--|
| Radionuclide | Relative Ratio¹ | Notes | Normalized to U-238¹ |
| U-238 | 85 | Progeny in equilibrium through Th-230 | 1 |
| U-235 | 3.87 | Progeny in equilibrium | 0.0455 |
| Ra-226 | 4 | Progeny in equilibrium | 0.047 |
| 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.

Wilkinson (1976) reported that the TCC plant was constructed to extract uranium via an organic extraction method similar to three plants constructed in Florida, in which UF₄ (green salt) was produced. However, other references indicate that the uranium concentrate being produced at TCC was similar to the Blockson materials. The Fernald operating contractor described the concentrates received from both Blockson and TCC as a uranous phosphate. A January 1955 AEC memorandum stated that concentrates of Blockson and TCC material were being resampled, and the AEC was discussing sampling methods to be used for these two materials in reference to hydroscopy and reproducibility of sample results from the two sources of uranium. The AEC made a distinction that the chemical characteristics of the Blockson and TCC material were different compared to the green salt being produced by Florida phosphate plants (Wunder, 1954; Barr, 1955). A specific description of the uranium extraction chemistry at TCC is not available; however, those reports from the AEC indicate that the material was not UF₄ and instead was similar to the Blockson uranous phosphate. The uranium compound produced at TCC is not known with certainty.

It is assumed that workers were routinely exposed to a drum of uranium concentrate throughout the period of uranium recovery operations. Surface contamination of the material is assumed to have been present inside the plant during the operational period and to have been in the facility from residual contamination after the recovery plant was shut down in 1954. Elevated radon concentrations may have been present in the facility from the quantities of Ra-226 that may have carried over into the phosphoric acid from the phosphate rock.

5.3.2 Source Term for the Phosphate Plant

During the AWE covered period dose to workers from exposure to various phosphate compounds at the plant must be considered whether or not those exposures were related to work for the AEC. The source term in the phosphate plant includes radionuclides in the phosphate rock and phosphoric acid discussed in Section 5.3.1, as well as radionuclides that are present in commercial phosphate products and wastes generated during production.

TCC produced dicalcium phosphate for animal feed. They also produced fertilizer. The available references do not include analytical data of the phosphates produced by TCC from 1953 through 1955. Information from one former worker suggests that all the phosphate rock had been converted to phosphoric acid by the wet process prior to production of products (Personal Communication, 2007a). An EEOICPA claimant supplied a copy of an article from the March 29, 1953, edition of the Houston Chronicle that discussed the TCC plant that was being constructed. The article described the plans for TCC to produce sulfuric acid, phosphoric acid, dicalcium phosphate, ammonia sulfate, and the recovery of uranium for sale to the AEC.

Analytical data from other phosphate plants were used to estimate the concentration of U-238 and associated radionuclides in products and wastes at TCC. The data indicates that the concentration of U-238 is enhanced, relative to phosphate rock, during production of dicalcium phosphate and phosphate fertilizers. Published literature indicates the U-238 concentration and relative radionuclide ratios in phosphates vary according to the methods of production. For a given phosphate rock concentration, an enhancement factor of two will provide a bounding average U-238 concentration in products and wastes at TCC. The available data also includes concentrations of other radionuclides in various products. The data is discussed in the paragraphs below.

Some products, e.g., normal superphosphates, are produced from phosphate rock without a filtration step. These are products that are characterized radiologically as having the radionuclides in the same approximate radioactivity ratios as found in the phosphate rock. Normal superphosphates and animal feed are examples. However, different plants have reported production of animal feed both from phosphoric acid and from phosphate rock (Journal, 1953; Menzel, 1968; FIPR, 1998; Gäfvert, 2001).

TCC used the wet process to produce phosphoric acid. Phosphate products that are produced from wet process phosphoric acid involve a filtration step that changes the relative concentration of some elements. Products produced from wet-process phosphoric acid are characterized by a much lower relative concentration of radium due to a large percentage of it being removed with the phosphogypsum waste. Although a relatively large percentage of the radium is found in the phosphogypsum, its concentration is not enhanced because the mass of phosphogypsum waste produced is larger than the mass of the phosphate rock reacted (FIPR, 1995).

Concentrated superphosphates, or triple superphosphates (TSP), are produced by reacting phosphate rock with phosphoric acid. This product also has an enhanced U-238 concentration, relative to phosphate rock. The Ra-226 concentration in TSP is lower than the U-238, but higher than that the Ra-226 concentration in ammoniated phosphates. Ammoniated phosphates are produced from reacting phosphoric acid with ammonia. The ammoniated phosphates have an enhanced U-238 concentration relative to phosphate rock, but much lower Ra-226 concentrations (Menzel, 1968; Roessler, 1979; FIPR, 1995; FIPR, 1998, Gäfvert, 2001).

The products produced from each of the methods differ in the ratios and concentrations of the radioactive elements. Table 5-4 lists analytical results from common phosphate products.

| Table 5-4: Radioactivity Concentrations in Materials Produced from Florida Phosphates | | | | |
|--|---------------------------|--------------------------|---------------------------|---------------------------|
| Material | Ra-226 (pCi/g) | U-238 (pCi/g) | Th-230 (pCi/g) | Th-232 (pCi/g) |
| Normal Superphosphates | 21.3 | 20.1 | 18 | 0.6 |
| Diammonium Phosphates | 5.6 | 63 | 65 | 0.4 |
| Concentrated Superphosphates | 21 | 58 | 48 | 1.3 |
| Monoammonium Phosphates | 5 | 55 | 50 | 1.7 |
| Phosphoric Acid | <1 | 25.3 | 28.3 | 3.1 |
| Gypsum | 33 | 6 | 13 | 0.3 |

Reproduced from Mills (1977) Table 2.

Table 5-4, reproduced from Mills (1977), does not have results for dicalcium phosphate animal feed, which was produced by TCC. A report from a modern DCP plant in Sweden that imported phosphate rock ore from central Florida indicated that all long-lived progeny in the U-238 series were at approximate equilibrium in the phosphate rock prior to production of DCP (Gäfvert, 2001). Data from the plant indicate most of the uranium from rock ended up in the DCP and had an enhanced U-238 concentration of about 120% of that found in the phosphate rock. The Th-230 and Ra-226 concentrations were very low in the DCP, and they showed up primarily in the sludge, although at concentrations noticeably lower than were found in the phosphate rock. The data indicates that the radionuclide concentrations in concentrated superphosphates or ammoniated phosphates are higher than in the animal feed. FIPR (1998) also reported the most significant concentration of dust came from dried processed fertilizers, such as triple superphosphate.

Analytical data from various phosphate products were reported in the 1998 FIPR report. Table 3 of the FIPR report has data from several sources on U-238 and Ra-226 concentrations, which is reproduced below in Table 5-5.

| Table 5-5: U-238 and Ra-226 Concentrations Reported by FIPR | | |
|--|------------------------------------|---|
| Area | U-238 (pCi/g) | Ra-226 (pCi/g) |
| Ore matrix | 38 ^c | 38 ^c |
| Clays | 44 ^a | 45 ^a 26 ^c 45 ^b |
| Sand Tailings | 5.3 ^a | 5 ^c 7.5 ^a |
| Rock Concentrate | 32 ^c | 37 ^c 42 ^d |
| Rock Pebble | 41 ^c 32-41 ^d | 42 ^c 37-42 |
| Sodium fluosilicate | | 0.28 ^d |
| Gypsum | <1 ^c 0.5-6 ^d | 26-33 ^d |
| NSP | | 21.3 ^b 25 ^d |
| TSP | 57 ^c | 20 ^c 21 ^b |
| MAP | 70 ^c | 5 ^b 4 ^c 5 ^d |
| DAP | 70 ^c | 5.6 ^b 4 ^c |
| Phosphoric Acid | 30 ^c | <1 ^c 0.4-0.7 ^d |

^a Guimond and Windham, 1975

^b Guimond, 1978

^c Roessler, 1979

^d Owen and Hyder, 1980

Notes: NSP = normal superphosphate; TSP = triple superphosphate;
MAP = monoammonium phosphate; DAP = diammonium phosphate.

The U-238 concentrations for MAP, DAP, and TSP in Table 5-5 were the average values for central Florida phosphates reported by Roessler et al., (1979). Additional data reported by Roessler (1979), not included in Table 5-5 above, showed the range of U-238 in the ammoniated phosphates varied up to 81.8 pCi/g and the TSP values varied up to 72.7 pCi/g. Roessler also reported the Ra-226 concentrations in filtrate tank sediment varied from 64.6 to 84.1 pCi/g. Ra-226 in the tank scale was reported at 384.8 pCi/g.

The scale is primarily a source of external exposure for workers and maintenance personnel in the phosphoric acid filtration area (FIPR, 1998).

Roessler reported that both the ammoniated phosphates and triple superphosphate had the U-238 concentrations approaching twice of the concentration in phosphate rock, as supported by the data in Tables 5-4 and 5-5. Bounding average uranium concentrations in central Florida phosphate rock will be assumed to have been concentrated up to a factor of two at TCC.

In this Evaluation Report, internal dose from phosphate plant operations at TCC is estimated based on bounding total dust concentrations at the plant (see Section 7.2). As stated in Section 5.3 a bounding uranium concentration of 0.014% is assumed for TCC phosphate rock. Assuming all uranium is U-238, and using a specific activity of 3.4×10^5 pCi/g, results in a U-238 concentration of 47.6 pCi/g. U-234 will be assumed in equilibrium with U-238; U-235 is disregarded because the radioactivity calculation of U-238/U-234 allow for the small amount of U-235 in the rock.

Application of a factor of 2.0 for enhanced concentration of U-238 in dry phosphate products results in a bounding U-238 concentration of 95 pCi/g. Based on the above data, Ra-226 and Th-230 will assumed to be in equilibrium with U-238. This likely overestimates potential concentration of Ra-226 (relative to U-238), but allows for short term exposure to Ra-226 in filtrate tank sediments.

Per the discussion in Section 5.3.1, Th-232 (and long lived progeny) is assumed be 3.3% of the U-238 concentration. Per Section 5.3.1, Po-210 and Pb-210 behavior in phosphate plants can vary, but an assumption of equilibrium with U-238 bounds potential exposure to these radionuclides in the phosphate materials that have the greatest dose significance.

A report from a phosphate plant in Idaho (EPA, 1978) found that Po-210 concentrations were elevated relative to U-238 during roasting of phosphate rock in a calciner. However, workers have stated that TCC did not roast the phosphate rock prior to processing (NIOSH, 2007a; NIOSH 2007b).

Bounding concentrations of the radionuclides of significance to internal dose at TCC are provided in Table 5-6.

| Table 5-6: 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,* Ac-227* | 4.3 |
| Th-232, Ra-228, Th-228 | 3.2 |

* U-235 progeny assumed in natural abundance relative to U-238. The U-238 and U-234 concentrations allow for dose from U-235.

Note: Short lived progeny not listed in this table are also assumed to be in equilibrium.

The values in Table 5-6 are the bounding average concentrations for continuous exposure. Although data indicates higher relative concentrations of some radionuclides may be present at certain locations, such as high radium content in filtrate tank scale, continuous exposure to bulk products at the concentrations in Table 5-6 should provide a bounding source term for the internal exposures discussed in Section 7.2. The external dose assessment in Section 7.3 considers dose from Ra-226 in tank and pipe scale at TCC.

5.4 Radiations for TCC

The primary source of radiological exposure from operations performed at TCC for the proposed SEC class was naturally-occurring radioactive material (NORM) contained in phosphate rock, primarily uranium and thorium, and their associated progeny, and technologically enhanced NORM, or TENORM. Potential exposure pathways and sources to be considered include:

- Internal and external exposure from uranium and associated radionuclides that were extracted and concentrated in the Uranium Recovery Plant.
- Internal and external dose from phosphate rock and manufactured phosphate products.
- Internal exposure from radon and radon progeny.

