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National Institute of Occupational Safety and Health

Review of NIOSH Site Profile

for

Bethlehem Steel Plant, Lackawanna, NY

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EXECUTIVE SUMMARY

S. Cohen and Associates (SC&A) evaluated the ORAUT-TKBS-0001, *Technical Basis Document for Development of an Exposure Matrix for Bethlehem Steel Corporation* (Bloom 2004) and OCAS-TIB-009, *Estimation of Ingestion Intakes* (OCAS 2004) prepared by Oak Ridge Associate Universities (ORAU) and approved by the National Institute for Occupational Safety and Health (NIOSH). The evaluation focused on the completeness, technical accuracy, adequacy of data, and compliance with stated objectives, as stipulated in *SC&A Standard Operating Procedure for Performing Site Profile Reviews* approved by the Advisory Board on March 18, 2004. (A fifth objective, "consistency among various site profiles," cannot be addressed until more reviews are completed.)

The NIOSH technical basis documents (TBDs), which together constitute the NIOSH site profiles for specific Department of Energy and Atomic Weapons Employer sites, are designed to support the conduct of individual dose reconstructions under the Energy Employee Occupational Illness Compensation Program Act of 2000. This is accomplished by compiling and analyzing data such as that related to facility operations and processes over time, radiological source term characterization, chemical and physical forms of the radionuclides, historic workplace conditions and practices, and incidents and accidents involving potential exposures. As the Advisory Board's support contractor, SC&A has been charged with independently evaluating the approach taken in NIOSH site profiles (encompassing technical basis documents and supporting technical information bulletins as they apply to the TBDs) to gauge their adequacy, completeness, and validity. This information will be used by the Advisory Board to advise the Secretary of Health and Human Services on the "scientific validity and quality" of dose reconstruction efforts performed.

RESULTS

The Bethlehem Steel site profile has clear strengths, including its focus on inhalation dose, the use of claimant-favorable solubility class for the respiratory tract, and the use of a minimum dose estimate to expedite favorable compensation claims. The decision to use operational air concentration data from the Simonds Saw and Steel (Simonds) plant to attempt to construct a maximum dose estimate for rolling days was also appropriate. NIOSH also took worker and site expert feedback into account by including an ingestion model in Revision 1 of ORAUT-TKBS-0001. However, this evaluation indicates that the site profile is not sufficiently claimant favorable and scientifically sound on several important points.

NIOSH and ORAU have applied the triangular distribution to various internal exposure scenarios based on field characterization data and published dose rates for uranium. Dose estimates include dose from inhalation, ingestion, submersion, electron exposure (shallow dose), photon exposure (deep dose), and dose from diagnostic x-rays. Air monitoring data were subdivided into either lower bound or upper bound estimates, which were in turn used to calculate internal inhalation dose. The intent of the profile was to make conservative assumptions that were claimant favorable and technically robust.

Despite the intent to adopt a conservative approach in the Bethlehem Steel site profile, the document is incomplete or technically inappropriate on several accounts. SC&A identified technical issues regarding statistical approach, lack of actual long-term breathing zone data, lack of conservatism in the TBD as compared to a previously published technical information bulletin (ORAUT-OTIB-0004), intake assumptions, exposure duration, and conditions that, either individually or in combination, may substantially influence the outcome of dose reconstruction.

Dose reconstruction accuracy is directly dependent on the accuracy of the site profile. The most significant issues that are likely to influence the outcome of dose reconstructions in non-claimant-favorable directions include the following:

Air concentration data were not critically evaluated. The available air concentration data are all short-term data. Many are general area air samples. Uncertainties in measurements are not discussed in the TBD. No direct, long-term breathing zone data are available. International Commission on Radiological Protection Publication 75 (ICRP 75), *General Principles for Radiation Protection of Workers*, recommends that datasets like the ones at Bethlehem Steel and Simonds used in the site profile should be evaluated and adjusted as necessary for application to individual worker doses. The site profile has not accomplished this effectively.

Statistical methods are not appropriate for the data available. SC&A's analysis shows that the use of the triangular distribution is not an appropriate statistical approach for the upper bound scenario, given the nature of the data. The use of the triangular distribution is complicated by the selection of statistically inappropriate values for the maximum parameters. Furthermore, the data used to generate the values have not been fully utilized or evaluated for uncertainty in the measured values.

Non-conservative assumptions regarding intake of radioactive material have been made. There was no indication of independent evaluation of worker dose due to involvement in high-risk jobs, incidents, or incident recovery. Assumptions such as the use of nasal versus oro-nasal breathing and use of the ICRP default values may lead to underestimation of inhalation dose. Further, the ingestion model does not properly represent the fraction of material ingested by the workers via large flakes and particles being deposited on food or ingested via hands.

External and internal dose from residual contamination is not appropriately considered in the site profile. Questionable and unrepresentative surveys were used to demonstrate the lack of residual contamination between and after rollings. In contrast, data from similar uranium processing facilities support the potential for exposure from residual radioactivity. Post-rolling resuspension was not taken into account.

Procedural nonconformances were identified. In development of a site profile, one of the objectives is to insure conformance with applicable regulations and internal procedures. The "worst-case" assumptions were not applied to dose reconstructions where compensation was denied. In another case, the more claimant-favorable methodologies outlined in *Technical Information Bulletin: Technical Basis for Estimating the Maximum Plausible Dose to Workers at Atomic Weapons Employer Facilities* (Anderson 2003), were not incorporated into the site profile.

CONCLUSIONS

The Bethlehem Steel site profile represents a reasonable approach to evaluating and estimating historic worker radiation dose at a late-1940s, early-1950s era uranium processing facility for which no or few dosimetry records exist. Clear strengths exist with respect to how inhalation dose is addressed, and how data from a similar operation at Simonds are applied to bridge the dearth of actual records at Bethlehem Steel. However, the site profile falls short in accomplishing its goal of assuring a claimant-favorable set of facility dose estimates, because it fails to adequately address inherent uncertainties in both the Bethlehem Steel and Simonds data, and it applies a statistical approach that is questionable given the actual data available for consideration. Assuming it can be appropriately corroborated, the input of former workers needs to be given particular attention as a source of historic operational reconstruction that can fill existing gaps in the standing record. As a “living document,” the Bethlehem Steel site profile can be improved as a fundamental basis for dose reconstruction analysis by consideration of the findings, observations, and issues presented in this review.

OVERVIEW OF OPPORTUNITIES FOR IMPROVEMENT

Apply the procedures and standards as discussed in this review, including use of ICRP 75 and appropriate portions of ORAUT-OTIB-0004. While 42 CFR 82 affords latitude in how NIOSH implements its requirements as reflected in its technical guidance documents on external and internal dosimetry, it is incumbent on NIOSH to adhere to recognized standards and established procedures, unless justification is provided in the site profile to support alternative approaches or procedures.

Assure that appropriate statistical methods are applied in analyzing air concentration data after adjustment according to ICRP 75. The triangular distribution is not the appropriate statistical treatment for the data used to construct the maximum exposure scenario in the TBD (Table 3). Further, the selection of the values for the maximum parameters is methodologically incorrect in both Tables 2 and 3.

Take oro-nasal breathing into account in inhalation doses. The dose conversion factors for light and heavy breathing should take account of the fact that many workers switch from nasal to oro-nasal breathing as the work becomes heavier. An upward adjustment to the percentage of heavy exercise and the consideration of oro-nasal breathing would ultimately increase the total uptake of uranium, and be more claimant favorable given the uncertainties involved.

Take into account ingestion of large particles via hands and via deposition on food, as well as ingestion during non-rolling periods. Attention needs to be given to several routes of additional ingestion exposure that would likely exceed that assumed by the site profile. These would include ingestion of large particles deposited on food via hands, and ingestion between rolling periods and after the rollings were completed.

Perform further document retrieval efforts to locate pertinent documents in relation to rollings during 1949 and 1950, and potential rollings post-1952. Although a records search was conducted at various locations, including the Fernald records center, the Environmental Measurements Laboratory, and various DOE record holdings, it is likely that pertinent records for the periods in question may exist at other locations, including Hanford, Savannah River, and other DOE sites.

Evaluate the potential impact of residual contamination between rollings and after completion of all rollings, and include this in both external and internal doses. Internal alpha radiation doses due to resuspension through the years 1949 to 1952 should take more careful account of continuous exposure from residual contamination. Internal doses from resuspension would also affect the period after the rollings were completed, although substantial attenuation would be expected over time given subsequent cleanup efforts. As discussed in this review, it may be possible to use available data to construct air concentration distributions between rollings, as well as to derive a decay parameter after rollings were complete.

Take into account site expert information and investigate worker accounts. With records and other documentation not available, it becomes particularly critical to interview former workers whose first-hand experience and association with Bethlehem Steel enable them to provide original perspectives and information concerning site practices and exposure history. While an initial meeting was conducted in July 2004, it is imperative that NIOSH fully review the information received on a timely basis and attempt to substantiate it for application in the site profile.

Create a list of high-risk jobs and incidents for consideration as a complement to the site profile to inform the individual dose reconstruction process.

Evaluate and update other Atomic Weapons Employer profiles as necessary in light of the findings, observations, and procedural nonconformances identified in this report.

ACRONYMS AND ABBREVIATIONS

Advisory Board	NIOSH Advisory Board on Radiation and Worker Health
AEC	Atomic Energy Commission
AWE	Atomic Weapon Employers
BLU	Best Linear Unbiased
DOE	Department of Energy
DPUI	Dose Per Unit Uptake
EEOICPA	Energy Employees Occupational Illness Compensation Program Act
FUSRAP	Formerly Utilized Sites Remedial Action Plan
ICRP	International Commission on Radiological Protection
IREP	Interactive RadioEpidemiologic Program
MAC	Maximum Allowable Concentration
MLE	Maximum Likelihood Estimate
NIOSH	National Institute for Occupational Safety and Health
OCAS	Office of Compensation Analysis and Support
ORAU	Oak Ridge Associated Universities
ORNL	Oak Ridge National Laboratory
PA	Posterior-Anterior
PFG	Photofluorography
PPE	Personnel Protective Equipment
SC&A	S. Cohen and Associates
Simonds	Simonds Saw and Steel
TBD	Technical Basis Document
UCL	Upper Confidence Limit

1.0 INTRODUCTION

This evaluation is directed at the ORAUT-TKBS-0001, *Technical Basis Document for Development of an Exposure Matrix for Bethlehem Steel Corporation* (Bloom 2004) and OCAS-TIB-009, *Estimation of Ingestion Intakes* (OCAS 2004) prepared by Oak Ridge Associate Universities (ORAU) and approved by the National Institute for Occupational Safety and Health (NIOSH). S. Cohen and Associates (SC&A), in direct support of the Advisory Board on Radiation and Worker Health (Advisory Board), has evaluated the approach taken in the site profile to gauge the adequacy, completeness, and validity of the information. The review is directed at "sampling" the site profile analysis and data for validation purposes. The review does not provide a rigorous quality control process, whereby actual analysis 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 influential in deriving dose reconstructions, bridging uncertainties, or correcting technical inaccuracies. This review does not explicitly address the issue of radiation exposures to cleanup workers and decommissioning workers beyond the rolling period. This review does address the issue of post-rolling exposures due to resuspension of uranium.

The site profiles serve as "site-specific guidance documents used in support of dose reconstructions." These site profiles provide the health physicists who conduct dose reconstructions on behalf of NIOSH with consistent general information and specifications to support their individual dose reconstructions. This report was prepared by SC&A to provide the Advisory Board with an evaluation of whether and how the site profile (also referred to as the technical basis document or TBD) can support dose reconstruction decisions. The criteria for evaluation include whether the TBD provides a basis for scientifically supportable dose reconstruction in a manner that is adequate, complete, efficient, and claimant favorable. Specifically, these criteria were viewed from the perspective of whether dose reconstructions based on the TBD would provide for robust compensation decisions.

The basic principle of dose reconstruction is to characterize the radiation environments to which workers were exposed, and determine the level of exposure the worker received in that environment through time. The hierarchy of data used for developing dose reconstruction methodologies is dosimeter readings and bioassay, coworker data and workplace monitoring data, and process description information or source term data. In the case of Bethlehem Steel, dosimeter and bioassay results were not available, while workplace monitoring data were present. This is further complicated by the illegibility of some of the available records. Air monitoring data was used to develop internal dose and submersion dose. Dose rate information from *Handbook of Safety Procedures for Processing Depleted Uranium* (U.S. Army 1989) and *Depth-dose Curves for ^{90}Sr and Natural and Depleted Uranium in Mylar* (Coleman et al. 1983) were used to derive external dose. In several areas, listed below, the TBD has done a commendable and successful job of addressing a series of technical challenges. In other areas, the TBD exhibits shortcomings that will influence some dose reconstructions in a substantial manner.

During a May 11-13, 2004, meeting with NIOSH and ORAU in Cincinnati, Ohio, SC&A was informed that the goal was to make the process of dose reconstruction scientifically robust from the point of view of the compensation decision. The approach of achieving the "best" estimate dose was not the goal, since that may, in many cases, take an enormous amount of resources without making a material difference to the compensation decision – that is, to deciding whether an organ dose was below or above the level where the probability of causation is 50%. Site profiles are considered "living documents" that are iterative in nature. The review takes these conditions into consideration.

A "minimum/maximum" approach for dose reconstruction has been adopted by NIOSH for the sake of dose reconstruction "efficiency." A minimum dose is estimated for those cases where a cancer appears likely to be compensable. If a minimum dose estimate is above the compensable limit, then the compensation decision and the corresponding dose estimate are regarded as robust, because any further refinement in the dose would lead to an even higher dose and increase the probability of causation even more above 50% than with the minimum dose estimate.

A maximum dose for those cancers that are likely to be non-compensable is also defined. If the largest possible dose that is scientifically reasonable and supportable results in a probability of causation that is less than 50%, then the denial decision and the dose on which it is based are regarded as robust. Since the dose is regarded as a maximum that cannot be adjusted upward in a technically defensible manner, the denial and the dose estimate on which it is based are regarded as robust.

The principal issues are divided into four categories: (1) ***findings***, which are significant issues likely to impact dose reconstructions and for which substantiating records, analysis or corroboration exist; (2) ***observations***, which are weaknesses or deficiencies in the TBD approach that deserve further investigation to determine the potential impact on dose reconstruction (these may also include inaccuracies in the TBD and findings that were not sufficiently substantiated by SC&A during its review); (3) ***procedural conformance issues***, which address discrepancies or inconsistencies in approach as they relate to requirements outlined in guidance documents, quality assurance program plans, and applicable procedures; and (4) program ***strengths***, which recognize those aspects of the TBD approach that are particularly insightful and technically sound.

2.0 ASSESSMENT CRITERIA AND METHOD

S. Cohen and Associates (SC&A) is charged with evaluating the approach set forth in the site profiles, which is used in the individual dose reconstruction process. These documents are reviewed for their completeness, technical accuracy, adequacy of data, and compliance with the stated objectives, as defined in *SC&A Standard Operating Procedure for Performing Site Profile Reviews*, approved by the Advisory Board on March 18, 2004. A fifth objective, "consistency among various site profiles," cannot be addressed until more reviews are completed. A review of ORAUT-TKBS-0001 and OCAS-TIB-009 is complete. This review is specific to the Bethlehem Steel site profile and supporting technical information bulletins; however, items identified in this report may be applied to other facilities. The review consisted of the following:

2.1 OBJECTIVE 1: COMPLETENESS OF DATA SOURCES

The available information referenced in the site profile was examined for applicability to operations at the Bethlehem Steel plant. A limited search for additional documents was completed based on the data made available by NIOSH to the SC&A team in August 2004. Data from facilities with similar operations to the Bethlehem Steel plant (i.e., Simonds Saw and Steel) were also reviewed.

2.2 OBJECTIVE 2: TECHNICAL ACCURACY

A critical assessment was made of how the sources of data identified in the site profile were used in developing technically defensible guidance or instruction. This included evaluating workplace-monitoring data (i.e., air sampling, survey); technical reports, including production reports, standards, and guidance documents; and literature related to uranium processing and handling.

2.3 OBJECTIVE 3: ADEQUACY OF DATA

Presentations and discussions with respect to site profile scope and dose reconstruction activities were held during a meeting with NIOSH and ORAU in Cincinnati, May 11 to 13, 2004. Furthermore, specific discussions were held with NIOSH regarding the Bethlehem Steel technical basis document (TBD). In this discussion, NIOSH was offered the opportunity to explain assumptions made and to clarify issues concerning application of the site profile. Attachment 1 summarizes the conference call between NIOSH and the SC&A team. Attachment 2 provides written questions sent to NIOSH during the course of the audit. Several site expert interviews were performed to obtain a more detailed understanding of the uranium rolling process. Written questions were provided to those site experts not readily accessible by phone. The SC&A team were also invited by NIOSH to attend a meeting with former Bethlehem Steel workers and their families during the July 1, 2004, workshop organized by NIOSH and ORAU in Hamburg, New York. A summary of site expert interviews, written responses, and information provided during the Hamburg meeting is provided in Attachment 3.

After compiling site expert interviews, documentation, and NIOSH input, issues raised were carefully evaluated. An assessment was conducted of the resultant data and guidance contained in the site profile to ascertain whether they are sufficiently detailed and complete for use in dose reconstruction. In addition, since there was limited data available for the Bethlehem Steel profile, the defensibility of the overall approach was also evaluated.

2.4 OBJECTIVE 4: CONSISTENCY AMONG SITE PROFILES

The Bethlehem Steel TBD review is the first to be issued. Limited comparisons between this and some other TBDs have been performed. As site profile reviews progress, further examination of common issues affecting more than one site will be noted and inconsistencies between TBDs will be documented by the audit team.

2.5 OBJECTIVE 5: REGULATORY COMPLIANCE

The Bethlehem Steel TBD was evaluated against the requirements outlined in the stated policy and directives contained in *Methods for Radiation Dose Reconstruction Under the Energy Employees Occupational Illness Compensation Program Act of 2000* (42 CFR 82), and the guidance and protocols defined in the OCAS-IG-001, *External Dose Reconstruction Implementation Guideline* (OCAS 2002a) and the OCAS-IG-002, *Internal Dose Reconstruction Implementation Guideline* (OCAS 2002b). It was also evaluated against the procedures set forth by NIOSH for estimating Atomic Weapons Employers (AWEs) doses in ORAUT-OTIB-0004, *Technical Information Bulletin: Technical Basis for Estimating the Maximum Plausible Dose to Workers at Atomic Weapons Employer Facilities* (Anderson 2003).

The Bethlehem Steel TBD was reviewed in relation to the following issues.

- Adequacy of air concentration data for individual dose estimation
- Internal dose assumptions, parameters, and conditions
- Statistical issues
- Uranium rolling history
- External exposure from contact with uranium
- Potential impact of exposure to residual contamination
- Medical x-ray doses
- Other considerations

Site expert input was used to assist the team in obtaining a comprehensive understanding of the uranium rolling process and the exposure conditions at the time to help identify areas where further investigation was needed, and to determine additional sources of data. Site experts provided additional documentation regarding Bethlehem Steel uranium rolling operations. The site expert summary (Attachment 3) was reviewed by the site experts themselves for accuracy of interpretation.

Information provided in the conference call by NIOSH was evaluated against the preliminary findings and observations to finalize the list of issues addressed in the audit report. This information also served to correct potential misinterpretations of the TBD by the audit team.

There are a number of findings and observations addressing the issue of how minimum and maximum doses are estimated for efficiency purposes. This is largely because the *inherent asymmetry between minimum dose and maximum dose calculations has not been adequately addressed* in the TBD. In the case of minimum doses, it is acceptable to leave out complex factors and take only a few data points that are consistent with minimum dose estimation. While there are many different ways to do this, it is possible to come up with parameters that could be generally accepted as minimal under the circumstances. Since no denials are based on the minimum calculations, the screening done by this approach can be made efficiently without compromising robustness of the compensation decision. As a result, compensation decisions can be relatively rapid and robust.

Estimating a maximum dose is a different matter. First, and most important, the dose must be a technically defensible maximum, since this estimate is used mainly to deny compensation, in the expectation that the result for probability of causation (PC) will be less than 50%. Since some values for the PC are in the 40% to 49% range, it is essential that the maximum dose estimate be both technically defensible in regard to completeness and adequacy of method and demonstrably claimant favorable. In other words, *all potentially significant factors need to be evaluated for the maximum dose*. This requires an exploration of many factors, some of which may turn out to be important, while others may not. Furthermore, there may be situations where even relatively minor factors may make a difference if the PC is at 48% or 49%. We have explored many issues in some detail in this Site Profile Review partly because of the concern that when compensation is denied at levels so close to 50%, the maximum dose estimate must be above reproach on the grounds of scientific soundness, as well as claimant favorability.

The Bethlehem Steel TBD does not meet the criteria for scientifically supportable and robust maximum dose estimates on several counts. The problems stem from a number of different sources, including an inadequate consideration of site expert testimony. The revised TBD was published 2 days prior to the worker meeting organized by NIOSH and ORAU in order to elicit technical information from workers. A considerable amount of information actually was developed at that meeting that could have been profitably used with the documentation that NIOSH and ORAU already have. Further, the revised TBD also inexplicably did not apply the more conservative approaches in ORAUT-OTIB-0004, even though they were clearly more claimant favorable than that set forth in the TBD.

There were three levels of review for this report. First, the report was reviewed internally by the SC&A team. Second, SC&A appointed Mike Thorne, who did not participate in the preparation of this document, as an internal reviewer to go over all aspects of this report. Third, SC&A gave NIOSH and ORAU an opportunity to comment on the final draft from the standpoint of factual accuracy. This is an important safeguard against missing key issues or misinterpreting some vital piece of information or calculation that NIOSH and ORAU may have done. Comments have been addressed and incorporated into this report as deemed appropriate by the SC&A team.

3.0 FINDINGS

There were a number of findings identified in the Bethlehem Steel site profile and the supporting technical information bulletin. In general, the findings related to the completeness of data sources, technical accuracy, and adequacy of data. As previously mentioned, comparisons between other site profiles were limited.

3.1 FINDING 1

In the absence of personnel monitoring data, workplace air monitoring data were the principal basis for dose estimates. The applicability of such data to individual workers, and the quality and reliability of the data were not addressed in the TBD.

The rate of airflow in the samplers and, in many cases, the total volume of air samples taken was relatively small for air samples at Bethlehem Steel. Overall, the data from Bethlehem Steel are too sparse to enable a defensible dose reconstruction. For instance, few data points are available for many locations and none for others. There are no data for most of the rollings. Bethlehem Steel data has been complemented with Simonds Saw and Steel (Simonds) data to create air concentration distributions. This is a reasonable approach, notwithstanding the important caveats cited below.

