Draft

ADVISORY BOARD ON

RADIATION AND WORKER HEALTH

National Institute for Occupational Safety and Health

Review of the Linde Ceramics Plant Special Exposure Cohort (SEC) Petition 00154 and the NIOSH SEC Petition Evaluation Report

Contract No. 200-2009-28555
SCA-TR-SEC2011-0006

Prepared by

Stephen L. Ostrow, PhD

S. Cohen & Associates
1608 Spring Hill Road, Suite 400
Vienna, VA 22182

Saliant, Inc.
5579 Catholic Church Road
Jefferson, Maryland 21755

July 2011

S. Cohen & Associates: ***Technical Support for the Advisory Board on Radiation and Worker Health Review of NIOSH Dose Reconstruction Program***	Document No. SCA-SEC2011-0006 Effective Date: Draft – July 11, 2011 Revision No: 0 – Draft
Review of the Linde Ceramics Plant Special Exposure Cohort (SEC) Petition 00154 and the NIOSH SEC Petition Evaluation Report	Page 2 of 23
Task Manager: _____ Date: _____ Stephen L. Ostrow, PhD	Supersedes: N/A
Project Manager: _____ Date: _____ John Mauro, PhD, CHP	Reviewer: John Mauro

TABLE OF CONTENTS

LIST OF TABLES

ABBREVIATIONS AND ACRONYMS

ABRWH or the Board	Advisory Board on Radiation and Worker Health
AEC	Atomic Energy Commission
AWE	Atomic Weapons Employer
CFR	Code of Federal Regulations
Ci	Curie (unit of activity)
DOE	Department of Energy
dpm	Disintegration per Minute
EEOICPA	Energy Employees Occupational Illness Compensation Program Act of 2000
ER	(SEC Petition) Evaluation Report
FUSRAP	Formerly Utilized Sites Remedial Action Program
L	Liter
MAC	Maximum Allowable Concentration (equivalent to 70 dpm alpha activity)
MED	Manhattan Engineering District
NIOSH	National Institute for Occupational Safety and Health
ORAUT	Oak Ridge Associated Universities Team
ORNL	Oak Ridge National Laboratory
pCi	pico-Curie
SC&A	S. Cohen & Associates
SEC	Special Exposure Cohort
SRDB	Site Research Database
TBD	Technical Basis Document
TIB	Technical Information Bulletin
WG	Work Group
WLM	Working Level Month (measure of radon exposure)

EXECUTIVE SUMMARY

The Advisory Board on Radiation and Worker Health (the Board) directed SC&A to perform a review of the Linde Special Exposure Cohort (SEC) Petition 00154 (SEC-00154 2009) and National Institute for Occupational Safety and Health's (NIOSH) response to it in its SEC Petition Evaluation Report (NIOSH 2010). The petition calls for adding the worker class to the SEC, defined as, "All employees who worked in any area at Linde Ceramics in Tonawanda, New York, from November 1, 1947 through December 31, 1953." NIOSH received the petition on November 5, 2009, qualified it on January 19, 2010, and produced its evaluation report on November 2, 2010, in which it asserts the following:

> *Based on its full research of the class under evaluation, NIOSH has obtained uranium urinalysis results, film badge reports, air monitoring data, and radiation contamination survey data for the time period evaluated. Based on its analysis of these available resources, NIOSH found no part of the class under evaluation for which it cannot estimate radiation doses with sufficient accuracy.*

SC&A examined the petition, the NIOSH petition evaluation report, and a number of supporting documents, to assist the Board in assessing the degree to which NIOSH can "estimate radiation doses with sufficient accuracy," using the criteria of 42 CFR 83. Important, related considerations are the adequacy and completeness of the data relied upon by NIOSH. This report presents the results of SC&A's investigations. Findings are summarized in Table 1. The table gives only a short description of each finding, and the main body of this report should be consulted for a full explanation. All findings relate to the reconstruction of internal or external exposure; there are no findings related to occupational medical or environmental exposures. The first three findings, which SC&A identified from the SEC-00154 Petition, are discussed further in Table 3; the last three findings result from SC&A's review of the petition, NIOSH's response, and other documents.

Table 1. Summary of Findings

No.	Internal/ External	Section	Description
SEC-00154 Petition Issues			
1			**Worker Class:** "NIOSH cannot with any certainty define whether employees were limited to work in specific buildings at the Linde Ceramics site" (p. 1). Hence, the class should consist of "all workers." Several included worker statements are cited in support of this assertion.
2			**Records/Data (SEC Category F3):** The petition refers to Issues 2 (Air Concentration Data) and 7 (Radon Exposure and Concentration) of SC&A 2009 in support of its claim that limitations of available DOE and/or AWE radiation exposure records "might prevent the completion of dose reconstructions for members of the class" (SEC-00154 2009). The petition goes on to assert: "Furthermore, there is insufficient bioassay data from 1947 through 1953 that can provide an accurate depiction of the resuspension of the inhalation particles that workers were subjected to during this time period.