5.4.1 Alpha

Alpha exposure at TCC occurred through intake via inhalation and ingestion. The primary uranium isotopes in the phosphate rock include U-238, U-234, and U-235. The most dosimetrically-significant associated radionuclides include Th-230, Ra-226, and Rn-222 (radon) and its progeny. Trace amounts of natural thorium (and associated progeny) are also present in phosphate rock (FIPR, 1995).

Personnel exposures to alpha sources are discussed in Section 7.2.

5.4.2 Beta

Beta exposure sources are discussed in Section 7.3 and include the following:

- Shallow dose from exposure to uranium concentrates.
- Skin dose from direct contact with material or contamination (e.g., handling and cleaning uranium filter media).

5.4.3 Neutron

Uranium compounds can be a source of neutrons from both spontaneous fission occurring in the isotopes of uranium and from alpha-neutron reactions with low atomic number materials, such as oxides and impurities. ORAUT-OTIB-0024 describes the expected neutron dose rates from various forms of uranium compounds. The neutron dose rates from exposure to the material at TCC are insignificant compared to the doses assumed to have occurred from other radiation types.

5.4.4 Photon

Photon personnel exposure sources are discussed in Section 7.3 and include the following:

- Exposure to uranium concentrates.
- Exposure to radium.
- Occupationally-required medical X-rays.

6.0 Summary of Available Monitoring Data

NIOSH did not find any personnel or workplace monitoring records for Texas City Chemicals for the period under evaluation. Limited site data is available after the phosphate plant closed in 1977.

7.0 Feasibility of Dose Reconstruction

The feasibility determination for the proposed class of employees covered by this evaluation report is governed by both EEOICPA and 42 C.F.R. § 83.13(c)(1). Under that Act and rule, NIOSH must establish whether or not it has access to sufficient information either to estimate the maximum radiation dose for every type of cancer for which radiation doses are reconstructed that could have been incurred under plausible circumstances by any member of the class, or to estimate the radiation doses to members of the class more precisely than a maximum dose estimate. If NIOSH has access to sufficient information for either case, NIOSH would then determine that it would be feasible to conduct dose reconstructions.

In determining feasibility, NIOSH begins by evaluating whether current or completed NIOSH dose reconstructions demonstrate the feasibility of estimating with sufficient accuracy the potential radiation exposures of the class under evaluation. If the conclusion is one of infeasibility, NIOSH systematically evaluates the sufficiency of different types of monitoring data, process and source or source term data, which together or individually might ensure that NIOSH can estimate either the maximum doses that members of the class might have incurred, or more precise quantities that reflect

the variability of exposures experienced by groups or individual members of the class as summarized in Section 7.5. This approach is discussed in OCAS's SEC Petition Evaluation Internal Procedures which are available at <http://www.cdc.gov/niosh/ocas>.

The next four major subsections of this Evaluation Report examine:

- The sufficiency and reliability of the available data. (Section 7.1)
- The feasibility of reconstructing internal radiation doses. (Section 7.2)
- The feasibility of reconstructing external radiation doses. (Section 7.3)
- The bases for petition SEC-00088 as submitted by the petitioner. (Section 7.4)

7.1 Pedigree of TCC Data

This subsection answers questions that need to be asked before performing a feasibility evaluation. Data Pedigree addresses the background, history, and origin of the data. It requires looking at site methodologies that may have changed over time; primary versus secondary data sources and whether they match; and whether data are internally consistent. All these issues form the bedrock of the researcher's confidence and later conclusions about the data's quality, credibility, reliability, representativeness, and sufficiency for determining the feasibility of dose reconstruction. The feasibility evaluation presupposes that data pedigree issues have been settled.

7.1.1 Internal Monitoring Data Review

NIOSH has been unable to find any record of internal monitoring of TCC workers or any dust or radioactivity airborne concentrations for the proposed class.

7.1.2 External Monitoring Data Review

NIOSH has been unable to find any record of external dosimetry monitoring of TCC workers or area radiation monitoring records for the proposed class.

7.2 Internal Radiation Doses at TCC

Internal dose from AEC-contracted work is evaluated below, as well as internal dose workers may have received from non-AEC work during the covered period. Radiation dose to workers from production of chemicals for commercial use is applicable for this evaluation whether or not it was directly related to AEC uranium recovery work, but only during the specified AWE covered period (OCAS-IG-003). Dose from residual contamination attributable to AEC work is also evaluated.

Shake-down operations at TCC began October 5, 1953 (Johnson, 1953). From that point on workers had the potential to be exposed to technologically enhanced concentrations of radionuclides from phosphate rock. There are no monitoring or analytical data available for TCC. Section 7.2.1 evaluates internal dose and provides bounding intake estimates from operation of the phosphate plant.

Internal dose from uranium recovery work for the AEC is considered in Section 7.2.2. Internal dose from the AEC development contract is discussed in Section 7.2.3.

7.2.1 Internal Dose from Operation of the Phosphate Plant

7.2.1.1 Monitoring Data from other Phosphate Plants

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 primary data used by NIOSH in the assessment of internal doses at wet process phosphate plants was taken from a 1998 report by the Florida Institute of Phosphate Research (FIPR) on dose at Florida phosphate plants that processed phosphate rock from central Florida, and a 1978 U. S. Environmental Protection Agency report of exposure to workers at an Idaho phosphate plant (FIPR, 1998; EPA, 1978).

The airborne measurement results from Idaho and the Florida plants were reviewed and high fugitive dust concentrations were reported from both studies in certain areas that handled dry phosphate rock or dry fertilizers. To estimate intakes of airborne radioactivity at TCC from phosphate plant operations, the 50.4 mg/m³ maximum measured dust concentration at the Idaho plant will be used as a bounding maximum average dust concentration. Radioactivity in the dust is calculated using the values in Table 5-6. The following paragraphs discuss the Idaho and Florida data and provide the rationale for using the Idaho dust concentration.

The Idaho plant and the Florida plants for which data are available were large plants, processing more phosphate rock and producing more phosphate compounds than TCC did in 1953 through 1955. The TCC plant was designed to process 100,000 tons of phosphate rock per year (AEC, 1953), equivalent to about 2,000 tons per week. A Florida phosphate plant used in the 1998 FIPR report was reported to have processed up to 2,000 tons per day (14,000 tons per week) of animal feed or ammoniated phosphates alone through the plant's dry products area. The Idaho phosphate plant referenced in this report was a plant in full production and processed one to two million tons of phosphate rock per year (20,000 to 40,000 tons per week). TCC was not operating at capacity during the AEC operational period, at least through mid-1955 (Greenleaf 1955). The uranium plant was shut down soon after startup because the phosphate plant could not maintain sufficient phosphoric acid production due to equipment problems. These facts indicate that TCC processed less phosphate rock at a lower rate from October 1953 through September 1955 than the Florida and Idaho plants discussed in this report. The Idaho and Florida plants are representative of large production facilities that handled large quantities of dry rock and phosphate products.

The chemical processes used in Idaho and Florida are similar to those used at TCC. According to publications of phosphate plant operations from the 1950s and from plants in the 1990s, the basic process of producing phosphoric acid by the wet process has not changed. Burnet (1957) described the methods utilized in the 1950s to produce phosphoric acid. The basic method involves digesting finely ground phosphate rock in sulfuric acid in a series of tanks to produce phosphoric acid and calcium sulfate (phosphogypsum). The reaction process is dependent on controlling rock particle size, acid concentration, reaction time, holding time, and recycle line ratios. The acid and gypsum products typically were separated in one of four types of continuous vacuum filters commonly available in the 1950s. One of those types was the Dorr-Oliver Process, which was the type of filtration used in the TCC plant (Corporate Profile, 1958).

The methods described by Burnet (1957) are very similar to methods used in modern phosphate plants (FIPR, 1998; FIPR, 1995). Although the basic chemical reactions and processes used in the plants are the same, the engineered controls of 1950s-era plants were likely less effective than more modern plants.

FIPR reported a few changes over time in process and practices used at wet process plants. Vacuum coolers are used in modern plants to control heat generated from digestion of phosphate rock in sulfuric acid. Burnet (1957) stated the method of cooling used in the 1950s was a recycle line in which a large amount of unseparated reactants from a downstream digester was fed back into the primary digester to cool and control temperature in the initial reaction. That method was replaced by the vacuum method in the Florida plants. That design change involves a wet process and has no impact on dust concentrations from dry materials in other areas of the facility.

FIPR also reported that the Florida plants being studied in the 1990s were utilizing a wet method for grinding rock that was first developed in 1973. Wet grinding reportedly reduced airborne dust emissions by 1,000 pounds per day (reference to the large Florida plants in FIPR 1998). Oil was also used on some surfaces in the shipping areas of the Florida plants to control dust. Airborne radioactivity concentrations in the ball mill and in some shipping areas were relatively low in the Florida Plants indicating the effective use of those dust controls. However, data from some areas indicated high levels of fugitive dust.

FIPR reported the greatest potential for internal dose in the following process areas, in order of decreasing dose potential: shipping, rock, dry products, phosphoric acid, and mine (FIPR 1998, p. 78). The mine category is not applicable to TCC since it did not mine rock. Phosphoric acid production is more of a concern for external dose and does not have as much significance for internal dose because the handling of liquids and wet materials are the predominate forms of the materials used in those areas. Although some intermittent exposure to dried sludge is likely, an assumption that the hypothetically maximally-exposed worker was continually exposed to dry phosphate rock or dry product results in larger intakes.

FIPR evaluated air concentrations at Florida phosphate plants in the 1990s (FIPR, 1998). Gross alpha and beta concentrations were reported. The lower limits of detection (LLD) for the air sample analyses were 1.0×10^{-12} $\mu\text{Ci/ml}$ and 1.2×10^{-12} $\mu\text{Ci/ml}$ for alpha and beta, respectively. Area airborne radioactivity results were recorded for several areas of phosphate rock work. Many samples were reported at the detection limits, however, those results are not considered because this evaluation considers the areas of highest potential dose. Table 7-1 provides the gross alpha results that were reported to be greater than or equal to 2.0×10^{-12} $\mu\text{Ci/ml}$, all of which were in areas that handled phosphate rock or dry products; the report provides descriptions of the work in those areas. FIPR reported that both high volume air samplers and personal air samplers were used. They selected sampling locations based on activities or areas that had the potential to generate dust.

| Table 7-1: Airborne Radioactivity Concentrations from Phosphates | | |
|---|---------------------------|-------------------------|
| Plant Area | Area Activity | Alpha μCi/ml |
| D | Dry Product, cage mill | 2.80E-12 |
| D | MAP | 2.00E-12 |
| D | GTSP | 4.20E-12 |
| H | Granular | 1.59E-11 |
| M | Washer | 2.20E-12 |
| M | Float Plant | 2.20E-12 |
| R | Rock Receiving, 3rd floor | 2.30E-11 |
| R | Rock, 3rd floor | 3.00E-12 |
| R | Rock ball mill | 2.00E-12 |

Reproduced from data in FIPR 1998, Table C-6.

Area key:

| | |
|---|--------------|
| D | Dry Products |
| H | Shipping |
| M | Mine |
| R | Rock |

Only the two highest results will be evaluated.

The single highest airborne alpha radioactivity sample of 2.3×10^{-11} μCi/ml was from the rock receiving area. That area of the plant received phosphate rock and processed it for digestion. The rock area of the plant would have U-238 and associated radionuclides in the same approximate concentration as received in the phosphate rock. The alpha activity measured on the air samples were assumed to consist primarily of the long lived radionuclides U-238, Th-230, U-234, Ra-226, and Po-210 in equilibrium. Dividing the total alpha concentration by 5 results in an alpha concentration of 4.6×10^{-12} μCi/ml for U-238 and each of the other four radionuclides.