However, it is important that the Simonds data be used in a manner that is scientifically appropriate. The use of data from similar facilities may, under certain circumstances, enhance the quality of a dose reconstruction; in others it may detract from it. In this specific instance, there is no reason to rule out the use of Simonds data as unhelpful. Both Simonds and Bethlehem Steel were rolling uranium bars for the Atomic Energy Commission (AEC), using similar methods and equipment. However, a detailed comparability is desirable prior to use of such data. For instance, the comparability of workplace factors such as ventilation, the manner in which the uranium was treated, the physical arrangements of the rolling mill, and cleanup practices are important. The TBD does not discuss the issue of how comparability, beyond similarity in operational process and time period, was established.

Both Bethlehem Steel and Simonds rolled uranium at moderately hot temperatures. In both cases, water was sprayed on the uranium during the rolling to keep the uranium temperature from rising. However, ventilation was installed at Simonds before the referenced December 1, 1948, survey, but after the indicated October 27, 1948, visit. There was no ventilation at Bethlehem Steel. Therefore, the only clearly usable Simonds dataset is the one from October 27, 1948. However, Simonds appears to have had some exhaust ventilation even on October 27, 1948, as indicated by sample L716 (NYOO 1948).

Bethlehem Steel reportedly had 18 roller stands. At least six rollers were used for uranium rolling. Two or three roller stands were used at Simonds, and the uranium was brought around and re-fed into the first stand. Bethlehem Steel operations included both experimental and production runs. Uranium was heated in a salt bath designed to reduce scaling at later times, and at times may have had a different coating than that at Simonds.

Both Simonds and Bethlehem Steel data indicate that the roller stands were the most, or among the most, contaminated workstations. There are no Bethlehem Steel data for most rollings. While the Simonds re-feeding would tend to increase the dust at roller number 1, the larger number of roller stands at Bethlehem Steel indicate that it may have had a larger number of stations with higher breathing zone contamination. Bethlehem Steel may also have had higher air concentrations than Simonds during incidents such as cobbles, since the larger number of rollers may have led to a greater rate of cobbling. SC&A has not investigated this issue, since a detailed study of the Simonds facility is beyond the scope of this review.

In summary, there are some factors that would tend to make the use of Simonds data claimant favorable for Bethlehem Steel workers, but others that would tend to make it claimant-unfavorable. The broad comparability of process, as well as the same general period during which the rolling took place, generally indicates the use of Simonds data is an appropriate way to construct a claimant-favorable distribution for Bethlehem Steel for rolling days, provided appropriate technical and statistical cautions are observed.

The TBD does not discuss the reliability of air sampling data used to determine the air concentration values. Total air sampling error includes error produced during collection and analysis of the air sample. One source of error for air samples from a dusty environment is self-absorption due to burial of the alpha particle in the filter. This may have been mitigated somewhat by the relatively short periods of sampling ranging from 4-45 minutes for the air sampling results from the January 26, 1952, rolling (Quigley and Heatherton 1952). Low air sampling velocity (0.02 m^3/min) and short collection periods resulted in low volume air samples. For instance, a 10-minute sample would take in 0.2 m^3 (typical for many samples), meaning that for each Maximum Allowable Concentration (MAC) of 70 disintegrations per minute per m^3, the deposition of alpha emitters on the filter would be only about 14 dpm (0.23 Bq).

There is also some error associated with assuming that general area air samples are indicative of the airborne concentration the workers inhaled. In this respect, the TBD has not taken ICRP 75, *General Principles for Radiation Protection of Workers*, recommendations into account. This issue is discussed under Section 5.1, Procedure Conformance Issue No. 1. This issue should be kept in mind when reading Findings 2 and 3 below. These findings take the air concentration data at face value and are intended, therefore, as a methodological evaluation of the Bethlehem Steel TBD. A reconstruction of the air concentration would also have to take into account the relevant aspects of ICRP 75 discussed in Section 5 of this report.

3.2 FINDING 2

The triangular distribution in Table 3 is not a statistically sound representation of the October 27, 1948, Simonds dataset. The upper bound of Table 3 is not claimant favorable.

The TBD uses a triangular distribution to represent the distribution of possible air concentration values and external exposure potential. The same distribution is also used to represent ingestion and external air submersion doses. The central purpose of analyzing air concentration data is to enable the calculation of individual radiation doses in a manner that is scientifically defensible and claimant favorable. This means that the doses for *individual workers with specific job* *assignments* need to be estimated. These assignments would, in general, tend to be in the vicinity of assigned job locations, which generally would not correspond to a random sampling of the facility air over the course of a typical workday. Examining data taken throughout the facility is part of this process. In the present instance, there are few data for individual workstations. There are no true breathing zone data in the sense of data taken from personal air samplers. This situation makes it necessary to examine the entire facility as well as individual workstation data to make inference about claimant favorable and scientifically defensible dose reconstructions for individuals.

Data from the whole facility represented in a distribution that gives a *facility* air concentration profile is part of this process. A particular frequency for air concentration in the profile itself represents the probability that a person would encounter that air concentration if the various locations were visited at random. But this is not how individuals typically experience the workplace. As a result, in the absence of detailed and adequate individual workstation data, there are two basic questions that statistical analysis must address. First, how well does the chosen distribution represent the facility air concentration data? Second, how is this distribution used in conjunction with data from specific workstations to estimate doses to individual workers in a way that is both scientifically defensible and claimant favorable? These are the central issues addressed in Findings 2 and 3 below and in Attachment 4.

The TBD has two tables showing air concentrations. They are Tables 2 and 3 of the TBD. NIOSH describes these tables as follows:

> *Tables 2 and 3 list the internal exposure matrix for the Bethlehem Steel site. Table 2 is a lower bound for estimating internal exposure and Table 3 is an upper bound.* (TBD, pg. 5)

This statement implies that the two tables represent the minimum expected facility air concentrations (Table 2) and the maximum expected facility air concentrations (Table 3). However, these same distributions are used to calculate internal doses experienced by individuals, and therefore appear to be treated as minimum and maximum individual exposure matrices since these distributions are used in individual dose reconstructions. Table 2 is not used to deny compensation, but to compensate claimants without further investigation. Table 3 appears to be used to both compensate and to deny compensation, depending on whether the probability of causation is greater than or less than 50%.

There are two related statistical issues regarding how the available air concentration data have been used in the TBD (assuming all data can be taken at face value). These relate to the choice of the probability distribution used to fit the data, and the choice of parameters. These general issues relate to both Tables 2 and 3. The primary focus of Table 3 in this set of findings derives from the fact that Table 3 is used to estimate maximum doses. Since this estimate is used to deny compensation, it is crucial to consider all relevant factors. Some comments on Table 2 are made in the subsequent finding. It is important to stress here that the statistical analysis takes the air concentration data at face value without adjustments recommended by ICRP 75. These adjustments would need to be considered for a reconstruction of an air concentration distribution that is technically sound in terms of the ICRP 75 recommendations, and statistically sound in terms of representing the available data by an appropriate distribution and parameters of that distribution. The questions of the nature and validity of air concentration data are discussed briefly in Section 5 and in Attachment 4.

The issues of the type of distribution and the choice of parameters are related. First the choice of distribution is considered followed by the issue of parameter values used in Table 3.

Figure A4-1 in Attachment 4 shows a Q-Q plot for the October 27, 1948, Simonds air concentration data for a fitted triangular distribution. This plot indicates that a triangular distribution is a poor choice of distribution for estimating an air concentration profile from the October 27, 1948, air concentration data. Figure A4-2 shows a Q-Q plot for the triangular distribution used in Table 3 of the TBD, assuming it represents Simonds October 27, 1948, data and indicates the same conclusion.[1] Even if the approach of using a mode of 2xMAC that the TBD states were based on Bethlehem Steel data, it does not change the essential result. Both figures also indicate that the triangular distribution is not demonstrably claimant favorable at the highest values of air concentration. Finally, the choice of parameters in Table 3 of the TBD is not in accordance with the basic principles of constructing a triangular representation of a set of data. Specifically, the upper bound of the distribution in Table 3 is less than the maximum measurement of about 1,070xMAC. The mode should be derived by a more explicit analysis that relates to the dataset being analyzed. However, it should be noted that this methodological issue does not have a significant impact in the present instance, since the choice of mode is unlikely to affect the overall computations significantly in this case.

Two approaches can be considered to address the issue of how the data regarding the most contaminated workstation can be analyzed. In the first approach, the points from the most contaminated workstation (of those measured on October 27, 1948, at Simonds) can be treated as coming from a distinct distribution, since the two highest readings are from Roller #1 (i.e., samples L709 and L710) and the third reading (L711) from that workstation is within the top five values. This allows us to estimate an upper bound for the air concentration at Simonds on that date. Unfortunately, there are only three measurements for the Roller #1 workstation, and an assumption must be made for a distribution to represent them. There is no a priori defensible way with which to fit these three points to a distribution. Various ways in which an upper bound can be derived yield varying estimates. For instance, the 95% confidence upper bound estimate, assuming a uniform distribution, is 1,785xMAC. A loguniform distribution for the same data yields an estimate of 3,375xMAC. One can also choose an unbounded distribution to represent three data points. These results are discussed in Part 3 of Attachment 4 (see Table A4-2). The basic statistical problem with this approach for estimating an upper bound for the air concentration at Roller #1 is that there are only three data points. The most comparable estimates to the upper bound of Table 3 would be the ones derived from the bounded distributions. They range from about 1,450xMAC to almost 3,400xMAC (rounded). Methodological details of these results are discussed in Attachment 4.

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[1] SC&A notes that Table 3 does not purport to represent the October 27, 1948 dataset. A sound methodology requires that it should. Hence, SC&A analyzed the distribution in Table 3 to examine whether it was a good fit of the data it should represent.

A second approach is to construct a distribution for the rolling operation as a whole on the date in question, and then adjust for the fact that some workers are at a greater risk because of their work locations. Figure A4-3 in Attachment 4 shows that a lognormal distribution to represent the October 27, 1948, data is a much better fit than a triangular distribution. The inappropriateness of a triangular distribution to represent this dataset is further discussed in Attachment 4.

However, the lognormal representation of the many workstations at the lower end of the air concentration range is not claimant favorable. This issue can be addressed by using the 95th percentile of this distribution as the basis for estimating the uranium intake. This value is about 570xMAC. However, this value is not claimant favorable for the most contaminated workstation, which is likely to be Roller #1, where the average of the three measured values is 700xMAC.

The procedure can be made claimant favorable for workers whom we know were at the more contaminated workstations and for those for whom there is no workstation information by using the 95th percentile value of the tail of the facility lognormal distribution. A suitable way to do this would be to assume that further measurements at the most contaminated workstation are bounded below by the lowest of the three air concentration measurements at that station. This value is given by the data point L711 and is 320xMAC. The 95th percentile estimate of the tail of the distribution can then be made. This is 4,350xMAC. This value would be exceeded in the most contaminated area at most 5% of the time. This point lies at about 99.3 percentile of the facility lognormal distribution. Effectively, we are using only the tail of the facility distribution to make the procedure claimant favorable for workers at high risk or for those with no workstation data.

As noted above, these values of 570xMAC and 4,350xMAC are not recommended values but methodological illustrations. Specifically, they do not take ICRP 75 recommendations into account. Attachment 4 covers statistical issues related to the October 27, 1948, dataset and Table 3 of the TBD in more detail. Some discussion of ICRP 75 is provided later in this report.

3.3 FINDING 3

The selection of the maximum value in the Lower Bound Internal Exposure Matrix (Table 2) is not technically sound.

SC&A has not performed a statistical analysis of the Bethlehem Steel data along the lines suggested above to examine whether the choice of a triangular distribution to represent the data is appropriate. Since the methodology is discussed extensively for Table 3, SC&A has not attempted to repeat the analysis for Table 2. These comments are limited to the choice of the maximum for the triangular distribution chosen for Table 2 of the TBD, which most affects the dose computations.

The available Bethlehem Steel air monitoring data has not been fully utilized to construct Table 2 of the TBD. The rationale for choice of parameters in Table 2 of the TBD is as follows:

> *For 1949 through 1952, the most likely value, or mode, was assumed to be 140 dpm/m^3, which corresponds to 2 MAC. The minimum value was assumed to be 0 dpm/m^3, which considers the possibility that there was no exposure. The maximum value for the lower bound matrix was assumed to be 4,900 dpm/m^3 (70 MAC), which is the maximum reading found in Bethlehem Steel air monitoring data (AEC 1951-1952).*

The TBD states that a value of 4,900 dpm/m^3 is the maximum value of air concentration found in Bethlehem Steel air monitoring data. SC&A found three readings above this value: 6,800, about 13,000, and 29,766 dpm/m^3 (Heatherton 1951, Miller 1951a and 1951b). The last two quoted values are not very legible and represent SC&A's best reading of the datasheets. There are other air sampling results that are only partially legible or not legible at all.

Table 2 of the TBD is not claimant favorable because the highest data points have been omitted. The maximum value in Table 2 should reflect the highest values of Bethlehem Steel air concentration measurements. Moreover, the upper bound of the triangular distribution cannot be less than the largest measurement. In general, the true upper bound will be greater than the largest measurement of the dataset, especially if the number of measurements is limited. A statistical analysis of the data is needed to determine the parameters. However, such analysis for the Bethlehem Steel dataset may be rendered very difficult because (1) there are no data for most rollings, (2) much of the data is illegible, and (3) measurements may not have been made for all relevant workstations. In addition, the ICRP 75 considerations discussed in this report would need to be taken into account.

It may be sufficient to use the simple approach chosen in Table 2 for the sake of efficiency, since workers are not denied compensation based on Table 2 estimates. However, even if a simple approach is used, it is still essential that it be scientifically and statistically defensible. For instance, the theoretical restraints for determining the upper and lower bound of the triangular distribution should be observed. That means that, in the case of Table 2, the upper bound parameter of the triangular distribution should not be less than the largest measurement of about 425xMAC. In contrast, the upper bound parameter in Table 2 of the TBD is 70xMAC. At the very least, the algorithm used for fitting the triangular distribution should be specified. Further, it does not seem more complex to use the approaches described in Attachment 4 than to fit a triangular distribution for the Bethlehem Steel data in a claimant-favorable way for use for minimum dose estimations that are the objective of Table 2.

3.4 FINDING 4

The assumption of nasal rather than oro-nasal breathing is not claimant favorable and defensible given the conditions of steel mill work.

With respect to the breathing rate applied for internal dose calculations, page 6 of 13 of the TBD states:

> *The breathing rate was calculated from the volume of air breathed for an adult light worker shown in International Commission on Radiological Protection*

(ICRP) Publication 66 (ICRP 1994, Table 6, p. 23). This category assumes an activity distribution of one-third sitting and two-thirds light exercise. The minimum and mode intakes, in pCi, were calculated by multiplying the appropriate air concentration by the breathing rate and the hours worked, and dividing by 2.2 dpm/pCi. Maximum intakes calculations used the same method but substituted the breathing rate for an adult heavy worker, which assumes an activity distribution of seven-eighths light exercise and one-eighth heavy exercise.

The ICRP default of 1.7 m^3 per hour air breathing rate was used for the maximum dose distribution (Table 3). This consisted of an activity distribution of seven-eighths light exercise and one-eighth heavy exercise for the upper bound matrix. This consisted of the workers being involved in heavy work only 12.5% of the time. At the time of the rollings, the Bethlehem Steel mill had no ventilation in the rolling facility. The work environment was hot due to the use of furnaces in the work area. Steel mill work during the applicable period of time involved heavy labor without the benefit of current-day computer automation. The dose conversion factor for light and heavy breathing should take into account the fact that many workers switch from nasal to oro-nasal breathing as the work becomes heavier.

In addition, due to the atmospheric conditions in the steel mill and the level of work, it is likely that workers were oro-nasal breathing rather than nasal breathing. There is large variability in normal respiratory parameter values between individuals, and for any individual there can also be large variations according to the activity undertaken. These can affect the dose per unit intake (DPUI) through their effect on regional deposition, but can also affect the intake (and hence dose) per unit exposure through change in the ventilation rate.

To illustrate this, values of the fraction of air passing through the nose for a mouth breather are given in Table 1 below. The term “nasal augmenter” refers to a normal nose breather.

Table 1: Fraction of Total Ventilatory Airflow Passing Through the Nose F_n (Reproduced from Table 3.1, ICRP Supporting Guidance 3) (ICRP 2002)

	F_n	
Level of Exertion (exercise)	**Nasal Augmenter**	**Mouth Breather**
Sleep	1.0	0.7
Rest (sitting)	1.0	0.7
Light Exercise	1.0	0.4
Heavy Exercise	0.5	0.3

According to ICRP guidance on the application of the respiratory tract model (Supporting Guidance 3, ICRP 2002, pp. 35-36):

(65) Generally, for both subjects, total and regional deposition does not vary markedly between the different levels of exercise. The main effect is that deposition in the bronchial (BB) region increases with increasing exercise. This is most noticeable for the nose breather during heavy exercise because of the

switch to oro-nasal breathing. Since deposition in the mouth is lower than in the nose, there is greater penetration to, and hence deposition in, the BB region. Similarly, regional deposition does not vary markedly with age. There is a clear systematic difference between nose and mouth breathers, the latter having lower extrathoracic deposition and correspondingly higher deposition in the thoracic (lung) regions. The difference is particularly great for 5 µm AMAD aerosols inhaled during light exercise, for which deposition in each of the thoracic regions BB, bb and AI is several times higher for mouth breathers than for nose breathers. Thus DPUI are unlikely to be very sensitive to differences in respiratory parameters, unless mouth breathing is involved.

(66) The ventilation rate, which determines the intake for exposure to a given air concentration, however, varies considerably according to the level of exercise. As an example, for an adult male, reference values for sleep, sitting, light, and heavy exercise are: 0.45, 0.54, 1.5 and 3.0 $m^3\ h^{-1}$*, respectively…*

The ICRP guidance then discusses the effect of exertion level for Type M ^{234}U specifically as an illustration (ICRP 2002, p. 36):

The dose per unit intake does not change much, less than a factor of two in most cases. Generally doses are somewhat (10–50%) higher for mouth breathers than for the default nose breathers. However, for a 5 µm AMAD aerosol at light exercise, the dose is about three times higher for mouth breathers. The dose per unit exposure varies more, because the volume of air inhaled increases with increasing exercise.

An upward adjustment to the percentage of heavy exercise and the consideration of oro-nasal breathing would ultimately increase the total uptake of uranium. The default assumptions made with respect to breathing are not claimant favorable and should be reevaluated based on the working conditions in a steel mill (ICRP 66) and the associated guidance document (ICRP 2002).

3.5 FINDING 5

The ingestion dose estimates in Table 4 of the TBD represent only a fraction of potential dose from ingestion of radioactive material.

The source of uranium dust was continuous in the mill during operation. Dust was made airborne by the milling and finishing process. It also dropped from the crane area either during movement of material or as a result of residual contamination. Bethlehem Steel did not have lunchrooms. Lunch and coffee breaks were taken adjacent to the operations. Workers used furnaces to heat their food. Water was supplied to the workers in the production area (Dimitroff 2004). This situation created a significant potential for ingestion of radioactive material by consumption of contaminated food and beverages, as well as swallowing dust.

The TBD considered ingestion via the settling of dust onto food and coffee. The deposition velocity used appears to correspond to 1-micron particles. This is one component of the ingestion dose. However, it is unlikely to be the main contributor to the ingestion dose. Table 4 estimates do not account for several routes of likely significant ingestion exposure, including ingestion of large particles deposited on food via hands, and ingestion between rolling periods and after the rollings were completed.

The rolling process at Bethlehem Steel produced particles highly variable in size. For instance, there were spallation flakes that developed when the material was rolled. Large particles on the floor also likely became briefly airborne during cleanup operations, such as hosing down floors. This would provide another mechanism for large-particle surface contamination. The assumption in OCAS-TIB-009 that the "primary" source of ingestion via the hands is from fine particles settling on surfaces from the air (p. 2) is questionable because this misses the large particle pathway, which is likely to be more significant under the circumstances of Bethlehem Steel.

These factors indicate that it is likely that surface dust directly deposited on food or ingested via hands becoming contaminated due to contact with contaminated surfaces consisted mainly of particles of relatively large size. The presence of large particles also raises questions about the assumption of equilibrium between deposition and removal assumed in OCAS-TIB-009, which is the basis for the Bethlehem Steel ingestion dose calculation. Finally, the assumption in OCAS-TIB-009 that food is covered all the time and therefore direct deposition on food need not be considered is not justified in view of the potential for large particle deposition.

In view of the foregoing, the results in Table 4 are likely to be considerably underestimated; they are not claimant favorable. Further, Table 4 estimates are about 50 times less than the estimates in the procedure specified by NIOSH for dose calculations for AWEs working with uranium metal.

Using the average of the distribution in Table 4, the total ingestion derived over 4 years of rolling calculated for rolling days amounts to only 7.0×10^5 pCi, which equals about 1 gram. This appears to be a considerable underestimate. For instance, in considering construction workers (not directly comparable but broadly similar due to the dusty environment at Bethlehem Steel), NCRP 129, *Recommended Screening Limits for Contaminated Surface Soil and Review of Factors Relevant to Site-Specific Studies,* Table 5.19, recommends a soil ingestion rate of 100 mg per day by adults. This can be used as a point of reference for ingestion of workplace dust. The data in NCRP 129 indicate that inadvertent consumption of more than 100 mg of dust per day can occur without, for example, rendering food unpalatable (NCRP 1999).

Not all the dust ingested via hands and deposition of large particles on food will be pure uranium, of course, but a large fraction can be expected to be uranium on rolling days. The NCRP 129 assumption of 100 mg per day can provide a reasonable upper bound for this part of the ingestion dose on rolling days. For 48 rolling days, the result would be 4.8 grams of uranium (NCRP 1999). Finally, ingestion of uranium particles also likely occurred on non-rolling days, since surfaces were not free of uranium once it was deposited. An argument can be made that ingestion doses via hands may have been as large or larger on the days immediately following rollings due to suspension and re-deposition of large particles on work surfaces during hosing operations.

Taken together, these factors are likely to have an upward effect on estimates of ingestion doses compared to the estimates in Table 4 of the TBD. The significance of these corrections would have to be evaluated by NIOSH and ORAU.

3.6 FINDING 6

The use of ICRP default particle deposition parameters is not claimant favorable for all organs.

The following statement is made with respect to uranium mill health issues in *Rolling Mill Report Hanford Works* (General Electric 1950).

