Draft

ADVISORY BOARD ON RADIATION AND WORKER HEALTH

National Institute of Occupational Safety and Health

Review of the NIOSH Site Profile for the Linde Ceramics Plant and Tonawanda Laboratory, Tonawanda, New York

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ACRONYMS AND ABBREVIATIONS

Advisory Board	Advisory Board on Radiation and Worker Health
AEC	U.S. Atomic Energy Commission
α	Alpha particle
AWE	Atomic Weapons Employer
β	Beta particle
CFR	*Code of Federal Regulations*
Ci	Curie (3.7×10^{10} disintegrations/sec)
cm	Centimeter
D&D	Decontamination and decommissioning
DOE	U.S. Department of Energy
dpm	Disintegration per minute
EEOICPA	Energy Employees Occupational Illness Compensation Program Act of 2000
EPA	U.S. Environmental Protection Agency
FUSRAP	Formerly Utilized Sites Remedial Action Program
GSD	Geometric standard deviation
GM	Geometric mean
HCA	High contamination area
HEPA	High-efficiency particulate air
ICRP	International Commission on Radiological Protection
in	Inch
INL	Idaho National Laboratory
IREP	Interactive RadioEpidemiologic Program
KERMA	Kinetic energy released in matter
keV	Kilo electron volt (1,000 electron volts)
kg	Kilogram
kV	Kilovolt
kVp	Kilovolt peak
kW	Kilowatt
lb	Pound
LLD	Lower limit of detection
LOD	Limit of detection
LOOW	Lake Ontario Ordnance Work
mA	Milliampere

MAC	Maximum allowable concentration
MED	Manhattan Engineering District
MCW	Mallinckrodt Chemical Works Plant
MDA	Minimum detectable activity
MDF	Materials Development Facility
mg	Milligram
mR	Milliroentgen
mrad	Millirad
mrem	Millirem
NIOSH	National Institute of Occupational Safety and Health
NYOO	New York Operations Office (of the Atomic Energy Commission)
OCAS	(NIOSH) Office of Compensation Analysis and Support
ORAU	Oak Ridge Associated Universities
ORISE	Oak Ridge Institute for Science and Education
ORNL	Oak Ridge National Laboratory
PA	Posterior-anterior
PAEC	Potential alpha energy concentration
PAEE	Potential alpha energy exposure
PAS	Personal air sampler
PDF	Portable document format
PFG	Photofluorography
PIC	Pocket ionization chamber (i.e., "pencil" dosimeter)
POC	Probability of causation
R	Roentgen
rad	Radiation absorbed dose
rem	Roentgen equivalent man
rep	Roentgen-equivalent-physical
RU	Recycled uranium
SC&A	S. Cohen & Associates, Inc.
SEC	Special exposure cohort
SRS	Savannah River Site
TBD	Technical Basis Document
TCE	Trichloroethylene
TIB	Technical Information Bulletin
TLD	Thermoluminescent dosimeter

UO_3	"Orange oxide"
UO_2	"Brown oxide"
UF_4	"Green salt"
WEC	William Environmental Company
WL	Working level (special unit for exposure to Rn-222 and its progeny)
WLM	Working level month

1.0 EXECUTIVE SUMMARY

Under the Energy Employees Occupational Illness Compensation Program Act (EEOICPA, or the Act) and Federal regulations defined in Title 42, Part 82, of the *Code of Federal Regulations* (42 CFR Part 82), the Advisory Board on Radiation and Worker Health (Advisory Board) is mandated to conduct an independent review of the methods and procedures used by the National Institute of Occupational Safety and Health (NIOSH) and its contractors for dose reconstruction.

As a contractor to the Advisory Board, S. Cohen & Associates (SC&A) has been charged under Task 1 to support the Advisory Board in this effort by independently evaluating the approach taken in a select number of NIOSH site profiles, that correspond to specific facilities at which energy and atomic weapons employees worked and were exposed to ionizing radiation, to gauge their adequacy, completeness, and validity. These evaluations will be used by the Advisory Board to advise the Secretary of Health and Human Services on the scientific validity, quality, and accuracy of dose reconstruction efforts performed by NIOSH and its contractors.

This report presents the results of SC&A's evaluation of ORAUT-TKBS-0025, *An Exposure Matrix for Linde Ceramics Plant (including Tonawanda Laboratory)* (Davidson 2005). This document is also commonly called the Linde Site Profile and the site, the Linde Site or Linde. Our review of the Linde Site Profile focused largely on the quality of available data that characterized the facility and its operations, and the methods prescribed by NIOSH for the use of those data in dose reconstruction. This review was conducted in accordance with *SC&A Standard Operating Procedure for Performing Site Profile Reviews* (SC&A 2004a).

The Linde Site Profile, supplementing individual claimant exposure data and information gathered in interviews with claimants, supports the performance of individual dose reconstructions under the EEOICPA. It contains compilations and analyses of data, such as those related to facility operations and processes, radiological source term characterizations, chemical and physical forms of the radionuclides, historic workplace conditions and practices, incidents involving potential exposures, limits of detection of radiation monitoring methods, and direction for assigning internal and external doses to monitored and unmonitored workers.

In addition, SC&A evaluated and made use of the following Technical Information Bulletins (TIBs) and the general NIOSH dose evaluation guidelines:

- ORAUT-OTIB-0002, *Technical Information Bulletin – Maximizing Internal Dose Estimates for Certain DOE Complex Claims* (Rollins 2004)

- ORAUT-OTIB-0006, *Technical Information Bulletin – Dose Reconstruction from Occupationally Related Diagnostic X-Ray Projections* (Kathren 2003)

- ORAUT-OTIB-0007, *Technical Information Bulletin – Occupational Dose from Elevated Ambient Levels of External Radiation* (Strom 2003)

- ORAUT-OTIB-0023, *Assignment of Missed Neutron Doses Based on Dosimeter Records* (Merwin 2005)

- OCAS-OTIB-009, *Technical Information Bulletin – Estimation of Ingestion Intakes* (NIOSH 2004)

- OCAS–IG-001, *External Dose Reconstruction Implementation Guideline* (Taulbee 2002)

- OCAS–IG-002, *Internal Dose Reconstruction Implementation Guideline* (Allen 2002)

The SC&A review also was informed by a number of outside sources and documents, including interviews with groups of former and retired Linde workers and site experts (summarized in Attachments 2 and 3); Manhattan Engineering District (MED)/New York Operations Office (NYOO) (U.S. Atomic Energy Commission) reports; some documents originally provided to NIOSH by retired site workers and Linde union representatives; contract and technical documents collected by attorneys in charge of the lawsuits brought by claimants; claimant files, documents and information used by NIOSH for the development of the Linde Site Profile; and other pertinent correspondences, including documents and information stored in the Oak Ridge Associated Universities (ORAU) database.

The SC&A review also took note of a relevant Special Exposure Cohort (SEC) petition. On October 12, 2005 (which is subsequent to the issue date of the site profile), NIOSH issued an evaluation report on SEC Petition 00044, submitted on September 29, 2005, covering a class of atomic weapons employees at the Linde Ceramics Plant from October 1, 1942, through October 31, 1947. In this report, NIOSH concluded that dose reconstruction could not be completed because of a lack of sufficient information:

> *Members of this class at the Linde Ceramics Plant may have received internal and external radiation exposures from the uranium and uranium progeny in the ores received and processed at the plant. NIOSH lacks any biological monitoring data or sufficient air monitoring information or sufficient process and radiological source information to estimate the potential airborne concentrations to which the proposed class may have been exposed (i.e., internal exposures).*

In light of the conclusions presented in the NIOSH evaluation report, it is not clear how a dose reconstructor should perform dose reconstruction for a claimant who worked at the site from October 1, 1942, to October 31, 1947.

The Linde Site was originally owned by Union Carbide, Linde Air Products Division, in 1936. It was also known as the Chandler Plant at one time. While portions of the land at the site were previously owned by the Town of Tonawanda, the Excelsior Steel Ball Company, the Metropolitan Commercial Corporation, and the Pullman Trolley Land Company, the land was not used by any of these owners. It is likely that at some point in the past, the land was farmed. Commercial industrial processes were conducted by the Linde Air Products Division of Union Carbide prior to MED operations in the 1940s. Union Carbide operations continued after the

MED-related activities ceased. In the 1990s, Praxair acquired the property and continued to perform commercial industrial processes, focusing primarily on research and development.

From October 1, 1942, to June 30, 1949, portions of the Linde Site were used for the separation of uranium ores. These processing activities, conducted under a MED contract, resulted in radioactive contamination (ACE 2000). A radiological survey report by Oak Ridge National Laboratory (ORNL) in 1978 states that the "site was used for the separation of uranium dioxide from uranium ores and for the conversion of uranium dioxide to uranium tetrafluoride during the period of 1940–1948" (ORNL 1978).

The Linde Site was selected for the MED contract because of its experience in the ceramics business, which involved processing uranium to produce salts used to color ceramic glazes. Under the MED contract, uranium ores from seven different sources were processed in Linde; four African (Belgian Congo) ores (three low-grade pitchblendes and torbernite), and three domestic ores (carnotite from Colorado) (BNI 1993).

The domestic ore tailings sent to Linde Site resulted from commercial processing, conducted primarily in the Western United States, to remove vanadium. The vanadium removal process resulted in disruption of the customary uranium decay chain composition and the removal of radium. For this reason, uranium supplied to Linde had low concentrations of radium compared to natural uranium and Th-230 concentrations. The African ores shipped to Linde as unprocessed mining ores contained uranium in equilibrium with all of the daughter products in its decay chain (e.g., Th-230 and Ra-226). The other constituents of the ores were similar to those of the domestic ores. Laboratory and pilot plant studies were conducted at Linde from 1942 to 1943, and uranium processing began at Linde in 1943 (BNI 1993). From mid-1943 to mid-1946, a total of about 28,000 tons of ores were processed (Aerospace 1981).

Five Linde buildings were involved in MED activities; Building 14 (built by Union Carbide in the mid-1930s) and Buildings 30, 31, 37, and 38 (built by MED on land owned by Union Carbide) (BNI 1993). Ownership of Buildings 30, 31, 37, and 38 was transferred to Linde when the MED contract was terminated (BNI 1993). Building 14 served as a pilot plant for the separation process carried out in Building 30. A three-phase process was used to separate uranium from the uranium ores and tailings. Phase I (conducted in Building 30) consisted of separating U_3O_8 from the feedstock materials by a series of process steps consisting of acid digestion, precipitation, and filtration. The filtrate (liquid remaining from the processing operations) from this step was discarded as liquid waste into the injection wells, storm sewers, or sanitary sewers, and the filter cake was discarded as solid waste and was ultimately transported to Ashland 1 (now Ashland Chemical Company in Tonawanda, New York) for storage. The U_3O_8 from Phase I was processed into uranium dioxide (UO_3) in Phase 2 (Building 30). In Phase 3 (conducted in Buildings 31 and 38), the uranium dioxide was converted to uranium tetrafluoride (UF_4). Residues from Phases 2 and 3 were reprocessed (Aerospace 1981). Building 37 was also used in the above operations (ORNL 1978, p. 2-3).

The principal solid waste resulting from Phase I was a solid, gelatinous filter cake consisting of impurities remaining after filtration of the uranium carbonate solutions. Phase I also produced insoluble precipitates of the dissolved constituents, which were combined with the tailings. The precipitated species include large quantities of silicon dioxide, iron hydroxide, calcium hydroxide, calcium carbonate, aluminum hydroxide, lead sulfate, lead vanadate, barium sulfate, barium carbonate, magnesium hydroxide, magnesium carbonate, and iron complexes of vanadium and phosphorus (Aerospace 1981).

Between 1943 and 1946, approximately 8,000 tons of filter cake from Phase I processing of domestic ores were taken from the temporary tailing pile at Linde and transported to Ashland 1. These residues contained approximately 0.54% uranium oxide (86,100 pounds of natural uranium), which corresponds to 26.5 curies of natural uranium activity. Because the residues from the African ore were relatively high in radium content compared with processed domestic ore residues, the African ore supplier required that the African ore residues be stored separately, so that the radium could be extracted. Between 1943 and 1946, approximately 18,600 metric tons (20,500 tons) of residues were shipped to the former Lake Ontario Ordnance Works (LOOW) in Lewiston, New York, where they could be isolated and stored in a secure area (Aerospace 1981). The production progress reports also showed that approximately 140 metric tons (154 tons) of African ore residues were shipped to Middlesex, New Jersey (Aerospace 1981).

Subsequent to the uranium operations, a radiation survey was conducted by the Health and Safety Division of the NYOO of the Atomic Energy Commission (AEC) in November of 1952 to determine the appropriate disposition of the equipment used in the uranium operations.

Currently, the Linde Site, comprising about 135 acres located at East Park Drive and Woodward Avenue, is owned by Praxair, Inc. The site is bounded on the north and south by other industry and small businesses, on the east by the CSX railroad tracks and Niagara Mohawk property and easements, and on the west by a park owned by Praxair, which is open to the public. The regional and vicinity locations of the Linde Site are shown in Figure 1-1.

The property contains office buildings, fabrication facilities, warehouse storage areas, material laydown areas, and parking lots, as shown in Figure 1-2. Access to the site is controlled by Praxair. Approximately 1,400 employees currently work there.

It has not been possible within the time and resources available and SC&A's scope for this review to examine in detail all aspects of the Linde Site Profile, due to the complexity and long history of the Linde Site, lack or scarcity of documentation for the early years of operations, and the many changes that have occurred over the decades. SC&A has selected only certain issues for detailed consideration and discussion, because they may significantly affect dose reconstruction, and, ultimately, determination of a claimant's petition for compensation.

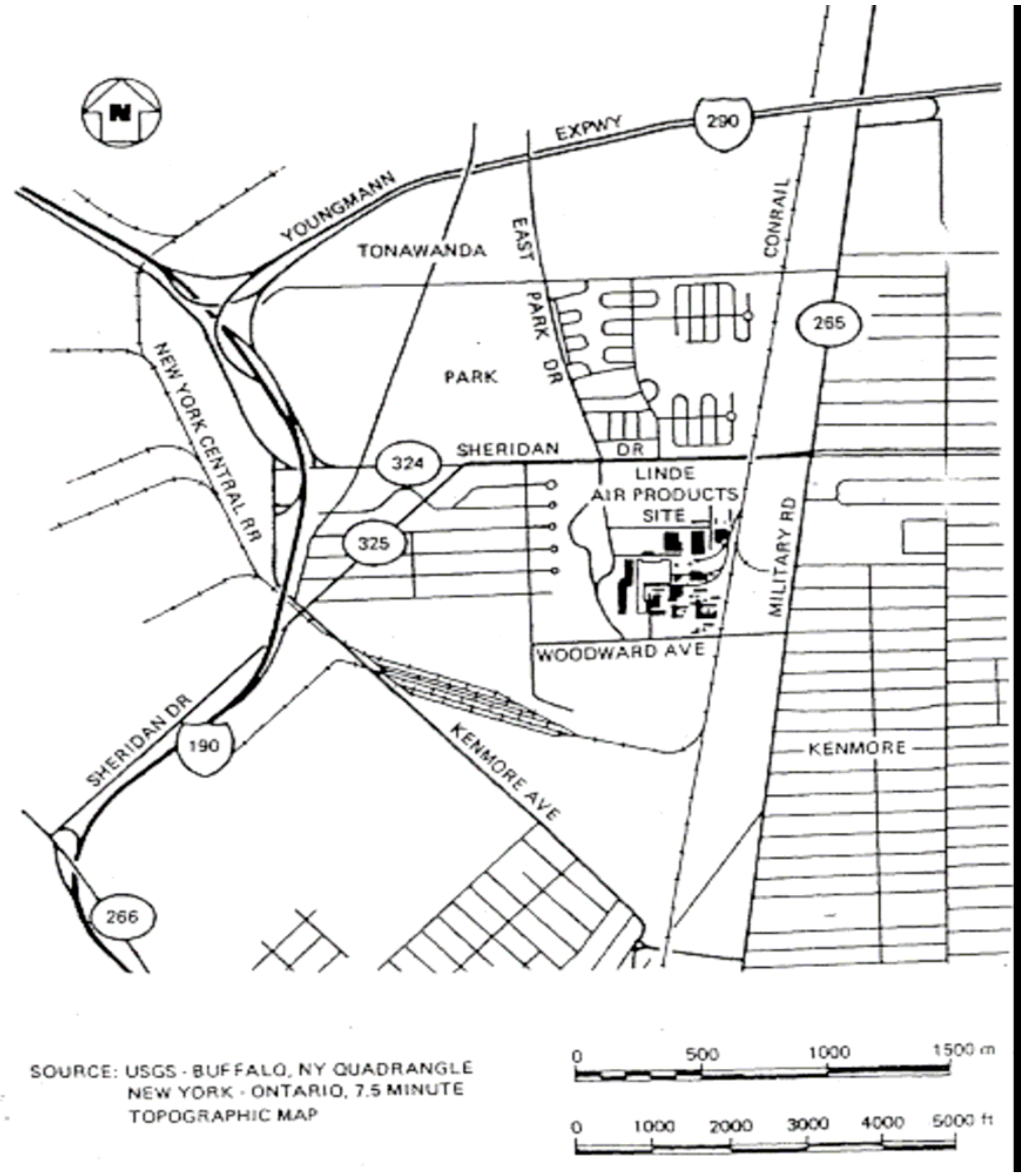


Figure 1-1: Location and Vicinity of Linde Site
(Source: BNI 1982)

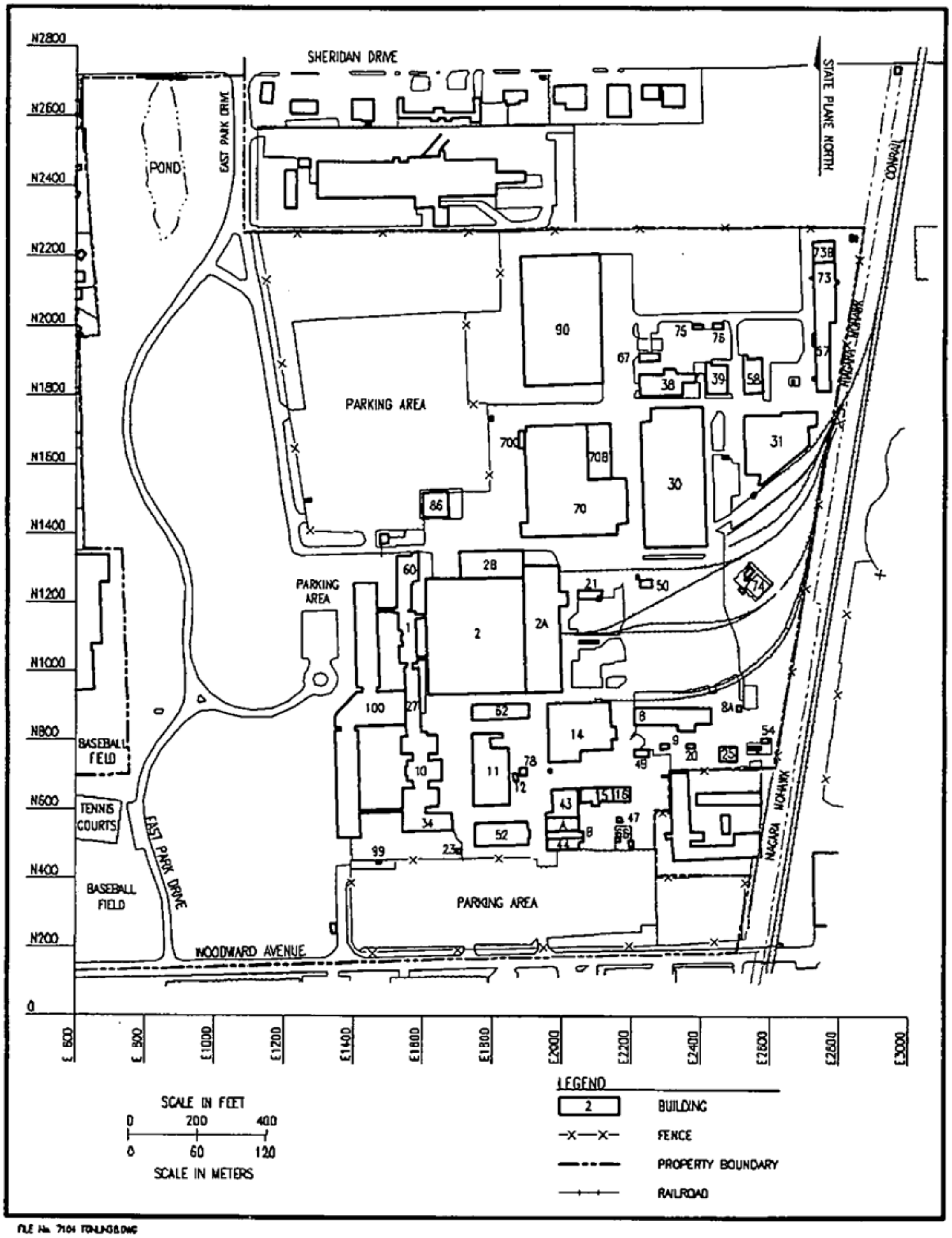
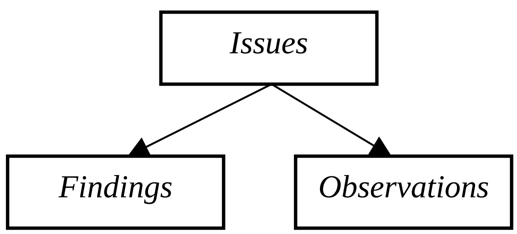


Figure 1-2: Linde Site Map
(Source: ACE 2000)

Based upon the *SC&A Standard Operating Procedure for Performing Site Profile Reviews* (SC&A 2004a), approved by the Advisory Board on March 18, 2004, the SC&A review has identified a number of issues. These issues are sorted into the following five categories:

(1) Completeness of data sources
(2) Technical accuracy
(3) Adequacy of data
(4) Consistency among site profiles
(5) Regulatory compliance

After the introduction and a description of the criteria and methods employed to perform the review, this report discusses the strengths of the site profile, followed by a description of the issues identified in this review. The issues were carefully assessed with respect to the five review criteria listed above. Eighteen of the issues are designated as "findings,"[1] because they represent what SC&A believes are deficiencies in the site profile that need to be corrected, and which have the potential to substantially impact at least some dose reconstructions. The remaining issues are designated as "observations," which represent areas that SC&A feels the site profile could improve.



These issues, and accompanying characterizations and section numbers where they are discussed in the report, are listed in Table 1-1. An issue resolution matrix, Table A-5, for these identified issues (findings and observations) is provided in Attachment 4 of this report. In addition, Section 1.2 summarizes the findings.

[1] Note: There are only 11 distinct findings, since some of the 18 are combined.

Table 1-1: Issue Matrix for the Linde Site Profile

Descriptions [(a)]	Issue Classification	Objective 1: Completeness Of Data	Objective 2: Technical Accuracy	Objective 3: Adequacy of Data	Objective 4: Site Profile Consistency	Objective 5: Regulatory Compliance
Issue 1: (5.1.1) Unsupported Assumptions and Significant Uncertainties in Information Used	Finding (1)			X	X	
Issue 2: (5.1.2.2) Use of Air Concentration Data	Finding (2)	X		X	X	X
Issue 3: (5.1.2.3) Urinalysis Data	Finding (3)	X		X	X	X
Issue 4: (5.1.2.2) Time-Weighted Averages	Finding (4)		X		X	
Issue 5: (5.1.2.4) Breathing Rate	Observation		X		X	
Issue 6: (5.1.2.5) Ingestion Rate	Observation		X		X	
Issue 7: (5.1.2.6) Radon Exposure and Concentration	Observation	X				
Issue 8: (5.1.2.7) Raffinate Trace Radionuclides	Finding (5)		X		X	
Issue 9: (5.1.2.8) Assigned Work Hours	Finding (6)		X		X	
Issue 10: (5.1.2.9) Surrogate Air Concentration Data	Finding (7)	X				
Issue 11: (5.1.2.10) Use of Geometric Mean Values	Finding (11)		X		X	
Issue 12: (5.1.2.11) Lack of Comprehensive Uncertainty Analysis	Finding (9)		X		X	X
Issue 13: (5.1.3) Complex Missed External Dose Surrogate System	Finding (8)	X	X	X		
Issue 14: (5.1.3.4) Film Badge Data	Finding (8)	X				
Issue 15: (5.1.3.5) Survey Measurement Data	Finding (8)	X				
Issue 16 (5.1.3.6) Time-Weighted Averages	Finding (4)		X		X	
Issue 17: (5.1.3.7) Contaminated Burlap Bags	Observation	X				
Issue 18: (5.1.3.8) Surrogate External Exposure Data	Finding (7)	X				
Issue 19: (5.1.3.9) Assigned Work Hours	Finding (6)		X		X	
Issue 20: (5.1.3.10) Use of Geometric Mean Values	Finding (11)		X		X	
Issue 21: (5.1.3.11) Lack of Comprehensive Uncertainty Analysis	Finding (9)		X		X	X
Issue 22: (5.1.4.1) Outdoor Doses	Finding (10)	X			X	

(a) Report section numbers discussing the issues are given after the issue number.

An "X" in the table indicates significant shortfalls in meeting the corresponding review objectives for the indicated topics in the Linde Site Profile. These shortfalls have been discussed either within the text of the findings themselves, or, in many cases, in special sections that address one or more of these shortfalls. The first column of the table indicates the primary place within the report that addresses each issue.

There is some redundancy in the report by virtue of the standard format adopted, where a single item may be discussed from different perspectives in several different places. For example, the SC&A site profile review procedure calls for both a "vertical" assessment for purposes of evaluating specific issues of adequacy and completeness, as well as a "horizontal" assessment of how the profile satisfies its intended purpose and scope.

1.1 SUMMARY OF STRENGTHS

For the purpose of reconstructing occupationally related doses (from medical, internal, external, and environmental sources) based on historical operations, NIOSH compiled many documents and data describing the radioactive materials, operations, and processes in the various MED-related buildings at Linde Site. The Linde Site Profile generally provides a wealth of useful information to aid the dose reconstructors, who have the task of determining individual claimant radiation exposures.

The Linde Site Profile, in addition to providing an overview of the site history (Section 2.0), site and plant layout (Section 2.1), facilities, and present status, and a framework in which to consider occupational exposures, describes the various steps of the uranium processing and separation operations in detail. It also describes the past operations and current cleanup efforts of seven buildings at Linde Site, including Buildings A, B, 14, 30, 31, 37, and 38, and also their associated uranium processing operations (Sections 2.2 and 2.3). The site profile lists major radionuclides of concern at these facilities and identifies potential sources of internal and external exposures. This information, the first strength, is very helpful to the dose reconstructions.

The most exceptional strength (the second strength) of the site profile is its thorough evaluation of different job categories of Linde workers. In some cases, the job categories are grouped into high-, medium-, and low-exposure ranking for the purpose of assigning missed doses. The Linde Site Profile presents, in Section 2.5, *Personnel, Job Categories and Workhours*, a list of different job titles, job categories, job duties, job functions, and their associated work hours. This job-related information is very useful for estimating missed doses by using co-worker or surrogate information, if the specific job function or location of the claimant cannot be ascertained.

The third strength is its extensive statistical analysis of existing airborne uranium dust concentrations, radon concentrations, film badge beta and gamma exposure measurements, and beta and gamma radiation measurements. In almost all cases, the site profile estimates geometric mean (GM) and geometric standard deviation (GSD) values for all potential missed dose categories. Based on these GM and GSD values, job categories are grouped into high-, medium-, and low-exposure ranking.

The fourth strength of the site profile is that it attempts, at least in many instances when working location, condition, and duration are unknown, to assign claimant-favorable missed doses for workers. For example, it assigns a gamma dose of 5.35 R/y for the whole body to all Linde Ceramics Plant personnel, based on the results for the most exposed group of monitored process workers (Davidson, Table 24, p. 54).

The major components of the Linde Occupational Internal Dose (Section 3.0) are provided in Table 11 for Linde Ceramics Plant workers (p. 37) and Table 12 for Tonawanda Laboratory workers (p. 38). These two tables present default assumptions that could be used to calculate missed worker internal dose for the period from October 1, 1942, to December 31, 1954. Missed dose default assumptions are based on inhalation intake estimates of radioactive particulates presented in Table 9 (p. 34) and uranium progeny activity fractions provided in Table 5 (p. 31). However, these two tables only present missed internal dose for workers from August 1, 1947, to December 31, 1954. The tables are easy and convenient for dose reconstructors to use if worker intake records are not available or complete, and exposures are not too high. On the other hand, these tables do not include all potential sources of missed internal doses for workers; these will be discussed in the following sections. The tables present recommended missed dose default assumptions for two periods of operations as follows:

(1) October 1, 1942 to October 31, 1947: The default missed worker intake or exposure values are designated as “reserved” in this period. In fact, this period has been recommended by NIOSH for SEC exemption for occupational internal exposures for Linde workers.

(2) November 1, 1947 to December 31, 1954: The default values or assumptions for this period are based on assumed uranium air concentration presented in Section 3.1 (p. 27) and assumed radon breath data provided in Section 3.5 (p. 32).

For missed Occupational Internal Dose after 1954, the site profile presents default worker intake values for three radionuclides of concern (i.e., U-234, Th-230, and Ra-226) in Table 39 (p. 74). These default values are based primarily on measurements of indoor airborne uranium concentrations and radon daughter concentrations.

Similarly, the major component of the Linde Occupational External Dose (Section 4.0) is provided in Table 36, *Summary – Annual External Exposure from AWE Operations*, *1942–1954* (p. 64). This table presents default missed dose values for beta, gamma, and neutron radiation exposures for workers in various years. Another strength of the site profile is its conservatism in estimating the missed neutron doses for workers.

For missed Occupational External Dose after 1954, the site profile presents the default penetrating and non-penetrating values in Table 39 (p. 74). These default values are based primarily on survey measurements.

The Occupational Medical Dose section (Section 5) is descriptive in presenting the requirements, but lacks substance. The site profile makes many assumptions in setting the relevant parameters, and provides no information on types of chest x-ray equipment, radiographic film, photoflurographic film, pelvis/lumbar spine x-ray equipment, or on worker medical records. In the end, the site profile instructs dose reconstructors to use the NIOSH TIB ORAUT-OTIB-0006, *Dose Reconstruction from Occupationally Related Diagnostic X-Ray Projections* (Kathren 2003), as the basis document for reconstructing occupational medical dose. Overall, SC&A believes that the default medical doses in ORAUT-OTIB-0006 are claimant favorable for the purpose of dose reconstruction.

The site profile does not formally evaluate missed occupational environmental doses. However, it does evaluate outdoor airborne radioactivity, radon concentrations, beta, and gamma sources. In some cases, NIOSH decided to ignore the estimated doses, due to their comparatively small quantities.

1.2 SUMMARY OF FINDINGS

Table 1-1 presents a list of 22 issues that were identified during the review process. Eighteen of these issues were judged potentially important enough to dose reconstruction to categorize as findings, and some of them subsequently were combined to yield 11 distinct findings. Those findings are summarized below in the order that SC&A believes is their level of significance to the dose reconstructions; references are given to report sections where more detailed discussions may be found. Specific issues of concern that were identified in our review, and which may affect each of the above-cited categories of dose reconstruction, are summarized briefly below. Full explanations of these issues are provided in the main text of the report.

Finding 1 (Issue 1): Unsupported Assumptions and Significant Uncertainties in Information Used (Section 5.1.1) – SC&A identified numerous assumptions or values used in missed dose estimations (both internal and external) in the site profile that are either not supported or not adequately supported by explanation, available data, technical study, or references. Many of these assumptions appear somewhat arbitrarily and without adequate technical basis. In some cases, an assumption is made or a value selected from a range of estimated values in order to bound a dose parameter that is not entirely justified or explained in the document. In other cases, the assumption or value selected is not deemed by SC&A as bounding. This is a flaw that could affect the credibility and validity of the assigned missed dose estimates in this site profile.

Finding 2 (Issue 2): Use of Air Concentration Data (Section 5.1.2.2) – The use of only airborne uranium dust concentration data (air concentration) in the site profile for missed occupational internal dose estimation is not defensible or claimant favorable, because there are significant uncertainties regarding the use of air concentration data to estimate worker inhalation intakes at uranium processing facilities. Several technical studies, including the 2003 Y-12 study, *Practical Use of Personal Air Sampling (PAS) Data in the Internal Dosimetry Program at the Y-12 National Security Complex* (Snapp 2003), and the Nuclear Regulatory Commission's NUREG-1400, *Air Sampling in the Workplace* (Hickey 1993), demonstrate that using air concentration data could lead to underestimating the worker intakes and subsequently the internal exposures. The Y-12 study shows as much as a 10-times difference between intakes derived from bioassay data and intakes derived from air concentration data. In addition, the sensitivity of survey instruments, locations of the air sampling, and air flow studies of the buildings are not considered in the Linde Site Profile; these factors would impact the accuracy of the air concentration data. Also, the air concentration data used are based on results of random grab air samples in general areas and breathing zones, but not on continuous area sampling measurements in high-risk or high-dose areas. Therefore, SC&A believes that using air concentration data only in the Linde Site Profile can lead to significant uncertainties in worker inhalation intakes, and the eventual underestimation of missed internal doses.

Finding 3 (Issue 3): Neglect of Urinalysis Data (Section 5.1.2.3) – Using air concentration data only, and neglecting urinalysis data for estimating worker inhalation intakes in the site profile, is not in full compliance with 42 CFR 82 requirements. There are 17 sets of urinalysis data for over 100 uranium workers in the ORAU database for the period between December 16, 1947, and January 30, 1950. The air concentration data used in the site profile are not complete to cover all periods of the Linde operation, and, therefore, deemed inadequate (see Finding 2). In spite of these shortcomings, NIOSH still decided to use only these air concentration data for occupational internal dose reconstruction. This approach is not in full compliance with the required "hierarchy of data" approach stipulated in 42 CFR 82.

