REPORT TO THE ADVISORY BOARD ON RADIATION AND WORKER HEALTH

National Institute of Occupational Safety and Health

Audit of Case #PIID* from the Bethlehem Steel Facility

Contract No. 200-2004-03805 Task Order No. 4

SCA-TR-TASK4-CNPIID*

Prepared by

John Mauro, PhD CHP S. Cohen & Associates 6858 Old Dominion Road, Suite 301
McLean, Virginia 22101

February 2005

<table>
<tr>
<td>

S. Cohen & Associates:

Technical Support for the Advisory Board on Radiation & Worker Health Review of NIOSH Dose Reconstruction Program

AUDIT OF CASE #PIID* FROM THE BETHLEHEM STEEL FACILITY

Task Manager: ____________________ Date: 02/04/05
Hans Behling, PhD, MPH

Project Manager: __________________ Date: 02/04/05
John Mauro, PhD, CHP

</td>
<td>

Document No.
SCA-TR-TASK4-CNPIID*

Effective Date: February 4, 2005

Revision No. 1

Supersedes:

Draft Rev. 0

</td>
</tr>
</table>

TABLE OF CONTENTS

SUMMARY

This report presents the results of an independent audit of a dose reconstruction performed by the National Institute of Occupational Safety and Health (NIOSH) for an energy employee (Case #PIID*) that worked at the Bethlehem Steel Corporation from PIID*, through PIID*. This time period includes the time period (1949 to 1952) when the Bethlehem Steel facility in Lackawanna, New York, was under contract with the Atomic Energy Commission (AEC) to develop rolling mill pass schedules for the rolling of 5-inch natural uranium billets into 1.5-inch rods to be used in nuclear reactors. As a result of the worker's employment at the facility during and following the uranium rolling operations, the worker likely experienced internal exposures due to the inhalation of airborne particles of uranium oxide and external exposure from working in the vicinity of the uranium billets, rods, and residual uranium. In addition, the worker is believed to have had routine x-rays as part of Bethlehem Steel's medical surveillance program. The worker was not provided with film badge or thermoluminescent dosimeters (TLDs) to measure external exposures, nor were bioassays performed to estimate internal exposures. As a result, exposures experienced by the worker were estimated using the exposure matrix provided in the site profile or Technical Background Document (TBD) prepared by NIOSH for the Bethlehem Steel plant (ORAUT-TKBS-0001, March 31, 2003).

In PIID*, following his employment, the energy employee was diagnosed with multiple myeloma. Table 1 summarizes the results of NIOSH's reconstruction of the doses to the energy employee's red bone marrow for the purpose of deriving the probability of causation (POC) using IREP. Table 1 also presents the results of the audit. The results of the audit are expressed in terms of whether we found the exposures to have been derived in a scientifically valid and claimant-favorable manner.

The implications of this audit are that there are many aspects of the methods used by NIOSH to reconstruct the doses to the bone marrow of this worker that do not appear to be entirely scientifically valid or claimant favorable. However, there are other aspects of the dose reconstruction methods that are conservative. On balance, it would appear that there are many issues associated with the dose reconstruction methods used by NIOSH that need to be more thoroughly explored and which may reveal that the reconstructed doses to this worker were not as scientifically robust or claimant favorable as represented in the dose reconstruction report for this worker and the supporting TBD.

Table 1. Summary of Internal and External Exposure to the Red Bone Marrow as Estimated by NIOSH, Along with the Audit Results

(The values reported here are the modes of a triangular distribution)

Exposure Scenario	NIOSH Derived Annual Doses (rem)	Scientifically Valid?	Claimant Favorable?
Internal exposure from inhalation (alpha) during operations	About 3E-3 during AEC operations	We have concerns	We have concerns
Internal exposures from ingestion (alpha) during operations	Negligible	We have concerns	We have concerns
Internal exposure from inhalation (alpha) of residual resuspended particles following the conclusion of operations	Negligible	We have concerns	We have concerns
External exposures during operations (PIID*)			
Ground surface contamination (chronic)	Negligible	Yes, considering the method used to derive exposures to from uranium sources	Yes, considering the method used to derive exposures to from uranium sources
Natural Uranium Source (chronic)	0.1	Yes	Yes
Submersion in airborne plume (chronic)	Negligible	Yes	NA*
Diagnostic x-rays (acute)	0.027	Yes	Not necessarily
Chronic external exposure to residual contamination following the conclusion of AEC operations in 1952	Assumed to be negligible	Cannot be determined	Not likely

* NA refers to not applicable.