Table 1. Summary of Findings

No.	Internal/ External	Section	Description
			NIOSH cannot estimate with sufficient accuracy how much of that resuspension of inhalation particles was process emission versus resuspension."
3			**Monitoring Workers (SEC Category F1):** The petition claims that workers who should have been monitored were not, and refers to attached worker statements in support.
Issues Identified by SC&A			
4	I/E	3.2.1.2	**Utility Tunnel Timeline:** Although there has been a considerable amount of discussion between NIOSH, SC&A, and the petitioners about the timeline for tunnel construction, SC&A still does not believe that the timing is clear, and SC&A would like NIOSH to provide a consolidated, illustrated (with plot plans showing the tunnel locations), well-documented report supporting its assumptions.
5	I	3.2.1.2	**Utility Tunnel Radon Exposure:** The NIOSH SEC-00154 Petition Evaluation Report assumption of a 10 pCi/L radon level present in the utility tunnels should be replaced by the 99.31 pCi/L plausible upper-bound estimate of the NIOSH SEC-00107 Petition Evaluation Report (Rev. 1), whose methodology was developed subsequent to the release of the NIOSH SEC-00154 report.
6	E	3.3.2	**Job Categories:** Based on worker written and oral statements in the SEC-00154 Petition and in other places (e.g., SC&A 2010), it may have been common for workers formally assigned to a particular task in a particular area to be informally reassigned to other tasks in other areas in a fluid fashion to accommodate changing task requirements. Hence, given these uncertainties, a claimant-favorable approach would be to assign unmonitored or partially monitored workers with the highest external exposures experienced during a given time period.

1.0 INTRODUCTION

1.1 SCOPE AND PURPOSE OF THE SEC REVIEW

The Advisory Board on Radiation and Worker Health (the Board) directed S. Cohen and Associates (SC&A) to perform a review of the Linde Special Exposure Cohort (SEC) Petition-00154 (SEC-00154 2009) and the National Institute for Occupational Safety and Health (NIOSH) SEC Petition Evaluation Report (ER) (NIOSH 2010), which responds to that petition. This report presents the results of SC&A's review of the Linde SEC Petition and the NIOSH ER.

The scope of this review addresses specific issues of concern raised in the petition and NIOSH's response to those concerns, as given in the ER. In addition, SC&A identified issues that it believed need to be addressed, but were not explicitly identified by the petitioners.

In the course of its assessment, SC&A reviewed selected documents that were considered relevant to the petition, including the following:

- Documents referenced in the petition
- Documents referenced/cited in the ER and site profile [NIOSH 2009, also known as the Technical Basis Document (TBD)]
- Documents contained in the NIOSH Site Research Database (SRDB)
- Other relevant documents

The purpose of this review is to provide the Board with an independent assessment of issues and concerns that may impact the feasibility of dose reconstruction during the SEC period and NIOSH's response and proposed methods for addressing them. Following a formal, multi-step issues resolution process, any unresolved findings may then be used by the Board to determine whether radiation doses can be estimated with sufficient accuracy, as defined in 42 CFR §83.13(c)(1); adequacy and completeness of the data are important factors to consider.

1.2 TECHNICAL APPROACH AND REVIEW CRITERIA

The approach used by SC&A to perform this review follows the protocols described in the draft report prepared by SC&A entitled, *Board Procedures for Review of Special Exposure Cohort Petitions and Petition Evaluation Reports*, Revision 1 (SC&A 2006b) and the *Report to the Working Group on Special Exposure Cohort Petition Review* (SC&A 2006a). The latter is a set of draft guidelines prepared by a Board-designated work group (WG) for evaluation of SEC petitions performed by NIOSH and the Board. The former is a set of draft procedures prepared by SC&A and approved by the Board for use by SC&A on an interim basis (ABRWH 2006, pg. 132). The procedures are designed to help ensure compliance with Title 42, Part 83, of the *Code of Federal Regulations* (42 CFR 83) and implement the guidelines provided in the report of the WG.

Key review criteria identified in the report of the WG include the following; the individual criteria have differing degrees of applicability depending on the details of a particular SEC petition and ER:

- Timeliness (It should be noted that SC&A does not evaluate timeliness in its SEC reviews, but leaves it for consideration by the Advisory Board)
- Fairness
- Understandability
- Consistency
- Credibility and validity of datasets, including pedigree of the data, methods used to acquire the data, relationship to other sources of information, and internal consistency
- Representativeness and completeness of the exposure data with respect to the area of the facility, the time period of exposure, the types of workers, and processes covered by the data

SC&A's implementation of the SEC review process includes the following steps:

(1) Conduct a critical review of the petition and relevant reports, documents, and data that are enclosed and/or referenced in the petition/reports.

(2) Interview petitioners, claimants, workers, etc. Note that this was done as part of the site profile review process and in conjunction with reviewing Linde SEC Petition 00107 (SEC-00107 2008) and NIOSH's petition ER (NIOSH 2008) for that petition (SC&A 2010). SC&A reviewed worker statements provided in SEC Petition 00154, but did not find it necessary to perform additional interviews in support of this report.

(3) Identify additional issues/concerns that emerged from SC&A's document review, which are independent of those stated in the petition.

(4) As part of the SEC review, develop technical positions for issues identified in the petition, and present SC&A's independent findings.