The second highest alpha result in the Florida study was 1.59×10^{-11} μCi/ml in the Shipping granular area. Granular triple superphosphate (GTSP) has an enhanced U-238 concentration, as discussed in Section 5.3.2. Table 5-4 provides a U-238 concentration of 58 pCi/g in concentrated superphosphates. The table also provides concentration of other significant alpha emitting radionuclides, but it does not include U-234, which would be similar to U-238. Assuming U-234 is equivalent to U-238 at 58 pCi/g in concentrated superphosphate, and disregarding relatively insignificant quantities of other alpha emitters not listed, the total long lived alpha activity in TSP would be about 186 pCi/g. The U-238 accounts for 31% (58/186) of that activity. Applying the 31% value to the 1.59×10^{-11} μCi/ml alpha result from the Florida data in Table 7-1 results in a U-238 concentration of about 4.9×10^{-12} μCi/ml, slightly higher than the U-238 airborne radioactivity estimate for the Rock area discussed in the previous paragraph.

Table 21 of the FIPR report provided concentrations of Ra-226, U-238, and Th-232 from 17 long term composite samples of dust accumulation. The U-238 data is used to estimate a range of total dust from the 4.9×10^{-12} μCi/ml U-238 air concentration derived from the Granular result in Table 7-1. Disregarding four samples identified as gypsum or rock (lower in U-238), the U-238 specific activity in the composite samples ranged from 29.11 to 72.85 pCi/g, with a mean of 56.62 pCi/g and a standard deviation of 13.17 pCi/g. The average 56.62 pCi/g U-238 concentration is very similar to the

values for Concentrated Superphosphates and TSP in Tables 5-4 and 5-5, respectively. Combining the U-238 specific activity with the highest derived U-238 airborne radioactivity of 4.9×10^{-12} $\mu\text{Ci/ml}$, the total dust is estimated to be about 87 mg/m^3 (range is from $68\text{-}169 \text{ mg/m}^3$). The 87 mg/m^3 is only a nominal value based on a range of likely U-238 concentrations in the highest total alpha result from Florida.

For the Idaho plant, the U.S. Environmental Protection Agency (EPA) reported results of a thorough study of dust-loading and radionuclide concentrations in air during phosphate rock processing in 1975. The phosphate rock used at the Idaho plant did not come from central Florida and had lower radioactivity content. But after calcining, the reported U-238 concentration in rock used at the Idaho plant was similar to the concentration reported for the rock used in the Florida plants and that reported for TCC; the minor differences in radionuclide concentrations should not have an impact on the total airborne dust generated. As seen in the Florida data, the data from the Idaho plant indicates that internal doses are the highest in areas in which phosphate rock and dry phosphate products were handled or processed.

The air samples used in the Idaho study were collected with a two cubic feet per minute portable sampler at various locations. Radionuclide concentrations were reported with uncertainties. The detection limits were not provided, although some analytical results are reported as less than values. The filters were also measured for total dust loading.

The total dust measurements reported from the Idaho plant, sorted in descending order, are presented in Table 7-2. The two highest dust results were reported to be 50.4 mg/m^3 and 33.9 mg/m^3 at the calciner and the TSP dryer, respectively.

| Table 7-2: Dust Concentrations at a Phosphate Plant in Idaho | |
|---|--|
| Material / Area | Dust Loading (mg/m^3) |
| Calciner | 50.4 |
| TSP dryer | 33.9 |
| 200 Ammophos plant dryer | 18.6 |
| Phos. Acid digester | 15.3 |
| 100 Ammophos plant dryer | 8.68 |
| 100 plant storage | 8.61 |
| Outside control room | 6.5 |
| Grinder mill | 6.29 |
| Ore unloading, storage | 5.43 |
| 200 plant storage | 4.12 |
| Continuous filter | 2.72 |
| Acidulation TSP disch. | 2.63 |
| Calciner control room | 1.73 |
| Control room | 1.5 |
| TSP storage | 1.37 |
| Library | 0.92 |

The calciner dust, at 50.4 mg/m^3 , would have been fugitive dust from phosphate rock prior to chemical processing. The air was sampled for 1 hour, 41 minutes. The reported U-238 concentration was 1 pCi/m^3 (equivalent to $1 \times 10^{-12} \text{ } \mu\text{Ci/ml}$).

The TSP (triple superphosphate, or concentrated superphosphate) dust, at 33.9 mg/m^3 , had a slightly enhanced U-238 concentration (relative to the calcined ore) based on the isotopic data of the bulk material, which was also provided. The air was sampled for 3 hours, 29 minutes. Although the TSP dust concentration was lower than the calciner dust, the reported U-238 air concentration was a little higher at 1.4 pCi/m^3 (equivalent to $1.4 \times 10^{-12} \text{ } \mu\text{Ci/ml}$).

The Idaho plant data also included radioactivity concentrations of other significant radionuclides. The concentration and ratio results are a little different than the values reported in Section 5.3.2 for phosphates produced from central Florida ores, however, those differences are relatively minor and the bounding values used in this evaluation allow for the reported range of concentrations.

The highest airborne concentrations reported for both the Florida plants and the Idaho plant were at levels to which workers are not likely continuously exposed due to the extreme dust loading. However, FIPR noted they observed workers had to enter areas near piles of dry product with very high dust concentrations and poor visibility. Photographs of phosphate plants are available showing localized white clouds during movement of bulk material.

The bounding concentration for workers at TCC will be based on a limiting average dust concentration, which for this evaluation is the 50.4 mg/m^3 concentration. The highest reported dust concentration cannot be assumed to be an absolute maximum instantaneous dust concentration, however, 50.4 mg/m^3 likely provides an upper bound average concentration to which a worker would have been exposed. An evaluation performed by Wesley R. Van Pelt Associates for the S. Cohen & Associates review of the Bethlehem Steel site profile concluded that about 30 mg/m^3 provides a plausible upper bound dust concentration for continuous exposure in the work place (S. Cohen & Associates, 2005). The air sample at the Idaho calciner was taken over a 1 hour, 41 minute period, indicating that some exposures at this concentration were possible, although actual worker exposure to that concentration in the Idaho plant are not available.

7.2.1.2 Inhalation and Ingestion Intakes from Phosphates

A 2,500-hour work-year is assumed. Exposure to 50.4 mg/m^3 , at a breathing rate of $1.2 \text{ m}^3/\text{hr}$, 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 5-6 to determine an annual U-238 intake of $1.44 \times 10^{-4} \text{ pCi}$. Conversion of the result into a calendar-day intake results in a 39 pCi/day chronic inhalation of U-238. The other radionuclides identified in the source term in Table 5-6 were calculated similarly and the inhalation intakes are provided in Table 7-3 below.

A chronic ingestion mode of intake is assumed to have occurred as a function of the airborne radioactivity, assuming a workday ingestion of 0.2 times the amount of airborne radioactivity in one cubic meter of air (OCAS-TIB-009). A 300-day work-year was assumed for that calculation resulting in a chronic U-238 ingestion of 0.79 pCi per calendar day. Other radionuclides were calculated similarly.

The bounding intakes for ingestion and inhalation in the phosphate plant are listed in Table 7-3.

| Table 7-3: Intakes from Operation of the Phosphate Plant | | |
|---|-------------------------------|------------------------------|
| Radionuclides | Inhalation pCi/day | Ingestion pCi/day |
| U-238, Th-230, U-234, Ra-226, Pb-210, Po-210 | 39 | 0.79 |
| Pa-231, Ac-227 | 1.8 | 0.036 |
| Th-232, Ra-228, Th-228 | 1.3 | 0.026 |

7.2.2 Internal Dose from Uranium Recovery

As discussed in Section 5.1, 400 pounds of uranium concentrates were produced between October 1953 and March 1954. One report indicated 303 pounds were produced through December 1953. For this evaluation a 100-pound per month production is assumed for October 1953 through March 1954. This rate and time span provides an assumption of 600 pounds uranium concentrate produced. Although this is 50% 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 (NRC, 2002a; Eidson, 1984; Personal Communication, 2002). The 1953 AEC contract specified that TCC was to produce uranium concentrates containing at least 50% U₃O₈. Similar requirements were found in the contract with Blockson. The Blockson uranium recovery process produced concentrates that were reported to analyze from 40 - 60% U₃O₈ (Stoltz, 1958).

Blockson produced roughly 3,000 pounds of concentrates per month for the AEC, and the workers were monitored for uranium intakes. TCC produced less than 100 pounds per month intermittently over a few months. A 100-pound per month production rate at TCC would be comparable to a single day of production at Blockson, and the uranium source available for inhalation from uranium recovery work at TCC would have been only about 3% of the source at Blockson. The Blockson plant is known to have required dust collectors for uranium recovery and required housekeeping on each shift to reduce dust. Although the source difference can be quantified, unknown differences in the design and operation of the plants prevent a direct comparison of intakes for the two plants.

TCC activities associated with packaging and sampling ore concentrates may or may not have had controls such as ventilation and an enclosed drumming station. Additionally, some exposure to dry products would have occurred as a result of product sampling, building maintenance, and loose surface contamination.

Inhalation intakes for workers engaged in uranium recovery work at TCC are estimated based on worker exposure to airborne uranium concentrates at other facilities. During the 10-year period from 1948 through 1958, the Health and Safety Laboratory (HASL) of the U.S. Atomic Energy

Commission conducted 60 complete evaluations of occupational hazards in seven uranium refining plants. The evaluations consisted of measurements of more than 20,000 individual dust samples. These data are summarized in a paper published in November 1960 by the American Academy of Occupational Medicine, entitled *The Industrial Hygiene of Uranium Refining* (Christofano, 1960). In this paper, data are presented for various uranium refining operations, including ore handling, ore sampling, uranium concentrate sampling, ore digestion, solvent extraction, denitration, oxide reduction, hydrofluorination, drum transfer operations, reduction to metal, recasting, fluorination, and scrap recovery.

The AEC uranium concentrate sampling operation described in the paper involved the routine handling of 1000-lb. samples of concentrate, 70% to 90% U_3O_8 . Three plants were studied. Specific tasks associated with this operation, in order of decreasing exposure, included dumping the concentrate (during which airborne gross alpha concentrations ranged from 700 to 4800 dpm/m³), delidding and lidding drums, pipe sampling, and general area. The daily average exposure of workers to airborne alpha radioactivity ranged from 90 to 190 dpm/m³. The workers who dumped the ore concentrates were exposed without dust controls. Some controls were in place by the AEC in the latter period of the study, but the observed concentrations did not improve because of an increase in production.

TCC only produced 400 pounds of uranium concentrates over the lifetime of the operation (less than half of a 55-gallon drum). In contrast, the concentrate-handling operations described by Christofano involved routine handling of 1000 pound batches of ore concentrates containing 70% to 90% U_3O_8 . Exposure to workers handling the ore concentrates at those plants were used to estimate bounding exposure to TCC workers in the Uranium Recovery Plant. For this evaluation, NIOSH assumes that workers were exposed to the maximum daily average alpha concentration of 190 dpm/m³ during periods of active uranium extraction work. However, the Uranium Recovery Plant at TCC operated intermittently for just a few months, so, as previously indicated a favorable assumption of 100 pounds of uranium per month is assumed for October 1953 through March 1954.

As indicated above, a 100-pound per month production rate is assumed for October 5, 1953 through March 1954, to provide a bounding rate of production during this period. For this evaluation, a 25-pound batch is assumed to have been processed every week. 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.

Using a 1.2 m³/hr inhalation rate and a 10-hour work day, a 2-day exposure to 190 dpm/m³ results in an inhalation intake of 4,560 dpm, or 2,054 pCi, in the Uranium Recovery Building. The ore concentrates reported by Christofano were materials that had been previously processed to remove the radium. For this evaluation the alpha activity in those samples is assumed to be 100% uranium. Although some non-uranium radionuclides, principally Th-230, may have been present in the alpha results reported by Christofano, the assumption of all uranium maximizes the potential uranium intake. Assuming U-238 is one half of total uranium, results in a 1,027 pCi U-238 inhalation intake for the 2-day period. If workers extracted uranium 2 days per week, they would have been exposed to lower levels of airborne radioactivity 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 remainder of the work-week.

Estimates were made of the airborne uranium in the Uranium Recovery Building on days in which it was idle. The potential contamination levels would have been low initially and increased as more uranium concentrates were produced, i.e., each batch that was processed is assumed to result in an increased potential for airborne radioactivity from residual contamination on subsequent idle days.