Finding 4 (Issues 4 and 16): Time-Weighted Averages (Sections 5.1.2.2 and 5.1.3.6) – Time-weighted averages of internal and external exposure values contain significant uncertainties and frequently fail to capture dose to workers in areas of high uranium dust concentration. Even using the maximum time-weighted average, dose values would not represent maximized dose values and may have limitations when used for denial of claims; nor do they give claimants the benefit of the doubt in the face of uncertainties. Individual doses could be far greater than these averages, even when the job description, work location, and work duration are known. Procedures for estimating 95^{th} percentile values, for instance, would need to be developed in which the claimant is given the benefit of the doubt in the face of significant uncertainties. The site profile does not evaluate these potential uncertainties and lacks the required procedures for dealing with them. Other issues include uncertainties about the lengths of a workday and a workweek, as well as number of overtime hours, all of which must be addressed when considering time-weighting (see Finding 6).

Finding 5 (Issue 8): Raffinate Trace Radionuclides Not Addressed (Uranium Progeny) (Section 5.1.2.7) – The dose consequences of raffinate trace radionuclides are not adequately addressed in the site profile**.** Specifically, raffinate contains Ac-227 and Pa-231, which are in the U-235 decay chain, as well as Th-230, which is part of the U-238 chain. Inhalation of even small quantities of some raffinates, such as filter cake (one of the waste products at Linde Site), could result in significant doses to the workers. The issue of potential airborne contamination of raffinates must be more carefully assessed. In addition, NIOSH lists Ac-227 and Pa-231 in Tables 5, 11, and 12 as radionuclides of concern for internal exposure to Linde workers (Davidson 2005, p. 37), but does not include them in Table 39 for worker exposure during the cleanup period. NIOSH should address these issues as well. In Tables 11 and 12, inhalation intake values are not listed for Th-230, Ac-227, and Pa-231 for the period from 1947 to 1954. NIOSH should further evaluate the potential exposure pathways for internal exposure of raffinate trace radionuclides, and investigate the relative impact of trace radionuclide intakes to the total dose.

Finding 6 (Issues 9 and 19): Inconsistent Work Hours Assigned (Sections 5.1.2.8 and 5.1.3.9) – The number of work hours used in calculating occupational internal and external doses for workers are inconsistent for different periods of Linde operations and, therefore, not claimant favorable. Table 4 (Davidson 2005, p. 24), and many other places, state that employees worked longer than 40 hours per week. In fact, workers, in some cases, worked typical workweeks of 9 hours per day for 6 days a week, and for a total of 50 weeks per year. But, in most instances, NIOSH uses the standard 40-hour workweek assumption for the missed dose estimation. This approach is not only inconsistent, but also not claimant favorable.

Finding 7 (Issues 10 and 18): Inappropriate Data Applications as Surrogates for Missed Dose Estimation (Sections 5.1.2.9 and 5.1.3.8) – Using the GM of air concentration data of seven Atomic Weapons Employer (AWE) facilities in New York from a 1949 AEC/NYOO report (AEC 1949a) as surrogate data to develop Linde site-specific worker inhalation intakes for the entire period of Linde Operation from 1942 to 1954 is over-reaching, and may underestimate the missed occupational internal doses. This approach is inappropriate because the surrogate data are very limited and not representative of the actual Linde operation conditions, where ventilation was often poor or non-existent and adequate radiation protection practices had not yet been developed in the earlier years. The lack of complete film badge data for the period from 1942 to 1954 at Linde represents a period for which the potential for unaccounted beta and gamma doses is greatest. NIOSH's use of pre-cleanup survey data for the pre-production period from 1942 to 1943, the use of eight solid ore samples data for the period from 1943 to 1946, the use of a 1-day survey data in six locations in Building 30 for the period from 1946 to 1947, the use of two 1-day pre-cleanup survey data after vacuuming and flushing in Building 30 for 1949, and the use of post-decontamination survey data for 1950 is complex, over-reaching, inadequately supported, and not claimant favorable. In addition, the use of the 1948 film badge data collected during the removal of equipment in Building 30 for assigning both beta and gamma doses for the period from 1949 to 1954 is not appropriate, because these data do not account for external doses to workers from exposures to contaminated burlap bags, contaminated soil, and other contaminated sources during the cleanup activities.

Finding 8 (Issues 13, 14 and 15): Complex Missed External Dose Surrogate System (Sections 5.1.3, 5.1.3.4, and 5.1.3.5 – The Linde Site Profile uses a very complex scheme of surrogate data to estimate missed occupational external dose to workers from 1942 to the present. NIOSH uses a combination of film badge data, solid sample analysis results, and facility field measurements to fill exposure data gaps in order to cover the entire period of the Linde operations. However, these surrogate data are limited and, most importantly, not facility- or building-specific. The procedure for estimating missed beta and gamma doses is not very easy to follow, since, in many cases, there are no clear or sometimes any explanation why an assumption is made. Even when a clear explanation is presented, the rationale for the assumption is often either not consistent or technically sound. These weaknesses lead SC&A to conclude that NIOSH's external dose assumptions are not claimant favorable to workers.

Finding 9 (Issues 12 and 21): Lack of Comprehensive Uncertainty Analysis for Assigned Missed Doses (Sections 5.1.2.11 and 5.1.3.11 – An assessment of uncertainties, as required by OCAS-IG-001 and OCAS-IG-002, has not been adequately developed for (1) air concentration and radon measurement data used, in lieu of bioassay data, to assign internal dose and for external exposure data, including film badge beta and gamma measurements, and (2) survey measurements used to assign external dose. As described in the site profile, "little information was available" during the periods of production and non-production. In fact, the site profile uses different words to indicate if the information gathered is uncertain, such as "probably," "likely," and "assumes." It gives the strong impression that the available data gathered are inaccurate and uncertain. NIOSH should develop a method to determine best estimates and their uncertainties, as well as the 95th percentile value of time-weighted values of inhalation intake, radon intake, beta dose, gamma dose, and neutron dose, for both internal and external dose calculations.

Finding 10 (Issue 21): Outdoor Doses (Section 5.1.4.1) – The Linde Site Profile does not discuss environmental contamination or missed occupational environmental doses in detail, although there are some source documents in the ORAU database with site-specific environmental contamination information. NIOSH did consider, however, several potential pathways of outdoor beta and gamma exposures. It also evaluated outdoor radon concentrations and some outdoor air radioactivity data for the period from July 2000 to June 2004 (Davidson 2005, Table 38, p. 72). NIOSH should evaluate more thoroughly all potential environmental exposure pathways to workers, including used burlap bags, waste piles, contaminated soils, and the contaminated underground tunnel system, and provide clearer guidance in estimating missed occupational environmental or outdoor doses.

Finding 11 (Issues 11 and 20): Use of Geometric Mean Values (Sections 5.1.2.10 and 5.1.3.10) – The statistical approach used in the Linde Site Profile may not be claimant favorable. In Tables 6, 13, 14, 15, 17, 18, 21, 23, 24, 25, 26, 29, 30, 31, 32, and 33, the site profile lists the GM or the GSD values for various assigned default assumptions. First, there are no supporting calculations or data to show how these geometrical quantities were calculated. Second, the use of geometric means and standard deviations of airborne radon concentrations (for example) as default values could be considered claimant neutral and not claimant favorable. Unless there is good reason to believe that a given worker was exposed to the full distribution of the measured concentrations and could not have experienced protracted exposures to higher than average radon concentrations, it may be more appropriate to use the upper 95th percentile as the default exposure level. NIOSH's use of the GSD approach may not address very high, short-term, episodic exposures; short-term exposure during incidents; and radon intakes during the performance of tasks with a potential for high transient air concentrations.

1.3 OPPORTUNITIES FOR IMPROVEMENT

Not withstanding the many positive, helpful features of the Linde Site Profile in providing guidance to the dose reconstructors, SC&A identified 13 observations (the first 5 of which appear in the issue table (Table 1-1) that represent potential opportunities for improvement. These are summarized below:

Observation 1 (Issue 5): Breathing Rate (Section 5.1.2.4) – NIOSH assumed non-conservative, inconsistent breathing rates and breathing types. The site profile assumed a breathing rate of 1.2 m^3/hr. This value implies that workers were primarily involved in light exercise during the course of the day, certainly not the case for the workers hauling bags of ore. A single value may not be consistent with the working conditions in the facility during the early years of operation, and is inconsistent with other NIOSH site profiles, such as for Mallinckrodt, Bethlehem Steel, and Y-12. In addition, NIOSH has not considered oro-nasal breathing, which produces greater deposition in the lung than nasal breathing. NIOSH should consider a breathing rate of 1.7 m^3/hour for Linde dose reconstruction.

Observation 2 (Issue 5): Oro-Nasal Breathing (Sections 5.1.2.4 and 5.2) – The effect of oro-nasal breathing is relatively important for the workers who were working as loaders during the production years, and sweepers and sandblasters during the cleanup years. NIOSH should evaluate the potential missed worker doses in these areas.

Observation 3 (Issue 6): Ingestion Rate (Section 5.1.2.5) – NIOSH estimates worker ingestion rates of uranium by multiplying the air concentrations by a factor of 0.2. This factor of 0.2 is based on NIOSH's OCAS-OTIB-009, *Estimation of Ingestion Intakes* (NIOSH 2004). SC&A believes that this factor may not be claimant favorable. As part of SC&A's review of the Bethlehem Steel site profile and its review of OCAS-OTIB-009, SC&A has expressed concern that ingestion doses may not be directly related to airborne concentration of radionuclides because surface contamination can occur from spills and the direct deposition of flakes of uranium oxide onto surfaces. Hence, NIOSH should consider revising this aspect of the Linde Site Profile.

Observation 4 (Issue 8): Radon Exposure and Concentration (Section 5.1.2.6) – The Linde Site Profile uses the "lowest indoor concentrations measured at the Ceramics Plant during African ore processing" as the upper limit to both indoor and outdoor radon concentrations during pre-production and initial production periods, because there was no direct measurement (Davidson 2005, p. 32). For the period of African ore processing, the assumed outdoor radon concentration, 10 pCi/L, is based on the lower limit of detection. This radon concentration value is based on the GM of 13 measurements during that period. For the period of domestic ore processing, the radon concentration value, both indoor and outdoor, is assumed to be 10 pCi/L. SC&A believes these assumed radon concentration values based on the GM of measurements are not claimant favorable and not representative of the actual worker exposure conditions during the periods of operation from 1942 to 1954.

Observation 5 (Issue 17): Contaminated Burlap Bags (Section 5.1.3.7) – The Linde Site Profile indicates that there were tens of thousand of used burlap bags stacked up in the storage area behind Building 30. In addition, during the site expert interviews, past Linde workers described that they had been sitting on these contaminated burlap bags during break and lunch time. NIOSH should evaluate beta and gamma doses to workers.

Other observations not identified in the issue table include the following:

Observation 6: **Resuspension Rate (Section 5.2) –** NIOSH should consider an exponential model for resuspension intakes that takes into account the gradual increase over time in ore dust levels and radon levels at Linde facilities.

Observation 7: Film Badge Data Gap (Section 5.1.3.4) – NIOSH should improve the use of film badge data, because significant gaps exist for time periods when workers were not monitored for external or internal exposure.

Observation 8: Use of Site Expert Input (Section 5.2) – It is critical for NIOSH to conduct interviews with former workers and other site experts, and integrate first-hand experience and/or association with the Linde Site, so as to provide further insight on job category information, site practices/processes/conditions, management practices, and data integrity. NIOSH should make a greater effort to take into account site expert information and to investigate worker accounts. First-hand experience and association with the Linde facilities enable site experts and workers to provide original perspectives and information concerning site practices and exposure histories that may not appear in the official records.

Observation 9: Missing Worker Medical and Exposure Records (Section 5.2) – NIOSH should look into the possibility of many missing dose records in Linde worker files. From interviews of retired, past, and current workers, there appear to be many incident reports, occurrence reports, contamination reports, and worker uptake reports that were not included in the worker records. NIOSH holds the position that the dosimetry records accurately reflect all the doses workers received while working at Linde. The suspected incompleteness of the worker records is a serious issue, since it may lead to significant underestimation of workers' radiation dose.

Observation 10: Angular Dependence Correction Factors (Section 5.2) – NIOSH should provide angular dependence (anatomic geometry) correction factors for external gamma doses, particularly for low-photon energies, where the angular dependence of the sensitivity of the dosimeter is most pronounced. These correction factors are used to account for, for example, the bias introduced by a dosimeter worn at the neck level and the higher doses received by tissues/organs below the waist.

Observation 11: Examples of Dose Calculation (Section 5.2) – NIOSH should provide an example (or examples) in the site profile of a hypothetical dose reconstruction using recorded records, missed dose assignment, and dose assignments when dosimeters read zero dose.

Observation 12: Inconsistencies Exist among the Seven Site Profiles Currently under SC&A's Review (Section 6.1.4) – Whereas, dosimeter adjustment factors are applied to recorded external dose at the Savannah River Site (SRS), Idaho, Y-12, Rocky Flats, and Hanford to estimate Hp(10) doses, the Mallinckrodt and Bethlehem site profiles do not recommend an adjustment to recorded film doses. It also appears that the Linde Site Profile did not consider the laboratory, radiological, and environmental uncertainties in the personal dosimetry program. Lastly, the Linde Site Profile did not consider the occupational dose from environmental exposure, as was done in the Idaho, SRS, Y-12, Rocky Flats, and Hanford site profiles.

Observation 13: Inappropriate Application of Residual Contamination Data (Section 5.1.2) – Data used for reconstructing potential missed internal and external doses during years of residual contamination are not representative of actual conditions. For example, 1976 Building 30 air concentration data were used for missed internal dose estimation for the entire residual period, and 1982 BNI survey data were used for estimating missed external doses. There are significant gaps in these surrogate data that do not address potential worker exposures while working in the complex and contaminated underground tunnels and handling contaminated waste from cleanup activities.

2.0 SCOPE AND INTRODUCTION

> *When the United States government and its contractors first became interested in uranium, Linde Air Products, then a division of Union Carbide and Carbon Corporation, operated Tonawanda Laboratory, which had been producing U_3O_8 that was sold as a coloring agent for ceramics. Because of the great interest in obtaining uranium that could be used to create the experimental uranium piles, Linde was contracted to develop uranium chemical processes and build a facility that could process large amounts of uranium ore. This commissioned facility was called the Linde Ceramics Plant* (Davidson 2005, p. 10).
>
> *Tonawanda Laboratory and the Linde Ceramics Plant were located on land owned by Union Carbide at East Park Drive and Woodward Avenue in Tonawanda, New York (ORNL 1978, Fig. 3). The site is near the intersection of Riverview Boulevard and Woodward Avenue. It is north of Woodward Avenue, east of East Park Drive, and west of the Conrail railroad tracks. Tonawanda site buildings involved in MED/AEC work are shown in Figure 1. Tonawanda Laboratory occupied Building 14, and the Ceramics Plant used Buildings 30, 31, 37, 38, and A. Building B contained MED offices. Ownership of the Ceramics Plant buildings was transferred to Linde after the site cleanup that began with the shutdown of production in 1949. The transfer probably was completed in 1954. In the 1990s, the site was acquired by Praxair, Inc. (ACE Buffalo 2003). As of this writing (2005), it is owned by Praxair* (Davidson 2005, p. 11).

Under the Energy Employees Occupational Illness Compensation Program Act of 2000 (EEOICPA) and Federal regulations defined in Title 42, Part 82, *Methods for Radiation Dose Reconstruction Under the Energy Employees Occupational Illness Compensation Program,* of the *Code of Federal Regulations* (42 CFR Part 82), the Advisory Board on Radiation and Worker Health (Advisory Board) is mandated to conduct an independent review of the methods and procedures used by the National Institute for Occupational Safety and Health (NIOSH) and its contractors for dose reconstruction. As a contractor to the Advisory Board, S. Cohen and Associates (SC&A) has been charged to support the Advisory Board in this effort by independently evaluating a select number of site profiles that correspond to specific facilities at which energy employees worked and were exposed to ionizing radiation.

This report provides a review of the Linde Site Profile, ORAUT-TKBS-0025, *An Exposure Matrix for Linde Ceramics Plant (including Tonawanda Laboratory)* (Davidson 2005), and related documents in order to accomplish the following:

- Determine the completeness of the information gathered by NIOSH in behalf of the site profile, with a view to assessing the profile's adequacy and accuracy in supporting individual dose reconstructions
- Assess the technical merit of the data/information
- Assess NIOSH's use of the data in dose reconstructions

SC&A's review of the Linde Site Profile focuses on the quality and completeness of the data characterizing the facility and its operations, and the methods prescribed by NIOSH for the use of these data in the dose reconstruction process. The review was conducted in accordance with *Standard Operating Procedure for Performing Site Profile Reviews* (SC&A 2004a). The criteria for evaluation include whether the Site Profile provides a basis for scientifically supportable dose reconstructions in a manner that is adequate, complete, efficient, and (especially) claimant favorable. Specifically, these criteria were viewed from the perspective of whether dose reconstructions based on the site profile would support robust compensation decisions.

The review is directed at "sampling" the site profile analyses and data for validation purposes; the review does not provide a rigorous quality control process, whereby actual analyses and calculations are duplicated or verified. The scope and depth of the review are focused on aspects or parameters of the site profile that would be particularly important in deriving dose reconstructions, bridging uncertainties, or correcting technical inaccuracies.

The basic goal of dose reconstruction is to characterize the radiation environments to which workers were exposed, using detailed individual worker dose records to the greatest extent possible, and, where gaps exist, supplementing the dose records with site profile data, which present potential exposures pathways at different time periods. The hierarchy of data used for developing dose reconstruction methodologies is (1) film badge and urinalysis data, (2) co-worker data and workplace monitoring data, and (3) process description information or source term data.

In accordance with directions provided by the Advisory Board and the SC&A site profile review procedure, this report is organized into the following sections:

(1) Executive Summary
(2) Scope and Introduction
(3) Assessment Criteria and Method
(4) Site Profile Strengths
(5) Vertical Issues
(6) Overall Adequacy of the Linde Site Profile as a Basis for Dose Reconstruction

Based on the issues identified in each of these sections, SC&A prepared a list (Tables 1-1 and 6-1) of "issues" briefly described in the Executive Summary and later in the report; this list functions as a convenient roadmap to the issues discussed throughout the report. Issues are designated as "findings" if SC&A believes that they represent deficiencies in the site profile that need to be corrected and which have the potential to have a substantial impact on at least some dose reconstructions. Issues are designated as "observations" if they simply raise questions, which, if addressed, would improve the site profile and may possibly reveal deficiencies that will need to be addressed in future revisions of the site profile. In this review, SC&A has identified 22 issues, categorized into 11 findings (five sets of 2 issues and one set of 3 issues are combined), and 4 observations (plus another 8 observations not connected with an issue). The site profile, in many ways, has done a successful job in addressing a series of difficult technical challenges. In other areas, the site profile exhibits shortcomings that may influence some dose reconstructions in a substantial manner.

Since many of the issues that surface in the report correspond to more than one of the major objectives (i.e., strengths, completeness of data, technical accuracy, consistency among site profiles, and regulatory compliance), there is a degree of redundancy in the SC&A report, where different sections may address the same issue, but from different perspectives. For example, the SC&A site profile review procedure calls for both a "vertical" assessment for purposes of evaluating specific issues of adequacy and completeness, as well as a "horizontal" assessment of how the profile satisfies its intended purpose and scope.

3.0 ASSESSMENT CRITERIA AND METHOD

SC&A is charged with evaluating the approach set forth in the site profile used in the individual dose reconstruction process. SC&A reviewed the site profile documents with respect to the degree to which technically sound judgments or assumptions are employed, and assessed the degree to which they fulfill the objectives delineated in SC&A's review procedure.

3.1 OBJECTIVES

Documents are reviewed for their completeness, technical accuracy, adequacy of data, consistency with other site profiles, and compliance with the stated objectives, as defined in the *SC&A Standard Operating Procedure for Performing Site Profile Reviews* (SC&A 2004a). These objectives are discussed in the following sections:

3.1.1 Objective 1: Completeness of Data Sources

SC&A reviewed the site profile with respect to Objective 1, which requires SC&A to identify principal sources of data and information that are essential to the development of the site profile. The two elements examined under this objective are (1) determining if the site profile makes proper use of available data considered relevant and significant to the dose reconstruction, and (2) investigating whether other relevant/significant sources are available, but are not used in the development of the site profile. For example, if relevant data are available in site technical reports or other site documents for particular processes, and if the TBDs have not taken these data into consideration, this would constitute a completeness of data issue. The Oak Ridge Associated Universities (ORAU) site profile document database, including the referenced sources in the technical basis documents (TBDs), was evaluated to determine the relevance and use of the data collected by NIOSH to the development of the site profile. Additionally, SC&A evaluated selected records publicly available relating to the Linde site and records provided by site experts.

3.1.2 Objective 2: Technical Accuracy

SC&A reviewed the site profile with respect to Objective 2, which requires SC&A to perform a critical assessment of the methods used in the site profile to develop technically defensible guidance or instruction, including evaluating field characterization data, source term data, technical reports, standards and guidance documents, and literature related to processes that occurred at the Linde Site. The goal of this objective is to first analyze the data according to sound scientific principles, and then evaluate this information in the context of compensation. For example, if SC&A found that the technical approach used by NIOSH was not scientifically sound or claimant favorable, this would constitute a technical accuracy issue.

3.1.3 Objective 3: Adequacy of Data

SC&A reviewed the site profile with respect to Objective 3, which requires SC&A to determine whether the data and guidance presented in the site profile are sufficiently detailed and complete to conduct dose reconstruction, and whether a defensible approach has been developed in the absence of data. In addition, this objective requires SC&A to assess the credibility of the data used for dose reconstruction. The adequacy of the data identifies gaps in the facility data that may influence the outcome of the dose reconstruction process. For example, if a site did not monitor all workers exposed to neutrons who should have been monitored, this would be considered a gap and, thus, an inadequacy in the data.

3.1.4 Objective 4: Consistency Among Site Profiles

SC&A reviewed the site profile with respect to Objective 4, which requires SC&A to identify common elements within site profiles completed or reviewed to date, as appropriate. In order to accomplish this objective, the Linde Site Profile was compared to the Mallinckrodt, Bethlehem, Y-12, and other site profiles and TBDs. Both the Mallinckrodt and Y-12 site profiles are appropriate for comparison, as the sites had similar uranium processes. This assessment was conducted to identify areas of inconsistencies and determine the potential significance of any inconsistencies with regard to the dose reconstruction process.

3.1.5 Objective 5: Regulatory Compliance

SC&A reviewed the site profile with respect to Objective 5, which requires evaluation of the degree to which the site profile complies with stated policy and directives contained in 42 CFR Part 82. In addition, SC&A evaluated the site profile for adherence to general quality assurance policies and procedures utilized for the performance of dose reconstructions. In order to place the above objectives into the proper context as they pertain to the site profile, it is important to briefly review key elements of the dose reconstruction process, as specified in 42 CFR Part 82. Federal regulations specify that a dose reconstruction can be broadly placed into one of three discrete categories. These three categories differ greatly in terms of their dependence on the availability, completeness, and accuracy/uncertainty of available dose data. The first two categories represent “extreme cases,” where, in the first (Category 1), exposures are so obviously high as to lead quickly to a probability of causation (POC) of at least 50% and, in the second (Category 2), exposures are so obviously low, as to lead quickly to determination of a POC of less than 50%. The third category (Category 3) is the most difficult one to assess, as the claimant’s exposure falls between the two extremes of the first two categories.

Category 1: Least challenged by any deficiencies in available dose/monitoring data are dose reconstructions for which even a partial assessment (or minimized dose(s)) corresponds to a POC value in excess of 50%, and assures compensability to the claimant. Such partial/incomplete dose reconstructions with a POC greater than 50% may, in some cases, involve only a limited amount of external or internal data. In extreme cases, even a total absence of a positive measurement may suffice for an assigned organ dose that results in a POC greater than 50%. For this reason, dose reconstructions in behalf of this category may only be marginally affected by incomplete/missing data or uncertainty of the measurements. In fact, regulatory guidelines recommend the use of a partial/incomplete dose reconstruction, the minimization of dose, and the exclusion of uncertainty for reasons of process efficiency, as long as this limited effort produces a POC of greater than or equal to 50%.

Category 2: A second category of dose reconstruction is defined by Federal guidance, which recommends the use of "worst-case" assumptions. The purpose of worst-case assumptions in dose reconstruction is to derive maximal or highly improbable dose assignments. For example, a worst-case assumption may place a worker at a given work location 24 hours per day and 365 days per year; while not logical, the assumption is certainly upper bounding on exposure time. The use of such maximized (or upper bound) values, however, is limited to those instances where the resultant maximized doses yield POC values below 50%, which are not compensated. For this second category, the dose reconstructor needs only to ensure that all potential internal and external exposure pathways have been considered.

The obvious benefit of worst-case assumptions and the use of maximized doses in dose reconstruction is efficiency. Efficiency is achieved by the fact that maximized doses avoid the need for precise data and eliminates consideration for the uncertainty of the dose. Lastly, the use of bounding values in dose reconstruction minimizes any controversy regarding the decision not to compensate a claim.

Although simplistic in design, to satisfy this type of a dose reconstruction, the site profile must, at a minimum, provide information and data that clearly identify (1) all potential radionuclides, (2) all potential modes of exposure, and (3) upper limits for each contaminant and mode of exposure. Thus, for external exposures, for example, maximum dose rates must be identified in time and space that correspond to a worker's employment period, work locations, and job assignment. Similarly, in order to maximize internal exposures, the highest plausible air concentrations and surface contaminations must be identified.

Category 3: The most complex and challenging dose reconstruction represents claims where the case cannot be dealt with under one of the two categories above. For instance, when a minimum dose estimate does not result in compensation, a next step is required to make a more complete estimate. Or, when a worst-case dose estimate that has assumptions that may be physically implausible results in a POC greater than 50%, denial is not possible. A more refined estimate may be required to support a recommendation either to deny or to compensate the claimant. In such dose reconstructions, which may be represented as "reasonable," NIOSH has committed to resolve uncertainties in favor of the claimant. According to 42 CFR Part 82, NIOSH interprets "reasonable estimates" of radiation dose to mean the following:

> *. . . estimates calculated using a substantial basis of fact and the application of science-based, logical assumptions to supplement or interpret the factual basis. Claimants will in no case be harmed by any level of uncertainty involved in their claims, since assumptions applied by NIOSH will consistently give the benefit of the doubt to claimants.*

3.2 ASSESSMENT METHODOLOGY

In order to assess the degree of compliance with the five objectives described above, SC&A reviewed the site profile, pertinent TIBs, and other relevant documents, giving due consideration to the three categories of dose reconstructions that the site profile is intended to support

(Section 3.1.5). The Linde Site Profile generally provides well-organized and somewhat or partially user-friendly information for the dose reconstructor when adequate data are available to do that comprehensively. During the course of its review, SC&A was cognizant of the fact that the site profile is not required by the EEOICPA or by 42 CFR Part 82, which implements the statute. Site profiles were developed by NIOSH as a resource to the dose reconstructors for identifying site-specific practices, parameter values, and factors that are relevant to dose reconstruction, and which may be used to supplement a claimant's own employment and exposure record. Based on information provided by NIOSH personnel, SC&A understands that site profiles are living documents, which are revised, refined, and supplemented with TIBs as required, to help dose reconstructors. Site profiles are not intended to be prescriptive or necessarily complete in terms of addressing every possible issue that may be relevant to a given dose reconstruction. In addition, they are not intended for the "layman," but for the health physics personnel immersed in the review process. The principal documents and data sources SC&A examined in the course of its review, and which were most influential in informing SC&A's assessment, are the following:

- ORAUT-TKBS-0025, *An Exposure Matrix for Linde Ceramics Plant (including Tonawanda Laboratory)* (Davidson 2005) – This document represents the entire Linde Site Profile. It consists of six major sections; (1) Introduction, (2) Site Description and Operational History, (3) Estimation of Internal Exposure, 1942–1954, (4) Estimation of External Exposure, 1942–1954, (5) Occupational Medical Exposure, and (6) Estimation of Exposures from Residual Contamination After 1954.

  – Section 1 provides a useful overview and explains the role of other sections in support of the dose reconstruction process. Hence, the introduction helps in framing the scope of the site profile.

  – Section 2, in addition to providing an overview of the site history (Section 2.0), layout, facilities (Section 2.1), source term (Section 2.2), activities (Section 2.3), and present status, and a framework in which to consider occupational exposures, describes in detail the various steps of the uranium processing and separation operations.

  – Section 3 describes the various sources of internal exposure to workers at the Linde Site. It also presents default assumptions that are to be used by dose reconstructors to estimate missed worker internal dose for the period from October 1, 1942, to December 31, 1954.

  – Section 4 describes the various available external exposure data sources for dose reconstruction. It also presents default missed dose values for beta, gamma, and neutron radiation exposures for workers in various years at the site.

  – Section 5 is descriptive in the requirements of occupational medical monitoring. It eventually provides instruction to dose reconstructors to use the appropriate NIOSH

Technical Information Bulletin (TIB) as the basis for reconstructing occupational medical doses.

– Section 6 presents NIOSH's approach in estimating internal and external doses to workers as a result of residual contaminants in various Linde facilities and locations after 1954.

- ORAUT-OTIB-0002, *Technical Information Bulletin – Maximizing Internal Dose Estimates for Certain DOE Complex Claims* (Rollins 2004)
- ORAUT-OTIB-0006, *Technical Information Bulletin – Dose Reconstruction from Occupationally Related Diagnostic X-Ray Projections* (Kathren 2003)
- ORAUT-OTIB-0007, *Technical Information Bulletin – Occupational Dose from Elevated Ambient Levels of External Radiation* (Strom 2003)
- ORAUT-OTIB-0023, *Assignment of Missed Neutron Doses Based on Dosimeter Records* (Merwin 2005)
- OCAS-OTIB-009, *Technical Information Bulletin – Estimation of Ingestion Intakes* (NIOSH 2004)
- OCAS-IG-001, *External Dose Reconstruction Implementation Guideline* (Taulbee 2002)
- OCAS-IG-002, *Internal Dose Reconstruction Implementation Guideline* (Allen 2002)

In accordance with SC&A's site profile review procedure, the reviewers performed an initial assessment of the site profile, its supporting documentation, and several relevant TIBs. SC&A then submitted written questions (Attachment 1) to NIOSH with regard to assumptions and methodologies used in the site profile. SC&A expects to discuss the issues raised in a teleconference with staff members of NIOSH, ORAU and ORAU subcontractors (note, this has not happened as of the date of this assessment due to schedule constraint). NIOSH, ORAU, and ORAU subcontractor personnel will subsequently be given the opportunity to comment on the SC&A account of the teleconference, and the revised account will be included in a revision of this report.

SC&A conducted site expert interviews to help obtain a comprehensive understanding of the radiation protection program, site operations, and environmental contamination that might be present in some areas. While it is recognized that peoples' memories may not be wholly reliable, especially when trying to recall information from decades ago that may not have seemed significant at the time, the interviews, especially taken in the aggregate, provided much useful insight from the perspective of the Linde workers themselves. Attachment 2 presents advance questions for the site interviews, and Attachment 3 provides summaries of the interviews conducted by SC&A in the Tonawanda area during the course of this review. The site experts interviewed include current, former, and retired staff from dosimetry, radiation control, operations, environmental monitoring, maintenance, instrumentation, electrical, mechanical, security, engineering, management, and other support organizations. Each summary is an edited paraphrase of conversations held with a number of site experts, rather than a verbatim transcript. Personnel statements have been grouped into categories to provide a linkage with various portions of the Linde Site Profile. References that may identify specific site experts have been omitted for privacy reasons. Interviewed individuals were given the opportunity to review the interview summary for accuracy and corrections were made where necessary. This is an important safeguard against missing key issues or misinterpreting some vital piece of information. Most, but not all, of the individuals interviewed by SC&A provided comments on the summaries.

Information provided in the expected teleconference with NIOSH mentioned above will be evaluated against the preliminary findings to finalize the vertical issues addressed in the report (Section 5). There are three levels of review for this report. First, SC&A team members review it internally. Second, SC&A engages an outside consultant, who has not participated in the preparation of this document, to review all aspects of this report. The third level, referred to as the expanded review cycle, will consist of a review of this draft by the Advisory Board and NIOSH. The first two review levels have been completed.

Upon delivery of this draft to NIOSH and the Advisory Board, the report will be posted on the Advisory Board's web site. The report will then under go an expanded review by a Board-designated working group. The working group will address of the issues identified in this report and, based on direction provided by the working group and the Board, SC&A and/or NIOSH may be directed to perform follow-up investigations that could result in revisions to this report or to the site profile, or both.

Finally, it is important to note that SC&A's review of the Site Profile and its supporting TIBs is not exhaustive. These are large, complex documents, and SC&A used its judgment in selecting those issues that we believe would be important with respect to dose reconstruction.

4.0 SITE PROFILE STRENGTHS

In developing a site profile, the assumptions used must be fair, consistent, and scientifically robust, and uncertainties and inadequacies in source data must be explicitly addressed. The development of the site profile must also consider efficiency in the process of analyzing individual exposure histories, so that claims can be processed in a timely manner; this is clearly in the best interest of the claimants. With this perspective in mind, SC&A identified a number of strengths in the Linde Site Profile. These strengths are described in the following sections.

4.1 COMPLETENESS OF DATA SOURCES

The site profile exhibits the following strengths in terms of the completeness of its data sources:

(1) In an effort to be comprehensive in addressing the range of facilities and processes, NIOSH compiled facility-specific information from a number of descriptions and historical records. NIOSH drew upon information contained in 153 reports and documents cited in the reference section of the site profile. Seven buildings were identified as the Linde facilities used for uranium-related processing and operations. A concerted effort was made to characterize the principal types and relative importance of the various radionuclides that may have contributed to internal and external exposures at the various facilities and associated processes over the life of the facilities. SC&A considers this compilation to be an important strength of the report. In addition, NIOSH compiled an historical timeline (Table 1 of the site profile) for the purpose of identifying key dates of events, activities, and operations.