SC&A's report with its findings will subsequently undergo a multi-step issues resolution process. Resolution includes a transparent review and discussion of draft findings with members of the Board's WG, petitioners, claimants, and interested members of the public. This resolution process is intended to ensure that each finding is evaluated on its technical basis in a fair and impartial manner.

1.3 BACKGROUND INFORMATION

The site profile (NIOSH 2009), as well as the NIOSH SEC-00154 Petition ER (NIOSH 2010), present extensive background information on the history and operations of the Linde plant; a brief summary is presented here for the purpose of orientation.

In October 1942, the Linde Ceramics Plant, located in Tonawanda, New York, was contracted by the U.S. government to develop appropriate facilities and methods to perform large-scale

processing of domestic and African uranium ores for the Manhattan Engineer District (MED) as part of its mission to develop nuclear weapons. Linde was selected for the MED contract because of its experience in the ceramics business, part of which involved processing uranium to produce salts used to color ceramic glazes. The operational period continued until contract termination in 1949.

Linde processed seven different types of ore—four African ores and three domestic ores; the former entered the site unprocessed and contained all members of the uranium decay chain, while the latter included tailings from vanadium processing that had most of the radium removed before being sent to Linde. Table 5-2 of the SEC-00154 Petition ER (NIOSH 2010) details the properties of the uranium feed material. However, NIOSH does not use this information in its dose reconstructions, relying instead on internal and external exposure data, as well as models using those data.

Processing consisted of three steps: Step I – separation of uranium oxide (U_3O_8) from the incoming ore by acid digestion, precipitation, and filtration (terminated July 31, 1946); Step II – conversion of the uranium oxide to uranium dioxide (UO_2; terminated March 8, 1944); and Step III – conversion of the uranium dioxide to uranium tetrafluoride (UF_4; terminated June 30, 1949 after earlier standby and restart). Hence, Steps I and II operations terminated before the start date (November 1, 1947) of the SEC 00154 period, but Step III continued into the SEC 00154 period (end date December 31, 1953). As noted in the site profile (NIOSH 2009), Linde received ores in various steps from other sites for processing and shipped ores in various steps to other sites for further processing. Beginning in 1949, shortly before the end of Step III production, the Linde site underwent decontamination and cleanup, and in 1954, the site was released for private use. This period is referred to as the "decontamination period." Section 2.6 of the site profile provides details on the decontamination and cleanup activities.

The post-1954 era at the Linde site is known as the "residual period," and it was during this time that the various buildings at the site began to undergo renovation and remediation. In 1976, Oak Ridge National Laboratory (ORNL) performed a radiological survey, and in 1980, Linde was designated as a FUSRAP (Formerly Utilized Sites Remedial Action Program) site. Linde then underwent two periods of FUSRAP remediation, from 1988–1992 and in 1996. All of the uranium processing buildings except Building 31 were demolished during this remediation period. Table 2-1 of the Linde Site Profile (NIOSH 2009) provides a convenient table of key dates in the life of the Linde plant, while Table 5-3 of the SEC-00154 Petition ER (NIOSH 2010) provides a timeline specifically for the SEC-00154 period; the latter is reproduced below in Table 2 for convenient reference:

Table 2. Linde Ceramics Timeline for the Period Under Evaluation

Year	Event(s)
1947	Step III production resumes.
1948	Steps I and II process equipment dismantling begins.
1949	Step III production ends. Decontamination of Building 30 continues.
1950	Decontamination of Building 30 complete.
1952	Step III dismantlement begins.
1954	AEC contractual work comes to an end with completion of clean-up activities. Building 38 released to Linde.

Reproduced from NIOSH 2010, Table 5-3

It should be noted that the SEC petition in question, SEC-00154, covers the time period from November 1, 1947, through December 31, 1953. A previously approved SEC petition covers the operations time period from October 1, 1942, through October 31, 1947, and SEC Petition 00107 covers the residual time period from January 1, 1954, through July 31, 2006. The Advisory Board recommended granting the latter petition for the time period from January 1, 1954, through December 31, 1969 (renovation period) and denying it for the time period from January 1, 1970, through July 21, 2006 (post-renovation period).

1.4 ORGANIZATION OF THE REPORT

Following this introductory section, Section 2 presents an overview of SEC Petition 00154 and identifies the issues that it raises, and also presents a summary of NIOSH's ER responding to the petition. Section 3 constitutes SC&A's assessment of the petition and NIOSH's response, and Section 4 contains a list of documents referenced in this report.

2.0 OVERVIEW OF SEC PETITION 00154 AND THE NIOSH SEC PETITION EVALUATION REPORT

NIOSH received SEC Petition 00154 on November 5, 2009, and qualified it on January 22, 2010, with the following petitioner class definition, as expressed in its SEC petition ER of November 2, 2010:

> *All employees who worked at the Linde Ceramics Plant in Tonawanda, New York, from November 1, 1947 through December 31, 1953* (NIOSH 2010, p. 3).

NIOSH claims that there are sufficient data to estimate the radiation doses to workers during the SEC period. NIOSH 2010 states:

> *Based on its full research of the class under evaluation, NIOSH has obtained uranium urinalysis results, film badge reports, air monitoring data, and radiation contamination survey data for the time period evaluated. Based on its analysis of these available resources,* ***NIOSH found no part of the class under evaluation for which it cannot estimate radiation doses with sufficient accuracy****.*
> [Emphasis added.]

