Draft

MOUND LABORATORY SITE
POTENTIAL EXPOSURES TO STABLE METAL TRITIDES
REVISION 1

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Record of Revisions

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1 (Draft)	07/06/2012	Changes made to Sections 5.2 and 5.4 to reflected reasonable changes in parameter values, as opposed to maximum changes in parameter values as listed in Rev. 0.

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ABBREVIATIONS AND ACRONYMS

AI	alveolar interstitial region
AIDE	Activity and Internal Dose Estimates
ABRWH	Advisory Board on Radiation and Worker Health
AMAD	Aerodynamic Median Activity Diameter
Bq	Becquerel
BR	breathing rate
CAM	Continuous Air Monitor
CDE	Committed Dose Equivalent
CF	conversion factor
CFR	*Code of Federal Regulations*
cm^2	square centimeter
cpm	counts per minute
D&D	Decontamination and Decommissioning
DCF	Dose Conversion Factor
DNFSB	Defense Nuclear Facility Safety Board
DOE	Department of Energy
dpm	disintegrations per minute
DWL	derived working limits
EEOICPA	Energy Employees Occupational Illness Compensation Program Act
ER	Evaluation Report
ET	extrathoracic region
GI	gastro-intestinal
GM	geometric mean
GSD	geometric standard deviation
HP	Health Physics
Hr	Hour
HTO	Tritiated water
IAEA	International Atomic Energy Agency
IC	Ionization Chamber
ICRP	International Commission on Radiation Protection
IMBA	Integrated Modules for Bioassay Analysis

IREP	Interactive RadioEpidemiological Program
ITP	Insoluble Tritiated Particle
keV	kiloelectron volt
LLI	lower large intestine
LN	lymphatics and lymph nodes
LS	liquid scintillation
LSC	Liquid Scintillation Counter
m	meter
m^2	square meter
m^3	cubic meter
µCi	microcurie
µm	micrometer
ML	Mound Laboratory
MORE	Mound Occupational Radiation Exposure Records
MPC	maximum permissible concentration
mrem	millirem
NCRP	National Council on Radiation Protection and Measurements
NIOSH	National Institute for Occupational Safety and Health
NRC	U.S. Nuclear Regulatory Commission
ORAUT	Oak Ridge Associated Universities Team
OSTI	Office of Scientific and Technical Information
OTIB	ORAUT Technical Information Bulletin
PC	proportional counter
R	Research Building
rem	roentgen equivalent man
RF	Resuspension Factor
RSTC	R/SW Tritium Complex
SAF	self-absorption factor
SAFβ	Self Absorption Factor, beta: fraction of betas emitted that escape the particle surface and are counted in the LSC system
SAFe	Self Absorption Factor, energy: fraction of energy available to impart dose to the lung
SC&A	S. Cohen and Associates (SC&A, Inc.)

SEC	Special Exposure Cohort
SI	small intestine
SRDB	Site Research Data Base
SMT	Stable Metal Tritide
STC	Special Tritium Compound
STP	stable tritiated particulate
Sv	Sievert
SW	Semi-Works Building
TBD	Technical Basis Document
TH	Thoracic
ULI	upper large intestine
yr	year

EXECUTIVE SUMMARY

The origin of SC&A's concern over dose reconstruction for special tritium compounds (STCs)[1] at Mound is founded in their clear presence and exposure potential in certain Mound operations and the lack of site-specific personnel monitoring or source term characterization data for STCs upon which to base dose reconstruction. As in some other Special Exposure Cohort (SEC) reviews, NIOSH has proposed a model that substitutes a related radionuclide form, in this case tritium, to permit the use of swipe samples from STC operations where STC-containing tritium was processed to enable extraction. However, in this instance, SC&A is not only concerned that such a model is being proposed in the absence of site-specific or empirical STC data, but also because it is being used as a threshold to define a "theoretical" exposure potential, not as a means for dose reconstruction, and because it fails to consider the uncertainty ranges associated with the various assumptions employed in the model. This last issue is, of course, critical in any dose reconstruction under the Energy Employee Occupational Illness Compensation Program Act (EEOICPA), but even more so when the model would exclude a particular exposure source from being dose reconstructed. It appears that NIOSH is not offering the proposed dose reconstruction methodology as a coworker model, but as a means to demonstrate that exposure to STCs does not represent a source of radiological health endangerment. If this is, in fact, the argument that is being made by NIOSH, it represents an important policy decision that warrants explicit consideration by the Advisory Board.

As such, the Advisory Board needs to view this proposed model in the context of a Board policy precedent that requires its judgment on (1) the acceptability of this *de facto* determination of *de minimus* dose as a threshold for whether dose reconstruction is conducted for exposures to Type S special tritium compounds at Mound; and (2) the use of a conceptual model to derive worker dose, where site-specific and empirical values for STCs are lacking, and for which a range of uncertainties exist for the modeling parameters that drive the end result.

[1] Special Tritium Compounds (STCs), Stable Metal Tritides (SMTs), Insoluble Tritiated Particles (ITPs), metal tritides, tritium compounds and tritides are used (and have been used) interchangeably for the same compound of interest defined as metal compounds, such as titanium and hafnium, that absorb and store tritium atoms in the crystalline structure of the metal.

1.0 INTRODUCTION

1.1 BACKGROUND

On October 14, 2011, the Mound Work Group and SC&A received by e-mail a set of files that describe the National Institute for Occupational Safety and Health's (NIOSH's) approach for assigning a plausible upper bound on the inhalation exposures of Mound workers exposed to Special Tritium Compounds (STCs). As discussed on numerous occasions, it is not feasible to reconstruct the internal doses to workers from the inhalation of metal tritides based on tritium bioassay data or tritium air sampling data, because the vast majority of tritium observed in either urine or in air samples is expected to be tritiated water, and it is not possible to determine what fraction of the historic dose may have been contributed by insoluble inhaled metal tritides. Our review of air sampling data also revealed that the air samples were prefiltered, which implies that the analysis of air samples for tritium excluded tritides. Inspection of the air sampling records was not able to uncover any data where the prefilters were analyzed for tritium. In theory, if such data existed, it could have been one means of estimating the airborne concentration of tritides. In practice, however, a quantitative analysis of tritium particulates based on air filter samples is very difficult, as discussed in Section 4.2.2 of this report. Finally, we have determined that it is inappropriate to assume that all the observed levels of tritium in urine and/or air samples are metal tritides, because such a condition would result in exposure conditions that are implausible and derived doses to the respiratory tract that are implausibly high.

To address this challenging problem, NIOSH has developed a method for bounding internal dose associated with the intake of tritium particulate aerosols at the Mound Laboratory. Of particular interest are exposures to Type S insoluble STCs, such as hafnium tritide, that could deliver more dose per intake than other more soluble tritiated compounds. The NIOSH methodology takes advantage of the large amount of tritium swipe data that has been collected at Mound. The swipe data represent the amount of tritium contamination on surfaces, a portion of which can be assumed to be metal tritides. Given information on the amount of metal tritides on surfaces, the airborne concentration of metal tritides can be estimated by the use of a resuspension factor (RF). This white paper summarizes SC&A's review of the data and assumptions and the inherent uncertainties of the values used to derive dose estimates that form the basis for the proposed methodology, and our concerns regarding its applicability for the stated purpose of bounding doses from intakes of STCs at the Mound laboratory.

1.2 SUMMARY OF STC DELIBERATIONS

The December 2007 Mound Special Exposure Cohort (SEC) Evaluation Report (ER) (NIOSH 2007) observed that "limited information is available on the metal tritides to which workers could have been exposed," and notes that a lung clearance class of "S" should be assumed for hafnium tritides and for all metal tritides other than lithium. In its initial SEC issues matrix, SC&A questioned the ability to bound tritium doses from STCs with the limited monitoring data for STCs available in Mound records. Likewise, SC&A cited Sullivan (1996), in his letter to the Department of Energy (DOE), which indicated a technology shortfall in the monitoring, characterization, and dose assignment from partially soluble and highly insoluble tritium compounds, particularly as it pertains to reliance on air monitoring and contamination swiping.

While STCs were long known to Mound researchers and operators, their dosimetric properties were less understood and not recognized for their significance until the 1990s, when the advent of extensive decontamination and decommissioning activities at Mound elevated attention within the operating contractor and DOE, and led to specific control and monitoring requirements. SC&A also questioned whether existing metabolic models applicable to tritides, such as those provided in ORAUT-OTIB-0066 (ORAUT 2007) and ORAUT-OTIB-0011 (ORAUT 2004), could adequately address this issue in the absence of Mound-specific parameters, such as the identity of compounds and their respective solubilities, potential exposure locations, workers affected, and time periods.

NIOSH responded to SC&A's issues by indicating that hafnium tritide was the STC compound that exhibited the bounding insolubility and (after some iterative deliberation with the work group and SC&A) represented an exposure potential at Mound; that all others identified were either of greater solubility (i.e., of "intermediate" solubility) or had negligible exposure significance. After conducting its own interviews, NIOSH concluded in its October 2009 response paper that the historic exposure potential for hafnium tritide was limited to a "very small, discrete group of workers (10 individuals) known to NIOSH…by name" (NIOSH 2009). The NIOSH response discussed how a bounding dose estimation model is available in OTIB-0066, and that abundant site-specific monitoring data are available from extensive tritium bioassay records. It further noted that site-specific parameters cited by SC&A are either not relevant or represented site profile issues, except for the location where hafnium tritide was handled, which was indicated as being known to NIOSH. NIOSH also acknowledged that it "has proposed to consider exposure to intermediate solubility class tritium compounds for any Mound worker on the tritium bioassay program."[2]

SC&A expressed concern as to whether all workers in all operations involving hafnium tritide could be accounted for at Mound, which if not the case, would undercut NIOSH's premise for its proposed dose reconstruction approach for hafnium tritide. Subsequently, both SC&A and NIOSH personnel made a series of onsite visits to the Office of Scientific and Technical Information (OSTI) records archives at Oak Ridge to conduct document searches related to hafnium tritide activities at Mound. These reviews suggested to SC&A that the actual nature of activities at Mound would make the compilation of a complete and accurate roster of potentially exposed Mound workers for hafnium tritide infeasible, and that potential worker exposure to hafnium tritide, while probably small relative to tritium, could not be ruled out and likely occurred at some exposure level.

NIOSH continues to believe it can identify those workers who had an exposure potential to hafnium tritide and that, in their opinion, the exposure potential for hafnium tritide was very low, although "not zero," based on interviews with key former tritium operators (Ulsh 2010). However, SC&A believes such an approach falls short for the following reasons, based on the same interviews:

[2] SC&A agrees with NIOSH regarding the extensive nature of operations with intermediate soluble tritides as compared with hafnium tritide; the status of NIOSH's proposal to assign additional dose commensurate with potential exposure to these intermediate soluble tritides is not clear.

(1) NIOSH did not consider support worker categories (e.g., technicians, maintenance, crafts, housekeeping, etc.), as well as decontamination and decommissioning (D&D) personnel, all of whom had some degree of exposure potential and for whom the compilation of an accurate roster would be unlikely at this point, because such workers were drawn from facility-wide, if not plant-wide, support functions or were of temporary work status.

(2) Mound handled STCs from other DOE facilities, which may have introduced highly insoluble compounds that had comparable exposure pathways.

(3) The frequency of tritium Continuous Air Monitor (CAM) alarms in hafnium tritide handling areas confirms that the integrity of gloveboxes was breached frequently enough to provide an exposure pathway to the workers who frequented these handling areas.

On June 30, 2009, and again, on April 7, 2010, secure meetings were held at DOE Germantown for NIOSH, work group members, and SC&A to discuss site-specific circumstances and information regarding the preceding issues. Based on this information, at its July 27, 2010, meeting, the work group considered forwarding the tritides issue to the full Advisory Board for consideration, but held off pending additional research by NIOSH regarding the feasibility of using tritium swipe data for dose reconstruction purposes for support workers in the period 1980 forward (including the D&D phase). Another key aspect of that review was to be whether those workers with exposure potential could be identified. Portions of what would become a formal NIOSH white paper on this subject were provided to the work group and SC&A on October 14, 2011 (these advance "pieces" of the review consisted of informal drafts of a summary of "Resuspension of Tritide Surface Contamination at Mound," [untitled] SMT Exposures in R-108 and SW-8 in the 1980s, and "PC-5 Gas Proportional Counter Tritium Counting Efficiency Discussions"), in advance of the work group's November 7, 2011, meeting.

In the e-mail forwarding this advance material, NIOSH emphasized that "it has been, and continues to be NIOSH's position that exposure to the most insoluble of these compounds was limited to a special cohort of workers, identified by name." In forwarding the preceding material pertinent to the use of swipe data available for the relevant locations and time periods at Mound, NIOSH notes that the "take home message" is that by applying "multiple extremely conservative assumptions,"[3] the calculated doses are extremely small ("order of a few millirem") and that NIOSH's position is therefore supported: "that the exposure potential for these materials for anybody other than the named group of workers is extremely low."

At the November 7, 2011, work group meeting, NIOSH made it clear that it is "not proposing this [model] as necessarily a dose reconstruction methodology;" that "even under worst-case

[3].Defined as:
1. A detector efficiency of 4%.
2. Assuming that all tritium activity on the swipes is from insoluble SMTs, even though these materials composed a very small fraction of the tritium Mound worked with. In addition, with the exception of accident scenarios, these materials were always handled inside containment designed to isolate tritium gas (which is more mobile than particulate tritium).
3. All swipe results were treated as if they were Type S solubility metal tritides, even though the very large majority of the small inventory of SMTs Mound handled over its history were Type M.
4. A conservative value for a resuspension factor.
5. 95th percentile air concentrations and 95th percentile organ doses are reported

assumptions it doesn't give you a dose which is not (sic) sufficiently accurate."[4] NIOSH claims that [tritides] is not an SEC issue, because its conservative smear-based model analysis shows that the resulting dose is "small" or "extremely low," and that the model applied is both "plausible" and "bounding." It was emphasized by NIOSH that this approach is no different than substituting the most insoluble form of a particular radionuclide to achieve a bounding dose estimation, e.g., substituting Type S uranium or Super Type S plutonium for their higher solubility forms. NIOSH considers tritides an insoluble, bonded compound of hydrogen, fluoride, and oxygen, and substituting the most insoluble form is viewed as simply adopting a "claimant-favorable" assumption for dose reconstruction.