An estimate was made of the surface contamination resulting from the deposition of 190 dpm/m^3 airborne uranium. The calculation was made assuming one two-day batch operation per week for 24 weeks to account for 600 total pounds of uranium as discussed in Section 5.2.2. The suspended material is assumed to have settled out of the air with a settling velocity of $7.5 \times 10^{-4} \text{ m/s}$, which is in the range of deposition velocities measured in various studies (NRC, 2002b). The settling time for each batch was assumed to be 48 hours, although the period during which elevated airborne was present was likely less because only part of the operation involved dry materials. Assuming 190 dpm/m^3 for 48 hours for 24 batches, results in a total of $5.9 \times 10^5 \text{ dpm/m}^2$ settling on surfaces by the time the uranium plant closed in March 1954. It is assumed that none of this had been removed by other processes. A resuspension factor of $1 \times 10^{-6}/\text{m}$ was applied to the contamination level to determine an airborne total uranium concentration of $5.9 \times 10^{-1} \text{ dpm/m}^3$. Thus it is assumed that the airborne uranium in the Uranium Recovery Plant on idle days gradually increased to that concentration.

Assuming a 10-hour day, the daily workday intake on idle days in the Uranium Recovery Plant would gradually increase to 7.1 dpm, or 3.2 pCi. Table 7-3 lists the bounding U-238 inhalation intake of 39 pCi/calendar day from phosphate plant work. Converting that to a 6 day workweek results in a 45.5 pCi U-238 daily workday intake, which is higher than estimated for the Uranium Recovery Plant when it was idle. Therefore, during the AEC covered period, intakes from phosphate plant work are assumed on days in which uranium was not extracted. This results in a weekly U-238 inhalation intake of 1,209 pCi (1,027 pCi from the uranium plant and 182 pCi from the phosphate plant). This intake rate would bound intakes from October 5, 1953, through March 31, 1954.

Ingestion intakes are estimated as a function of the inhalation intakes (OCAS-TIB-009). If the 1,209 pCi weekly inhalation intake is assumed to have occurred over a fifty-hour period at a breathing rate of $1.2 \text{ m}^3/\text{hr}$, then the average air concentration could be estimated to be 20.15 pCi/m^3 . Applying a factor of 0.2 results in a workday U-238 ingestion of 4.03 pCi. Assuming a 6-day exposure per week results in a weekly U-238 ingestion intake of 24.18 pCi.

Inhalation and ingestion intakes of other radionuclides were calculated as a function of the U-238 intake per the respective ratios for the Uranium Recovery Plant and the Phosphate Plant, as discussed in Sections 5.3.1 and 5.3.2, respectively. Intakes were normalized to calendar days and the results are presented in Table 7-4. The calendar day intake rates in Table 7-4 are applicable from October 3, 1953, through March 31, 1954.

Table 7-4: Intakes from Operation of the Uranium Recovery Plant

| Radionuclides | Uranium Plant Inhalation (pCi/week) | Fertilizer Plant Inhalation (pCi/week) | Combined Inhalation (pCi/cal-day)* | Combined Ingestion (pCi/cal-day)* |
|--------------------------------------|-------------------------------------|--|------------------------------------|-----------------------------------|
| U-238, Th-230, U-234, Pb-210, Po-210 | 1,027 | 182 | 173 | 3.5 |
| Pa-231, Ac-227 | 48.0 | 8.29 | 8.0 | 0.16 |
| Ra-226 | 48.3 | 182 | 33 | 0.66 |
| Th-232, Ra-228, Th-228 | 33.9 | 6.00 | 5.7 | 0.11 |

Notes: Combined intakes are normalized to units of calendar days and represent intakes based on an assumption of a partial week worked in uranium production and a partial week worked in fertilizer production.

7.2.3 Internal Dose during the Development Period

As discussed in Section 5.1.2, the Development work done by TCC for the AEC involved laboratory-scale research into methods of separating chemical species of mined phosphate ores and did not involve extraction of uranium other than sample analyses. This would have exposed workers to low levels of NORM, with essentially the same source term as the phosphate fertilizer plant. The intakes of radioactive material by the workers involved in the development work would be expected to be lower than the intakes of workers involving handling large quantities of dry material, whether it was from uranium extraction or from operation of the animal feed and fertilizer plant. Therefore, dose received by workers from AEC-contracted research on phosphate ores would be less than dose received by other activities in other areas of the TCC facility. No attempt is made to provide a task-specific dose estimate because the activities were limited in scope and duration, and the research was intermittent according to reports from the AEC (Greenleaf, 1955).

7.2.4 Internal Dose from Residual Contamination

Dose from residual contamination in the Uranium Recovery Plant and from residual contamination in other areas at TCC is considered. TCC performed laboratory-scale research (Development work) for the AEC after the uranium plant was shut down. The materials used for that research did not come from TCC's phosphate plant operations; the AEC furnished small quantities of phosphate materials for the research that would result in insignificant doses (see Section 7.2.3). Although TCC continued to operate the phosphate plant after the Uranium Recovery Plant closed, the phosphate materials used at TCC (excluding AEC Development work) were not used in connection with AEC work, and dose to workers from work with non-AEC-related materials are assigned only through September 1955.

The source term related to AEC activities starting April 1, 1954, would have been from residual contamination in the facility. Sources to consider include the Uranium Recovery Plant and other areas of the TCC facility in which contamination can be attributed to materials used to produce the 400 pounds of uranium concentrate for the AEC.

Section 7.2.2 estimated a bounding intake in the Uranium Recovery Building. The U-238 intake for the days in which the plant was not extracting uranium was 3.2 pCi per work-day. The uranium plant did not operate after March 1954. This value will be used for the U-238 intake rate from residual

contamination in the Uranium Recovery Building starting April 1, 1954. If a 6-day work-week is assumed, it is equivalent to a 2.74 pCi/calendar-day intake rate.

Intakes from residual contamination from AEC-related activities outside of the Uranium Recovery Plant were considered. Uranium recovery for the AEC ended by March 1954, so the phosphate materials in process as of April 1, 1954, are unrelated to AEC work. The development work involved insignificant source compared to the uranium plant or phosphate plant.

Section 7.2.1 showed that the highest potential intake from the fertilizer plant was from exposure to dry fertilizer products. The U-238 intake estimates from fertilizer in Table 7-3 were derived under the assumption that no uranium was removed for the AEC uranium recovery work. That was done to provide an estimate of dose from fertilizer during the covered period through September 1955 when the uranium plant was idle or shut down.

Although the materials in process prior to April 1, 1954, would include both AEC related and non-AEC related sources of residual contamination (because the Uranium Plant operated only intermittently for the few months), calculations of dose from residual contamination assumes that all the material in process prior to April 1954 was AEC-related, with adjustments noted below.

For AEC-related residual contamination in the fertilizer plant (from processing phosphates used for recovering 400 pounds of uranium), the radiological source term available for inhalation would be lower because it would have had a significant amount of the uranium and associated radionuclides removed and sold to the AEC prior to the phosphates being used for fertilizer. If a nominal 50% uranium recovery for the AEC is assumed (lower than the 85% reported for Blockson) and none was lost and discarded to phosphogypsum piles, then 50% of the uranium would be available as a contaminant for residual contamination on surfaces. Thus when 50% recovery of uranium is assumed the residual source term (related to the 400 pounds of recovered uranium) the U-238 source term in the phosphate plant is reduced by 50%. This would reduce the bounding U-238 inhalation intake from phosphates listed in Table 7-3 to about 20 pCi per calendar day, which will be used as a bounding intake rate from residual contamination from the fertilizer plant on April 1, 1954.

Comparison of the two derived intake rates as of April 1, 1954, 2.74 pCi from the Uranium Recovery Plant and 20 pCi from the fertilizer plant, indicates that the intake rate from residual contamination in the fertilizer plant is higher than the intake rate estimated from residual contamination in the Uranium Recovery Building; therefore, the intake rate from the fertilizer plant will be assumed for residual contamination intake calculations starting April 1, 1954. The simplified method used to overestimate the residual contamination in the phosphate plant provides reasonable bounding intakes.

Intake rates from residual contamination after April 1, 1954, is estimated based on consideration of depletion factors to account for a gradual reduction of contamination once the AEC work stopped. ORAUT-OTIB-0070, Table 3-1, provides depletion factors to apply to derived intakes from residual contamination in a facility. Factors are based on a 1%-per-day depletion rate. Favorable factors to apply to intake rates are 1.0 for year 1 (no depletion assumed), and 0.03 for year 2. Depletion factors from the 3rd year on are held steady at 0.0007 to account for a steady source of contamination. Therefore, the U-238 intake rate from residual contamination is 20 pCi/calendar-day starting April 1, 1954, 0.60 pCi/calendar-day starting April 1, 1955, and 0.014 pCi/calendar-day starting April 1, 1956, and continuing through the end of covered employment.

The intake rate from residual radioactivity related to AEC uranium recovery work is less than the intake rate from on-going fertilizer operations, which are covered exposures through September 1955. Therefore, the fertilizer plant intake rates are applied through the end of the TCC's covered AWE period on September 30, 1955. Starting October 1, 1955, intakes from residual contamination apply until the end of covered employment. The residual intakes of other radionuclides are applied at the same ratios as that applied to intakes from fertilizer operations as done in Table 7-3. Ingestion intakes were also estimated using the same methods as in Table 7-3.

Table 7-5 summarizes the bounding intakes during the residual contamination period beginning in October 1955.

| Table 7-5: Intakes from Residual Contamination | | | |
|---|------------------------------|-------------------------------|------------------------------|
| Radionuclides | Year | Inhalation (pCi/d) | Ingestion (pCi/d) |
| U-238, Th-230, U-234, Ra-226, Pb-210, Po-210 | Oct. 1, 1955 – Mar. 31, 1956 | 0.60 | 0.012 |
| Pa-231, Ac-227 | Oct. 1, 1955 – Mar. 31, 1956 | 0.027 | 0.0005 |
| Th-232, Ra-228, Th-228 | Oct. 1, 1955 – Mar. 31, 1956 | 0.020 | 0.0004 |
| U-238, Th-230, U-234, Ra-226, Pb-210, Po-210 | Apr. 1, 1956 – end | 0.014 | 0.0003 |
| Pa-231, Ac-227 | Apr. 1, 1956 – end | 0.0006 | <0.0001 |
| Th-232, Ra-228, Th-228 | Apr. 1, 1956 – end | 0.0005 | <0.0001 |

Notes: Intakes are in units of calendar days.

7.2.5 Radon Exposures

The naturally occurring Ra-226 in phosphate rock exposed workers to radon (Rn-222), and short-lived radon progeny. Exposures to radon primarily affect the lungs; however, some internal dose to other tissues is possible, although relatively insignificant compared to doses from other sources.

7.2.5.1 Operational Period

There are no radon monitoring data available for TCC during the AEC operational period or from any operating period at TCC. NIOSH considered two methods to estimate radon concentrations at TCC: 1) using measured data from other facilities; and 2) using source term and process information to model potential radon concentrations.

The radon concentrations at phosphate plants monitored from the 1970s through the 1990s were reviewed and reported by the Florida Institute of Phosphate Research (FIPR 1998). The reported data vary significantly, with maximum concentrations reported over 70 pCi/L. FIPR measured radon in Florida phosphate plants in the 1990s and reported that all areas, other than phosphate rock tunnels, have average radon concentration less the EPA guideline (for residences) of 4 pCi/L; the occupied work areas were reported to be not significantly different than background radon levels. The references indicate workers were not typically exposed to the observed higher concentrations.

Although the phosphate rock source term is similar, there is not enough information to relate radon concentrations in the TCC Acid Plant in the 1950s to radon levels reported at phosphate plants in

more recent years. There is no assurance that the TCC plant in 1953 operated with similar effective ventilation as the plants in the 1970s or later.