1.0 INTRODUCTION

This report presents the results of an independent audit of a dose reconstruction performed by the National Institute of Occupational Safety and Health (NIOSH) for an energy employee that worked at the Bethlehem Steel facility in Lackawanna, New York. This audit is one of several dose reconstruction audits being performed by S. Cohen & Associates (SC&A, Inc.) on behalf of the Advisory Board on Radiation and Worker Health.

This audit report makes extensive use of the findings provided in a separate report prepared by SC&A entitled *Review of NIOSH Site profile for Bethlehem Steel Plant, Lackawanna, NY* (SCA-TR-TASK1-001, October 2004). The review of the site profile prepared by SC&A is currently being reviewed by NIOSH. We expect that NIOSH will provide comments on the SC&A site profile review that, upon consideration by SC&A, may affect the findings of this audit report.

This report has been prepared taking into consideration this extensive factual accuracy and technical review process.

Part one of this audit report presents a summary of our understanding of the doses derived by NIOSH, along with a brief description of the basic approach and assumptions employed by NIOSH to derive the doses. This material is extracted directly from the final dose reconstruction report published by NIOSH for this case, along with supporting documentation, including the Technical Basis Document (TBD) for the Bethlehem Steel facility (ORAUT-TKBS-0001, March 31, 2003). This section of the report summarizes our understanding of the methods used by NIOSH to reconstruct the doses to workers, and also serves as a baseline for the discussion and audit provided in Section 3 of this report.

Part two of the audit process (provided in Section 3 of this report) consists of an attempt to independently reproduce doses derived by NIOSH and a discussion of the validity of the methods employed. The doses selected for review are based on the judgment of the reviewers as to the importance of the particular doses to the totality of the doses experienced by the energy employee. The reason for this step in the audit process is to provide the author, NIOSH, and the Advisory Board with a level of assurance that the auditors understand how NIOSH went about deriving the doses provided in their dose reconstruction report. In the process of attempting to reproduce the NIOSH derived doses, we also provide a critical review of the fundamental data, information, models, and assumptions used by NIOSH to perform the dose reconstruction. This review draws heavily from a draft review of the TBD prepared by SC&A and submitted to the Advisory Board in October 2004.[1] This part of the audit explores the degree to which the data are adequate to support the dose reconstruction, and whether the models and assumptions adopted by NIOSH to perform the dose reconstruction are scientifically sound and claimant favorable. Areas where the methods are found to meet these criteria, or are deemed to be inadequate with regard to these criteria, are identified and discussed. The report is not exhaustive in the review of these matters, but is limited to those areas of inquiry that are judged by the auditors to be significant with respect to the dose reconstruction and the derivation of the probability of causation (POC).

[1] SC&A's review of the Bethlehem Steel TBD was delivered to the Advisory Board in draft form in October 2004. The report is entitled *Review of the NIOSH Site Profile for Bethlehem Steel Plant, Lackawanna, NY*, Contract No. 200-2004-03805, Task Order No. 1, SCA-TR-TASK1-001, October 2004. The Board has not yet officially accepted the report, and NIOSH has not yet had an opportunity to respond to the SC&A's findings.

Methods employed by NIOSH that are found to be either scientifically inappropriate or not necessarily clamant favorable are identified, but no attempt is made to correct these deficiencies and redo the dose calculations. It is assumed that NIOSH and the Advisory Board will have an opportunity to consider the results of this audit and determine whether a revision of the dose reconstruction is needed, and if so, how to go about making the necessary revisions.