In January 2012, NIOSH released its December 20, 2011, draft white paper (NIOSH 2011a), which as indicated earlier, consisted of the advance analyses that were provided to the work group in October 2011. In the paper's executive summary, NIOSH notes that:

> *The dose method presented here makes use of the contamination swipe data to estimate the SMT concentration resulting from the aerodynamic entrapment and/or mechanical resuspension of surface contamination for estimating the inhalation dose…more than 62,000 swipe data entries for Rooms R-108 and SW-8 collectively were used in the assessment. The maximum annual CDE associated with intakes of the SMT is 226 mrem to the critical organ…"*

The paper further indicates that the review focused on "tritium research, development, analytical recovery, enrichment, and surveillance activities" in the Research (R) and Semi-Works (SW) buildings at Mound, specifically rooms R-108 and SW-8, with operations starting "in the 1960s in these rooms and [continuing] beyond the 1980s." In its analysis, NIOSH notes that it is presenting "an alternative method of more precisely bounding doses for workers who had a theoretical potential for exposure to SMTs at the Mound Laboratory." That "this is accomplished by applying a resuspension factor defined as the ratio between the airborne concentration of a pollutant per cubic meter directly over a contaminated surface and the areal pollutant surface contamination." NIOSH further notes that "the outcomes of this dose assessment provide ceiling values for potential SMT exposures at the Mound Laboratory during the 1960s through the 1980s."

At a secure meeting at DOE Germantown on January 6, 2012, individuals from NIOSH, the work group, and SC&A, clarified facility-specific technical issues associated with this recent white paper and the new proposal. SC&A raised a concern over how this approach would address the D&D phase at Mound, where engineered controls for residual tritides would have been lacking and a wholly different population of support workers would have been involved. SC&A also raised questions regarding how radiological self-absorption within tritide compounds

[4] SC&A agrees with this position, in that there are inherent uncertainties associated with inferring surface contamination from swipe counts, which are subject to a host of variables, such as assumed removal factor (affected by chemical form of tritium and how it is absorbed on a particular surface), area swiped (function of individual sampling technique), instrument efficiency, self-absorption of contaminant (proven for tritide compounds), and other factors. The collective contributions of these uncertainties cannot be specified with "sufficient accuracy," albeit they can be conservatively bounded or "maximized," as has been proposed by NIOSH in its approach.

would be addressed, as well as the implications of a 2008 Sandia study (Coffey and Burkhart 2008), which found a delayed count response phenomenon for liquid scintillation counting of erbium tritide. Finally, a need was expressed by the work group to reconfirm identifiable operators and support staff for all hafnium tritide activities for which an exposure potential is identified, whether small or large.

SC&A also received from NIOSH additional tritium swipe sample data recently found for the two rooms in question. These additional datasets, contained in two spreadsheets compiled by NIOSH ('SMT exposures in R-108 SW-8 10-6 pre 1980.xls' and 'SMT exposures in R-108 SW-8 10-6 in 1980s.xls'), provide supplemental data in the form of health physics daily summary values for time periods prior to 1985. SC&A reviewed these data for completeness and found that gaps occur for the R-108 room from January 1983 to May 1983, July 1986 to June 1988, and January 1989 to June 1989. No data were compiled for 1987, and the only year with an intake defined for each month was 1985. For the SW-8 room, the following gaps in the available swipe data were observed:

- September 1969
- December 1969 through September 1972
- December 1972 through June 1975
- September 1975 through May 1976
- August 1977 through December 1977
- All of 1980
- March 1986
- July 1986 through December 1986
- September 1987 through December 1987
- July 1988 through December 1988
- July 1989 through December 1989

On April 4, 2012, NIOSH released a new white paper (NIOSH 2012), dated March 30, 2012, which presented the "bounding and best estimate internal dose associated with the intake of insoluble tritium particulate aerosols in the R/SW Tritium Complex (RSTC) at the Mound Laboratory." This new white paper analyzed additional swipe sample data for the rooms SW-13 (covering 1974 through 1989) and SW-150 (covering 1968 through 1989). Unlike the results presented in the preceding white paper, NIOSH estimated the "accumulated dose…for a Case Study that can typically be found in the dose reconstruction program…with "the bounding and best estimate annual dose equivalents to the lung associated with intakes of the SMT are 0.48 mrem and 0.12 mrem, respectively." As in the prior white paper, NIOSH concludes that their assessment "demonstrates that calculated exposures from the inhalation of insoluble metal tritides at Mound were small (in the millirem range), plausible, and bounding." Based on this analysis, NIOSH concludes that "the worker protection practices and health physics program used at Mound for protection against insoluble tritides, and the processes in which they were encountered, indicates that the SMTs did not present any internal dose to workers, theoretically and physically" (NIOSH 2012). This paper also provided an assessment of exposure potential from D&D activities as gleaned from interviews with three former Mound workers.

The Mound Work Group met on April 10, 2012, and discussed both NIOSH white papers, in terms of the adequacy and completeness of the swipe data, the key assumptions and parameters contained in the proposed dose estimation models, and the implications of applying such a model as a threshold means to determine the exposure potential for SMTs at Mound. While SC&A had prepared a detailed response to the December 2011 white paper, that response was withheld while additional review was performed for the white paper issued on March 30, 2012, and received on April 4, 2012. The following assessment constitutes this augmented review, albeit limited time prior to the next work group meeting (scheduled for June 5, 2012) did not permit adequate follow-up regarding NIOSH's recent findings for the exposure potential of SMTs in D&D activities at Mound.

This report is organized, as follows:

Section 2.0 of this report highlights concerns regarding the plausibility of the proposed approach and its related assumptions, and its use as a threshold basis for determining the exposure potential of SMTs at Mound.

Section 3.0 describes the NIOSH model for SMT dose reconstruction, contrasting the differing assumptions and parameters applied in the most recent "best-estimate" bounding model, with the earlier "extreme" bounding model.

Section 4.0 reviews the adequacy and completeness of the swipe data used in these models, as well as the assumptions made by NIOSH in applying its model to this data. SC&A believes that the data are essentially complete and adequate, provided a suitable rationale can be developed to bridge missing data by extrapolating from other onsite data collected for adjacent time periods.

Section 5.0 provides an evaluation of the inherent uncertainties associated with the variables found in the NIOSH dose estimations calculated for SMTs at Mound Laboratory, offering a perspective on the "sensitivity" of the end result as a function of what value is assigned to critical model parameters. Included is a review of the variability in the derived doses that arises by varying the exposure duration and latency time after an exposure.

Section 6.0 provides a comparison between the NIOSH method to evaluate lung dose, as presented in its most recent white paper (NIOSH 2012), and a DOE method provided in their 2008 report, *DOE Handbook – Tritium Handling and Safe Storage* (DOE 2008). Again, the focus is on rationalizing any differences found between the respective methodologies and quantifying variability associated with the assumptions used.

Three appendices are included that provide an extrapolation of intakes assuming a full year of SMT exposure, as well as background regarding available documents in the Site Research Data Base (SRDB) and factual or transcription errors found by SC&A during its review.

2.0 STATEMENT OF CONCERN: PLAUSIBILITY OF PROPOSED APPROACH AND RELATED ASSUMPTIONS

The origin of SC&A's concern over dose reconstruction for STCs at Mound is founded in their clear presence in certain Mound operations, and the lack of site-specific personnel monitoring or source term characterization data upon which to base dose reconstruction. As in some other SEC reviews, NIOSH has proposed a model that substitutes a related radionuclide form, in this case tritium, to permit the use of swipe samples from STC operations where STC-containing tritium was processed to enable extraction. However, in this instance, SC&A is not only concerned that such a model is being proposed in the absence of site-specific or empirical STC data, but also because it is being used as a threshold to define exposure potential, not as a means for dose reconstruction, and because it fails to consider the uncertainty ranges associated with the various assumptions employed in the model. This last issue is, of course, critical in any dose reconstruction under EEOICPA, but even more so when the model would exclude a particular exposure source from being dose reconstructed.

As will be confirmed later in this report, the assumptions cited by NIOSH in its proposed approach are reasonable, based on the scientific literature, and within the range of plausible values that could be assigned for the exposure scenario outlined (albeit with attendant uncertainties, an issue pertinent to the application of this model for this purpose). The detector efficiency assumption is at the lower range of reported values, but is certainly a conservative assumption. Based on SC&A's review of the literature, it is apparent that the variability and uncertainty in resuspension factors is enormous, but that a resuspension factor of 5E-5/m, as used by NIOSH, is claimant favorable and within the range of values reported. The 95th percentile air concentrations and 95th percentile organ doses are conservative approaches that have been employed previously by NIOSH in dose reconstruction.

Taken in isolation, this model would seem to offer a simplifying means to bound levels of tritide activity that may have been present in the workplace.[5] However, as broached at the November 7, 2011, work group meeting, SC&A has reservations regarding the plausibility of a proposed model that relies on workplace tritium contamination swipes and hypothesizes that all the tritium activity on these swipes be from insoluble SMTs in order to derive a maximum annual dose level. This approach does not provide an upper bound for dose reconstruction purposes, but a "theoretical" lower threshold for exposure potential where such potential has been already established by the work group in former worker interviews. Likewise, at the April 10, 2012, work group meeting, SC&A emphasized that with the lack of site-specific or other empirical bases, the inherent uncertainties associated with each of the assumptions employed in NIOSH's model require consideration, given their compounding influence on any dose estimate.

For context, it needs to be re-emphasized that for hafnium tritides (and other STCs), there were no bioassays conducted and no workplace monitoring performed; there were no measurements of relative concentrations of tritides to HTO, and no reliable means to ascertain same from the contamination swipes taken. And it is clear that it would not be plausible for all of the HTO

[5] While STCs were, indeed, routinely handled in containment, they were also intermittently released into the workplace via glovebox leaks, which were relatively common at Mound and other tritium operations of that era.

measured on the swipes to consist of tritides. In response to this and other concerns, NIOSH responded (during the November 2011 work group meeting) that they would be in agreement with SC&A's concern if the resulting calculated doses were "extremely high values," i.e., "tens of rems, hundreds of rems, thousands of rems" (ABRWH 2011). It was further noted that the smears provide a source term that, "under some very conservative assumptions" can generate relatively low doses in the mrem range. NIOSH elaborated further that "there are oftentimes good reasons why people aren't monitored for bioassay, and it has to do with the source term that's available." NIOSH further observed that it approached bounding assumptions like this "all the time" and offered the example of how Type S or Type Super S uranium or plutonium have been assumed to provide for a conservative bounding estimation of dose when solubility uncertainties arose. It was observed that tritides are like a more insoluble compound of hydrogen; that there is no distinction between them and how solubility has been addressed in the past.

The illustrative example that was offered by NIOSH was how high-fired plutonium was handled during the Rocky Flats SEC review. First, it needs to be recalled that the Mound "maximizing" method proposed at the November 2011 meeting (as well as the "best-estimate" method proposed at the April 2012 meeting) was not being offered by NIOSH as a dose reconstruction method, but rather as a means to determine whether exposure potential would have been "very small" or in the context of the EEOICPA, "negligible," or not for the support workers involved. However, SC&A believes that this comparison, i.e., Rocky Flats high-fired plutonium to Mound tritides, while analogous on one hand because they both address insoluble compounds, is also dissimilar because of fundamental differences in how they are supported by actual site monitoring data. It is noteworthy that the upper-bound assumption for high-fired plutonium (factor of 4 dose estimation over Type S Pu-239) was grounded in the Transuranium Dose Registry autopsy data from which the assumed parameter was derived, as well as the considerable plutonium monitoring data derived from a rigorous and routine bioassay program at Rocky Flats for all workers, both operators and support personnel. In contrast, given the complete lack of tritide bioassay, workplace monitoring data, or a measure of the relative concentrations of tritides to HTO, the proposed approach for tritides at Mound must rely on contamination swipes of workplace surfaces, for which the representativeness for all workers with exposure potential is questionable. When NIOSH assumed all of the plutonium at Rocky Flats was high-fired for purposes of an upper-bound dose reconstruction [under ORAUT-OTIB-0049 (ORAUT 2010)], it was with the knowledge that this approach would be plausible and

sufficiently accurate, as validated by autopsy data, and founded on this extensive bioassay monitoring data.[6]

While the assumption that all of the tritium activity picked up on the swipe is from insoluble SMTs is extremely conservative and not plausible in the normal sense of the word, it was clarified (see above) that this assumption is being used solely to "maximize" or "bound" the "theoretical" potential exposure attributable to tritides, and not dose reconstruct with sufficient accuracy, with the objective to determine if the resulting dose would be significant[7] under that conservative scenario. However, whether it is the "extreme" bounding organ dose of 226 mrem CDE to the LN(TH) or the "best-estimate" bounding dose of 0.48 mrem to the lung, NIOSH considers the "calculated exposures from the inhalation of insoluble metal tritides at Mound to be "small" and "in the millirem range."

From NIOSH's modeling, though, it is not clear what is ultimately limiting, bounding, or just a best estimate. In its March 2012 white paper, NIOSH shows the limiting lung dose as 0.48 mrem (95th percentile) and 0.12 mrem (50th percentile), assuming a 2-year exposure and 10-year latency period. However, applying NIOSH's case study method, the limiting dose should be 92.9 mrem to the "Al" (95th percentile) and 23.8 mrem to the "Al" (50th percentile). If a longer latency time than 10 years is assumed, the LN(TH) then becomes the limiting organ. For example, if the 50-year CDE is calculated based on a single year exposure to the highest annual intake, the limiting dose would be 85.1 mrem to the LN(TH) at the 95th percentile and 21.5 mrem to the LN(TH) at the 50th percentile.

In providing this methodology, NIOSH does not *a priori* acknowledge any potential exposure to these individuals, and therefore, is not proposing to demonstrate dose reconstructability "with sufficient accuracy." In fact, as noted earlier, NIOSH commented during the November 7, 2011, work group discussions that even under the worst-case assumptions used in the model, it does not afford a dose estimate with sufficient accuracy; it is merely an upper-bound dose parameter for determining whether support workers should be excluded from consideration for exposure potential to insoluble tritides.