NIOSH also considered modeling radon concentrations using source term and process information. Under steady-state conditions of production, the average activity concentration of radon in the plant can be estimated according to the following equation:

$$C = \frac{R S \varepsilon}{r V} \quad (1)$$

Where:

- C = activity concentration of Rn-222 in the plant, Bq/m³
- R = processing rate of ore, kg/s
- S = specific activity of Ra-226 in phosphate rock, Bq/kg
- ε = total emanation coefficient of radon from all sources in the plant
- r = outside air exchange rate inside the plant, s⁻¹
- V = volume of the plant, m³

As indicated above, building volume is needed to model radon concentration in the phosphoric acid plant. The size (volume) of the phosphoric acid plant at Texas City Chemicals is unknown. There is a distant overhead picture of the TCC site in the October 1955 issue of *Rock Products*; it shows several buildings, silos, and an open area that appears to be the phosphogypsum pile. The large plant in the picture is likely the phosphoric acid plant (they also manufactured sulfuric acid), but estimating the building volume based on that distant aerial photograph could, at best, only be done with unknown accuracy. NIOSH does not know the layout of the Acid Plant and how it may have been partitioned or if radium-bearing phosphates may have also been stored in the building.

Although NIOSH believes it can reasonably model radon exposures at an operating phosphate facility from given source term and other defined parameters, there are significant unknowns in the model input parameters at Texas City Chemicals. These include the uncertainty in building volume and layout, ore processing rate, and unknown work conditions due to equipment problems. Therefore, NIOSH concludes that maximum radon exposures cannot be modeled with sufficient accuracy for work in the phosphoric acid plant. NIOSH also has no data to determine whether or not a particular worker was exposed in the plant. Therefore, maximum radon exposure for all workers at Texas City Chemicals who were employed between October 5, 1953, through September 1955, cannot be reconstructed.

Exposure to radon from phosphoric acid production is not covered exposure under EEOICPA after September 1955. NIOSH has determined that maximum radon exposures from residual contamination related to AEC work can be estimated with sufficient accuracy.

7.2.5.2 Residual Period

The AWE period at Texas City ends in September 1955, which is the end of a contract to do laboratory scale development work on leached-zone phosphate ores.

Four areas of potential radon exposure were considered to provide an estimate of the maximum radon exposures during the residual contamination period. Radon exposures from residual contamination were considered in the: (1) laboratory where AEC research was done, (2) the acid plant where phosphate rock was digested, (3) the uranium extraction plant, and (4) the phosphogypsum piles.

The laboratory work involved separation of different chemical species in phosphate ores (P_2O_5 and Al_2O_3). The radiological source term for the work was very similar to the other phosphate ores used in production at the plant, but involved very small quantities in comparison to other activities. Small quantities of Ra-226 likely were present as residual contamination in the Uranium Recovery Building when it was closed in March 1954, but the Ra-226 primarily was removed with the phosphogypsum during phosphoric acid production prior to uranium recovery. Radon exposures that could be attributed to materials that were used in AEC related work at TCC during the residual contamination period would be primarily from the phosphogypsum pile (or stack) containing the many tons of waste generated in producing phosphoric acid.

There are radon flux monitoring results available from the phosphogypsum stacks at TCC taken from February 1983 through September 1984. The results of those tests were summarized by the United States District Court for the Southern District of Texas in a 1988 judgment on a lawsuit between the current and former owners of the property (Court records, 1989). The combined average flux from those measurements was $10.5 \text{ pCi/m}^2\text{-s}$. The TCC stacks had been inactive since 1970. The court reported that flux measurements from similar inactive stacks in Florida and another plant (location not identified) were 4.5 and $4.4 \text{ pCi/m}^2\text{-s}$, respectively. Radon gas concentrations at TCC were also measured on top of the phosphogypsum stack and near the Administration Building some 200 to 300 yards from the stack; radon concentrations above background (0.14 pCi/L), were reported to be 0.42 pCi/L and 0.32 pCi/L , respectively. Radon concentrations at other locations on the TCC property were lower.

Court records for the TCC case indicate the measurements were made when the stacks had been inactive for a number of years and cited EPA's findings that radon flux from inactive phosphogypsum piles was nearly 5 times less than from active piles due to formation of crust on the pile surface. The highest net radon concentration reported at TCC from the 1980s study was on the pile at 0.42 pCi/L . Assuming the active pile would have been 5 times higher indicates that a concentration of 2.1 pCi/L would have been present when the pile was active. This value compares reasonably well to reports by the Florida Institute for Phosphate Research (FIPR 1998). FIPR reported radon results for some outdoor areas from Florida plants that had detectable elevated radon concentrations, including phosphogypsum stacks (or piles). The results were highly variable and statistics were reported for 5 locations with elevated results. The median radon concentration for the areas ranged from 1.07 to 2.72 pCi/L . The 2.1 pCi/L estimate for TCC during periods in which the pile was active should provide a reasonable bounding estimate for exposure to radon gas from phosphogypsum at TCC, given that workers do not continuously occupy waste piles. However, only a fraction of the phosphogypsum at TCC can be attributed to AEC activities.

The amount of phosphate rock that was processed to extract the 400 pounds of uranium that was sold to the AEC can be estimated. The central Florida phosphate ores used by TCC reportedly contained about 0.01% uranium (Johnson, 1953), although some references have reported slightly higher concentrations. If a nominal 50% overall uranium recovery is assumed for TCC's uranium recovery process (lower than the recovery reported by Blockson's process), phosphate ore containing 800

pounds of uranium was used to produce 400 pounds of uranium for the AEC through March 1954. At a concentration of 0.01% and a recovery of 50%, 8×10^6 pounds, or 4,000 tons, of phosphate rock would be required to recover 400 pounds of uranium. If this quantity was spread out over 4 months of intermittent operation (full plant production started in December 1954), 1,000 tons of phosphate rock was processed per month, presuming uranium had been recovered from all the phosphate rock that was processed during that period.

At capacity TCC could have processed over 8,000 tons phosphate rock per month, although the plant was not operating at capacity due to equipment problems. They were operating at less than capacity as late as February 1955 (date of last known AEC documented site visit) because new equipment had not yet arrived.

If it is assumed that TCC processed phosphate rock at no more than 1,000 tons per month from December 1953 through the end of the AEC period in September 1955, about 22,000 tons of phosphate rock would have been processed, of which approximately 4,000 tons, or 18%, was related to AEC work.

According to a brief filed with the United States Court of Appeals for the Fifth Circuit in 1989, the former Texas City Chemicals site had over one million tons of radioactive waste stored on site, most of it in the phosphogypsum piles that encompassed 35 acres of the 114 acre site. The phosphogypsum waste was from production of phosphoric acid from the days of ownership by Texas City Chemicals, Inc., through about 1970. According to the court papers phosphoric acid production ended in about 1970; the phosphogypsum stacks were inactive from 1970 until the plant was closed in 1977 and remained inactive after plant closure (Court Records, 1989).

Based on the reported capacity of the plant, one million pounds of waste is a plausible phosphogypsum mass over the years in which the phosphogypsum stacks were active (FIPR, 1995). Using one million tons as an estimate of total phosphogypsum waste in 1970, the estimated 4,000 tons related to AEC work represented 0.4% of the total phosphogypsum when the stacks were closed.

For calculation purposes, phosphogypsum is assumed to have been added to the piles at a steady rate starting in 1957. TCC shut down and filed bankruptcy in early 1956 and was reopened in late 1956 under new ownership. The September 1955 estimate for 22,000 tons of total waste is assumed for the time when TCC closed and filed bankruptcy in early 1956. The amount of waste is assumed to have increased at a constant rate of 69,857 tons per year from 1957 and reached one million tons by the end of 1970.

Based on the above discussion, a 2.1 pCi/L radon concentration is assumed for exposure to the active phosphogypsum pile throughout the period under evaluation. The estimated concentration attributable to the AEC at the start of the year is assumed for the entire year. Thus, 0.38 pCi/L ($2.1 \text{ pCi/L} * 0.18$) is assumed for all of 1957. Table 7-6 below shows the estimated bounding radon concentrations from AEC-related waste in each year. The residual contamination period for TCC is listed as ending in 1977, which is before the date of the radon measurements, therefore, radon is assumed to remain constant at the estimated 1971 levels until the end of covered employment.

Although the waste piles are not typically occupied, it is assumed a worker may worked routinely in the vicinity of the piles, which should provide an estimate of the maximum radon exposure

attributable to AEC work. A 0.4 equilibrium factor is assumed to convert pCi/L radon gas to working level months (WLM) based on a 2500 hour work year and 1.0 working level (WL) per 100 pCi/L. The 1955 exposure is prorated for exposure starting October 1, 1955. The radon gas concentration and annual exposures for AEC residual radon is provided in Table 7-6.

| Table 7-6: Residual Radon | | | | | |
|----------------------------------|--------------------------|------------------------|---------------------|-------------------------|----------------|
| Year | Total waste, tons | AEC waste, tons | Fraction AEC | AEC radon, pCi/L | AEC WLM |
| 1955 | 22,000 | 4000 | 0.18 | 0.38 | *0.0056 |
| 1956 | 22,000 | 4000 | 0.18 | 0.38 | 0.022 |
| 1957 | 22,000 | 4000 | 0.18 | 0.38 | 0.022 |
| 1958 | 91,857 | 4000 | 0.044 | 0.091 | 0.0054 |
| 1959 | 161,714 | 4000 | 0.025 | 0.052 | 0.0031 |
| 1960 | 231,571 | 4000 | 0.017 | 0.036 | 0.0021 |
| 1961 | 301,429 | 4000 | 0.013 | 0.028 | 0.0016 |
| 1962 | 371,286 | 4000 | 0.011 | 0.023 | 0.0013 |
| 1963 | 441,143 | 4000 | 0.009 | 0.019 | 0.0011 |
| 1964 | 511,000 | 4000 | 0.008 | 0.016 | 0.0010 |
| 1965 | 580,857 | 4000 | 0.0069 | 0.014 | 0.0009 |
| 1966 | 650,714 | 4000 | 0.0061 | 0.013 | 0.0008 |
| 1967 | 720,571 | 4000 | 0.0056 | 0.012 | 0.00069 |
| 1968 | 790,429 | 4000 | 0.0051 | 0.011 | 0.00063 |
| 1969 | 860,286 | 4000 | 0.0046 | 0.010 | 0.00057 |
| 1970 | 930,143 | 4000 | 0.0043 | 0.0090 | 0.00053 |
| 1971 | 1,000,000 | 4000 | 0.0040 | 0.0084 | 0.00049 |

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

7.2.6 Internal Dose Reconstruction Feasibility Conclusion

This evaluation concludes that maximum radon exposures from phosphate plant operations at TCC cannot be reconstructed with sufficient accuracy. Dose from phosphate plant operations are not covered past September 30, 1955. Other than radon exposures, NIOSH concludes that internal doses can be reconstructed during the AEC covered period.

During the residual contamination period beginning October 1, 1955, NIOSH concludes that maximum internal and external doses from all sources can be reconstructed.