(2) The site profile thoroughly evaluates different job categories of workers for the entire period of operation from 1942 to the present. In some cases, the job categories were grouped into high-, medium-, and low-exposure ranking for the purpose of assigning missed doses. Section 2.5, *Personnel, Job Categories and Workhours*, presents the list of different job titles, job categories, job duties, job functions, and their associated work hours for Linde workers. This job-related information is very useful for dose reconstructors to estimate missed doses for the claimant by using co-worker or surrogate information if the specific job function or location of the claimant cannot be ascertained.

(3) For the purpose of developing data needed to reconstruct missed internal doses based on historical operations, NIOSH compiled a significant amount of data identifying the radioactive materials at the Linde Site, and describing the relevant operations and their associated processes. Notwithstanding this achievement, however, there are opportunities for improvement in the data sets and guidance for the dose reconstructors for reconstructing missed internal exposures, and also for identifying missed internal doses due to deficient work practices and inadequate instrumentation.

(4) In compiling historical data needed to reconstruct missed external (gamma, beta, and neutron) doses, NIOSH compiled a significant amount of data identifying potential external radiation sources at various Linde buildings, and describing the relevant

operations and their associated processes. NIOSH also compiled data related to external dosimetry over the site's entire operating history. From these gathered data, NIOSH developed the missed gamma and neutron dose values for different time periods. Opportunities for improvement remain, however, in the areas of adding the missed beta dose values and identifying high-risk (with respect to exposure) jobs.

4.2 TECHNICAL ACCURACY/CLAIMANT FAVORABILITY

The Linde Site Profile exhibits the following strengths, in terms of technical accuracy and claimant favorability:

(1) The site profile performed extensive statistical analysis of existing airborne uranium dust concentrations, radon concentrations, film badge beta and gamma exposure measurements, and beta and gamma radiation measurements. In almost all cases, the site profile estimates GM and GSD values for all potential missed dose categories. Based on these GM and GSD values, job categories are grouped into high-, medium-, and low-exposure ranking.

(2) In many instances, when working location, condition, and duration are unknown, the site profile attempts to assign the highest missed doses for workers. For example, it assigns a gamma dose of 5.35 R/y for the whole body to all personnel based on the results for the most exposed group of monitored process workers (Davidson 2005, Table 24, p. 54).

(3) In lieu of any neutron measurements or personnel neutron monitoring data, the occupational neutron dose section of the site profile has adequately bound the potential missed neutron dose rates and annual neutron dose to workers. NIOSH's approach is based primarily on potential alpha-neutron sources during the Linde operation period from 1943 to 1946. The assigned neutron doses to workers for different operation periods are considered to be claimant favorable.

(4) The Occupational Medical Dose section (Section 5) is descriptive in presenting the requirements, but lacks substance. The site profile uses many assumptions in the parameters, but provides no information on actual chest x-ray equipment, radiographic film, photoflurographic film, pelvis/lumbar spine x-ray equipment, or worker medical records. In the end, the discussion is not particularly relevant, since the site profile finally instructs dose reconstructors to use the NIOSH TIB ORAUT-OTIB-0006, *Dose Reconstruction from Occupationally Related Diagnostic X-Ray Projections*, as the basis document for reconstructing occupational medical dose for workers. Overall, SC&A believes that using the default medical doses in ORAUT-OTIB-0006 is claimant favorable for the purpose of Linde dose reconstruction.

4.3 ADEQUACY OF DATA

The Linde Site Profile suffers from not having access to adequate historical information and exposure data that were compiled as a part of the Linde operations. In most cases, NIOSH was forced to make many assumptions that appear arbitrary and unsupported.

4.4 CONSISTENCY AMONG SITE PROFILES

Although Linde, Mallinckrodt, and Y-12 missions overlapped to a significant extent, there are many differences in the facility designs, processes, and radiological practices. In some cases, these differences require site-specific assumptions in dose determinations.

NIOSH has made a concerted effort to recognize and address site-specific issues in the TBDs. With respect to the Interactive RadioEpidemiologic Program (IREP) input parameters, the Linde, Mallinkrodt, and Y-12 site profiles are consistent in many cases. This consistency was especially apparent in the occupational medical exposure sections.

4.5 REGULATORY COMPLIANCE

The Linde Site Profile attempts to use personnel monitoring data as much as possible, including film badge beta and gamma dose data and worker urinalysis results, to determine worker external and internal doses. The purpose of this attempt is to satisfy the requirements outlined in 42 CFR Part 82, which specifies the hierarchy of data that are to be used in dose reconstruction. However, NIOSH has not always complied with the hierarchy of data required in §82.2 and its implementation guides for monitored workers. The following two examples show NIOSH's attempt to use pertinent hierarchy of data, such as bioassay and film badge doses, for dose reconstruction.

(1) For missed occupational external dose, the site profile uses a complex surrogate data system, involving film badge beta and gamma measurements, survey measurements, uranium solid sample results, and uranium source data, to represent potential missed doses to workers in different periods of Linde operation. However, the film badge beta and gamma measurements are limited in scope and quantity, and may not be reliably extendable to represent the entire period.

(2) For missed occupational internal dose, the site profile does not use limited worker urinalysis data available to estimate potential missed doses to workers in different periods of operation. It uses mainly airborne uranium dust concentration data for estimating worker inhalation intakes and ingestion intakes. However, NIOSH did use the available urinalysis data as predictive data (Table 10 of the site profile) to evaluate the reasonableness of the estimated inhalation and ingestion intake values derived from the airborne uranium dust concentration data.

5.0 VERTICAL ISSUES

SC&A has developed a list of issues regarding the Linde Site Profile, which relate to the five objectives defined in the SC&A site profile review procedure (SC&A 2004a). Some issues pertain to a particular objective, while others pertain to several objectives. A matrix relating the objectives and the relative importance of each issue is provided in Section 6.0 (also in Table 1-1). The issues identified as findings map into the four broad categories discussed in Section 5.1, and the issues identified as observations map into the two broad categories discussed in Section 5.2. Many of the issues raised are applicable to other DOE and AWE sites, and should be considered in the preparation and revision of their site profiles.

5.1 DISCUSSION OF ISSUES

5.1.1 Unsupported Assumptions and Significant Uncertainties in Information Used in this Site Profile

SC&A has identified numerous assumptions or values used in missed dose estimates (both internal and external) in the site profile that are not adequately supported by explanation, data, technical studies, or references, making them appear somewhat arbitrary and without adequate technical bases. In some cases, an assumption is made or a value selected from a range of estimated values in order to bound a dose parameter, that is not entirely justified or explained. In other cases, an assumption or value selected is not seen by SC&A as bounding. In addition, NIOSH seems to have missed several buildings and areas that could have contributed to worker exposures. These are flaws that affect the credibility and validity of the missed dose estimates.

The Linde Site Profile strongly conveys the impression that there are many significant unknowns and uncertainties in historical and operational information regarding the site, which was in operation since the Manhattan Project, with respect to its facilities, operations, service timelines, remedial activities, and radiation protection practices. For example, the site profile identifies only seven buildings that were used for the MED uranium processing project, while there is evidence of the existence of several others, where workers may have been exposed to radiation. Many former Linde workers at SC&A's site expert interviews in Buffalo, New York, identified more buildings (Buildings 1, 2, 19, 39, 52, 54, 57, and 59) that had been involved directly or indirectly with the MED uranium processing operations. In addition, several exterior areas and spaces adjacent to Buildings 30, 75, and 76 were purportedly used for staging uranium ore or processed waste piles during and after the MED operations, and were not considered by NIOSH in evaluating potential exposures to workers. Furthermore, two buildings have uncertain status; it is not possible to definitively verify through known reference documents the existence of Buildings A and B during the MED operation period and, if they were there during that period, to identify their MED-related functions.

Examples follow of NIOSH assumptions used to establish the historical framework for estimating missed occupational doses. Many qualifying statements and expressions of uncertainty appear, and these assumptions, which are not accompanied by adequate explanations of their rationales, do not appear to be claimant favorable. The site profile states the following in the beginning of Section 3.0, Estimation of Internal Exposure, 1942–1954:

> *This document **assumes** that Tonawanda Laboratory's primary internal exposure occurred from October 1, 1942 to December 31, 1946. ….. Tonawanda Laboratory AEC work is **assumed** to have stopped radiation work after December 31, 1946, although some workers might have visited the Ceramics Plant buildings. The exact levels of contamination remaining at the Ceramics Plant and the nature of worker activities in areas of residual activity are **unknown** for the standby and rehabilitation periods. ….. Continued lower level exposures to uranium progeny and to radon are **assumed**, because some radioactive waste was disposed on site and because initial cleanup was not completed until the end of 1954; however, for the Ceramics Plant the uranium exposures **would have** dominated during the 1947 to 1954 period.* [Emphasis added.] (Davidson 2005, p. 26)

Section 3.1, Estimation of Particulate Intakes, notes that "the pre-1947 operational period intakes are reserved. Therefore, the pre-1947 information is provided only as a description of what the likely upper bound exposures might have been, and is not currently planned for use in Linde dose reconstruction" (Davidson 2005, p. 27). The site profile section discusses the pre-1947 period (making many assumptions and frequently using expressions indicating uncertainty), and states that "although short-term exposures might have exceeded 300 MAC, it is very unlikely. … [Nonetheless,] the assumption of air concentrations at 300 MAC seems adequate to provide a quick estimate of exposure" (Davidson 2005, p. 28). The site profile does not explore adequately which workers, under what conditions, may have received exposures exceeding 300 MAC, but, overall, this assumption appears conservative for the pre-1947 period (and, in any event, is not used in the dose reconstruction).

The site profile then moves to the period after ore processing operations and assumes, without any supporting data, that exposures were substantially lower. It is interesting also to note that the document assumes that most workers' exposures are even lower, based on later data from Linde and from other sites. While the data from other sites may be applicable to Linde, the site profile does not demonstrate this:

> *After the ore processing, Linde began a standby period. It was initially and **arbitrarily assumed** that exposures decreased to 1 MAC during the standby period at the Ceramics Plant, and that exposures decreased to 0.1 MAC at the Tonawanda Laboratory after cleanup in 1946 until the end of cleanup at the Ceramics Plant in 1954. Based on reviews of later air concentrations at Linde, and reviews of air concentration data from other sites, it is **believed** that most workers' exposures **would** have been much lower during these periods.* [Emphasis added]. (Davidson 2005, p. 28)

After the standby period, the site profile states that the bounding exposure to workers is (arbitrarily) assumed to be 33 MAC for the Ceramics Plant. The following quotation illustrates the acknowledged degree of uncertainty in this assumption:

> *Beginning November 1, 1947 at Linde Ceramics, workers were* ***assumed*** *to be exposed to 33 MAC and it was* ***assumed*** *this exposure continued through cleanup in 1954. Uranium progeny are not included in this later period, because only refined uranium was used and because the dose from intakes of contamination left from earlier work* ***would*** *have been insignificant compared to the dose to uranium during operations.* (Davidson 2005, p. 28) [Emphasis added.]

The site profile section continues by making an apparently "claimant-unfavorable," or at least poorly justified, assumption about the length of the workweek, "To simplify calculations, it **assumed** that the workweek was 40 work hours long during all years, although it is **likely** that the workweek for many was in excess of 40 work hours especially during the earlier years. The **assumed** air concentrations are sufficiently large to account for any differences in actual hours exposed" (Davidson 2005, p. 28) [Emphasis added]. Hence, as illustrated by the preceding few examples, the credibility of the site profile and its claim to be claimant favorable appear to be compromised by the many unsupported or poorly justified assumptions that are made throughout. These issues, as well as others, are discussed in more detail in the following sections.

5.1.2 Occupational Internal Dose

The Linde Site profile discusses different periods in the plant's history, with different operational scenarios and exposure pathways in each period. One division is presented in Table 5-1:

Table 5-1: Time Periods

Period	Also Called	Name
October 1, 1942 – September 14, 1947	Pre-1947	Operation and Standby Period
September 15, 1947 – June 30, 1949	1947–1949	Production Period
July 1, 1949 – December 31, 1954	1949–1954	Cleanup Period
January 1, 1955 – Present	After 1954	Post-Cleanup Period

The site profile estimates missed occupational internal exposures to workers at the Linde Ceramics Plant and Tonawanda Laboratory from 1942 to the present time via two separate pathways; *inhalation* and *ingestion*. For the *inhalation pathway*, the site profile estimates the particulate intakes by workers from a set of very limited measured airborne uranium dust concentration data (Davidson 2005, p. 30). These air concentration data consist of airborne dust radioactivity measured in general areas and breathing zones associated with various production locations and tasks, radon breath data used to determine the amount of radium inhaled in the body (Davidson 2005, p. 31), and uranium progeny in the airborne dust (Davidson 2005, p. 31). For the *ingestion pathway*, the site profile estimates the worker intakes from the air concentration data by multiplying the air concentration (worker inhalation intake quantities in dpm per cubic meter) by a factor of 0.2 (Davidson 2005, p. 35). The site profile also estimates separately the missed internal doses for workers, considering different operational histories and exposure scenarios.

For the uranium progeny intake, the site profile estimates the inhalation and ingestion intakes by apportioning the air concentration value among uranium and its progeny using the alpha ratios of uranium and progeny. However, the site profile only applies this approach for uranium progeny to the Tonawanda Laboratory, not to the Linde Ceramics Plant. It further assumes that the uranium progenies were not present in the Linde Ceramics Plant after 1947 (Davidson 2005, Table 11, p. 37).

The site profile relies heavily on a single document, *Health Hazards in NYOO Facilities Producing and Processing Uranium: A Status Report*, April 1, 1949, to determine air concentrations of uranium and its progeny (AEC 1949a) (Davidson 2005, p. 27). Section 3.1 of the site profile outlines the methodology of the NYOO study:

> *In 1949, the Medical Division of the NYOO published a report on the health hazards at seven facilities that produced and/or processed uranium for the AEC. These facilities included Mallinckrodt Chemical Works, Harshaw Chemical Company, Linde Air Products, Electro Metallurgical Company, and Vitro Manufacturing Company. The AEC used the information on work tasks with measured air concentrations in breathing zones, general areas and process areas to determine average air concentrations weighted by exposure times and summed these time-weighted air concentrations to determine daily time-weighted average air concentrations by job categories.* (Davidson 2005, p. 27)

NIOSH derives from the NYOO report a single, primary air concentration value of 33 MAC for the Linde worker inhalation intake beginning in November 1, 1947, and continuing through the cleanup period in 1954.[2] NIOSH represents this value as a conservative, claimant-favorable, upper bound, claiming the unlikelihood of anyone receiving a greater exposure for any significant length of time. The site profile offers the following guidance:

(1) Linde Ceramics Plant

- Pre-1947: reserved by NIOSH (short-term may exceed 300 MAC) (Davidson 2005, p. 28)[3]
- Standby Period (August 1, 1946–September 14, 1946): reserved (1 MAC) (Davidson 2005, p. 28)[3]
- Rehabilitation Period (September 15, 1947–October 31, 1947): reserved (see Section 5.1.2.1)[3]
- November 1, 1947–December 31, 1954: 33 MAC
- January 1, 1955–Present: 100 dpm/y U (Davidson 2005, p. 72)

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[2] As noted earlier in this section, the site profile derives ingestion intake from the inhalation intake data.

[3] These time periods are covered by the SEC petition (i.e., October 1, 1942, to October 31, 1947). Nevertheless, the site profile review includes these time periods for completeness. It is important to emphasize that the time periods following the period covered by the petition are of particular interest to this report.

(2) Tonawanda Laboratory

- Pre-1947: reserved
- Cleanup Period (August 1, 1946–December 31, 1946): reserved
- January 1, 1947–December 31, 1954: 0.1 MAC
- January 1, 1955–Present: 100 dpm/y U (Davidson 2005, p. 72)

The site profile occupational internal dosimetry section (Section 3, p. 26) summarizes NIOSH's review of existing historical documents and data related to worker internal exposures at both the Linde Ceramics Plant and the Tonawanda Laboratory. Data include urinalysis records, airborne concentrations, and radon breath measurements. In addition, NIOSH's contractor, ORAU, has compiled a list of historical documents and data files for Linde operations from early 1942 to the present (the "ORAU database"). ORAU interviewed two past Linde management staff members to obtain first-hand Linde operational information (Dupree 1983). ORAU also interviewed six Linde workers to understand more about the site operational environment.

5.1.2.1 Special Exposure Cohort Petition

On October 12, 2005, NIOSH issued an evaluation report on the Special Exposure Cohort (SEC) Petition 00044, covering a class of atomic weapons employees at the Linde Ceramics Plant from October 1, 1942, through October 31, 1947. The SEC period begins at the start of the Operation and Standby Period, and somewhat overlaps the next period, The Production Period, as defined in the table in Section 5.1.2 of this SC&A review. NIOSH concluded that dose reconstruction could not be completed because of a lack of sufficient biological or air monitoring, and process and radiological source information to estimate internal exposures to workers.

In anticipation of this SEC evaluation conclusion, NIOSH decided to categorize all data and parameters pertinent to estimating occupational internal dose for workers for the period from October 1, 1942, to October 31, 1947, as "reserved" in the site profile. Nonetheless, the site profile contains information from the period covered by the SEC Petition in order to present a whole picture to the dose reconstructors.

5.1.2.2 Use of Air Concentration Data

Following the time period covered by the SEC petition (see Section 5.1.2.1), the site profile uses a "bounding" air concentration of 33 MAC as the benchmark value to estimate missed inhalation intake for workers at Linde Ceramics Plant and Tonawanda Laboratory. The site profile indicates the basis for this assumption:

> *Up until the time of the 1949 AEC report, surveys by the NYOO indicated that out of 648 exposed workers at these plants, 9% were exposed to uranium air concentrations greater than 125 MAC (greater than 6250 mg/m^3), 9% were exposed at 25–125 MAC (1250–6250 mg/m^3), and 82% were exposed to less than 25 MAC (less than 1250 mg/m^3). Linde's maximum time weighted exposure*

> *during this period was 33 or 32 MAC (the data in the report's text and its graph differed).* (Davidson 2005, p. 27)

Airborne dust concentration surveys were performed in October and November 1948 at the Linde Site. None of the 65 employees involved in the survey were exposed to dust concentration levels above 33 MAC. Accordingly, a default chronic dust loading of 33 MAC for the time period after October 1947 may appear to be a reasonable upper bound. However, the exclusive use of airborne uranium dust concentration data (air concentration) at Linde, or, for that matter, at any uranium processing facility, for missed occupational internal dose estimation may not be claimant favorable. Several technical studies, including the 2003 Y-12 study, *Practical Use of Personal Air Sampling (PAS) Data in the Internal Dosimetry Program at the Y-12 National Security Complex* (Snapp 2003), and the Nuclear Regulatory Commission's NUREG-1400, *Air Sampling in the Workplace* (Hickey 1993), demonstrate that relying on air concentration data could lead to underestimating the worker intakes and, consequently, the internal exposures. The Y-12 study shows as high as a factor of 10 underestimation from using intakes derived from air concentration data rather than the preferred bioassay data. In addition, the sensitivity of survey instruments, locations of the air sampling, and air flow studies of the buildings are not considered in the Linde Site Profile; these factors impact the accuracy of the air concentration data. It is also important to note that the air concentration data used are based on results of random grab-air samples in general areas and breathing zones, but not on results of continuous area samples in high-risk or high-dose areas. Therefore, SC&A believes that using air concentration data only in the Linde Site Profile can lead to significant uncertainties in worker inhalation intakes and the possible underestimation of missed internal doses. Furthermore, the use of time-averaged measurement data rather than, say, 95th percentile data, may fail to capture worker exposures in areas of high uranium dust concentrations. The time-averaging issue is discussed later in this section.

Other issues with the maximum time-weighted average approach include uncertainties about the length of a workday and number of overtime hours, and the maximum air concentration value. These issues must be addressed when considering time-weighting. For example, the Linde Site Profile presents in different places various workweek lengths, including 40 hours, 48 hours, and 54 hours. This inconsistency is discussed further in Section 5.1.2.8.

Therefore, SC&A believes that using the 33 MAC value may not be justified, even though it has been called the maximum time-weighted exposure during this period. The value of 33 MAC may not be claimant favorable for some workers, since it does not address acute or abnormal intake scenarios. Hence, it is not demonstrably claimant favorable and defensible. In fact, the site profile does not address or identify any acute or abnormal intake scenarios at Linde at all; it is difficult to believe without strong evidence that none occurred.

In summary, SC&A has identified the following list of potential flaws with using a default airborne uranium concentration of 33 MAC for the time period of September 15, 1947–December 31, 1954:

(1) The measured air concentrations at the seven AWE facilities of the NYOO study were made in breathing zones, general areas, and process areas. The facility average air

concentrations were used instead of area-specific or task-specific air concentrations. Therefore, these concentrations are not representative of a specific task or job category at Linde and do not take into consideration job categories where the potential for exposure may have been well above 33 MAC.

(2) The average air concentrations were time-weighted by exposure times and summed to determine daily time-weighted average air concentrations by job category. The resulting air concentrations may not be representative of a specific period of operation at Linde.

(3) The NYOO report indicates that 9% of the workers in these seven AWE plants were exposed to uranium dust concentrations greater than 125 MAC, i.e., about 4 times the assumed 33 MAC bounding concentration used at Linde. This "bounding" air concentration value is not bounding for at least 9% of the workers, and, therefore, is not necessarily claimant favorable.

(4) This site profile claims that the value of 33 MAC is the "*maximum*" time-weighted average air concentration value for Linde. However, NIOSH indicates that a worker might receive a short-term (acute) exposure, exceeding 300 MAC (Davidson 2005, p. 28).

(5) NIOSH did not perform any uncertainty estimation and analysis for the air concentration data used to derive the maximum time-weighted average air concentration values, as required by 42 CFR Part 81.11. SC&A believes that this is not in compliance with the requirements of the regulation.

(6) Several technical studies, including the Y-12 study and NUREG-1400, show that using air concentration data could lead to underestimating the worker intakes and subsequently the internal exposures to the workers. The Y-12 study shows as much as a factor of 10 difference between intakes derived from urinalysis (bioassay) data and intakes derived from air concentration data, with the latter underestimating the exposure.

(7) The site profile does not provide any information or analysis on the sensitivity of survey instruments used to measure airborne uranium dust concentrations, locations of the air concentration measurements, and air flow studies of the buildings. This information is needed in order to determine the validity of the air concentration data and the uncertainties associated with them.

(8) NIOSH assumes the air concentration value of 1 MAC for the Linde Ceramics Plant during the standby period, and 0.1 MAC after the cleanup period for the Tonawanda Plant. These two assumptions are based entirely on the derived value of 33 MAC for the operational period. SC&A believes that this approach may not be claimant favorable.

If inhalation values are at issue, then so are the derived ingestion values, since the latter are determined by multiplying the former by a factor of 0.2. There also appears to be problems with this approach to deriving ingestion intakes because (1) there may be little relationship between the contamination on surfaces and that in the air (as seems to be the case for many uranium processing facilities), and (2) using air concentration data for determining worker inhalation intakes may also lead to the underestimation of missed ingestion doses. This issue is discussed at greater length in Section 5.1.2.5.

With all these unknowns and shortcomings, the use of measured airborne uranium dust concentration data alone for estimating missed occupational internal dose is questionable. The derived missed worker intake values presented in Tables 11 and 12 of the site profile are considered by SC&A as not necessarily claimant favorable.

5.1.2.3 Urinalysis Data

The site profile indicates that there are some urinalysis data reported for the Linde workers (Davidson 2005, p. 29). These data, however, are not used to estimate worker internal doses (from uranium intake). Instead, NIOSH uses very limited air concentration data, as discussed in Section 5.1.2.2 of this report. In Section 3.8 (Davidson 2005, p. 35), the site profile uses the urinalysis data cursorily together with some urinalysis data from other AWE or DOE facilities as predictive references to validate the upper-bound chronic exposure quantity of workers to uranium dust and its progeny as 300 MAC. However, the site profile does not adequately explain why the potentially valuable urinalysis data were not used for dose reconstruction, as required by 42 CFR Parts 81.5 and 81.6.

In addition, using air concentration data only and neglecting urinalysis data for estimating worker inhalation intakes is not fully compliant with the required "hierarchy of data" approach stipulated in 42 CFR 82.42, which gives greatest importance to bioassay data. There are seventeen sets of urinalysis data for over 100 uranium workers in the ORAU Database for the period between December 16, 1947 and January 30, 1950. The air concentration data used in the site profile do not cover all periods of the Linde operation and suffer from the deficiencies discussed in Section 5.1.2.2 of this report, and, therefore, are deemed inadequate (see Finding 2). In spite of these shortcomings, NIOSH still decided to use only these air concentration data for occupational internal dose reconstruction. The urinalysis results should have been used by NIOSH for estimating worker inhalation intakes by Linde workers during that covered period of time, instead of using measured air concentration data from other periods of time.

5.1.2.4 Breathing Rate

The inhalation pathway is the primary uranium intake mechanism for the workers engaged in uranium processing operations at Linde. The site profile selects a breathing rate of 1.2 m^3/hr for worker intake (Davidson 2005, p. 35), which corresponds to the assumption that workers were primarily involved in light exercise during the course of the day. A single value for the breathing rate, however, may not be consistent with the working conditions in the facility during the early years of operation, and is inconsistent with practices in other NIOSH site profiles, such as Mallinckrodt, Bethlehem Steel, Y-12, INL, SRS, and Hanford. NIOSH should consider a higher breathing rate for Linde, representative of more strenuous exertion. For example, ore movers held heavy burlap bags close to their chests as they moved the ore between boxcars and storage/production areas. They moved rapidly and lifted and carried heavy loads, suggesting that the assumed breathing rate of 1.2 m^3/hr is too low. A minimum rate of 1.4 to 1.7 m^3/hr would be more representative and should be used instead. In addition, NIOSH has not considered oro-nasal breathing (characteristic of heavy labor), which produces greater deposition in the lung than nasal breathing alone.

5.1.2.5 Ingestion Rate

There are several potential ingestion pathways for Linde workers, including eating contaminated lunches, drinking contaminated water, touching the mouth with contaminated hands, and oro-nasal ingestion. The Linde Site Profile assumes an overall uranium ingestion rate of 0.2 (i.e., 20%) of the inhalation intake values for workers; "The amount of activity ingested on a daily basis can be approximated by assuming it to be 0.2 times the activity per cubic meter of air" (Davidson 2005, p. 35).

Since the inhalation intake is estimated by using air concentration data, SC&A believes that the NIOSH approach could lead to the underestimation of ingestion intake and eventual missed ingestion doses for Linde workers. This air concentration issue is discussed at length in Section 5.1.2.2. In addition, for uranium processing plants, the ingestion rate of uranium may not be proportional to the airborne uranium concentration, because the dust loading on surfaces may be more directly related to spills and the direct deposition of large flakes of uranium that were never actually airborne.

5.1.2.6 Radon Exposure and Concentration

The Linde Site Profile treats radon exposures in Section 3.5:

> *During Ceramics Plant pre-production and initial production (which involved only domestic ore processing), the only source of radon was African ore processing at Tonawanda Laboratory. The indoor and outdoor radon concentrations to which Ceramics Plant workers were exposed were assumed to equal the outdoor concentration resulting from Tonawanda Laboratory work. No direct measurement of this was available. An estimate was made based on the* ***lowest indoor concentrations measured at the Ceramics Plant during African ore processing****. These were viewed as indicating the upper limit to the outdoor concentration since outdoor air is drawn indoors for ventilation. Approximately 20% of the measurements in the Ceramics Plant ore processing building yielded results of 10 pCi/L or less, with most of these results at or near 10. Therefore,* ***10 pCi/L was taken as the estimated outdoor concentration****.*
> (Davidson 2005, p. 32)

Despite the above paragraph, SC&A is not clear why NIOSH uses the lowest indoor concentrations during African ore processing as the upper limit to both indoor and outdoor radon concentrations. With the presence of radium in the process areas and the waste produced, the radon levels could be quite high.

5.1.2.7 Raffinate Trace Radionuclides

The dose consequences of raffinate trace radionuclides have not been adequately addressed in the Linde Site Profile. Raffinate contains Ac-227 and Pa-231, which are in the U-235 decay chain, as well as Th-230, which is in the U-238 decay chain. Inhalation of even small quantities of some raffinates, such as filter cake (one of the waste products at Linde), could result in significant doses to the workers. The issue of potential airborne contamination of raffinates must be more carefully assessed. In addition, NIOSH lists Ac-227 and Pa-231 in Tables 5, 11, and 12 of the site profile as radionuclides of concern for internal exposure to Linde workers (Davidson 2005, p. 37), but NIOSH does not include them in Table 39 for worker exposure during the cleanup period. In Tables 11 and 12, inhalation intake values are not listed for Th-230, Ac-227, and Pa-231 at all for the period from 1947 to 1954. NIOSH should further evaluate the potential exposure pathways for internal exposure of raffinate trace radionuclides, and investigate the relative impact of trace radionuclide intakes to the total dose.

5.1.2.8 Assigned Weekly/Annual Work Hours

The number of work hours used in calculating occupational internal and external doses for workers is inconsistent for different periods of Linde operations and, therefore, not claimant favorable, since the maximum is not used in most places. The site profile represents in Table 4 (Davidson 2005, p. 24), as well as in several other places, that workers routinely worked more than 40-hours per week, and, in some cases, as many as 54-hours per week (i.e., six 9-hour days) for 50 weeks per year (2,700 hours per year). But in many instances, NIOSH uses the standard 40-hours per week assumption for missed dose estimations. This approach is not only inconsistent, but also not claimant favorable.

The following is a list of different weekly work hours or annual work hours assigned in the Linde Site Profile for missed occupational internal dose estimation (Davidson 2005):

- Airborne uranium dust concentrations: 40-hours per week (p. 28)
- Radon concentrations: 2,040-hours per year (p. 32)
- Uranium inhalation intakes values: 2,000-hours per year (p. 35)
- Uranium ingestion intake values: 8-hours per day, 250 days per year (p. 35)
- Residual year occupational annual internal exposure: 2,000-hours per year (p. 72)

These different and sometimes not claimant-favorable work-hour assumptions would underestimate worker inhalation and ingestion intake and, in turn, missed occupational internal dose to workers at Linde. NIOSH should use a set of consistent and claimant-favorable work hours.

5.1.2.9 Surrogate Air Concentration Data

Using the GM of air concentration data of seven AWE facilities in New York from a 1949 AEC/NYOO report (AEC 1949a) as surrogate data to develop Linde site-specific worker inhalation intakes for the entire period of Linde Operation from 1942 to 1954 appears over-reaching and may potentially underestimate the missed occupational internal dose to workers. This approach is inappropriate, because the surrogate data are very limited and not representative of the actual Linde operation conditions, since ventilation was poor or non-existent and adequate radiation protection practices had not yet been developed in the earlier years of the Linde site operation. In addition, the Linde Site Profile uses daily weighted-average, not the upper bound or the 95th percentile values, of the exposure levels measured for workers as surrogate concentrations for the dust exposure levels of workers. As a result, the estimated missed internal dose to workers is not claimant favorable. SC&A believes that these surrogate data do not provide the best estimates for the reconstruction of missed occupational internal dose to workers for the period from 1942 to 1947. NIOSH should re-evaluate this approach.

5.1.2.10 Geometric Values

The statistical analysis approach used in the Linde Site Profile is not bounding and, most importantly, not claimant favorable. In Table 6 of the Occupational Internal Dose Section (Davidson 2005, p. 33), the site profile lists the GM or the GSD values for measured radon concentrations during African ore processing. First, there are no supporting calculations or data to show how these geometrical quantities were calculated. Second, these geometrical values would not provide "maximized" default values or assumptions to produce claimant-favorable worker doses. Third, NIOSH does not provide comparison of these geometrical values with NIOSH-prescribed 95th percentile values. For example, NIOSH's use of the GSD values is not claimant favorable for routine day-long exposures of production workers in Linde process buildings. In addition, this statistical approach may not address very high, short-term, episodic airborne concentrations; short-term intakes during incidents; and intakes during the performance of tasks with a potential for high transient airborne concentrations. Since actual data were not available, 95th percentile, not GM, should be used to bound the potential inhalation and ingestion intakes, and to assign claimant-favorable missed occupational internal dose to workers.

5.1.2.11 Lack of Comprehensive Uncertainty Analysis

Providing geometrical values (GM and GSD) for inhalation intakes and radon concentration levels does not represent compliance with required uncertainty analysis. There are no uncertainties or errors from various sources (measurement, laboratory, and instrument) estimated for different assumptions, parameters, and factors used in the estimation of missed occupational internal dose in the Linde Site Profile.

An assessment of uncertainties, as required by OCAS-IG-001 and OCAS-IG-002, has not been adequately developed for air concentration and radon measurement data used instead of bioassay data to assign internal dose. As described in the site profile, "little information was available" during the periods of production and non-production. In fact, the site profile uses different words to indicate that the information gathered is "uncertain," such as "probably," "likely," and "assumes." It gives the strong impression that the available data gathered are inaccurate and uncertain. Therefore, NIOSH should develop a method to determine best-estimates and their uncertainties, as well as the 95th percentile value of time-weighted values of inhalation intake, radon intake, and ingestion intake for internal dose calculations.

There are many assumptions and surrogate data used, with different degrees of uncertainty, in the estimation of occupational internal dose to workers for the period from 1942 to 1954. The accuracy and representation of these assumptions and surrogate data are questionable. Therefore, without associated uncertainty factors identified and applied, the eventual internal dose estimations are not properly supported. NIOSH should revise the Linde Site Profile to include uncertainty analysis, as required by 42 CFR 81.

5.1.3 Occupational External Dose

The Linde Site Profile uses a very complex scheme, combining film badge data, uranium solid sample analysis results, and facility radiation field measurements, to estimate missed occupational external dose to workers from 1942 to the present time. These data are limited, however, and not Linde facility/building-specific. Furthermore, the site profile uses different sets of data to estimate worker beta and gamma doses separately.