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[6] For Rocky Flats, NIOSH acknowledged that high-fired plutonium oxide (Pu-239) may exhibit long-term retention in the lung exceeding that predicted by the default Type S model represented in conventional retention models. NIOSH addressed this issue in ORAUT-OTIB-0049 (ORAUT 2010), where lung dose adjustment factors were empirically derived from in-vivo bioassay results and from urine results, as well as adjustment factors for systemic organs, gastro-intestinal (GI) tract and the extra-thoracic (ET) region. Specific design cases were the basis for determining the more bounding adjustment factors. Finally, autopsy cases were used by NIOSH to validate the conservatism of these empirically based assumptions. While an analogy was drawn at the November 7th Mound work group meeting between this empirical approach for high-fired plutonium at Rocky Flats and the "maximizing" approach proposed for STCs at Mound, what is analogous is that "bounding" for "solubility" is being modeled, not the premise and supporting data or analyses behind it. While the OTIB-0049 model is based on both site-specific bioassay and lung count data, as validated by autopsy measurements, the "swipe" approach does not model or estimate tritide dose from any site-specific characterization information for tritides; it merely projects a hypothetical dose based on a "substitute" source-term, HTO, for which monitoring data are available.

[7] It is unclear how "significance" is defined by NIOSH for exposure potential suitable for dose reconstruction; while NIOSH observed (as noted) that it would share SC&A's concerns over STCs if they resulted in "extremely high" doses from conservative calculations, NIOSH staff also acknowledged at the March 2012 work group meeting that 1 mrem has been used as a *de facto* threshold for dose reconstruction consideration in the past.

NIOSH's suggestion at the same meeting that "there are often times good reasons why people aren't monitored for bioassay, and it has to do with the source term that's available," does not comport with the operational history of tritide handling at Mound and other DOE sites. STCs have had a long history of applications across the DOE complex, particularly at Mound. However, DOE and its contractors did not fully appreciate its dosimetric and radiological control implications until the 1990s (during terminal D&D operations at Mound and other sites), and did not issue revised guidelines for monitoring and control until 2004 (DOE 2004). This very insoluble form of tritide was not previously addressed under a bioassay regime, because its radiological concerns were underappreciated, and available monitoring techniques were either not applied effectively or did not exist at the time. There is no evidence that suggests, as NIOSH does, that the insoluble form of tritides was not considered a significant exposure pathway or one for which any worker potentially exposed did not warrant bioassay; it merely was not recognized then as the dosimetric concern that it would become later. In fact, tritides were the subject of Defense Nuclear Facility Safety Board (DNSFB) review and correspondence to DOE (DNFSB 1999), a DOE-wide review (DOE 1999), and resulted in the issuance of its own technical basis document (TBD), both at Mound (Mound 2000) and on a DOE-wide level (DOE 2004).

For Mound, it is assumed that the swiping of surfaces in the four rooms in question represented the extent of HTO contamination, and that the tritide particulates would behave similarly to HTO upon release and be present on surfaces subject to routine swiping. However, support activities involve changing out room air filters, glovebox maintenance, and housekeeping, all of which entailed exposure pathways not likely represented by the surface swiping regime involved, and for which historic respiratory protection practice is not firmly established. NIOSH has not determined the representativeness of the swiping surveys to levels of HTO and tritide contamination to which support workers may have been exposed in these types of activities, and whether they represented upper bounds for what was likely more direct contact with contaminated surfaces and equipment.

For Mound support workers that had access to the four rooms in question, there has not been any new information presented to the work group that they were not exposed to insoluble tritides. As noted earlier, work group members participated in secure meetings wherein that question was settled to their satisfaction: Mound support service workers had potential exposure to hafnium tritides in the course of their work during both operating and D&D periods,[8] and have not been identified, by name, to date. Given the lack of bioassay and air monitoring data and suitable source term characterization data, the work group has deemed the dose reconstructability of support worker exposures to hafnium tritide to be a legitimate SEC issue requiring a demonstration by NIOSH of plausible dose reconstructability with sufficient accuracy. The proposed bounding methods provided have not been directed at providing that demonstration, but rather as a means to illustrate through a model that this exposure pathway leads to theoretically "small" doses, thereby making dose reconstruction not.

[8] In its most recent white paper, "Potential Stable Metal Tritide Exposures at the Mound Laboratory," (NIOSH 2012), NIOSH provides interview summaries for three former Mound workers it re-interviewed regarding potential D&D exposures to STCs, with a conclusion that such exposure did not take place. SC&A has not had sufficient time to conduct follow-up research regarding these accounts.

With respect to the "extreme case" model presented by NIOSH, it is not clear why NIOSH considers 226 (corrected to 1,532) mrem/year CDE to the critical organ (the maximum swipe-based estimate) to construe anything other than a legitimate exposure potential requiring dose reconstruction. As a point of comparison, such annual internal dose levels are comparable (order of magnitude) to those likely to have been accrued by workers exposed to depleted uranium in Pantex disassembly, mixed activation products in the early years at Los Alamos, and U-238 dust at early steel rolling mills, all of which received SEC consideration by NIOSH and the Board. Likewise, they are not inconsistent with the low doses experienced from medical x-rays and occupational environmental radiation sources, which are routinely considered in claimant dose reconstructions. As past Board practice has been to only exclude "negligible" radiation exposures from SEC consideration, this level of potential exposure would certainly not fit this definition of negligibility.

In its subsequent "best-estimate" model, however, NIOSH revised its model parameters to be more "realistic" and has reduced the resulting "upper-bound" target organ dose estimates by over an order of magnitude as a function of the target organ and latency period selected.[9] While this calculated dose value was deemed by NIOSH to also be "small," as in the "extreme" case, it has also apparently fallen below NIOSH's *de facto* threshold for an exposure potential subject to dose reconstruction (1 mrem) and would now, in effect, be considered *de minimus*.[10] As discussed at the April 2012 work group meeting, NIOSH observed that the basis for 1 mrem threshold is thought to be a limitation in the Interactive RadioEpidemiological Program (IREP) dose estimation model that restricts input exposure parameters to 1 mrem. Subsequent discussions with SC&A personnel involved directly in dose reconstruction reviews, however, indicate that radionuclide-specific input values of less than 1 mrem are actually common and apparently can be accomplished by IREP. It is not clear from any of these exchanges what the technical basis is for a 1 mrem dose threshold for dose reconstruction consideration by NIOSH under the EEOICPA and how that threshold is or should be applied for dose reconstructions to ensure claimant favorability.

Beyond concern over NIOSH's basis for defining a *de minimus* exposure potential for dose reconstruction, SC&A also finds that NIOSH has not adequately considered the uncertainties incumbent for a model that lacks either a site-specific or empirical basis for its assumptions. As discussed at the April 2012 work group meeting, each of these assumed parameters—for example the resuspension factor, dose conversion factor, swiping and counting efficiencies, self-absorption correction factor, exposure duration, and latency time after the exposure—introduce a range of uncertainties to the modeling calculation that would be compounding and can lead to a wide range of dose estimation results as a function of relative conservatism. In fact, NIOSH itself has demonstrated this circumstance by its presentation of both an "extreme" bounding case and a "best-estimate" bounding case for its estimate of exposures to STCs at Mound, based on

[9] Corrected limiting dose from NIOSH 2011b: 1,532 mrem 50-year CDE to the LN(TH). Corrected limiting dose from NIOSH 2012 using the case study approach (2-year exposure, 10-year latency) is 92.9 mrem to the AI, based on the 95th percentile contamination values.

[10] Although it should be noted that SC&A has found that the corrected limiting lung dose based on the NIOSH 2012 case study is 3.73 mrem at the 95th percentile level of contamination (as compared with the stated 0.48 mrem).

use of correspondingly very conservative ("extreme") or less conservative ("best-estimate") numerical assumptions.

To illustrate the range of uncertainties attendant to these modeling assumptions, SC&A has provided analyses in Sections 5.0 and 6.0, based on the scientific literature, that address the variability of parameters used in the most recent NIOSH model, as well as contrasting these same variables between that model and one provided by DOE in its *Tritium Handling and Safe Storage* handbook (DOE 2008). As can be seen by the results in these two sections, the total range of uncertainty based on the extreme high and low values of assumed modeling parameters would be a factor of 0.0003 to 8,112 than that of NIOSH's resulting dose estimate from its March 2012 paper, and more significantly (see SC&A discussion in Section 4.3), a factor of 0.02 to 135 than that of the same result, assuming a constant resuspension factor (RF = 5E-5/m), as proposed in that paper.[11] Likewise, the self-absorption factor ("SAFe") derived by NIOSH yields lower doses to the lung for STC than the method presented in the DOE handbook (DOE 2008) by a factor of approximately 0.45.

Essentially, NIOSH is proposing a new analytic model (use of HTO swipe data) to bridge a wide data gap at Mound (lack of hafnium tritide monitoring and source term characterization data), not as a means of conducting bounding dose estimation or reconstruction, but as a means to define a level of "theoretical" worker tritide exposure that can be considered insignificant or equivalent to "negligible." In this context, NIOSH is not offering the proposed dose estimation methodology as a coworker model, but as a means to demonstrate that exposure to STCs does not represent a source of radiological health endangerment. If this is, in fact, the argument that is being made by NIOSH, it represents an important policy decision that warrants explicit consideration by the Advisory Board.

As such, the Advisory Board needs to view this proposed model in the context of a Board policy precedent that requires its judgment on (1) the acceptability of this *de facto* determination of *de minimus* dose as a threshold for whether dose reconstruction is conducted for exposures to hafnium tritide at Mound, and (2) the use of a conceptual model for which site-specific and empirical values for STCs are lacking, and for which a wide range of uncertainties exist for the modeling parameters that drive the end-result.

[11] In this latter case, SC&A acknowledges that, while conservative and clearly bounding, NIOSH's use of an RF of 3E-5/m in its earlier "extreme" model estimate is beyond what the literature and NRC have recommended. However, as pointed out later by SC&A in Section 4.3, an argument can be made that even the 5E-5/m value should be 2.5E-4/m, a factor of 5 higher to account for the fact that the starting point for this calculation is swipe data and not total surface contamination.

3.0 DESCRIPTION OF NIOSH MODEL FOR TRITIDE DOSE RECONSTRUCTION

NIOSH 2011a proposes a model that calculates the airborne radionuclide concentration in a room or area based on the measured surface contamination within that room or area. Mathematically, the NIOSH model is:

$$C = \frac{M\ 100}{e_m\ k}\ RF \qquad (3\text{-}1)$$

Where:
- C = Tritide air concentration ($\mu Ci/m^3$)
- M = Tritium measurement ($cpm/100\ cm^2$)
- 100 = Area of measurement (cm^2)
- e_m = Detector efficiency (unitless)
  - = 0.01
- k = Conversion factor ($dpm/\mu Ci$)
  - = 2.22×10^6 ($dpm/\mu Ci$)
- RF = Resuspension factor (m^{-1})
  - = 0.00005 (m^{-1})

NIOSH 2012 applies "best-estimate" parameter values of 0.01 for detector efficiency and a resuspension factor of 5E-5 m^{-1}, as discussed in detail in later sections of this report. The derivation and appropriateness of the detector efficiency and the resuspension factor in NIOSH 2011a are described in detail in Sections 3.3 and 3.4, respectively. The disintegration per minute (dpm) to microcurie conversion factor needs no discussion, which leaves the tritium measurement as the only parameter in equation 3-1 that needs further explanation. A brief explanation is provided below of the tritium measurements used and the data that were used specifically to calculate the 50th and 95th percentile tritide air concentrations. (NIOSH 2012 presents both 50th and 95th percentile air concentrations). Figures 1 and 2 were taken from the Mound SW Building contamination survey datasheets (Connell 2010a) and show contamination in room R-108 on October 30, 1985, and in room SW-8 on November 6, 1985. Section 3.1 presents a detailed review of the completeness and appropriateness of the Mound contamination survey datasheets as they relate to the tritide problem.

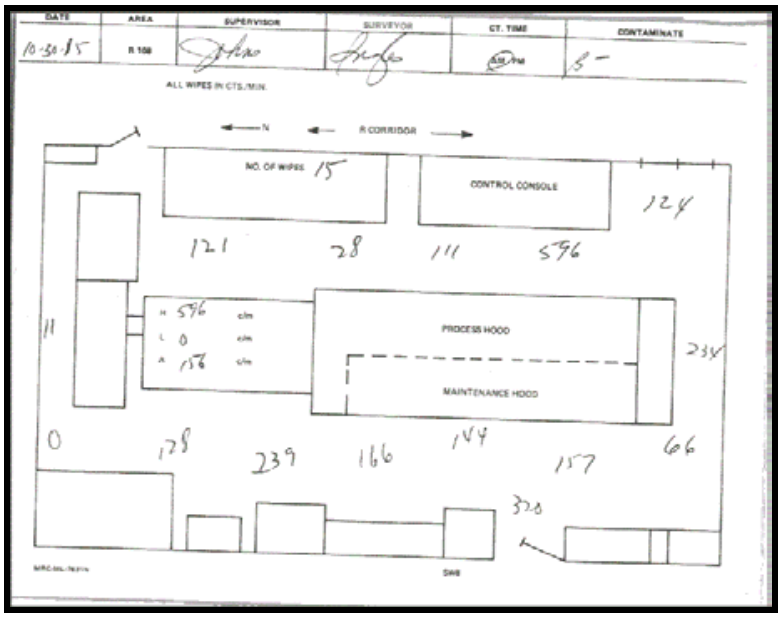

Figure 1. R-108 Tritium Swipe Data for October 30, 1985

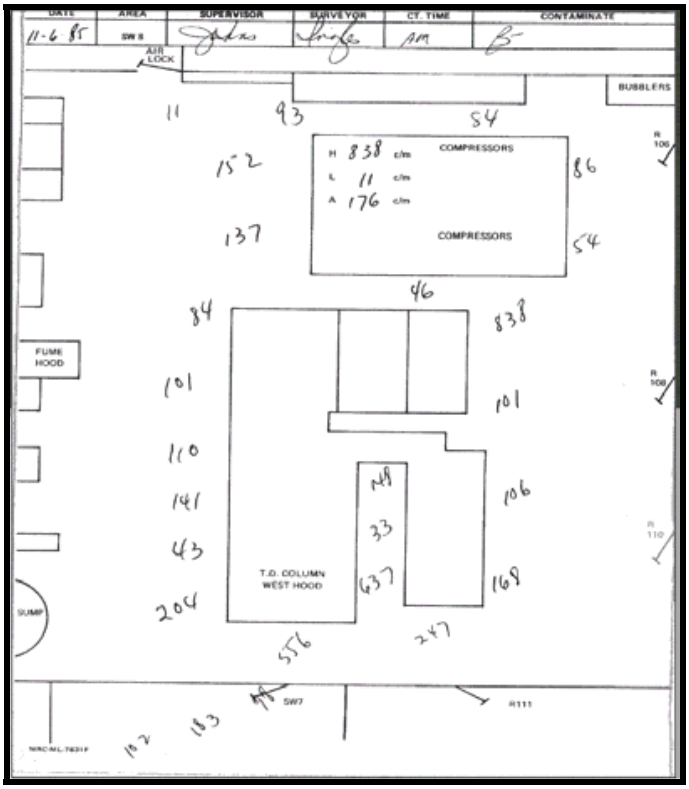

Figure 2. SW-8 Tritium Swipe Data for November 6, 1985

To arrive at the 95th percentile air concentration, an air concentration was calculated for each swipe data point. For example, from the Figure 1 datasheet, 15 swipe data were collected and 15 air concentrations were calculated for room R-108. For the total month of October 1985, 357 swipe data were collected and 357 air concentrations were calculated for room R-108. To

calculate the 95th percentile room R-108 air concentration for October 1985, the natural logarithms of those 357 air concentrations were plotted against their calculated z-scores as shown in Figure 3.