> *The oxide, as it breaks loose from the rod surface, has a wide range of particle size all the way from flakes approximately ½" in diameter to particles so fine that they will remain airborne in still air for several hours.*

To the extent that fine metal uranium particles are not oxidized before they are breathed, with an AMAD smaller than 5 micron, a higher dose to systemic organs can be projected. Using the ICRP CD-ROM, *Database of Dose Coefficients: Workers and Members of the Public* (ICRP 1998) the following results were obtained:

- For Type F ^{234}U – The 50-year committed doses for the adrenals (used as an example of a nonmetabolic organ) for 0.01 µm particles are 2.8 times higher than for 1 µm particles and 2.3 times higher than for 5 µm particles. The 50-year committed doses for the adrenals for 0.1 µm particles are 1.6 times higher than for 1 µm particles and 1.3 times higher than for 5 µm particles. Similar results are obtained for bone surfaces.

- For Type M ^{234}U – The 50-year committed doses for the adrenals (used as an example of a nonmetabolic organ) for 0.01 µm particles are 2.7 times higher than for 1 µm particles and 3.7 times higher than for 5 µm particles. The 50-year committed doses for the adrenals for 0.1 µm particles are 2.2 times higher than for 1 µm particles and 3.1 times higher than for 5 µm particles. Similar results are obtained for bone surfaces.

- For Type S ^{234}U – The 50-year committed doses for the lungs for 0.01 µm particles are 5.8 times higher than for 1 µm particles and 10 times higher than for 5 µm particles. The 50-year committed doses for the lungs for 0.1 µm particles are 2.8 times higher than for 1 µm particles and 4.9 times higher than for 5 µm particles.

Thus, neither a 5-micron nor a 1-micron particle size assumption is claimant favorable by itself under all applicable circumstances. Particle size and solubility considerations should be examined for claimant-favorability with regard to the specific organ for which the dose is being estimated.

3.7 FINDING 7

The rationale for exclusion of external and internal dose from exposure to residual contamination is questionable.

Rolling operations generate airborne radioactivity as demonstrated by the positive air samples taken at both Bethlehem Steel and Simonds. Following the rolling operations, the dust in the air would "fall out." Given that uranium dust particles were created in the rolling and finishing operations, there is a potential for internal contamination in the equipment given that there apparently had not been any attempt at the time to dismantle the equipment and clean the inside. Equipment contamination is further indicated by analysis of grease samples, such as the one completed from the April 26-27, 1952, rolling (Heatherton 1952a). Simonds data, which are more plentiful, indicate that residual contamination was a concern between rollings (NYOO 1949).

The TBD does not include assignment of dose from potential exposure to residual contamination between and after the cessation of uranium rolling activities. On page 3 of 13, the TBD states:

> *Because of material accountability procedures, scale, residue and cropped ends were collected and fine debris was vacuumed, packaged, and returned to the AEC (LaMastra 1976; Range 1976; ORNL 1980*[a]*; DOE 1985). Radiological surveys in 1976 and 1980 of the original facility and equipment, which were still in existence, identified no residual contamination above natural background levels (LaMastra 1976; ORNL 1980*[a]*; DOE 1985).*

Based on the 1976 and 1980 Formerly Utilized Sites Remedial Action Program (FUSRAP) surveys, the TBD indicates that residual contamination was not a source of exposure. The 1976 and 1980 surveys are not relevant to the situation prevailing during the period when the rollings took place. The purpose of these surveys was to evaluate Bethlehem Steel for inclusion in the FUSRAP. *The Survey of Rolling Mill Used by Bethlehem Steel Corporation, Lackawanna, New York* issued in September 1980 by the Health and Safety Research Division (ORNL 1980b) states the following:

> *The following conditions were present at the site of the bar mill at the time of the present survey: (1) the original bar mill used at the time of Atomic Energy Commission (AEC) activities was stored as scrap and was removed for recycling within the last six months; (2) the floor and pit where the bar mill was located during operations was covered by a new concrete floor varying in thickness up to a maximum of approximately 1 m; (3) the stand and shoe plates associated with the bar mill were removed and scrapped. The only remaining equipment at the Lackawanna Plant used during AEC activities is a shear used for cropping the 3.8-cm uranium rods. However, the shear was not located in its original location at the time of AEC-related operations.*

Maintenance and repair were performed on the equipment in the rolling mill over the period of operations, which means that original parts may not have existed in 1976 and 1980 when the surveys were performed. Performing surveys decades after the actual operations on equipment that may or may not have been used at the time of operations is not representative of the radiological contamination conditions during or immediately after operations. Area and personnel contamination surveys of the time would be more representative of the level of residual contamination. It is also relevant to note that the NIOSH Technical Information Bulletin ORAUT-OTIB-0004 utilizes a more claimant-favorable approach for addressing residual contamination. The decay constant for residual radioactivity persistence in the workplace assumed in that report is 0.01 per day. This means that residual contamination would be about 2.6% after 1 year and less than 0.1% after 2 years. After two decades, no detectable contamination would be expected even if the original contamination was very high. We have not evaluated the validity of the decay constant as yet, but note here that the TBD is not consistent with other parts of NIOSH technical work.

Limited survey data relating to surface contamination on and around the equipment before and after the cleaning following the September 1952 rolling are available (Heatherton 1952b). There are a number of limitations with respect to the September 1952 survey data:

- The smear samples relate to only one rolling.
- There are a limited number of survey samples available to demonstrate lack of contamination.
- Direct survey readings have not been provided.
- The exact location of the smears is unknown. For instance, the location of the floor samples is unknown. As another example, the roller stand samples do not identify whether the smear was taken on the roller or at a location near it that would be more representative of dust deposition on the clothing of workers.
- The units of measure for the smears are listed in dpm/m^3 rather than activity per unit area. Details of the smear analysis (i.e., counting instrument and smear area) are not available, so recalculation is not possible to correct the problem.
- The air concentration data during this rolling were lower than concentrations from previous rollings, ultimately affecting the level of contamination.

The values identified in the “after cleaning” survey were higher than those of the “before cleaning” survey. But the nature of the “cleaning” – that is what was being cleaned – is unspecified on the sample sheets. The TBD contains no discussion or analysis of the sample sheets or even a reference to them. The sample values may have indicated less than the radiological control limits of the time, but these radiological control limits have not been defined. In light of the wrong units and lack of details that would enable recalculation of the contamination per unit area, the uncertainties related to sample locations, and the absence of direct survey measurements, reliance on the September 1952 survey to rule out exposure to residual contamination is not scientifically appropriate or claimant favorable. In addition to these problems, there is also an absence of contamination survey values related to personnel and personal effects that would indicate potential exposure to individuals.

Data from Simonds Saw and Steel indicate serious residual contamination. For instance, the *Simonds Saw and Steel, Summary of the Three Surveys, October 27, 1948 to February 15, 1949* (AEC 1949b) states (emphasis added):

> *Readings were taken of the working area on October 27th and December 1st, during the period of rolling. The results of these readings show a considerable quantity of alpha radiation when the meter was held in direct contact with the floor. The readings on the floor in general vary between 10,000 and 40,000 alpha disintegrations per minute on both of these days. Readings taken on the benches and desks in the area at the same time showed a concentration of 2500-3000 alpha d/m.* ***On February 15, during an interim period between two rolling cycles****, a similar set of readings was taken. No uranium was being handled at this time. The readings at this time varied between 3,000 and 35,000 d/m,* ***somewhat lower than the previous results but still showing a considerable degree of contamination****. The results of these studies are shown in Table II. Beta and gamma readings that were taken coincident with the alpha measurements show a maximum of 15 mr/hr in direct contact with the floor. However, most of the readings are 2 mr/hr or less. It was found that the highest radiation measurements both in alpha and beta-gamma were found when the instrument was in direct contact with the dirt floor, which exists in many operating areas. The steel floor on which the rolling is carried out showed a much lower radiation figure* (NYOO 1949).

The referenced Table II of the 1949 Atomic Energy Commission (AEC) report, referring to Simonds data, is reproduced below for convenience.

Table 2: Radiation Measurements in the Mill Area (Reproduction of Table II, AEC 1949b)

	During Rolling (10/27/48)		During Rolling (12/1/48)		After Rolling (2/15/49)
	α *	βγ **	α	βγ	α
East Roller 1	50,000	10.0	12,000	1.0	12,000
East Center Line	25,000	2.0	16,000	1.0	18,000
East Bench	5,000	0.5	10,000	0.5	3,000
Desk	2,500	---	2,500	---	2,500
West Roller 2	15,000	0.5	11,000	---	8,000
West After Vacuum	5,000	0.5	11,000	---	---
West Roller 1	35,000	2.0	35,000	---	3,000
West Center Line	18,000	2.0	7,500	---	5,000
Furnace Area	50,000	12.0	80,000	15.0	10,000
Shear	30,000	10.0	25,000	1.5	6,000
West Bench	3,000	0.5	3,000	---	2,500
Shipping & Receiving	40,000	---	30,000	4.5	---

* Values are in units of dpm/100 cm^2.

** Values are in units of mrep/hr.

These data from Simonds indicate that residual contamination on the ground a month-and-a-half after a rolling was only moderately diminished. The conclusion in the TBD that no significant residual contamination was present at Bethlehem Steel is questionable and deserves further consideration.

Klevin (1950), in reference to Simonds Saw and Steel, states:

> *Without major process modifications, it will probably not be possible to reduce airborne uranium during operations significantly below 150 micrograms/cubic meter (3x MPL).*

Klevin (1950) further states the following in regard to airborne concentration levels after cleanup.

> *An airborne concentration of approximately 15 micrograms/ cubic meter (0.3xMPL) is the level below which it will be extremely difficult to clean the present plant between operations.*

These data indicate that workers outside regular uranium rolling periods experienced external beta-gamma radiation, as well as internal alpha radiation exposure. There is no comparable dataset from Bethlehem Steel. In light of this evidence from Simonds regarding residual contamination, the use of limited and questionable smear sample data or data taken decades after the end of rolling at Bethlehem Steel cannot be considered claimant favorable unless there are more and better smear data that are subjected to a rigorous analysis. In the absence of such data, which do not appear to be available, using data from Simonds in a claimant-favorable manner for making estimates regarding internal and external exposure during the periods between rollings and for a finite period after rollings ceased would be scientifically reasonable.

Internal alpha radiation doses due to resuspension throughout the years 1949 to 1952 should take into account continuous exposure from residual contamination. Although dust levels due to resuspension are expected to be lower than the higher readings that occurred during the rollings, the time-integrated exposures between rollings may be higher given the longer time of exposure. A claimant-favorable assumption about the exposure time due to resuspension would be the entire working year.

Internal doses from resuspension would also affect the period after the rollings were completed. Hosing down and other methods of partial cleanup would result in some attenuation of ground contamination after 1952. The rate of attenuation will be difficult to determine because the steel dust would be deposited on top of the uranium dust. Worker testimony and an examination of the literature regarding steel plant operation and maintenance of the time should be essential components in any attempt to estimate the attenuation rate. The unsettled question of the rollings that may have occurred in 1955 and/or 1956 will complicate this study.

In summary, there is a potential for both internal and external doses from resuspension of residual contamination. The rationale for excluding doses from residual contamination is questionable. Dose reconstructions cannot be regarded as claimant favorable if residual contamination is not addressed more fully with representative data and analysis.

3.8 FINDING 8

The external dose (beta and gamma) due to various modes of contact with uranium, including handling, inspections, finishing of the material, and heavy dust loading on clothing and skin, has not been evaluated in the TBD.

The TBD discusses assignment of surface dose from beta emission, deep dose from photon emission, and external dose from submersion in uranium dust. Uranium and its daughters have a wide distribution of beta and gamma emissions. The radionuclide of highest dose consequence is ^{234m}Pa, which emits a 2.29 MeV beta (maximum energy) at a high yield. The contact beta dose rate for natural uranium is 230 mrad/hour per the TBD. The *Guide to Good Practices for Occupational Radiation Protection at Uranium Facilities*, Figure 6-3, (DOE 2000) states that the contact gamma dose rate is less than 10 mrem/hour. Although gamma radiation is not the primary external exposure hazard, the gamma dose rate can become significant in areas where large quantities of uranium are stored. In addition, the brehmstrahlung contribution from ^{234m}Pa can contribute a significant portion of the gamma dose. The D(0.07) dose rate from a slab of natural uranium metal at 1 cm is 1.99 mSv/hour (199 mrem/hour) with no shielding (DOE 2000).

The use of an upper bound distribution to calculate external doses due to immersion in contaminated air is appropriate. However, the upper bound distribution in Table 3, as discussed in detail below, does not represent a maximum distribution that fully reflects available data and sound statistical analysis. Since Table 3 of the TBD does not reflect an upper bound distribution, the values in Table 5 of the TBD are correspondingly lower than they should be.

Moreover, the doses from immersion in uranium dust do not account for the doses from the deposition of uranium on the exposed parts of the body and on clothing or on the skin when dust got under clothing. Workers have indicated that they did not secure their clothing to their person; therefore, it is expected that dust would deposit inside their gloves, if worn, and clothing. Dust would also settle in their hair and on their faces. Workers reused clothing, as they were required to provide their own clothing from home. Some individuals would wash their clothes a few times per week, but others would wear them until they wore out and discarded them. In some circumstances, gloves were not available or not worn due to the nature of the work. In a dusty atmosphere such as a steel mill, dust would settle on worker clothing and on uncovered parts of the body, such as faces and hands. This is indicated by the film badge study done at the Simonds facility (NYOO 1949). This route of exposure would likely exceed the immersion doses calculated in Table 5 of the TBD, notably for the skin and organs close to the skin surface, such as gonads.

An experiment at Simonds was completed using film badges to ascertain the external radiation dose rate due to deposition of resuspended particles on clothing. Twenty badges were positioned at a height of 5 feet and exposed for 192 hours. The experiment was described as follows:

> *In order to determine the long-term direct radiation to individuals, 20 film badges were suspended at about a five foot level from the floor and left in the area for a period of about 192 successive hours. When recovered, these badges were found to be coated with a considerable film of dust. Although this was blown off before*

> *transshipment to the laboratory, it is undoubtedly true that a great deal of the reading found on the badges was a result of dust contact. The maximum radiation level found on any of these films was 5.6 mr/hr of beta or 0.34 mr/hr of gamma. In view of the intense local radiation that would be caused by a film of dust, it is felt that the hazard from the direct radiation in this operation is insignificant.* (NYOO 1949)

These measurements provide data for external beta-gamma radiation and for residual uranium that would be deposited on the skin and clothing of a worker. Workers were not issued coveralls, but wore their own clothing. As the steel plant was rough on clothing, workers would use the same clothing for as many as two to three weeks without washing or discarding them. Many would leave their clothing at the plant and change before going home and wear the same clothing the next day. Hence, the film badge experiment at Simonds might describe the doses due to dust deposited on skin and clothing. The shielding provided by clothing, especially in the summertime may have been minimal for some parts of the body. Workers sometimes unbuttoned their shirts; others, especially in areas far from the toilets, would use the vicinity of the workplace as a toilet.

The film badge experiment indicates that external doses from resuspended uranium that is re-deposited on clothing may be higher than the dose due to air submersion discussed in Table 5 of the TBD. As a result, external dose due to resuspended dust in periods between rollings requires further evaluation. The resuspension rate will be a critical parameter that will need to be evaluated for the specific circumstances prevailing at Bethlehem Steel.

The *Trip Report to Simonds Saw and Steel Co., Lockport, New York* (Heatherton et al. 1957) states that, although there were no large quantities of radioactive material found in the plant, the dose rate readings were slightly above background in all areas. Dose rates at 3 feet from the floor were 0.2 mrep/hour beta/gamma. Given this dose rate from residual contamination, workers could receive 10 mrep/week assuming a 50-hour work week. The readings above were taken in July 1957 after the facility had discontinued its uranium rolling operations. Dose rates from residual contamination during the period the facility was involved in uranium rolling would likely be higher due to the gradual buildup of uranium dust. The contribution to external dose caused by residual contamination after the completion of all rollings has not been considered in the TBD. This evaluation should include internal and external doses. The rate of attenuation of the residual contamination from washdown and vacuuming of the floor would be a critical parameter.

High exposure episodes may also have occurred, as for instance during air hosing of the area. Site experts indicate that air hosing occurred using a central compressed air supply. Vacuuming was apparently done using a mobile vacuum cleaner.

Regarding exposure from proximity to uranium, page 8 of 13 of the TBD states the following:

> *A triangular distribution for electron exposure from uranium was determined in the following manner:*

- *The minimum was estimated by assuming the worker was 1 meter from an extended uranium source for 1 hour (per 10-hour shift). The estimated dose rate for this scenario was 90 mrad/hour (US Army 1989).*

- *Survey data of the Simonds facility were used to estimate the mode. The highest value measured during those surveys was 15 mrad/hr (AEC 1949b). To be claimant favorable, this dose rate was assumed for an entire 10-hour shift.*

- *A maximum value was estimated by assuming the worker was 0.3 meter (1 foot) from an extended uranium source for 6 hours (150 mrad/hr) and 1 meter away for 4 hours (90 mrad/hr).*

The highest measured value during surveys performed at Simonds from October 1948 through February 1949 was 15 mrad/hour (NYOO 1949). The measurements referred to were taken in direct contact with the floor. These measurements did not include survey points in the immediate vicinity of the stored uranium or uranium undergoing processing. The 15 mrad/hour dose rate, therefore, may not be indicative of process or finishing area dose rates and it should not be represented as such.

The TBD assumes a triangular distribution for external exposure. The maximum parameter is determined by assuming a worker would be exposed to 150 mrad/hr for 6 hours and 90 mrad/hr for 4 hours. The shift total for this scenario is 1,260 mrad for a 10-hour shift. The mode is assumed to be 150 mrad and the minimum 90 mrad for a 10-hour shift. The average value for this distribution would be 500 mrad per shift. A worker in direct contact with natural uranium could receive beta exposure at a rate of about 230 mrad/hour shallow dose and less than 10 mrem/hour deep dose. Many jobs required direct contact with uranium during rolling operations. Other operations required the worker to be in close proximity (within 1 foot) of the uranium. This was especially true for inspectors, chippers, scarfers, rollers, shearers, straighteners, and others involved in finishing work. The goal was to produce a billet within a tight tolerance, so all abnormalities on the billet would have to be examined and fixed. Given the nature of this work, it was not uncommon to handle material being rolled. Taking into account the surface dose rates for natural uranium, which is the claimant-favorable assumption, the maximum shallow and deep doses are underestimated by the current methodology in the TBD.

A number of special external exposure conditions were identified by site experts, which were not considered or mentioned in the TBD:

- Two to three men manually transferred billets against their abdomen to the secondary work area.

- Straighteners were responsible for correcting bends or bows in the uranium.

- Grinders removed jagged edges or seams to correct imperfections in the uranium.

- Furnace men worked in and around the furnaces to repair holes.

- Guide setters, assistant rollers, and rollers were required to adjust the mills while they were rolling, placing them within 1 foot of the material.

- Inspectors were involved in near proximity or contact evaluation of the billets.

- Chippers and scarfers used air guns and torches, respectively, to eliminate slag or impurities from the uranium.

- Individuals loaded and unloaded billets and ingots from the trucks or railcars.

- Workers were involved in cleanup of the scale pits.

- When cobbling occurred, the line was stopped and the cobbles had to be manually removed from the rollers.

The workers at Bethlehem Steel were not told that they were working with uranium. Therefore, they did not know the additional precautions that needed to be taken to avoid radiation exposure. They were not trained in the principles of time, distance, and shielding, and did not realize that more pronounced beta exposure would result if they were in direct contact with the metal. What the workers knew was that this material had to be rolled to very strict tolerances. Mill and secondary area workers were in close proximity to (< 12") or in contact with the uranium oxide on a frequent basis. The length of time during a shift they were in contact with the uranium metal depended on their specific job. In determining a maximum value for external exposure, this direct contact should be taken into account. These routes of external exposure, which are not specifically addressed in the TBD, may be especially significant for some nonmetabolic cancers, such as skin cancer and cancers of male genitalia.

4.0 OBSERVATIONS

SC&A made a number of observations identified in its review of the Bethlehem Steel site profile and the supporting technical information bulletin. These observations relate to technical and process questions or issues concerning the completeness of data sources, technical accuracy, and adequacy of data. There were no observations related to regulatory compliance.

4.1 OBSERVATION 1

The input of the site experts has not yet been adequately evaluated to determine the impact of dose reconstruction efforts.

Site expert information provided valuable understanding of operating conditions and non-routine occurrences. Input from site experts was not investigated and integrated into assumptions used for determining worker dose when the technical basis document (TBD) was first prepared, and with the exception of ingestion dose, when it was revised. This was an important contributor to some of the gaps and deficiencies that were identified in the TBD. Although a worker meeting was scheduled to be held in Hamburg, New York, on July 1, 2004, to allow workers to provide input with respect to the Bethlehem Steel TBD, NIOSH Revision 1 was issued on June 29, 2004. In addition, during the conference call with the audit team (see Attachment 1), NIOSH only stated that it was "reviewing this [July 1 meeting] information and looking for documentation to back up worker testimony." NIOSH did not indicate specific plans to update the TBD based on information provided in Hamburg, such as those related to incidents like cobbling and related handling of uranium.

4.2 OBSERVATION 2

A comprehensive records search of relevant rolling operations documents was not performed to investigate worker testimony regarding additional rollings after 1952.

Page 3 of 13 in the TBD describes rolling processes as follows:

> *The rolling experiments generally took place on weekends because the mills were in full use 5 days per week. The work only involved the 10-in. bar mill and associated billet preparation and handling equipment (LaMastra 1976; Range 1976; Thornton 1977; ORNL 1980*[a]*; DOE 1985).*

In Table 1 of the TBD, the number of rollings identified through documentation includes four experimental rollings, eight production rollings, and an additional rolling of unknown type. These rollings were performed from April 1951 through October 1952. In the absence of documented data, one rolling per month was assumed for 1949 and 1950 equating to 120 hours of exposure. In 1951 and 1952, a total exposure period of 130 and 110 hours, respectively, was assumed. Per the August 12, 2004, conference call between NIOSH and SC&A, NIOSH indicated that the assumption of 48 rollings is considered claimant favorable.

Documentation clearly states that a contract was in place between Bethlehem Steel and the AEC in 1949:

In 1949, the U.S. Atomic Energy Commission (AEC) contracted with Bethlehem Steel Corporation (BSC) to develop improved rolling mill pass schedules. BSC conducted this work under contracts AT(30-1)-1279 and AT(30-1)-1156, which were subcontracts with National Lead of Ohio (DOE 1985). The pass schedules were for the rolling of 5-in. natural uranium billets into 1.5-in. rods for use in nuclear reactors (LaMastra 1976; DOE 1985) for production of plutonium.