2.0 SUMMARY OF DOSES

The energy employee worked at the Bethlehem Steel Corporation from PIID*,, through PIID*. This time period includes the time period (1949 to 1952) when the Bethlehem Steel facility in Lackawanna, New York was under contract with the Atomic Energy Commission (AEC) to develop rolling mill pass schedules for the rolling of 5-inch natural uranium billets into 1.5-inch rods to be used in nuclear reactors. In PIID*, following employment, the energy employee was diagnosed with multiple myeloma. Table 2 presents the results of NIOSH's reconstruction of the doses to the energy employee's red bone marrow for the purpose of deriving the probability of causation (POC) using IREP.

The notations used in Table 2 to present the doses include the year in which the dose was received by the organ of interest, the statistical distribution that was used, and the key parameters for the distribution. For example, for exposure period number 1 in Table 2 (PIID*), internal exposure of the bone marrow to alpha emitters is assumed to have a triangular distribution with a minimum of 0, a mode of 1.35E-3, and a maximum of 9.57E-1 rem due to the inhalation of uranium dust. A discussion of various types of statistical distributions and other parameters used as input to NIOSH-IREP is provided in NIOSH (2002). The internal dose to the organ of interest was determined by NIOSH to have a range of 0 to 24.2 rem, with a mode of 0.034 rem. The external dose to the organ of interest was determined by NIOSH to have a range of 0.07 to 1.23 rem, with a mode of 0.56 rem. Based on these reconstructed doses, the POC was determined to be less than 50%, and the claim was denied.

The final dose reconstruction report and the technical basis document (TBD) provide detailed descriptions of the methods and assumptions used by NIOSH to derive the doses presented in Table 2. As may be noted, Table 2 presents doses in terms of annual doses due to internal alpha exposure resulting from the inhalation of uranium, and external exposure from low energy and higher energy gamma emissions associated with working at the facility. These include external exposures due to working in the vicinity of the uranium and diagnostic x-rays performed as part of job-related routine medical surveillance. None of the dose estimates are based on the use of dosimeters worn by the energy employee, such as film badges or TLDs, which, if used, would have provided a generally reliable method for determining external doses to the organ of concern. In addition, none of the dose estimates are based on bioassay data, such as urine or fecal analysis, or whole-body counting, which would have provided a generally reliable basis for estimating internal doses to most organs from the inhalation and/or ingestion of uranium. Instead, the doses were derived indirectly, using the generic methodologies described in the TBD.

Table 2. Doses to the Red Bone Marrow of the Employee as Derived by NIOSH for Use as

Input to IREP for the Purpose of Deriving Probability of Causation

The following table was deleted – please see hard copy #3.

3.0 INDEPENDENT REPRODUCTION AND REVIEW OF SELECTED NIOSH DERIVED DOSES

This section presents a series of hand and computer calculations that attempt to reproduce selected doses derived by NIOSH. In so doing, we will have confirmed that we understand how NIOSH performed the dose reconstruction and that the calculations are correct, given the models and assumptions employed by NIOSH. In the process of attempting to reproduce the doses, we also discuss and critically review the data, models, and assumptions employed by NIOSH to reconstruct the doses.

3.1 INTERNAL DOSE FROM INHALATION

As indicated in Table 2, the annual alpha doses to the red bone marrow were determined by NIOSH to build up to a peak mode of 3.76E-3 rem/y in PIID*, with a minimum of 0 and a maximum of 2.67. After PIID*, when AEC rolling operations ceased, the annual alpha doses to the red bone marrow gradually decline due to gradual clearance of the uranium from the bone marrow. In this section, the peak annual alpha dose delivered to the bone marrow in PIID* is checked by reviewing the source documents, and by performing hand and IMBA calculations.