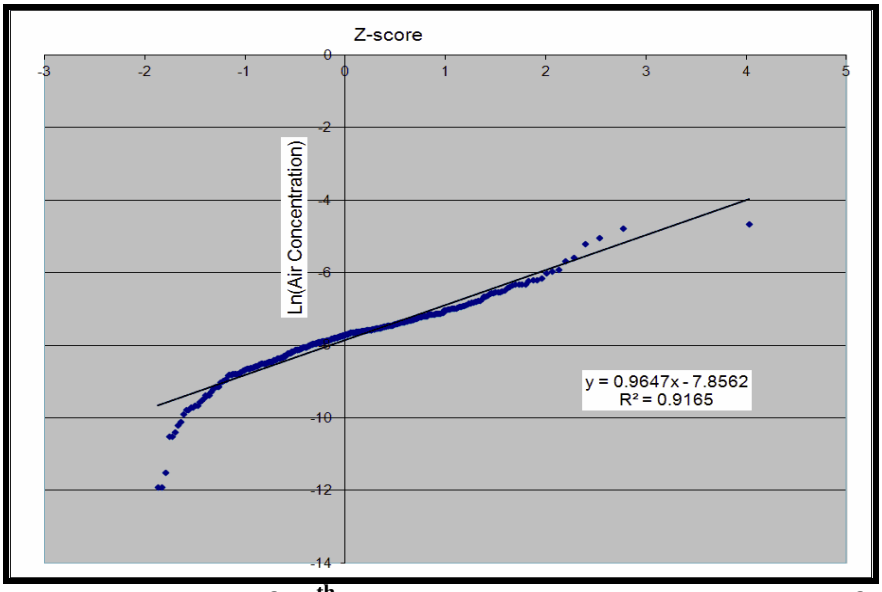

Figure 3. Calculation of 95th Percentile Tritide Air Concentration for R-108, October 1985

$$I = C\ BR\ O_c \qquad (3\text{-}2)$$

Where:
- I = Monthly tritide intake (µCi/month)
- C = 95th percentile tritide air concentration (µCi/m^3)
- BR = Breathing rate (m^3/hr)
  - = 1.2 (m^3/hr)
- O_c = Occupancy factor (hr/month)
  - = 167 (hr/month)

Once the monthly tritide intake has been calculated, it is a simple matter to calculate dose, as shown by the following equation:

$$D = DCF\ 1000 \sum_{m=1}^{12} I_m \qquad (3\text{-}3)$$

Where:
- D = Annual tritide dose (mrem)
- DCF = Tritide inhalation dose factor (rem/µCi)
- 1000 = Conversion factor (mrem/rem)
- I_m = Tritide intake for month, m (µCi/month)

4.0 REVIEW OF NIOSH DATA AND ASSUMPTIONS

4.1 REVIEW OF DATA ADEQUACY AND COMPLETENESS

This section presents a comprehensive review of the completeness of the available swipe data proposed for use in bounding potential exposures to SMT's. This review focuses on four facets of the original dataset, which covers rooms R-108 and SW-8:

- Temporal data coverage (what time periods are covered by the data)
- Availability of additional data sources
- Inconsistencies in the annual dose calculations made using the data
- An analysis of identified transcription errors and the overall effect of these errors on the calculated annual doses

Each of these facets is presented in Sections 4.1.1–4.1.4, respectively. Subsequent to this review, additional data were compiled and analyzed in NIOSH 2012 for rooms SW-13 and SW-150. These data are discussed in Section 4.1.5.

4.1.1 Temporal Data Coverage

This section analyzes the completeness of the tritium swipe sample dataset compiled by NIOSH in the two spreadsheets 'SMT exposures in R-108 SW-8 10-6 pre 1980.xls,' 'SMT exposures in R-108 SW-8 10-6 in 1980s.xls.' Tables 1 and 2 show the available swipe data by intake evaluation period, as defined by NIOSH, for rooms R-108 and SW-8, respectively. Intake evaluation periods are generally on a monthly basis; however, NIOSH notes in their white paper:

> *For those months that there was insufficiency in the data population for a 95th-percentile calculation, the data for a number of months were combined for use in the analysis.* (NIOSH 2012)

Figures 4–6 visually depict the number of swipe samples by the intake periods shown in Tables 1–2 for rooms R-108 (Figure 4) and SW-8 (Figures 5–6).

As shown in Table 1 and Figure 4, data compiled by NIOSH for room R-108 begin in June of 1983 and extend to the end of 1989. Gaps in the available data occur from January 1983 to May 1983, July 1986 to June 1988, and January 1989 to June 1989. No data were compiled for 1987, and the only year with an intake defined for each month was 1985. Intake evaluation periods averaged approximately 282 swipe samples each. Derived air concentrations are based on the surface activity concentration in μCi/m^2 and an RF of 3E-3/m. The actual 95th percentile surface concentration measurements are provided in the NIOSH evaluation and are not replicated here. This also applies to Table 2 for SW-8.

Table 1. Swipe Data Availability for Room R-108 (1983–1989)

Year	Intake Evaluation Period	Number of Swipe Samples	95th Percentile Derived Air Concentration (µCi/m^3)	Year	Intake Evaluation Period	Number of Swipe Samples	95th Percentile Derived Air Concentration (µCi/m^3)
1983	Jun–Aug	141	6.54E-03	**1986**	Jan	349	1.80E-03
	Sep–Dec	186	3.24E-03		Feb	320	1.65E-03
1984	Jan–Apr	246	2.43E-03		Apr	351	2.62E-03
	May–Aug	264	2.64E-03		May	336	1.96E-03
	Sep–Dec	270	7.96E-03		Jun	286	1.54E-03
1985	Jan	292	5.19E-04	**1987**	***No Data***	***NA***	***NA***
	Feb	282	1.36E-03	**1988**	Jul	326	1.84E-03
	Mar	222	1.28E-03		Aug	365	2.42E-03
	Apr	316	1.75E-03		Sep	329	2.08E-03
	May	294	1.76E-03		Oct	321	1.54E-03
	Jun	236	1.17E-03		Nov	297	1.46E-03
	Jul	252	1.19E-03		Dec	236	1.17E-03
	Aug	245	1.98E-03	**1989**	Jul	305	2.23E-03
	Sep	264	2.19E-03		Aug	334	2.55E-03
	Oct	357	1.89E-03		Sep	292	1.24E-03
	Nov	292	1.65E-03		Oct	325	2.53E-03
	Dec	279	9.98E-04		Nov	291	2.02E-03
					Dec	236	1.17E-03

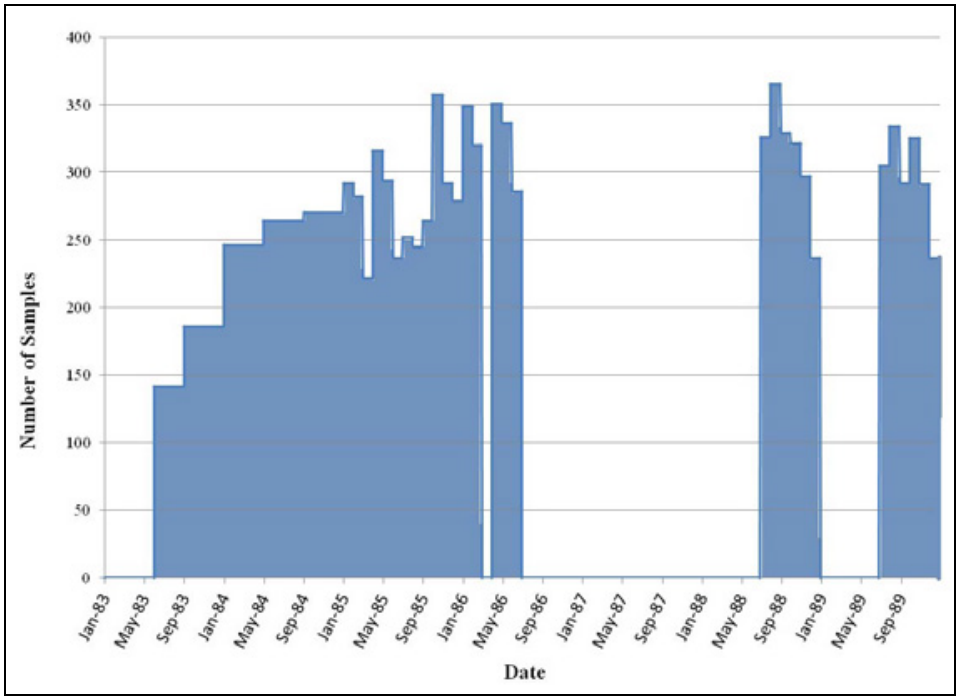

Figure 4. Number of Samples by Period for Room R-108 (1983–1989)

As shown in Table 3 and Figures 5–6, data compiled by NIOSH for room SW-8 begin in January of 1969 and extend to the end of 1989. The following gaps in the available swipe data were observed:

- September 1969
- December 1969 through September 1972
- December 1972 through June 1975
- September 1975 through May 1976
- August 1977 through December 1977
- All of 1980
- March 1986
- July 1986 through December 1986
- September 1987 through December 1987
- July 1988 through December 1988
- July 1989 through December 1989

During the earlier part of the evaluated period (1969 to 1979), intake periods were generally on a monthly basis and were generally on the order of 40–50 samples (the average sample size during this period was ~51). The smallest sample size observed was for October of 1972, which only used 12 samples to evaluate the 95th percentile surface contamination. There were only 3 cases during this earlier period in which data for more than 1 month were combined to allow for the calculation of the 95th percentile (July–August 1975, June–July 1976, and January–February 1978). In each case, one of the paired months had less than 10 data points associated with it. The only year during this earlier period when each month contained enough data to be evaluated separately was 1979.

During the later evaluated period (1980–1989), the number of swipe samples that were identified seem to increase, particularly starting in 1985 when the number of samples per month was consistently over 400 (this coincides with the availability of the raw swipe data instead of daily summary data). However, it is not clear why certain months were combined into a single intake period. For example, January and February of 1981 were evaluated based on 24 swipe samples for each month; however, the next intake period combines 4 months (March through June) with 120 total samples. Closer examination of these 4 months shows that each month had at least 24 samples, which were deemed an adequate number for the 2 preceding months (and twice the minimum number of samples used to analyze a given month in NIOSH's analysis of the earlier period). From 1981 to 1984, no single month had less than 24 data points. Therefore, it is unclear why these months were combined into a single intake period instead of evaluated individually.

Table 2. Swipe Data Availability for Room SW-8 (1969–1989)

Year	Intake Evaluation Period	Number of Swipe Samples	95th Percentile Derived Air Concentration (µCi/m³)	Year	Intake Evaluation Period	Number of Swipe Samples	95th Percentile Derived Air Concentration (µCi/m³)
1969	Jan	44	4.40E-03	1980	*No Data*	*NA*	*NA*
	Feb	20	3.04E-03	1981	Jan	24	6.63E-03
	Mar	306	6.18E-03		Feb	24	6.35E-03
	Apr	63	3.36E-03		Mar-Jun	120	4.43E-03
	May	81	4.29E-03		Jun-Oct	123	9.41E-03
	Jun	65	4.32E-03		Nov-Dec	54	4.61E-03
	Jul	93	1.32E-02	1982	Jan-Apr	129	7.81E-03
	Aug	131	3.34E-03		May-Aug	216	1.23E-02
	Oct	46	7.92E-03		Sep-Dec	225	9.76E-03
	Nov	51	6.77E-03	1983	Jan-Apr	189	7.11E-03
1970	*No Data*	*NA*	*NA*		May-Aug	234	8.44E-03
1971	*No Data*	*NA*	*NA*		Sep-Dec	189	1.14E-02
1972	Oct	12	8.97E-03	1984	Jan-Apr	237	1.33E-02
	Nov	75	4.27E-03		May-Aug	261	3.69E-03
1973	*No Data*	*NA*	*NA*		Sep-Dec	270	1.19E-02
1974	*No Data*	*NA*	*NA*	1985	Jan	459	1.75E-03
1975	July-Aug	21	3.53E-02		Feb	516	2.02E-03
1976	Jun-July	60	1.85E-02		Mar	359	2.01E-03
	Aug	30	8.73E-03		Apr	466	3.24E-03
	Sep	48	9.74E-03		May	482	2.26E-03
	Oct	51	1.62E-02		Jun	406	1.56E-03
	Nov	48	9.16E-03		Jul	448	1.59E-03
	Dec	45	5.76E-03		Aug	450	2.56E-03
1977	Jan	54	4.86E-03		Sep	423	3.96E-03
	Feb	51	6.28E-03		Oct	510	3.04E-03
	Mar	48	1.17E-02		Nov	379	3.33E-03
	Apr	51	7.70E-03		Dec	335	1.37E-03
	May	57	8.28E-03	1986	Jan	483	3.73E-03
	Jun	48	7.74E-03		Feb	438	2.47E-03
	Jul	54	8.17E-03		Apr	481	4.31E-03
1978	Jan-Feb	33	2.96E-03		May	461	1.70E-03
	Mar	36	4.21E-03		Jun	449	2.57E-03
	Apr	32	5.83E-03	1987	Jan	449	3.33E-03
	May	36	7.41E-03		Feb	432	5.26E-03
	Jun	45	2.83E-03		Mar	431	4.23E-03
	July	36	9.32E-03		Apr	466	4.74E-03
	Aug	42	6.16E-03		May	458	3.14E-03
	SEP	42	7.34E-03		Jun	448	5.24E-03