The absence of documentation from 1949 to 1950 for specific rollings creates an uncertainty about how many rollings were done in those years, rather than whether they were done. Therefore, it is difficult to assess whether the assumption of rolling on a single day per month in 1949 and 1950 can be considered claimant favorable for those years. The assumption of 12 rollings in 1949 and another 12 in 1950 is reasonable and may be claimant favorable in light of 1951 and 1952 data. But there is no conclusive evidence that this assumption is actually claimant favorable. This reservation should be seen in light of the considerable acceleration in the U.S. nuclear weapons program that took place in the aftermath of the first Soviet nuclear weapon test on August 29, 1949. Overall, the total of 48 rollings can be considered reasonable and may also be considered claimant favorable for this period in light of available information in the April 1951 to October 1952 period. However, this claimant favorability cannot be definitely established, due to missing records and documents.

The assumption about 48 rollings during the 1949-1952 period and its presumed claimant-favorability should not be used to make any statements outside of that period. Specifically, the summary provided in the elimination report states that the project was completed in 1952. This conclusion was reached without the benefit of site expert interviews and supporting documentation. The TBD acknowledges that there may have been some rolling in 1955, according to a letter from Paul Kansanovich (Compensation Agent, L.U.) to Robert Anderson (Bethlehem Steel) in 1979. Two former Bethlehem Steel employees have provided statements that uranium rollings took place at Bethlehem Steel in 1955 and 1956. These rollings are not being considered in the dose reconstruction, as they are outside the qualifying years of 1949-1952. No documentation has been located with respect to post-1952 rollings, either in support of or in contradiction to the workers' accounts. The decision to rule out rollings beyond 1952 is not a claimant-favorable assumption.

Further, one site expert raised the possibility that National Lead of Ohio may have sub-contracted rolling to Bethlehem Steel when their rolling mill was down and they needed to meet production quotas. Also, until the Fernald records center is searched for any pertinent records for these operations, the completeness of the records reviewed is questionable. NIOSH has claimed that the rollings in 1955 might have been of Navy material and would therefore not be covered under Energy Employee Occupational Illness Compensation Program Act of 2000 (EEOIPCA). Such a supposition is inappropriate in the absence of evidence.

There was an incomplete investigation of rollings at the Bethlehem Steel site. Although a search for records pertaining to Bethlehem Steel was performed at the Fernald records center, the DOE Office of Worker Advocacy, the Environmental Measurements Laboratory records storage, DOE Headquarters, and the DOE Germantown records facility, an equivalent search was not performed at other DOE facilities and records repositories. Given that the AEC managed the inventory of uranium, Mallinckrodt Chemical Works may have a record of uranium supplied to the steel mills. Hanford, Chalk River Experiment, and the Savannah River Project, which received uranium billets for analysis and/or use (NLO 1952a), may also have records of receipt of this material. Argonne National Laboratory and DuPont may have been involved as demonstrated by their participation in the uranium rolling meeting held May 28, 1951 (McCrosky 1951). A review of physical inventory records at these facilities may provide a more complete history of the rollings at Bethlehem Steel and other Atomic Weapons Employer (AWE) sites.

In the preliminary record collection for evaluation of the site profile, several records were identified at the Hanford Declassified Document Retrieval System (DDRS). In these reports, they discuss the rolling of uranium at both Bethlehem Steel and Allegheny-Ludlum Steel. Additional reports from other sources also provided information on rollings at Bethlehem Steel.

For example, *Trip Report: Experimental Rolling of Thirty Tons of Uranium by the Simulated Fernald Process* (Hanford Works 1952) indicates that 30 tons of case uranium billets were rolled to Hanford diameter at Allegheny-Ludlum Steel and Bethlehem Steel on February 16, 1952. This date is not included in the listed rollings and indicates that an exhaustive records search was not completed, as this document was available in the public domain. (SC&A notes that a rolling for February 1952 was added as an assumption in the TBD. The comment here applies only with regard to a lack of completeness in the search of relevant records and the potential for additional rollings to be found, if such a search were conducted.) Workers have also suggested that records may be available at the Saylorsburg, Pennsylvania, records storage facility of the former Bethlehem Steel Corporation.

SC&A recognizes that the period for which workers are covered is not determined by NIOSH, but by the DOE. However, NIOSH can refer information and evidence to the DOE to consider as a basis for extending this period. While the worker testimony is uncorroborated by documentation so far, the document search is not complete. Therefore, a reference of the matter to the DOE for further evaluation and a more complete document search appears appropriate, especially given that there is an indicated willingness to provide testimony under oath.

4.3 OBSERVATION 3

The assumption of 10 hours of work per day may not be claimant favorable based on available documentation and statements provided by site experts.

With respect to the length of exposure applied for internal and external dose calculations, page 5 of 13 of the TBD states:

> *The number of exposure hours per year was determined by assuming 12 10-hour workdays per year for 1949 and 1950. This assumption is conservative considering no documentation indicates any rollings took place during those years. If there were rollings, it is assumed they took place only on weekends. Reports from 1951 and 1952 indicate that, with the exception of the April 1951 (Summary 1951), August 1952 (Bowman et al. 1952), and September 1952*

> *(Schneider and Yocce no date) rollings, rollings occurred on only one weekend day per month. For 1951, an additional 10 hours was added to account for the additional weekday in April, resulting in 13 10-hour workdays. For 1952, in addition to the eight documented rollings, it was assumed that one rolling each took place in February, May, and June, resulting in 11 10-hour workdays.*

A 10-hour workday was assumed during rollings. However, the time to complete the rollings was dependent on the problems (e.g., salt bath leaks, cobbling, secondary finishing work) encountered during operations. Information from various reports (Hanford Works 1951 and 1952, NLO 1952b and 1952c) indicates that cobbling frequently occurred during rollings, lengthening the time it took to complete the operations. Rolling and finishing operations were followed by cleanup. If cobbling took place in the first half of the stands, the recovery time could be several hours. Workers reported that they worked from 8-16 hours during these rollings. The assumption of 10-hours per day exposure may not be uniformly claimant favorable based on statements provided by several site experts.

4.4 OBSERVATION 4

The TBD has not considered several pathways of internal exposure resulting from incidents such as cobbles, repairs of furnaces, salt bath leaks, and uptake via injuries (i.e., burns, cuts, scrapes).

The TBD focuses on the potential internal exposures from routine operation of the rolling mills. Incidents at the facility were common and included formation of cobbles and subsequent mitigation, salt bath leaks, furnace repairs, and loss of uranium. The basis for the maximum value was an air sample taken adjacent to a rolling stand at Simonds Saw and Steel. This would not necessarily be representative of the exposures received during incidents and/or routine occurrences. Although the intent of the TBD is to address most of the claimant situations, there is no indication in the TBD when individualized dose estimates must be considered.

4.4.1 Cobbles

Uranium was more difficult to roll because it was not heated to as high a temperature as steel. During uranium rollings they often had what was called a cobbling. A cobbling results from a misfeed or a jam by the metal. When a cobble occurred, the workers had to clear the area to prevent burns from flying metal. A crane had to remove the cobble and workers with “hot gloves” would cut it into pieces with a torch until the mill was cleared. As the cobble was burned into small pieces, it also created slag and drips. The mill would not continue to operate when a cobble was in a roller. The time to remove the cobbles varied from 10 minutes to several hours.

The potential routes of exposure include inhalation, direct incorporation of uranium metal and oxide fines via burns and scratches, and direct contact with uranium metal. The rods would have had some oxide scale. In addition, as the metal was being burned, it created metal oxide fines and metal fumes in close proximity to the worker. The lack of long-term breathing zone data increases the importance of taking these incidents into consideration. The triangular distributions employed in the site profile do not necessarily capture the exposures associated with these incidents.

4.4.2 Salt Bath Leaks

Salt baths were contained in steel pans held together by welds. These welds failed resulting in leakage from the salt baths. The salt baths were lined with fire brick and workers occasionally had to replace this brick (NLO 1952a). The leaks resulted in a cessation of work until repair and cleanup of the leaks were completed. This may have created exposure potential outside of the times required for rolling.

4.4.3 Furnace Damage

Two types of furnaces were used at Bethlehem Steel. A permanent furnace was used for the normal rolling process. A temporary furnace was used for billets that were received in "roughed" form from other steel mills. This was required because the billets were started at the finishing stands and not at the beginning of the process. The temporary furnaces had to be removed upon completion of the rollings.

Occasionally there was a burnout or leak in the furnace. A group of workers were responsible for temporarily repairing holes or leaks while the mill was still operating. Once the mill was shut down for maintenance, the bricklayers could enter the furnace to complete a more permanent fix. This likely resulted in internal exposure from excessive amounts of dust and external exposure from direct contact with and submersion in uranium dust.

4.4.4 Loss of Uranium

During the August 27, 1951, uranium rolling operations, 100 lbs of oxide fell to the floor during air-cooling. Blisters of about 0.1 inch appeared at the point where the rod rested on the rails. The surface oxidized (Hanford Works 1951). It is not clear from the report how much of the uranium was recovered. In addition, uranium that fell into inaccessible places was not retrieved. The average loss per billet was determined by the weight difference between the ingot or roughed billet and the final billet. The average total loss of uranium was estimated at 88-94 lbs, depending on whether a round or square ingot was rolled (NLO 1952b). This indicates significant potential for large flake deposition on food, exposure between rollings and after the completion of rollings, and exposure to workers cleaning scale pits outside of the times when rollings were occurring.

The air concentration distribution discussed in Findings 2 and 3 above applies directly to days in which rollings were done. The selected distribution of airborne dust concentrations at the facility represents an average distribution over time and space. Measurements from all over the facility (and in the case of NIOSH Table 3, from two facilities) are used in the TBD to construct a composite distribution. When actual individual exposure measurements are available at a facility, the range of individual mean exposures usually is quite broad, with a long tail due to infrequent, unanticipated "events" that result in high exposures to a few individuals. However, breathing zone data are not available in these cases. Therefore, the use of a facility distribution based on available plant-wide data may not be favorable to the claimant, unless specific steps are taken to ensure that the chosen parameters actually include representation of the worst conditions that any single worker could have experienced.

Among the cautions regarding the use of Table 3 for maximum doses should be a discussion of unusual work conditions that are not captured in air concentration data. Working in and around contaminated furnace areas is one example. NIOSH should therefore create a list of unusual working conditions as well as high hazard workplace areas, such as at rollers, furnaces, and secondary processing. This list can guide those who take worker interviews to assure that relevant information is solicited about these items. If these conditions apply to the dose reconstruction at hand, then specific adjustments will have to be made to the calculated dose using a combination of available data and analytical techniques.

4.5 OBSERVATION 5

The TBD makes no distinction between routine dose assignment conditions and unique exposure conditions, such as high-risk work (e.g., loading and unloading of uranium, routine maintenance of equipment, clean out of pits).

Although the TBD is not considered all-inclusive, there is no reference to those activities that may require individualized dose reconstruction. There were a number of jobs performed in the steel mill. The relative exposure potential was highly dependent on the job an individual was performing. Many jobs required direct contact with uranium or work in the immediate vicinity of the metal. Those who were involved in rolling uranium and performing secondary finishing work, which involved machining on the metal, were likely exposed to a higher concentration of dust and scale than the average worker. Those workers who were very near rollers may have been exposed to even higher dust concentrations.

There were cropping and cutting operations involved with uranium bar production as a part of routine operations or with failure of the bar to form. Cropping and cutting generated uranium dust resulting in a potential internal exposure. To the extent that this occurred during rolling hours, the dust concentrations would be part of the assumptions about workplace environment made by NIOSH and ORAU. However, cropping and other specific operations performed by particular workers raise the difficult statistical problem of how facility data on air concentrations and even workplace data on concentrations (some of which are available for Bethlehem Steel) can be translated into statistically defensible individual dose estimates.

Cleanup and maintenance workers had a higher potential for inhalation of dust. Uranium billets were hosed down with water as the rolling was being done to wash off the scale. The steam dissipated into the air and the scale and dust were flushed into a sub-basement. The pits were cleaned out, likely resulting in exposure to cleanup workers, crane operators and railroad workers. Site experts indicated that the scale pit was manually shoveled about once in six months, perhaps creating an increase in the potential for exposure. The scale pit was cleaned out with a crane about once a week. This is based on site expert statements. Workers also participated in other cleanup activities, such as blowing lime off the walls, sweeping and/or vacuuming uranium dust, and cleaning out salt baths. These activities likely resulted in exposure to dust and material mixed with uranium. Further investigation is necessary regarding this issue.

Specifically, an evaluation of the validity of air sample data for specific workstations, including rolling stands, is needed, since spraying may result in a rapid falloff of air concentrations. This is indicated by a comparison of samples L709, L710, and L711 with sample L712 in the October 27, 1948, Simonds dataset (see Table A4-1 in Attachment 4).

4.6 OBSERVATION 6

There is no mention of estimates of dose from environmental releases in the Bethlehem Steel TBD as there are in subsequent site profiles, such as those completed for Mallinckrodt Chemical Works, Savannah River Site, and Hanford.

The lack of consideration of environmental doses for Bethlehem Steel is inconsistent with other site profiles that use environmental dose to assign dose to non-monitored workers who were not likely to receive exposure to radioactive material. The typical mode of disposal at the steel mill was to discharge waste to the air, ground, and to Lake Erie. Based on the policies and practices at Bethlehem Steel, there was a potential for environmental release and therefore environmental dose to workers. The contribution of this factor on dose outcomes is not clear, but should be further investigated. Regardless of whether this is determined to be a significant issue or not, it should be addressed in the technical basis document, if only briefly.

4.7 OBSERVATION 7

The Bethlehem Steel TBD assumes workers were given chest x-rays in a period of time when photofluorography was a prevalent technique.

The assumption was made that Bethlehem Steel workers received annual chest x-rays based on documentation for Simonds Saw and Steel facility (Simonds 1948). A conventional chest x-ray posterior-anterior (PA) view rather than photofluorography (PFG), which was a standard technique during the years 1949-1952, was assumed with a default value of 0.2 cGy for dose calculations. Lateral views of the chest were also not assessed. It would be more claimant favorable to assume that workers on site during the covered period had photofluorographic examinations in the absence of evidence to the contrary. A review of the actual x-rays would indicate the type of x-ray given (i.e., 14 x 17 for PA chest x-rays, 35 mm film for photofluorographic units). The entrance skin kerma dose for photofluorography ranges from 1-3 cGy, which is higher than the estimated doses in Table 7 of the TBD. ORAUT-OTIB-0006, *Dose Reconstruction from Occupationally Related Diagnostic X-ray Procedures* (Kathren et al. 2003), the generic DOE document for occupational medical x-rays, assumes a default value of 3 cGy. If the use of photofluorography is ruled out, it should be based on positive evidence and documented in the TBD.

5.0 PROCEDURAL CONFORMANCE

The dose reconstruction process must comply with the requirements of 42 CFR 82. As a method of effectively implementing these requirements, the National Institute of Occupational Safety and Health (NIOSH) has written technical guidance documents on external and internal dosimetry. Oak Ridge Associate Universities (ORAU) has committed to the use of these guidance documents in its quality assurance program plan. The issues identified below are cited circumstances where the Bethlehem Steel technical basis document (TBD) is not consistent with the guidance outlined in NIOSH's external dosimetry guidance document.

5.1 PROCEDURAL CONFORMANCE ISSUE 1

The TBD did not take into account ICRP 75 in assessing the validity of air concentration data for estimating individual worker doses.

ICRP 75 makes specific recommendations about the use of air concentration data of the type available for Bethlehem Steel and Simonds; that is, short-term air samples that are not true long-term breathing zone data for assignment of individual dose. Only two of the 38 Simonds samples are marked as breathing zone. Some of the Bethlehem Steel samples are marked as breathing zone, while others are general air. It is unclear whether any of the samples marked as "breathing zone" were actually breathing zone samples, such as those obtained by using lapel samplers. ORAUT-OTIB-0004 (p. 4) indicates that air samples of the time were not true breathing zone samples. All were short-term samples; in most cases they were a few minutes or a few tens of minutes. ICRP 75 addresses the accuracy of air samples for individual worker intake of radionuclides as follows:

> *Two sources of airborne contamination are particularly important: localized releases, and the resuspension of surface contamination. Both can be directly generated by the work activities of individual workers. Airborne contamination is often localized and transient. In particular, there can be very significant differences between the activity concentration in the breathing zone of a worker and the level measured at some nearby fixed location, the concentration in the breathing zone usually being higher….*
>
> *When area samplers are routinely used for quantitative determinations of intake, the representativeness of the results should be determined using a special monitoring program, often involving personal air samplers. Conversion factors relating the area measurement to the concentrations in the immediate breathing zone should be established and reviewed from time to time and after any significant changes to the operations. Despite this correction, area samplers, even if located close to the breathing zone of workers, may not always provide data that adequately represent the intake of each individual worker. This is particularly true in cases where the air contamination sources are localized and variable with time, often because they result from the workers' own actions or movements.*

ICRP 75 further cautions that air samples, such as personal air samplers, can have a bias; therefore, long-term averages, rather than single results from a shift or even a week, are preferable (ICRP 1997).

The TBD relies on the air samples to determine worker dose, and therefore should consider the accuracy and applicability of the air sample data. This is especially important given the limited nature of the data. The available air samples indicate that air concentrations were highly localized and variable with time. These are both situations in which a critical assessment of air concentration data is recommended. Moreover, critical evaluation of the Bethlehem Steel air data along the lines above is especially important because of the spraying of water on the uranium in the context of a lack of complete ventilation.

Some sample calculations illustrating the kinds of adjustments that may be made to the data in light of ICRP 75 are discussed in Attachment 4. As noted there, these adjustments will inevitably contain a substantial amount of judgment, especially in light of the facts that (1) much of the Bethlehem Steel data is missing (such as data for 1949 and 1950) and many documents and records have been destroyed, (2) Bethlehem Steel air samples also show high variation in time and workstation location, making the available data more difficult to interpret with confidence, and (3) the Simonds facility is only broadly comparable to Bethlehem Steel and has only one usable dataset.

Available data can be adjusted in a number of different ways in light of the ICRP 75 recommendations above. The different methods of adjustment yield widely divergent results. This raises the issue of whether it might be more defensible to proceed in a different manner – that whether all AWEs uranium metal working should be treated as a group and making claimant-favorable choices in that context. NIOSH has done this in ORAUT-OTIB-0004, but this document was not used in the TBD.

5.2 PROCEDURAL CONFORMANCE ISSUE 2

The TBD did not take into account the more claimant-favorable methodologies set forth for metal working AWEs in ORAUT-OTIB-0004 (Anderson 2003). As a result, the maximum dose estimates for Bethlehem Steel are underestimated in the TBD as compared to that derived in ORAUT-OTIB-0004.

ORAUT-OTIB-0004 was written explicitly for uranium metal working AWEs, and therefore applies to the Bethlehem Steel case. It defines its applicability as follows (p. 3):

> *The processes at these facilities included reduction and recasting, rolling, machining, and extruding of uranium, fuel element fabrication, scrap recovery, and recovery of uranium from phosphoric acid. A large number of the facilities handled uranium metal. The facilities relevant to this document were privately owned and the AEC work was done on a part-time basis or in addition to their normal commercial operations.*
>
> *This document applies only to facilities that handled uranium metal and is not to be used for facilities that processed thorium, radium, or uranium ores. The intake*

and dose rates in this exposure matrix are to be used in conjunction with the individual worker's covered employment dates, date of birth, and date of cancer diagnosis. If it is necessary to pro-rate intake and dose rates, it is acceptable to use values for a full year as this is an over-estimation and, thus, claimant-favorable. Because worker bioassay and dosimetry data cannot be ignored, the worker's data, if available, should be reviewed and it should be ensured that a dose reconstruction based on this exposure matrix is an overestimate and is, therefore, a claimant-favorable approach.

The Appendix to ORAUT-OTIB-0004, which lists the facilities to which it is applicable, specifically includes Bethlehem Steel. Revision 1 of the Bethlehem Steel TBD was published on June 29, 2004, more than six months after ORAUT-OTIB-0004 was published. Therefore the revised Bethlehem Steel TBD should have fully investigated the methodologies used for dose determination in ORAUT-OTIB-0004 as compared to the TBD.

SC&A will be reviewing the methodologies outlined in ORAUT-OTIB-0004 as part of the Task 3 review of procedures. The comments here are therefore limited in nature as they specifically apply to the Bethlehem Steel TBD. Following the review of ORAUT-OTIB-0004, further consideration will have to be given to incorporating the recommendations into this procedure and other affected technical documents.

There are important issues that are covered in ORAUT-OTIB-0004 that are not addressed in the Bethlehem Steel TBD:

- ORAUT-OTIB-0004 recommends that a 2,000-hour work year be used, even when the metal working only occurred part-time. It explicitly states that "the operations at the facilities for which this document is applicable were smaller, mostly part-time operations" (p.4). This issue clearly applies to Bethlehem Steel.

- ORAUT-OTIB-0004 recommends that a uranium dust level of 100xMAC be adopted for the entire year (p. 4). The TBD should have investigated whether this is more claimant favorable than the procedure adopted in Table 3 of the TBD. To be specific, the estimated exposure over four years (1949 to 1952) to contaminated air based on the average concentration derived from Table 3 of the TBD is 160,320 MAC-hours (334xMAC times 48 days of work at 10 hours per day). In contrast, ORAUT-OTIB-0004 yields an exposure estimate of 800,000 MAC-hours for the same period.

- Applying the full work year to part-time operations may allow for indirect consideration of resuspended uranium, as indicated on pg. 8 of ORAUT-OTIB-0004. However, whether it does so in the specific instance of Bethlehem Steel is an open question that requires analysis.

- ORAUT-OTIB-0004 notes that "early exposure studies were not very selective in terms of particle size (Stannard 1988). Also, the air concentration measurements represented the amount of uranium in the air where the workers were located, but not necessarily what was taken into the lung or the body" (p. 4). Therefore the recommendations of ICRP 75 regarding air samples apply. SC&A will review this question generically as part of Task 3. For the Bethlehem Steel TBD, the appropriate procedure would be to compare the dose derived from uranium dust levels, expressed in terms of MACs over 2,000 hours, recommended in the TBD with the sum of claimant-favorable dose from a technically and statistically sound analysis of the October 27, 1948, Simonds dataset, and resuspension data from Simonds, as discussed above. The more claimant favorable of the two should be used in the Bethlehem Steel TBD.

- ORAUT-OTIB-0004 makes provision for post-rolling doses from resuspended uranium. The Bethlehem Steel TBD does not cover this. This item should be included in the TBD. The specific parameters recommended in ORAUT-OTIB-0004 for post-rolling exposure would need to be evaluated in light of residual contamination data from the Simonds facility. SC&A will evaluate post-rolling parameters (notably the decay parameter of 0.01 per day) as part of its Task 3 review.