The first step in SC&A's analysis of the petition and NIOSH's response is to identify the petitioners' concerns as precisely as possible. Following a few forms, the petition consists of a short discussion of the proposed SEC class and an argument for granting the petition, followed by several supporting documents, including worker interviews, statements, and other material, as well as an SC&A report concerned with resolution of Linde site profile issues, appended in its entirety (SC&A 2009). The SC&A report, which was prepared at the request of the Board's Linde WG to help inform its deliberations related to the status of issues raised about the Linde site profile, stated the expressed issues and traced, in some detail, the disposition of each one through SC&A and NIOSH technical papers, and Linde WG meetings. SC&A found that all issues were resolved "in concept."[1]

SC&A determined that the petition raises three distinct issues. Table 3 summarizes these issues, along with NIOSH's response to them in its ER (see Section 7.4 of NIOSH 2010) and SC&A's assessment of whether NIOSH addressed the petition concerns in a satisfactory fashion.

[1] Some issues were effectively put in "abeyance" pending further agreed-upon actions by NIOSH.

Table 3. Linde SEC 00154 Petition Issues, NIOSH Petition Evaluation Report Responses, and SC&A Assessment

Linde SEC 00154 Petition Issue	NIOSH SEC Petition Evaluation Report	SC&A Comments
1. Worker Class: "NIOSH cannot with any certainty define whether employees were limited to work in specific buildings at the Linde Ceramics site" (pg. 1). Hence, the class should consist of "all workers." Several included worker statements are cited in support of this assertion.	NIOSH accepted the proposed class as applicable to: "All employees who worked in any area at the Linde Ceramics Plant in Tonawanda, New York, from November 1, 1947 through December 31, 1953."	NIOSH accepted the petition's class definition, so there is no further issue to consider.
2. Records/Data (SEC Category F3): The petition refers to Issues 2 (Air Concentration Data) and 7 (Radon Exposure and Concentration) of SC&A 2009 in support of its claim that limitations of available DOE and/or AWE radiation exposure records "might prevent the completion of dose reconstructions for members of the class" (SEC-00154 2009). The petition goes on to assert: "Furthermore, there is insufficient bioassay data from 1947 through 1953 that can provide an accurate depiction of the resuspension of the inhalation particles that workers were subjected to during this time period. NIOSH cannot estimate with sufficient accuracy how much of that resuspension of inhalation particles was process emission versus resuspension."	NIOSH concluded that the petition does not present adequate support for its assertion relative to the adequacy of exposure records; however, NIOSH believes that it has sufficient data on hand to reconstruct doses in an acceptable fashion. This is discussed in Section 7.4.2 of NIOSH 2010.	Site Profile Issues 2 and 7 of SC&A 2009, which form the basis of the petition's claim, were closed by the Linde Work Group as noted by NIOSH in Section 7.4.2 of NIOSH 2010. NIOSH investigated the areas further in its SEC 00154 Petition Evaluation Report, and concluded that it had sufficient information to estimate exposures with sufficient accuracy. This report discusses Issue 2 (air concentration and other internal dose concerns) in Section 3.2.2 and Issue 7 (aboveground radon) in Section 3.2.1.1, and believes that NIOSH has treated exposure estimations in acceptable fashions in both cases.
3. Monitoring Workers (SEC Category F1): The petition claims that workers who should have been monitored were not, and refers to attached worker statements in support of the assertion.	NIOSH concluded that the petition does not present adequate support for its assertion relative to the adequacy of exposure records; however, further investigation by NIOSH determined that "…monitoring did not adequately assess all potential exposures or exposure periods. Based on this information, NIOSH concluded that the F.1 basis is sufficiently supported" (NIOSH 2010, p. 9).	NIOSH accepted, with limitations, the petition's assertion, but its acceptance relied on evidence not presented in the petition to reach that conclusion. This formed the basis for NIOSH's qualification of the SEC petition. SC&A believes that NIOSH's coworker model for unmonitored and partially

Table 3. Linde SEC 00154 Petition Issues, NIOSH Petition Evaluation Report Responses, and SC&A Assessment

Linde SEC 00154 Petition Issue	NIOSH SEC Petition Evaluation Report	SC&A Comments
	Section 7.4.1 of NIOSH 2010 enumerates what monitoring data are available and notes that "Linde Ceramics Plant workers employed after the cessation of Step III operations [in 1949] were not radiation workers" and, therefore, were not monitored.	monitored workers addresses the petitioners' concerns; this is discussed in Section 3.2.2.

3.0 ASSESSMENT OF NIOSH'S ABILITY TO RECONSTRUCT EXPOSURES DURING THE SEC-00154 PERIOD

3.1 INTRODUCTION

The SEC petition raises a number of issues (summarized here in Table 1) related to reconstructing internal and external exposures to workers during the SEC-00154 period (November 1, 1947–December 31, 1953). No issues were raised with respect to occupational medical or environmental exposures. Selected elements of the internal and external exposure information and estimation procedures are examined in the following two subsections.