The starting point for this analysis is a description of the rolling operations and how workers were exposed to airborne particles of uranium. Uranium billets were shipped to Bethlehem Steel by freight cars, in which the billets were stored on site until the rolling operations were initiated. Since the facility was fully involved in rolling steel billets, uranium-rolling operations at Bethlehem Steel took place only on weekends. Table 1 of the TBD presents NIOSH's estimate of the dates when experimental and production rollings took place, along with an estimate of the number of billets that were rolled. In general, uranium rollings occurred on weekends, and, during the week, the workers returned to their normal activities, which involved rolling steel billets.

During the rolling operations, airborne uranium dust was generated primarily as a result of the oxidation and flaking of uranium particles as the billets were processed through the rollers. NIOSH performed a review of uranium dust loading measurements made at the Bethlehem Steel facility and another similar facility, Simonds Saw. Based on a review of these air-sampling data, NIOSH concluded that the amount of air-sampling data was very limited, making it difficult to construct a reliable characterization of the airborne uranium dust concentrations at the facility as a function of time and work location. Because of these uncertainties, NIOSH elected to construct two alternative distributions of the airborne uranium dust concentrations at the Bethlehem Steel facility. One distribution was considered a lower-bound estimate of the range of dust loadings throughout the facility, and the other was considered an upper-bound estimate of the uranium dust loadings throughout the facility. The lower-bound distribution was used as a basis for quickly determining whether a claimant should be compensated; i.e., if the reconstructed doses using the lower-bound distribution were determined to be compensable, the analysis was considered complete. However, if the use of the lower-bound distribution yielded doses that were not compensable, then the upper-bound distribution was used as the basis for rejecting a claim.

The dose reconstruction undergoing review in this report is for a worker whose claim was denied. As a result, the focus of attention of this review is the upper-end radionuclide concentration distribution employed by NIOSH, as provided in Table 2b of the TBD, and which is reproduced here as Table 3.

Table 3. Internal Exposure Matrix-Upper Bound

(Reproduced from Table 2b of the TBD)

Work period	Air Concentration (dpm/m3)			Breathing Rate (m3/hr)*	Hours	Annual Intake (pCi)		
	Min	Mode	Max	Light/heavy		Min	Mode	Max
PIID*	0	140	70,000	1.2/1.7	120	0	9.16E3	6.49E6
PIID*	0	140	70,000	1.2/1.7	120	0	9.16E3	6.49E6
PIID*	0	140	70,000	1.2/1.7	130	0	9.93E3	7.03E6
PIID*	0	140	70,000	1.2/1.7	110	0	8.40E3	5.95E6

* The breathing rate of 1.2 m^3/hr was used to calculate the minimum and mode intake. The breathing rate of 1.7 m^3/hr was used to calculate the maximum intake.

As an example, the uranium inhalation of 9.16E3 pCi for 1949 was derived as follows:

$$(140 \text{ dis/min per } m^3)/(60 \text{sec/min}) = 2.33 \text{ dis/sec per } m^3 = 63 \text{ pCi/ } m^3$$

$$(63 \text{ pCi/ } m^3)(1.2 \text{ m3/hr})(120 \text{ hr/yr}) = 9072 \text{ pCi/yr}$$

This value does not exactly match the value in Table 3, but the difference is small and it is not considered necessary to further evaluate the reasons for the difference.

In the TBD, NIOSH explains that the assumptions used to derive the uranium inhalation rates are conservative as applied to workers at the facility for several reasons. First, a mode of 140 dpm/ m^3 is higher than the actual average airborne dust loading observed at Bethlehem Steel, and the maximum value was actually obtained from Simonds Saw data, not Bethlehem Steel data, where the maximum observed airborne dust loading was much lower. Second, the number of hours of exposure per year is characterized as being an upper bound. For example, Table 1 of the TBD indicates that in PIID* and PIID* there were only 6 and 8 days of rollings, respectively. Assuming 10 work hours per day, this would correspond to 60 hours and 80 hours of exposure per year, as opposed to the work hours employed in the TBD (i.e., the TBD assumed exposure durations that were approximately twice these values). For the purpose of deriving doses to internal organs other than the lungs, it was conservatively assumed that the uranium was Absorption Type M, when it is generally believed that the chemical form of the uranium was more likely Absorption Type S. Finally, the particle size of the airborne dust was assumed to have an AMAD of 5 micron. This is the default value recommended for use by ICRP, and is considered a generally conservative assumption.