The site profile provides a list of external dose data for the Linde Ceramics Plant and Tonawanda Laboratory, including the following sets:

(1) 1949 Building 30 survey
- Beta/gamma at contact and at 3' (after vacuum cleaning and flushing)
- Beta/gamma at contact and at 3' (before decontamination)
- Beta/gamma at contact and at 3' (after decontamination)

(2) 1949 April 19 and 22 surveys
- Not clear whether the surveys performed for the whole site or just Building 30
- Beta/gamma at 1 cm and gamma at 1 m (before vacuum cleaning and flushing)
- Averaged gamma dose rate of 0.18 mR/hr about 4 times the estimated median contact gamma before decontamination (0.0438 mR/h from Table 13)
- Averaged gamma dose rate of 0.87 mrep/h about 1.3 times the estimated median beta before decontamination (0.675 mrem/h from Table 13)

(3) 1976 Building 30 survey
- Not clear whether the survey performed for the whole site or just Building 30
- Building 30 claimed to be the most contaminated building on site (not supported with document or data)

(4) Pre-production (1942–1943)
- Transport of uranium ore to Building 14
- Indoor and outdoor exposures by Linde workers to beta/gamma sources possible
- Used estimated Building 14 beta and gamma exposure rates before vacuum cleaning and flushing ("before") in Table 13
- Assumed these estimated "before" beta and gamma rates upper limit of outdoor levels

- Assumed exposure time of 0.5 hr/d, 6 d/wk, 50 wk/y for all site workers outdoors (i.e., 150 hrs per year)
- Assumed beta dose to whole body only for Linde workers
- Assumed no extremity doses (i.e., ignoring ore movers)

(5) Production (1943–1946)

- No film badge measurements available for this period of Linde operations
- Eight solid samples collected on January 23, 1944, for measurements of beta radiation (Davidson 2005, Table 19)
- Dose rates assumed at contact (R/8-hr) (Davidson 2005, p. 44)

(6) 1944 Radiation Surveys

- March 2 and 3 surveys conducted
- Identified two 200,000-lb piles and one 300,000-lb pile of 10% ore in the receiving room at the south end of Building 30
- Identified one 30' x 30' x 20' (~2,000,000-lb) pile of 8% ore in an unspecified location

NIOSH has attempted to assign "somewhat conservative" assumptions in some portions of the external dose assignments, but these assumptions may not be bounding. Thus, the overall external dose approach results in reconstructed doses that are not necessarily claimant favorable. The important external dose assignments include:

(1) For Production Period (1943–1946), the following external dose rates are assigned for all Linde workers:[4]

- A gamma exposure rate of 5.35 R/y for the whole body
- An outdoor gamma rate of 0.020 R/y for all workers

(2) For Rehabilitation and Production Period (1947–1949), the following external dose rates are assigned:[4]

- A beta dose rate of 1.95 rem/y for medium job category
- A beta dose rate of 1.00 rem/y for low job category
- A hands and forearm dose rate of 5.85 rem/y for medium job category
- A hands and forearm dose of rate of 1 rem/y for low job category
- An outdoor beta dose rate of 0.10 rem/y for the whole body for medium job category
- A gamma exposure rate of 1.61 R/y for the whole body for medium job category
- A gamma exposure rate of 0.48 R/y for the whole body for low job category

[4] Note that portions of these time periods are covered by the SEC petition, but are addressed here and in the site profile for completeness.

- An outdoor gamma exposure rate of 0.020 R/y for all workers

This complex scheme of estimating missed beta and gamma doses to Linde workers is not easy to follow. In many cases, there are no clear or, sometimes, any explanations why a particular assumption is made. Even when a clear explanation is presented, in many cases the rationale for the assumption is either inconsistent or not technically sound. These weaknesses lead SC&A to conclude that NIOSH's external dose assumptions may not be claimant favorable, especially for the more highly exposed workers.

An example of an unsupported assumption is the use of the factor of 3 shown in Table 13 (Davidson 2005, pp. 39–40) to estimate the beta and gamma dose rates in Building 30 before vacuum cleaning and flushing in 1949. The site profile compares the very limited "survey data" taken in April 1949, before the vacuum cleaning and flushing of Building 30 to the estimated median contact gamma level before decontamination (Davidson 2005, p. 40). The comparison results show that the typical gamma dose rates measured at 3 ft were about 4-times higher than the estimated median contact gamma dose rate before decontamination. It is not clear why NIOSH decided to use the factor of 3 instead of 4. The site profile states the following:

> *The measurements just before decontamination in 1949–1950 were made after the building had undergone vacuum cleaning and flushing. Brief, semi-quantitative reports were available for two one day surveys taken in April 1949, before the vacuum cleaning and flushing (Blatz 1949; Wolf 1949). Typical levels of gamma radiation measured at 3' on April 19 and at contact on April 22 were similar and averaged about 0.18 mR/h, about four times higher than the estimated median contact gamma level before decontamination. Typical levels of beta measured at contact on April 22 averaged about 0.87 mrep/h, about 1.3 times higher than the estimated median beta level before decontamination. The April results were the basis of the estimate in Table 13 that beta and gamma radiation levels before vacuum cleaning and flushing were three times higher than the values measured afterward.* (Davidson 2005, p. 40)

The site profile proceeds from this point to use values developed based on the factor of 3 in Table 13 as the primary technical basis for missed beta and gamma estimates for several periods of Linde operations and for all Linde buildings. This further propagates the uncertainties inherently imbedded in the factor of 3, and potentially underestimates the missed beta and gamma dose rates to workers.

Rather than comparing the median or average values for the external dose rate measurements before versus after decontamination, a ratio of the before versus after decontamination exposure rates could have been based on the upper 95th percentile confidence level of the means. Alternatively, the highest ratio observed at any given location could also have been used. In this way, there would be a higher level of assurance that pre-decontamination dose rates that are derived based on observed post-decontamination dose rates are claimant favorable.

5.1.3.1 Beta Dose

Section 4.1.3.1 of the site profile covers beta dose to workers during the production years, 1943–1946:[5]

> *It is striking that the 1943–1946 dose rates indicated in Table 19 are much higher than the 1947–1949 rates discussed in Section 4.1.4.1. For 1943–1946 Step I Process Operators, the beta dose rate is estimated as 263 rem/y. For 1947–1949, the job with the highest beta dose rate was that of a Step III Process Operator, and film badge data indicate that the beta dose rate was only about 2 rem/y ... Despite the high estimates, the 1943–1946 data do not appear unreasonable. The dose rates in Table 19 are typical of contact dose rates for uranium materials (see Table A-1). The worker exposure times were debated and reviewed within the MED. In the MED's interpretation of the data, with allowances for the protective measures (e.g., gloves) the rates were within the limit in effect at the time, 3.0 R per six-day week (Ferry 1944b) or 150 R/y. Therefore, the estimates in Table 19 are considered a valid basis for dose reconstruction.* (Davidson 2005, p. 44)

For the period of 1943–1946, NIOSH assumes the worker beta dose rates were three times higher than those of the period of 1947–1949. According to the site profile (Davidson 2005, p. 45), "the factor three increase accounts for potential exposure to radiation from waste products from unrefined uranium ore and for the possibility that procedures in 1943–1946 did not involve as much radiological protection." The basis of this assumption is that "unrefined uranium materials release approximately 2.6 times as much electron energy per uranium decay as refined uranium materials."

NIOSH establishes three exposure classes and determines the beta dose rates in Table 21 as follows:

- High exposure category:
  - 263 rem/yr (Table 19) x 0.84 = 221 rem/yr for hands and forearms
  - 88 rem/yr (Table 19) x 0.84 = 74 rem/yr for remainder of body
- Medium exposure category
  - 17.6 rem/yr for hands and forearms
  - 5.85 rem/yr for remainder of body
- Low exposure category
  - 3 rem/yr for hands and forearms
  - 3 rem/yr for remainder of body

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[5] This time period is covered by the SEC petition. However, it is important to keep in mind that skin cancer, which could be caused by external beta exposures, is not one of the presumptive cancers covered by the SEC rule.

For outdoor beta dose rate determination, NIOSH decided to assign a value of 0.10 rem/yr, which is derived from the beta dose rate at 3 ft before vacuum cleaning and flushing (i.e., 0.676 mrem/hr × 0.5 hr/d × 6 d/wk × 50 wk/yr). This value only addresses those working indoors all day. Those working outdoors about 8-hours per day should be assigned an outdoor beta dose rate of 1.6 rem/yr.

Table A-1 of the site profile shows the beta surface dose rates from uranium-containing materials in the range of 200 mrad/hr, i.e., 400 rad/yr or rem/yr (using 2,000 work hours per year). Table 30, however, shows the beta doses for the Step III Process in Building 30 of the Linde Ceramics Plant (1947–1949) in the range of 2 rem/yr, i.e., 1 mrem/hr (using 2,000 work hours per year). The beta dose rate estimated for Step I Process Operations in 1943–1946 was 263 rem/yr, which is less than the typical contact dose rates for uranium materials in Table A-1 by a factor of close to 2. In addition, the assumption made by NIOSH that Linde radiation protection programs could effectively limit Linde workers within the MED guidelines of 3.0 R per 6-day week, or 150 R/yr, is not very convincing, due to the fact that Linde did not have much of a radiation protection program. None of the site experts SC&A interviewed in Buffalo recalled that they had received any type of radiation protection training while working at the Linde Site.

In the Linde *Safety Rules and Practices Handbook*, there is only a very small section addressing radiation matter, titled "Radiation Areas." It states the following (pp. 22–23):

> *All of our radiation work is conducted under strict procedures set up by the State and Federal Governments. Special protective measures are taken to insure that none of our radiation workers are exposed to excessive amounts of radiation.*
>
> *All radiation work areas are clearly identified with radiation signs and/or lights and barricades for your protection. Do not enter these areas unless you have been specifically authorized to do so.*

Even though the estimates in Table 19 are close to the typical beta dose rates for uranium materials, they are not valid for bounding the potential beta doses workers might have received at the Linde Ceramics Plant and Tonawanda Laboratory during 1947–1949. In addition, the site profile attempts to use the dose values in Table 19 as surrogates for the entire period of 1943–1946 (Davidson 2005, p.45):

> *In order to use the data in Table 19 to estimate time-averaged beta dose rates applicable to the entire 1943–1946 production period at Linde, the ratio of the average dose rates to those measured in Table 19 was estimated. Table 20 documents the determination of the ratio. The grade range of the L-30 ore used at Linde was 8–12% (Aerospace Corporation 1981, Table B-1). To obtain the highest ratio, it was assumed that the measurements in Table 19 were made on the lowest L-30 ore grade, 8%. It was also assumed that beta dose was proportional to electron energy released per decay and the worker doses were proportional to the mass of ore processed. With these assumptions, it was*

> *estimated that average doses would have been 0.84 of the doses predicted by using the data in Table 19. Therefore, the estimated dose rates in Table 19 were multiplied by 0.84 to obtain time-averaged dose rates for 1943–1946 production. The results are in Table 21, which summarizes the results of all beta dose rate estimates in this section and groups the job categories into three groups (high, medium, and low).*

NIOSH believes that by determining the ratio of the average dose rates of different types of ores to those measured in Table 19 for 8% L-30 uranium ores, the time-averaged beta dose rates can be derived for workers at Linde during the period from 1943–1946. The highest ratio was determined in Table 20 to be 0.84, which was selected by NIOSH for the application. The Linde Site Profile does not provide details about how the beta dose rates are time-averaged.

SC&A has identified two potential flaws in this dose rate assignment. First, the dose rates in Table 19 are not necessarily bounding, because an individual could work with higher-grade uranium ore for a very long period of time in a processing area. Even when the highest ratio is used, there could be underestimation of the beta dose rates. Second, the time-averaged beta dose rates would not provide bounding dose rates for high-risk jobs. Therefore, this method and its determined beta dose rates may not be claimant favorable for all workers.

From the application of the beta dose rates presented in Table 19, NIOSH proceeds to determine beta dose rates for various job categories of workers at the Linde Ceramics Plant and Tonawanda Laboratory. These job categories are also grouped into three exposure potentials—high, medium, and low. However, the site profile does not provide support or explanation of how these beta dose rates are determined for each of these job categories in the three exposure groups. Additionally, NIOSH does not identify which estimated beta dose rates in Table 19 were used to determine the beta dose rates in Table 21.

5.1.3.2 Gamma Dose

NIOSH compiled the following external dose data for use in the site profile:

- 1946–1947 (Standby Period and is included in the time period covered by the SEC)
  - NIOSH assumes all Linde workers are a guard or a general worker remaining in office, production buildings, and outdoors
  - Gamma measurements (Howland 1946) in 6 locations in Building 30 at 1” from surface; 4 measurements read 0 R/8h, and 2 measurements 0.005R/8h (0.625 mR/h) near the atypically contaminated and radioactive ore dumping grill; NIOSH took indoor gamma and beta levels from a 1949 characterization (Table 13), before vacuum cleaning and flushing were performed (Davidson 2005).
  - Outdoor gamma/beta is assumed by NIOSH to be same as indoor rates; gamma and beta dose rates in offices and buildings were found to be zero; NIOSH uses exposure times of 9 h/d, 6 d/wk, and 50 wk/y; assumed beta extremity dose rate equals the beta dose rate to the whole body

- 1947–1949 (Rehabilitation and Production Period)
  - Weekly film badge measurements of beta and gamma exposure available
  - 6000 records from January 7, 1948, to December 12, 1949
  - Beta dose unit is rem equivalent to shallow dose at 0.07 mm Hp
  - Limit of detection was 35 mrem
  - Outdoor beta dose was assumed to be 0.1 rem/yr
  - Average beta level in Building 30 from Table 13 was 0.676 mrem/hr
    - Dose rate of 34.5 mrem/wk or 1.7 rem/y (assuming 8.5 h/d, 6 d/wk, 50 wk/y)
    - Equivalent to film badge LOD of 35 mrem/wk

For 1947–1949, NIOSH assumes that all Linde workers, including office workers, would receive a gamma dose of at least 1 rem/y. In addition, NIOSH uses the following assumptions for dose reconstructions:

- Medium job category: 1.95 rem/y (Davidson 2005, Table 30, highest category)
- Low job category: 1 rem/y (Davidson 2005, Table 30, lowest badged worker)

For extremity dose, NIOSH assumes the following:

- Medium job category: 5.85 rem/y (i.e., 3 × 1.95 rem/y)
- Low job category: 1 rem/y

For gamma dose, NIOSH determines the following:

- Limit of detection: 45 mR
- Outdoor gamma dose: 0.02 R/y

The average gamma level in Building 30 from Table 13 (Davidson 2005) in this period is 0.131 mR/h, i.e., 6.7 mR/wk or 0.34 R/y (assuming 8.5 h/d, 6 d/wk, 50 wk/y). This gamma dose rate is less than the film badge LOD value of 45 mR/wk. Therefore, NIOSH assumes the following:

- Medium job category: 1.61 R/y for the whole body (Davidson 2005, Table 32, highest from film badge)
- Low job category: 0.48 R/y for the whole body (i.e., 0.34 + 0.14 from Davidson 2005, Table 32)

The beta and gamma doses presented in Table 33 (Davidson 2005) for the Tonawanda Laboratory in the period from 1942–1946 are not supported. The Linde Site Profile does not provide a clear explanation of how these dose values are derived.

For the period from 1949–1954 (Cleanup Period), NIOSH uses dose rates from Table 13 (Davidson 2005), some film badge measurements of beta and gamma emitters during the 1948 removal of equipment from Building 30, and some floor and wall radiation levels measured at the start and end of the 1949/1950 decontamination of Building 30. The following is the NIOSH approach to estimating missed beta and gamma doses:

- The film badge measurements of beta and gamma radiation in Table 17 (Davidson 2005) include floor and wall radiation, in addition to radiation from contaminated equipment.

- Missed beta and gamma dose for cleanup workers should include also outdoor beta and gamma doses (Table 17), which equals estimated indoor floor and wall radiation levels at 3 feet before vacuum cleaning and flushing presented in Table 13 (Davidson 2005).

NIOSH assumes the following:

- Cleanup support workers would receive a beta and gamma dose that equals half of the beta, gamma, and outdoor doses in Table 17 (Davidson 2005).

- Non-cleanup workers would receive a beta and gamma dose that equals 5% of the gamma and outdoor gamma doses in Table 17 (Davidson 2005).

- Cleanup workers would receive an extremity dose that is 3 times beta dose to the remainder of the body.

It does not appear that NIOSH provides documentation supporting many of these assumptions, and it is not clear whether these assumptions are claimant favorable.

For the period after 1954 (Post-Cleanup Period), NIOSH uses mainly 1976 Building 30 survey data. It is not clear how the beta and gamma annual dose rates are estimated in Table 39 (Davidson 2005).

Documents in the ORAU database contain gamma radiation rates measured in June 11, 1945, at the Linde Site from high grade ore stored in 55-gal steel drums (15-gauge, 1000 lbs). These dose rates, however, were not used in this Linde Site Profile. Sources of the data used by NIOSH in estimating the missed external (beta and gamma) doses are summarized as follows:

- Eight solid samples of uranium material were collected in January 23, 1944, from Step I ore, ore tailings, barium cake, soda salt, and Step II iron cake. These samples were sent to laboratories of the Medical Section of the MED for radiological analyses. Results are compiled in Table 19 and used for estimating beta doses during the production period between 1943–1946. (Davidson 2005, p. 43)

- Gamma film badge data were available from January 31, 1944, to February 26, 1945, except for a 3-week gap (April 18, 1944–May 8, 1944). Results are compiled in Table 23 for five job categories (ball mill operator, loader, ore sampler, process operator, weighmaster) of the Step I African ore processing (January 31, 1944–November 12, 1944) ,and in Table 25 for six job categories (ball mill operator, cleanup, loader, ore sampler, process operator, weightmaster) of the Step I Domestic ore processing

(November 13, 1944–February 26, 1945). These results are used for estimating missed gamma doses during the production period between 1943–1945 (Davidson 2005, p. 47).

- Gamma radiation levels were measured at six locations inside Building 30 on October 22, 1946. These measurements were made at 1 inch above the surface of interest. Results were reported as R/8 hours and are compiled in Table 16 for estimating beta and gamma doses during the standby period of the Linde Site (Davidson 2005, p. 41).

- Weekly beta and gamma film badge data were available between 1947 and 1949 during the rehabilitation and production period at Linde Site. These weekly film badge data are categorized into different job categories in Tables 28 and 29. Results are compiled in Table 29 and Table 30 for estimating Step III worker beta doses, and in Table 31 and Table 32 for estimating Step III worker gamma doses during that period of operation (Davidson 2005, p. 54).

- Survey measurement data from two 1-day surveys in Building 30 on April 19 and April 22, 1949, were made before the building had undergone vacuum cleaning and flushing (Blatz 1949; Wolf, 1949). Results are compiled in Table 13 as the primary basis for estimating worker beta and gamma doses. The Linde Site Profile states on page 40, "The April results were the basis of the estimate in Table 13 that beta and gamma radiation levels before vacuum cleaning and flushing were three times higher than the values measured afterward" (Davidson 2005, p. 39).

- Beta and gamma film badge data were available during the 1948 removal of equipment from Building 30. These data were determined by NIOSH to include floor and wall radiation, in addition to radiation from contaminated equipment. Results are compiled in Table 17 and Table 18 for estimating cleanup and non-cleanup worker beta and gamma doses for the cleanup period between 1949 and 1954 (Davidson 2005, p. 41).

- Beta plus gamma survey measurement data from pre-decontamination (but after vacuum cleaning and flushing) and from post-decontamination of Building 30 in 1950 were available (Heatherton 1950). These measurement data were analyzed with the computer program LOGNORM4 to estimate the median measurements at 3 feet. Their median results are compiled in Table 13 for estimating worker beta and gamma doses (Davidson 2005, p. 39).

- Actual worker film badge data are available for the period from January 31 to November 12, 1944. However, many of these film badge data were average exposures for the entire period. Therefore, they are not representative of a particular job condition, a particular operation, a specific job location, or high-dose jobs. SC&A does not consider this averaging approach to be claimant favorable, because the average exposures do not represent the upper-bound dose rates, especially since historical and operational information are scarce for the Linde Site.

NIOSH determines the highest worker gamma dose rate to be 5.35 R/yr for the Loader job category in Table 24 (Davidson 2005, p. 50), but this gamma dose rate is based on the median of a lognormal distribution and, therefore, not representative of the upper-bound dose rates. Even though NIOSH applies this "maximum" gamma dose rate for the whole body to all Linde Plant employees during the period from 1943 to 1946, it may not be claimant favorable for workers who potentially might have been exposed to higher gamma dose rates in certain job conditions. However, SC&A believes that this value is claimant favorable for all other Linde employees. It is also instructive to note that gamma dose rates presented in Table 24 are averaged over a 1-year period. This makes them even less representative of the actual exposure conditions for workers who might have worked partially in Linde buildings and operations. NIOSH may want to consider using the upper 95th percentile of the mean for each of the three worker categories as a more claimant-favorable strategy. Alternatively, if it is known that specific locations/job categories had consistently high-exposure potential, the upper 95th percentile value of the full set of measurements may be appropriate as a default value for those workers whose job category/location is not known.

The outdoor gamma exposure rate of 0.02 R/yr (Davidson 2005, Table 13, p. 39) is assigned by NIOSH for all Linde workers. This rate is based on the exposure rate of 0.131 mR/hr and an exposure time of 0.5 hr/d for workers working indoors most of the working day. For those workers who worked outdoors the whole time during the day, the exposure rate should be 0.32 R/yr.

5.1.3.3 Neutron dose

There were no neutron exposure monitoring or measurements performed for workers at the Linde Site, based on information provided in the site profile and documents in the ORAU database. Even though there were large amounts of uranium present in various processes of the Linde operation, the only potentially significant source of neutron exposure to workers would have come from the (α,n) alpha-neutron reaction in materials where uranium was mixed with elements of low atomic number, such as fluorine and oxygen. The site profile states the following on page 62 (Davidson 2005):

> *Ceramics Plant (Buildings 30 and 38) personnel are assumed to be exposed to 1/10 of the daily production amount of U_3O_8 or UF_4 at a distance of 1 foot. This quantity of material is a claimant-favorable estimate of the time-averaged amount of material likely to have been close to the maximally exposed worker during a work shift. The factor of 10 reduction takes into account several factors: that the plant operated around the clock so that each shift dealt with only 1/3 of a day's throughput; that many workers were involved in each type of operation so that each worked closely with only a portion of a shift's throughput; that an individual working in the vicinity of a large quantity of material (e.g., barrels of finished product) would on the average have been much more than 1 foot distant because of the large volume it would have occupied; and that even a worker in a job that involved being close to large quantities of material also had other activities at larger distances from the source term.*

The calculated neutron dose rates and annual doses from the (α,n) sources are tabulated in Table 35 (Davidson 2005, p. 63). These dose rates and annual doses are listed separately for Building 30, Building 38, and Building 14. From these dose rates and annual doses presented in Table 35, NIOSH determines the annual neutron doses (rem) for various categories of workers (all workers, high, medium, low, cleanup, non-cleanup, research, office) during various periods of operation in Table 36.

However, the calculation of these neutron dose rates and annual doses cannot readily be reproduced, due to lack of supporting data and information. In addition, annual doses used in Table 36 do not match the dose rates compiled in Table 35. NIOSH needs to provide more supporting information, so that the dose reconstructor can use the information presented.

Table 36 summarizes all neutron-related data and is easy to use. However, it is pertinent to question whether these neutron data are claimant favorable and technically sound. SC&A did not find any information or discussion in the site profile regarding type and sensitivity of film badge and survey instruments used, measurement geometry, angular dependence, uncertainty, and correction factors.

5.1.3.4 Film Badge Data

The lack of complete beta and gamma film badge data for the period from 1942 to 1954 represents that there is a great potential for unaccounted beta and gamma doses. Available film badge and other radiation survey data are summarized in Table 5-2, reproduced below.

Table 5-2: Available Film Badge/Survey Data and Surrogated Data Used

Year	Beta Film Badge Data	Gamma Film Badge Data	Beta/Gamma Film Badge Data	Surrogate Data
1942				
1943				
1944		Step I process workers (January 31, 1944–November 12, 1994) for African ore		8 solid samples from various locations
1945		Step I process workers (November 13, 1944–February 26, 1945) for domestic ore		
1946				Survey measurements in six locations inside Building 30
1947			Weekly measurements	
1948			Building 30 equipment removal; weekly measurements (6000 records)	
1949			Weekly measurements (6000 records)	*Building 30 survey measurements

Table 5-2: Available Film Badge/Survey Data and Surrogated Data Used

Year	Beta Film Badge Data	Gamma Film Badge Data	Beta/Gamma Film Badge Data	Surrogate Data
1950				Beta plus gamma measurements in Building 30
1951				
1952				
1953				
1954				
Post-1954				Building 30 floor and wall radiation level measurements in 1976

*Primary surrogate data source

NIOSH developed a complex scheme, including using pre-cleanup survey data for the pre-production period from 1942 to 1943, uranium solid sample data for the period from 1943 to 1946, a 1-day survey data in six locations in Building 30 for the period from 1946 to 1947, two 1-day pre-cleanup survey data after vacuuming and flushing in Building 30 for 1949, and post-decontamination survey data for 1950. SC&A believes the missed occupational external doses estimated by using this scheme may not be claimant favorable for all workers. This complex surrogate external dose rate scheme is summarized in Table 5-3 below.

Table 5-3: Complex Surrogate External Dose Scheme*

	Missed Beta Dose	Missed Gamma Dose	Missed Neutron Dose
Linde Ceramics Plant (Buildings 30, 31, 37, 38)			
1942	Table 15	Table 15	NA
1943	Table 21	Table 21	Table 35
1944	Table 21	Table 21	Table 35
1945	Table 21	Table 21	Table 35
1946	Table 21	Table 21	Table 35
1947	NK	NK	NK
1948	p. 57/58	p. 59	Table 35
1949	pp. 57/59 & Table 18	p. 59 & Table 18	NK
1950	Table 18	Table 18	Table 18
1951	Table 18	Table 18	Table 18
1952	Table 18	Table 18	Table 18
1953	Table 18	Table 18	Table 18
1954	Table 18	Table 18	Table 18
Post-1954	Table 18	Table 18	Table 18
Tonawanda Laboratory (Building 14)			
1942	Table 33	Table 33	Table 35
1943	Table 33	Table 33	Table 35
1944	Table 33	Table 33	Table 35
1945	Table 33	Table 33	Table 35
1946	Table 33	Table 33	Table 35
1947–1954	Table 33	Table 33	Table 33

*All assigned external doses summarized in Table 36 (Davidson 2005, p. 64)
NK-Not Known

In addition, the use of the 1948 weekly film badge data for assigning both beta and gamma doses during the removal of equipment in Building 30 is not appropriate for the entire period from 1949 to 1954. These beta and gamma dose assignments in Table 36 contain median weekly photon doses and weekly median electron doses for use for unmonitored workers from 1942 to 1954. These assignments are not likely to capture the full range of external exposures during that time period. Table 36 does not appear to be representative of various facilities and job functions that defined Linde operations/processes.

Another problem occurring in Table 36 (Davidson 2005, p. 64) is that some of the beta and gamma doses cannot be reproduced or traced back to their sources. For example, there is no explanation or discussion on how the 1947 and 1949 (beta/gamma/neutron) doses are calculated, since they are all based on 1947–1949 weekly film badge data presented in Table 29 and Table 31 of the Linde Site Profile. Hence, it is not apparent that the assigned missed beta and gamma doses presented in Table 36 are technically sound and claimant favorable.

5.1.3.5 Survey Measurement Data

Several sets of survey measurement data were used in the Linde Site Profile to calculate the missed beta and gamma doses for workers from 1942 to 1954. These survey measurements do not cover the entire period of Linde operation. SC&A believes that NIOSH should improve the use of these data, because significant gaps exist for time periods when workers were not monitored for external or internal exposure. In addition, NIOSH did not evaluate or attempt to evaluate the adequacy, uncertainty, and accuracy of these data, which further weakens the assigned missed worker beta and gamma doses for the Linde workers.

There is no discussion or information regarding survey instrument geometry and sensitivity. NIOSH should provide angular dependence (anatomic geometry) correction factors for external gamma doses, particularly for low-photon energies, where the angular dependence of the sensitivity of the survey meter or dosimeter is most pronounced. These correction factors are used to account for, for example, the bias introduced by a dosimeter worn at the neck level and the higher doses received by tissues/organs below the waist.

5.1.3.6 Time-Weighted Averages

Similar to internal dose calculations (see Section 5.1.2.2 for discussion), time-weighted averages of external exposure values contain significant uncertainties and frequently fail to capture dose to workers in areas of high beta or gamma radiation fields. In the external dosimetry section of the site profile, NIOSH determines the time-weighted average beta and gamma radiation dose rates during the standby period from 1946 to 1947 by time-weighting the dose rates with average worker exposure times, and summing to determine annual time-weighted average by job category (Davidson 2005, p. 41). This approach could underestimate the dose rates for high-dose or high-risk tasks at the Linde Site. In addition, the site profile estimates time-averaged beta doses for the production period from 1943 to 1946:

> *With these assumptions, it was estimated that average doses would have been 0.84 of the doses predicted by using the data in Table 19. Therefore, the estimated dose rates in Table 19 were multiplied by 0.84 to obtain* ***time-averaged dose rates*** *for 1943–1946 production. The results are in Table 21, which summarizes the results of all beta dose rate estimates in this section and groups the job categories into three groups (high, medium, and low).*
> (Davidson 2005, p. 45)

Even when the site profile claims that the "maximum" time-weighted average dose values are used to provide upper-bound dose values, they would not represent maximized dose values for a worker, and may have limitations when used for denial of claims; nor do they give claimants the benefit of the doubt in the face of uncertainties associated with high-risk jobs. Individual doses could be far greater than these averages, even when the job description and work locations are known. Procedures for estimating 95th percentile values, for instance, would need to be developed, in which the claimant is given the benefit of the doubt. The Linde Site Profile lacks the needed procedures for dealing with these uncertainties.

Other issues with the maximum time-weighted average approach include uncertainties about the length of a workday, overtime hours, and the maximum air concentration value. These issues must be addressed when considering time-weighting. For example, the site profile presents various workweek lengths, including 40 hours, 48 hours, and 54 hours. This document uses inconsistent workweek lengths for different time-weighted averaging (Davidson 2005, p. 41).

5.1.3.7 Contaminated Burlap Bags

> *Olevitch (1944) reports the outdoor storage of contaminated ore bags that at times numbered in the thousands. In 1948, 1 mR/h gamma and 3,000 a dpm/ 100 cm^2 were measured from the soil in an area formerly used for storage of radioactive materials (Heatherton 1948h).* (Davidson 2005, p. 22)

During the SC&A-conducted interview in Buffalo, Linde site experts and past workers indicated that there were many thousands of used burlap bags stacked up in the open bay area behind Building 30 (see Attachment 3 of this review report). These bags were used for transporting uranium ore to Linde for processing. After the end of the operation period, the contaminated burlap bags were stored behind Building 30 awaiting disposal. Many Linde workers, operation staff, and administrative personnel sat on these contaminated bags during breaks and lunch periods. This practice continued for many years, exposing many people at close distances to beta and gamma radiation sources left over in the uranium-contaminated burlap bags. The site profile does not estimate the missed beta and gamma doses to workers resulting from sitting on or standing next to those burlap bags.

5.1.3.8 Surrogate External Exposure Data

The lack of complete film badge data from 1942 to 1954 at the Linde Site represents a period for which the potential for unaccounted beta and gamma doses is greatest. NIOSH's use of pre-cleanup survey data for the pre-production period from 1942 to 1943, 8 solid ore samples data for the period from 1943 to 1946, data from a 1-day survey of 6 locations in Building 30 for the period from 1946 to 1947, data from two 1-day pre-cleanup surveys after vacuuming and flushing in Building 30 for 1949, and post-decontamination survey data for 1950 is complex, over-reaching, inadequately supported, and may not be claimant favorable for many workers. In addition, the use of the 1948 film badge data collected during the removal of equipment in Building 30 for assigning both beta and gamma doses for the period from 1949 to 1954 is not appropriate, because these data do not account for external doses to workers from contaminated burlap bags, contaminated soil, and other contaminated sources during the cleanup activities.

The beta and gamma dose assignments presented in Table 36 contain median weekly photon doses and weekly median electron doses for unmonitored workers from 1942 to 1954. These dose assignments are not likely to capture the full range of external exposures to the workers. SC&A believes that assigned doses are not representative of potential exposures to workers in the many facilities, locations, and job functions that defined the Linde operations and processes.

5.1.3.9 Assigned Weekly/Annual Work Hours

In Table 4 and several other sections (Davidson, p. 24), the Linde Site Profile represents that personnel at Linde worked longer than the standard 40-hours workweek; as much as 9 hours per day, 6 days a week and 50 weeks per year. However, in calculating external exposure values, NIOSH inconsistently uses different work-hour values:

- Pre-production beta and gamma radiation levels (6 days per week, 50 weeks per year, Table 15, p. 40)
- Standby beta and gamma radiation levels (9 hours per day, 6 days per week, 50 weeks per year, Table 16, p. 41)
- Cleanup beta and gamma radiation levels (8.5 hours per day, 5/6 days per week, 50 weeks per year, Table 18, p. 43)
- Production beta radiation levels (up to 50 hours per week, Table 19, p. 44)
- Production year outdoor beta dose rates (6 days per week, 50 weeks per year, p. 46)
- Production gamma radiation levels (48 hours per week, p. 48)
- Production year outdoor gamma dose rates (6 days per week, 50 weeks per year, p. 54)
- Tonawanda Laboratory beta and gamma radiation levels (8.5 hours per day, 6 days per week, 50 weeks per year, Table 33, p. 60)
- Neutron exposure rates (8 hours per day, 6 days per week, 50 weeks per year, p. 61)

SC&A believes that applying these different work hours to the missed occupational external dose estimation would underestimate the missed dose or exposure assignments. NIOSH should use a set of consistent and claimant-favorable work hours for use in the dose reconstruction.

5.1.3.10 Use of Geometric Mean Values

Similar to the practice followed in the Occupational Internal Dose section of the site profile, the statistical approach used in the Occupational External Dose section may not be claimant favorable for many workers. In Tables 13, 14, 15, 17, 18, 21, 23, 24, 25, 26, 29, 30, 31, 32, and 33, the site profile lists the GM or the GSD values for various assigned external exposure values. There are no supporting calculations or data to show how these geometrical quantities were calculated. In addition, the applicability of these distributions to all job categories is not immediately apparent. In general, NIOSH's use of the GSD approach may not be claimant favorable for routine day-long exposures of some production workers. The NIOSH approach may not address very high, short-term, episodic exposures and short-term exposures during incidents. Since actual data were not available, the cited distributions may not be applicable to some workers.