Internal dose reconstruction, other than radon, for members of the evaluated class is feasible based on the use of source-term information at TCC and the use of measured doses of workers from other wet process phosphate plants. The above evaluations indicate that internal exposures, other than radon, can be bounded for both the operation of the uranium recovery plant and operation of the animal feed and fertilizer plant. Based on the claimant-favorable evaluations, the potential internal doses from the

uranium recovery plant bounds dose for the period in which the plant operated. Dose from fertilizer operations were higher when the uranium plant was idle and when the AEC work was limited to leached-zone phosphate development work. A summary of the bounding intakes and internal exposures for all periods at TCC is provided in Tables 7-7 and 7-8.

| Table 7-7: Summary of Intakes for Texas City Chemicals | | | |
|---|--|-------------------------------|------------------------------|
| Time Period | Radionuclides | Inhalation (pCi/d) | Ingestion (pCi/d) |
| October 5, 1953, through March 31, 1954 | U-238, Th-230, U-234, Pb-210, Po-210 | 173 | 3.5 |
| | Pa-231, Ac-227 | 8.0 | 0.16 |
| | Ra-226 | 33 | 0.66 |
| | Th-232, Ra-228, Th-228 | 5.7 | 0.11 |
| April 1, 1954, through September 30, 1955 | U-238, Th-230, U-234, Ra-226, Pb-210, Po-210 | 39 | 0.79 |
| | Pa-231, Ac-227 | 1.8 | 0.036 |
| | Th-232, Ra-228, Th-228 | 1.3 | 0.026 |
| October 1, 1955, through March 31, 1956 | U-238, Th-230, U-234, Ra-226, Pb-210, Po-210 | 0.60 | 0.012 |
| | Pa-231, Ac-227 | 0.027 | 0.0005 |
| | Th-232, Ra-228, Th-228 | 0.020 | 0.0004 |
| April 1, 1956, through the end of covered employment | U-238, Th-230, U-234, Ra-226, Pb-210, Po-210 | 0.014 | 0.0003 |
| | Pa-231, Ac-227 | 0.0006 | <0.0001 |
| | Th-232, Ra-228, Th-228 | 0.0005 | <0.0001 |

Notes: Values are normalized for a 365-day calendar year. All intakes are assumed to be bounding and applied as constants.

Material solubility should be based on claimant-favorable types available in ICRP Publication 68 (ICRP 1994).

| Table 7-8: Bounding Radon Exposures at Texas City Chemicals | | | |
|--|--------------------------|---------------|---------------------|
| Time Period | Component | Annual | Distribution |
| October 5 1953, through September 30, 1955 | Cannot be reconstructed. | | |
| October 1, 1955, through the end of covered employment | Radon progeny exposure | See Table 7-6 | Constant value |
| | Radon gas exposure | See Table 7-6 | Constant value |

7.3 External Radiation Doses at TCC

The principal source of external radiation doses for members of the proposed class was exposure to uranium, thorium, and their associated progeny. Because phosphate rock contains NORM, any work with this material potentially exposes workers to radioactivity. At TCC, uranium was extracted from phosphate rock and concentrated for use by the AEC. Employer-required medical X-ray examinations are another potential source of external radiation dose at TCC. External doses received by workers in the evaluated class from production of commercial phosphate products are also considered during the AEC covered period.

There are no dosimetry data or radiation measurements available for TCC. Therefore, NIOSH has considered worker doses using source-term information and measured doses of phosphate plant workers according to OCAS-IG-004, *The Use of Data from Other Facilities in the Completion of Dose Reconstruction Under the Energy Employees Occupational Illness Compensation Program Act*. The selection and use of modeled and measured data from other facilities are discussed below.

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) and others have also published data on worker doses. A 1998 FIPR report contains a summary of some of the data that had been previously reported in publications by the EPA, NCRP and others (FIPR 1998). Published data indicate average annual external doses received by workers at phosphoric acid and fertilizer plants are relatively low. FIPR found that it is extremely unlikely for a worker to exceed the 5,000 mrem per year total effective dose equivalent annual limit (TEDE) (FIPR 1998, p. 3). External dose is one component of the TEDE. The report was not specific to plants operating in the 1950s or in Texas, but the report presented data from studies as far back as 1977. The data considered in this Evaluation Report were from various phosphate plants that used similar phosphate rock to produce phosphoric acid by the wet process. Application of the data to TCC is discussed in the sections below.

7.3.1 External Dose from Operation of the Phosphate Plant

Shake-down operations of the fertilizer and animal feed plant began October 3, 1953, which is the start date assumed for workers being exposed to technically enhanced naturally occurring radioactive material (TENORM). Worker doses from phosphate plant operations are considered throughout the covered period ending September 1955. Potential dose to workers in this evaluation is based on estimates of dose received by workers in wet process phosphate plants.

TCC was producing animal feed and fertilizer. Phosphoric acid was being produced by the wet process (Barr, et al., 1955). The particular wet process used by TCC was known as the Dorr-Oliver Process (Corporate Profile 1958). The process involved adding an excess of sulfuric acid to ground phosphate rock to produce phosphogypsum and phosphoric acid. It utilized a series of digester tanks (attack tanks) followed by removal of phosphogypsum from the acid solution via a traveling pan filter or a horizontal rotary filter (Burnet, 1957). Former workers have provided descriptions of the acid plant digesters and described the filter as a large vacuum filter table (NIOSH, 2007).

Various publications have reported external photon doses from workers producing various products at wet process phosphoric acid plants. Ra-226 is a significant source of external dose in phosphate plants and has been reported to concentrate in filtrate tank sediments and scale inside piping (FIPR 1998, p.10). Higher than normal radiation levels from elevated Ra-226 concentrations have been found inside filter pans and inside piping used for transporting weak acid from filter washing.

A University of Florida study, as reported by FIPR, found gamma radiation levels in residues ranging from "100 to 1000 mR/hr;" however, it reported time-weighted average exposures were less than 25% of the standards for occupational exposure, although no actual dose values were provided. A 1980 Department of Energy Study reported average gamma exposure to phosphate workers at less than 0.03 mR/hr \pm 70% (FIPR 1998, p. 11). That rate would result in an exposure of 60 mR per year over a 2,000-hour work year. The reported uncertainty indicates that the 95th percentile exposure would be about 130 mR per year. FIPR also reported results from a 1980s study by Keaton. That was a study of dose to subcontractor maintenance personnel who routinely worked on filtration systems at phosphate plants.

The highest dose rates were found on the inside surfaces of pipes used to transport acid wash. The acid wash is a weak acid produced by washing the gypsum with water after the phosphogypsum had first been separated and washed with acid (return acid). Barium sulfate formed in the gypsum matrix plates out in the piping; the buildup can be significant in the weak acid wash lines because it is very insoluble in water. The dose rates are attributable to Ra-226 that replaces barium ions in the barium sulfate crystals. The amount of scale is a function of product throughput and was reported to be a condition that slowly builds over time. When pipes are cleaned with acid to remove the scale, data indicate the scale gradually builds back. Worker doses from those sources were reported to be effectively controlled by cleaning the scale from equipment every one to three years. Studies were performed of plant workers who worked with and around the filtration systems. Jobs included cleaning and replacing piping, changing filter cloth and sampling. Dose rates, job durations and frequency of work were considered. Dose to several categories of workers were reported; the highest exposed worker dose was estimated to be less than 0.220 rem per year (Lardinoye, 1982).

Workers at TCC from October 1953 through September 1955 were unlikely to have received doses as high as those received in fully operational plants that had been operating for a few years because the TCC plant was new, and upon startup it would not have the buildup of scale that is associated with production. The buildup of scale at TCC would also have been slow due to reduced production because of the failure of equipment to perform as designed. Although the plant was operating, it was not producing enough phosphoric acid to keep the Uranium Recovery Plant open.

The 1998 FIPR report summarized some of the exposures provided by others and presented results of new studies that were performed to better characterize the exposure of various groups of workers at phosphoric plants in Florida. Results were obtained from the deployment of LiF and aluminum oxide carbon dosimeters. The dosimeter deployment included concurrent monitoring with both dosimeter types to achieve optimal sensitivity and the most accurate estimate of deep dose equivalent. Of the seven categories of monitored workers, FIPR reported that the geometric mean of dose to personnel who worked in the phosphoric acid production areas and in rock handling areas received the highest external dose (FIPR 1998, p. 73). Other monitored areas were: dry product, shipping, mine, service, and general area. Appendix C of the FIPR report contains the dosimeter data for each category of

workers. The highest dose in each particular category is listed in Table 7-9 below. Reported results are annualized deep dose equivalent in mrem.

| Table 7-9: Maximum External Doses in Phosphate Plants | |
|--|----------------------------------|
| Job Type or Area | Highest annual dose, mrem |
| Dry Product | 210 |
| Shipping | 180 |
| Mine | 186 |
| Phosphoric Acid | 172 |
| Rock | 141 |
| Service | 184 |

Highest result for each category from FIPR (1998), Tables C1 through C4.

Consideration was also given to an evaluation of worker exposures reported by ORAU in ORAUT-OTIB-043, *Characterization of Occupational Exposure to Radium and Radon Progeny During Recovery of Uranium from Phosphate Materials*. The upper-bound dose for phosphate plant workers, outside of uranium recovery operations, was estimated to be 220 mrem/year, which is the same as reported by Lardinoye (1982) and only slightly higher than the maximum dose observed in the FIPR study.

For purposes of this Evaluation Report, a 220 mrem/year bounding external whole-body photon dose rate is assumed for work in the TCC phosphate plant after shake-down operations started October 5, 1953, which is equivalent to 0.00060 rem/calendar day. Dose from operation of the Uranium Recovery Plant is considered separately.

7.3.2 External Dose from Uranium Recovery

The Uranium Recovery Plant produced uranium intermittently upon startup of the fertilizer plant in October 1953. The problems with the fertilizer plant led to the shutdown of the uranium plant. As discussed in Section 7.2.2, the intermittent uranium extraction from phosphoric acid is assumed to have ended by the end of March 1954. External dose to workers during the operation of the uranium plant is based on modeled external doses from a drum of uranium product. Exposure to contaminated surfaces and air immersion were considered, but those doses are insignificant in comparison to the modeled dose received from exposure to bulk material. An assumption of working around bulk material provides a larger source term for exposure.

A bounding dose rate for exposure to uranium concentrates at TCC has been modeled similar to what was done for Blockson (OCAS-TKBS-0002); however, differences in the production levels and period of operation have been taken into consideration for TCC. Blockson produced roughly 3,000 pounds per month while TCC produced a total of 400 pounds from intermittent operations over a few months. The modeled external dose is based on a 30-gallon drum containing 400 pounds of U_3O_8 . The contract with the AEC specified a 30-gallon steel open head drum was to be used for delivery of the product to the AEC (AEC, 1953).

Uranium Recovery Plant workers would have handled the uranium concentrate and been in close proximity to the material during certain steps in the process. Product would have been dried and then transferred to a drum, which may have been a manual process. Also, the material would have been

sampled by TCC prior to shipment. Some other work in the plant may have required close work with the concentrate. Filtration of product may have required some direct hands-on work with the concentrated uranium product. To allow for the activities that may have required workers to be very close to bulk uranium concentrate, the external photon doses have been modeled based on work close to a drum that contained the entire 400 pounds of uranium produced by TCC. Although workers would not have been exposed to the full drum during the entire period, that scenario is assumed for the purpose of modeling a bounding external dose rate from exposure to uranium in the Uranium Recovery Plant.

The external doses were modeled based on the assumption that the concentrate had the isotopic ratios listed in Table 5-3, 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 per unit decay of ^{238}U was compiled from ENSDF files from NUCDAT (11/28/1005) located at http://www.nndc.bnl.gov/nudat2/indx_dec.jsp. These 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 number and energy of beta particle emissions per unit decay of ^{238}U was compiled from ENSDF using the NUCDAT 11-28-2005 database. These emissions were binned by emission probability. The resulting total beta emission probability per decay of ^{238}U was 4.19.

A density of 2 g/cm^3 was chosen to provide a claimant-favorable geometry. Based on previous evaluations (for Blockson), 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 74 were used to convert the photon flux to units of air kerma. Results are provided in Table 7-10.

| Table 7-10: Photons 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 is based on the assumptions for internal dose specified in Section 7.2.2. During the period of operation of the Uranium Extraction 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 that had been packaged. If a 10-hour work day is assumed, then 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 workweek is assumed, the 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 hypothetical maximally exposed worker's weekly external whole-body photon dose is bounded by assuming 4 hours exposure at 30 cm and 46 hours exposure at 100 cm from the drum of material. Applying the modeled air kerma hourly rates to these assumed hours results in a weekly dose (air kerma) of 0.040 rad; this is equivalent to 0.0057 rad per calendar day.