Table 2, which was reproduced directly from the dose reconstruction report, presents the annual alpha doses to the bone marrow for each year as a result of these inhalation rates and modeling assumptions. Our independent analysis using IMBA and the intake rates in Table 1 agrees with the doses provided in Table 2.

SC&A's independent review of the TBD identified a number of concerns regarding these assumptions, which indicate that the exposure matrix may not be entirely scientifically sound and claimant favorable. The principal concerns cited by SC&A in its site profile review of the TBD are as follows:

1. The actual air-sampling data does not fit a triangular distribution. A much better fit is obtained using a lognormal distribution.

2. The TBD claims that 70,000 dpm/m^3 is a reasonable upper bound for the dust loading at the facility. However, inspection of the original data reveals a number of measurements made at Simonds Saw that exceed 70,000 dpm/m^3.
3. The radionuclide concentration distribution is applied to all workers at the facility. However, some workers may have had job responsibilities or worked at locations where they experienced prolonged exposures at the upper end of the distribution.
4. The exposure matrix assumes that, immediately following each rolling campaign, the residue of uranium dust that settled on surfaces during uranium rollings was cleaned up. As a result, the TBD assumes that no inhalation exposures occurred during the work week while the workers were engaged in rolling steel. The SC&A review of the TBD provides evidence that there may have been substantial amounts of residual uranium dust on surfaces during the time periods between uranium rollings.
5. The TBD also assumes that, after uranium rolling operations were believed to cease in 1952, residual uranium dust was cleaned up and there was no potential for inhalation of resuspended dust subsequent to 1952.
6. The TBD assumed that there were no additional uranium rollings after 1952, when there is some indication that there may have been additional uranium rollings after 1952.
7. The TBD did not take into consideration that the rolling operations were physically demanding, requiring higher breathing rates and oro-nasal breathing, which would have resulted in greater quantities of inhaled uranium.
8. Interviews with workers revealed that there were off-normal conditions, accidents, and maintenance operations, where the potential existed for substantially higher inhalation rates for uranium during short periods of time.
9. The TBD did not take into consideration the possibility that the dust loading in the breathing zone of the workers may have been higher than that observed using general area air samplers. ICRP Reports Nos. 35 and 75 provide evidence that the dust loading in the breathing zone is often considerably higher than that determined by general air samplers.

The SC&A review of the TBD provides a detailed discussion of these issues. The implications are that there are many aspects of the exposure matrix used by NIOSH to reconstruct the internal doses to the bone marrow of this worker that do not appear to be entirely scientifically valid or claimant favorable. However, there are other aspects of the exposure matrix provided in the TBD that are conservative. On balance, it would appear that there are many issues associated with the exposure matrix used to derive internal exposures at Bethlehem Steel that need to be more thoroughly explored, and which may reveal that the reconstructed doses to this worker were not as scientifically robust or claimant favorable as represented in the TBD.

3.2 EXTERNAL EXPOSURES

NIOSH estimated the external dose using the TBD. Three sources of external exposures were explicitly considered, including (1) external exposure to the metallic uranium feedstock and rods prior to, during, and following rolling; (2) external exposure to airborne uranium dust; and
(3) annual x-ray exposures employed as part of the medical surveillance program. Table 4 summarizes these doses as reported in the NIOSH dose reconstruction report. The TBD also estimated the skin and shallow dose, but these exposures do not apply to exposure to red bone marrow and are not addressed here.