- Table 4 of the Bethlehem Steel TBD takes ingestion doses into account only for days on which rollings took place (12 or 13 days per year). In contrast, ORAUT-OTIB-0004 includes ingestion doses for 250 days per year. The annual ingestion of 3.14×10^6 pCi/year estimated in ORAUT-OTIB-0004 is about 50 times greater than the annual intake estimate indicated by the average of the triangular distribution in Table 4. SC&A notes that the ORAUT-OTIB-0004 estimate would be more claimant favorable than Table 4 of the TBD. However, SC&A recommends that the TBD take specific account of large particles and flakes settling on food in its evaluation of ingestion doses from rolling operations as noted above. An assessment of ingestion doses for the entire working year during and between rollings, taking flakes and large particles into account, is beyond the scope of this review. The same applies to post-rolling ingestion.

The use of the general approach specified in ORAUT-OTIB-0004 in the case of Bethlehem Steel has the advantage of bypassing many of the difficult issues relating to the statistical representation of the highly incomplete Bethlehem Steel datasets and the application of the Simonds October 27, 1948, dataset to Bethlehem Steel. These issues are discussed in more detail in Attachment 4. We have not evaluated the specific parameters chosen to represent all uranium metal AWEs as part of this review, since they are beyond its scope. However, the general approach does suggest itself as potentially more defensible in that data from many facilities are being used to create a claimant-favorable approach. We would note one caution in this context. The application of any approach that is general, whether of a facility air concentration distribution or a set of parameters across AWEs, raises the risk that some workers in especially high-risk jobs (or high-risk facilities) may not be treated in a claimant-favorable way. Therefore, we note in this context as well, that a list of high-risk jobs and incidents for Bethlehem Steel would be a useful guide for individual dose reconstruction whatever approach may be chosen for estimating doses.

5.3 PROCEDURAL CONFORMANCE ISSUE 3

42 CFR 82 requires that efficient approaches to estimating doses when compensation is denied should be worst-case estimates. The maximum dose estimation procedure in the Bethlehem Steel TBD is not defensible as a worst-case estimate that can be used to deny compensation.

42 CFR 82.10(k)(3) requires NIOSH to make worst-case assumptions in cases where an efficient procedure is used to deny compensation:

> *(3) Research and analysis indicated under steps described in paragraphs (f)–(j) of this section have been completed. Worst-case assumptions will be employed under condition 2 to limit further research and analysis only for claims for which it is evident that further research and analysis will not produce a compensable level of radiation dose (a dose producing a probability of causation of 50% or greater), because using worst-case assumptions it can be determined that the employee could not have incurred a compensable level of radiation dose.*

A review of two individual dose reconstructions for Bethlehem Steel indicates that NIOSH is using Table 3 of the TBD as the basis for satisfying the requirements for compensation under 42 CFR 82.10(k)(1) "cumulative dose is sufficient to qualify the claimant for compensation (*i.e.,* the dose produces a probability of causation of 50% or greater"), and also for "worst-case" calculations resulting in denial under 82.10(k)(3) above. While the use of the TBD under 82.10(k)(1) for making affirmative compensation decisions is appropriate because Table 3 does not make worst-case assumptions as discussed in detail in the Findings above, its use for denial is inappropriate for the same reason. The workplace air concentration data for Bethlehem Steel are grossly incomplete. There are no data available for most rollings. Air concentration data are short-term samples that should not be used without the necessary adjustments based on ICRP 75. It will be very difficult to do this, given the incomplete nature of the Bethlehem Steel data. The data from a comparable facility (Simonds) are useful, but limited to one day of comparable data, with at most three samples from any specific location. Moreover, as previously noted, these data have not been analyzed in what SC&A considers a statistically defensible manner. Since these and other items noted in the findings above and in Attachment 4 indicate that the analysis in the TBD is incomplete in important respects, its representation as a "worst-case" exposure assessment is inappropriate.

The problem can be addressed in one of two ways. NIOSH can attempt to re-do the analysis with Bethlehem Steel and Simonds data, using the analysis such as that provided in the findings and in Attachment 4, thereby attempting to make the TBD a reasonably complete document for estimating doses for compensation purposes. NIOSH can also use the general procedures set forth in ORAUT-OTIB-0004, which it has specifically designated "to provide guidance for estimating the maximum plausible dose to workers at Atomic Weapons Employers (AWEs)," including Bethlehem Steel. The general approach in ORAUT-OTIB-0004, which is based on pooling data from many uranium metal facilities, could be used as a substitute for re-analysis of the Bethlehem Steel and Simonds data, with appropriate cautions as discussed in Procedural Conformance 2 and incorporation of recommendations from the ORAUT-OTIB-0004 Task 3 review. The differences in methods applied between the procedure in the TBD and those in this review are great enough that they may affect compensation decisions in some cases, especially where the Probability of Causation is just below 50%.

The detailed discussion in the findings and observations, as well as in the procedure conformance issues above, leads to the conclusion that the Bethlehem Steel TBD has not adopted worst-case procedures for estimating maximum doses as the basis upon which compensation is denied.

Further, the TBD also does not adequately follow 42 CFR 82.17(b) and (c), which state:

> *(b) A quantitative characterization of the radiation environment in which the covered employee worked, based on an analysis of historical workplace monitoring information such as area dosimeter readings, general area radiation and radioactive contamination survey results, air sampling data; or,*
>
> *(c) A quantitative characterization of the radiation environment in which the employee worked, based on analysis of data describing processes involving radioactive materials, the source materials, occupational tasks and locations, and radiation safety practices.*

The analysis in Findings 1 and 2, in Procedural Conformance Issues 1 and 2, and in Attachment 4 shows that NIOSH has not properly characterized the workplace environment for the purposes of compensation dose estimation. For instance, no adjustments to air monitoring data for short-term samples that are not true breathing zone samples were made, or even considered. As another example, no statistical and technical analyses were made for individuals who worked in the most hazardous jobs or workstations.

6.0 STRENGTHS

The site profiles developed under the Energy Employees Occupational Illness Compensation Program Act (EEOICPA) for use in dose reconstructions are considered living documents and therefore can be updated as new information becomes available. As such, each specific exposure situation is not intended to be addressed in the site profile. The dose reconstructor has the option to deviate from this standardized procedure should the individual claimant information indicate this approach should be taken. With this perspective in mind, there were a number of strengths identified in the Bethlehem Steel TBD. These strengths are listed below:

- The TBD was developed to cover all eligible workers at Bethlehem Steel. This includes workers (1) who were involved with and who did not work in the area in which uranium rolling process (including associated activities such as maintenance, cleanup, loading of product, and unloading of raw material) was done and (2) those who were not. SC&A's analysis regarding the aspects of the TBD that do not result in claimant-favorable dose reconstruction results does not apply to the latter group.

- The use of air concentrations to evaluate minimum doses for lung and metabolic cancers in the absence of dosimeter and bioassay data is appropriate for those cases that are compensable.

- The assumption that air contamination is a principal pathway for internal radiation when assessing dose to certain organs, such as the lung and respiratory tract, is technically sound.

- The assumption about Type S for solubility for lung and respiratory tract doses is technically reasonable and claimant favorable

- The minimum dose approach to making rapid decisions for favorable compensation claims is appropriate. Denial of compensation cannot be made on the basis of an admittedly minimum dose. NIOSH and ORAU are not doing this. The overall approach of using minimum dose estimates to make rapid favorable compensation decisions whenever possible is both efficient and technically sound.

- The approach of complementing the limited Bethlehem Steel data with Simonds data and using the latter to construct a maximum dose distribution is also efficient and technically sound, albeit with the limitations discussed earlier.

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ATTACHMENT 1

Conference Call with NIOSH and SC&A[2]

Date: August 12, 2004
Time: 10:00 am – 11:20 am

Participants:

John Mauro, Joe Fitzgerald, Kathy Robertson-DeMers, Arjun Makhijani, Tim Taulbee, Tom Tomes, Dave Allen, and Stu Hinnefield

General Discussion

The purpose of this conversation is to validate some of the key issues that we have identified.

SC&A Inquiry: Where did you look for records?

NIOSH Response: We searched for records related to Bethlehem Steel at the DOE Office of Worker Advocacy, the Fernald records center, the Environmental Measurements Laboratory records storage, DOE Headquarters (Robert Anders personal files), and the DOE Germantown records facility.

SC&A Inquiry: What are you going to do with worker input from the July 1, 2004, meeting in Hamburg, New York?

NIOSH Response: We are in the process of reviewing this information and looking for documentation to back up worker testimony.

SC&A Inquiry: Where is Appendix B for October 27, 1948? Is this available for our review? This contains the raw air sampling data sheets. It is comparable to that available in the December 1948 report.

NIOSH Response: This information is filed with the Simonds Saw data. Appendix B is available and will be provided to you.

SC&A Inquiry: We need the NIOSH 2004 reference in order to review the ingestion dose calculations.

NIOSH Response: We will e-mail this to John.

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[2] These meeting minutes were prepared by SC&A and provided to NIOSH for review on August 20, 2004. No comments were received other than a telephone call that indicated that airborne radionuclides concentration data that exceeded 1,000 MAC occurred in non-occupied locations at the facility.

SC&A Inquiry: Regarding NOSH comment on excluding data points over 1000xMAC in a triangular distribution, did NIOSH do a statistical analysis in determining the 1000xMAC? At least the highest measurement should be used and some percentage higher than this. There are air sampling measurements higher than 1000xMAC in the October 27, 1948, Simonds Saw trip report.

NIOSH Response: The intent of NIOSH was to use the highest measurement at Simonds Saw for the maximum value in the upper bound matrix. They will review the October 27, 1948, data to determine if there are higher air sampling measurements than the one assumed in the TBD. It was not NIOSH's intention to drop the highest value. NIOSH agreed in concept that the highest value should be used and indicated that they will get back to us on this matter.

SC&A Inquiry: Did NIOSH consider using the oro-nasal breathing deposition and DCF factors from ICRP? There is a significant difference in the results between mouth breathing and nasal breathing. The mouth doesn't retain the dust particles like the nasal hairs do.

NIOSH Response: Nasal breathing was used as the default assumption. The only change made from Table 2 to Table 3 was the change in breathing rate from 1.2 to 1.7 m^3. We are using ICRP defaults whenever there is no other information. The default is nasal breathing.

SC&A Inquiry: Did NIOSH consider using Simonds Saw data from 1948 to assess the mode for Table 3? How was 2xMAC determined?

NIOSH Response: The averages for a few sets of data were determined. The mode for the upper bound matrix was taken as the highest average of Bethlehem Steel data. There were four days of air sampling data.

SC&A Inquiry: We have investigated the engineering controls at both Bethlehem Steel and Simonds Saw. Simonds Saw had a number of engineering controls in place, including ventilation. Bethlehem Steel had no ventilation except the natural breeze. What is NIOSH's feeling on not using data from 1949 and later? Did you use post-1948 data in your analysis? The data is not comparable after 1948. Have you considered using a mode from the 1948 Simonds Saw data for Table 3?

NIOSH Response: Our intent was to use the highest number for the upper bound of Table 3.

SC&A Inquiry: Simonds Saw data indicates a lot of residual dust. All evidence in the TBD indicates all the dust, scale, and other waste was taken away. This does not appear to be a valid assumption. There were a lot of losses (i.e., ~ 70 to ~ 94 pounds per ingot), and some of the losses appear to be residual radioactivity, as indicated by Simonds Saw data. Have you considered using the Simonds Saw residual radioactivity data to account for residual radioactivity at Bethlehem Steel? There is indication that residual radioactivity existed between rollings.

NIOSH Response: Most of the losses were from cropping of the uranium. Most of these crops were collected.

We have a survey of the area at Bethlehem Steel from 1952. The survey did not indicate significant residual contamination. It is our opinion that the difference in residual radioactivity between Simonds Saw and Bethlehem Steel is from the difference in production levels. The data from this September 14, 1952, survey was from before and after cleaning. This was the last roll performed at Bethlehem Steel.

SC&A Inquiry: Where were the survey points taken?

NIOSH Response: The points were taken at the approach to the shear, cooling table, Stands 1-6, floors, etc. The highest value was at the shear and was 979 dpm/smear. The survey results on the floor were in single and double digits. The shear appears to be the worst spot.

SC&A Inquiry: Were there any survey points in the Secondary Finishing Area?

NIOSH Response: There are no readings for the Secondary Finishing Area. There are two surveys, with one taken before cleaning and the other taken after.

SC&A Inquiry: Simonds Saw badge experiment indicates high clothing deposition, and worker testimony indicates re-use of clothes for several days. Can NIOSH comment on external dose from dust deposition on clothes and the body?

NIOSH Response: The Simonds Saw film badge data was not considered because the time period over which the film was exposed was not comparable to the time period when the rolling took place. The Simonds Saw data would also have more buildup of residual radioactivity in terms of production.

We have a memo talking about how it was moved. The Pinkerton Agency guards escorted the material at all times.

SC&A Inquiry: Did this data include time between rollings?

NIOSH Response: The resulting dose rate from deposition on clothing is 5 mrad/hour. Given the limited exposure time, this did not amount to a significant exposure.

SC&A Inquiry: According to the workers, they had to provide their own clothing for the job. Some workers took their clothes home once or twice a week for washing. Others wore their clothes for several weeks and then discarded them. This would contribute to the length of exposure.

NIOSH Response: We will look into this.

SC&A Inquiry: Many workers were in contact with uranium metal. Some reported sitting on the uranium. A Hooker was responsible for unloading uranium from the trucks. They stayed in the trucks until all the uranium was unloaded. The doses due to contact with uranium could have been higher than the external doses in the TBD. This activity may have also resulted in exposure outside the 10-hour period.

NIOSH Response: We have documentation indicating that the material was escorted by guards.

As a result, we do not believe that workers sat on uranium billets. Statements by workers regarding sitting on billets may have applied to sitting on steel billets. Even if the workers sat on the uranium metal, it would not result in a significant dose to organs other than the skin and testicles. The surface gamma dose rate for uranium is 8 mrad/hour. Given the length of exposure, this would result in a dose of 60-100 mrem/year. This dose is not anywhere near the 50-rem dose required to cause a PC of 50% for the bladder. The beta dose conversion factors for uranium are not significant for organs other than the skin and testicles. Beta dose would be on the order of microrads.

SC&A Inquiry: It would not matter for some organs, but it would matter for others. It would matter for skin or male genitalia.

NIOSH Response: The skin cancer would have to be in the exposed area. Skin cancer location doesn't typically relate to the area of high external exposure. Most skin cancers we have are for the face. Also, most skin cancer claims have been paid. No attenuation for beta was assumed for skin dose reconstruction.

SC&A Comment: Contact with uranium dose could be higher than the external doses in the TBD. Sitting on billets and handling uranium at various times was not always within the 10-hour period.

NIOSH Response: The material was under guard, and this was not considered because of that. There was no loitering.

SC&A Inquiry: Many workers have reported that they worked up to two shifts in some cases during uranium rollings. Was this accounted for?

NIOSH Response: We don't have a real good indication of how long people actually worked. Double shifts were not uncommon. We were under the impression rollings took 8 hours, so we extended it to 10 hours. Some of this is compensated for when we assumed 48 rollings rather than merely going with the documented rollings.

SC&A Comment: The length of the rolling was dependent on the incidents that occurred. Cobbling occurred frequently and would stop the line completely. If it cobbled at the end, it would be taken care of quickly. If the cobbling was at the beginning, it may have taken several hours to remove.

NIOSH Response: Some of this is compensated for when we assumed 48 rollings rather than merely going with the documented rollings. There is only evidence of 13 rollings. The duration of the rollings should be weighted in context.

SC&A Inquiry: Some workers may have had high exposure during maintenance, such as crawling into a furnace, cleaning out scale pits, and cleaning up salt bath leaks. Has NIOSH considered these activities? This maintenance work was likely outside the rolling time.

NIOSH Response: There is not a lot of information on scale pits. Based on the survey data and the introduction of steel scale into those pits, the concentration of uranium would be negligible.

SC&A Inquiry: How does NIOSH propose to deal with sworn affidavits regarding 1955 and/or 1956 rollings, especially when combined with the fact that (i) documents have been destroyed and (ii) there are archives that NIOSH has not looked at?

NIOSH Response: There is no information available in the DOE records to support these claims.

SC&A Inquiry: What is the procedure for incorporating affidavits into technical documents? Do you think that the Fernald data is complete?

NIOSH Response: No data set is complete.

SC&A Inquiry: Have you looked for records through Bethlehem Steel Corporation?

NIOSH Response: Bill Murray was trying to make contact with Bethlehem Steel Corporation. We are unsure where they are with this process.

SC&A Inquiry: Should we have the workers send a copy of the affidavits to you?

NIOSH Response: Have them sent to Roger Anders of the DOE or the appropriate contact for that DOE site.

SC&A Inquiry: Should we have a copy sent to you?

NIOSH Response: You can send a copy to us, and we will make sure it gets to the right people.

The covered employment period includes work for DOE and its predecessor. The work period is set up by DOE. If we encounter evidence to the contrary, we provide it to DOE.

SC&A Inquiry: I understand that workers are offered a hearing by the DOL when they are denied. Has NIOSH received information from DOL hearings that might be useful in dose reconstructions?

NIOSH Response: The DOL does send statements of facts or questions occasionally.

SC&A Inquiry: What is your position on the deep dose issue from x-rays as provided by Hans Behling?

NIOSH Response: We are still looking at it.

SC&A Inquiry: Given the many factors that add to dose, does NIOSH think that its 40%-plus cases are robust? Or that skin cancer and near-surface organ cancer cases are robust?

NIOSH Response: A number of the cases between 40% and 50% have been held up. The ones that have gone through are robust. You must remember that the PC is not linear. To change the PC from 45% to 50%, you essentially have to double the dose.

SC&A Inquiry: Has NIOSH done any sensitivity testing of the triangular verses uniform distribution methodology for assessing dose? Is this something worth looking into?

NIOSH Response: Note that if there is a significant change in the TBD, cases are reopened and reevaluated. We have done some sensitivity analysis to see how statistics change the outcome of the PC.

***SC&A Inquiry*:** Are there any Technical Information Bulletins for Bethlehem Steel?

***NIOSH Response*:** No, none other than the ingestion TIB that we intend to send you.

Action Items:

NIOSH has agreed to provide the following items to the SC&A team:

Appendix B from the October 1948 Rolling
Ingestion Technical Information Bulletin
Bethlehem Steel Survey Data from 1952
Pinkerton Guard Memo

SC&A team agreed to provide the following items to NIOSH:

Simonds Saw Data Sheet for December 1948
(Kathy Robertson-DeMers provided filename and page number to John Mauro for forwarding to NIOSH.)

ATTACHMENT 2

Bethlehem Steel Questions Submitted to NIOSH

The evaluation of the Bethlehem Steel Site Profile has included review of some source records, interviews with former Bethlehem Steel workers, and an analysis of the rolling process in general. We are sending you this memorandum defining the issues that we consider important regarding the completeness and adequacy of the site profile, as part of our preparation for drafting our site profile review. For that reason we would appreciate an early response, especially as NIOSH and ORAU are already familiar with the comments of the workers during the July 1, 2004, meeting organized by NIOSH.

The documents identified to date primarily include information gained from the FUSRAP site, labor unions, congressional staff, newspaper articles, uranium metallurgy reports, and reference books. These documents constitute only a fraction of the source information listed in *Technical Basis Document: Basis for Development of an Exposure Matrix for Bethlehem Steel Corporation, ORAUT-TKBS-0001*. The National Institute for Occupational Safety and Health (NIOSH) to date has not provided the source documentation available in their database. This includes critical information, such as the air sample data upon which NIOSH is basing its assumptions for internal dose. Not having access to these data has hampered our work. Please send us the source documentation so that we can proceed with our reviews in a timely manner.

In addition to document review, Arjun Makhijani attended a July 1, 2004, meeting organized by NIOSH in Hamburg, New York, with some Bethlehem Steel workers, members of their families, and representatives from NIOSH and ORAU. The workers discussed the rolling process in some detail, including failures in the rolling process, facility cleaning operations, facility maintenance and repair, and potential sources of residual contamination in both the workplace and the environment. As a result of document reviews and interviews with workers, a number of issues with respect to the Bethlehem Steel technical basis document (TBD) have surfaced. What follows is a summary of these issues and questions. The questions relate to the list of issues. This memorandum discusses the issues first, followed by the questions we would like to discuss at our next conference call.

I. ISSUES

There are a number of routes of exposure that were not discussed in the Bethlehem Steel TBD. These routes include those from routine operations as well as incident situations. We recognize that the airborne radionuclide concentration distributions provided in the TBD were designed to capture the uncertainty in the range of operational conditions. Nevertheless, we would like to discuss how the following routine and off-normal operating conditions may have impacted some workers at the facility.

A. Potential Routine Exposures not in the TBD

- Billets and product bars were stored on site, creating a potential for external exposure and possibly some internal exposure (due to fines and scale on the rods and billets).

- Workers sat on uranium billets that were stored in the bar mill. Sitting on billets is of concern with respect to external dose, and could affect doses to several organs significantly, including skin, bladder, prostate, and testicles. (Note that one worker commented on unexplained swelling of testicles at the time.)

- Ingestion doses from contamination of food and water due to uranium dust settling on their food and beverages. Workers ate in the bar mill.

  (Note: NIOSH indicated at the Advisory Board meeting in Buffalo that an ingestion model was under development. This model was not made available for review.)

- Cleanup was not done properly; it was perfunctory. This creates the potential for long-term exposure for the four years of rolling and even afterwards.

- The uranium was cleaned with brooms and water hoses. Air hoses were also used from time to time. This creates a potential for exposure of clean-up workers. It also creates a potential for re-suspension and re-deposition on working and other surfaces.

- Uranium billets were hosed down with water as the rolling was being done to wash off the scale. The scale and dust were flushed into a sub-basement. The pits were cleaned out, likely resulting in exposure to clean-up workers, crane operators, and railroad workers. Worker testified that the scale pit was manually shoveled also about once in six months, perhaps creating an additional potential for increased exposure. The scale pit was cleaned out with a crane about once a week.

- Doses from deposition of uranium on steel stored in the mill and subsequent re-suspension.

- Workers crawled into furnaces to repair them. This likely resulted in a substantial increase in internal and external exposures for some workers.

- There was a high potential for internal contamination of equipment (e.g., furnaces) by uranium dust. The residual uranium could create the potential for exposure long after uranium operations were completed.

- Workers blew lime off the walls, which may have been mixed up with uranium.

- There were emissions via a roof vent or stack.

- It is unclear how the salt baths were cleaned out. It is assumed that the salt baths were emptied and the material was dumped. There would be some uranium contamination in the salt.

