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

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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 as a PIID* from PIID*, through PIID*, except for military service from PIID*, to 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 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*, the energy employee was diagnosed with liver cancer. Table 1 summarizes the results of NIOSH's reconstruction of the doses to the energy employee's liver 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.

Table 1. Summary of Internal and External Exposure to the Liver 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 0.2 during AEC operations	*	*
Internal exposures from ingestion (alpha) during operations	ND**		
Internal exposure from inhalation (alpha) of residual resuspended particles following the conclusion of operations	ND		
External exposures during operations (PIID*)			
Ground surface contamination (chronic)	ND		
Natural Uranium Source 30-250 keV (chronic)	0.10	Yes	Yes
Natural Uranium Source >250 keV (chronic)	0.11	Yes	Yes
Submersion in airborne plume (chronic)	Negligible	Yes	NA
Diagnostic x-rays (acute)	0.022	Yes	Not necessarily
Chronic external exposure to residual contamination following the conclusion of AEC operations in PIID*	ND		

* This audit reveals that there are some aspects of the methods used by NIOSH to reconstruct the doses to the liver of this worker that do not appear to be entirely scientifically valid or claimant favorable. However, since the claimant was compensated, our findings are of interest more from a theoretical, rather than a practical, perspective.

** ND refers to Not Determined because the uranium dust inhalation doses alone were sufficient to consider the dose reconstruction complete.

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.

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 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 review 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 regarding the validity of the methods employed. The doses selected for review are based on the judgment of the auditors 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 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 reviewers 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 as a PIID* from PIID*, through PIID*, except for military service from PIID*, to 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 liver cancer. Table 2 presents the results of NIOSH's reconstruction of the doses to the energy employee's liver 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 liver to alpha emitters is assumed to have a triangular distribution with a minimum of 0, a mode of 5.20E-4, and a maximum of 0.369 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 31.8 rem, with a mode of 0.045 rem. The worker was also assumed to have an external photon dose of 0.27 to 1.18 rem to the liver. Based on these reconstructed doses, the POC was determined to be greater than 50% and the claimant was compensated.

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 to the liver due to internal alpha exposure resulting from the inhalation, and external exposure from working in the vicinity of uranium billets and rods, and also from periodic x-ray examinations. None of the dose estimates are based on the use of dosimeters worn by the energy employee, such as film badges or thermoluminescent dosimeters 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 Liver of the Employee as Derived by NIOSH for Use as Input to IREP for the Purpose of Deriving Probability of Causation

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3.0 INDEPENDENT REPRODUCTION AND REVIEW OF SELECTED NIOSH DERIVED DOSES

This section presents the results of IMBA 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 liver were determined by NIOSH to build up to a peak mode of 2.82E-3 rem in PIID*, with a minimum of 0 and a maximum of 2 rem. After PIID*, after AEC rolling operations ceased in PIID*, the annual alpha doses to the liver gradually decline due to gradual clearance of the uranium from the liver. In this section, the annual alpha dose delivered to the liver is checked by reviewing the source documents and by performing 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 granted. As a result, the focus of attention of this review is the lower-end radionuclide concentration distribution employed by NIOSH, as provided in Table 2a of the TBD, and which is reproduced here as Table 3.

Table 3. Internal Exposure Matrix - Lower Bound
(Reproduced from Table 2a 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	4,900	1.2/1.7	120	0	9.16E3	4.54E5
PIID*	0	140	4,900	1.2/1.7	120	0	9.16E3	4.54E5
PIID*	0	140	4,900	1.2/1.7	130	0	9.93E3	4.92E5
PIID*	0	140	4,900	1.2/1.7	110	0	8.40E3	4.17E5

* The breathing rate of 1.2 m3/hr was used to calculate the minimum and mode intake. The breathing rate of 1.7m3/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 dis/min per m3)/(60sec/min) = 2.33 dis/sec per m3 = 63 pCi/m3

(63 pCi/m3)(1.2 m3/hr)(120 hr/yr) = 9072 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 above inhalation rates are reasonable because the values represent the lowest, mode, and maximum values observed at Bethlehem Steel. However, as described in Section 3.3 of the SC&A review of the TBD, we have some concerns with the selection of a triangular distribution for the data set, and we believe there are some air samples that were higher than the maximum value selected by NIOSH. Nevertheless, since the low-end table is not used to deny compensation, these concerns are not important to the audit of this case. On the other hand, the number of hours of exposure per year is conservative. For example, Table 1 of the TBD indicates that in PIID* and PIID*, there were only 6 and 7 days of rollings, respectively. Assuming 10 work hours per day, this would correspond to 60 and 70 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 the liver, it was assumed that the uranium was Absorption Type M, and the particle size of the airborne dust was assumed to have an AMAD of 5 micron. These assumptions are claimant favorable.

Table 2 of this report, which was reproduced directly from the dose reconstruction report, presents the annual alpha doses to the liver 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 of the TBD agrees with the doses provided in Table 2 of this report.

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) annual x-ray exposures employed as part of the medical surveillance program; and (3) external exposure due to submersion to airborne uranium dust. 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 the liver and are not addressed here.

Table 4. Summary of External Photon Exposures to the Liver as Reported by NIOSH

Source of Exposure	Approximate Annual Organ Doses to Photons (rem)		
	Minimum	Mode	Maximum
Uranium sources (30-250 keV)	0.01	0.1	0.1
Uranium sources (<250 keV)	0.06	0.11	0.11
X-rays	0	0.022	0.086
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 the liver 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/cm2 (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 liver doses can be reproduced as follows:

(2 mrad/hr)(120 hrs/yr)(0.001 rem/mrem)(0.748)/2 + (2 mrad/hr)(120 hrs/yr)(0.001) rem/mrem)(0.886)/2 = 0.09 + 0.106 = 0.196 rem/yr

This value is in close 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 liver dose to workers from external sources of uranium is scientifically valid and claimant favorable.

3.2.2 External Annual Doses to the Liver 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 doses to Liver due to Routine, Work-Related Medical X-Ray Examinations

The 0.022 rem annual dose to the liver from medical examinations of workers at Bethlehem Steel, as estimated in the TBD, is somewhat higher than the value of 9.02E-2 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 ORAUT-OTIB-0006, but the differences are too small to be of significance). However, in accordance with the guidance provided in ORAUT-OTIB-0006, lacking information to the contrary, it would have been more claimant favorable to assume that at least some examinations included photofluorography, because 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 liver dose of 0.135 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.

3.2.4 Other Sources of External Exposure

NIOSH did not address other potential sources of external exposure, such as exposure to uranium deposited on surfaces during rollings, in between rollings, and following the completion of rollings. However, since the exposures that were explicitly addressed by NIOSH were sufficient to result in a probability of causation in excess of 50%, no additional analysis was needed.

3.3 CONCLUSIONS

We have found that the dose reconstruction is reasonable and appropriate for efficiently determining that the worker's cancer is compensable.

REFERENCES

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

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