Table 2. Swipe Data Availability for Room SW-8 (1969–1989)

Year	Intake Evaluation Period	Number of Swipe Samples	95th Percentile Derived Air Concentration (µCi/m^3)	Year	Intake Evaluation Period	Number of Swipe Samples	95th Percentile Derived Air Concentration (µCi/m^3)
	Oct	42	9.38E-03		Jul	407	3.39E-03
	Nov	30	6.02E-03		Aug	492	3.01E-03
	Dec	39	5.60E-03	**1988**	Jan	456	1.65E-03
1979	Jan	24	2.12E-03		Feb	300	4.48E-03
	Feb	33	6.66E-05		Mar	490	1.62E-03
	Mar	45	5.00E-03		Apr	480	1.42E-03
	Apr	24	4.78E-03		May	450	1.04E-03
	May	36	6.72E-03		Jun	366	9.12E-04
	Jun	45	5.68E-03	**1989**	Jan	449	1.34E-03
	July	39	2.05E-02		Feb	576	1.70E-03
	Aug	48	1.10E-02		Mar	474	1.21E-03
	Sept	33	7.47E-03		Apr	582	1.86E-03
	Oct	36	2.18E-03		May	470	1.63E-03
	Nov	42	2.57E-03		Jun	349	1.94E-03
	Dec	27	2.52E-03				

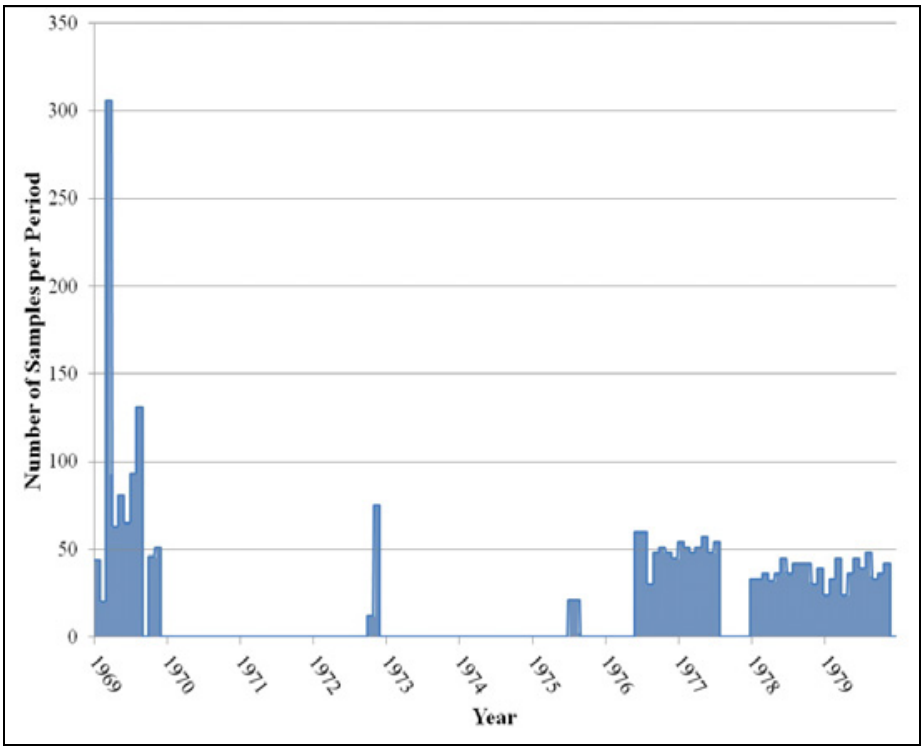

Figure 5. Number of Samples by Period for Room SW-8 (1969–1979)

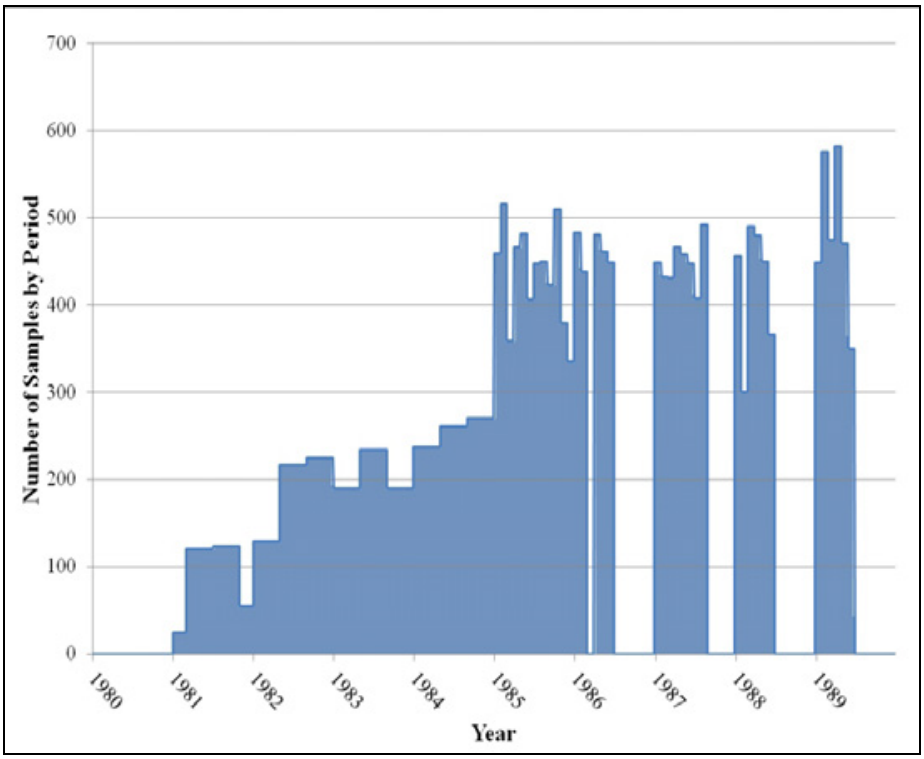

Figure 6. Number of Samples by Period for Room SW-8 (1980–1989)

4.1.2 Availability of Additional Data Sources

It is clear from the list of researched documents provided by NIOSH and the size of the files reviewed and transcribed that great effort went towards compiling the available swipe data. Nevertheless, SC&A performed an additional search of available documentation on the SRDB to determine whether additional data may now be available to fill in some of the gaps present in the data analysis and bolster the available sample sizes for months that already have data identified and compiled.

SC&A was able to find one document (Connell 2009) for room SW-8 in 1980 that contained daily summary statistics (minimum, maximum, and average) of swipe data for select days and months. It is important to note that this type of summary data was used by NIOSH for time periods in which the raw swipe data were not available (years prior to 1985 for both R-108 and SW-8, with the exception of 1969 for SW-8 in which raw data were identified). Table 3 shows the number of potential data points for SW-8 in 1980 by month.

Table 3. Available Health Physics Trend Data for Room SW-8 in 1980

Month	Number of Data Points	Overview of Data Magnitude (cpm/100 cm^2)		
		Minimum Value	Maximum Value	Average Value
January	39	0	1,150	205.3
February	39	0	3,743	658.9
March	39	0	2,185	354.7
April	33	11	2,771	594.4
May	33	6	3,679	792.6
June	0	-	-	-
July	0	-	-	-
August	0	-	-	-
September	0	-	-	-
October	6	67	2,000	616.7
November	27	9	3,361	462.4
December	18	52	6,593	1,528.3

Source: Connell 2009

For the years 1985 through 1989, NIOSH identified and compiled raw swipe data in calculating the 95th percentile surface contamination. Use of raw data is obviously preferable to the HP Trend Reports, which only contain the minimum, maximum, and average swipe results for a given day. However, raw data gaps have been found for several of the months from 1986–1989; therefore, it may be beneficial to use the HP Trend Reports to fill in the identified data gaps. Tables 4–7 show the available HP trend data for months with no raw data available. Therefore, additional data and reports exist that would help bolster the dataset already compiled by NIOSH.

Table 4. Available 1986 HP Trend Data for Months with No Available Raw Data

Relevant Months	Number of Data Points*	Room SW-8: Overview of the Magnitude of Available Results (cpm/100 cm^2)			Room R-108: Overview of the Magnitude of Available Results (cpm/100 cm^2)		
		Min Value	Max Value	Average Value	Min Value	Max Value	Average Value
March	60	0	6,824	727.3	0	8,483	656.1
July	63	0	12,571	1,117.0	0	5,293	442.9
August	60	0	4,733	665.2	0	3,930	357.6
September	63	0	5,047	734.7	0	2,250	353.7
October	69	0	4,933	588.4	0	1,957	310.9
November	54	0	2,829	424.4	0	2,700	239.7
December	51	0	8,237	900.9	0	1,686	343.9

*Applies to both rooms SW-8 and R-108
Sources: Connell 2010b and 2010c

Table 5. Available 1987 HP Trend Data for Months with No Available Raw Data

Relevant Months	Number of Data Points in HP Trend Reports*	Room SW-8: Overview of the Magnitude of Available Results (cpm/100 cm^2)			Room R-108: Overview of the Magnitude of Available Results (cpm/100 cm^2)		
		Min Value	Max Value	Average Value	Min Value	Max Value	Average Value
January	60	*Raw data available*			0	2,086	431.5
February	60	*Raw data available*			0	2,867	512.6
March	66	*Raw data available*			0	2,819	517.0
April	63	*Raw data available*			0	3,200	464.7
May	48	*Raw data available*			0	3,883	335.1
June	66	*Raw data available*			0	16,076	601.4
July	66	*Raw data available*			0	2,180	301.0
August	63	*Raw data available*			0	6,266	550.7
September	60	0	3,011	570.0	0	9,050	700.8
October	60**	0	25,897	874.3	0	1,744	384.6
November	66	0	16,843	667.7	0	1,270	230.4
December	63	0	4,287	591.8	0	14,626	748.2

* Applies to both rooms SW-8 and R-108 except where noted
** Value applies to room SW-8, room R-108 value is 51
Sources: Connell 2010e and 2010f

Table 6. Available 1988 HP Trend Data for Months with No Available Raw Data

Relevant Months	Number of Data Points*	Room SW-8: Overview of the Magnitude of Available Results (cpm/100 cm^2)			Room R-108: Overview of the Magnitude of Available Results (cpm/100 cm^2)		
		Min Value	Max Value	Average Value	Min Value	Max Value	Average Value
January	60	*Raw data available*			0	1,469	286.7
February	63	*Raw data available*			0	1,786	273.7
March	57	*Raw data available*			0	4,691	407.4
April	30	*Raw data available*			0	1,997	215.0
May	63	*Raw data available*			0	3,014	383.4
June	66	*Raw data available*			0	4,174	625.3
July	60	0	11,727	519.6	*Raw data available*		
August	54	0	53,223	2,101.4	*Raw data available*		
September	63	0	2,269	363.0	*Raw data available*		
October	63	0	4,253	405.8	*Raw data available*		
November	51	0	7,222	414.3	*Raw data available*		
December	36	0	3,389	258.9	*Raw data available*		

*Applies to both rooms SW-8 and R-108
Sources: Connell 2010g and 2010h

Table 7. Available 1989 HP Trend Data for Months with No Available Raw Data

Relevant Months	Number of Data Points*	Room SW-8: Overview of the Magnitude of Available Results (cpm/100 cm^2)			Room R-108: Overview of the Magnitude of Available Results (cpm/100 cm^2)		
		Min Value	Max Value	Average Value	Min Value	Max Value	Average Value
January	48	*Raw data available*			**0**	**2,809**	**280.5**
February	45	*Raw data available*			**0**	**4,199**	**503.7**
March	51	*Raw data available*			**0**	**7,784**	**687.2**
April	30	*Raw data available*			**0**	**1,276**	**320.2**
May	36	*Raw data available*			**43**	**4,588**	**503.4**
June	66	*Raw data available*			**31**	**20,136**	**792.8**
July	42	0	1,869	273.6	*Raw data available*		
August	39	0	2,313	351.7	*Raw data available*		
September	30	0	2,265	277.0	*Raw data available*		
October	15	0	574	135.2	*Raw data available*		
November	48	0	1,864	276.9	*Raw data available*		
December	30	0	1,129	212.5	*Raw data available*		

*Applies to both rooms SW-8 and R-108
Sources: Connell 2010i and 2010j

4.1.3 Dose Calculation Inconsistencies Identified in Spreadsheets

NIOSH has derived annual 50-year committed organ dose values by calculating monthly intakes based on the 95th percentile surface contamination (and associated air concentration) in each respective room. These monthly intakes are then summed to get an annual intake value, which can then be converted to a committed dose using appropriate dose conversion factors. However, annual doses appear to be underestimated for years in which data do not exist for all 12 months. Further complicating the annual dose calculations is the fact that when data for multiple months were combined to derive a single 95th percentile value, intakes were calculated assuming only a single month's exposure time. An example of each of these calculational errors is shown below based on the methodology presented in NIOSH 2011a (the "extreme" bounding case).

Example 1: Underestimation of Annual Doses for Years with Data Gaps

For this example, the annual dose calculation for SW-8 in 1972 is considered. Data for 1972 were limited to October (12 samples) and November (75 samples); these were treated by NIOSH as two discrete intake periods. Table 8 details the calculational steps taken by NIOSH to derive the annual dose for 1972.