5.1.3.11 Lack of a Comprehensive Uncertainty Analysis

As described in the site profile, "little information was available" during the periods of production and non-production. In fact, the site profile uses different words to indicate the information gathered is "uncertain," such as "probably," "likely," and "assumes." It gives the strong impression that the available data gathered are inaccurate and uncertain. Therefore, NIOSH should develop a more comprehensive characterization of the uncertainties in external exposures, as described in OCAS-IG-001.

There are many assumptions and surrogate data used, with different degrees of uncertainty associated with them, in the estimation of occupational external dose to workers for the period from 1942 to 1954. The accuracy and representation of these assumptions and surrogate data are questionable. Therefore, without associated uncertainty factors identified and applied, the eventual external dose estimates are not adequately supported. NIOSH should revise the Linde Site Profile to include an uncertainty analysis, as required by 42 CFR 81.

5.1.4 Occupational Environmental Dose

The Linde Site Profile does not provide a separate section on potential missed occupational environmental dose to workers, and does not address or systematically discuss any potential worker environmental exposure pathways for the entire period from 1942 to the present time. However, in some of the site profile sections, NIOSH does identify some potential worker exposure to outdoor radon activities and gamma radiation levels in different periods of operation.

During the site interview, Linde site experts and past workers indicated that there were significant environmental contaminations in external areas of Linde Site, including the following:

- Contaminated pond and stream
- Contaminated parking lots
- Contaminated stormwater sumps
- Contaminated underground tunnels
- Contaminated rooftops

- Contaminated burlap bags
- Ore tailing piles
- Process waste piles
- Incineration exhausts
- Contaminated injection wells
- Burial plots

The site profile provides discussions of some of these sources of environmental contamination as follows:

> *Olevitch (1944) reports the outdoor storage of contaminated ore bags that at times numbered in the thousands. In 1948, 1 mR/h gamma and 3,000 a dpm/ 100 cm^2 were measured from the soil in an area formerly used for storage of radioactive materials (Heatherton 1948h).* (Davidson 2005, p. 22)
>
> *Notes from the Worker Outreach Meeting on April 18, 2005 mention contamination associated with Building 57, and an additional review of the BNI 1993 remedial investigation report shows areas of residual radioactive contamination were associated with areas in or near Buildings 57, 58 and 90. The highest indoor radiation levels were found in the principal production buildings, 30 and 38. Linde was designated as a FUSRAP site in 1980. Additional radiological surveys and decontamination efforts followed (BNI 1993). These led eventually to demolition of Building 14 and all of the Linde Ceramics buildings involved in MED/AEC work except Building 31. Table 1 shows demolition dates. As of 2004, Building 31 remained in use, and onsite soil remediation was in progress with completion scheduled for 2007 (Pilon 2004).* (Davidson 2005, p. 26)

5.1.4.1 Outdoor Doses

Although the Linde Site Profile does not address missed occupational environmental doses to workers, NIOSH does evaluate several potential outdoor beta and gamma sources. In some cases, however, NIOSH ignores the outdoor doses (Section 4.1.3.1.2, p. 46; Section 4.1.3.2.2, p. 54) after the doses are calculated. In other cases, NIOSH uses them in the external dose calculations (Table 32, OD added, p. 59). The site profile also evaluates outdoor radon concentrations, but not on direct measurement (Section 3.5.1, p. 32), and presents some outdoor airborne radioactivity data for July 2000 through June 2004 (Davidson 2005, Table 38, p. 72).

Potentially, the missed occupational environmental doses to workers are small, as compared to missed occupational internal and external doses. As a principle of claimant-favorability and completeness of dose reconstruction required by EECIOPCA, however, NIOSH should evaluate the potential missed environmental doses to production workers, support workers, administrative personnel, cleanup workers, and other facility workers in different periods of the Linde operation from 1942 to the present time.

5.2 OTHER OBSERVATIONS

In addition to the specific findings and observations that appear in other sections of this review report, there are several general observations that can be made.

- The content and organization of the Linde Site Profile are quite uneven, where useful assumptions, default values, and specific guidance for dose reconstructors are often buried among general discussions about site activities, history, and technical information about dosimetry, which may or may not have practical application.

- This site profile does not provide examples to assist dose reconstructors in using recorded records, missed dose assignment, and dose assignments when dosimeters read zero dose.

- It is critical for NIOSH to conduct interviews with former workers and other site experts and integrate first-hand experience and/or association with Linde Site, so as to provide further insights on job category information, site practices, processes and conditions, management practices, and data integrity. First-hand experience and association with the Linde facilities enable site experts and workers to provide original perspectives and information concerning site practices and exposure histories that may not appear in the official records. NIOSH tends to conduct worker outreach meetings after the site profiles are completed.

- The site profile does not provide much information on Linde worker records or files. During the site interviews, many site experts indicated that they had not seen their own dosimetry or personnel records. They believe that there appear to be many incident reports, occurrence reports, contamination reports, and worker uptake reports that were not included in the records. NIOSH should look into the possibility of many missing dose records in Linde worker files. The suspected incompleteness of the worker records is a serious issue, since it may lead to significant underestimation of workers' radiation doses.

- NIOSH should provide angular dependence (anatomic geometry) correction factors for external gamma doses, particularly for low-photon energies, where the angular dependence of the sensitivity of the dosimeter is most pronounced. These correction factors are used to account for, for example, the bias introduced by a dosimeter worn at the neck level, and the higher doses received by tissues/organs below the waist.

- NIOSH did not evaluate soil-sampling data at different facilities to determine potential worker intakes from resuspension of radioactive materials deposited on facility grounds and fugitive emissions from radiologically contaminated soil piles. NIOSH should consider an exponential model for resuspension intakes that takes account of the gradual increase in ore dust levels or radon levels at Linde facilities.

6.0 OVERALL ADEQUACY OF THE LINDE SITE PROFILE AS A BASIS FOR DOSE RECONSTRUCTION

The SC&A site profile review procedure calls for both a "vertical" assessment (Section 5) of a site profile for purposes of evaluating specific issues of adequacy and completeness, and a "horizontal" assessment of how the profile satisfies its intended purpose and scope. This section addresses the latter objective by evaluating (1) how, and to what extent, the site profile satisfies each of the five objectives defined by the Advisory Board for ascertaining adequacy; (2) the usability of the site profile for its intended purpose (i.e., to provide a generalized technical resource for the dose reconstructor when individual dose records are unavailable); and (3) generic technical or policy issues that transcend any single site profile that need to be addressed by the Advisory Board and NIOSH. As mentioned in the Introduction, the practice of addressing the same items from several different perspectives has led to some redundancy in the report.

6.1 SATISFYING THE FIVE OBJECTIVES

The SC&A review procedure, as approved by the Advisory Board, requires that each site profile be evaluated against five measures of adequacy; (1) completeness of data sources, (2) technical accuracy, (3) adequacy of data, (4) site profile consistency, and (5) regulatory compliance. The SC&A review of the Linde Site Profile finds that several shortcomings and potential issues of varying significance need to be addressed. Many of the issues involve the use of unsupported or unexplained assumptions in the dose estimates, a lack of sufficient conservatism or consistency in some key assumptions or estimation approaches, incomplete analyses of data, incomplete reflection of operational or dosimetric history, or a lack of regulatory compliance with the hierarchy of data and uncertainty analysis requirements. Key issues are summarized below and in Table 6-1 (a duplicate of Table 1-1), which provides a matrix representation of the identified issues sorted according to the SC&A findings and observations. Detailed discussions of these issues are provided in Section 5 of this report.

An "X" in the table indicates significant shortfalls in meeting the corresponding review objectives for the indicated topics in the site profile. These shortfalls have been discussed either within the text of the findings themselves, or, in many cases, in special sections that address one or more of these shortfalls. The first column of the table indicates the primary place within the report that treats each issue. The last column of the table presents three categories of potential related regulatory non-compliance concerns for the listed issues. These three categories are defined again briefly as follows:

- **Category 1:** Least challenged by any deficiencies in available dose or monitoring data are dose reconstructions for which even a partial assessment (or minimized dose(s)) corresponds to a probability of causation (POC) value in excess of 50%, and assures compensability to the claimant.

- **Category 2:** The use of upper-bound values is limited to those instances where the resultant maximized doses yield POC values below 50%, which are not compensated.

For this second category, the dose reconstructor needs only to ensure that all potential internal and external exposure pathways have been considered.

- **Category 3:** The most complex and challenging dose reconstruction represents claims where the case cannot be dealt with under one of the previous two categories and a detailed analysis is required.

Table 6-1: Issue Matrix for the Linde Site Profile

Descriptions [a]	Issue Classification	Objective 1: Completeness Of Data	Objective 2: Technical Accuracy	Objective 3: Adequacy of Data	Objective 4: Site Profile Consistency	Objective 5: Regulatory Compliance
Issue 1: (5.1.1) Unsupported Assumptions and Significant Uncertainties in Information Used	Finding (1)			X	X	
Issue 2: (5.1.2.2) Use of Air Concentration Data	Finding (2)	X		X	X	X
Issue 3: (5.1.2.3) Urinalysis Data	Finding (3)	X		X	X	X
Issue 4: (5.1.2.2) Time-Weighted Averages	Finding (4)		X		X	
Issue 5: (5.1.2.4) Breathing Rate	Observation		X		X	
Issue 6: (5.1.2.5) Ingestion Rate	Observation		X		X	
Issue 7: (5.1.2.6) Radon Exposure and Concentration	Observation	X				
Issue 8: (5.1.2.7) Raffinate Trace Radionuclides	Finding (5)		X		X	
Issue 9: (5.1.2.8) Assigned Work Hours	Finding (6)		X		X	
Issue 10: (5.1.2.9) Surrogate Air Concentration Data	Finding (7)	X				
Issue 11: (5.1.2.10) Use of Geometric Mean Values	Finding (11)		X		X	
Issue 12: (5.1.2.11) Lack of Comprehensive Uncertainty Analysis	Finding (9)		X		X	X
Issue 13: (5.1.3) Complex Missed External Dose Surrogate System	Finding (8)	X	X	X		
Issue 14: (5.1.3.4) Film Badge Data	Finding (8)	X				
Issue 15: (5.1.3.5) Survey Measurement Data	Finding (8)	X				
Issue 16: (5.1.3.6) Time-Weighted Averages	Finding (4)		X		X	
Issue 17: (5.1.3.7) Contaminated Burlap Bags	Observation	X				
Issue 18: (5.1.3.8) Surrogate External Exposure Data	Finding (7)	X				
Issue 19: (5.1.3.9) Assigned Work Hours	Finding (6)		X		X	
Issue 20: (5.1.3.10) Use of Geometric Mean Values	Finding (11)		X		X	
Issue 21: (5.1.3.11) Lack of Comprehensive Uncertainty Analysis	Finding (9)		X		X	X
Issue 22: (5.1.4.1) Outdoor Doses	Finding (10)	X			X	

(a) Report section numbers discussing the issues are given after the issue number.

6.1.1 Objective 1: Completeness of Data Sources

The breadth of data sources used as a basis for the Linde Site Profile is evident in the 153 reports, papers, and other documents cited as references, including a number of authoritative historical documents dating back to the start of site operations in the 1940s. In addition, there are other technical and regulatory documents gathered by NIOSH that are deposited in the ORAU database. Based on a review of the Linde Site Profile (Davidson 2005), it is evident that NIOSH compiled information and characterized activities and operations in seven buildings and processes at the Linde Site. In fact, this review cites, in Section 4.0 of this report, the compilation of worker job categories and high-risk jobs as strengths. Also noteworthy is the use of the film badge beta and gamma measurement data, in addition to uranium solid sample results and survey measurements, as part of the missed occupational external dose estimation process. Notwithstanding the general adequacy of the data sources, SC&A has identified a number of areas as deficient:

(1) NIOSH did not adequately use the available worker urinalysis data as part of the missed occupational internal dose estimate. There are a total of 17 sets of urinalysis data in the collected Linde documents (Linde 2004a and 2004b) for the period from December 16, 1947, to January 31, 1950. Even though NIOSH did use these urinalysis data for predictive comparison, the neglect of these data is deemed deficient.

(2) NIOSH did not adequately compile historical data on medical x-ray equipment and techniques used at Linde Site. The Occupational Medical Dose section (Site Profile Section 5) is descriptive in the requirements, but lacking in substance. It provides no information on chest x-ray equipment used, radiographic film used, photoflurographic film used, pelvis/lumbar spine x-ray equipment used, or worker medical records. In the end, the site profile instructs dose reconstructors to use the NIOSH TIB ORAUT-OTIB-0006, *Dose Reconstruction from Occupationally Related Diagnostic X-Ray Projections*, as the basis document for reconstructing occupational medical dose for workers. Overall, SC&A believes that using the default medical doses in ORAUT-OTIB-0006 is claimant favorable for the purpose of Linde dose reconstruction.

(3) NIOSH did not develop missed occupational environmental dose to workers, even though the site profile provides some information pertinent to this exposure pathway. This deficiency is considered minor due to the relatively low potential exposures expected from this pathway.

(4) Using the GM of 1949 air-concentration data as surrogate intake values for the entire period of 1942–1948, and using results of 8 solid samples from a 1944 report as surrogate beta dose values for the entire period of 1943–1946, may not be representative of, and may underestimate, the missed dose to some workers. This approach of applying narrowly defined exposure data as surrogate data to estimate a broad range of missed internal or external doses for Linde workers is inappropriate, because the applied data are very limited and not representative of the actual operation conditions. In addition, the assigned missed internal and external doses do not appear to be claimant favorable for workers who had a potential to experience elevated internal and external exposures.

(5) SC&A found a lack of characterization of contaminated soil or process waste materials stored outdoors at Linde buildings, such as Building 30, in the site profile. For example,

large quantities of ore stored in four ore piles in early 1944 onsite at Linde were not treated.

(6) SC&A found a lack of characterization of potential worker exposures at the waste tank farm, and in remediation and waste management in general. The list of radionuclides provided for those operations is incomplete and increases the potential for missed dose.

(7) SC&A found an inadequate characterization of worker internal exposures. The site profile did not evaluate the worker urinalysis data for the period from December 16, 1947, to January 31, 1950. Even though these personnel monitoring data do not cover the more problematic early years of the Linde site operation from 1942 to 1947, the use of these data would not be supportive for the dose reconstruction. Instead, the Linde site profile uses very limited measured airborne uranium dust concentrations, and applies them to the entire period of operation. SC&A believes that these data are not sufficient to reconstruct missed internal doses.

(8) The site profile does not characterize or provide any information on the potential missed worker external doses due to extremity exposure, skin contamination, and whole-body exposure to residual contamination in used burlap bags stored in different locations, such as Building 30. Page 22 of the site profile indicated thousands of contaminated burlap bags were stored in Building 30.

(9) The Linde Site Profile lacks characterization of the potential missed internal and external doses for workers, who had performed maintenance work in the Linde underground tunnel system in the post-1954 period. These tunnels might have been contaminated cumulatively by storm-water runoff and melting snow water that washed down uranium dust and contaminated process waste piles during different periods of Linde operation. There is no indication that there were any radiation surveys or cleanup performed inside these tunnels. SC&A believes that this constitutes a deficiency in data collection.

(10) SC&A found that the site profile is deficient in evaluating many potential exposure pathways to workers, including rooftops and parking areas contaminated by uranium dust emitted from unfiltered ventilation systems on top of Buildings 14, 30, 31, 37, and 38.

6.1.2 Objective 2: Technical Accuracy

There are a number of issues identified in the course of this review that may be classified as deficiencies in technical accuracy:

(1) There are deficiencies in evaluating dose consequences of raffinate trace radionuclides in the Linde Site Profile**.** Raffinate contains Ac-227 and Pa-231, which are in the U-235 decay chain, as well as Th-230. Possible doses from raffinate-related exposures have not been evaluated in the site profile. Inhalation of even small quantities of some raffinates, such as filter cake (one of the waste products at Linde), could result in significant doses to the workers. The issue of potential airborne contamination of raffinates must be more

carefully assessed. In addition, NIOSH lists Ac-227 and Pa-231 in Tables 5, 11, and 12 of the site profile as radionuclides of concern for internal exposure to Linde workers (Davidson 2005, p. 37), but does not include them in Table 39 for worker exposure during the cleanup period; NIOSH should address these issues. In Tables 11 and 12, inhalation intake values are not listed for Th-230, Ac-227, and Pa-231 for the period from 1947 to 1954. NIOSH should further evaluate the potential exposure pathways for internal exposure of raffinate trace radionuclides, and investigate the relative impact of trace radionuclide intakes to the total dose.

(2) Using the GM of 1949 air-concentration data as surrogate intake values for the entire period of 1942–1948, and using results of 8 solid samples from a 1944 report as surrogate beta dose values for the entire period of 1943–1946, may not be representative of, and may underestimate, the dose to some workers. This approach of applying narrowly defined exposure data as surrogate data to estimate missed internal or external dose for Linde workers is inappropriate, because the applied data are very limited and may not be representative of the actual operating conditions. In addition, the assigned missed internal and external doses do not appear to be claimant favorable for many workers.

(3) Time-weighted averages of internal and external exposure values contain significant uncertainties and frequently fail to capture dose to workers in areas of high uranium dust concentrations. Even using the maximum time-weighted average dose values would not represent maximized dose values and may have limitations when used for denial of claims; nor do they give claimants the benefit of the doubt in the face of uncertainties. Individual doses could be far greater than these averages, even when the job description, work location, and work duration are known. Procedures for estimating 95th percentile values, for instance, would need to be developed in which the claimant is given the benefit of the doubt in the face of significant uncertainties. The Linde Site Profile does not evaluate these potential uncertainties, and lacks the required procedures for dealing with them. Other issues include uncertainties about the length of a workday and the length of a workweek, as well as overtime hours; these must be addressed when considering time-weighting (see Finding 7). For example, NIOSH (Davidson 2005, p. 27) uses the maximum time-weighted exposure of 33 MAC instead of the maximum exposure of 125 MAC, even though it is noted that 9% of the exposed workers experienced the maximum exposure. This approach may not give many workers the benefit of the doubt (see Finding 1, also).

(4) The number of work hours assumed in calculating occupational internal and external doses for workers is inconsistent for different periods of Linde operations and, therefore, may not be claimant favorable. The site profile has represented in Table 4 (Davidson 2005, p. 24), and in many other places, that workers had longer workweeks than 40 hours, and, in some cases, worked as much as 9 hours per day for 6 days a week and 50 weeks per year. But, in most instances, NIOSH uses the standard 40 hours per week assumption for the missed dose estimation. This approach is inconsistent and not claimant favorable for some workers.

(5) The Linde Site Profile does not evaluate soil-sampling data at different facilities to determine potential worker intakes from resuspension of radioactive materials deposited on facility grounds and fugitive emissions from radiologically contaminated soil piles. NIOSH should consider an exponential model for resuspension intakes that takes account of the gradual increase in ore dust levels or radon levels over time.

(6) After the end of the operation period, many thousands of contaminated burlap bags were stored behind Building 30 awaiting disposal. Many Linde workers, operations staff, and administrative personnel sat on these bags during breaks and lunch periods over many years. These personnel had been exposed at close distances to beta and gamma radiation sources left over in those uranium-contaminated burlap bags. The site profile does not estimate the missed beta and gamma doses to workers resulting from sitting or standing next to the contaminated burlap bags.

(7) The Linde Site Profile assumes a breathing rate of 1.2 m^3/hour for worker intake. This value implies that workers were primarily involved in light activities during the course of the day. A single value, however, may not be consistent with the working conditions in the facility during the early years of operation, and is inconsistent with other NIOSH site profiles, such as for Mallinckrodt, Bethlehem Steel, Y-12, INL, SRS, and Hanford. NIOSH should consider a higher breathing rate of 1.7 m^3/hour for the Linde dose reconstruction, which is more consistent with heavy labor from operations, such as hauling heavy burlap bags of ore.

(8) The Linde Site Profile assumes an overall uranium ingestion rate of 0.2 of the inhalation intake values for workers. Since the inhalation intake is estimated by using air concentration data, SC&A believes that the NIOSH approach could lead to the underestimation of ingestion intake for some workers.

6.1.3 Objective 3: Adequacy of Data

(1) There are numerous assumptions in parametric values feeding into missed dose estimations (both internal and external) made in the site profile that are either not supported or not adequately supported by explanation, available data, technical study, or references. Many of these parametric assumptions are made seemingly arbitrarily without adequate technical bases. In some cases, a value is selected as the assumption from a range of rough estimated values to bound a dose parameter that is not entirely justified or explained in the document. In other cases, the value selected does not appear to be bounding. This is a flaw that could adversely affect the credibility and validity of the assigned missed dose estimates in the site profile.

(2) There are significant uncertainties in historical information and data regarding Linde facilities, operations, timelines, and practices. The site profile identifies only seven buildings at Linde that were used for the MED uranium processing project. However, it is not possible to clearly verify the existence of Building A and Building B during the MED operation period and, notwithstanding, to identify their MED-related functions.

During the site expert interviews, however, many past Linde workers identified other buildings that had been involved directly or indirectly with the uranium processing operations. These buildings include Buildings 1, 2, 19, 39, 52, 54, 57, and 59. There are also outside areas used for staging uranium ore or waste piles that are adjacent to Buildings 30, 75, and 76. In addition, NIOSH makes a large number of facility operation-related and functional assumptions in this site profile in order to provide a framework for dose reconstruction.

(3) The air concentration data used in the site profile do not appear to be claimant favorable, due to significant expert criticism regarding using air concentration data to estimate worker inhalation intakes at uranium processing facilities. Several technical studies, including the 2003 Y-12 study, *Practical Use of Personal Air Sampling (PAS) Data in the Internal Dosimetry Program at the Y-12 National Security Complex* (Snapp 2003), and the Nuclear Regulatory Commission's NUREG-1400, *Air Sampling in the Workplace* (Hickey 1993), demonstrate that using air concentration data could lead to underestimating the worker intakes and, subsequently, the internal exposures. The Y-12 study shows as much as a factor of 10 difference between intakes derived from bioassay data and intakes derived from air concentration data (with the bioassay data producing the higher doses). In addition, the sensitivity of survey instruments, locations of the air samples, and air flow studies of the buildings are not presented in the Linde Site Profile report. It is also important to point out that the air concentration data used are based on results of random grab-air samples in general areas and breathing zones, and not the results of continuous area sampling. Lack of more complete air sampling data and neglecting bioassay data could lead to significant uncertainties in worker intakes and underestimation of missed inhalation doses.

(4) Using air concentration data only, but neglecting urinalysis data, to estimate worker inhalation intakes in the Linde Site Profile is not in full compliance with 42 CFR 82 requirements. There are 8 sets of urinalysis data for over 100 uranium workers in the ORAU database for the period between December 16, 1947, and January 30, 1950. The air concentration data used in the site profile also are not complete and are deemed inadequate (see Finding 2). However, NIOSH and ORAU decided to use only these air concentration data for dose reconstruction. This approach is not fully compliant with the hierarchy approach stipulated in 42 CFR 82.

(5) The Linde Site Profile uses a very complex scheme of surrogate data to estimate missed occupational external dose to workers from 1942 to the present. NIOSH uses a combination of film badge data, solid sample analysis results, and facility field measurements to fill exposure data gaps in order to cover the entire period of the Linde operations. These surrogate data are, however, limited and, most importantly, not facility- or building-specific. In many cases, the site profile uses different sets of data to estimate worker beta and gamma doses separately. Even though NIOSH attempts to use partially conservative assumptions in portions of the external dose estimation, the overall approach is questionable and potentially flawed, and may lead to assigned missed internal doses that are not claimant favorable.

(6) SC&A also found that the site profile does not fully develop procedures and guidelines for dose reconstructors for gaps in environmental, internal, and external doses that could lead to a significant underestimation of worker dose. Input from interviewed site experts indicates that there were situations where reactor workers were not provided neutron dosimeters or were not monitored on a continual basis, and where processing facility workers were not monitored when they had positive nose smears. Data either presented in the site profile, or on which the site profile is based, cannot be considered adequate unless an evaluation is conducted of the comprehensiveness of the neutron-monitoring and bioassay programs, and of what extent existing dose estimation assumptions and methodologies address this potential missed dose.

(7) The statistical approach used in the Linde Site Profile may not be claimant favorable. In Tables 6, 13, 14, 15, 17, 18, 21, 23, 24, 25, 26, 29, 30, 31, 32, and 33, the site profile lists the GM or the GSD values for various assigned default assumptions. First, there are no supporting calculations or data to show how these geometrical quantities were calculated. Second, the use of geometric means and standard deviations of airborne radon concentrations (for example) as default values could be considered claimant-neutral and not claimant-favorable. Unless there is good reason to believe that a given worker was exposed to the full distribution of the measured concentrations and could not have experienced protracted exposures to higher than average radon concentrations, it may be more appropriate to use the upper 95th percentile as the default exposure level. NIOSH's use of the GSD approach may not address very high, short-term, episodic exposures; short-term exposure during incidents; and radon intakes during the performance of tasks with a potential for high transient air concentrations.

6.1.4 Objective 4: Consistency Among Site Profiles

Selected processes and assumptions contained in the Linde Site Profile are compared with those of MCW, Bethlehem Steel, Y-12, INL, SRS, and Hanford site profiles. Mallinckrodt, Bethlehem Steel, and Y-12 have some attributes of an AWE and some attributes of a larger DOE facility, which made comparisons with DOE and AWE facilities appropriate.

There are a number of key elements in the Linde Site Profile that are similar to elements commonly used by NIOSH in other site profiles. These include a site description, and occupational medical dose, internal dose, and external dose discussions. Occupational medical dose represents dose from x-rays required as a condition of employment and is usually tracked via site medical records. Internal dose represents dose from radioactive material inhaled or ingested into the body, including that resulting from residual contamination. External dose represents exposure to sources of radiation external to the body from beta particles, photons, neutrons, and other particles. However, one large difference between the Linde Site Profile and other site profiles is the omission of the Occupational Environmental Dose section in the former, which accounts for doses resulting from exposure to radioactive material that has been released to the air, water, or soil, or from exposure to waste piles or contaminated soil or ground.
Table 6-2 contains a summary of the key site profile elements addressed in each of the site profiles.

Table 6-2: Site Profile Key Element Comparison

Element	Linde	MCW	Bethlehem	Y-12	INL	SRS	Hanford
Site Description	Included	Included	Included	Included	Included	Included	Included
Medical Dose	Included	Included	Included	Included	Included	Included	Included
Internal Dose	Included	Included	Included	Included	Included	Included	Included
External Dose	Included	Included	Included	Included	Included	Included	Included
Environmental Dose	Not Included	Not Included	Not Included	Included	Included	Included	Included

(1) Although Y-12, INL, Hanford, and SRS have sections on the development and assignment of environmental dose, this is absent from the MCW and Bethlehem Steel site profiles, as well as the Linde Site Profile. In the case of Linde, there are available information and data indicating the presence of soil and ground contamination in different locations of the Linde Site. Section 2.3.4, Other Radiological Activities, of the Linde Site Profile states the following:

> *Early on, radioactive liquid wastes were discharged to the Tonawanda sanitary sewage system. Due to the nature of the liquids, this became a problem, and Linde began to dispose of liquid wastes into onsite wells that sometimes overflowed. Later still, liquid wastes were discharged to a drainage ditch that led to a sewer conduit (BNI 1993, pp. 1-9 to 1-15).* (Davidson 2005, p. 21)
>
> *After MED work began at the Tonawanda site, there was potential exposure of workers to radiation and radioactivity when outdoors. Portions of the site are known to have been contaminated with radioactivity (Heatherton 1948h; ORNL 1978; BNI 1982); resuspension would have produced airborne radioactivity. One source of ground contamination and airborne radioactivity was the ore unloading process, which involved transporting ore in buggies — sometimes in bulk and sometimes in bags - from box cars to Building 30 (see the section on Step I operations in Section 2.3.2.1). Outdoor areas of the site were sometimes used for storage of radioactive materials. Olevitch (1944) reports the outdoor storage of contaminated ore bags that at times numbered in the thousands. In 1948, 1 mR/h gamma and 3,000 a dpm/100 cm^2 were measured from the soil in an area formerly used for storage of radioactive materials (Heatherton 1948h).*
>
> *An additional source was the release of liquid effluents either to onsite wells that sometimes overflowed, or to an onsite drainage ditch (BNI 1993, pp. 1-9 to 1-15). Airborne effluents from the plant were an additional source of outdoor radioactivity.*

> *In 1949, Linde workers were used to unload drums of K-65 shipped by rail to the Lake Ontario Ordnance Works at Modeltown, New York (Wolf 1949; Heatherton 1949a). Linde film badges were worn during this work.*
>
> *At the April 18, 2005, Worker Outreach Meeting, strontium was mentioned. Summary information from the meeting did not indicate if this was radioactive on nonradioactive strontium, or if this was process material or a sealed source. Because no mention of radioactive strontium was found in the available Linde documents, it is believed likely that this source might have been a sealed radioactive source, nonradioactive material or a small quantity in comparison to the uranium source term. The estimates of uranium exposure based on estimates of exposure periods and source term, which were based on worst case assumptions when a parameter was not well supported by available information would be sufficiently bounding to account for small amounts of radioactive strontium.* (Davidson 2005, p. 22)

In addition, Section 2.7, Post MED/AEC Operations, of the Linde Site Profile states the following:

> *The Formerly Utilized Sites Remedial Action Program (FUSRAP) began in 1976. Oak Ridge National Laboratory (ORNL 1978) surveyed the Linde Tonawanda from October 18 through November 5, 1976 to determine if remediation would be required. Radiation and radioactive contamination measurements were made inside Buildings 14, 30, 31, 37 and 38; on the Tonawanda property outside the buildings; and at nearby offsite locations. Linde employees noted that Building 30 renovation occurred in the 1960s and could have resulted in elevated employee radiation exposures. Notes from the Worker Outreach Meeting on April 18, 2005 mention contamination associated with Building 57, and an additional review of the BNI 1993 remedial investigation report shows areas of residual radioactive contamination were associated with areas in or near Buildings 57, 58 and 90. The highest indoor radiation levels were found in the principal production buildings, 30 and 38. Linde was designated as a FUSRAP site in 1980. Additional radiological surveys and decontamination efforts followed (BNI 1993). These led eventually to demolition of Building 14 and all of the Linde Ceramics buildings involved in MED/AEC work except Building 31. Table 1 shows demolition dates. As of 2004, Building 31 remained in use, and onsite soil remediation was in progress with completion scheduled for 2007 (Pilon 2004).*

Based on post-operational concentrations of radioactive material in the soil and water, it is reasonable to expect similar or greater levels of environmental release during the production years. This is further collaborated by site expert interviews, stating that uranium dust and fumes were released from production buildings. The likelihood of exposure from environmental release is significant and requires further consideration in the site profile. Also, for consistency and completeness of the site profile, environmental exposure should be addressed, whether or not the dose consequences are judged to be significant.

(2) The assignment of dose for occupational medical exposure is discussed in ORAUT-TIB-0006 (Kathren 2003), which is applicable to both AWE and DOE facilities. In the cases of Y-12, INL, Hanford, and SRS, there were considerable data on the particular x-ray units and medical monitoring procedures. Due to the lack of medical records at Linde, MCW, and Bethlehem Steel, an annual standard chest x-ray was assumed for each covered year of the facility. The SRS and Hanford TBDs assumed early x-rays included photofluorography (PFG), while the Linde and MCW site profiles did not include PFG. Photofluorography was a common technique prior to 1960 (OCAS 2002) and should be considered unless solid evidence to the contrary can be provided. Additionally, the MCW site profile utilizes different analogue organs for input into IREP than the SRS TBD. In the case of default assumptions, such as kVp, mAs, source-to-image distance, and uncertainty, the approach is consistent among the site profiles examined.

(3) The methodology for assignment of internal dose is somewhat specific to each site. In the case of Linde, MCW, Y-12, INL, SRS, and Hanford, urinalysis data were available for a portion of the covered period. This information was used as the primary source for internal dose calculation for MCW, Y-12, INL, SRS, and Hanford, supplemented with air concentration data. Instead, the Linde Site Profile uses only airborne uranium dust concentration data as the primary source for missed occupational internal dose calculation. Urinalysis data is used as a predictive comparison only. Other issues of concern in internal dose assumptions between Linde and the other site profiles include the following:

- Linde, Bethlehem Steel, and MCW site profiles have statistical procedures and or data tables that result in dose estimates that do not give claimants the benefit of the doubt in the face of uncertainties in at least some cases.
- The Linde Site Profile uses inconsistent work hours, while the Bethlehem Steel Site Profile assumes 10-hour workdays, and the MCW Site Profile assumes 2,000 hours per year (effectively, an 8-hour workday.)
- The Linde Site Profile assumes a factor of 0.2 of inhalation intake for ingestion intake, while an explicit analysis of ingestion dose is included in the Bethlehem Steel Site Profile (Revision 01), and ingestion dose was deemed to be negligible in the MCW Site Profile. Large particle ingestion was not taken into account in any of the three cases.

(4) In the case of Linde, MCW, Y-12, INL, SRS, and Hanford, film badge data is used as a primary source of external exposure, where available. Some inconsistencies in external dose assumptions between Linde and the other site profiles include the following:

- Adjustment factors are applied to recorded external dose at SRS and Hanford to estimate Hp(1.0) doses. The Linde Site Profile does not recommend any adjustment to recorded dose. The site profile, therefore, does not take into consideration the laboratory, radiological, and environmental uncertainties in the personal dosimetry program.
- Due to the limited nature of the film badge data, the Linde Site Profile supplements the external dose calculations with survey measurements. However, the site profile did not take into consideration the radiological and environmental uncertainty associated with the survey instruments. Therefore, no adjustment factors are recommended to the measurements or the estimated missed external dose.
- The Linde Site Profile assumes various numbers of work hours per week, while the Bethlehem Site Profile assumes 10-hour workdays and the MCW Site Profile assumes 2,000 hours per year (effectively an 8-hour workday.)