- Workers handled billets and rods during loading and unloading and also sometimes to straighten them.

- Repairs of breakdown during furnace operation were performed during operation. What might have been the particulate levels during repairs? Were repairs of this nature considered part of the rolling operation, and, if so, did they create the potential for increased exposures?

- Dust from cranes came down on workers. Dust coming down after completion of rollings and after all rollings were done would have the potential for additional exposures.

- Uranium dust settled on steel rolls and scrap, creating exposure potential.

- Workers tracked contamination home on clothes and in their cars. Also, emissions created offsite dust.

- The butts, scraps, and scale may have been fed into the blast furnace. This would cause a mixing of steel and uranium resulting in a potential for some exposure.

- There were cropping and cutting operations involved with uranium billet production as a part of routine operations or with failure of the billet to form. Cropping and cutting can generate uranium dust resulting in a potential internal exposure.

B. Potential Exposures due to Incidents

1. Cobbles

Billets that are being rolled sometimes get twisted during the rolling and the bars get completely tangled. This is called a cobble. Workers have to get out of the way and then cut up the cobble into small pieces, creating dust. The pieces were then loaded and transported offsite. The hot pieces led to burns and scratches. As the cobble is burned into small pieces, they also create slag and drips over gratings and sluiceways, which are then flushed into scale pits.

In addition to exposure via the inhalation pathway, such transients create the potential for direct incorporation of uranium metal and oxide fines via burns and scratches. The rods would have had some oxide scale.

2. Salt Bath Leaks

There were salt bath leaks. The welds on the steel pan containing the salt bath failed each time, according to Ed Walker, who cites a 1952 National Lead of Ohio (NLO) document to that effect. On one occasion, the leaks stopped the whole operation for four hours. The repair and cleanup of the leaks may have created exposure potential during time periods not explicitly addressed in the TBD.

3. 1977 Fire

If the 1976 ERDA documents are correct, there would be no exposure from the 1977 fire. However, worker testimony regarding lack of clean-up, scale pits, and contamination outside the building creates some doubt regarding the claims made by ERDA. This raises a question about how much residual uranium there may have been in the dust on site during the 1977 fire. The steel was covered with grease to prevent rust, and this led to a vigorous fire due to the oil and grease all over the site.

II. GENERAL QUESTIONS RELATED TO BETHLEHEM STEEL

1. We have prepared above a list of possible internal and external exposure potential situations at Bethlehem Steel that do not appear to be taken into account in the TBD. Can NIOSH/ORAU comment on each one as to whether it should be included in a revised TBD and in revised dose calculations?

2. Page 2 the TBD states: "Because of material accountability procedures, scale, residue and cropped ends were collected and fine debris was vacuumed, packaged, and sent back to the AEC;" pg. 5 of the TBD identifies the following total number of 10-hour exposure workdays for the years 1949 through 1952:

Year	No. of Exposure Workdays (days)	Total Exposure Time (Hours)
1949	12	120
1950	12	120
1951	13	130
1952	11	110

In Tables 2a and 2b, the TBD derives annual intakes from inhalation based on the above-cited number of hours.

In brief, the TBD not only assumes that internal exposure was limited to the inhalation pathway, but further assumes that this exposure was exclusively confined to those workdays when uranium billets were processed based on "accountability procedures."

NIOSH's model assumptions raise serious questions regarding their validity and conservatism for the following reasons:

Description provided by W.H. Finkeledey in the April 3, 1950, report "Rolling Mill Report Hanford Works," Document No. GEH-16600.

The following passage on pp. 3-4 provides an insight about airborne environments associated with the uranium billet rolling process:

> *The health problem results from dispersion in the air of radioactive uranium oxide, a coating of which forms on the surface of the metal as it is being rolled. At the temperatures reached in rolling, oxidation of the metal is very rapid and even actual burning of the metal in local areas frequently occurs. The oxide scale layer builds up quickly to a relatively thick, brittle and non-adherent coating and the distortion of the billet and rod surface during the rolling mill operation, as well as the friction between the roll surfaces and the rod itself, causes the scale to readily flack off. The oxide, as it breaks loose from the rod surface, has a wide range of particle size all the way from flakes approximately ½" in diameter to particles so fine that they will remain air-borne in still air for several hours. Since any practical approach to the rolling mill operation rules out the use of an inert, non-oxidizing atmosphere to surround the rod at all stages of its rolling, the rolling of uranium metal is accompanied by the production of uranium oxide which takes place rapidly at all times as long as the metal is above 300˚ C. Another contributing factor to the formation of oxide occurs when the rod slides over a stationary surface during its rolling in the upper temperature range. The friction so developed frequently raises the temperature sufficiently to induce active burning of the metal to start at such contact points.* [Emphasis added.]

Since internal exposure through inhalation is dominated by micron-sized particles, as described above, the mere need for "material accountability" of tons of rolled uranium would not likely depend on the insignificant collection of micron-sized particles that were not likely to have been collected, but would remain in the workplace well beyond the episodic dates of rolling uranium billets. The assumption of total accountability as assumed by NIOSH is further contradicted by recent testimony of scale being flushed into the scale pit, provided by former workers at Bethlehem Steel (Arjun Makhijani, *Notes of meeting in Hamburg, NY on Bethlehem Steel operations for AEC, July 1, 2004*, meeting organized by NIOSH/ORAU.) Furthermore, according to the report *Extraction and Metallurgy of Uranium, Thorium and Beryllium* (Section 3.4.1), in the best circumstances, a metal loss of 0.9% could be expected, though much of this might be recovered, of course.

Some doubt is also thrown on to the AEC claim that dust and fines were collected by a September 12, 1951, trip report (W.T. Kattner, *Trip report: Visit to AEC New York Operations Office, Lackawanna Plant, Bethlehem Steel Company, Argonne National Laboratory, August 24-29, 1951*. The starting page number for this document in the Hanford documents database is HW-22347). On page 2, the document states that "[d]uring air cooling, about 100 pounds of oxide fell on the floor and blisters about 1/10 inch high appeared at the points where the rods rested upon the rails." This is a huge amount of dust from one operation involving a partial rolling of 23 bars, which had been reduced to 1.73 inch diameter at another location (Watervliet, NY -- see the same page in the document cited in this paragraph). This raises questions of how much uranium might have been discharged to the scale pit during the washing that accompanied each rolling. Note that the uranium dust on the floor would likely be mixed up with far larger amounts of steel dust. The description of this also puts the AEC claim regarding recovery of fines into question. Did NIOSH/ORAU make estimates of how much uranium may have been lost in this way?

3. Table 1 on pg. 3 of 14 lists the documented rollings at the Bethlehem Steel Corporation in Lackawanna, New York. Hanford was one of the sites that received and analyzed the uranium billets. As a result, they documented the analysis. *Trip Report: Experimental Rolling of Thirty Tons of Uranium By The Simulated Fernald Process* (HW-23697) indicates that 30 tons of case uranium billets were rolled to Hanford specifications at Allegheny-Ludlum Steel and Bethlehem Steel on February 16, 1952.

   The TBD acknowledges that there may have been some rollings in 1955 according to a letter from Paul Kansanovich (Compensation Agent, L.U.) to Robert Anderson (Bethlehem Steel) in 1979. Worker testimony is that there was something that went on that was secret in 1956, probably uranium rolling. NIOSH/ORAU has the opinion that this might have been Navy work, which is not covered under the law. The only available documentation with respect to rollings post-1952 is two affidavits signed by two Bethlehem Steel workers. Furthermore, one worker, John Dimitroff, has raised the possibility that Fernald may have sub-contracted rollings to Bethlehem Steel when their rolling mill was down and they needed to meet production quotas. NIOSH/ORAU responded that this would show up in Fernald documents. This presumes that Fernald documents are complete and Fernald materials accounts sound. However, the latter are questionable. For instance, the Book-Physical Inventory Difference (B-PID) at Fernald over its operation ran into hundreds of tons.

   Has NIOSH/ORAU performed a comprehensive records review for records associated with Bethlehem Steel operations at facilities other than Fernald, such as Hanford, the Savannah River Site, and the Chalk River Experiment, which ultimately received the uranium rods from Bethlehem Steel? If so, how was the information included in the analysis? What is the claimant-favorable approach to the number of rollings in the post-1952 operations?

4. Workers claim that crops were put back into the furnace along with steel, and that uranium fines and scale from the scale pit were fed into the blast furnace. Has NIOSH/ORAU looked into this before accepting the AEC claim regarding careful materials accountability?

5. The reliance on dose reconstruction on field data, including air samples, leads to questions regarding the effectiveness of instruments used at the time. What instruments were used to count the air sample activity? Were air sample analyses performed using portable or fixed instrumentation? What was the estimated minimum detectable activity for these instruments? Were the instruments fully functional in the field conditions

presented by rolling uranium? What correction factors were applied to the data (i.e., crossover, self-absorption, collection efficiencies, etc.)?

6. Does NIOSH have any data on the uncertainties in the measurements of air concentrations in the late 1940s and early 1950s? They were generally reported as deterministic values. How does one determine if these are claimant favorable? SC&A would like copies of all the documents showing the air sampling data and any others that would shed some light on the reliability of the measurements, the method of analysis used, and the characteristic of the samplers (such as airflow rates and filter types). This request includes instrument manuals for the instruments used at the time.

7. Given that this area of the country has an elevated radon background, what type of corrections were done to account for natural radon and thoron levels?

8. NIOSH/ORAU has assumed an average number of hours of exposure as 120 per year, but this would account for only direct rolling time. Does the exposure time need to be changed by the many additional routes of exposure both during 1949-1952 and subsequent to termination of uranium rolling? For instance, if these other sources of routine air contamination amounted to 1.0xMAC for four work years, with 2,000 work hours per year, then the total exposure equivalent in MAC-hours would be 8,000 MAC-hours. This compares to an exposure of 960 MAC-hours over four years corresponding to the mode of the triangular distribution (2xMAC) used in the TBD.

9. More generally, it would appear that a number of items in the list of issues above may significantly modify the time distribution of air concentrations of uranium and hence also of individual worker exposure. These items are not in the TBD. Has NIOSH evaluated this issue since the publication of the TBD? Which items does NIOSH believe are significant enough to lead to changes in facility radiological characterization or in estimates of individual worker radiation exposure? (We address the statistical aspects of these questions in Section III below.)

10. Does the exposure time need to be changed with respect to the workers' claims that they worked double shifts?

11. Did NIOSH/ORAU investigate the level of activity performed by steel mill workers and take this into account in determining breathing rates?

12. Why did NIOSH/ORAU choose to use a constant value for estimated maximum external dose due to submersion and use a triangular distribution for other types of exposure?

13. Do the Table 3 skin doses take into account deposition of dust on skin? How much? How long? From bullet points on page 8 and the semi-infinite plane model discussed on page 7, it seems that skin deposition is not taken into account. Is this right?

14. On pg. 8 of 14 NIOSH/ORAU refers to the use of a shielding factor for clothing in the case of male genitals and breast cancer. What shielding factor is being used?

15. When calculating external photon exposure, what exposure time was assumed?

16. There appears to be a need for a default assumption regarding the appropriate electron organ dose conversion factor to apply at uranium facilities. What progress has NIOSH made in assigning appropriate organ dose conversion factors?

17. One claimant indicated that her husband had worked with radioactive cobalt at Bethlehem Steel. Radioactive cobalt is used in the automotive industry to test steel quality. Has NIOSH/ORAU investigated whether radioactive cobalt was used in the uranium rolling process as some sort of quality check?

The TBD does not address the potential for exposure from residual radioactivity. They reference surveys performed in 1976 and 1980 under the FUSRAP program, which showed no detectable contamination above background. The intent of these surveys was to demonstrate that there was no potential for radiological exposure at that time and following the time period the survey was performed. The survey was not comprehensive with respect to the entire rolling operation (e.g., furnaces, cranes, etc.). The floor and the pit where the bar mill was located was covered with a new concrete floor. Has NIOSH performed a comprehensive search of records relating to contamination and radiation surveys performed during uranium billet production operations? Has NIOSH/ORAU estimated potential dose from residual contamination on the floor, equipment, scrap metal, and building structures?

18. There is no mention of environmental dose in the TBD. Has NIOSH/ORAU considered potential dose due to releases from the stacks or vents?

19. Has NIOSH/ORAU investigated the waste disposal procedures for Bethlehem Steel and potential exposure from waste disposal sites?

20. The x-ray dose assumptions in the TBD appear to have the same issues as we have raised before. Does NIOSH/ORAU agree?

21. Does worker testimony indicate enough uncertainty regarding external and internal routes of exposure to warrant a re-examination of the assumption that certain cancers, such as prostate and bladder cancer, are not likely to be compensable for Bethlehem Steel workers? For instance, does NIOSH believe that doses from sitting on uranium billets during lunchtime or other breaks should be estimated?

22. Worker testimony indicates that there may be documents at Saylorsberg, PA, Bethlehem Steel HQ. NIOSH/ORAU indicated at the July 1, 2004, meeting in Buffalo that it has not examined this possibility for documents and that it will do so. Is NIOSH going to undertake a document retrieval mission there and, if so, will it be possible for SC&A to designate one or two people to accompany the mission?

III. STATISTICAL QUESTIONS RELATED TO BETHLEHEM STEEL

We have several questions relating to statistical matters, other than those related to the validity of the measurements and uncertainties in the reported concentrations.

1. The air concentration measurements are based on samples taken in particular areas for short time periods. How are the distributions in Tables 2a and 2b based on these measurements to be converted to distributions that represent individual exposure?

2. Specifically, assuming that the data are valid and that credible confidence bounds (and an appropriate probability distribution) can be established, do we have sufficient air concentration data over (1) time, (2) space and (3) process type (in regard to coatings and method of heating) to come up with a claimant-favorable air concentration distribution or any credible air concentration distribution for the periods during which rollings occurred? What confidence bound would one use? 90%? 95%?

3. What was the technical basis for selecting 140 dpm/m^3 as the mode? (It should be noted that SC&A has not been able to obtain documents that contain the limited survey data referenced in the TBD.) Is it reasonable to assume a single mode for two distributions for which the maximum air concentrations varied by more than a factor of 14? Has NIOSH/ORAU done sensitivity calculations regarding the effect of the choice of the mode in Tables 2a and 2b on various types of cancers and various ages at which the cancers might be contracted? And has NIOSH/ORAU done sensitivity calculations as regards the choice of distribution? If so, could NIOSH/ORAU supply the results of its calculations to SC&A? We have performed a few preliminary sensitivity calculations for a couple of different cancer types (lung, prostate, bone). These calculations indicate that the choice of mode does not significantly affect the outcome regarding the probability of causation (PC) for the non-metabolic cancers that we looked at. This is because the PC appears to be dominated by the upper limit of the triangular distribution. For these cases, other routes and times of exposure (such as sitting on billets, re-suspension, accidents, and maintenance work may be more important – see below). On the other hand, the choice of mode may affect the PC in cases where the PC using Tables 2a or 2b is already large – that is, not far from 50%. Does NIOSH agree that such sensitivity calculations are a crucial check on the robustness of the PC result? What kind of sensitivity calculations should be performed? (We stress that our calculations are preliminary and were done only in order to explore what role this single factor, the choice of mode in Tables 2a and 2b, may play in the estimate of the PC in various circumstances.)

4. Given the many uncertainties, has NIOSH considered using a single upper bound number for air concentration, such as the 1,000xMAC in Table 2b, to calculate all doses, so far as the routine exposures during the times of production are concerned?

5. Given the uncertainties and the many problems with using air concentration data, has NIOSH/ORAU considered any alternative approaches for estimating routine exposure during production? For instance, has NIOSH considered an estimation procedure based on production data and data on losses? If so, would NIOSH share the results of its investigation into alternative methods?

6. The issues and questions in Sections I and II indicate that there are a number of pathways and times of exposure that may be significant that are not considered in the TBD. At present, the TBD assumes a deterministic time for non-zero air concentrations for each year of rolling (see columns 1 and 6 of Tables 2a and 2b). These times of exposure are limited to the assumed annual integrated duration of the rollings for the facility as a whole. Incidents are not explicitly taken into account. Given the worker testimony that NIOSH and ORAU have heard since that time (including on July 1, 2004) and other feedback, would it be reasonable to attempt to create a new time distribution of uranium air concentrations that would include factors such as re-suspension and maintenance work? Should a new distribution be constructed for the rolling mill as a whole, or should different time-dependent distributions be estimated for workstations and/or for job descriptions? Would such profiles of air concentrations over time be deterministic (along the lines of the present TBD) or probabilistic? In the latter case, what would guide the choice of the distribution and its parameters? Finally, are Bethlehem Steel data or data from comparable facilities of sufficient quantity and quality to create a scientifically supportable, claimant-favorable air concentration profile(s)?

7. How would new facility, work station, or job description profiles for uranium air concentrations over time be used to create individual worker exposure scenarios? For instance, how would incidents (such as cobbles or the 1977 fire), maintenance of furnaces and the rolling mill area, double-shift work, sitting on billets during breaks, ingestion, external doses due to immersion in contaminated air, etc. be integrated into overall, scientifically supportable internal and external dose estimates or probability distributions of internal and external doses for individual workers? What kind of probability distribution and claimant-favorable assumptions would need to be made for the various factors that may be important in individual exposure estimation? Finally, what are the sensitivity tests that would need to be done in order to test the robustness of the assumptions in regard to the determinations of the probabilities of causation for various metabolic and non-metabolic cancers?

ATTACHMENT 3

Summary of Site Expert Interviews

Over the course of the audit on Bethlehem Steel, Arjun Makhijani and Kathy Robertson-DeMers have had an opportunity to talk to a number of site experts. These site experts included a Crane Operator, a Recorder, an Apprentice Bricklayer, and an individual who worked both in operations and environmental safety and health. Arjun Makhijani also attended the meeting sponsored by NIOSH in Hamburg, New York, on July 1, 2004. The information the workers provided has been invaluable in providing us with a working knowledge of how a steel mill works, what level of effort is involved in the work, and what the working conditions are in a steel mill.

Below is a summary of various workers' interviews as they relate to the vertical issues outlined in the Bethlehem Steel review. This information provided is not a verbatim discussion, but is a summary of information from several interviews with several individuals. Individuals have provided this information based on their personal experience. It is recognized that these former worker recollections and statements may need to be further substantiated before adoption in the TBD. However, they stand as critical operational feedback where records and other documentation are lacking. These interview notes are provided in that context; former worker input is similarly reflected in our discussion and, with the preceding qualifications in mind, has contributed to our findings and observations.

Bethlehem Steel Company owned a number of steel plants, including the one in Lackawanna, New York. The home office of Bethlehem Steel was in Bethlehem, Pennsylvania. The Bethlehem Steel plant in Lackawanna, New York, extended a few miles along the Lake Erie shoreline and 1.5 miles on the other side of the road. There were over 100 buildings. The plant was like its own community with a hospital, restaurants, a fire department, and police. Approximately 25,000 employees worked at Bethlehem Steel. About 63 individuals per shift were required to operate the 10" mill and another 25 or so support employees were present. This did not include the individuals in the Secondary Work Area. The mill building was broken up into bays. The mill was about 120 feet x 1,000 feet x 90 feet. The building that the mill was a part of may have been as much as a third of a mile long.

Under optimum conditions 300-400 tons of material per 8-hour shift could be processed through the mill. Several routine and non-routine situations slowed down the process with uranium. First, samples approximately 18" long were torched off the billet for examination. They were cooled in a cold-water trough and taken to a desk. The metal was examined as a quality control check. Secondly, non-routine situations such as cobbling, salt bath leaks, or power outages would stop rolling operations. The shutdown time for cobbling depended on the stand where the cobbling occurred. If the uranium was relatively thin, it took as little as 10 minutes to correct. If the uranium was early on in the process, it could take several hours to fix.

1. URANIUM ROLLING HISTORY

Some workers clearly remember additional rollings in 1955 and 1956. Two former workers at Bethlehem Steel issued a Deposition of Fact that rollings took place post-1952. One individual indicated he was involved in a uranium rolling in April or May 1956, a few months before he was drafted into the Army. The second worker reported that several rollings occurred in 1955. Rollings usually only took one day, although there were multiple shifts.

Workers are concerned about the absence of records on rollings that occurred at Bethlehem Steel. Some workers suggested that records may be available in Saylorsburg, Pennsylvania, where the records storage facility was located. Another worker suggested we talk to Bob Custer, who was the Assistant Superintendent of the mill. A number of workers have indicated that records were destroyed.

2. EXTERNAL EXPOSURE FROM CONTACT WITH URANIUM

Due to the nature of the milling process, workers handled the uranium metal at various stages of the shipping and receiving, milling, and secondary finishing work. Some of the jobs that required direct contact with the uranium included:

- Inspectors who had to perform hands-on inspection of the metal
- Chippers who were responsible for removing impurities or slag from the metal with an air gun
- Scarfers who used a torch to remove deeper impurities from the metal with a torch
- Shearers who had to manually feed the material into the blades
- Laborers that would physically place the material in the shipping area after shearing
- Straighteners who had to remove bulges from the product

Due to the nature of the uranium, it often had to be manually fed into the rolls using levers, bars, or sledgehammers. The product was checked throughout the rolling process, as the tolerance was tight. In many cases the workers in the rolling process and secondary finishing area were within six inches to one foot of the uranium metal. At times the uranium was in direct contact with parts of the body. Specifically, uranium was handled with gloved and ungloved hands and carried against the abdomen to the finishing area. Some workers indicated that they sat on uranium billets stored in the rolling mill area.

Workers did not know what the material was, although some of them noted that truck signage indicated it was radioactive material. Some workers were aware the material was used for the atomic bomb program. They were not provided radiation safety training. The only thing they were told was not to take it home; otherwise they would become sterile. Some men ignored this warning and took pieces home anyway.

Uranium was usually brought in several days before the rollings on trucks or railroad cars and staged in the Billet Yard. Workers indicated that this material was guarded. The overhead crane would come in with the chains, pick up the billets, and put them on the backside of the furnace (i.e., charging table). The Hookers who hooked chains to the uranium for unloading remained in the truck or railcar adjacent to the uranium until all the billets were unloaded. There were two types of rollings – right out of the furnace or the salt baths. The rollings from the salt baths were semi-finished billets, which were heated in salt baths and then fed into mill at around Stand 6.

Internal Dose Assumptions, Parameters, and Conditions

The workers brought up a number of issues that related to the potential dose from uptake of uranium.

(a) Calculation of Intake

Dust would commonly deposit in their nose and mouth. They often blew soot/dust out of their nose after work. There was dust buildup in their throats due to the dusty working conditions. One worker indicated that when he retired, it took him two weeks to finally clear his nose. Those workers who experienced both uranium and steel rollings indicated that uranium did not create as much dust as steel.