7.3.3 External Dose during the Development Period

TCC received leached-zone phosphate ores from the AEC for contracted research work. The initial work was reported to involve hundreds of grams of samples. A drum of the ore was also received in early 1954 and the AEC provided three 25-pound samples of leached-zone material to TCC in 1955. The development work involved experimental methods to separate phosphate from undesirable species in the leached-zone ore, such as alumina and silica. Uranium analyses were made along with the analyses of the primary species of concern (Kopf, 1954; Cutter, 1954; Greenleaf, 1955).

Workers involved with the leached-zone research were handling far less material than those workers involved with phosphate production at TCC. The leached-zone ore had similar radiological constituents as the phosphate rock; the development work also did not involve the extraction of radionuclides, other than for sample analysis. Therefore, dose to workers involved with leached-zone ore research would have been much lower than dose to workers involved with production of fertilizers with TENORM. Since dose to workers from fertilizer operations is also covered during the proposed SEC period, evaluation of the much lower dose to a few workers from intermittent development is not needed.

7.3.4 Shallow Dose

Electron radiation is considered as a source of shallow dose for workers at TCC. Shallow dose from exposure to uranium product in the Uranium Recovery Plant and shallow dose from phosphate materials processed at TCC are considered.

Radionuclides that contribute to electron dose from the source term specified in Table 5-3 for uranium recovery operations include Pa-234m and Bi-210 in addition to short-lived Ra-226 progeny, primarily Bi-214 and Pb-214. Several of the other radionuclides contribute marginally to the external dose. All of those radionuclides would be present prior to the phosphogypsum filtration step where most of the Ra-226 and progeny and some other radionuclides are removed with the phosphogypsum.

7.3.4.1 Shallow Dose from the Phosphate Plant

The beta-emitting radionuclides in the various materials and wastes would be distributed throughout the material in low concentrations roughly equivalent to concentration of U-238 in phosphate rock. Some dry phosphate products may have enhanced U-238 concentrations if the phosphoric acid used was not diverted over to the Uranium Recovery Plant, which is probable because uranium production was shut down during all but a few months of the AEC covered period. The most significant beta

dose from the source term would be from Pa-234m, which emits a 2.29 MeV maximum-energy beta particle.

The beta dose from phosphates is derived from reported beta dose rates from yellowcake. Based on Figure 2 of NRC Regulatory Guide 8.30, the dose rate at 30 cm (one foot) from the surface of aged yellowcake is between 1 and 2 mrem/hr. For this evaluation 2 mrem/hr is presumed. The yellowcake beta dose rate at 30 cm is for U_3O_8 (aged for Pa-234m to be in equilibrium with U-238). The beta dose rate was from Pa-234m, Th-234 and Th-231, Pa-234m is the primary contributor to the dose and has the highest maximum energy (2.29 MeV). An estimate will be made of the number of 2.29 MeV beta particles that are generated per unit time on the surface of yellowcake and the number that are generated per unit time on the surface of various phosphate materials. For this evaluation, the number of decays on the surface of the materials will be determined by using a material depth equivalent to the maximum range of the 2.29 MeV beta, which is different for the various materials. The factors used in the calculations are selected to provide a bounding favorable ratio of the flux of beta particles from phosphates versus yellowcake. The ratio will be used to derive phosphate beta dose from yellowcake beta dose. The factors used, and the rationale, follow.

Table 5-4 lists U-238-specific activities in several typical phosphate fertilizers. Diammonium phosphate (DAP), $(NH_4)_2HPO_4$, was the highest at 63 pCi/g. This concentration is assumed for TCC based on the uranium not having been recovered from the phosphates (prior to fertilizer production) for sale to the AEC. DAP has a density of about 1.6 g/cm^3 . The rock would have a relatively high percentage of P_2O_5 (density = 2.39 g/cm^3) and would include calcium carbonate (density $< 3 \text{ g/cm}^3$) and small amounts of aluminum and iron oxides as well as small amounts of other impurities. The phosphogypsum waste would have significantly less U-238 and Pa-234m. Other common phosphate fertilizers may have been produced; TCC produced dicalcium phosphate as animal feed. The chemical processes at TCC included handling large volumes of phosphates in a slurry from which the insoluble gypsum was filtered out of solution.

The number of Pa-234m beta particles produced per cm^2 of the surface of the phosphate materials was calculated using assumptions selected to overestimate the true rate. Water was assumed to be the medium to overestimate the effective range of the 2.29 MeV beta particle in the phosphate products and slurries. The maximum range of a 2.29 MeV beta is approximately 1 cm in water, thus for estimating the number of Pa-234m betas per cm^2 , only the top 1 cm of material was considered. The U-238 and Pa-234m concentration are assumed to be 63 pCi/g. To bound the number of atoms in 1 cm of material, an upper average density of 3 g/cm^3 is assumed, based on a review of the densities of the various compounds. Assuming equilibrium with U-238, there are 0.98 beta particles (for the Pa-234m 2.29 MeV max beta) for every decay of U-238, resulting in 411 betas produced per minute per cm^2 of material (top 1 cm). This rate will be compared to the rate from the more highly radioactive surface of yellowcake, for which beta dose rates are available.

The density of yellowcake is assumed to be 2.055 g/cm^3 . The maximum range of a 2.29 MeV beta particle in yellowcake would be less than the 1 cm range in water. The maximum range of a 2.29 MeV beta particle in lead is approximately 0.1 cm. This is considered a reasonable value to use for this calculation to underestimate the maximum range in yellowcake. Thus, only the number of 2.29 MeV betas from the top 0.1 cm of the surface of yellowcake is considered. Assuming equilibrium with U-238, there are 0.98 beta particles (for the Pa-234m 2.29 MeV max beta) for every decay of U-238. Yellowcake is assumed to be 85% U-238. A U-238 specific activity of $7.5 \times 10^5 \text{ dpm/g}$ is used.

This results in the generation of 1.284×10^5 beta particles per minute per cm^2 of yellowcake (top 0.1 cm).

The calculated number of Pa-234m beta particles per cm^2 from yellowcake was divided by the calculated number from the phosphate material. The number from yellowcake was higher by a factor of 312 ($1.284 \times 10^5 \text{ min}^{-1}/411 \text{ min}^{-1}$). For comparison purposes, the concentration of the U-238 in yellowcake is several thousand times higher than it is in phosphate rock. The factor of 312 was determined by using favorable values to intentionally minimize the ratio for the purpose of deriving a reasonable bounding beta dose rate from the phosphate material. A check of the maximum range of beta particles was also made for a 0.5 MeV beta particle to see if the above ratio would be similar for beta particles of less energy. The difference in maximum range between a water absorber to a lead absorber is approximately a factor of 10, which is similar to the relative difference noted above for a 2.29 MeV particle. Therefore, the estimated ratio is assumed to be favorable for a range of energies that contribute significantly to electron dose from phosphate materials.

The dose rate taken from the NRC publication is for aged yellowcake that accounts for dose from Pa-234m, Th-234, and Th-231. However, the source term in the phosphate plant at TCC is considered to have additional radionuclides according to the ratios presented in Section 5.3.2, Table 5-6. The skin dose coefficients for each radionuclide in Table 5-6, and associated progeny, were evaluated using Federal Guidance Report No. 12, Table III.1, Dose Coefficients for Air Submersion (EPA, 1993). Those coefficients indicate that Pa-234m, Th-234, and Th-231 would account for about 23% of the skin dose for all the radionuclides in the phosphate source term at the relative concentrations assumed for phosphates in Table 5-6.

The 2 mrem/hr yellowcake beta dose rate was multiplied by a factor of 4.3 ($1/0.23$) to allow for radionuclides in the phosphate source term that are not in aged yellowcake. Then the rate was divided by 312 to adjust for lower flux of beta particles from the surface of phosphates (relative to yellowcake), resulting in a dose equivalent rate of 0.028 mrem/hr.

$$2 \text{ mrem/hr} * 4.3 * 1/312 = 0.028 \text{ mrem/hr}$$

If a 2500-hour work year is assumed, the annual dose would be 70 mrem or 0.070 rem/year. Shallow dose is assigned as electrons with energy greater than 15 keV.

7.3.4.2 Shallow Dose from the Uranium Recovery Plant

Beta dose to the skin is estimated by assuming work on uranium recovery 2 days per week from October 5, 1953, through March 31, 1954. Exposure to an open drum of uranium product or concentrated material in process would provide a source for shallow dose from electrons greater than that received from working with phosphate fertilizers. Using the assumptions in Section 7.3.2, it is assumed the intermittent uranium extraction work was a two-day per week process and that a worker spent 2 hours per day at a distance of 30 cm (one foot) from a concentrated uranium source and 8 hours per day at a distance of 100 cm from the uranium concentrates. Beta dose in the Uranium Recovery Building is assumed insignificant for the remaining hours per week. However, if 50 hours worked per week is assumed, a worker could have received beta dose during an additional 30 hours per week from working with phosphates.

For the purpose of this evaluation, the uranium concentrate is assumed to be yellowcake to provide a favorable estimate of dose received at TCC. Based on Figure 2 of NRC Regulatory Guide 8.30, the dose rate at 30 cm (one foot) from the surface of aged yellowcake is between 1 and 2 mrem/hr. For this evaluation 2 mrem/hr is presumed. That rate is also used for the 100-cm distance. Using the time and distance exposure model from Section 7.3.2, it is assumed that workers were exposed to yellowcake for 20 hours per week.

The rate taken from the NRC publication is from aged yellowcake that accounts for dose from Pa-234m, Th-234, and Th-231. However, the source term in the Uranium Recovery Plant is considered to have additional radionuclides according to the ratios presented in Section 5.3.1, Table 5-3. The skin dose coefficients for each radionuclide in Table 5-3, and associated progeny, were evaluated using Federal Guidance Report No. 12, Table III.1, Dose Coefficients for Air Submersion (EPA, 1993). Those coefficients indicate that Pa-234m, Th-234, and Th-231 would account for about 57% of the skin dose for all the nuclides in the Uranium Recovery Plant source term at the relative concentrations listed in Table 5-6.

The 2 mrem/hr yellowcake beta dose rate was multiplied by a factor of 1.8 (1/0.57) to allow for radionuclides in the Uranium Recovery Plant source term that are not in aged yellowcake, resulting in a dose equivalent rate of 3.6 mrem/hr (0.0036 rem/hr).

$$2 \text{ mrem/hr} * 1.8 = 3.6 \text{ mrem/hr}$$

For 20 hours per week exposure in the Uranium Recovery Plant, this results in 72 mrem per week beta dose. For the remaining 30 hours per week, beta exposure from phosphates at a rate of 0.028 mrem/hr is presumed (see Section 7.3.4.1 above), resulting in an additional 0.84 mrem. This results in weekly beta exposure of 73 mrem (0.073 rem/week), or 0.00020 rem per calendar day from October 5, 1953, through March 31, 1954.

Shallow Dose from Deposition on Skin

It is also assumed that there was a potential for workers to receive a shallow dose from electrons due to skin contaminated with yellowcake. The amount of skin contamination can be calculated by using the measured deposition velocity of 4- μm particles to skin of 0.012 m/s (Andersson, 2002; Fogh, 1999), assuming that the material was deposited on the skin for an entire 8-hour shift. Modeled dose from this method is negligible when compared to the shallow dose estimate from the exposure to drums of yellowcake (discussed above) and the estimated skin dose from contaminated clothing discussed below.

Beta Dose from Contaminated Clothing

Skin dose from contamination transfer to the skin, and from contact with contaminated work clothing, was also considered. Mallinckrodt Chemical Company dose rate studies from contaminated clothing were evaluated and average dose rates from contaminated clothing at Mallinckrodt indicate a level of 1.5 mrem/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 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, or 0.0021 rem per calendar day. Electron dose from work clothing in the phosphate plant is considered insignificant, compared to the other estimated doses, due to the relatively low concentration of radionuclides. Doses are applied as electrons $> 15\text{keV}$.

7.3.4.3 Extremity Dose

Extremity dose is considered for work with the uranium concentrates in the fertilizer plant and in the Uranium Recovery Plant. Former Blockson workers stated that during filtering operations, their hands were directly exposed to filter cake containing uranium, sometimes without gloves (OCAS-TKBS-0002). For the purpose of this evaluation, it is assumed that similar exposures occurred at TCC. Doses from filtering operations have been estimated for the hands and forearms; maintenance personnel may also have had extremity dose.