(5) SC&A recognizes that operations, exposure conditions, and facility designs vary, even in facilities with the same production mission. We have presented some comparisons of the Linde Site Profile with other site profiles. Based on the source term and the workplace conditions at the Linde Site, variations in assumptions may be justified. Further explanation in the Linde Site Profile, however, is required to account for the alternate assumptions versus other site profiles in light of the similarities in source terms at MCW, Y-12, portions of Hanford, and portions of the SRS.

6.1.5 Objective 5: Regulatory Compliance

NIOSH generally has complied with the hierarchy of data required under 42 CFR Part 82 and its implementation guides. However, SC&A has identified some significant shortcomings of the data used in the review process of the Linde Site Profile that may lead to dose reconstructions that are not claimant favorable. It is especially crucial for NIOSH to re-evaluate the technical basis of the missed dose assumptions:

(1) Using air concentration data, but neglecting urinalysis data, to estimate worker inhalation intakes in the Linde Site Profile is not in full compliance with 42 CFR 82 requirements. There are 8 sets of urinalysis data for over 100 uranium workers in the ORAU database for the period between December 16, 1947, and January 30, 1950. The air concentration data used in the Linde Site Profile are not complete and are deemed inadequate (see Finding 2). However, NIOSH uses these air concentration data only for dose reconstruction. This approach is not in full compliance with the hierarchy approach stipulated in 42 CFR 82.

(2) An assessment of uncertainties, as required by OCAS-IG-001 and OCAS-IG-002, has not been adequately developed for air concentration and radon measurement data used in lieu of bioassay data. As characterized in the site profile, “little information was available” during the periods of production and non-production. In fact, the site profile uses different words to indicate that the information gathered is “uncertain,” such as

"probably," "likely," and "assumes." It gives the strong impression that the available data gathered are inaccurate and uncertain. NIOSH should develop a method to determine best estimates and their uncertainties, as well as upper 95th percentile values of time-weighted inhalation intake, radon intake, beta dose, gamma dose, and neutron dose, for both internal and external dose calculations.

6.2 USABILITY OF SITE PROFILE FOR INTENDED PURPOSE

SC&A has identified seven criteria that reflect the intent of the EEOICPA and the regulatory requirements of 42 CFR Part 82 for dose reconstruction. Because the purpose of a site profile is to support the dose reconstruction process, it is critical that the site profile assumptions, analytic approaches, and procedural directions be clear, accurate, complete, and auditable (i.e., sufficiently documented). SC&A used the following seven objectives to guide its review of the Linde Site Profile to determine whether it meets these criteria:

- Objective 1 − Determine the degree to which procedures support a process that is expeditious and timely for dose reconstruction
- Objective 2 − Determine whether procedures provide adequate guidance to be efficient in select instances where a more detailed approach to dose reconstruction would not affect the outcome
- Objective 3 − Assess the extent to which procedures account for all potential exposures, and ensure that resultant doses are complete and are based on adequate data
- Objective 4 − Assess procedures for providing a consistent approach to dose reconstruction, regardless of claimants' exposures by time and employment locations
- Objective 5 − Evaluate procedures with regard to fairness and the extent to which the claimant is given the benefit of the doubt when there are unknowns and uncertainties concerning radiation exposures
- Objective 6 − Evaluate procedures for their approach to quantifying the uncertainty distribution of annual dose estimates that is consistent with and supports a Department of Labor probability of causation estimate at the upper 99% confidence level
- Objective 7 − Assess the scientific and technical quality of methods and guidance contained in procedures to ensure that they reflect the proper balance between current/consensus scientific methods and dose reconstruction efficiency

The following items address these objectives:

(1) The Linde Site Profile does not meet the objectives in the Occupational Medical Dose section in assessing the potential organ doses to workers who received medical x-ray examinations over the entire operating history of the Linde Site. However, the Linde Site

Profile is adequate to instruct the dose reconstructors to use the appropriate TIB for the estimation of missed occupational medical dose to workers.

(2) The Linde Site Profile does not meet the objectives in assessing the potential occupational environmental doses to Linde workers. In fact, the Linde Site Profile does not present any environmental exposure data.

(3) The Linde Occupational Internal Dose section does not use available, though limited, urinalysis data; instead, it uses only airborne uranium dust concentration data for the estimate of missed occupational internal dose to workers.

(4) The Occupational Internal Dose section uses very limited surrogate data from 1944 for the internal dose calculations for the entire period of 1942 to 1949 that are not fully supported.

(5) The Occupational External Dose section uses a very complex surrogate data system to estimate missed occupational external dose to workers for the entire period.

(6) The site profile does not meet the objective in assessing potential occupational environmental dose, because it neglects evaluating doses from burlap bags, contaminated soil, contaminated rooftops, contaminated underground tunnels, contaminated injection wells, waste tanks, waste piles, and other potential airborne sources.

(7) The site profile makes a number of assumptions that are not claimant favorable, and in many cases, are either not supported or fully supported; it does not meet the objectives.

6.3 UNRESOLVED POLICY OR GENERIC TECHNICAL ISSUES

A number of issues are identified that are common to the Linde, MCW, Bethlehem Steel, Y-12, Rocky Flats, INL, Hanford, and SRS site profiles and, in some cases, represent potential generic policy issues that transcend any individual site profile. These issues may involve the interpretation of existing standards, how certain critical worker populations should be profiled for historic radiation exposure (e.g., construction workers and early workers), and how exposure itself should be analyzed (e.g., treatment of incidents and statistical treatment of dose distributions). NIOSH indicates that it may develop separate TIBs in order to address some of these generic issues. The following presents those issues identified in the Linde Site Profile Review that SC&A believes represent transcendent issues that need to be considered by NIOSH as unresolved policy or generic technical issues.

(1) Direction on the applicability and usability of the site profiles, TBDs, and/or TIBs to individual dose reconstructions is absent.

(2) Examples of dose reconstruction are seldom provided in the site profiles, TBDs, and/or TIBs. Examples are extremely useful for dose reconstructors to follow and use the guidance accurately.

(3) Adequacy and completeness of worker records are essential to claimant-favorable dose reconstructions. None of the site profiles address this issue or give direction on resolving issues with missing records.

(4) Site expert testimony indicates that many workers moved from one plant to the next on the same site, creating a complicating factor in determining overall exposure. Establishment of an accurate worker history is crucial in such cases. This is especially difficult to accomplish in cases of family-member claimants, where the survivors cannot be expected to have a good grasp of where and when the worker was stationed.

(5) Statistical techniques used in the application of the data to individual workers should be considered. However, using statistical averages may not be claimant favorable, since in most compensable cases, they would not provide the upper bound for missed worker doses. For example, in the Linde Site Profile, GM are used to estimate the missed worker doses instead of a more appropriate and claimant-favorable upper 95^{th} percentile value.

(6) Dose from impurities and/or daughter products in radioactive material received and processed at sites should be assessed.

(7) Assumptions on solubility, breathing rate, and ingestion should be addressed.

(8) A correction factor for external gamma doses should be considered to account for angular dependence of dosimeter sensitivities.

(9) Direction with respect to consideration of incidents and high-risk (dose) jobs in individual dose reconstructions should be provided. In the case of the Linde Site Profile, high-risk job categories are much better defined and classified than in other site profiles or TBDs.

(10) Availability of monitoring records for subcontractor and/or visitor personnel while working on or visiting a facility should be ascertained. In the case of the Linde Site Profile, no discussion was made on this subject.

(11) Dose to construction workers and other early workers should be assessed. In the case of the Linde Site Profile, no discussion was made on this subject.

(12) Unique exposure conditions for cleanup and decontamination and decommissioning workers should be considered. The relative impact of each of these items on dose reconstruction is site-specific and requires independent evaluation in each site profile or TBD.

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ATTACHMENT 1: CONFERENCE CALL WITH NIOSH AND SC&A

SC&A Questions/Comments for NIOSH Regarding Linde Site Profile

SC&A's evaluation of the Linde site profile (the "Site Profile"), *An Exposure Matrix for Linde Ceramics Plant (including Tonawanda Laboratory)* (ORAUT-TKBS-0025, Rev. 00, 5/31/05, Davidson 2005) reviewed reference documents, source records, and interviews with former Linde workers and retirees. The documents include primarily sources obtained from the FUSRAP site, declassified documents regarding early worker exposures, and a majority of the key reference and source documents contained in the NIOSH/ORAU Site Research Database. In addition to document review, Kathy Robertson-Demers and Desmond Chan conducted interviews with 17 Linde site experts in Buffalo, New York, on January 12–14, 2006. The workers discussed the functions and operations they individually performed at the various Linde buildings and facilities that made up the Linde Ceramics Plant. As a result of the document reviews and interviews with the workers, a number of issues with respect to the Site Profile have surfaced, and SC&A has formulated the following questions to help inform its Linde Site Profile review. For convenience and clarity, the questions have been organized into sections of related issues.

General Questions

1. The Site Profile estimates airborne concentrations between October 1, 1942, and December 31, 1954, for the Linde Ceramics Plant in Table 9 (p. 34); internal exposures to workers at the Ceramics Plant between October 1, 1942, and December 31, 1954, in Table 11 (p. 37); and internal exposures to workers at the Tonawanda Lab between October 1, 1942, and December 31, 1954, in Table 12 (p. 38). However, the cells for the period between 1942 and 1947 are designated as "reserved." Please clarify what is meant by this designation; will these data be provided in a future revision of the Site Profile?

2. The Linde workers that SC&A interviewed indicated that their employment and medical records were shipped to Union Carbide's record repository in Vermont. Has NIOSH/ORAU visited this repository to review these records? If a visit was conducted and the records evaluated, what do the records contain? Are they sufficient to support individual claimant dose reconstruction? Were they used to develop the Site Profile?

3. The Site Profile mentions that there were episodic events at Linde and Tonawanda during the production and cleanup periods. Did NIOSH/ORAU construct a list of incidents or determine the frequency of episodic problems? Did NIOSH/ORAU determine the potential exposure to workers who were present or participated in the activities?

4. On October 12, 2005, NIOSH issued an evaluation report on the Special Exposure Cohort (SEC) Petition 00044, submitted on September 29, 2005, covering a class of atomic weapons employees at the Linde Ceramics Plant from October 1, 1942, to October 31,

1947. In this report, NIOSH concludes that dose reconstruction could not be completed because of a lack of sufficient information.

> *Members of this class at the Linde Ceramics Plant may have received internal and external radiation exposures from the uranium and uranium progeny in the ores received and processed at the plant. NIOSH lacks any biological monitoring data or sufficient air monitoring information or sufficient process and radiological source information to estimate the potential airborne concentrations to which the proposed class may have been exposed (i.e., internal exposures).*

What guidance would NIOSH/ORAU provide to dose reconstructors on evaluating non-presumptive cancers, such as prostate cancers and skin cancers? How should a dose reconstructor evaluate worker external exposures for the period between October 1, 1942, and October 31, 1947? How could a dose reconstructor separate external exposures from internal exposures during this period? Is NIOSH going to issue a revision of the Site Profile taking into account the SEC conclusions?

Site Description and Operational History

1. Personnel interviewed by SC&A indicated that there was an extensive underground tunnel system connecting many of the buildings at the Linde Site that was frequently flooded by rain or melting snow, and contaminated with radioactivity. Did NIOSH/ORAU take into account potential missing exposures to workers in these tunnels?

2. Personnel interviewed by SC&A indicated that several MED (Manhattan Engineering District)-era buildings at the Linde Site were wooden with cinder blocks, and that the wooden structures could not be decontaminated. Did NIOSH/ORAU take this fact into consideration when estimating potential exposures to workers after the MED period?

3. The 2000 Army Corps of Engineers Record of Decision for Linde indicates that there were 8,000 tons of filter cakes sent to Ashland, 20,500 tons of waste material sent to LOOW, and other material sent to duPont and other facilities. Where were these material stored and staged in Linde before they were transported off the site? How were they controlled? How were they transported? The Mallinckrodt Site Profile indicates that material shipped from Linde was transported in 55-gallon drums. Were similar drums also used in shipping filter cakes? The Linde Site Profile does not provide information or exposure estimates for unmonitored workers outside the identified production buildings in moving, loading, and transporting these waste materials; has NIOSH/ORAU considered missed doses to the unmonitored workers involved in transporting these waste materials? Similarly, page 10 of the Site Profile states: "The Ceramics Plant produced uranium materials for the MED and the AEC from 1943 to 1946 and from 1947 to 1949. In the 1947 to 1949 period (and perhaps earlier), Linde received UO_2 for processing from Mallinckrodt Chemical Works (AEC 1949a)." How was the UO_2 transported to the production facilities at Linde and then unloaded? Has NIOSH/ORAU considered missed doses to unmonitored workers involved in moving, loading, unloading, and transporting these uranium products?

4. On page 14 of the Site Profile, the description of Building 31 (Ceramics Plant) states, "A partially-readable 1945 plant drawing indicates that it contained…a small number of associated offices (Linde Database 1945)." Based on the former and retired worker interviews, many of the MED production buildings consisted of administrative and clerical offices right next to the production areas. There were no separated ventilation systems, engineering barriers, or separated entrance or egress in the building for these administrative offices. Production workers and administrative staff could move from offices to production areas (or vice versa) without any monitoring or radiological control. Has NIOSH/ORAU considered potential missed internal and external doses to the administrative workers from the production operations? In the Linde Site Profile for the standby period from 1946 to 1947, the gamma and beta radiation rates in an office building were assumed to be zero, leading one to believe that NIOSH/ORAU did not consider potential missed doses to office workers from potential significant cross contamination. Please confirm and explain the basis of this assumption.

5. During the former and retired worker interviews, the workers indicated that the contaminated piping in Building 30 and other buildings were not removed and were, instead, reused for new production and operations. Did NIOSH/ORAU consider the potential missed exposures to workers from previously contaminated piping in subsequent activities?

Occupational Environmental Doses

1. The Linde Site Profile does not address potential occupational environmental dose to workers in a separate section. However, SC&A found many places in the Site Profile indicating the potential for such exposure from outdoor, airborne radon or uranium dust, contaminated material, soil, or waste piles. Examples include:

> *After MED work began at the Tonawanda site, there was potential exposure of workers to radiation and radioactivity when outdoors. Portions of the site are known to have been contaminated with radioactivity (Heatherton 1948h; ORNL 1978; BNI 1982); resuspension would have produced airborne radioactivity. One source of ground contamination and airborne radioactivity was the ore unloading process, which involved transporting ore in buggies — sometimes in bulk and sometimes in bags — from box cars to Building 30 ... Outdoor areas of the site were sometimes used for storage of radioactive materials. Olevitch (1944) reports the outdoor storage of contaminated ore bags that at times numbered in the thousands. In 1948, 1 mR/h gamma and 3,000 a dpm/ 100 cm2 were measured from the soil in an area formerly used for storage of radioactive materials (Heatherton 1948h).* (p. 22)
>
> *An additional source was the release of liquid effluents either to onsite wells that sometimes overflowed, or to an onsite drainage ditch (BNI 1993, pp. 1-9 to 1-15). Airborne effluents from the plant were an additional source of outdoor radioactivity.* (p. 22)

The average outdoor beta dose rate to which workers would have been exposed during production was assumed to be at most equal to the indoor level in Building 30 based on the reasoning in Section 4.1.2.1. Therefore, the outdoor beta rate was estimated as 0.676 mrem/h (based on beta dose rate at 3' before vacuum cleaning and flushing given in Table 13). For 0.5 h/wd exposure, 6 wd/wk, and 50 wk/y, the average worker exposure would have been 0.10 rem/y. This is negligible compared to the indoor doses given the approximate nature of the estimates and was ignored. (p. 46)

The average outdoor gamma exposure rate to which workers would have been exposed during production was assumed to be at most equal to the indoor level in Building 30 based on the reasoning in Section 4.1.2.1. Therefore, the outdoor gamma rate was estimated as 0.131 mR/h based on the level before vacuuming and flushing in Table 13. For 0.5 h/wd exposure, 6 wd/wk, and 50 wk/y, the average worker exposure would have been 0.020 R/y. This is negligible compared to the indoor exposures given the approximate nature of the estimates and was ignored. (p. 54)

In recent years, outdoor air radioactivity has been measured in conjunction with the site soil remediation program (ACE Buffalo 2004b). Table 38 displays the highest monthly average air concentrations of Ra-226, Th-230 and U-238 for July 2000 through June 2004. Assuming that the measured U-238 is part of a natural uranium source term, the total uranium concentration would be the U-238 concentration divided by the fraction of activity due to U-238, 0.4886, or 4.3E-04 pCi/m^3. The activity ratios of Th-230 and Ra-226 to uranium are 0.84 and 1.7, respectively. (p. 72)

Table 38. Highest monthly outdoor airborne radionuclide concentrations at Linde Tonawanda site, 2000-2004.

Nuclide	Highest monthly concentration (pCi/m^3)[a]
Ra-226	7.5E-04
Th-230	3.6E-04
U-238	2.1E-04

a. Per analysis of data from ACE Buffalo 2004b.

Since discussions of potential occupational environmental doses are scattered throughout the Site Profile, has NIOSH/ORAU provided adequate and comprehensive guidance to reviewers to determine doses to workers (monitored and unmonitored), who may have been exposed to environmental sources of radioactivity during their outdoor activities (loading, unloading, moving, transportation, cleanup)? Specifically, did NIOSH/ORAU consider potential occupational environmental doses to unmonitored (non-production) workers who might have worked near the MED buildings?

2. During the site expert interviews, the workers indicated that there were large ventilators in different MED buildings, such as Buildings 14, 30, and 38. These ventilators were not equipped with any special filtering systems, and uranium ore and dust were vented out directly to the outside atmosphere. Did NIOSH/ORAU consider environmental exposures to workers from these exhaust streams? Did NIOSH/ORAU consider cumulative contamination on rooftops, external building structures, parking lots, soils, and open areas within the Linde perimeter?

Occupational Internal Doses

1. Section 3.0 of the Site Profile, *Estimation of Internal Exposure*, 1942–1954, states:

   > *To expedite preparation of this document, the Linde information is considered in conjunction with information from facilities that did similar types of uranium processing to establish preliminary estimates of internal intakes and exposures. These estimates are considered best estimates, until data can be further considered. It is believed that additional analysis of the data will lower at least some of the intakes and exposures estimated in this section.* (p. 26)

   a. Which are these similar uranium processing facilities that were used in conjunction with Linde to establish preliminary estimates of internal intakes and exposures? What is meant by "preliminary?"

   b. What similarities did these facilities have to Linde? What information did NIOSH and ORAU use from these facilities? Are data from these facilities used as surrogate data for Linde? If so, please identify these data and their sources.

   c. What is the definition for best estimates? Are they worst-case estimates, geometrical means, or statistical averages? Did NIOSH/ORAU estimate the uncertainties associated with these estimates?

   d. What does NIOSH/ORAU mean by "be further considered?" Why does NIOSH/ORAU believe that additional analysis of the data would lower the intake and exposure estimates?

2. On page 27 (third full paragraph) of the Site Profile, it is stated, "indications are that some of the higher routine (versus episodic) exposures occurred at the uranium ore processing facilities." Can NIOSH/ORAU elaborate on what indications lead to this conclusion? How much higher were these routine exposures? Did NIOSH/ORAU establish the bounding conditions for these exposures or estimate missed doses in reference to these higher routine exposures?

3. The Linde Site Profile recognizes that African ore involved significantly higher exposures to Th-230, Ra-226, and Rn-222. The ingrowth of Th-230 and Pa-231 was not considered significant to the production period, but these isotopes may have been contributors to external dose during and after the production period. In addition, the extraction of uranium would leave a raffinate with a higher concentration of these radionuclides, as well as Ra-226. Did NIOSH/ORAU consider the dose contribution of

these isotopes? What data or references can NIOSH/ORAU provide to support the conclusion that uranium progeny would not contribute to worker doses in this period?

4. The Site Profile lists Ac-227 and Pa-231 as radionuclides of concern for internal exposure to Linde workers up to 1954 in Tables 5 (p. 31), 11 (p. 37), and 12 (p. 38). However, these isotopes are not included in Table 39 (p. 74) for worker exposure during the subsequent cleanup period; please clarify.

5. On page 28 of the Site Profile, NIOSH/ORAU assumes air concentrations at 300 MAC (maximum allowable air concentration MAC or preferred level PL) adequate to provide a quick estimate of exposure even though short term exposures might be higher. What is the basis of the 300 MAC value for Linde? What were the potential short-term exposures, and what kind of job categories might these exposures relate to?

   On the same page (third paragraph) of the Site Profile, it states:

   > *Beginning November 1, 1947 at Linde Ceramics, workers were assumed to be exposed to 33 MAC and it was assumed this exposure continued through cleanup in 1954. Uranium progeny are not included in this later period, because only refined uranium was used and because the dose from intakes of contamination left from earlier work would have been insignificant compared to the dose to uranium during operations.* (p. 28)

   What is the basis to assume 33 MAC as the intake concentration for workers from November 1, 1947, through December 31, 1954, when earlier on the page the Site Profile assumes 300 MAC? The 33 MAC value is a time-averaged statistical mean value and not a bounding, worst-case concentration for workers, who might have been involved with higher short-term exposures; hence, this value does not appear to be claimant favorable.

6. Page 28 of the Site Profile states:

   > *It was initially and arbitrarily assumed that exposures decreased to 1 MAC during the standby period at the Ceramics Plant, and that exposures decreased to 0.1 MAC at the Tonawanda Laboratory after cleanup in 1946 until the end of cleanup at the Ceramics Plant in 1954. Based on reviews of later air concentrations at Linde, and reviews of air concentration data from other sites, it is believed that most workers' exposures would have been much lower during these periods.* (p. 28)

   What basis did NIOSH/ORAU use to decrease to 1 and 0.1 MAC? Can NIOSH/ORAU provide data to support this assumption and references for the "later air concentrations at Linde?"

7. The Site Profile uses several different workweek hour assumptions for missed dose calculations. In many cases, the value of 40 hours per week is used. However, Table 4 (p. 24) assumes that Linde workers could have worked as much as 51 or 54 hours per week. The differences of 11 or 14 hours per week would give significantly greater dose values; 27% or 35%, respectively. What basis does NIOSH/ORAU have to conclude that

other factors, such as “assumed” air concentrations, are sufficiently large to account for these differences, as stated on page 28 (fourth paragraph)?

> *To simplify calculations, it assumed that the workweek was 40 hours long during all years, although it is likely that the workweek for many was in excess of 40 hours especially during the earlier years. The assumed air concentrations are sufficiently large to account for any differences in actual hours exposed.* (p. 28)

Assuming that one likely, but unquantified, overestimate is sufficient to account for another underestimate does not appear conservative: i.e., claimant favorable.

8. Page 35 of the Site Profile states:

> *For example, the annual uranium inhalation intake due to chronic exposure at 0.1 MAC is estimated by multiplying the air concentration of 7 dpm/m^3 by the alpha fraction of uranium, 0.402; the ICRP 66 (ICRP 1994) recommended breathing rate of 1.2 m^3/h; and the assumed 2000 work-hours per calendar year. This results in an annual chronic inhalation intake of 6.75E+03 dpm, which is equal to a daily intake rate of 18.5 dpm/day. For the assumed exposure at 33 MAC, no alpha activity is apportioned to progeny so the daily uranium intake would be 1.52E+04 dpm/day.* (p. 35)

Why did NIOSH/ORAU choose the value of 1.2 m^3/h for Linde, while 1.4 m^3/h or 1.7 m^3/h for heavy work was used for the Mallinckrodt Chemical Plant? Similarly, why did NIOSH/ORAU use 2,000 work hours per calendar year instead of 2,040 hours (on page 32) or, more conservatively, 2,550 or 2,700 hours per calendar year (Table 4)?

9. Page 29 of the Site Profile states that “individual uranium urinalysis data from November 1947 to 1950 are available for some Linde Ceramics workers (Linde Ceramics Plant Urinalysis Data 1947–1950).” How many workers have these individual urinalysis data in their files? How complete are these data? For those workers who have no individual urinalysis data, what recommendation is given to the dose reconstructor?

10. Section 3.2.2, Uranium Air Concentrations, states:

> *This site profile currently uses an estimate of Linde’s largest time weighted air concentration reported by AEC (1949a) to estimate intakes during uranium operations. Other Linde particulate air concentration data were reviewed and considered, but are not discussed here.* (p. 30)

What are the other particulate air concentration data reviewed and considered by NIOSH/ORAU? Do these data have higher or lower values than the “largest time weighted air concentration?”

11. Section 3.3.1, Radon Breath Data, states: "Room background concentrations of radon were sometimes subtracted from the results and sometimes not" (p. 31, 2nd para.). How did NIOSH/ORAU handle these variations in data?

12. Section 3.3.1, Radon Breath Data, states:

    Radon breath results are the starting point for dose reconstruction, so it might be necessary to back-calculate breath results from either Ra-226 burdens or tolerance levels. The original records might have sufficient information for this determination. This information has not yet been tabulated for inclusion in the site profile. (p. 31, 2nd para.)

    Why might the original records have sufficient information for this determination? Will the information be included in future revisions of the Site Profile?

13. Section 3.4, Uranium Progeny, states:

    This along with the claimant-favorable assumptions made in the estimation of worker dust exposures is judged to provide sufficient overestimation to balance any underestimation associated with the handling of waste products. (p. 31)

    On what basis does NIOSH/ORAU think the assumptions made in the worker dust exposures are claimant favorable? Are they not "time-average" values? Can NIOSH/ORAU list the areas of underestimation associated with the handling of waste products?

14. How did NIOSH/ORAU arrive at the 22.4 pCi/L value (p. 33) as radon exposure for workers who did not work or have their offices in the process buildings prior to standby?

15. Section 3.5.3, Tonawanda Laboratory Radon Exposures, states:

    For dose reconstruction, it is assumed that African ore processing at Tonawanda Laboratory occurred during its whole MED period, but that the peak concentrations of radon were equal to the medium values at the Ceramics Plant. It is assumed that after MED research and initial cleanup at the Laboratory ended, the radon concentration dropped to 10 pCi/L, the level in the Ceramics Plant after it switched from African ore processing to domestic ore processing, and remained there until the end of the cleanup at the Laboratory. After the end of its cleanup, radon exposure in the Laboratory was based on the highest geometric mean PAEC determined for a Tonawanda site building from measurements made in 1981, 1.68E-02 WL for Building 31 (based on analysis of data in BNI 1982, Table B-3). …. Radon exposure rates provided here are annual PAEE rates in WLM/y. Each value is assumed to be the median of a lognormal distribution with a GSD of 3.43. This GSD is based on the location category having the highest GSD (3.43 per Table 6). (p. 34)

    Can NIOSH/ORAU explain what is meant by "the peak concentrations of radon were equal to the medium values?" What is the highest geometric mean PAEC (potential alpha energy concentration)? What are PAEE rates? Why is the median of a lognormal distribution with a GSD of 3.43 claimant favorable for Linde dose reconstruction?

16. Section 3.7, Ingestion Intake Estimates, states:

> *NIOSH (2004) indicates that the ingestion rate, in terms of dpm for an 8-hour workday, can be estimated by multiplying the air concentration in dpm per cubic meter by a factor of 0.2, so the uranium ingestion rate based on an air concentration of 7 alpha dpm/m^3 would be 0.563 dpm/workday. To adjust this to ingestion intake per calendar day, 0.563 dpm/workday is multiplied by 250 workdays per year and divided by 365 days per year, which equals 0.385 dpm/day. For the assumed exposure at 33 MAC, no alpha activity is apportioned to progeny so the daily uranium intake would be 316 dpm/day.* (p. 35)

What is the basis for the factor of 0.2 used for ingestion intake? Why is the assumption of an 8-hour workday, 250 workdays per year (i.e., 2,000 WH/y), seen as claimant favorable when it is likely that many workers put in more hours?

17. Section 3.8, Consideration of Bioassay Data, states:

> *Given a chronic exposure to uranium and its alpha emitting progeny at 300 MAC, the activity fraction of Ra-226 would be 0.196, which means that the chronic inhalation rate would be 2.7E+04 dpm/. This gives a whole body activity of 2.6E+05 dpm at one year, and about 4.0E+05 dpm at 4 years (calculated using IMBA Expert (OCAS), Version 3.2.20). The Ra-226 body activity was estimated using the largest breath radon result found for Linde, 2.2 pCi/L, by multiplying the radon result by a conversion factor of 2.52E+05 pCi/(pCi/L) (ORAUT 2005). This gives a body activity of 5.5 E+05 pCi, which is equal to 1.2 E+06 dpm, and is within a factor of 3 of the estimated intake from a 4-year chronic exposure to 300 MAC. Because other Linde radon breath analyses are lower and because a chronic exposure scenario may not best represent a worker's exposure pattern, the assumption of 300 MAC chronic exposure was believed to be adequate for reconstructing doses in the pre-1947 research and production period, but at this time this period is reserved.* (p. 36)

Can NIOSH/ORAU provide the calculation sheets for further review, including all parameters used? Given the concern with chronic exposure scenario, did NIOSH/ORAU develop a list of episodic or acute exposure scenarios at Linde?

18. In Section 3.9, Occupational Internal Dose Reconstruction Assumptions and Summary 1942–1954:

    a. What is meant by "for workers, whose work location is considered indeterminate, intakes for the Ceramics Plant are assumed" (p. 36)? What are the assumed intakes? Why is this approach claimant favorable? What intakes should the dose reconstructor use if a worker's work location can be determined, since the Site Profile does not provide intake value by location?

b. Why is the "dose distribution for particulate intakes … assumed to be constant" (p. 36). Is this approach claimant favorable? Is 3.43 the largest GSD value? How does it compare with the 95th percentile value?

c. The retired workers and site experts SC&A interviewed indicated that they had never undergone any bioassay or urinalysis while they worked at Linde Site. Do the Linde employee files reflect this comment?

d. Urinalyses for uranium until 1950 were suspect (see page 40 of the Mallinckrodt Site Profile). Do NIOSH and ORAU feel confident that the Linde data could be used to produce claimant-favorable dose reconstruction?

Occupational External Doses

1. The Section on Beta Radiation states that "Workers who frequently handled significant quantities of beta-emitting materials were assumed to have higher beta doses to the hands and forearms than to the remainder of the body (p. 38)." Did NIOSH/ORAU consider that these workers might have carried burlap bags containing radioactive material close to their chests when they were loading or unloading the uranium ores? The site experts SC&A interviewed indicated that workers frequently sat on the burlap bags during lunch and break times for many years, even after the MED project was completed. Did NIOSH/ORAU consider exposures to workers from these bags?

2. Section 4.4, External Dose Reconstruction Summary 1942–1954, states:

   Each estimate is considered to be the median of a lognormal distribution. A GSD of 3.0 is assigned to all beta and gamma dose estimates based on the typical GSD levels estimated for the underlying data, i.e., beta and gamma doses are assigned as lognormal distributions with GSDs of 3, and an acute exposure rate. Neutron doses are assigned as a constant distribution and a chronic exposure rate (p. 63)

   How is this approach, assigning the median of a lognormal distribution as the bounding dose value, claimant favorable for determining beta, gamma, and neutron doses? Other examples include:

   a. For Step I process workers, NIOSH/ORAU assigns an exposure rate of 5.35 R/y to all workers for dose reconstruction purposes (based on Table 24). Again, this exposure rate for the loaders is the median of a lognormal distribution with a GSD of 2.61.

   b. For the rehabilitation and production period from 1947 to 1949, the Site Profile assumes the medium beta dose category is 1.95 R/y and the low beta dose category 1.0 R/y (p. 57).

   c. For the rehabilitation and production period from 1947 to 1949, NIOSH/ORAU assumes the medium gamma dose category to be equal to the highest gamma dose rates of 1.61 R/y (p. 59).

3. Section 4.1.2.1, Pre-production, 1942–1943, presents external exposures during non-production periods at Linde. It states: "The beta dose rate was assumed to apply to the whole body with no added dose to the hands and forearms because it is unlikely that there was any significant handling of radioactive materials by Ceramics Plant workers in this period (p. 40)." Didn't some workers transport and unload the uranium ores from boxcars in this period?

4. Can NIOSH and ORAU provide support to the external exposure time given in Section 4.1.2.1 (p. 40) of 0.5 h/d, which totals 150 hours per year, from 1942 to 1943?

5. Section 4.1.3, Production, 1943–1946, estimates worker doses in subsection 4.1.3.1.1. The latter states:

   > *In order to use the data in Table 19 to estimate time-averaged beta dose rates applicable to the entire 1943–1946 production period at Linde, the ratio of the average dose rates to those measured in Table 19 was estimated. Table 20 documents the determination of the ratio. The grade range of the L-30 ore used at Linde was 8-12% (Aerospace Corporation 1981, Table B-1). To obtain the highest ratio, it was assumed that the measurements in Table 19 were made on the lowest L-30 ore grade, 8%. It was also assumed that beta dose was proportional to electron energy released per decay and the worker doses were proportional to the mass of ore processed. With these assumptions, it was estimated that average doses would have been 0.84 of the doses predicted by using the data in Table 19. Therefore, the estimated dose rates in Table 19 were multiplied by 0.84 to obtain time-averaged dose rates for 1943–1946 production. The results are in Table 21, which summarizes the results of all beta dose rate estimates in this section and groups the job categories into three groups (high, medium, and low).* (p. 45)

   Data in Table 19 (p. 44) represent beta exposure rates based on a 1-day radiation survey of the Linde facilities on January 23, 1944, during processing of a particular batch of African ore. How can NIOSH/ORAU justify using this single data point (and, how is it claimant favorable?) to estimate time-averaged beta dose rates for the entire 1943–1946 production period at Linde? What correction factors did NIOSH and ORAU make to account for uncertainties? Please define these three groups of job categories associated with beta dose rates.

6. The Estimation of Worker Doses section (Section 4.1.2.1.1) states:

   > *Workers in 1943–1946 who held jobs analogous to ones in 1947–1949 were assigned three times the 1947–1949 beta dose rates. The factor three increase accounts for potential exposure to radiation from waste products from unrefined uranium ore and for the possibility that procedures in 1943–1946 did not involve as much radiation protection.* (p. 45)

   What is the justification for the factor of three; is it claimant favorable?