The steel industry was one of the heaviest industries in existence at that time. The level of physical activity was very high. Men could sometimes lose 10 to 12 lbs of water weight during a shift and were given salt pills to counter this loss of water. It was not a pleasant place to work. The workers were involved in heavy labor as long as the mill was running. If there was a loss of power or a shutdown, they were allowed to take a break for the period of the shutdown. Some workers had to work at even harder or heavier jobs after a breakdown to get the mill going again.

Employees worked one to two shifts (8-16 hours) during uranium rolling depending on their job. In addition, maintenance activities occurred outside the uranium rolling shifts. Often, maintenance was done on equipment during times when the mill was shutdown or when they were cleaning the scale pits. At times the workers would routinely be scheduled to work on holidays. Overtime would be optional if they wanted to make extra money.

(b) Ingestion Dose

The workers ate their meals in the production area, because they did not have a lunchroom. They typically ate sandwiches, leftovers, soup, etc. There were no stoves in the plant. They would cook or heat their meals on the furnace or the hot metal. Dust would settle on the food and in beverages if it wasn't wrapped or covered.

Workers did indicate that at the first two rollings, the industrial hygienist took samples of the drinking water.

Additional ingestion probably occurred because of the dusty air.

(c) Routine Exposure Conditions

Dust escaped into the ambient air. The largest concentration of dust was in the mill area. During activities when the mill was down, there was clear visibility. When they started rolling, the visibility was cut in half.

Scale was formed on the uranium metal as it cooled down. Scale was actually bits and pieces of the metal. Scale was an issue in the Secondary Work Area.

The mill proper did not have a stack. The furnace had a damper like a fireplace. There were windows up near the crane and fans without motors in the ceiling. The fans were not usable without the motors. Occasionally, a Crane Operator would open a window. The company was concerned about compliance issues so they made them close the windows. The steel on the side of the building sometimes blew off.

There was no exhaust ventilation on the operating rollers. The mill was an open mill and did not have enclosures surrounding the rollers or descalers. The rollers did have grating underneath, so that water and scale would drop to the subbasement. The only "dust contaminant" measure taken was to hang old rags, pants, and burlap over the stands and to wet the metal with water. The rags were actually put there to prevent the workers from getting doused with water. The water used to control the temperature on the metal would either run down into the subbasement or dissipate in the air. The only ventilation came from the wind entering the building through the end of the mill opened to the Billet Yard.

There was a portable vacuum system that was used to clean up periphery dust after uranium rollings. GM counters were used to locate larger pieces of uranium around the beds. Vacuuming was not always completed underneath equipment. There was no effort made to clean the inside of equipment.

Workers had to supply their own clothing. The nature of the work made clothing get very dirty. Some workers took their clothes home once or twice a week for washing. Other workers wore their clothes two to three weeks and then discarded them. Some workers wore long underwear to keep them cool in the summer and warm in the winter. They also wore heavy socks to keep their feet from getting black.

There was a changing room available with showers. The workers indicated that the dust would run off their bodies in the shower and color the water. Dust settled in their hair, so they had to wash their hair. Some workers changed and took showers prior to going home and others wore their clothes home. They would put on the same clothes the next workday.

PPE for hot work involved asbestos gloves and suits. Leather gloves were used for laborious tasks. In some cases they provided workers with safety glasses and helmets. Bethlehem Steel provided gloves for the first uranium rolling, but discontinued this practice after the first rolling. Contact work with uranium metal was performed with and without gloves. The workers could feel abnormalities in the billets and perform inspections better without gloves. Gloves were not secured with tape.

Although there were bathroom facilities, some employees worked up to a half mile away from the bathrooms and chose to relieve themselves in the production areas. This saved time as there were production incentives, which would sometimes cause fistfights among workers.

(d) Non-routine Exposure Conditions

Several incidents or occurrences happened during the uranium rolling process. Uranium was more difficult to roll because it was not heated to as high a temperature. During uranium rollings, they often had what was called a cobbling. A cobbling results from a misfeed or a jam by the metal. When a cobble happened the men had to clear the area to prevent burns from flying metal. A crane had to remove the cobble and men with hot gloves would cut it into pieces with a torch until the mill was cleared. The mill would not continue to operate when a cobble was in a roller. The time to remove the cobbles varied from 10 minutes to several hours.

The bricklayers were actively involved in maintenance of the furnaces at the plant. When there was a burnout or leak in the furnace, the "Hot Dog Gang" would be called in to perform an immediate repair. There was direct contact with the contents of the furnace. The operations continued during this time. During maintenance shutdown, they would let the furnace cool off and the regular bricklayers would come in and do a permanent fix on the furnace.

The salt baths were contained in welded steel shells. The welds in the salt baths would fail at times and cause a leak in the salt bath. One time this stopped rolling for four hours.

During shearing of the material, the uranium would spark resulting in a bright light, which in some cases hurt the worker's eyes. Although steel did spark when sheared, the level of sparking and the brightness of the light were less than with uranium.

3. POTENTIAL IMPACT OF EXPOSURE TO RESIDUAL CONTAMINATION

The floor of the mill was made of varying materials. There was grating under the rollers, steel plates over openings to the subbasement (pits), and float-finished concrete. Float-finished concrete is rough to help prevent slipping. There was also an accumulation of dirt and oil on the floor. A power cleaner was used to hold the dust down. When you used it, dust would blow all over the place. When workers returned to the mill on a Monday after weekend rollings, there was still dust present.

The water and scale would wash down through the grating into the scale pits. Water used to cool rolls and to clean was discharged into Lake Erie, which was approximately a half a mile away.

The rollers were switched out prior to each rolling depending on the specifications required for the roll. When the rolls were worn out or broken, they were thrown into the scrap car. There were stands 1 though 18, and each one of these stands had two rolls. When rolls became worn, the roll shop had lathes where the rolls were turned down. The shavings would go into the scrap pan. It would all eventually end up in the blast furnace.

Cleaning the inside of equipment was not a part of the routine cleanup operation. They also did not remove the burlap or rags from the stands after rollings. The AEC was more concerned about retrieving bigger pieces.

4. STATISTICAL ISSUES

Workers indicated that there were air, water, and other samples taken during the first two rollings. They do not remember it after that. They made no comments on the use of the triangular distribution. They were very concerned about the use of Simonds Saw air sampling data, as they didn't feel the facilities were comparable.

5. MEDICAL X-RAY DOSES

When asked if they had medical exams, most workers said that they did not. At least one worker remembers having an annual exam with x-ray, urinalysis and blood sampling. There is indication that some workers received exams and others did not. Bethlehem Steel did have its own hospital at one time called Moses Taylor Hospital. The plant also had its own infirmary, fire department, and police squad.

6. ODDS AND ENDS

(a) Rollers, Assistant Rollers, Mill Hands, Millwrights, Crane Operators, Laborers, Foremen, Cooling Bed Operators, Shearmen, Slipmakers, Gaugers, Cradle Men, Speed Operators, Looper Operators, Rougher Operators, Section Men, Chippers, Scarfers, and Inspectors were some of the individuals that were involved in the rolling process. There were also maintenance crews for the mill.

(b) Workers have indicated that when they have tried to get records from the National Archives or from the International Steel Group, they have had no success.

(c) Salt baths were cleaned by dumping the contents on the plant property.

(d) Dust was visible on cars outside the mill. It was seen on the streets of Lackawanna. The dust was either metal dust from rolling or blast furnace dust.

(e) Steel mill workers typically remained working at one steel mill and did not transfer to other mills. However, there were ups and downs where workers were laid off.

(f) Water dripped from the uranium when it was removed from the salt bath.

(g) Men were offered financial incentives for keeping the mill running.

The workers did not make any comments with respect to the solubility of the material.

ATTACHMENT 4

Statistical Approach Regarding Analysis of Air Concentration Data

This statistical appendix covers the following:

- Some basic principles that should guide the use of data when statistical models are used to represent it
- An analysis of whether the triangular distribution used in Table 3 is a statistically appropriate way to represent the data
- An analysis of the data relating to the most contaminated workstation on October 27, 1948, to the extent represented by air samples taken on that date
- An approach to fitting the Simonds October 27, 1948, dataset by a distribution more appropriate than the triangular, along with computations illustrating adjustments that might be made to compensate for claimant favorableness at the most contaminated workstations

The TBD has used triangular distributions to represent uranium air concentrations at Bethlehem Steel. Table 2 represents a distribution for estimating minimum inhalation dose. For reasons discussed in the body of this report, it is not discussed here. Table 3, which is used to calculate maximum inhalation doses, is the focus of this analysis. 42 CFR 82 requires maximum radiation doses determined "using worst-case assumptions" to be estimated in such a way that "it can be determined that the employee could not have incurred a compensable level of radiation dose" (42CFR82.10(k)(3)).

1. SOME BASIC PRINCIPLES

The dataset that is represented in one distribution should be coherent and internally consistent in that chosen distribution, and its application should be appropriate for determining individual doses of the claimants. As discussed in Finding 2, there are very few data points for individual workstations. As a result, the statistical issues relate to the combined use of a facility air concentration distribution and considerations of its use with workstation and other data to derive scientifically defensible, claimant-favorable dose estimates for individuals. The distribution chosen to represent the air concentration data points for the facility should be statistically sound. Table 3 of the TBD does not fit this criterion. The TBD states that the upper bound parameter is derived from air concentration data from the Simonds facility. As discussed in the main body of this report, Simonds data may be used for representing Bethlehem Steel concentrations, but this should be done with care.

We focus here on the issue of the method by which an appropriate facility distribution can be determined, and also on how the choices of values for use in maximum dose calculations can be made claimant favorable. We note that since there are differences of detail between Simonds and Bethlehem Steel, within overall comparability, it is preferable to use the data from Simonds alone to determine the distribution for use in Table 3. But the analysis below regarding lack of claimant favorability applies in any case, even if one considers only the single issue of how the data from Simonds are to be used to determine an upper limit for contamination in a uranium metal rolling facility. If NIOSH did not want to use Simonds data, it could have chosen other ways to address claimant favorability (for example by using the approach in ORAUT-OTIB-0004, as discussed in Procedural Conformance Issue 2). But once the choice to use Simonds data was made, it was essential that statistically defensible procedures be used to represent it. We discuss (1) ways in which only the data from the most contaminated workstation can be used to determine a maximum contamination estimate, and (2) how the entire October 27, 1948, Simonds dataset can be used to derive claimant-favorable and statistically defensible air concentration estimates. The latter is a two-step process. First, a suitable air concentration distribution for the facility is determined. Second, data from highly contaminated workstations are used to determine claimant-favorable values for especially hazardous locations.

The second basic principle is that the parameters chosen for the distribution should not violate the mathematical conditions required of the form of the distribution.

The requirement that dose estimates should be claimant favorable requires a third basic principle to be respected. If the claimants are known to have consistently been exposed to unusually high levels of contamination, then specific adjustments need to be made to ensure claimant favorability (see Section 4 of this attachment).

Finally, these statistical principles must be complemented by a technical analysis of the validity of the data for the purposes to which it is being applied. Specifically, Section 5 of the report discusses two questions – (1) the quality of the data (including uncertainties), and (2) the applicability of the general air and near workstation short-term samples to individual worker intake (ICRP 75).

2. THE TRIANGULAR DISTRIBUTION

The TBD uses an upper bound of 1,000xMAC for Table 3, a mode of 2xMAC and a minimum of zero. The minimum should be somewhat greater than zero, due to the detection limit of the instrument, but since this makes no material difference to the calculations, a zero value for the minimum can be used.

There is no generally accepted method for fitting the triangular distribution. One way to test whether a triangular distribution is a good fit is to use the method of maximum likelihood, because it respects the constraints of the problem. These are that there should be no data larger than the fitted upper bound and none below the fitted lower bound. Further, in this context the lower bound should be non-negative. This method is well known as being best in many contexts.

We have used a standard statistical technique called the Q-Q plot to assess whether the triangular distribution is a good fit for the October 27, 1948, Simonds dataset. The Q-Q plot for a triangular distribution derived by the method of maximum likelihood is shown in Figure A4-1. The October 27, 1948, data points are shown in Table A4-1. SC&A recognizes that NIOSH was not trying to fit this dataset, but to use the Simonds data to find a maximum for the triangular distribution for estimating maximum doses. The discussion in Sections 3 and part of Section 4 of this attachment focuses on this crucial problem. In this section, we assess whether a triangular distribution is an appropriate way to represent the October 27, 1948, Simonds dataset (the only one comparable to the conditions at Bethlehem Steel, where there was no ventilation). This is because finding a claimant-favorable way to assess the maximum dose or the upper limit of contamination at Simonds requires a representation of all or part of the dataset in a statistically appropriate way.

The Q-Q plot compares the actual data (sorted in ascending order) shown on the vertical axis in Figure A4-1 with the fitted points shown on the horizontal axis. The quantile is the increment used to fit the data, which is simply equal to (1/(number of data points)). In this case the number of data points is 38. Evidently the triangular distribution results in a very poor fit. In a good fit, the points would lie more or less along the straight line. Figure A4-2 shows a Q-Q plot for the triangular distribution in Table 3 of the TBD, assuming it represents the Simonds data. It is almost the same as that in Figure A4-1 and also a very poor fit. The choice of a triangular distribution to represent the dataset in question is therefore methodologically incorrect. As an aside, we note that all points, except that corresponding to the largest measurement, lie below the line. The maximum value is somewhat above the line. This means that, all other things being equal (e.g., ignoring issues relating to the validity of the air concentration data points themselves), the chosen distribution would provide a claimant-favorable estimate for locations that represent low air concentrations, except for workers in the most contaminated locations. Moreover, since the Simonds and Bethlehem Steel facilities are different in that the latter has more roller stations, this problem could be compounded. The main issue that emerges from the Q-Q plot is that the triangular distribution is not a methodologically appropriate way to model the October 27, 1948, Simonds dataset. Simply choosing a number near the largest measurement is also not appropriate. Using the Simonds data to find a maximum value for contamination or for assessing upper limit doses requires some statistical modeling of part or all of the October 27, 1948, Simonds dataset. This can be done in two ways that are discussed in the next two sections. Section 3 discusses the use of the data from the most contaminated workstation. Section 4 discusses how a facility air concentration profile can be constructed and how it can be used to determine claimant-favorable values for most workers and also for workers in the most contaminated workstations.

Another problem with the lack of fit at the high end of the distribution is that the October 27, 1948, data include measurements at only two of the three roller stations. This is because only two rollers were used that day, as opposed to three at other times (Spiegl 1949). This may make this particular dataset, the only comparable one available, less representative of the more contaminated areas at Bethlehem Steel for at least some rollings. At least six rollers were used at Bethlehem Steel (Sanderson 1952).

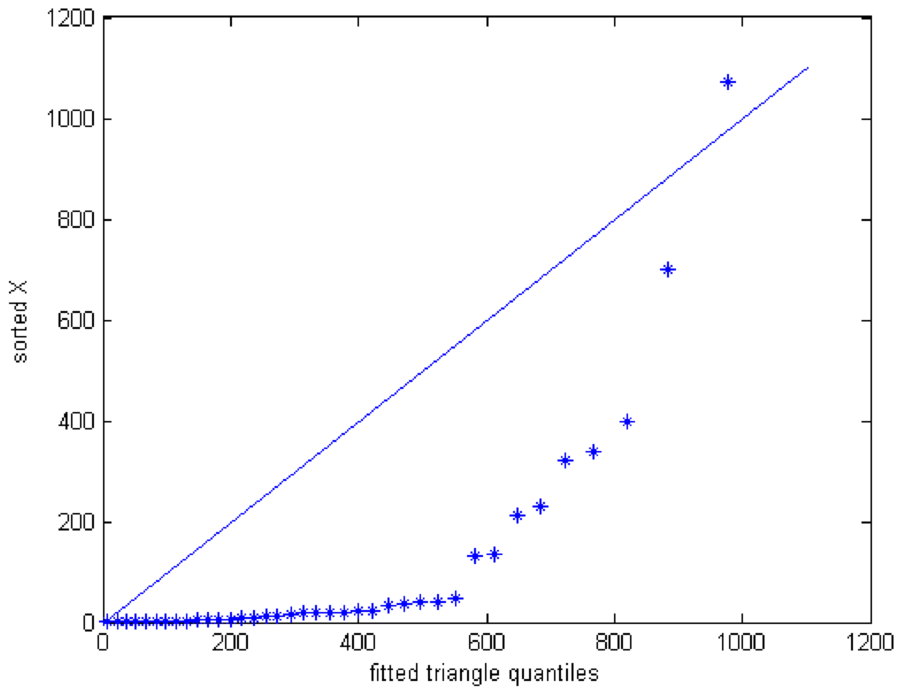

Figure A4-1. Q-Q Plot for Triangular Distribution Fitted by the Method of Maximum Likelihood

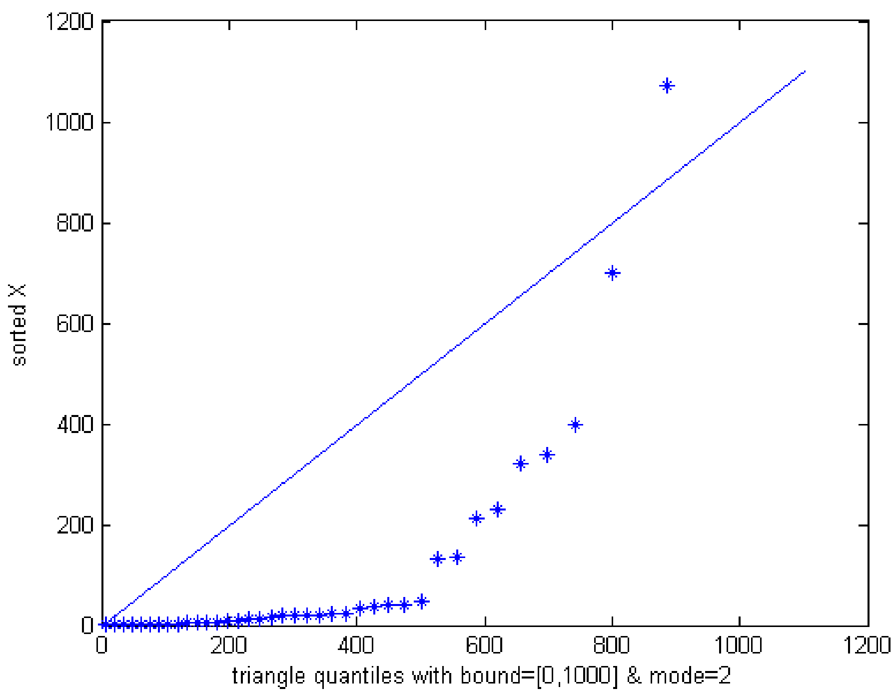

Figure A4-2: Q-Q plot for a Fitted Triangular Distribution with Parameters 0, 2xMAC, and 1,000xMAC

Table A4-1: October 27, 1948, Air Concentration Data: Simonds Saw and Steel

Sample Numbers	Type	dpm/m^3	xMAC
L700	general air between furnace and rollers south end	1410	20.14
L701	general air in front of furnace closed	42	0.60
L702	general air [illegible] N.W. of rolling platform	24	0.34
L703	mark U bars	2740	39.14
L704	general air in front of weigh scales near furnace	675	9.64
L705	remove scale and quench	3390	48.43
L706	take bar out of furnace	1470	21.00
L707	take bar out of furnace	1260	18.00
L708	take bar out of furnace	1615	23.07
L709	roller #1	49000	700.00
L710	roller #1	75000	1071.43
L711	roller #1	22400	320.00
L712	general air near roller 1	9250	132.14
L713	general air removing scale and quenching	1065	15.21
L714	general air at SW side of rollers near collector exhaust	147	2.10
L715	general air 8 ft SW and above first roller	63	0.90
L716	air sample exhaust from dust collector sampled 6' stack	126	1.80
L718	roller 2	14800	211.43
L719	roller 2	23800	340.00
L720	roller 2	27900	398.57
L721	roller #2 opposite end	943	13.47
L722	roller #2 opposite end	836	11.94
L723	roller #2 opposite end	418	5.97
L724	operators place rod thru descaler	9350	133.57
L725	operators place rod thru descaler	16150	230.71
L726	operators place rod thru descaler	2420	34.57
L727	BZ sample 3 rods going thru descaler	354	5.06
L728	general air middle of rolling west side 10' from roller	31	0.44
L730	general air by shears operator cutting rods	353	5.04
L731	general air center of locker room	24	0.34
L732	operator takes rod through roller #1 (opp. end)	1255	17.93
L733	operator takes rod through roller #1 (opp. end)	236	3.37
L734	operator takes rod thru roller #2 (opp. end)	2700	38.57
L735	general air middle (opp. end) of rollers #1 and #2 in operation	231	3.30
L736	general air rec. and ship weigh, drop rods to floor	330	4.71
L737	general air box car while loading and dropping bars	2740	39.14
L738	BZ scale man weighing bars dropping to floor	630	9.00
L741	general air in front of crane front of scales crane, bars dropped	1700	24.29

Note: Control measurements not included. 1 MAC = 70 dpm/m^3. Workstation descriptions are abbreviated. Source Appendix B, NYOO 1948.

In summary, the most basic arguments against the chosen approach and parameters in Table 3 are as follows:

- The triangular distribution is a poor fit for the October 27, 1948, data
- Table 3 does not respect the constraint that the fitted upper bound should be greater than the largest observed data point
- Other approaches should be used to develop the parameters needed for maximum dose estimation

3. MODELING THE UPPER BOUND OF AIR CONTAMINATION AT SIMONDS

It is possible to estimate an upper bound for the facility air concentration at Simonds by modeling the data at the most contaminated workstation. SC&A has done several different calculations to show how this can be done. All approaches result in values for the maximum air concentration greater than the value of 1,000xMAC chosen in Table 3. The most comparable values deriving from bounded distributions that have been estimated range from 1,447xMAC to 3,375xMAC. A triangular distribution was not used to model this data, since there is no generally accepted way of deriving the parameters and its use would be questionable here, since the analysis involves only three data points.

The workstation represented by sample points L709, L710, and L711 was probably the most contaminated workstation on October 27, 1948, at Simonds. The work there is noted as "Operator nearest furnaces places bar into 1st roller bar lengthened" (NYOO 1948). These three data points include the two highest measurements. All three are included in the five highest readings in the dataset.

Due to the very small sample size, no single statistical estimation procedure can provide a reliable estimate of the upper bound of air concentrations at this location and therefore for the facility as a whole. Various estimates of the upper bound parameter are derived using several common probability distributions as models for the data.