3.2 INTERNAL EXPOSURE

There is clearly a measure of subjectivity involved in deciding whether sufficient information is available for NIOSH to do bounding calculations, per EEOICPA and 42 CFR §83.13(c)(1), 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." In the case of SEC-00154 for the Linde Ceramics Plant, NIOSH has stated that bounding exposures can be estimated:

> *Information available from the site profile and additional resources is sufficient to document or estimate the maximum internal and external potential exposure to members of the evaluated class under plausible circumstances during the specified period* (NIOSH 2010, pg. 3).

The ensuing discussion on bounding internal exposures at Linde during the subject period considers two intertwined issues:

- Whether or not adequate information exists to perform plausible bounding calculations
- Whether or not the approach taken by NIOSH in the SEC-00154 Petition ER (and, by reference, the site profile) is indeed bounding and scientifically justifiable

Internal exposures could have arisen from two different pathways; breathing in radon and breathing in or ingesting particles containing radioactive uranium and its progeny. These pathways will be discussed in turn.

3.2.1 Radon Exposures

Radon is a gaseous, radioactive daughter product of radium on the U-238 decay chain (it is also a product on other decay chains, which is not important here). There were several sources of radon at Linde during the period of concern. The uranium feed ores contained radium; the African ores contained a much higher amount than the domestic ores, since the latter generally were preprocessed to remove radium. Hence, the African ores were much more prolific generators of radon than the domestic ores, and workers may have been exposed to radon during ore processing operations. In addition, workers may have been exposed to radon from radioactive wastes that were disposed of onsite until the end of 1954 (after the December 31,

1953, end of the SEC period), when the initial cleanup was completed (NIOSH 2009), including in the form of liquid waste containing radioactive material that was placed into injection wells around the site (those wells overflowed on occasion). Finally, although not a consequence of Linde operations, soil naturally contains radium from uranium decay and evolves radon gas; this may be an issue for workers in any underground tunnels that were constructed at the Linde site.

3.2.1.1 Aboveground

The NIOSH SEC-00154 Petition ER acknowledges that, "…NIOSH did not locate any radon monitoring data for the period under evaluation; therefore, a data sufficiency and pedigree evaluation is not possible for radon monitoring data during the 1947–1953 time period" (NIOSH 2010, Section 7.1.1). Consequently, NIOSH devised a method for bounding internal radon doses:

> *During Ceramics Plant production, the only source of radon was African ore processing. No direct radon measurements during the period of Step III operations are available. An estimate was made based on the lowest measured indoor concentrations at the Linde site during African ore processing. Approximately 20% of the measurements in the Linde ore-processing building yielded results of 10 pCi/L or less, with most of these results at or near 10 pCi/L. Therefore, 10 pCi/L was assumed to be the outdoor air concentration. After the end of African ore processing, radon concentration in the main ore-processing building (Building 30) and all other Linde Ceramics Plant buildings was assumed to remain at the 10-pCi/L level due to the removal of uranium ores and their raffinates. Concentrations in other Linde buildings were also assumed to be 10 pCi/L until the end of clean-up in those buildings.*
>
> *Because the locations of many workers are likely to be unknown, it was assumed that all workers were exposed to 10 pCi/L of radon from November 1, 1947, through December 31, 1953. As mentioned in Section 5.2, exposure to radon and other uranium progeny are not believed to be a significant source of internal exposure due to the age of the source and product materials, and the fact that the processing residues were shipped offsite for storage. Because there is a lack of source material to increase the radon concentration during the evaluated period, the assumption of a 10 pCi/L radon concentration represents a sufficiently accurate estimate for the purposes of bounding internal exposures for the class under evaluation* (NIOSH 2010, Section 7.2.3.2).

NIOSH's approach, stated above, is consistent with what it presents in the Linde Site Profile (NIOSH 2009, Section 3.5.1). Table 3-5, reproduced here as Table 4, summarizes the radon exposure during the time period of SEC Petition 00154:

Table 4. Ceramics Plant Worker Radon Exposure Rates, 1947 to 1954

Period/Work Location	Time-weighted Concentration (pCi/L)	Exposure Rate (WLM/yr)
11/1/1947 – 7/7/1954		
All workers	10.0	0.480

Source: NIOSH 2009, Table 3-5

As NIOSH notes, radon measurements associated with Step III processing are not available. However, through the course of several exchanges of technical information with NIOSH in writing and during Linde WG meetings, SC&A examined and accepted the above-quoted method of bounding internal radon exposures and the assumption of a 10 pCi/L radon concentration for all workers (since their locations cannot be established with certainty), as reported in SC&A's assessment (SC&A 2009, Issue 7) of the disposition of the Linde Site Profile issues. Therefore, SC&A considers this method acceptable with regard to reconstructing radon exposures to workers above ground during the SEC-00154 time period.