7. Table 33 (p. 60) of Section 4.2, Tonawanda Laboratory Beta and Gamma Exposure, assumes the 1942–1954 beta and extremity doses to workers to be one half of the value of the most exposed Ceramics Plant process workers during the 1943–1946 production period. What bases support this assumption as claimant favorable?

8. What factors did NOSH/ORAU use for correcting film badge underestimates of low-energy photon exposures at Linde? Is NIOSH/ORAU planning to publish a Technical Information Bulletin similar to ORAUT-OTIB-0010, 1/12/2004 Rev. 00, for Atomic Weapons facilities for the period prior to 1970?

9. What type of film badges were used at Linde Site? Can sensitivity data be provided? Were TLDs used in the later years of the cleanup period?

10. What types of survey equipment were used by MED/AEC/NYOO at Linde? What were the LODs for the equipment?

Occupational Medical Doses

No comments.

Residual Contamination After 1954

1. Section 6.1.1, Internal Exposure, provides Table 38 (p. 72) displaying the highest monthly average air concentration of Ra-226, Th-230, and U-238 for July 2000–June 2004. How should dose reconstructors use these data in the period of 2000–2004 for determining internal doses for cleanup workers in 1950s, 1960s, 1970s, 1980s, and 1990s?

2. Section 6.1.1, Internal Exposure, states:

> *Building 30 was found in 1976 to be the most contaminated building on the site (ORNL 1978). The indoor airborne uranium concentration in 1976 was measured as 1.90E-02 pCi U/m^3 (ORNL 1978, Table 14). This larger uranium air concentration is used to estimate a chronic intake. To maintain the consistent intake units and estimate the annual intake, the uranium air concentration of 1.90E-02 pCi/m^3 is multiplied by 2.22 dpm/pCi, a breathing rate of 1.2 m^3/h and 2000 work-hours/y. The annual intake rate is estimated at 100 dpm/y for all Tonawanda employees beginning in 1955. Dividing by 365 days/y give a daily uranium inhalation intake rate of 0.277 dpm/day. The Th-230 and Ra-226 daily inhalation intake rates would be 0.233 and 0.471 dpm/d, respectively. Ingestion intake rates are estimated using the steps described in Section 3.7. The summarized intake results are shown in Table 39. It is unlikely that uranium would be in a chemical form consistent with type F absorption during the residual contamination period, so it is assumed that only types M and S would be inhaled after 1954. Th-230 could be type M or S, and Ra-226 is type M.* (p. 72)

There were other radiation surveys done at Linde before 1976. Did NIOSH/ORAU compare this "larger uranium air concentration" (2nd sentence) to those survey data? Is there a higher concentration than 1.90E-02 pCi U/m^3, since it is denoted as the *larger*, not the *largest*? The paragraph following the above states:

> *Workers noted that Building 30 renovations occurred in the 1960s that could have influenced air concentrations. Specific details of the renovation, including the actual period of renovation, dust control measures, location of work and occupancy of areas are not available. It is reasonable to assume that renovations could have resulted in elevated airborne radioactivity.* (p. 72)

With these renovations in mind, how could the Site Profile assume that this "larger uranium air concentration" could bound the airborne concentration value? Did NIOSH/ORAU perform any uncertainty analysis of the concentration data?

3. The text following the above indicates that a factor of 14 was assumed to be reasonable to describe the uncertainty at the 95th percentile associated with the possibility of elevated intakes during Building 30 renovations (p. 72). How did NIOSH/ORAU arrive at this factor of 14?

4. What does the Site Profile mean by "other progeny are partially accounted for by the assigned radon exposure (p. 72)?" What are these progenies and how is the "partially" compensated for?

5. Section 6.1.1 subsection, Radon Daughters, estimates the radon exposure post-1954 to be 2.01E-01 WLM/y, based on 55 measurements of radon daughter concentration in 1976 and 1981 (p. 73). This value is derived by multiplying 12 work-months per year by the geometric mean PAEC of 1.68E-02 WL, with a GSD of 1.89. Is this radon exposure claimant favorable or bounding for worker exposure in the 1950s, 1960s, and early 1970s?

6. Section 6.1.2, External Beta and Gamma Exposure (post-1954), states:

   > *BNI 1982 (p. B-12) stated that the points of maximum radiation determined in the ground surveys were slightly displaced from but in general agreement with those determined in a 1979 aerial radiological survey. The total number of readings =25 µR/h reported by BNI was 16. The net readings (after subtraction of 8 µR/h to correct for background) had a geometric mean of 94.0 µR/h and a GSD of 3.95. This was taken as an estimate of worker exposure rate when outdoors. This estimate was assumed to apply from January 1, 1955 to the present (2005).* (p. 73)

   Why is the geometric mean of 94.0 µR/h considered claimant favorable for estimating worker outdoors exposure rates, especially in the 1950s, 1960s, and 1970s? Is there any correction made for natural attenuation over that time period?

7. Table 39 in Section 6.3, Dose Reconstruction Summary, 1955 to Present, shows annual internal and external exposures to residual activity (p. 74). Can NIOSH/ORAU explain

how this table was developed? Where do the penetrating and non-penetrating exposure values come from?

Other Issues

1. Section 2.3.4, Other Radiological Activities, states:

   > *In 1949, Linde workers were used to unload drums of K-65 shipped by rail to the Lake Ontario Ordnance Works at Modeltown, New York (Wolf 1949, Heatherton 1949a). Linde film badges were worn during this work.* (p. 22)

   How were the exposure received by these Linde workers at the LOOW handled in the Site Profile? Were the workers credited with the exposure?

2. The above section states (p. 21) that radioactive liquid wastes were discharges into onsite injection wells. These wells sometimes overflowed and became clogged; workers were required to descend into these wells to perform maintenance and unclog them. Did NIOSH/ORAU consider the exposure of workers to radioactive waste inside the wells?

3. The text following the above states:

   > *The estimates of uranium exposure based on estimates of exposure periods and source term, which were based on worst case assumptions when a parameter was not well supported by available information would be sufficiently bounding to account for small amounts of radioactive strontium.* (p. 22)

   What are the worst-case assumptions referenced? How much is a small amount?

4. Section 2.6, Decontamination During the MED/AEC Contract Period, states: "a systematic radiation survey was conducted to identify area of contamination" (p. 25). However, this systematic survey was not performed until the entire building was vacuum cleaned and flushed with water. For this reason, the true contamination level after the production process ended in the facilities is not known. How does NIOSH/ORAU estimate the potential internal and external doses to workers during the production period? How did NIOSH/ORAU estimate the potential internal and external doses to workers performing the vacuuming and flushing? How were the radioactive wastes handled during the vacuuming and flushing process?

5. The above section goes on to say:

   > *The memorandum reported "overall" floor and wall levels to be 1.01 "mreps/hr/ft^2" beta plus gamma. This was considered excessive. The memorandum cited data indicating that this could be reduced to 0.065 (mreps/hr)/ft^2 by covering contaminated floor areas with asphalt tile.* (p. 25)

   How did NIOSH/ORAU use this information in the dose reconstruction for cleanup workers and also the workers later occupying Building 38? How should the dose reconstructor use this information for the cleanup workers?

6. Section 2.7, Post MED/AEC Operations (p. 26), discusses elevated employee radiation exposures and residual radioactive contamination associated with areas in or near Buildings 57, 58, and 90. What were these three buildings used for? They are not discussed or described in Section 2.1. What are the radioactive contaminants associated with these buildings? What types of worker radiation exposures were there? How high were these exposures?

7. In the late 1940s, the Manhattan Engineering District (MED) established permissible doses for external radiation in places where workers were handling and processing uranium and its compounds. These limits were 500 mR beta equivalents per day or 3,500 mR beta equivalents per week. How are these two dose limits used in the dose reconstruction for Linde? Did NIOSH/ORAU take these two dose limits into account when considering the bounding or worst-case scenarios?

ATTACHMENT 2: ADVANCE QUESTIONS FOR SITE EXPERT INTERVIEWS

General Worker Questions

1. Which plant did you work in and what tasks did you perform. Did these tasks involve radioactive material? If so, what type?

2. When did the AEC work at Tonawanda Laboratory begin and end?

3. When did Ceramics Plant personnel start to handle radioactive material?

4. How many people worked at Linde during the AEC years?

5. Describe the layout of the facility (e.g., buildings, processes, etc.)? Describe the work with radioactive material in the following buildings. During what years was this work performed.
    - Building A
    - Building B
    - Building 14 (Tonawanda Laboratory)
    - Building 30
    - Building 31
    - Building 37
    - Building 38
    - Storage Areas
    - Waste Disposal Areas

6. Did the Tonawanda Laboratory serve as a pilot plant for the development of uranium processing methods?

7. Describe the process flow for each step of uranium processing, how long each process took, and what it involved?

8. Where did you receive the uranium ore from?

9. How was the uranium transported to and from the site? What type of containers used for transportation of the ores?

10. Who were the railroad workers employed by?

11. Who opened the boxcars when they first arrived? How was this done?

12. Where were uranium ores stored? How were they stored?

13. How were these uranium ores transported from the boxcars to the staging areas? To the storage areas? To the process areas?

14. How were uranium ores taken out of the containers? What equipment was used? Where were the workers involved? Were they wearing special protective equipment?

15. Were there any security or entry logs maintained for any areas of the plant?

16. Describe "high risk jobs" (i.e., jobs that posed a higher level of exposure risk), how many, and what type of workers were involved with these jobs?

17. Were employees frequently transferred between the different processes or did they maintain the same job for a majority of their career? Did your tasks and assignments change routinely?

18. Was there daily movement between the laboratory and the ceramics plant?

19. How many hours a day and per week did you routinely work? Did your work include work on Saturdays, Sundays and/or holidays?

20. Where was support personnel (e.g., health physics technicians, foreman, security, etc.) located in relation to the immediate production lines, machining or maintenance?

21. What was the relationship between the administrative and production areas? Were these areas attached to one another? Did administrative folks enter the production area?

22. Was production paperwork sent from the production areas into the administrative areas? Was this paperwork surveyed to determine if it was contaminated?

23. Were there operations at Linde that involved enriched uranium (e.g., higher in U-235 content)?

24. Were there any operations at the plant involving thorium processing?

25. How long was the uranium stored prior to and after processing at the facility? Where was it stored, and how much contact did workers have with stored material?

26. Were there recycling operations at Linde? If so, please explain.

27. Is the information provided in Table 2 of the site profile complete?

28. Where was the waste stored and/or disposed of from the processes?

29. Were you ever involved in waste clean-up operations and if so describe?

30. Was there a tailings pond?

31. Explain the process of abrading?

32. Upon completion of operations what was done with the equipment?

33. Was there any regular facility sweeping and dusting done? If so, how often? When it was done, how was it done? Were the workers wearing any protective equipment?

34. During the early (1940s/1950s) remediation, for those buildings not demolished, was the ventilation system removed, replaced or decontaminated?

35. What is the status of Buildings 31 and 37? When were they remediated?

36. What chemical exposures have you received in conjunction with radiation exposure? Were these chemical exposures simultaneous with radiation exposure?

37. What was the corporate attitude towards safety of the worker? How did this change over time?

38. Was there any worker training in the areas of personnel safety, operation, and equipment use?

39. Was any protective equipment, such as glove, PC, respirator, dosimeter, safety glass, provided to the workers?

External Exposure

1. The early monitoring programs monitored only a portion of the workforce. Which workers were monitored?

2. Did you ever wear pocket ionization chambers (also called PICs or pencils) at the plant?

3. Were you aware of the use of co-worker exposure data to assign a dose? If so, what problems or advantages do you see in doing this?

4. How were individuals directed to wear their beta/gamma dosimeter?

5. Where were the dosimeters stored? Were they allowed to be taken home?

6. Were workers ever given neutron badges?

7. Where were badges stored historically? Were individuals allowed to take them home?

8. Was extremity dosimetry assigned to workers?

9. Are/were there conditions where partial body exposures (e.g., skin, lens of eye, gonads, chest, etc.) would have significantly exceeded whole body exposure measured by the routine dosimeter? If so, explain.

10. Was/Is there an area dosimetry program at Linde?

11. Was the time you spent in particular areas limited in any way? If so, under what conditions? How was the time spent in the area monitored?

12. Are you aware historically of unsanctioned practices by workers with respect to their dosimeter or bioassay samples (e.g., putting them on sources, not wearing them, etc.)?

13. Specifically, did you ever sit on the uranium? Did other workers sit on the uranium? Was there a lot of lifting of uranium metal pieces and setting them down?

14. What operations at the Linde plant are manual versus automated? What operations involved hands-on work with uranium or other radioactive material?

15. How many hours in an 8-hour period did you have direct contact with uranium or associated waste?

16. Were workers surveyed before they began the work day and surveyed before they left the plant?

17. Was there any area survey done by the health physics technicians? If so, how often was it done? Daily? Weekly? Monthly?

Radiation Operations

1. Did you know you were working with radioactive material?

2. Did you receive radiological worker training? If so, when did this training begin?

3. Did you have a plant health physicist or safety officer? If so, who was this?

4. Did Linde use Radiation Work Permits or Special Work Permits? If so, did these permits include requirements for dosimetry and minimizing dose?

5. Did Linde use postings to alert workers when they were entering radiation areas?

6. Is there field characterization data? If so, where is this data located? How can we obtain a copy?

7. Was x-ray equipment or radioactive sources used to examine the uranium for quality purposes?

8. Did Linde Plant handle radionuclides other than uranium? This would include Research and Development activities. If so, what were these radionuclides and in what quantity were they handled?

9. Workers indicated to NIOSH that there was strontium at Linde. Can you please provide more details?

10. When did Linde upgrade the ventilation system to support uranium work? If so, what type of ventilation system was used? Was there any filtering capability, like HEPA filter?

11. Was there any air sampling taken by the health physics technicians? If so, how often it was done? Where were the sampling results kept?

12. What types of maintenance work involved with the uranium operation and process? Did these maintenance workers require the support of mechanics or electricians? How close were these workers to the processing uranium streams?

13. How were liquid wastes handled in the operation?

14. How were solid wastes handled in the operation?

Internal Dosimetry

1. Which jobs involved heavy work (e.g., strenuous labor)?

2. Which jobs involved light work?

3. Did you ever work with the lathes, grinders or milling machines? If so describe your work and what you perceived as potential hazards?

4. Did you work in areas with visible dust?

5. Were your lungs irritated by the dust you inhaled?

6. Did you wear any respirator? If so, what type of respirator?

7. What were the floors of the building made of? Were the floors cleaned regularly to reduce dust in the general areas?

8. Where did you take your coffee or lunch breaks?

9. Were there showers or change rooms at the facility? Did you shower and change your work clothing before leaving for home?

10. What type of protective equipment did you wear? (e.g., respirators, hoods, painters masks, gloves, company issued clothes, hats, booties, safety shoes, goggles, face shields, aprons, lab coats, etc.)

11. Were there situations where an individual in the immediate vicinity of the work wore protective equipment yet an individual standing near that individual did not? If so, please explain?

12. How were respirators assigned? Did an individual use the same respirator more than one time? If so, where was the respirator stored in between uses?

13. What particular forms of uranium did you work with and were there situations where you felt you were likely to receive a higher dose than normal?

14. Did you hear of or know of uranium fires? Do you remember anyone discussing uranium hydride or spontaneous combustion problems?

15. Did you fire the uranium oxide? In what set was this done? At what temperature?

16. Historically, who was put on a bioassay program (i.e. submitting urine samples for detection of radiation)?

17. Were there any employees that were exposed to radionuclides who were not on an adequate bioassay program?

18. For those monitored via urinalysis, what directions were given for submitting the samples? Were you asked to wait for a specific period before collecting the sample or could you start right away?

19. Did safety or outside organizations perform routine air sampling of the general area and worker breathing zones?

20. Are thoron and radon occupational exposure issues in any areas of the facility? If so, where?

21. Were you exposed to fumes? If so, explain.

22. Did Linde Plant process and/or store recycled uranium?

23. Do you feel NIOSH integrated worker input into the site profile?

24. Was there a clean room assigned for worker lunching and drinking? Where did you keep your lunch bags?

25. Did you change into work clothes when you entered the plant? If not, how was the condition of your clothes when you arrived home? Dusty?

Medical Exposure

1. What were the medical exam requirements for workers in the present and historically? Did workers receive medical exams and if so what did these exams involve?

2. What did the medical exams include?

3. Did workers receive medical chest x-rays while at Linde and if so how often was that typically done?

4. Where were chest x-rays done?

5. How frequently did Linde employees have medical exams?

6. How frequently were they given x-rays as a part of this exam?

7. How many x-rays were taken per exam? Which direction were you facing?

8. Did you receive pelvic x-rays?

9. Was photofluorography used at any time? Were 4” x 5” films ever used for x-rays?

10. Are there other items which you would like to add that would help evaluate medical x-ray exposure?

11. Have you seen your personal record file? Were you ever provided with your dose record? How often it was provided?

12. Was there any fire hazard in the operation? Please explain.

Environmental Monitoring

1. How were these environmental releases documented? Where are these records located?

2. Are you aware of historical particulate and gaseous releases from facilities to the environment? If so, describe these.

3. Did Linde have a formal environmental monitoring program in place during the production years? During remediation years?

4. What is the extent of outdoor contamination at Linde in the soil, groundwater, vegetation, etc.? (Both historically and currently)

5. What is the average distance of the plant buildings from the site boundaries? How close is the site boundary from the neighboring residential areas?

6. What is the relationship between Linde and the state of New York? Is the state actively involved in oversight of work at Linde?

7. What EPA-regulated activities are currently occurring at Linde?

8. Were there radiological releases from Linde facilities other than uranium? If so, what radionuclides were involved and when did these releases occur?

9. Were there any significant episodic releases from Linde?

10. What controls did Linde implement over time to reduce environmental emissions from the facility? Were these controls effective?

11. Were there any burning operations at Linde involving radioactive material? If so, please explain.

Records

1. Who currently maintains the historical records related to Linde operations?

2. Do radiation exposure records exist? If so, what type of records (e.g., bioassay data dosimeter records, air sampling, radon breath analysis, radiation surveys, etc.)? How complete are these records?

3. Were your dosimeter and bioassay results made available to you routinely? When did this begin?

4. Are you aware of any code names encountered in the records and their meanings?

5. How were incident, spills, personnel contamination, etc. documented? Where are these reports stored?

6. Has dose of record been modified for any reason over time?

7. Has the site destroyed any dosimetry, bioassay, or field radiological records in the past? If so, what were they?

8. Can you recommend resources (i.e., technical reports, books, films, etc.) that may be helpful in understanding the historical operations of the site?

9. When you left the facility, did they provide you a copy of your personal dosimetry record?

Facility Clean Up Operation

1. What was done during cleanup as compared to D & D?

2. Were facility sweeping and dusting and vacuuming done?

3. How were the wastes generated handled?

4. Were workers provided with respirator and other protective equipment?

Facility Decontamination and Decommissioning Operation

1. Was sandblasting used in the D&D of the facility? If so, where was it used?

2. Was there high dust level during the sandblasting process? Was water mist used to reduce dust level?

3. Were respirator or protective equipment provided to workers during sandblasting?

4. What else was done during D &D?

5. Was there any air monitoring, personnel survey, and area survey done during D & D?

ATTACHMENT 3: SUMMARY OF SITE EXPERT INTERVIEWS

FORMER WORKERS

Interviews were conducted with seventeen former Linde Ceramics Plant and Tonawanda Laboratory employees. Years worked onsite at Linde Site represented by those interviewed range from 1951 to 1998. The interviews were conducted by Desmond Chan and Kathryn Robertson-DeMers, members of the SC&A Linde review team. The purpose of these interviews was to receive first-hand accounts of safety and personnel monitoring practices at Linde and to better understand how operations and remediation activities were conducted. Interviews were done in person on January 12–14, 2006, in Buffalo, New York. Interviewees were selected to represent a reasonable cross-section of production areas and job categories. Interviewees were originally obtained through the FACTS ("For A Clean Tonawanda Site") organization and the NIOSH/ORAU team. An effort was made to contact living safety staff; however, SC&A was unsuccessful in locating them. A brief tour of the perimeter of the Linde Site was conducted to visualize the proximity of various operations, the level of remediation underway, and the structure of buildings still existing from the Manhattan Engineering District (MED) era. Although SC&A tried to contact personnel from Linde who worked on the MED, we were unsuccessful in finding individuals who were alive and coherent by the completion of this summary.

Workers were briefed on the purpose of the interviews and the Linde Site Profile. They were asked to provide their names in case there were follow-up questions. Participants were reminded that they would be provided the opportunity to review the interview summaries prior to inclusion into this report. Interviewees were told that there were aspects of the Linde operations that were classified and this information could not be divulged.

Former Linde workers interviewed worked throughout the Linde Site due to the nature of their jobs. Some of the primary buildings associated with their work included Buildings 1, 2, 2B, 8, 10, 11, 14, 19, 27, 30, 31, 33, 34, 37, 38, 39, 43, 44A, 44B, 57, 59, 69, 70, 70A, 70B, 90, 98, 99, 100, 100S, and 100N. There were only a few select operations on the site that were not readily accessible to all workers. The job categories represented in the interviews included:

- Fabrication Shop and Maintenance
- Tool and Die Making
- Inspection
- Laboratory Mechanic
- Maintenance Foreman/Supervisor
- Pipefitter
- Draftsman/Designer
- Building and Grounds Supervisor
- Engineering Administration
- Chemical Operator

- Heating, Ventilation and Air Conditioning Mechanic
- Administrative Services (Office Manager, Secretary, Timekeeper, Accounting, Printing Department)
- Research and Development
- Project Management
- Painter
- Shear Operator
- Truck Driver
- Welder
- Graphics Art Supervisor
- Electrician
- Millwright.

The information the workers provided to SC&A has been invaluable in providing us with a working knowledge of the various site operations and the safety program. All interviews have been documented and summarized below. This summary is not a verbatim discussion, but is a summary of information from multiple interviews with many individuals. The information provided by the interviewees was based entirely on their personal experience at Linde Site. It is recognized that these site expert and former Linde worker recollections and statements may need to be further substantiated. However, they stand as critical operational feedback and reality reference checks. These interview summaries are provided in that context. Linde site expert input is similarly reflected in our discussion. With the preceding qualifications in mind, this summary has contributed to our findings and observations.

General

The MED project activities at the Linde Site involved the use of Buildings A, B, 14, 30, 31, 38, and 57. Buildings 31 and 38 were used for processing and production of uranium. Upstairs in Building 31, there was experimental work related to the project. The floors of most buildings were made of pitted and/or finished concrete. There were some areas with dirt floors. Buildings 30 and 57 were set up to receive the uranium ore. The railroad tracks came right into the site for uranium ore deliveries. The railroad workers were not employed by Union Carbide. When the trains reached the gate, a Linde Train Operator would move the train from the gate into the Manufacturing Areas. Domestic ore was shipped in open boxcars. African ore was shipped in burlap bags which had to be unloaded manually. The end products were put into boxes which were stacked on railcars for shipping offsite to other facilities.

Linde is in close proximity to the neighboring residential population and commercial structures. The site is located in the town of Tonawanda, New York. Building 30 was approximately 300–400 feet from the site perimeter. Nuclear piles were put right next to the fence line. Rattlesnake Creek and Two Mile Creek both run through the length of Linde property.

The Linde Site is still operational although current operations do not involve radioactive material. The site has undergone and continues to undergo extensive remediation. There are significant levels of radioactive contamination in the parking lots, soil, wells, creeks passing through the property, and in some of the older buildings. Linde bought the golf course neighboring the facility due to environmental contamination. Part of the remediation of the site includes removing contamination from the creeks.

Those accessing the Linde Site were required to have a company badge. Both salaried and hourly employees had access to nearly all buildings onsite. Their work took them to areas throughout the site requiring that they entered all buildings and production areas except that indicated below. Support staff such as engineering workers frequently visited the work areas and shops to ensure equipment and systems were working smoothly. Generally, the administrative support staff did not go into the production areas, but there were exceptions such as those that delivered mail or distributed paychecks. They delivered mails to all the onsite buildings, including offices, production areas, laboratories, receiving areas, shipping areas, and maintenance shops, at least twice every day. These mail delivery personnel were not wearing any special protective clothing or equipment. Very likely, they carried contaminants from production areas to offices and other areas within the Linde Site.

It is important to note that Linde maintained a license to handle radioactive material after the end of the MED Project. This license was primarily for work being conducted onsite by the military. It is unknown what specific radionuclides were included in the military programs. Access to this building required a security clearance and the building was guarded. Most Linde employees did not have access to this building. The project involved testing special gas mixtures for deep sea divers. Krypton-85 gas was believed to be used in some military projects.

There were also offices for administrative staff located in various production buildings, such as Building 14 and Building 30. A special engineering barrier or separation from production or operation areas was used. Office staff and operational workers were allowed to move freely between offices and production areas without egress monitoring or restriction.

Site experts indicated that they worked the standard 40 hours per week plus 10%–20% average overtime. The amount of overtime varied based on the production schedule. Regularly, workers would work 8 hours per day with 45 minutes lunch break. In 1952–1954, there were workers working 7 days and 24 hours in Building 14 performing maintenance and chemical operations. Building 14 was not renovated before the new equipment was installed to produce silicon products. The old MED project system structures, including ventilators and piping, were still in place without undergoing cleanup or remediation. They used four crews with scheduled shifts for the entire operation in Building 14. Support workers were housed in the building at this time.

In Building 52, there was a locker room in the northwest corner of the building. Workers would come through the guard shack (Building 23) to reach Building 52. They changed into work clothes in the locker room and then entered the production area to work.

There were about 3,000 employees at Linde Site in the early 1950s. The number of employees gradually was reduced to 2,000 employees in the 1990s.

Site Description

The southwest corner of the site was referred to as the Tonawanda Laboratory. This included Buildings 10, 11, 12, 13, 14, 15, 16, 23, 34, 43, 44, 47, 52, 62, 66 and 100. The factory area made up the remainder of the site and included the production facilities used during the MED project. Table A3.1 below describes the buildings on the Linde site and their current status.

Table A3.1. Descriptions of Select Linde Buildings

Building	Description	Current Status
A	Manhattan Engineering District offices	Torn down
B	Administrative	Torn down
1	Administrative Support	Current
2	Factory Manufacturing Area	Converted to laboratories; Current
8	Old Powerhouse	Pending tear down
9	Meter and Generating Room	Renovations
10	Laboratory Administration with Labs; Navy Laboratory	Current
11	Instrument Service Department, Silicon Rubber, Silicon, Dynamonitor Lab, Navy Project	Remodeled half the building in the late-1960s to create office area and large computer room; Remodeled again to remove the computer room and add labs upstairs
14	R&D Laboratory, Uranium Processing; High Flux Tubing; Silicon Production; Experimental Laboratory; Oxygen manufacturing	In Process of being Torn Down
15	Engineering Laboratory; Cryogenic Laboratory; Garages; Krypton-85 gases used	Renovations several times; Current
16	Engineering Laboratory	Renovations several times; Current
19	Metal Fabrication Building	Torn down; New Powerhouse built where this building was previously
23	Guard Shack	Torn down
25	Battery House	Torn down
27	Engineering Department	Current
29	Maintenance Department	Torn down
30	Ceramics Building; Storage; Offices; wooden building with cinder blocks and dirt floor	Torn Down
31	Molecular Sieves; Research Laboratory; U-processing	Pending tear down; Renovated in 1957
33	Engineering Department	Torn Down
34	Molecular Sieves Laboratory Building	Pending tear down
37	Storage; High Flux Cooling Area	Torn Down
38	Rare Gas Laboratory; U-processing; wooden building with cinder blocks and dirt floor	Torn Down
39	Laboratory Building; wooden building with cinder blocks and dirt floor	Torn Down

Table A3.1. Descriptions of Select Linde Buildings

Building	Description	Current Status
43/43A	Machine Shop; Silicon Shipping Department; Waste Water	Current
43B/44	Animal Research; Navy OTEC Laboratory; Cryogenics Laboratory	Current
50	Car Shop	Torn Down
52	Gas Laboratory	Current (see Bldg. 34)
54	Furnace for Burning Chemicals (old incinerator)	Torn Down
57	Storage Area for finished products	Torn Down; Connected to Bldg. 73
58	High Pressure Testing Laboratory; bomb test	Torn Down
59	Nuclear Testing Laboratory; Source Storage Area; Cobalt Laboratory	Torn Down
60	Engineering Building	Current
62	Laboratory Fabrication Shop; Instrumentation and Works Engineering	Laboratories were remodeled; Current
67	Laboratory; Shelf Generating Reactor/Incinerator used for burning	Renovated in the late-1970s; Torn Down
69	Tunnel Complex	A portion of the tunnel has been removed.
70	Truck Manufacturing; Acid Deck; UOP Testing Area	Paved over the Acid Deck; Current; Renovated many times
73/73A/73B	Storage; Molecular Sieve Storage Area, Union Oil Products (UOP) operations; High-flux Operations; Offices – Three	Renovations to connect to Building 57; Current
74	Substation	Current
90	Warehouse Building	Current

Following the MED years, Linde was devoted to other projects. Laboratory personnel were involved in Research and Development on silicon rubber. They were experimenting with different materials to strengthen silicon. Under the UNOX Waste Water Treatment Projects project, they performed various tests on waste water to develop better ways of cleaning the water. The Union Oil Products (UOP) (later it was referred to as merely UOP) project coated tubing for the chemical industry. Building 54 housed a furnace which was used to burn chemicals and waste.

Lathes, grinders, and milling machines were found in shops throughout the site. This type of evasive work occurred in the Machine and Instrument Shops located in Buildings 2, 11, 18, 19, 37, 43, and 62. There was a Tool Crib in both Buildings 1 and 2, where machining and grinding of metal cutting tools (such as bits and drills) and equipment parts were done.

Linde had a complete system of tunnels beneath the facility. These tunnels were referred to as Building 69. They were generally six feet in diameter and ran throughout the property connecting various buildings. The steam lines, piping, and other utilities were located inside the tunnels. These tunnels also provided walk and crawl spaces for maintenance workers. The main tunnel linked the Powerhouse (Building 8) to Building 39. The tunnel branches were connected to other major buildings, including Buildings 2A, 8, 8A, 10, 11, 14, 30, 31, 38, 39, 58, 59, 70, and 75.

Building 14 was a Research and Development Laboratory. It was involved in the purification of uranium ore during the MED era. The building had an open high bay, offices, and laboratories. There were change areas and showers within the building. The building had a large ventilator in the high bay without any special filtration system. The building housed a furnace and an arc furnace. After the MED project was completed, they decontaminated the building once. Later, they removed all the uranium production systems and laboratory equipment. They removed the concrete floor of the building due to contamination. But they did not remove the entire floor and also the contaminated walls. In addition, they did not remove the sanitary, sewage, storm water, and plumbing piping. The sanitary, sewage, and storm water lines went directly out to the public sewage system. The remaining piping was used and connected to new production systems in the building in later years. Although they went through this effort, a few years ago they found that the building was still contaminated.

Linde was the world's largest manufacturer and production plant for T-200 in the 1970s. They took part of the wall down between the two bays. The sheet metal was brought into Building 70 from Yard 70 and put on the flame bed. The flame bed operator would square the sheet and then make or cut holes necessary to put piping and other material through. The roller was down in the pit. The sheet would be set on a ramp and pushed into the roller to make a shell casing. It was tack welded. It was then transported to Building 14 where it was welded with a big Boom Welder (suspended welding torch). The shell would not fit under the Boom Welder so a base was added to the Boom Welder to make it taller. Tracks were laid down for a trolley. The trolley transported the shell to the Boom Welder. The installation of the tracks required bolting the tracks to the floor. The offset was put in a pit. A shell (radius of 16') was laid out and put on rollers. After this was completed, an offset roller could be set up. Holes were drilled in the floor with drills. The off setter was lowered into the pit and mounted to bolts in the wall. The shell was set in the off setter and the rollers were used to align the shells. The process was repeated several times to create a column. The final column when finished had a head welded on it. The shell was taken to the high or low bay shop in Building 2/2A. The welded casting was transported to the shop for partial assembly. The shell was then sent to Wickwire where additional parts were assembled. This required hands-on assembly. Final assembly was completed at Burn Harbor. No respiratory protection was worn during this operation.

Building 14 was used for fabrication also. Bechtel had two experimental columns to be used for radioactive work. Part of the column was put down in the ground. Construction of several columns required specialized welders, fabricators, and metalsmiths. The construction effort involved several shifts of 4- or 5-man crews.

In the late 1950s, the Stores Department was located in Building 30. This department shipped, received, and delivered parts, oxygen cylinders, and production units. Truck drivers delivered both clean and contaminated parts to all facilities at Linde. The clean and contaminated parts were all together in the truck during transportation. There was no specific precaution or instruction to handle them differently.

Early Uranium Production Years

Each employee was provided one new set of work clothes every year, including a shirt, pants, goggles, leather gloves, and work shoes. There were no masks, laboratory coats, or shoe covers assigned to workers. They were not provided with any radiation film badge or monitor unless working on special projects and/or radiography. After working at Linde for more than one year, workers were provided with more than one set of work clothes. They would take one set home to wash and use the second set at work alternatively. When workers entered the buildings, they first went into the locker room and changed out of their street clothes into work clothes.

During the MED project era, people going into and leaving the production areas in the Building 31 were required to go through a monitor. The exact type of monitor is unknown but individuals had to clear the monitor prior to exit from this area. If they were not able to clear the monitor they had to shower again and pass through the monitor a second time. Shower facilities were available for about 100 workers to wash up at the end of the day before they left the Linde Site. Normally, workers did not want to wait in line to take shower. Many workers went home with their soiled and contaminated street clothes. There were no health physics personnel in the locker room to survey or check out the workers before they left.

There were radiation signs posted during the production years in the MED project buildings, such as Buildings 14, 30, 31, 38, and 39. The postings were not specific about the type of radiation hazards involved. After 1952, many radiation signs were removed. The only radiation sign posted after 1952 was at the time of x-ray radiography work. All workers were told that there was no radiation hazard at Linde after the MED project was completed. There was no fixed radiation or airborne monitoring equipment used in any of the buildings.