Table 8. Steps Used by NIOSH in Calculating Doses for 1972

Step	Description	Assumed Parameter Values	Calculation Step	Comments
1	Raw data are compiled	Various swipe results	N/A	Starting point for the annual dose calculation; Multiple raw floor swipes, data are in units of cpm/100 cm^2.
2	Account for detector efficiency	Detector Efficiency: 4%	Divide raw values by 0.04	Values converted to dpm/100 cm^2.
3	Convert dpm to µCi	Conversion Factor: 2.22E+06 dpm/µCi	Divide values by 2.22E+06	Values converted to µCi/100 cm^2.
4	Apply resuspension factor	Resuspension factor: 3E-03 m^{-1} Unit Conversion: µCi/100 cm^2 × $(100\ cm/m)^2$	Multiply values by 100 and 3E-03 m^{-1}	Resuspension factor is applied to obtain airborne concentration based on each swipe sample, values given in µCi/m^3.
5	Calculate 95th percentile air concentration	N/A	October 95th percentile concentration: 8.97E-03 µCi/m^3 November 95th percentile concentration: 4.27E-03 µCi/m^3	Calculated airborne concentrations are fit to a lognormal distribution and the mean and standard deviation are calculated. These are used to derive the 95th percentile air concentration.
6	Calculate monthly intake	Breathing Rate: 1.2 m^3/hr Exposure Time: 167 hrs/month	October Intake: 8.97E-03*(1.2)*(167) = 1.79 µCi November Intake: 4.27E-03*(1.2)*(167) = 8.54E-01 µCi	Exposure time based on 2,000 hours divided by 12 months = 167 hours/month.
`7	Calculate annual intake	N/A	October Intake + November Intake 1.79 + 8.54E-01 = 2.65 µCi	***Annual intake is only based on 2 months of exposure (167*2= 334 hours total exposure for year).***
8	Convert intake to committed lung dose	Dose conversion factor: 3.68E-03 rem/µCi Unit conversion: 1,000 mrem/rem	2.65*(1000)*(3.68E-03) = 9.74 mrem CDE to the lung	***Derived CDE dose for the year are based on an annual intake, which is representative of only 2 months of exposure.***

Note that the value obtained from Table 8 (9.74 mrem CDE to the lung) is consistent with the value reported on page 28 of NIOSH 2012. Since this value is based on only 2 months' worth of exposure, the actual annual dose would be much higher if data were available for the remaining months. If we assume the average monthly intake for the remaining months is 1.325 µCi (2.65/2), then the total intake for 1972 could be estimated at 15.9 µCi (1.325*12). This results in a new CDE to the lung of 58.5 mrem, which is a factor of 6 higher than the reported dose.

Example 2: Underestimation of Annual Doses where Data for Multiple Months have been Pooled Together

As noted earlier in this report and in the NIOSH white paper, for situations where a given month did not have sufficient data to calculate the 95th percentile, the data for multiple months may be pooled together to determine the appropriate air concentration. For this example, the annual dose for room SW-8 in 1983 will be examined. The reader is referred to Table 8 for the calculational steps taken to reach an annual dose; the difference here is that intakes are not calculated using a single month's data, but rather multiple consecutive months in the given year. A tabulation of the main values reported by NIOSH for this year is given in Table 9.

Table 9. Values Reported by NIOSH in Annual Dose Calculation for 1983

Intake Period Considered	Derived 95th Percentile Air Concentration (µCi/m^3)	Associated Intake* (µCi)	CDE to the Lung** (mrem)
January–April	7.11E-03	1.42E+00	5.23E+00
May–August	8.44E-03	1.69E+00	6.20E+00
September–December	1.14E-02	2.28E+00	8.40E+00
Annual Totals:		**5.39E+00**	**1.98E+01**

* Intake derived by multiplying 95th air concentration by 1.2 (m^3/hour) and 167 (hours)

** CDE to the lung based on DCF value of 3.68 mrem/µCi

Similar to Example 1, the issue is that a full year of exposure has not been considered. In this example, 3 intake periods are considered, each representing 4 months; however, the actual intakes are based only on 1 month of exposure (167 hours for each intake period). If each calculated intake in Table 10 is extrapolated to the full exposure period it represents, the resulting CDE to the lung increases from 1.98E+01 mrem to 7.93E+01 mrem (factor of 4).

These types of 'exposure time' errors are pervasive in the NIOSH calculations, owing to the large number of years with data gaps and/or several months of data being pooled together. Tables 10 and 11 provide corrected intakes adjusted to full-year exposures. Please refer to Attachment 1 for the actual calculation of the extrapolated intakes.

Table 10. Original NIOSH Intakes Compared to Adjusted Intakes for a Full Year Exposure for Room R-108

Year	Original NIOSH Intake (µCi)	Intake Adjusted to Full Year (µCi)	Ratio (Adjusted/ Original)
1983	1.96E+00	1.12E+01	5.71E+00
1984	2.60E+00	1.04E+01	4.00E+00
1985	3.56E+00	3.56E+00	1.00E+00
1986	1.92E+00	4.60E+00	2.40E+00
1987	*Data not compiled/analyzed*		
1988	2.11E+00	4.22E+00	2.00E+00
1989	2.35E+00	4.70E+00	2.00E+00

Table 11. Original NIOSH Intakes Compared to Adjusted Intakes for a Full Year Exposure for Room SW-8

Year	Original NIOSH Intake (µCi)	Intake Adjusted to Full Year (µCi)	Ratio (Adjusted/ Original)
1969	1.14E+01	1.36E+01	1.20E+00
1970	*Data not available and/or compiled*		
1971	*Data not available and/or compiled*		
1972	2.65E+00	1.59E+01	6.00E+00
1973	*Data not available and/or compiled*		
1974	*Data not available and/or compiled*		
1975	7.07E+00	8.48E+01	1.20E+01
1976	1.36E+01	2.97E+01	2.18E+00
1977	1.09E+01	1.88E+01	1.71E+00
1978	1.34E+01	1.40E+01	1.04E+00
1979	1.47E+01	1.47E+01	1.00E+00
1980	*Data not available and/or compiled*		
1981	6.28E+00	1.55E+01	2.47E+00
1982	5.98E+00	2.39E+01	4.00E+00
1983	5.39E+00	2.16E+01	4.00E+00
1984	5.79E+00	2.32E+01	4.00E+00
1985	5.75E+00	5.75E+00	1.00E+00
1986	2.96E+00	7.11E+00	2.40E+00
1987	6.48E+00	9.72E+00	1.50E+00
1988	2.23E+00	4.46E+00	2.00E+00
1989	1.94E+00	3.88E+00	2.00E+00

As shown in Tables 10 and 11, the reported annual intakes have been underestimated by up to a factor of 12 (1975). Likewise, the calculated organ CDEs would also change in proportion to the increase in intake. NIOSH reports the highest dose commitment to select organs observed using the compiled swipe data in Table 5 of their white paper. SC&A has recreated the information from Table 5 in Table 12 of this report, which includes the new 'maximum' organ doses when the annual intake values are scaled to a full year of exposure.

Table 12. Comparison of Limiting Organ CDEs Based on NIOSH Intake Estimates versus Intake Estimates Extrapolated to a Full Year of Exposure

Organ	NIOSH Limiting CDE Organ Doses - mrem (based on data from 1979)	Adjusted CDE Organ Doses to Full Year - mrem (based on data from 1975)
Lung	54.1	**311.7**
LN (ET)	177	**1,022.3**
LN (TH)	266	**1,532.2**
AI	162	**931.3**
ET	0.189	1.1
U.L.I.	2.52	14.5
LLI	7.37	42.5
SI	0.424	2.4
Colon	4.62	26.6

4.1.4 Brief Evaluation of Potential Transcription Errors

In preparation for the Mound Work Group meeting held on November 7, 2011, SC&A compiled available Health Physics Trend Reports for the years in the early 1980s (1981–1984), which currently had no swipe data associated with the SMT exposure model. These same source data were transcribed by NIOSH in their most recent tritide model, which is the subject of this review. Therefore, it was possible to evaluate potential transcription errors by comparing the two independently compiled datasets and resolving any inconsistencies by referencing the hardcopy records. This analysis of potential errors is the subject of this section (and also Attachment 2). A summary of the error analysis is presented in Table 13.

Three types of "errors" were analyzed and described below:

(1) Transcription errors: Data points were transcribed from the hardcopy records; however, one or more of the digits were incorrect.

(2) Missing data: Data points were missed when compiling relevant data from the hardcopy records.

(3) Duplicate data: The same sample values appear more than once in the compiled dataset, likely a result of the repetition of sample analysis sheets within the source documents.

Table 13. Overview of Transcription Error Analysis for the Years 1981–1984

Analysis Category	Total Number Identified	Percent of Total
Total Data Compiled by NIOSH 1981–1984	3,402*	N/A
Transcription Errors	56	1.7%
Under-reported Samples	37	1.1%
Over-reported Samples	19	0.6%
Change in Net CPM for the Entire Dataset with Transcription Errors Corrected	N/A	-2.7%
Missing Data	54	1.6%
Duplicate Data	81	2.4%

* Note: The total number of data available from 1981 to 1984 would change from 3,402 to 3,375 if duplicate entries are removed and missing entries are included.

As seen in Table 13, the number of transcription errors was relatively low at only 1.7%. While a higher percentage of these transcription errors resulted in the samples being under-reported, the net effect of these errors actually resulted in the total counts per minute (cpm) for the dataset being reduced by 2.7%. The number of data points missing from the NIOSH compilation was also relatively low at 1.6% and can generally be correlated with a "missed page" in the source documents. As mentioned previously, the duplication of data points in the NIOSH dataset is likely the result of specific pages of the HP summary reports being repeated in the source documents. A description of each error found, along with the associated reference to the hardcopy source documents, can be found in Attachment 2.

4.1.5 Evaluation of Additional Data Compiled in NIOSH 2012

On March 30, 2012, NIOSH released a white paper titled, *Potential Stable Metal Tritide Exposures at the Mound Laboratory* (NIOSH 2012), which presented a revised methodology for evaluating tritide exposures. This revised methodology also included additional data from rooms SW-13 and SW-150 to supplement the earlier dataset, which covered rooms R-108 and SW-8. Unlike the original data evaluation, which analyzed the data on a monthly basis (or, when unavailable, grouped several months together), the swipe data for SW-13 and SW-150 were grouped and analyzed by year.

A potential concern with this type of approach is that the annual derived values could be unduly weighted by months that contained more sampling data, but may not have been representative of the normal conditions throughout the year. As part of its review of this additional dataset, SC&A broke down the data by month to compare the relative magnitude of the swipe data when weighted by month versus pooling all of the data into a single annual dataset. This comparison, as well as the overview of data coverage for rooms SW-13 and SW-150, are shown in Tables 14 and 15, respectively. The comparisons of calculated annual average values versus the monthly weighted average values are plotted in Figures 7 and 8.

As seen in Table 14, data for SW-13 extended from 1974 to 1989, with the largest temporal gap being an 8-month period from the end of 1988 into 1989. The comparison of the ratio of the annual average values to the monthly weighted values was fairly consistent with the highest

discrepancies occurring in 1975 and 1985, in which the monthly weighted values were 21% and 28% higher, respectively.

Table 14. Overview of Available Surface Contamination Swipe Results for Room SW-13 by Year

Year	Overview of Sampling			Quantitative Results (cpm/100 cm^2)		
	# Months with Sampling Data	Average # Samples per Sampled Month	# Consecutive Months with No Sampling	Yearly Average	Average Weighted by Month	Ratio (Weighted by Month/Grouped)
1974	11	6	1	2729.8	2646.6	0.97
1975	7	6	4	2637.4	3204.3	1.21
1976	6	7	6	884.8	800.7	0.90
1977	12	9	0	1727.4	1658.9	0.96
1978	12	10	0	1209.6	1388.7	1.15
1979	12	15	0	420.8	392.0	0.93
1980	8	11	4	363.8	382.2	1.05
1981	12	11	0	537.4	531.8	0.99
1982	12	11	0	955.7	969.1	1.01
1983	12	10	0	1932.3	2008.6	1.04
1984	12	8	0	1542.8	1554.8	1.01
1985	12	154	0	474.5	606.5	1.28
1986	4	201	6	369.3	344.7	0.93
1987	10	469	2	303.7	303.5	1.00
1988	4	510	6	398.2	400.2	1.00
1989	6	468	8*	329.7	302.6	0.92

*8 consecutive months with no sampling include 2 months at the end of 1988

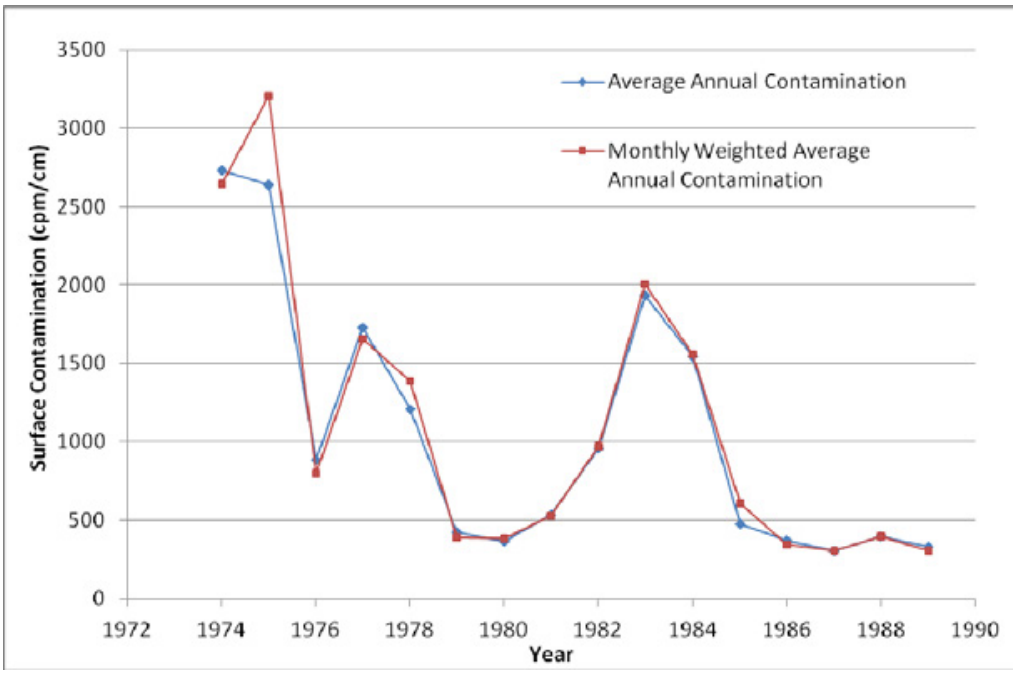

Figure 7. Comparison of the Annual Average Surface Contamination versus the Monthly Weighted Average Annual Surface Contamination for Room SW-13

As seen in Table 15, data for room SW-150 extended from 1968 to 1989, with the largest temporal gap being 10 months beginning in late 1987 and extending into 1988. Similar to SW-13, the comparison of the ratio of the annual average results versus the monthly weighted annual results showed generally good agreement. The largest discrepancies occurred in 1978 and 1985, in which the monthly weighted average was 35% and 26% higher, respectively.