3.2.1.2 Tunnels

The Linde Site had a system of utility tunnels underground from building to building, several branches of which still exist today; individual tunnel sections were built at different times over the years. Tunnel segment sizes varied, with a maximum of about 8–10 ft high and 15 ft wide. Several exhaust fans (approximately 6 ft in diameter) provided ventilation, with an estimated average air exchange rate of approximately once every 10 hours. The tunnels were never continuously occupied and were never used to carry or store radioactive material, although some workers spent extended periods working in them on utility-related projects, and other workers passed through them from one building to another without having to go aboveground and be exposed to the weather (this was not an authorized practice, but worker interviews and statements indicated that the tunnels represented a customary "short cut" and even a "resting place"). The issue of dose to workers in the tunnels was considered during evaluation of Linde SEC Petition 00107, the residual time period, which follows the time period under consideration in SEC Petition 00154. Part of the issue relevant to the latter petition concerns when individual tunnel segments were constructed.

The NIOSH SEC-00154 Petition ER (NIOSH 2010) discusses the utility tunnels and, after referring to various documents, including tunnel drawings, asserts that "the utility tunnel sections near the Ceramics Plant (Buildings, 30, 31, 37 and 38) were constructed in 1957 and 1961, which is after the December 31, 1953 end date of the covered period... There was also a utility tunnel section running between Building 14 (the "Tonawanda Laboratory") and Building 8 (the "Power House") that was assumed to be in existence during the SEC period" (Section 5.1).

Issue 4: Utility Tunnel Timeline. Although there has been a considerable amount of discussion among NIOSH, SC&A, and the petitioners about the timeline for tunnel construction, SC&A still does not believe that the timing is clear, and SC&A would like NIOSH to provide a consolidated, illustrated (with plot plans showing the tunnel locations), well-documented report supporting its assumptions.

After some discussion, the NIOSH SEC-00154 Petition ER (NIOSH 2010) concludes that:

> *…there is no evidence of an increased radium source-term for soils near the utility tunnel section running between Building 14 (the "Tonawanda Laboratory") and Building 8 (the "Power House"), which was assumed to be in existence during the SEC period. Therefore, NIOSH believes that a 10 pCi/L radon level that has been established for surface buildings in the Ceramics Plant will be bounding for these worker exposures during the SEC-00154 petition period* (Section 7.2.3.2).

However, subsequent to the release of NIOSH 2010, long, detailed exchanges of technical information in writing and at Linde WG meetings resulted in NIOSH adopting a different methodology for estimating radon exposures in the tunnels. The final methodology (based on measured radon concentrations in basements in the vicinity of the Linde plant) is presented in Attachment 3 of Rev. 1 of the NIOSH SEC-00107 Petition ER (NIOSH 2011), which concludes:

> *NIOSH proposes that the 95th percentile value of 99.31 pCi/L provides a plausible upper bound estimate for radon exposure in the Linde utility tunnels for* ***all years*** *at the Linde site beginning from the first MED production through the present time.* (Emphasis added.)

The final, settled value is approximately a factor of 10 higher than that proposed in the NIOSH SEC-00154 Petition ER and should be applied to the SEC-00154 period in accordance with the above statement. In addition, since it cannot be established where particular employees were actually located (compelling worker testimony and statements indicate that worker assignments were quite flexible, with workers filling in wherever they were needed), the utility tunnel radon exposure dose should be applied to all workers on the site during the subject period. A related issue, which is actually a dose reconstruction rather than an SEC issue, is the tunnel occupancy factor to assign to workers. NIOSH has proposed adopting a 20% factor. However, based on worker testimony and statements to the effect that workers often casually walked through the tunnels and may have even rested there, this factor may be too low. Whichever value is chosen, however, does not affect the feasibility of assigning tunnel radon doses.

Issue 5: Utility Tunnel Radon Exposure. The NIOSH SEC-00154 Petition ER assumption of a 10 pCi/L radon level present in the utility tunnels should be replaced by the 99.31 pCi/L plausible upper-bound estimate of the NIOSH SEC-00107 Petition ER (Rev. 1), whose methodology was developed subsequent to the release of the NIOSH SEC-00154 report.

3.2.2 Bounding Internal Doses

The special cases of radon exposure above ground and in the utility tunnels were discussed in the previous sections. The main pathway for internal exposure to operating plant personnel, however, was inhalation and/or ingestion of uranium compounds associated with the different processing steps, while the main pathway for non-operating personnel was inhalation and/or ingestion of resuspended particles from plant activities and from decontamination activities.

As reported in Section 6.1 of NIOSH 2010, NIOSH has located uranium urinalysis (bioassay) data taken over the time period of interest for SEC Petition 00154, and summarizes what's available in Table 6-1 of the SEC-00154 Petition ER (reproduced here as Table 5). Step III operations ceased in 1949; hence, the subsequent large drop in bioassays.

Table 5. Number of Available Linde Bioassay Records per Year

Year	# of Samples
1947	75
1948	372
1949	183
1950	11

Source: NIOSH 2010, Table 6-1

The urinalysis data pertain to 41 of the 43 workers identified as Step III process workers, as NIOSH determined by examining a number of log sheets, log books, and other sources of information. However, NIOSH acknowledges that since it does not have evidence that every employee who should have been monitored was, in fact, monitored, it will use the bioassay data as input to construct a coworker model in accordance with ORAUT-OTIB-0019 (ORAUT 2005) methodology for unmonitored or incompletely monitored workers; the coworker model covers the period from November 1947 through January 1950 (Step III shutdown occurred on June 30, 1949 and D&D operations of Building 30 were completed by March 29, 1950) and is documented in Attachment D of the Linde Site Profile (NIOSH 2009); that attachment should be consulted for detailed information on how the coworker model was constructed.