During the early 1950s, the dust levels in Building 31 were so high that Linde brought in Dr. Joseph Shister from the University of Buffalo to evaluate the work areas. He confirmed that the dust levels were high and not safe for inside workers.

In Building 30, they had the same dust problems. Dust would come off the overhead rafters. Sometimes, they would fall right onto workers' lunch. During the MED period, they stacked all the contaminated burlap bags in storage area of Building 30. These contaminated burlap bags were kept in there until they were removed to be burned in the incinerator in the late 1950s. Many people working in Building 30, including operation personnel, secretaries, and maintenance workers, would sit on those bags resting or eating their lunch. This went on for many years.

In order to lower the worker exposure during this production period, Linde did rotate people into the production work areas on a weekly and monthly basis.

The union went through discussion and arbitration with Linde to improve the situation and to get more money for working in such a dirty and dusty environment.

Office and other support staff were housed in Building 30. There were offices also in the second floor. In the south end of Building 30, they had a truck shop in 1960s. It had a room with sealed, reinforced concrete retention walls for shielding purpose. This room was used to store African ore during the MED period. There were about 75–100 workers working in Building 30 at any time.

Characterization

Building 14 (Tonawanda Laboratory), Building 31, Main Building 30, Powerhouse, Building A (fabrication), Buildings 1 and 2 (fabrication), Building 37 (maintenance), Building 38, the soil staging area and parking lot outside Building 30, and the wells are areas of potential contamination through the years. Residual radiation was found in several buildings including Buildings 8, 14, 19, 30, 31 37, 38, 39, 57 (localized), and 59.

In the back of Building 30, there were two areas where uranium ore was stored in about 1951. By 1954, this area had been cleared of the uranium. The ore was stored in canvas bags with about 50 lbs of ore each. There were several pallets of these bags. Individuals worked in the immediate area, some even having desks there. It was a very dusty location with only a door for ventilation. Individuals spent approximately half their time in this area. Site experts indicated that there were some radioactive rods [not fuel rods] stored in Building 30 in the corridor for some period of time. Individuals use to walk over these rods.

In surveys conducted by Oak Ridge and other organizations, Building 30 was found to be the most contaminated building onsite with respect to residual radiation. Building 30 also had a contaminated parking lot adjacent to it. It took six to seven years to remove the equipment from this building and renovate it.

Radon exposure was clearly an issue at Linde. The level of Radon was dependent on the location onsite and the ventilation system in place during the years in question. Employees became concerned about the Radon levels at the site in the later years. One employee brought in a Radon detector from home. When the company found out they asked her what she was doing. They became very upset.

115 core samples were taken throughout the site in the late 1980s. There was also drilling around the perimeter of the property. Samples have also been taken from storm sewers and run off water. In later years, the site safety staff was observed outside of 100 Building in white suits conducting sampling activities.

The extent of the soil and well remediation during the initial cleanup period in 1949–1954 is unclear. In the 1970s, the Army Corp of Engineers did a baseline study of the contamination at Linde Site prior to cleanup of the facilities. The tunnel system at the site was initially believed to be uncontaminated. Later, contamination was found in this area. The Army Corp of Engineers continues to find contamination as they proceed with remediation.

The former workers interviewed indicated that there was no plutonium ever used onsite at Linde Site.

Building Remediation and Remodeling

There are a number of buildings on the Linde Site that have undergone renovation after the Manhattan Engineering District project to remove contamination and upgrade facilities. These renovations took place after the initial post-MED cleanup in the late 1940s/early 1950s. Site experts were involved in renovations on Buildings 9, 14, 15, 16, 30, 39, 57, 58, and 73. Several buildings including Building 14 and Building 30 were eventually torn down due to residual contamination.

In 1957, Building 30 was renovated. Workers would be working in the building offices and in the receiving department on the first floor while the renovation workers were jack-hammering the contaminated concrete floor. Dust was kicked up everywhere. They removed the machines in the building and put new equipment in. In the process, dust came off from overhead beams and rafters. There was no cleanup of the dust cumulated in the overhead beams, thrust, shears, ceilings, walls, rafters, and structures when they completed the MED project.

Building 30 underwent a second renovation from 1961–1968. During renovation, there were jack-hammering of the concrete/dirt floors, removal and replacement of beams, shearing or cutting of steel and aluminum materials, and spray painting over previously existing paint. Equipment such as cut off machines, shears, and saws were moved around. The primary concern with Building 30, which processed uranium during production years, during this period was the residual contamination both in and outside the building. There were several tanks underneath Building 30 that served as disposal tanks during the MED era. Shearing operations caused dust to drop down from the ceiling. During some remediation operations, such as removal of the rafters, safety set up pumps to monitor airborne dust. Building 30 had four Gravity Ventilators which were found to be contaminated. These ventilators worked similar to a chimney with very little particulate filtration. They were constantly sucking out the dust inside the building during the production years and during the remediation period. Concerns were expressed regarding roof-top contamination, environmental contamination, soil contamination, parking lot contamination, and offsite contamination. Sandblasting was used during the renovation of this building to remove contamination from the floors, walls, etc. Equipment was removed, or sanded and repainted to make it look like new. All radioactive material labels were removed at this time. Although the equipment and building was painted to contain the radioactive material, this process did not contain all the radioactive material.

Contractors were hired to assist the Linde staff during renovations and remediation. Linde personnel provided on-the-job oversight of contractor activities. They were involved in hand-digging dirt, cutting holes in roof and tiles, replacing roofing and windows, and other construction activities. Both Building 2 and 2A had their roofs removed and replaced because they were contaminated.

Later on, Linde wanted to make the entire first floor offices with false ceilings. They ended up digging up the entire floor and the surrounding walls. The renovation process created so much dust for workers working in the building at the time.

For Buildings 18, 19, and 57, there were five ventilators without special filtration system on the roof tops. They used cranes to take them down. After they took them down onto the ground, maintenance used wired brushes to clean them inside out. The maintenance workers were not provided with any special protective equipment, face masks, gloves, clothes, shoes, or radiation monitors while they were performing the cleaning work. They were all contaminated.

Facility Decontamination and Decommissioning Operation

Residual contamination from the MED production years was and is still a significant issue at Linde. Site experts indicate that the entire Linde site was contaminated even following the initial cleanup of the site in the late 1940s and early 1950s. Contamination was not limited to the surface, but penetrated the ground.

Waste generated as a part of the MED activities was moved several times to other areas onsite. Some of the contaminated wastes were dumped into the old quarry, which was opened in the early 1940s. This included waste material from production and contaminated dirt from remediation. There was also a yard storage area in this part of the plant.

Prior to the construction of Building 90, the surface soil was removed due to contamination and moved near the fence line outside of Building 73. The material was manually shoveled and transported to this area. There was a main door that led out between the building and the fence. On summer days it was opened to cool the building. Food was grilled in this area.

Eventually, the dirt was moved to an area near Buildings 75 and 76. They then moved this dirt to the Northwest corner of the property, and eventually offsite. Contaminated dirt from under Pad 19 was moved to the back of the property. The dirt piles were capped with dirt, covered with canvas, and landscaped with grass. Some of the waste shipped offsite was sent to Envirocare in Clive, Utah. Other waste was shipped to the Ashland sites and Lake Ontario Ordnance Works. The site experts referred to the onsite dirt piles as the “nuclear piles.” Material shipped from the site had a waste designation of 11E2. 11E2 waste is the waste produced by extraction or concentration of uranium or thorium from any ore processed primarily for its source materials (i.e., uranium, thorium or both).

There were several waste disposal wells onsite. Two were located south of Building 8, one was near Building 30, one was near Building 39, one was in the vicinity of the Yard Storage, and one was at the side of Building 19 between the building and the railroad tracks. The well near Building 19 was filled with concrete. Uranium waste from processing was dumped down these wells. There was also a quarry located outside Building 31. There are no tailing ponds onsite.

There is a buried vault on the property with unknown contents. A radiography company was brought in to locate the vault so it could be removed. They were not successful.

Radiography and Sources

There was an established radiography program for monitoring the quality of manufactured units and performing Research and Development. Standard x-ray units were also used for quality control. There were two sizes of film used for industrial radiography. The larger film was approximately 20” x 22”. The smaller film was lead packed and used to check seals. Film approximately 5” x 10” was procured in 1944. The purpose is unknown. The site housed a sealed ^{90}Sr source in Building 59 in a lead vault. Union Carbide used sources in the 1970s to study the effects of high radiation exposure on metal strength. They wanted to know how exposures affected the welds of material. The inspection department located in Building 31 handled a portable ^{60}Co. They used this ^{60}Co source to inspect the wells, storage tanks, and trucking tanks. Engineering controls were in place to prevent excessive exposure from sources. Areas were roped off and signs were posted.

Former radiographers indicated that there were hot spots under the vending machine and near the bathroom. As an experiment, one technician laid film under the vending machines with three lead pennies on top of the film. The film was left in place for two days. When the film was developed, there was an image where the penny had been placed.

Radiation Safety

The corporate philosophy towards industrial safety was stringent. Workers were required to wear safety glasses, safety shoes, and in some cases hardhats. There was fall protection equipment available if needed. Eye wash stations, guard rails, and toe plates were built into the facilities. Workers were told not to worry about radiation as the radioactivity was within the limits. No details were shared with the workers.

Linde provided the workers with goggles, hardhats, gloves, welding masks, painter/dust masks, and coveralls. A majority of the workers wore clothes from home; although, some individuals were provided with coveralls or smocks. A locker room was available for individuals to change into work clothes and store their lunch and personal items. Showers were available for workers but they were not required to take a shower before they left the site. It often took more than one shower to get the powder out of your pores. Personnel monitoring (egress monitoring) was not required prior to leaving the site. There was no portal monitor used to screen workers entering and exiting work areas after the MED project was completed. There were times when outside contractors wore protective clothing and Linde employees did not.

During work clothes would get extremely soiled. Workers washed their soiled work clothes at home. There was no instruction to separate work clothes from clothes of family members.

There were various types of respiratory protection used ranging from dust masks to full-face respirators with cartridges. Although dust masks were disposable, they were used more than once by some workers.

Although some stored lunches in their lockers, most workers ate their lunch at their own work site in the production areas or in the locker rooms. They seldom washed their hands before they ate. Coffee was available for workers. There were facilities where they could warm up soup. In the later years vending machines were installed. The food vendor for the company stored food in Building 37.

Visible dust was noted during some jobs. When shearing took place in Building 30, dust would drop from the support beams above. Buildings 14 and 30 were particularly dirty. The dust irritated some individuals' respiratory tract, especially where fine metal powders were located. Some site experts reported returning home having to blow dirt out of their nose to clear it. This was especially true in Building 30 when shearing activities were underway. Dust would come down from the ceiling. Floors had to be swept two to three times per day to control the dust in some areas.

Safety personnel were involved in periodic surveys and job-specific general area air sampling during the renovation period. For example, when they cut and replaced the rafters, safety ran a couple of air samplers in the vicinity of the work. These air samples were not within the breathing zone of the workers. In the early 1970s, a nuclear physicist was working at the Linde site. This individual controlled work related to pumps, tanks, and digging on the site. Periodically, he used a Geiger counter to evaluate whether work involved residual radioactivity. Although radiation was detected in some circumstances, the levels were not reported to the union or workers on the job of concern.

There was not routine radiation monitoring during the breach of system in building previously used in the MED years. Maintenance workers removed piping and entire duct systems. The ducts were filthy and required vacuuming once per year. Standard filters and a limited number of dust bags were found in some facilities. Early ventilation was obtained primarily through windows and doors.

Although site experts worked throughout the site, they did not recollect seeing radiation postings until the remediation process began. It is believed that the Army Corp of Engineers was responsible for their placement. At this point, some site experts recollected seeing postings in Buildings 14, 31, 10, 52, and 59.

Note that during the tour of the site perimeter radiation postings were seen on the fence in certain areas. Workers were dressed in white coveralls, booties, and gloves. There was soil remediation in the area and an individual was monitoring the area with a Geiger-Mueller Counter.

During the time period after the MED work, site experts indicated that Radiation Work Permits or Special Work Permits were not used. There was a Hazardous Work Permit for certain jobs which primarily dealt with potential industrial hazards.

Personnel Monitoring

External monitoring was limited to the X-ray Department and those individuals working in Building 31. Badge exchanges were as frequent as daily. Those who were assigned dosimeters stored them in a badge rack at the facility. They were instructed to wear the dosimeter between the neck and waist on the outside of clothing. Those site experts were not provided with radiation exposure reports, but were merely told their dose was within the limits. There was at least one situation in the early 1990s were a few workers received dose in excess of the limit. The cause of the higher dose was believed to be radiography related.

In the 1950s, six (6) workers from Linde Site were sent to Lake Ontario Ordnance Work Plant to repackage K-65 to be shipped to Fernald. They were given film badges to wear during their work. No dose record was ever provided to these six workers after they finished this work.

Site experts indicated that pocket ionization chambers (i.e., pencils), extremity dosimetry, and timekeeping were not a part of the radiation safety program at Linde post-MED period. They did not recollect an area dosimetry program.

None of the site experts interviewed submitted bioassay samples. There was monitoring during the MED work for personnel in Building 31. The facility also had a policy where overexposed individuals would be reassigned.

Job-related safety meetings were held periodically, but often focused on industrial safety. When the union representatives asked about exposure to radiation, they were told by the safety representatives that radiation was not a problem.

Environmental Monitoring

There was no environmental monitoring system found within the boundaries of Linde Site. There was also no fence-line monitoring equipment used at Linde Site. In the later years, AEC and Army Corps of Engineers performed environmental surveys of the Linde properties and found radioactive contamination in creeks, rooftops, open areas, parking lots, soils, wells, and neighboring areas.

There were four drainage sumps within the Linde Site. They were either at or near Buildings 2/2A, 8/8A, 10, and 30. These sumps drained directly out to the Tonawanda City public sewage lines. There was no filtration or treatment systems built in these sumps. In addition, there were four injection wells within Linde for liquid waste disposal. These wells were at or around Buildings 8, 30, 73, and 75/67. There were also pumps installed in different places within the Linde Site. In 1996, the pump situated next to Buildings 30 and 31 was surveyed by safety personnel using a GM counter. It was found to be contaminated. An outside contractor, William Environmental Company (WEC), was brought in to decontaminate the pump. WEC workers pulled the pump out without any personal protective equipment. They bare-handedly cleaned the pump out.

The sump in the shower room did not have any filtration system to filter out contaminants. Later the sewage piping was found to be contaminated.

The town of Tonawanda supplied the drinking water for the Linde Site. There were back flows onsite at Linde to help prevent water from getting offsite.

Off-normal Occurrences

No large incidents were reported by site experts; however, there were small fires periodically.

The underground tunnels were frequently flooded with rain or snow water. Contaminants from buildings, operations, dirt piles, and soils would wash down into this tunnel system without any stoppage or barrier. Maintenance workers would regularly go through flood water in the tunnel to access utility and equipment. For example, a maintenance crew went down the tunnel to replace all the brackets for the 4160 cable line underneath Building 31. They were wearing helmets for head protection. During the welding process, the weld exploded and hit the welder on his eyebrow through the helmet. Two weeks later, the wound in the eyebrow of the welder was still bleeding. Later on, he was diagnosed with skin cancer. Safety personnel detected contamination in the Building 14 tunnel access area in later years.

In Building 14, the maintenance personnel were working the utility system. A Linde safety employee used a Geiger counter and a cutie pie to survey the working areas. The reading went off the scale because it was too hot. They notified the MED/AEC office. They sent someone to check the area out. But they never heard the results back from AEC or safety. The results of the survey were not shared with the employees involved in the incident.

Maintenance removed roof leaders (5-in pipe to drain the roof) from Building 30. A seam grinder was used to cut the pipes. The operations continued during this renovation activity. The nuclear physicist came in to perform a survey and told the foreman that the material could not be shipped to the scrap file. The pipes were placed on a cart and stored in a corner. The pipes were eventually cut down and shipped to the nuclear pile.

There was a situation where a contractor was brought in to dig up a water line. The individuals started digging in the area. Safety came around with a GM counter and indicated that the work had to stop due to the presence of radioactivity. There was no hand or foot survey performed following exit from the hole.

Medical Exposure

The company gave periodic physicals to all employees. During the MED era the physicals were more extensive and included:

- Urinalysis
- Blood Analysis
- Chest X-ray (front and side view)
- EKG
- Hearing Test
- Vision Test
- General Physical

In the 1940s, workers were given physical examination once a year. For workers working in special projects, like uranium separation buildings, they might receive physical examination every six months. In the 1950s, medical examination for Linde employees was changed to every 5 years. For those who worked for special projects, they would still receive medical examination every six months.

If an employee was expected to travel internationally, they also provided the appropriate inoculations. In later years, medical examination became age-based. Medical records contain the results of physicals and any information on work related injuries and treatment.

In 1981, the company wanted to expand the physical examination to include pulmonary function tests, x-rays, and blood testing. The company would not provide the workers with an explanation of why this was necessary. This led workers to ask whether safety conditions were appropriate. These additional tests became optional since the company refused to provide an explanation for why the extra tests were necessary.

Records

Personnel records were maintained on a Cardex file which provided the date, job title, job code, and demographic information. The Cardex file is not directly linkable to a building or area of the site. Claimants have had some difficulty obtaining personnel, medical, and/or monitoring records from Union Carbide.

Union Carbide shipped records to a repository (salt mine) in Vermont, which was commonly referred to as "the cave." These records were inventoried prior to shipment. Older records were typed on mylar paper which was fragile and crumbling in some cases. Project-related documentation was typically kept onsite for 3 years, and then shipped offsite. Some records were taken to the incinerator and burned, although the content of these records was unknown. The records in Vermont include project-related records, personnel records, and medical records. The site eventually started to scan drawings and other records into electronic form.

Maintenance took copies of paperwork to the job site for reference. They would throw these records away after the job.

The only dose record ever provided by Linde management to a worker was during a Building 14 incident in 1950s. A worker was exposed to high dose when the door exploded open.

Chemical Exposure

Site experts indicated that they had received chemical exposure also. Some of the chemicals mentioned during the course of the interviews were silicon rubber, asbestos, molecular sieves, ozone, mercury, acid fumes, metal powders (e.g., aluminum, copper, steel), acetone, trichloroethylene (TCE), and other chemicals used in the laboratories. There were lime pits around Building 30. The company historically dumped TCE to the environment.

The acid deck was used to clean parts with various chemicals. The company provided special protective clothing for work with corrosives and silicon. Acid burns still occurred as a result of working with acids.

Miscellaneous

During the course of the interview, several individuals indicated that there were numerous illnesses and cancer deaths associated with the Linde worker population. One individual had been diagnosed with asbestosis. Within the 100 Building, eight (8) individuals (i.e., engineers, technicians, clerical workers) developed cancer over a short period of time, although they were not routinely assigned to the production areas.

Sources of Additional Information:

The FACTS organization offered SC&A the opportunity to review six boxes of documents which included FUSRAP documents, Linde contracts, health and safety records, and job title descriptions. SC&A also met with Mr. Francis Amendola, Attorney, to review technical documents that his law firm collected for their client regarding Linde claims. Additional references or resources recommended by site experts included FUSRAP documents, and worker meeting notes.

ATTACHMENT 4: ISSUE RESOLUTION MATRIX FOR FINDINGS AND KEY OBSERVATIONS

Table A-4: Issue Resolution Matrix for Linde Findings and Key Observations

Comment Number	TBD Number	Finding Number	Issue Number and Description	SC&A Page No.	NIOSH Response	Board Action
1	ORAUT-TKBS-0025	1	**Issue 1: (5.1.1) Unsupported Assumptions and Significant Uncertainties in Information Used** – SC&A has identified numerous assumption or values used in missed dose estimations (both internal and external) in the Linde Site Profile that are not either supported or adequately supported by explanation, available data, technical study, or references. Many of these parametric assumptions are made arbitrarily without adequate technical basis. In some cases, an assumption was made or a value was selected from a range of estimated values in order to bound a dose parameter that is not entirely justified or explained in the document. In other cases, the assumption or value selected is not deemed by SC&A as bounding. This is a serious flaw that significantly affects the credibility and validity of the assigned missed dose estimates in this Linde Site Profile.	38		
2	ORAUT-TKBS-0025	2	**Issue 2: (5.1.2.2) Use of Air Concentration Data** – The use of airborne uranium dust concentration data (air concentration) as the sole basis for missed occupational internal dose estimation is not defensible and claimant favorable, because there are significant uncertainties regarding using air concentration data to estimate worker inhalation intakes at uranium processing facilities. Several technical studies, including the 2003 Y-12 study, *Practical Use of Personal Air Sampling (PAS) Data in the Internal Dosimetry Program at the Y-12 National Security Complex* (Snapp 2003), and the Nuclear Regulatory Commission's NUREG 1400, *Air Sampling in the Workplace* (Hickey 1993), demonstrate that using air concentration data would lead to underestimating the worker intakes and subsequently the internal exposures. The Y-12 study shows as high as 10 times difference (underestimation) between intakes derived from bioassay data and intakes derived from air concentration data.	42		
3	ORAUT-TKBS-0025	3	**Issue 3: (5.1.2.3) Urinalysis Data** – Using air concentration data only, but neglecting urinalysis data, to estimate worker inhalation intakes in the Linde Site Profile is not in full compliance with 42 CFR 82 requirements. There are eight sets of urinalysis data for over 100 uranium workers in the ORAU Database for the period between December 16, 1947, and January 30, 1950. The air concentration data used in the site profile are not complete either and are deemed inadequate (see Finding 2). However, NIOSH decided to use these air concentration data only for dose reconstruction. This approach is not in full compliance with the hierarchy approach stipulated in 42 CFR 82.	45		
4	ORAUT-TKBS-0025	4	**Issue 4: (5.1.2.2) Time-Weighted Averages** – Time-weighted averages of internal and external exposure values contain significant uncertainties and frequently fail to capture dose to workers in areas of high uranium dust concentration. The site profile uses time-weighted calculations to determine average dose values for both internal and external pathways. In the internal dosimetry section, NIOSH determines the time-weighted average	42		

Table A-4: Issue Resolution Matrix for Linde Findings and Key Observations

Comment Number	TBD Number	Finding Number	Issue Number and Description	SC&A Page No.	NIOSH Response	Board Action
			air concentration value of 33 MAC by time weighting the air concentration data with average worker exposure times and summing to determine daily time-weighted average air concentrations by job categories. This calculational approach would potentially underestimate the average air concentrations for high dose or risk tasks that a claimant might have participated in at Linde Site.			
5	ORAUT-TKBS-0025	O	**Issue 5: (5.1.2.4) Breathing Rate** – The Linde Site Profile assumed a breathing rate of 1.2 m^3/hour for worker intake. This value implies that workers were primarily involved in light exercise during the course of the day. A single value may not be consistent with the working conditions in the facility, especially during the early years of operation, and is inconsistent with other NIOSH site profiles, such as Mallinckrodt, Bethlehem Steel, Y-12, INL, SRS, and Hanford.	45		
6	ORAUT-TKBS-0025	O	**Issue 6: (5.1.2.5) Ingestion Rate** – The Linde Site Profile determines the worker ingestion intake by multiplying the inhalation intake by 0.2 (20%). Since the inhalation intake is estimated by using air concentration data, SC&A believes that the NIOSH approach would lead to the underestimation of ingestion intake and eventual missed ingestion doses for Linde workers.	45		
7	ORAUT-TKBS-0025	O	**Issue 7: (5.1.2.6) Radon Exposure and Concentration** – The Site Profile used the "lowest indoor concentrations measured at the Ceramics Plant during African ore processing" as the upper limit to both indoor and outdoor radon concentrations. The assumed indoor radon concentration of 10 pCi/L is based on the lower limit of detection. SC&A believes these assumed radon concentration values based on the GM of measurements are not claimant favorable and representative of the actual exposure conditions that the Linde workers experienced during the period of operation from 1942 to 1954.	46		
8	ORAUT-TKBS-0025	5	**Issue 8: (5.1.2.7) Raffinate Trace Radionuclides** – The dose consequences of raffinate trace radionuclides have not been adequately addressed in the Linde Site Profile**.** Raffinate contains Ac-227 and Pa-231, which are in the U-235 decay chain, as well as Th-230. Possible doses from raffinate-related exposures have not been evaluated in the site profile. Inhalation of even small quantities of some raffinates, such as filter cake (one of the waste products at Linde Site), could result in significant doses to the workers. The issue of potential airborne contamination of raffinates must be more carefully assessed.	46		
9	ORAUT-TKBS-0025	6	**Issue 9: (5.1.2.8) Assigned Work Hours** – The number of work hours used in calculating occupational internal and external doses for workers is inconsistent for different periods of Linde operations and, therefore, not claimant favorable. The site profile represents in Table 4 (Davidson 2005, p. 24), and in many other places, that workers at Linde had longer workweeks than 40 hours per week, and, in some cases, the workweeks were as long as 9 hours per day, for 6 days a week and 50 weeks per year. But, in most instances, NIOSH uses the standard 40 hours per week assumption for the missed dose estimation. This approach is not only inconsistent but also not claimant favorable.	47		
10	ORAUT-TKBS-0025	7	**Issue 10: (5.1.2.9) Surrogate Air Concentration Data** – Using the GM of air concentration data of seven AWE	47		

Table A-4: Issue Resolution Matrix for Linde Findings and Key Observations

Comment Number	TBD Number	Finding Number	Issue Number and Description	SC&A Page No.	NIOSH Response	Board Action
			facilities in New York from a 1949 AEC/NYOO report (AEC 1949a) as surrogate data to develop Linde site-specific worker inhalation intakes for the entire period of Linde Operation from 1942 to 1954, is over-reaching and may, potentially, underestimate the missed occupational internal dose to workers. This approach is inappropriate because the surrogate data are very limited and not representative of the actual Linde operation condition because, at Linde, ventilation was poor or non-existent, and adequate radiation protection practices had not yet been developed in the earlier years of operation.			
11	ORAUT-TKBS-0025	11	**Issue 11: (5.1.2.10) Use of Geometric Mean Values** – The statistical analysis approach used in the Linde Site Profile is not bounding and, most importantly, not claimant favorable. In Table 6 of the Occupational Internal Dose Section (Davidson 2005, p. 33), the site profile lists the geometrical means or the geometrical standard deviation values for measured radon concentrations during African ore processing. Firstly, there are no supporting calculations or data to show how these geometrical quantities are calculated. Secondly, the use of geometric means and standard deviations of airborne radon concentrations as default values could be considered claimant neutral and not claimant favorable. Unless there is good reason to believe that a given worker was exposed to the full distribution of the measured concentrations and could not have experienced protracted exposures to higher than average radon concentrations, it may be more appropriate to use the upper 95th percentile as the default exposure level.	48		
12	ORAUT-TKBS-0025	9	**Issue 12: (5.1.2.11) Lack of Comprehensive Uncertainty Analysis** – There are no uncertainties or potential errors estimated for different assumed parameters and factors used in the estimation of occupational internal dose in the site profile. An assessment of uncertainties, as required by OCAS-IG-001 and OCAS-IG-002, has not been adequately developed for air concentration and radon measurement data used in lieu of the absence of adequate bioassay data to assign internal dose.	48		
13	ORAUT-TKBS-0025	8	**Issue 13: (5.1.3) Complex Missed External Dose Surrogate System** – The Linde Site Profile uses a very complex scheme to evaluate missed occupational external dose to Linde workers from 1942 to the present time. In this scheme, NIOSH/ORAU used a combination of film badge data, solid sample analysis results, and facility field measurements to estimate missed external doses to workers in different periods of the Linde operations. These data are, however, limited and, most importantly, not facility/building specific. Furthermore, the Linde Site Profile uses different sets of data to estimate worker beta and gamma doses separately.	49		
14	ORAUT-TKBS-0025	8	**Issue 14: (5.1.3.4) Film Badge Data** – The use of the 1948 weekly film badge data for assigning both beta and gamma doses during the removal of equipment in Building 30 is not appropriate for the entire period from 1949 to 1954. These beta and gamma dose assignments in Table 36 contain median weekly photon doses and weekly median electron doses for use of unmonitored workers from 1942 to 1954. These dose assignments are not likely to capture the full range of external exposures during that time period. Table 36 is hardly representative of various facilities and job functions that defined Linde	58		

Table A-4: Issue Resolution Matrix for Linde Findings and Key Observations

Comment Number	TBD Number	Finding Number	Issue Number and Description	SC&A Page No.	NIOSH Response	Board Action
			operations and processes. Another problem in Table 36 is that some of the beta and gamma doses cannot be reproduced or traced back to the original sources. For example, there is no explanation or discussion on how the 1947 and 1949 (beta/gamma/neutron) doses were calculated, since they are all based on 1947–1949 weekly film badge data presented in Table 29 and Table 31 of the site profile.			
15	ORAUT-TKBS-0025	8	**Issue 15: (5.1.3.5) Survey Measurement Data** – Several sets of survey measurement data were used in the Linde Site Profile to calculate the missed beta and gamma doses for workers from 1942 to 1954. These survey measurements do not cover the entire period of Linde operation. SC&A believes that NIOSH should improve the use of these film badge data, because significant gaps exist for time periods when workers were not monitored for external or internal exposure. In addition, NIOSH did not evaluate or attempt to evaluate the adequacy, uncertainty, and accuracy of these data. This further weakens the assigned missed worker beta and gamma doses for the Linde workers.	60		
16	ORAUT-TKBS-0025	4	**Issue 16: (5.1.3.6) Time-Weighted Averages** – Time-weighted averages of external exposure values contain significant uncertainties and frequently fail to capture doses to workers in areas of high beta or gamma fields. In the external dosimetry section of the Site Profile, NIOSH determines the time-weighted average beta and gamma radiation dose rates during the standby period from 1946 to 1947 by time-weighting the dose rates with average worker exposure times and summing to yield annual time-weighted average by job category (Davidson 2005, p. 41). This approach would certainly underestimate the dose rates for high-dose or high-risk tasks in which a claimant might have participated at the Linde Site.	61		
17	ORAUT-TKBS-0025	O	**Issue 17: (5.1.3.7) Contaminated Burlap Bags** – During the interview in Buffalo, Linde site experts and past workers indicated that there were many thousands of used burlap bags stacked up in the open bay area behind Building 30 (see Attachment 3 of this review report). These burlap bags were used for transporting uranium ore to the Linde site for processing. After the end of the operation period, these contaminated burlap bags were stored behind Building 30 awaiting disposal. Many Linde workers, operation staff and administrative personnel, sat on these contaminated bags during break and lunch periods over the period of many years. They definitely had been exposed at close distance to beta and gamma radiation sources left over in those uranium contaminated bags. The Linde Site Profile does not estimate the missed beta and gamma doses to workers resulting from sitting or standing next to those contaminated burlap bags.	61		
18	ORAUT-TKBS-0025	7	**Issue 18: (5.1.3.8) Surrogate External Exposure Data** – The lack of complete film badge data for the period from 1942 to 1954 at Linde Site represents a period for which the potential for unaccounted beta and gamma doses is greatest. NIOSH's use of pre-cleanup survey data for the pre-production period from 1942 to 1943, the use of eight solid ore samples data for the period from 1943 to 1946, the use of a 1-day survey data in six locations in Building 30 for the period from 1946 to 1947, the use of two 1-day pre-cleanup survey data after	62		

Table A-4: Issue Resolution Matrix for Linde Findings and Key Observations

Comment Number	TBD Number	Finding Number	Issue Number and Description	SC&A Page No.	NIOSH Response	Board Action
			vacuuming and flushing in Building 30 for 1949, and the use of post-decontamination survey data for 1950 is complex, over-reaching, inadequately supported, and, likely, not claimant favorable. In addition, the use of the 1948 film badge data collected during the removal of equipment in Building 30 for assigning both beta and gamma doses for the period from 1949 to 1954 is not appropriate, because these data do not account for external exposures to contaminated burlap bags, contaminated soil, and other contaminated sources during the cleanup activities.			
19	ORAUT-TKBS-0025	6	**Issue 19: (5.1.3.9) Assigned Work Hours** – The Linde Site Profile states in Table 4 (Davidson 2005, p. 24) and several other sections that workers had longer workweeks than the standard 40 hours; as high as 9 hours per day, 6 days a week and 50 weeks per year. However, in calculating external exposure values, NIOSH uses different work-hour values. SC&A believes that applying these different work-hour values to the missed occupational external dose estimation would underestimate the eventual missed dose or exposure assignments. NIOSH should use a set of consistent and claimant-favorable work hours for use in the dose reconstruction.	62		
20	ORAUT-TKBS-0025	11	**Issue 20: (5.1.3.10) Geometric Values** – The geometrical approach used in the Linde Site Profile is not bounding and, most importantly, not claimant favorable. In Tables 13, 14, 15, 17, 18, 21, 23, 24, 25, 26, 29, 30, 31, 32, and 33, the site profile lists the geometrical means or the geometrical standard deviation values for various assigned default assumptions. Firstly, there are no supporting calculations or data to show how these geometrical quantities are calculated. Secondly, the geometrical approach does not provide maximized default values to arrive at claimant-favorable worker doses. Thirdly, NIOSH does not provide comparison of this geometrical approach with NIOSH-prescribed 95th percentile values. NIOSH should re-evaluate the uncertainties associated with this geometrical approach.	63		
21	ORAUT-TKBS-0025	9	**Issue 21: (5.1.3.11) Lack of Comprehensive Uncertainty Analysis** – An assessment of uncertainties, as required by OCAS-IG-001 and OCAS-IG-002, has not been adequately developed for air concentration and radon measurement data used in lieu of bioassay data to assign internal dose; and, for external exposure data (including film badge beta and gamma measurements, and survey measurements), used to assign external dose.	63		
22	ORAUT-TKBS-0025	10	**Issue 22: (5.1.4.1) Outdoor Doses** – The Linde Site Profile does not address missed occupational environmental doses to workers. NIOSH did evaluate several potential outdoor beta and gamma exposures to workers, but, in some cases, NIOSH ignores the outdoor doses (Section 4.1.3.1.2, p. 46; Section 4.1.3.2.2, p. 54) after the doses are calculated.	64		

Note: O-Observation