Table 15. Overview of Available Surface Contamination Swipe Results for Room SW-150 by Year

Year	Overview of Sampling			Quantitative Results (cpm/100 cm^2)		
	# Months with Sampling Data	Average # Swipes per Sampled Month	# Consecutive Months with no Sampling	Yearly Average	Average Weighted by Month	Ratio (Weighted by Month/Grouped)
1968	12	8	0	3282.1	3218.7	0.98
1969	9	70	3	550.0	535.7	0.97
1970	12	8	0	2436.1	2438.8	1.00
1971	12	8	0	3347.5	3643.9	1.09
1972	12	8	0	1983.1	1840.1	0.93
1973	12	8	0	1876.2	1698.0	0.91
1974	12	8	0	1866.1	1804.6	0.97
1975	12	9	0	1951.4	1837.9	0.94
1976	5	10	7	3009.2	2990.0	0.99
1977	12	9	0	3198.5	3263.1	1.02
1978	12	9	0	1564.2	2118.0	1.35
1979	12	12	0	439.1	433.4	0.99
1980	8	11	4	236.7	263.3	1.11
1981	12	11	0	318.2	313.6	0.99
1982	12	11	0	740.5	735.6	0.99
1983	12	16	0	1020.1	1049.4	1.03
1984	12	20	0	1294.1	1296.7	1.00
1985	12	197	0	474.8	598.7	1.26
1986	4	334	6	325.7	328.7	1.01
1987	8	497	4	187.0	184.9	0.99
1988	6	485	10*	235.8	241.8	1.03
1989	6	460	6	132.2	131.8	1.00

*10 consecutive months with no sampling include 4 months at the end of 1987

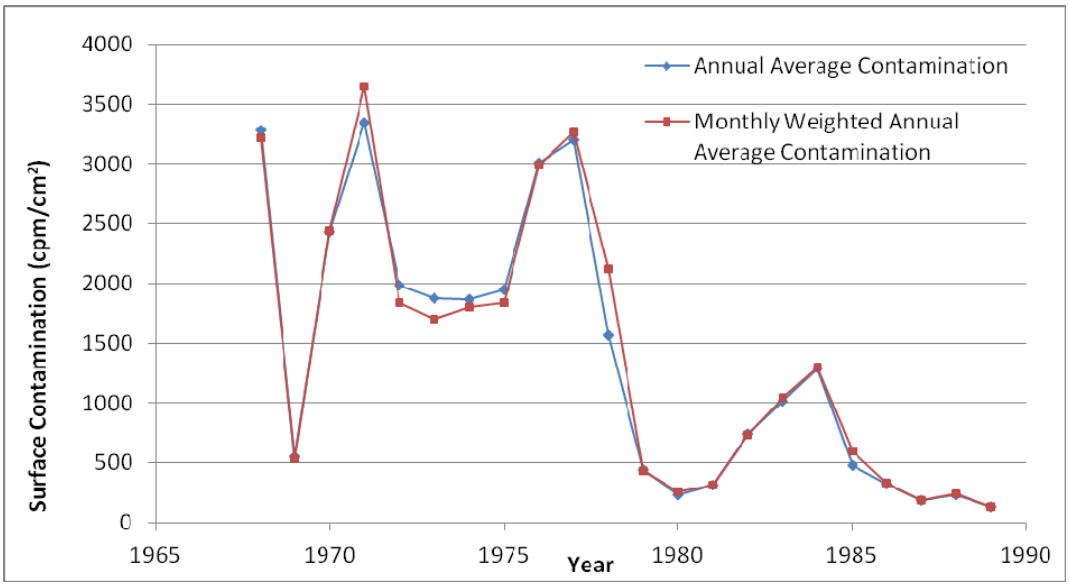

Figure 8. Comparison of the Annual Average Surface Contamination versus the Monthly Weighted Average Annual Surface Contamination for Room SW-150

As shown in Tables 14 and 15, the temporal data coverage for rooms SW-13 and SW-150 is generally complete, with gaps extending no longer than 8 and 10 months, respectively. Though the ratio of the annual average and the monthly weighted average was generally consistent, NIOSH should examine the feasibility of evaluating the data on a monthly basis to maintain consistency with the previous data analysis for rooms R-108 and SW-8.

NIOSH 2012 presents a case study example, which applies their model to a hypothetical worker scenario. Specifically, the case study assumes a worker was exposed for 2 years to the highest observed levels of annual contamination for each room (R-108, SW-8, SW-13, and SW-150) with the dose evaluated 10 years after the exposure. NIOSH 2012 presents the results of this case study in Table 1 of their white paper (presented below as Figure 9).

Table 1: Maximum Potential SMT Doses to the Lung (mrem)

Room	Best Est. (50th percentile) Swipe Values			Bounding (95th percentile) Swipe Values		
	$\sum_{j=1}^{12} AD_{1,j}$	$\sum_{j=1}^{11} AD_{2,j}$	Total	$\sum_{j=1}^{12} AD_{1,j}$	$\sum_{j=1}^{11} AD_{2,j}$	Total
SW-150	0.04	0.04	0.08	0.16	0.15	0.31
SW-13	0.04	0.03	0.07	0.12	0.11	0.23
R-108	0.02	0.01	0.03	0.10	0.07	0.17
SW-8	0.02	0.11	0.12	0.30	0.19	0.48

Note: The respective two years with the highest air concentrations associated with the specified rooms are:

	95th percentile		50th percentile	
	Year 1	Year 2	Year 1	Year 2
SW-150	1968	1977	1968	1977
SW-13	1975	1974	1974	1975
R-108	1985	1984	1985	1989
SW-8	1977	1975	1986	1969

Figure 9. Recreation of NIOSH 2012 Table 1

A review of the case study shows that similar errors occur in this dose calculation as were identified in Section 4.1.3 of this report. Specifically, derived intakes have not been extrapolated to a full year. This is particularly significant for rooms SW-13 and SW-150, since the data has been pooled together into a single annual dataset, though derived intakes are based on only a single month of exposure time. If these errors are corrected, the resulting doses that are shown in Figure 9 would increase to the values shown in Table 16. Table 17 shows the ratio of the corrected values in Table 16 to the original values shown in Figure 9. Based on these updated values, the limiting lung dose at the 95th percentile for room SW-150 is approximately 3.73 mrem. It is noteworthy that the corrected 95th percentile lung dose is notably higher than the 1-mrem threshold cited by NIOSH at the last work group meeting.

Table 16. SC&A Corrected Potential SMT Doses to the Lung Based on NIOSH 2012 Case Study Example

Room	Best Estimate (50th Percentile)			Bounding (95th Percentile)		
	12 Year Dose (Year 1)	11 Year Dose (Year 2)	Total	12 Year Dose (Year 1)	11 Year Dose (Year 2)	Total
SW-150	0.48	0.47	0.95	1.91	1.82	3.73
SW-13	0.46	0.34	0.80	1.49	1.3	2.79
R-108	0.02	0.03	0.05	0.10	0.28	0.37
SW-8	0.04	0.13	0.17	0.51	2.26	2.77

Table 17. Ratio of SC&A Corrected Case Study Lung Doses shown in Table 16 to Original NIOSH 2012 Case Study Values shown in Figure 9

Room	Best Estimate (50th Percentile)			Bounding (95th Percentile)		
	12 Year Dose (Year 1)	11 Year Dose (Year 2)	Total	12 Year Dose (Year 1)	11 Year Dose (Year 2)	Total
SW-150	12.0	11.8	11.9	11.9	12.1	12.0
SW-13	11.5	11.3	11.4	12.4	11.8	12.1
R-108	1.0	3.0	1.7	1.0	4.0	2.2
SW-8	2.0	1.2	1.4	1.7	11.9	5.8

4.1.6 Concluding Statements on Data Adequacy and Completeness

Based on the review of the underlying data presented in Sections 3.2.1–3.2.4, SC&A concludes that the dataset is complete and adequate for rooms R-108 beginning in 1983 and SW-8 beginning in 1976. Any chronological gaps that were identified were generally on the order of a few months and can likely be analyzed using surrogate data from previous intake periods. Similarly, the dataset for rooms SW-13 and SW-150 are complete, with data gaps never extending more than 10 months, and were generally on the order of 6 months or less. Many years contained data for all 12 months for these rooms.

However, if possible, NIOSH would benefit from a discussion of the identified gaps in the context of exposure conditions both before and after the periods without data to assure that any surrogate approach is accurate and appropriate.

4.2 REVIEW OF DETECTOR EFFICIENCY AND TRITIUM AIR SAMPLE FILTERS FOR SMTS

4.2.1 Evaluation of 4% Detector Efficiency

NIOSH provided an analysis of the Mound Lab SMT issue in an e-mail of October 14, 2011 (NIOSH 2011b), with an attachment titled "PC5 Eff.docx." This was a 1-page document that provided a summary of the methods used by NIOSH to derive a tritium counting efficiency of 4% for the PC-5 gas-flow proportional counter (PC) from swipes by comparing the response of the PC-5 to a liquid scintillation counter (LSC); i.e., the recorded swipe results obtained by the PC-5 would be divided by 0.04 to obtain the tritium dpm value for the swipe.

NIOSH used documents from the SRDB that contained data sheets with both the PC-5 cpm values and the LSC dpm values recorded for the same swipes for the years 1990 and 1991. These documents are:

Table #1 SRDB Numbers

- 81787, pp. 8–247 (Connell 2010k)
- 81788, pp. 2–628 (Connell 2010L)
- 81907, pp. 425–700 (Connell 2010m)
- 81908, pp. 58–62 (Connell 2010n)
- 81909, pp. 2–692 (Connell 2010o)

A sample of 356 of these data pairs was transcribed for evaluation in the spreadsheet titled, "Mound LSC & PC5 comparison" (NIOSH 2011c). These data pairs are contained in the following documents:

Table #2 SRDB Numbers

- 81787, pp. 28–38, 44, 50, 60, 70, 80, 90, 100, 110 (Connell 2010k)
- 81788, pp. 2, 20 (Connell 2010L)

These data pairs were sorted according to the observed [PC-5 (CPM)]/[LSC (DPM)] values and it was found that 277 pairs fit the criteria of this value, being less than 0.20 (i.e., <20%); this value was selected because efficiencies greater than this for a PC-5 system would indicate betas of greater than the maximum energy of 17 keV (tritium). The correlation of these data was moderately strong, with a Variance table P-value less than 0.05. The R-Squared statistic indicates that the linear model as fitted explains 38% of the variability in the PC-5 data.

SC&A's Evaluation

SC&A reviewed the above-listed and other relevant documents, and spot checked some of the efficiency values using the raw data. SC&A analyzed the data (removing zero PC-5 counts and those with ≥ 20% efficiency, as previously discussed) and arrived at an efficiency of approximately 10%; i.e., #dpm = PC-5 (cpm)/0.10. The relationship is illustrated in Figure 10, which also plots the values of 4% and 10% of the LSC dpm values.

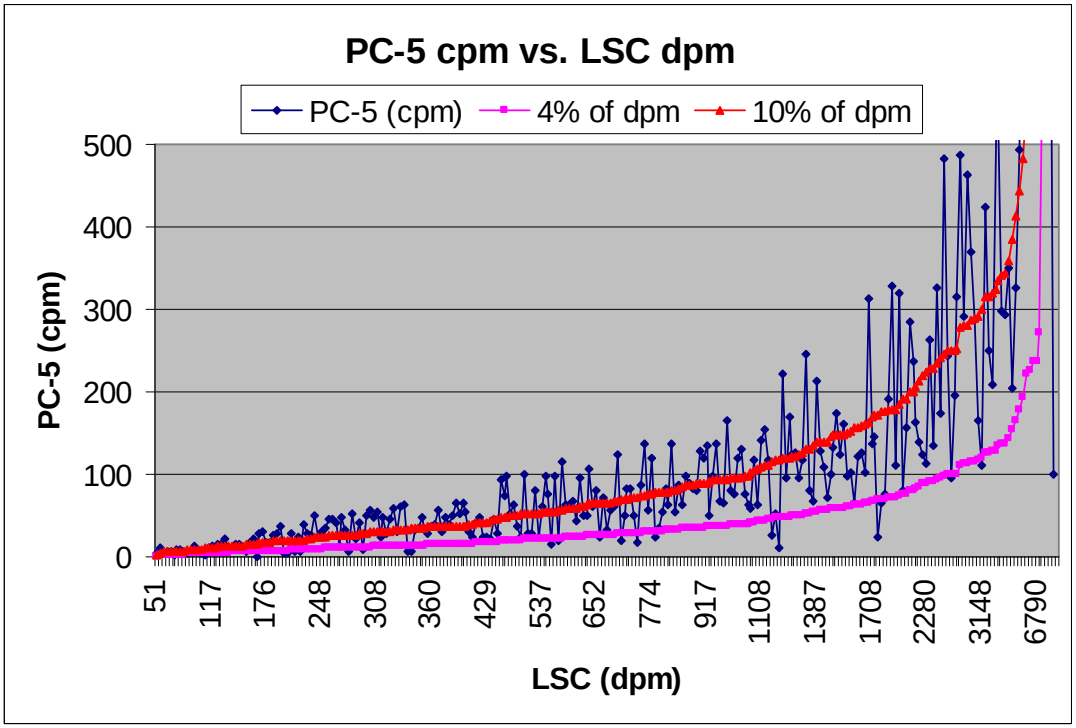

Figure 10. PC-5 (cpm) vs. LSC (dpm) and 4% and 10% of LSC dpm Values

As can be seen from this figure, the PC-5 system appears to have an efficiency that is reasonably represented by the 10% efficiency line. Ranking the data provides a median efficiency of 10.2% and a 50th percentile of 9.8%. The NIOSH-recommended PC-5 efficiency of 4% is, therefore, very conservative, but claimant favorable. However, SC&A did have the following questions concerning the data used:

(1) What was the criterion applied to the data pairs in the documents listed in Table 1 SRDB Numbers above to arrive at the list of documents and page numbers in Table 2 SRDB Numbers above?