There are two general classes of probability distributions to consider, including bounded and unbounded families of distributions. Bounded distributions are defined on a finite interval. Examples of bounded distributions are the uniform(*a, b*), which is a flat distribution defined on the interval between *a* and *b* and the loguniform, which is a flat distribution but for the logarithms of the data points. The triangular distribution is also bounded, but for reasons stated above, we do not consider it here. In the case of the two types of bounded distributions considered here, estimation of the parameters of the distribution includes direct estimation of the upper bound parameter *b*.

The lognormal (μ, σ^2) distribution is a common example of an unbounded distribution, constructed using the logarithms of the data points. In this case, the estimates derived for μ and σ are used indirectly to make an estimate of the upper bound. Since the lognormal distribution is unbounded, a choice must be made to select a value for the upper bound parameter. The upper bound of a (one-sided) 95% prediction interval was selected to represent the upper bound of exposures. On average, a future measurement has a 5% chance of exceeding the 95% prediction bound.

Parameter estimates may be based on the maximum likelihood criterion (which may be biased in some cases), the minimum variance unbiased criterion, or the best linear unbiased criterion, among others. In general, maximum likelihood estimates are used in this discussion, unless a clear bias exists that is not claimant favorable. In these few cases, unbiased estimates are considered more appropriate. The parametric estimation process is best summarized as "fitting a distribution to the data using the selected criterion." Once the parameters of the distribution are estimated, an estimate of the upper bound parameter is made based on the best-fitting probability distribution.

3.1 Uniform Distribution

There are standard procedures for estimating the lower and upper parameters *a* and *b* of a uniform probability distribution on an unknown interval. The maximum likelihood estimators (MLEs) of *a* and *b* are $a^{MLE} = X_{min}$ and $b^{MLE} = X_{max}$, where X_{min} and X_{max} are the smallest and largest observed values, respectively. However, the MLEs are known to be statistically biased. The direction of this bias works against the claimant.

The best linear unbiased (BLU) estimators for the lower and upper bounds of a uniform distribution have a wider spread than the MLEs:[3]

$$a^{BLU} = X_{min} - \text{range}/(n-1),$$

and

$$b^{BLU} = X_{max} + \text{range}/(n-1).$$

The additional terms are a fraction of the range = $X_{max} - X_{min}$. The difference between the MLEs and BLU estimators is small for larger sample sizes, but the difference is very large for a sample size of n = 3. The BLU estimate for the upper bound parameter exceeds the maximum observed value (i.e., the MLE) by one-half of the range.

The BLU estimators improve the situation to a condition of being unbiased, but not necessarily claimant favorable. The range of uncertainty in the estimated upper bound must also be addressed. An approximate (one-sided) 95% upper confidence limit for b is given by:

$$UCL_{.95}(b) = X_{max} + \text{range}\cdot(1 + z_{.95}\, S_n) / (n - 1),$$

where $z_{.95} = 1.645$ is the 95th percentile of the standard normal distribution and $S_n^2 = n(n-1)/((n+1)(n+2))$. The 95% UCL for *b* has a larger fraction of the range added to the maximum observed value. For n=3, the result is $UCL_{.95}(b) = X_{max} + \text{range}\cdot(0.95)$.

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[3] Johnson, Kotz, and Balakrishnan, (1994), Continuous Univariate Distributions, Volume II, 2nd. Ed., John Wiley and Sons. All results are derived from equations 26.25a and 26.25b on page 286, using the alternative parameterization of equation 26.1 on page 276 with α = L and β = U.

The Simonds sample numbers L709, L710, and L711 were all taken at the same place; feeding the metal into roller # 1. The recorded alpha measurements for these samples were 49,000, 75,000 and 22,400 dpm/m^3, respectively. The three observations at roller #1 rank number 1, 2 and 5 in the full data set for that day, indicating that exposure for a good part of the day at this workstation is probably the worst case for worker exposure at Simonds. The maximum value of 75,000 dpm/m^3 is equivalent to 1071 MAC, while the range is 751 MAC. The maximum and range are sufficient statistics for estimating the upper bound *b* and the 95% UCL for *b*. The upper bound estimate is:

$$b^{BLU} = 1071 + 751/2 = 1447 \text{ MAC}.$$

The 95% upper confidence limit for *b* is:

$$UCL_{.95}(b) = 1071 + (751)(0.95) = 1785 \text{ MAC}.$$

3.2 Loguniform Distribution

Since the air concentration data vary widely and are highly non-uniform, the above procedures for the upper bound of the uniform distribution may be applied to the logarithms of the observed values. If the sample values have a loguniform(*a, b*) distribution, then the logarithms of the values have a uniform distribution on the interval from ln(*a*) to ln(*b*), where the symbol ln denotes the natural logarithm. Estimates for the lower and upper bounds of the loguniform distribution are obtained from:

$$\ln(a) = \ln(X_{min}) - \ln(X_{max} / X_{min}) / (n - 1).$$

and

$$\ln(b) = \ln(X_{max}) + \ln(X_{max} / X_{min}) / (n - 1).$$

An approximate (one-sided) 95% upper confidence limit for the upper bound b is derived from:

$$\ln(UCL_{.95}(b)) = \ln(X_{max}) + \ln(X_{max} / X_{min}) [(1 + z_{.95} S_n) / (n - 1)],$$

where $z_{.95}$ and S_n^2 are defined as in Section 3.1.

With the very small sample size, the uncertainties in estimating the upper bound of the distribution are large. This is particularly true for the loguniform model, due to the exponential effect of uncertainty. If we assume a loguniform distribution for the three Simonds observations, the corresponding results are significantly higher than were obtained using the uniform distribution. The estimated upper bound for the air concentrations at roller # 1 is:

$$\ln(b) = \ln(1071) + \ln(1071/320) / 2 = 7.580,$$

or

$$b = \exp\{ 7.580 \} = 1960 \text{ MAC}.$$

The 95% upper confidence limit for the upper bound is:

$$\ln(UCL_{.95}(b)) = \ln(1071) + \ln(1071 / 320) (.95) = 8.124,$$

or $UCL_{.95}(b) = \exp\{ 8.124 \} = 3,375$ MAC. The loguniform estimates of the upper bound and the 95% UCL for the upper bound at the roller #1 workstation are substantially higher than the estimates generated using the uniform distribution.

3.3 Normal Distribution

Now consider two unbounded distributions for these same three data points; the normal distribution and the lognormal distribution. The normal distribution is an unlikely candidate for air concentration measurements, but provides a good example to introduce terminology used for the lognormal distribution. For unbounded distributions, a 95% prediction bound ($p_{.95}$) is calculated for the next observation.

The normal (μ, σ^2) distribution is the most common of the unbounded distributions, with μ representing the mean of the distribution and σ^2 representing the variance. Parameter estimation for the normal distribution is well known. The MLE for μ is the simple arithmetic average of the observed values,

$$\mu^{MLE} = (X_1 + ... + X_n) / n.$$

The MLE for μ is also an unbiased estimate of the mean and the median of the normal distribution.

The standard deviation is calculated from the estimate for the variance σ^2. Two common variance estimates are the maximum likelihood estimate and the unbiased estimate. The MLE for σ^2 is:

$$S^2 = \Sigma (X_i - \mu^{MLE})^2 / n.$$

The MLE for the variance is biased. The unbiased estimate for σ^2 is $nS^2/(n-1)$. To be claimant favorable, the unbiased estimate of the variance is used as an alternative to the MLE.

The mean of the normal distribution is estimated as 697 MAC. The unbiased estimate of the standard deviation is 376 MAC. The 95% prediction bound for a normal distribution with these parameter values is $\mu^{MLE} + k_n t_{2,0.95} S$, where $t_{2,.95} = 2.92$ is 95th percentile of the t-distribution with 2 degrees of freedom and $k_n = \text{sqrt}((n+1)/n) = 1.155$. The estimated value of the 95% prediction bound is:

$$p_{.95} = 697 + (1.155)(2.92)(376) = 1965 \text{ MAC}.$$

3.4 Lognormal Distribution

The lognormal (μ,σ^2) distribution is the most common distribution used as a model for short-term air concentration measurements. Parameter estimation for the lognormal distribution is based on the logarithms of the observations. The parameter μ represents the mean of the logarithms, while σ^2 represents the standard deviation of the logarithms. Using the theory for the normal distribution described above, the estimate for μ is the simple arithmetic average of the logarithms of the three measurements,

$$\mu^{MLE} = (\ln(X_1) + ... + \ln(X_n)\ ) / n = 6.432.$$

The value $\exp\{\mu^{MLE}\}$ provides an estimate of the median of the lognormal distribution, but is not a good estimate of the mean of the distribution. The estimate of the mean of the lognormal depends on the estimates of the median and the standard deviation of the logarithms.

Following the procedure for an unbiased estimate of the variance of the normal distribution, the usual estimate for σ^2 of the lognormal distribution is:

$$S^2 = \Sigma\ (\ln(X_i) - \mu^{MLE}\ )^2 / \ (n-1) = 0.3757,$$

and S = 0.6129 MAC is the estimated standard deviation of the logarithms. The 95% prediction bound for the next observation is estimated by $\exp\{\mu^{MLE} + k_n\ t_{2,.95}\ S\}$, where $t_{2,.95} = 2.92$ is 95% of the t distribution with 2 degrees of freedom, and k_n = sqrt((n+1)/n). The estimated value of the 95% prediction bound for the lognormal distribution model is:

$$p_{.95} = \exp\{6.432 + (1.155)(2.92)(0.6129)\} = 4910 \text{ MAC}.$$

Using the maximum likelihood estimate of the variance produces a more conservative estimate of the 95% prediction bound. Using the MLE, the estimate for σ^2 of the lognormal distribution is:

$$S^2 = \Sigma\ (\ln(X_i) - \mu^{MLE}\ )^2 / n = 0.2505,$$

and S = 0.5005 MAC is the estimated standard deviation of the logarithms. The 95% prediction bound for a lognormal distribution with the MLE parameter values is estimated by:

$$p_{.95} = \exp\{6.432 + (1.155)(2.92)(0.5005)\} = 3360 \text{ MAC}.$$

3.5 Results

Due to the small sample size used in this analysis, it is not possible to select a single probability distribution for the Roller # 1 measurements. The strategy of using many commonly encountered distributions demonstrates that a wide range of results is possible using a variety of standard statistical procedures.

A variety of bounded and unbounded probability distributions were examined as possible modes for the three measurements at Roller #1, using both maximum likelihood and unbiased estimation procedures. As shown in Table A4-2, all estimates of the upper bound of the bounded distributions and all estimates of the 95% prediction bound for the unbounded distributions exceed the upper limit of the upper bound triangular distribution of 1,000 MAC reported in Table 3 of the TBD.

The various values for bounded distributions range from about 1,450xMAC to almost 3,400xMAC. This set of estimates would most closely correspond to a choice of an upper bound for a facility air concentration based on a bounded distribution and the assumption that the above workstation is the most contaminated one.

Estimates of the 95% prediction bound for the unbounded distributions range from a low of 1,965xMAC for the normal distribution up to 4,910xMAC for the lognormal distribution using the unbiased variance estimates. The range of over a factor of 3 between the lowest and highest estimates in Table A4-2 illustrates the difficulties presented by the small data set available for the most contaminated workstation. The point here is that given the limited data, it is possible to come up with a wide variety of estimates for the upper bound. Technical constraints such as data on uranium losses and/or visibility would have to be introduced to supplement the data to narrow the choice for the upper bound.

Table A4-2. Estimates of the Upper Bound or 95% Prediction Bound for Airborne Uranium Concentrations in MAC Units for Selected Bounded and Unbounded Probability Distributions (1 MAC = 70 dpm/m^3)

Type of Distribution	Estimate of Upper Bound (b)	95% Upper Confidence Limit for b $UCL_{.95}(b)$	Estimate of 95% Prediction Bound ($p_{.95}$)
Uniform(a,b)	1,447	1,785	--
Loguniform(a,b)	1,960	3,375	--
Normal(μ,σ^2)	--	--	1, 965
Lognormal(μ,σ^2) - Use unbiased σ^2	--	--	4, 910
Lognormal(μ,σ^2) - Use MLE for σ^2	--	--	3,360

4. A LOGNORMAL FACILITY AIR CONCENTRATION DISTRIBUTION

An alternative approach to estimating a maximum of the facility air concentration distribution is to model the entire dataset using a lognormal distribution. The Q-Q plot for this is shown in Figure A4-3. The fit is done using the maximum likelihood method applied to the distribution of the log data; it has a mean $\mu = 2.82$ and a variance $\sigma^2 = 4.57$.

Figure A4-3 is a plot showing the original data on the Y-axis and the fitted lognormal distribution also in multiples of MAC on the X-axis. It is evidently a much better fit for the dataset than the triangular distribution. Note that it does not represent the high end of the air concentrations well, but it is somewhat claimant favorable there. But it is not claimant favorable for the lower values of air concentration.

The problem of lack of claimant favorability for workstations at the low end of reported air concentrations can be addressed by using the 95th percentile value of this distribution as a claimant-favorable estimate. This value is about 570xMAC. (This is without regard to the issue of the validity of using unadjusted air concentration data, as per ICRP 75, discussed below.) This can be compared to the average of the triangular distribution in Table 3 of the TBD, which is 334xMAC.

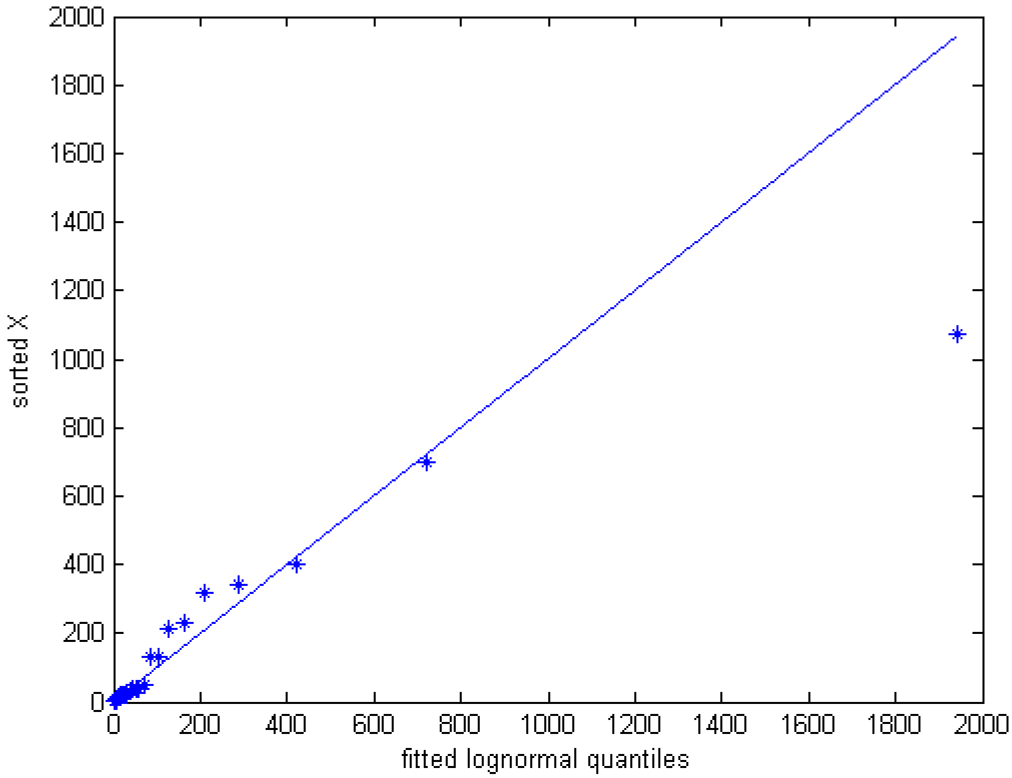

Figure A4-3. Q-Q Plot of the Original Data with Fitted Lognormal Distribution

Note that the 95th percentile value is not claimant favorable for highly contaminated workstations. This is because we know that the average of the three measurements at Roller #1 is 700xMAC, which is greater than the 95th percentile of the lognormal distribution. Therefore a claimant-favorable estimate for the most contaminated workstation must be considerably greater than 700xMAC, especially given that there are only three data points for this workstation. A claimant-favorable adjustment can made by making a specific modification for the upper bound of this distribution using these three data points (L709, L710, and L711).

4.1 A Methodology for Adjusting Upper Bounds on Exposure of the Lognormal Distribution

As before, we identify Roller # 1 as the source of the largest exposure. As noted above, the two highest air concentration measurements are at this station. The third measurement is among the top five, with the other two being at Roller #2. We identify the tail of the facility distribution as these top five measurements. It therefore includes all three points at Roller #1.

We assume that the lowest measurement in the tail of the distribution, which consists of measurements at the two most contaminated workstations, is L. A claimant-favorable solution is to take L = 320xMAC, which is the lowest measured value of the five data points in question (L709, L710, L711, as well as L719 and L720). The 95th percentile point on this tail, calculated using the t-distribution with 37 degrees of freedom of the logarithms of the 38 data points, would be about 8.379. This amounts to about 4,350xMAC.[4]

In sum, for exposure estimation of workers known not to be in highly contaminated areas, the 95th percentile value of the entire facility distribution may be regarded as a claimant-favorable estimate. This is about 570xMAC. For workers for whom there is no information about workstations (as for instance when the claimants are family members and do not have the information) or for workers in the more contaminated workstations, the 95th percentile of the adjusted tail of the distribution may be regarded as a claimant-favorable estimate. This would be about 4,350xMAC. As noted in the report, these figures are given here to provide methodological illustrations and not as recommendations for use, since actual values depend on more than statistical methodology. In particular, they also depend on evaluation of air concentration data.

5. AIR CONCENTRATION DATA

The air concentration dataset of October 27, 1948, is a mixture of general air samples taken over a few minutes to a few tens of minutes, with samples marked as taken at specific workstations. Only two samples are marked as breathing zone samples. There are more breathing zone samples in the Bethlehem Steel datasets. However, it is unclear how breathing zone samples were taken during the late 1940s and early 1950s, and whether they represented true sampling of the breathing zone. The implications of each of these three for use of the data would be different. The TBD has not addressed these issues.

ICRP 75 suggests that there are significant differences between the activity concentration in the worker breathing zone and the concentration measured at a fixed location, with the concentration in the breathing zone usually higher. ICRP 75 further recommends that conversion factors relating the area measurement to the concentrations in the immediate breathing zone should be established and applied. The use of such factors involves a great deal of judgment. There are no long-term data for validation. The air concentrations are highly variable with time and location. There was more than one process used at Bethlehem Steel. Much of the data is destroyed or lost. Some of the existing data is illegible. ICRP 35, *General Principles of Monitoring for Radiation Protection of Workers: A Report of Committee 4 of the ICRP*, the predecessor of ICRP 75, has suggested that under the circumstances at Bethlehem Steel, the actual breathing zone air concentrations may be two or three orders of magnitude different than general air samples (ICRP 1982). Sherwood has shown that air concentrations employees are exposed to can vary by 100-fold (Sherwood 1966).

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[4] The upper tail portion of the facility lognormal distribution was selected to represent the distribution of air concentrations near roller 1. The upper bound of a 95% prediction interval for this left-truncated distribution is located at the 99.3 percentile of the facility lognormal distribution. Hence, the 95% prediction bound for the roller 1 work station can be estimated by using the 99.3 percentile of a t-distribution with 37 degrees of freedom (corresponding to 38 data points) = mean + (sqrt(39/38))*2.566*(standard deviation), where the mean and standard deviation are estimated from the logarithms of the data points. In this case these estimates are about 2.82 and 2.14, respectively (rounded).

For instance, if the general air samples and the two exhaust-duct-related samples from the October 27, 1948, dataset are dropped, a set that is related to workplaces only is obtained. This can be taken at face value. In this case, the 95th percentile of a lognormal distribution works out to about 810xMAC. If the data values are adjusted upward by an order of magnitude, the result obviously would be ten times higher at about 8,100xMAC.

In view of the combined difficulties of the Bethlehem Steel, as well as Simonds datasets, the general approach that NIOSH developed in ORAUT-OTIB-0004 for all uranium metalworking AWE facilities is a possible attractive alternative. This is because instead of attempting to adjust the data on a facility-specific basis in light of ICRP 75, ORAUT-OTIB-0004 has used a different set of principles for examining all metalworking AWEs together to develop a claimant-favorable approach that might be more generally applicable. However, the constraint that some workers in highly contaminated areas may be exposed to more than the general procedure adopted must be kept in mind in making individual dose estimates.

6. SUMMARY AND CONCLUSIONS

The air concentration dataset from October 27, 1948, at Simonds has been modeled in order to assess the appropriateness of the distribution and the parameters used in Table 3 of the TBD to calculate maximum doses. In order to illustrate the method, these data have been taken at face value and no technical adjustments are made as recommended by ICRP 75. The results should be taken as illustrative of the methods we suggest, rather than definitive. More detailed discussion of the approaches for estimating dose is discussed in the main body of the report. In summary:

- The triangular distribution in Table 3 of the TBD is not appropriate on three counts. First, its mode has not been selected from the Simonds dataset. Second, the triangular distribution is a very poor fit for the data. Third, the maximum value in Table 3 violates the rule that the estimate of the upper bound parameter of a triangular distribution must be larger than the largest data point.

- A value for the upper bound of the facility air distribution can be obtained by modeling the most contaminated workstation as having its own air concentration distribution. A variety of widely differing estimates is possible, depending on the choice of distribution, since there are only three data points. The estimates for bounded distributions, which would be most comparable to the triangular case used in Table 3 of the TBD, range from about 1,450xMAC to almost 3,400xMAC.

- The entire facility air concentration can be modeled by a lognormal distribution. This is a much better fit for the data than a triangular distribution. The difference between this approach and the one just above is that, in this case, the air data for the most contaminated workstation are assumed to be part of a single facility air concentration distribution. In this illustration, the 95th percentile value of this distribution, which is about 570xMAC, may be used for assessing intake by workers who are not known to work in highly contaminated locations. But this is not claimant favorable for workers at the latter locations. In this case, the 95th

percentile value of the tail of the distribution defined as the five highest concentrations can be used. This is about 4,350xMAC.

- When air sampling issues are taken into account in light of ICRP 75, the entire estimation procedure becomes more complex and more disposed to subjective interpretation. A comparison of the application of ICRP 75 strictures to specific facilities with the approach taken in ORAUT-OTIB-0004 is needed to examine which approach is more scientifically defensible. Given the many difficulties with data from individual facilities, the general approach in ORAUT-OTIB-0004 obtained by examining data at many uranium metal working AWEs may be an attractive alternative and more technically defensible. A comparison of the two approaches is beyond the scope of this review. SC&A will review ORAUT-OTIB-0004 under Task 3.