Table 4. Summary of External Photon Exposures to Red Bone Marrow as Reported by NIOSH

Source of Exposure	Approximate Annual Organ Doses to Photons (rem)		
	Minimum	Mode	Maximum
Uranium sources	0.02	0.1	0.2
X-rays	0	0.027	0.105
Submersion	Negligible (<<1 mrem)		

This section attempts to reproduce these values and then discusses the degree to which these estimated doses are scientifically robust and claimant favorable.

3.2.1 External Exposures to Uranium Sources

The external exposure to red bone marrow from external uranium sources were derived by NIOSH by assuming the worker was exposed to a semi-infinite plane source of natural uranium. The TBD sites several references as the basis for deriving the deep photon dose from this exposure setting. Citing reports by Coleman et al. 1983 and U.S. Army 1989, the TBD estimated a deep dose rate of 2 mrad/hr at a depth of 1,000 mg/cm^2 (i.e. 1 cm depth dose). NIOSH further assumed that the 2 mrad/hr deep dose rate from the uranium source is evenly divided between photons with energies E=30-250 keV and E=>250 keV, and that the exposure orientation was anterior-posterior.

The TBD also cites a report by U.S. AEC 1948b as the basis for assumptions regarding exposure time and distance. For the mode, NIOSH assumed the worker was located 1 meter away from the extended source for 1 hour per 10-hour work shift. For the maximum dose, NIOSH assumed the worker was located 0.3 meters from the source for 6

hours per shift and 1 meter for 4 hours per shift. Based on Table 2b of the TBD, the worker is assumed to work about twelve 10-hour shifts per year and that external exposures only occurred during these time periods.
Based on the above assumptions, the red bone marrow doses can be reproduced as follows:

(2 mrad/hr)(120 hrs/yr)(0.001 rem/mrem)(0.479)/2 + (2 mrad/hr)(120 hrs/yr)(0.001) rem/mrem)(0.746)/2 = 0.057 + 0.0895 = 0.147 rem/yr

This value is in agreement with the value reported by NIOSH for the mode.

As a means of checking on the 2 mrad/hr 1 cm absorbed dose rate, we ran MicroShield to determine the dose rate at a point 1 meter away from an effectively infinite slab of natural uranium metal with its short-lived progeny in equilibrium. The result of the analysis is a dose rate of 2 mrad/hr, in total agreement with the value reported in the TBD.

With respect to the exposure distances and durations, these certainly appear to be claimant favorable, unless the uranium was stored in the immediate vicinity of the workers while they were rolling steel during the intervening work week. However, there is no indication in the literature that this was the case. Accordingly, it certainly appears that the methods used by NIOSH to estimate the red bone marrow dose to workers from external sources of uranium is scientifically valid and claimant favorable.

3.2.2 External Annual Doses to Red Bone Marrow Due to Submersion in Air Containing Uranium Dust

NIOSH concluded that this dose was negligible (below 1 mrem/year), and our analysis revealed the same result.

3.2.3 External Annual Doses to Red Bone Marrow Due to Photons from Contaminated Surfaces

The approach used by NIOSH to derive the external doses to red bone marrow from uranium sources assumed that the worker was exposed to an infinite slab of uranium. This approach not only accounts for exposure to sources of uranium, such as billets and rods, it also more than accounts for exposure to surfaces contaminated with dust during rolling operations. However, NIOSH assumes that the dust is thoroughly cleaned up upon completion of each uranium rolling campaign. If the cleanup was not thorough, there would be some continual external exposure to low levels of uranium dust on surfaces during the work week. However, the marginal additional exposures that may be associated with residual uranium following cleanup were probably small and more than accounted for by the conservatism inherent in the methods used to derive external exposures to sources of uranium.