The coworker model approach was developed by NIOSH in response to SC&A comments (Issues 2, 3, 4, and 10) and accepted by SC&A and the Linde WG during the site profile review process, as documented in SC&A 2009. Furthermore, SC&A evaluated the TIB as part of its assignment from the Advisory Board to review NIOSH procedures and resolve issues, and determined that all issues have been resolved. Hence, application of this TIB here is appropriate and the TIB itself is satisfactory.

From log sheets, log books, and other sources of information, NIOSH has also located breathing zone, general air sampling, and contamination survey data that were taken during the operational period (NIOSH 2010). Table 6 reproduces NIOSH's Table 6-2 summarizing the available data. The number of air samples peaked in 1949, the last year of Step III processing operations.

Table 6. Number of Available Air Monitoring Records Per Year

Year	# of Samples	
	General Air	Breathing Zone
1947	6	0
1948	57	50
1949	150	109
1950	37	19

Source: NIOSH 2010, Table 6-2

Decontamination operations began before the end of Step III processing and continued for a few years afterward; the initial cleanup period may have ended in 1954. Dust concentration data

were obtained from Table V of Heatherton 1950 for different decontamination methods for the concrete and cinderblock surfaces, as well as the building rafters in Building 30 (which housed Steps I and II processing equipment), including sandblasting, vacuum cleaning, flame cleaning, and pneumatic hammering. NIOSH also has access to the original sample logs containing the data and descriptions of the decontamination processes, as well as general area dust sample data. Table 7 reproduces decontamination data from Heatherton 1950:

Table 7. Air Concentrations Measured During 1948–1949 Clean-up of Building 30

Process	Number of Measurements	Air Concentration (MAC[(a)] alpha dust)		
		min.	max.	avg.
Vacuum cleaning	17	0.1	5.3	1.2
Removing concrete floor with pneumatic hammer	6	4.2	25	10
Flame cleaning	6	1.7	13	6.6
Sandblasting	5	7.0	49	22
One-half hour after sandblasting	3	1.0	1	1

(a) – 1 MAC is equivalent to 70 dpm gross alpha activity.
Source: Heatherton 1950, Table V

Raffinates, which are waste material from the uranium processing, were removed from the Linde site prior to the end of operations, so workers after that period would only have been exposed to any remaining residual contamination. Attachment 1 of NIOSH 2009 summarizes available data on uranium and uranium progeny concentrations in different materials at Linde, which can be used to estimate personnel exposures.

NIOSH believes that it has sufficient bioassay and air sample data and can use applicable methodology (such as ORAUT-OTIB-0019 to estimate doses to unmonitored personnel from monitored coworker data) from the Linde Site Profile (NIOSH 2009) to estimate a bounding internal dose estimate from exposure to airborne particulates. NIOSH notes that Step III operational period urinalysis data are used to estimate maximum exposures for workers in the post-operations period through December 31, 1953. As stated before, all site profile issues identified by SC&A and the Linde WG, which included data and methodology items, have been resolved to the satisfaction of the Linde WG, as summarized in SC&A 2009.

3.3 EXTERNAL EXPOSURE

The primary sources of external radiation exposures to Linde workers during the SEC-00154 time period were uranium and uranium progeny during the operations period (direct and resuspended contamination), which ended in 1949, and the decontamination period, which continued to the end of the SEC-00154 time period on December 31, 1953 (resuspended contamination). Section 6.2 of NIOSH 2010 summarizes available external monitoring data, which include film badge data from 1947 to 1949. NIOSH 2010 reports:

> *No personnel external dosimetry data have been identified for Linde Ceramics workers prior to the start of or after the cessation of Step III operations. However, NIOSH does have access to radiological dose rate and contamination data documenting site contamination for the period under evaluation in this report...* (Section 6.2)

External exposures to personnel in the utility tunnels will be discussed separately in the next section.

3.3.1 Tunnel Exposures

Section 3.2.1.2 of this report outlines some of the information available pertaining to the existence and use of utility tunnels that ran under the Linde plant. A detailed 2001 FUSRAP survey for the U.S. Army Corps of Engineers (Army Corps 2002) looked at beta surface contamination levels on the inner surface of the tunnels (many of which may not have been built until after the end of the SEC-00154 period), with 6 to 8 circumferential measurements taken 1 meter apart through the length of the tunnels. In addition, hot spots were located and surveyed separately. As stated in NIOSH 2010, "The beta contamination levels were then converted to individual isotopic activities based on gamma spectroscopy analysis of soil samples taken during site remediation" (Section 6.3). The surface contamination would have accounted for any radioactive effluents seeping into the tunnels from the surrounding soil. The isotopic activities were then used to determine skin and effective dose rates by radionuclides using the claimant-favorable assumption of applying the 95^{th} percentile surface contamination level (including hotspots) to the entire length of the tunnel. SC&A accepted this procedure in its review of the SEC-00107 Petition.