Surface dose rates on yellowcake have been reported to be about 203 mrad per hour (DOE, 2000).

For extremity dose in the fertilizer plant, the 203 mrad per hour rate for yellowcake was multiplied by a factor of 4.3 to allow for other radionuclides and divided by 312 to allow for the lower concentration of uranium in phosphate products (see Section 7.3.4.1), resulting in a beta dose rate of 2.8 mrad per hour.

For the Uranium Recovery Plant extremity exposures, an estimate was made of shallow dose to the hands and forearms based on direct contact with pure yellowcake; yellowcake concentration in the product delivered to the AEC was estimated to be 40% to 60%. A factor of 1.8 was applied to the 203 mrad per hour dose rate for yellowcake to allow for additional radionuclides (see Section 7.3.4.2), resulting in a beta dose rate of 365 mrad per hour. For dose modeling, operation of the Uranium Recovery Plant was assumed to have occurred over a 2-day period (see Section 7.3.4.2). Small amounts of uranium were recovered, and the modeled 2-day period per batch allowed for overnight drying and packaging of recovered yellowcake (see Section 7.2.2). For extremity dose, the time of direct contact with yellowcake in the Uranium Recovery Plant is assumed to be 1 hour per week during the period in which the plant operated. This results in a dose to the skin of the hands and forearms of 365 mrad per week.

To bound extremity dose, calculations are performed for two periods: (1) from the start of plant operations in October 1953 through April 1954 doses are assumed to have occurred from both fertilizer plant and uranium plant work as done in Section 7.3.4.2; and (2) from May 1, 1954, through the end of the covered period exposure is modeled only from the fertilizer plant because the uranium plant was shut down.

Prior to April 1954, workers are assumed to have 1 hour of extremity dose per week from the uranium plant (365 mrem per hour) and 5 hours of extremity dose per week from the phosphate plant (2.8 mrem per hour), resulting in a dose of 379 mrem per week, or 0.054 rem per calendar day.

Starting May 1, 1954, 1 hour per day, 6 days per week, extremity exposure at the fertilizer plant (2.8 mrem per hour) is presumed, resulting in a dose of 17 mrem per week, or 0.0024 rem per calendar day.

7.3.5 External Dose from Residual Contamination

External photon dose from residual contamination is considered. The modeled external dose rates from uranium recovery operations were based on a model source term that would no longer be present because the drum of yellowcake would be gone (delivered to AEC). Dose from residual contamination in the Blockson facility is used to bound dose from residual contamination at TCC. Blockson's uranium 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 information in Section 5.0 of the Blockson Technical Basis Document, the photon dose from residual contamination at TCC will be assumed to be 0.06 R/yr (OCAS-TKBS-0002). For TCC the dose rate will be applied as a constant because the TCC uranium plant produced less than 1% of the total uranium produced at Blockson. This dose rate is applicable to the Uranium Recovery Plant starting April 1, 1954, and continuing throughout the residual contamination period. However, the photon dose from the fertilizer plant is higher and will be applied through the end of the AWE period in September 1955.

Beta dose from residual contamination is considered insignificant once the yellowcake was removed from the facility.

7.3.6 External Dose from X-ray Examinations

There is no specific information available on occupational X-ray exposure that workers may have received during the covered period. The formal contract (that replaced the 1952 letter contract) between the AEC and TCC in 1953 had a provision requiring TCC "to conform to all minimum health and safety regulations and requirements of the Commission" (AEC, 1953). The AEC considered an annual chest X-ray to be standard procedure for phosphate plant workers engaged in uranium recovery work (AEC, 1953b). Since there are no available records to determine which workers may have been required by TCC to have X-ray examinations, an annual chest X-ray examination is presumed to have been administered to all workers during the AEC covered period of 1953 through 1955. Doses should be assigned according to the recommendations in ORAU-OTIB-006.

7.3.7 External Dose Summary

This evaluation estimated bounding external doses for members of the proposed class. The estimated doses are summarized in Table 7-11.

| Table 7-11: Summary of External Doses for Texas City Chemicals | | | |
|---|--|--|---|
| Time Period | Dose¹ | 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 |
| | 0.010 rem/day | Electrons >15 keV | Shallow dose from yellowcake |
| | 0.0021 rem/day | Electrons >15 keV | Shallow dose from contaminated clothing |
| | 0.054 rem/day (operators and maintenance workers) | Electrons >15 keV | Shallow dose to skin of hands and forearms |
| April 1, 1954, through March 31, 1955 | 0.00060 rem/day | Photons 50% 30 - 250 keV 50% > 250 keV | Deep dose equivalent |
| | 0.00020 rem/day | Electrons >15 keV | Shallow dose from phosphates |
| | 0.0024 rem/day (operators and maintenance workers) | Electrons >15 keV | Shallow dose to skin of hands and forearms |
| April 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.

7.3.8 External Dose Reconstruction Feasibility Conclusion

This evaluation concludes that external dose reconstruction from uranium extraction operations for members of the proposed class is feasible based on source term information. Favorable exposure time estimates can be applied to modeled external dose rates. For work outside of the Uranium Recovery Plant, external dose data from other phosphate plants provides a basis for estimating dose to workers in the phosphate plant during the evaluated period.

7.4 Evaluation of Petition Basis for SEC-00088

The following assertions, made on behalf of petition SEC-00088 for the Texas City Chemicals, Inc., site, were evaluated. Information and affidavit statements provided by the petitioner are summarized in the italicized statements below; the comments that follow are from NIOSH.

Radiation monitoring records for members of the proposed class may have been lost, falsified, or destroyed.

Information regarding monitoring from TCC is unavailable.

NIOSH has been unable to obtain any radiation monitoring records for members of the proposed class. At this time, it is not known if radiation monitoring records ever existed. If they were generated, they appear to have been lost or destroyed. In the absence of exposure data for TCC, NIOSH has developed claimant-favorable methods to estimate

worker doses from uranium recovery work at TCC. These methodologies are described in Sections 7.2 and 7.3.

7.5 Summary of Feasibility Findings for Petition SEC-00088

This report evaluates the feasibility for completing dose reconstructions for employees at the TCC from October 5, 1953, through December 31, 1956. NIOSH found that the process descriptions and source term data available are sufficient to complete dose reconstructions for the proposed class of employees with the exception of radon exposures through September 1955.

NIOSH finds that all doses can be reconstructed after September 1955.

Table 7-12 summarizes the results of the feasibility findings at TCC for each exposure source.

| Table 7-12: Summary of Feasibility Findings for SEC-00088 | | |
|--|--------------------------------|------------------------------------|
| October 5, 1953 through December 31, 1956 | | |
| Source of Exposure | Reconstruction Feasible | Reconstruction Not Feasible |
| Internal | X | |
| - U-238 and associated progeny | X | |
| - U-235 and associated progeny | X | |
| - Th-232 and associated progeny | X | |
| - Radon during AWE period (ended September 30, 1955) | | X |
| - Radon during Residual Period | X | |
| External | X | |
| - Gamma | X | |
| - Beta | X | |
| - Neutron | X | |
| - Occupational Medical X-ray | X | |

Although NIOSH found that it is not possible to completely reconstruct radiation doses for the proposed class, NIOSH intends to use any monitoring data that may become available for an individual claim (and that can be interpreted using existing NIOSH dose reconstruction processes or procedures). Therefore, dose reconstructions for individuals employed at Texas City Chemicals during the period from October 5, 1953 through September 30, 1960, but who do not qualify for inclusion in the SEC, may be performed using these data as appropriate.

8.0 Evaluation of Health Endangerment for Petition SEC-00088

The health endangerment determination for the class of employees covered by this evaluation report is governed by both EEOICPA and 42 C.F.R. § 83.13(c)(3). Under these requirements, if it is not feasible to estimate with sufficient accuracy radiation doses for members of the class, NIOSH must also determine that there is a reasonable likelihood that such radiation doses may have endangered the health of members of the class. Section 83.13 requires NIOSH to assume that any duration of unprotected exposure may have endangered the health of members of a class when it has been

established that the class may have been exposed to radiation during a discrete incident likely to have involved levels of exposure similarly high to those occurring during nuclear criticality incidents. If the occurrence of such an exceptionally high-level exposure has not been established, then NIOSH is required to specify that health was endangered for those workers who were employed for a number of work days aggregating at least 250 work days within the parameters established for the class or in combination with work days within the parameters established for one or more other classes of employees in the SEC.

Due to the lack of radon monitoring data for workers who were processing Ra-226-bearing materials in the production of phosphoric acid, and the lack of sufficient facility information to model potential radon exposures, it is not feasible to estimate radon exposures in the phosphoric acid plant at Texas City Chemicals with sufficient accuracy. There are no data to associate specific individuals with work in that plant or to conclude a worker was not exposed in the plant; therefore, NIOSH cannot estimate the maximum radiation dose for members of the NIOSH-proposed class with sufficient accuracy.

NIOSH's evaluation determined that it is not feasible to estimate radiation dose for members of the NIOSH-proposed class with sufficient accuracy based on the sum of information available from accessible resources. Modification of the class definition regarding health endangerment and minimum required employment periods, therefore, is required.

9.0 Class Conclusion for Petition SEC-00088

The petitioner requested evaluation of all laborers from January 1, 1952, through December 31, 1956. Since the filing of the petition, the start date for TCC as an AWE facility was changed from January 1, 1952, to October 5, 1953, and the end date was changed from December 31, 1956, to September 1955.

In this evaluation, NIOSH considered exposures to all workers in order to bound the estimates of potential exposure for the petitioner's proposed class of "laborers." The petitioner-requested class was modified because radiation monitoring records are unavailable for TCC workers for the specified period, and all TCC employees were potentially exposed to radioactive materials as a result of AEC-related uranium extraction processes.

Based on its research, NIOSH modified the petitioner-requested class to define a single class of employees for which NIOSH cannot estimate radiation doses with sufficient accuracy. The NIOSH-proposed 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 in the Special Exposure Cohort.

NIOSH concluded that maximum radiation dose from residual contamination starting October 1, 1955, can be reconstructed.

NIOSH has carefully reviewed all material submitted by the petitioner, including the specific assertions stated in the petition, and has responded herein (see Section 7.4). NIOSH has also reviewed available technical resources and many other references, including the Site Research Database, for

information relevant to SEC-00088. In addition, NIOSH reviewed its NOCTS dose reconstruction database to identify EEOICPA-related dose reconstructions that might provide information relevant to the petition evaluation.

These actions are based on existing, approved NIOSH processes used in dose reconstruction for claims under EEOICPA. NIOSH's guiding principle in conducting these dose reconstructions is to ensure that the assumptions used are fair, consistent, and well-grounded in the best available science. Simultaneously, uncertainties in the science and data must be handled to the advantage, rather than to the detriment, of the petitioners. When adequate personal dose monitoring information is not available, or is very limited, NIOSH may use the highest reasonably possible radiation dose, based on reliable science, documented experience, and relevant data to determine the feasibility of reconstructing the dose of an SEC petition class. NIOSH concludes that it has complied with these standards of performance in determining the feasibility or infeasibility of reconstructing dose for the class under evaluation.

10.0 References

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42 C.F.R. pt. 82, *Methods for Radiation Dose Reconstruction Under the Energy Employees Occupational Illness Compensation Program Act of 2000*; Final Rule; May 2, 2002; SRDB Ref ID: 19392.

42 C.F.R. pt. 83, *Procedures for Designating Classes of Employees as Members of the Special Exposure Cohort Under the Energy Employees Occupational Illness Compensation Program Act of 2000*; Final Rule; May 28, 2004; SRDB Ref ID: 22001.

42 U.S.C. §§ 7384-7385 [EEOICPA], *Energy Employees Occupational Illness Compensation Program Act of 2000*, as amended; OCAS website (<http://www.cdc.gov/niosh/ocas>).

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