3.2.4 External doses to Red Bone Marrow Due to Routine, Work-Related Medical X-Ray Examinations

The 0.027 rem annual dose to the red bone marrow from medical examinations of workers at Bethlehem Steel, as estimated in the TBD, is consistent with the value of 0.018 rem for pre-1970 PA x-rays provided in Table 4.0-1 of ORAUT-OTIB-0006 (we are not quite sure of the reasons for the small difference between the TBD and the values in OTIB-0006, but the differences are too small to be of significance). However, in accordance with the guidance provided in OTIB006, lacking information to the contrary, it would have been more claimant favorable to assume that at least some examinations included photofluorography, as such examinations were a matter of standard practice prior to 1960. Table 4.0-1 recommends a default pre-1970 photofluorographic entrance kerma dose of 3,000 mrem, with a corresponding red bone marrow dose of 0.276 rem per photofluorograph. If the worker had, in fact, received some photofluoroscopic examinations, the annual doses to the organ of interest would have been substantially greater than the values employed in the dose reconstruction.

3.3 CONCLUSIONS

We have found that many aspects of the dose reconstruction are scientifically robust and claimant favorable, but other aspects are not. The scientifically robust and claimant favorable aspects of the dose reconstruction are as follows:

1. The use of an effectively infinite slab of uranium as the source of external exposure to uranium, and that the workers were continually exposed to this source at a distance of 1 meter for the entire time that the rolling operations took place, is an extremely claimant-favorable assumption and may offset many of the less claimant-favorable assumptions described below.
2. The assumption that the inhaled uranium is Absorption Type M and that the particle size distribution has an AMAD of 5 microns is claimant favorable for the purposes of deriving inhalation exposures to red bone marrow.

Some of the less scientifically robust and claimant-favorable assumptions are as follows:

1. The use of a triangular distribution for the airborne uranium concentrations at the facility during rolling as the basis for all worker inhalation exposures does not appear to be scientifically robust or necessarily favorable to all claimants. The reason is that a lognormal distribution appears to provide a much better fit to the data, and, more importantly, it does not seem to be appropriate to assume that all workers experienced the same airborne dust exposure distribution.
2. It is likely that the dust loading in the breathing zone of workers was higher than in the general environment of the facility, and this possibility was not taken into consideration in the reconstruction of the inhalation doses.

3. Given the strenuous nature of the work, consideration should have been given to the possibility that the workers had relatively high breathing rates, which included oro-nasal breathing, which would have increased the estimate of internal doses.

4. There was likely some residual uranium dust on surfaces between rollings and following the termination of rollings that was not taken into consideration in the reconstruction of the inhalation doses.

5. Routine diagnostic medical examinations may have included photofluoroscopic examinations, which would have greatly increased the estimated bone marrow dose associated with annual diagnostic x-ray examinations.

6. Inadvertent ingestion of uranium-contaminated soot appears to have been significantly underestimated, given information available in the literature addressing this issue.

REFERENCES

EPA 1997, “Exposure Factors Handbook,” EPA/600/P-95/002Fa, August 1997.

ICRP 1995, International Commission on Radiological Protection, “Age-dependent Doses to Members of the Public from Intake of Radionuclides: Part 4 Inhalation Dose Coefficients,” ICRP Publication 71, 1995.

Kathren, R.L., Shockley, V.E., Thomas, E.M., Taulbee, T.D., Technical Information Bulletin: Dose Reconstruction from Occupationally Related Diagnostic X-ray Procedures, ORAUT-OTIB-0006, 2003.

NIOSH 2002, “NIOSH-Interactive Radioepidemiological Program (NIOSH-IREP) Technical Documentation,” Final Report. June 18, 2002

NIOSH 2002a, “External Dose Reconstruction Implementation Guideline,” OCAS-IG-0001, Rev 1, August 2002.

ORAUT-TKBS-0001, Technical Basis Document: Basis for Development of an Exposure Matrix for Bethlehem Steel Corporation, March 31, 2003.

ORAUT-OTIB-0006, Technical Information Bulletin: Dose Reconstruction from Occupationally Related Diagnostic X-ray Procedures, December 29, 2003.

ORAT-OTIB-0004, Technical Information Bulletin: Technical Basis for Estimating the Maximum Plausible Dose to Workers at Atomic Weapons Employer Facilities, December 04, 2003.