NIOSH 2010 assumes a 2-months per year occupancy factor for workers in the tunnels and, as discussed in the SEC-00107 review process, worker documents and statements suggest that occupancy, at least for some workers, may have exceeded that amount. As before, however, the choice of occupancy factor is a dose reconstruction issue, not an SEC issue, so it is not cited here.

3.3.2 Bounding External Exposures

NIOSH has available a printout of about 6,000 weekly film badge results of beta and gamma exposures for the 1948–1949 period, with many of the records labeled with a job title, allowing NIOSH to perform a statistical analysis of the exposure data by job activity and work area. The methodology appears in the site profile (NIOSH 2009). NIOSH also has available the results of radiation surveys performed at the end of the operational period in 1949, as well as the initial FUSRAP survey of 1976, ORNL 1978 (which found Building 30, the location of Steps I and II processing, to be the most contaminated), to bound external exposures during standby periods and for outdoor areas. NIOSH believes it has sufficient data and applicable methodology (appearing in the site profile, NIOSH 2009) to reconstruct external doses for the workers during the SEC-00154 Petition period.

Section 7.3.4 of the SEC-00154 Petition ER states:

> *External monitoring data summarized in Section 7.3.1.1 can be used as the basis to bound external photon and beta exposure for Linde site workers. Adjustments to these data to account for specific job categories and work areas can be made based on job description and category information that is also contained within the dataset. Adjustments for what are termed "high-" and "low-" risk employees*

are provided in ORAUT-TKBS-0025 [the site profile]*; however, additional adjustments can be made using the available dataset, as appropriate, based on individual claim dynamics.*

For non-operations periods and following cessation of Step III operations, the site profile categorizes workers into three groups; cleanup worker, cleanup support worker, and non-cleanup worker. Dose rates for each group by year appears in Table 4-24 of the site profile.

Issue 6: Job Categories. Based on worker written and oral statements in the SEC-00154 Petition and in other places (e.g., SC&A 2010), it may have been common for workers formally assigned to a particular task in a particular area to be informally reassigned to other tasks in other areas in a fluid fashion to accommodate changing task requirements. Given these uncertainties, a claimant-favorable approach would be to assign unmonitored or partially monitored workers with the highest external exposures experienced during a given time period.

4.0 REFERENCES

42 CFR 83. Title 42, Part 83, of the Code of Federal Regulations. *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, Federal Register/ Vol. 69, No. 104/Friday, May 28, 2004, p. 30764.

ABRWH 2006. *Transcript of the 38th Meeting of the Advisory Board on Radiation and Worker Health, held at the Marriott Metro Center, Washington, DC, on June 16, 2006.* U.S. Department of Health and Human Services, Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health.

Army Corps 2002. *Dose Assessment for the Existing Surface Contamination Within the Linde Utility Tunnel Complex*, FUSRAP Linde Remedial Action; U.S. Army Corps of Engineers, Buffalo District; January 2002.

Heatherton, R.C. 1950. *Decontamination and Survey of Uranium Refinery Plant*, NYO-1536; December 14, 1950; SRDB Ref ID: 29822.

NIOSH 2008. *SEC Petition Evaluation Report, Petition SEC-00107: Linde Ceramics Plant*, Rev. 0, November 3, 2008.

NIOSH 2009. *An Exposure Matrix for Linde Ceramics Plant (including Tonawanda Laboratory)*, ORAUT-TKBS-0025, Rev. 01, PC-1, November 10, 2009.

NIOSH 2010. *SEC Petition Evaluation Report, Petition SEC-00154: Linde Ceramics Plant*, Submittal Date: November 2, 2010.

NIOSH 2011. *SEC Petition Evaluation Report, Petition SEC-00107: Linde Ceramics Plant*, Rev. 1, January 28, 2011.

ORAUT 2005. *Analysis of Coworker Bioassay Data for Internal Dose Assignment*, Rev. 1, October 7, 2005.

ORNL 1978. *Formerly Utilized MED/AEC Sites Remedial Action Program—Radiological Survey of the Former Linde Uranium Refinery, Tonawanda, New York*, W-7405-ENG-26; Oak Ridge National Laboratory (ORNL); May 1978.

SC&A 2006a. *Report to the Working Group on Special Exposure Cohort Petition Review*, Draft, January 16, 2006.

SC&A 2006b. *Board Procedures for Review of Special Exposure Cohort Petitions and Petition Evaluation Reports*, Revision 1. SCA-TR-TASK5-0002, June 12, 2006.

SC&A 2009. *Assessment of the Disposition of SC&A's Linde Site Profile Review Issues in Response to SEC Petitioner Concerns, draft*, August 20, 2009.

SC&A 2010. *Linde Worker Interview Notes: Niagara Falls, New York, May 19-21, 2010,* SC&A draft, May 27, 2010.

SEC-00107 2008. *Linde Ceramics SEC Petitions: SEC00106, November 1, 1947 through December 31, 1953; SEC00107, January 1, 1954 through July 31, 2006 – Linde Ceramics Facility, Tonawanda, New York*, March 19, 2008.

SEC-00154 2009. Linde Ceramics SEC [00154] Petition Application: November 1, 1947 through December 31, 1953, November 5, 2009.