(2) Were the main areas emphasized in the data used representative of surfaces in R-108 and SW-8 during the 1980s?

4.2.2 Tritium Air Sample Filters for SMT

A continuous air sampler for tritium usually consists of an ionization chamber (IC) in which air is continuously drawn through the IC by an air pump connected to the outlet of the IC. The inlet air port of such a system must have a filter to prevent dust and other particles from entering the IC and causing interference and false positive readings. These inlet filters are designed to trap most all particulate matter, letting only gaseous materials pass through the IC. Airborne SMT would be trapped on the inlet filter, and theoretically could be analyzed for particulate tritium contents to determine SMT concentration in the sampled air. However, in practice, this is a very difficult process because of the many variables present, especially for the very low average energy of tritium betas (~5 keV). Dust loading would vary and affect the detection of the tritium beta particles, as would the depth of the SMT in the filter medium. Variation in the concentrations of other beta-emitting interfering radionuclides (natural and man-made) would also interfere with the tritium analyses. Additionally, release of the SMT from the filter contaminants and the filter medium causes changes in the count rate as a function of time. Counting the filters for SMT by PC or LSC, under controlled conditions, has not been successful in the documents reviewed (Sullivan 1996; Powers 1998; Sharfi 2000). Therefore, it would be expected to be very difficult to obtain any quantitative relationship of SMT air concentration to PC, or LSC, count rates from filters on IC inlets, or any filter, from the 1980s or 1990s.

4.3 REVIEW OF RESUSPENSION FACTOR

The STC bounding methodology proposed by NIOSH depends to a large extent on the integrity and applicability of the selected resuspension factor (RF). The RF is simply an empirically determined ratio of the air concentration of radioactive material above a surface (Bq/m^3) to the concentration on the surface (Bq/m^2). However, there is some ambiguity in the denominator of this calculation. If the surface contamination is based on swipe samples, the denominator is removable contamination. If the surface contamination is based on estimates of the total amount of dust or radioactive material surfaces, the denominator is the total amount of radioactivity or dust per unit surface area. Regulatory Guide 1.86 (NRC 1974) recommends that the resuspendable (or readily removable) amount of radioactivity on a surface is about 20% of the total amount of radioactive material on a surface. Therefore, the product of the tritide surface contamination with an appropriately selected RF, taking into consideration how the level of

surface contamination was determined, yields an estimate of the airborne tritide concentration to which workers may have been exposed.[12]

In its initial evaluation of resuspension factors that would place an upper bound on airborne tritides due to resuspension processes, NIOSH originally elected to use an RF of 3E-3/m (i.e., 3E-3 Bq/m^3 per Bq per m^2). SC&A's original review of that RF (in the withheld predecessor to this paper) concluded that 3E-3/m was certainly bounding, if not implausibly high, especially when used to derive an annual average airborne loading of tritides. In its white paper dated March 30, 2012, NIOSH elected to use a more plausible, but still bounding, RF of 5E-5/m. This section of SC&A's report presents a review of this revised RF, as adopted by NIOSH for use in determining the airborne levels of metal tritides relative to metal tritides on contaminated surfaces, as determined by swipe samples at Mound.[13]

It must be kept in mind that RFs are used primarily after operations cease and there is no source of radioactivity being injected directly into the ambient working environment by leakage or other processes associated with operations. It is not apparent that NIOSH is restricting the use of the RF approach to post-operational scenarios, where the air can only become contaminated by resuspension processes.

NIOSH selected an RF of 5E-5/m by citing ORAUT-OTIB-0070, *Dose Reconstruction During Residual Radioactivity Periods at Atomic Weapons Employer Facilities* (ORAUT 2012). SC&A had previously reviewed OTIB-0070 in support of the Procedures Subcommittee, and, after a number of meetings and exchanges of white papers, SC&A concurred with the commitments made by NIOSH to revise OTIB-0070, which included the use of an RF of 5E-5/m. In the interest of full documentation, SC&A revisits this subject here.

One of the most widely referenced reports dealing with the subject of RFs is *DOE Handbook: Airborne Release Fractions/Rates and Respirable Fractions for Nonreactor Nuclear Facilities* (DOE 1994). This report, in turn, cites the seminal paper on this subject, *Particle Resuspension: A Review* (Sehmel 1980). SC&A reviewed this paper, the source documents cited in this paper, and more recent publications on this subject. We found that an RF of 5E-5/m represents a scientifically sound upper bound of the average annual RFs that might have been experienced **during the residual period at any facility and applicable only if the residual surface contamination, as determined at the facility, is based on total deposited radioactivity**. As used in the white paper presented by the NIOSH contractor, we are concerned that the RF of 5E-5/m will be used during operational periods, when direct airborne leakage is possible, and

[12] In addition, it could be argued that the resuspension factor, in combination with knowledge of the levels of surface contamination, could be used to estimate airborne concentration of radionuclides from both resuspension of surface contamination and from direct airborne contamination due to the direct release of aerosols into the air (e.g., leakage of aerosols during processing) if the resuspension factor selected for use was originally derived under the following conditions: (1) operations that introduced radioactive materials directly into the air were taking place, (2) quasi-equilibrium was established between surface and airborne activity, and (3) the conditions under which the resuspension factor was derived are similar to the conditions under which the resuspension factor is being employed.

[13] A significant portion of the material provided in this report was originally provided in an unpublished draft document titled, *Radiological Assessment for Clearance of Equipment and Materials from Nuclear Facilities – Main Report* (NRC 1998). SC&A used the material in this unpublished draft report as a starting point for the preparation of this report.

applied to measures of surface contamination that are based on swipe samples without any correction factor to adjust for the difference between total surface contamination and removable surface contamination (i.e., swipe sample data). The following briefly summarizes the literature on indoor RFs in order to provide the Mound Work Group with the basis of this conclusion.

Measured RFs vary over very wide ranges. Kennedy and Strenge (1992) reported RFs from approximately 1E-11 to 1E-2 m^{-1}, which suggests that resuspension is a complex process of several parameters, and that the specific conditions present at the time of measurement are critical. For modeling purposes, an RF is a lumped parameter that is used to account for a complex combination of mechanisms that are poorly understood, but whose net effect is observed in the real world.

The RF is affected by a number of physical factors that include the following:

- Type of disturbance
- Intensity of disturbance
- Time since deposition
- Nature of the surface
- Particle size distribution
- Climatic conditions
- Type of deposition
- Chemical properties of the contaminant
- Surface chemistry
- Room geometry and characteristics

A general discussion of these factors is provided in Beyeler et al. (1999).

When choosing an appropriate value for an RF, one must consider the nature of contamination on the surface (e.g., how tightly it is bound to the surface) and balancing the driving forces that cause the material on the surface to become airborne with the mechanisms that remove the material from the air. Clearly, the concept of RFs applies to solid particles and does not apply to gases.

The primary force that will resuspend particles indoors can be expected to be mechanical forces associated with rubbing and abrasion of surfaces. These forces are typically associated with human activity. In buildings, air currents caused by normal ventilation or by vibrations are not expected to be a major cause of resuspension of particles (NRC 2002, also referred to as NUREG-1720). Moreover, RFs determined from mechanical disturbance can be an order of magnitude higher than RFs determined with only air currents (Beyeler et al. 1999). Higher RFs were measured when driving forces were increased and when surface contamination was loosely bound and easily removable (NUREG-1720). It is important to assess the types and intensity of the applied driving forces in order to select appropriate RF values for any dust inhalation exposure scenario.

How the surface radioactivity is bound to the surface will have a major effect on the RF. For particles to become airborne, the bond between the particles and the surface (e.g., floor or wall)

must be broken by the driving forces. Particles that are tightly bound to the surface are not easily resuspended, whereas particles that are loosely bound, like freshly deposited material, will be more easily resuspended. Tightly bound particles require greater mechanical force to break the bonds and become resuspended. For similar surface radioactivity levels and particle size distributions, surfaces with a large portion of tightly bound particles will yield smaller RFs.

As discussed in Beyeler et al. (1999), resuspension appears to be generally higher for smaller diameter particles. For example, Beyeler et al. (1999) found that the RF decreases with particle diameter in the range of 1 to 5 microns. The distribution of particle size may also change with time as mechanical forces are applied.

Although larger particles may be resuspended, gravitational settling removes them from the air more rapidly than smaller particles. Note also that particles larger than about 50 microns aerodynamic median activity diameter (AMAD) are readily cleared from the ET region and do not appreciably contribute to tissue dose in the respiratory tract (ICRP 1994a). Particles smaller than 50 µm AMAD comprise the "respirable fraction." Nevertheless, larger particles can be important, because they can be measured as "removable" by wipe tests, leading to the erroneous conclusion that a higher fraction of resuspendable particles may be present that can actually contribute to dose. In this context, significant removable activity as larger particles may cause the RF to be underestimated (NUREG-1720). Since the RF is a ratio, the numerator is equivalent to the measured airborne concentration, whereas the denominator is set equal to the measured surface activity.

SC&A's review of the literature on indoor resuspension factors that can be considered appropriate for the resuspension of metal tritides is summarized in Table 18. The range of RFs cited in Table 18 is 2 E-8 m^{-1} to 4 E-3 m^{-1}. The reported data are generally from (1) operating facilities; (2) facilities undergoing D&D; (3) facilities that have ceased operations, but have residual contamination on surfaces that was being resuspended due to worker activities; and (4) from experiments that examined resuspension of liquid- or powder-contaminated material that had been uniformly applied to clean surfaces in a laboratory-like setting. As best we can tell, the RFs cited in Table 18 were determined based on the total amount of radioactivity or dust on a surface and not the amount that is removable. This distinction is important, because if the starting point for driving airborne radioactivity by the use of RFs is swipe sample data (i.e., removable contamination), as is the case for the tritide data, the resuspension factors, as reported in Table 18, should be multiplied by an adjustment factor. As mentioned above, the NRC recommends using an adjustment factor of 5 to account for the difference between RFs based on removable versus total surface contamination. This would seem to imply that the range of RFs in Table 18 might require an adjustment factor of about 5 when applied to surface contamination reported in terms of removable contamination; i.e., the adjusted range of RFs would therefore be about E-7 m^{-1} to 2 E-2 m^{-1}.

The highest values are typically associated with inefficient ventilation, excessive mechanical disturbance, or dusty conditions. Typically, the purpose of these studies was to help determine radiation protection safety guidelines for loose residual surface radioactivity.

Table 18. Representative Reported Indoor Resuspension Data*

Reference	Resuspension factor or range	Comments
Barns (1959)	4E-5 m^{-1} (confined space) 2E-6 m^{-1} (open air)	Reported for "dusty operations;" 10^{-5} m^{-1} recommended for most laboratory work.
Breslin et al. (1966)	About 3E-6	Based on average activities on surfaces and in air at a uranium processing plant during operations.
Eisenbud et al. (1954)	1E-7 to 5E-7/m	Based on average activity on surfaces and in air observed at an operating uranium and radium processing facility.
Fish et al. (1967)	1.9E-4/m	Based on experimental data where zinc sulfide and cupric sulfide powder (1–3 microns mass median diameter) was spread onto asphalt tile floors and painted drywall. Measurements made 10 minutes after sweeping the surfaces and without ventilation.
Ikezawa (1980)	Mean value of 1.8E-E-4/m during D&D activities	Measurements made during the cleanup of a room after the accidental release of plutonium from a hot cell.
Nardi (1999)	Average RF of 1.7E-7/m during D&D	Average values observed during the decontamination using shot-blasting of a room contaminated with Co-60 and Cs-137, and no ventilation.
Ruhter and Zurliene (1988)	5.5E-8 to 1.1E-7/m	Measurements made during the cleanup of the TMI 2 Auxiliary Building 6 months after the accident.
Spangler (1988)	4.25E-7 to 7.79E-6/m	Uranium storage area during handling of containers.
Stewart (1967)	1E-6 m^{-1} (quiescent conditions) 1E-5–1E-4 m^{-1} ("operational" conditions)	Based on a review of numerous outdoor experimental studies. The author believes these findings are generally applicable to indoor environments. The report indicates that excessively high particulate resuspension values indoors are likely to indicate some degree of inefficiency in the ventilation system.
Glauberman et al. 1967	5E-5/m to 1E-2/m	Measurements made at a uranium metals machining facility under a broad range of operations: (1) sources of air with and without contamination other than resuspension, (2) with and without operating building ventilation, (3) varying levels of surface disturbance.
Brunskill (1967)	2E-4–4E-3 m^{-1}	Numerous measurements in small rooms at Windscale (mixture of radionuclides) with various types of personnel movement, including introduction of loose contamination on coveralls. Lower recommended values were measured for a large area of "loose" contamination on concrete; "much smaller" values were found for linoleum floor.
Jones and Pond (1967)	2E-8–5E-5 m^{-1} 5E-5 m^{-1} (recommended for worst practical conditions)	Results of extensive plutonium (oxide and nitrate) experimental studies performed indoors on a wide variety of surfaces. Estimated that 10%–20% of total airborne radioactivity was respirable. Suggested that recommended value could be an order of magnitude lower for average conditions.
Dunster (1967)	2E-6–4E-5 m^{-1} 2E-6 m^{-1} (recommended safe value for long-term use)	Highest values from digging through dusty building rubble and in an enclosed and unventilated space.

Table 18. Representative Reported Indoor Resuspension Data*

Reference	Resuspension factor or range	Comments
Spangler and Willis (1967)	4E-5 m^{-1} (derived)	This value is calculated using equation for equilibrium airborne concentration in a small room from a surface concentration and recommended values appropriate for calculating 40-hr maximum permissible concentration (MPC) levels. The authors used published resuspension rates (hr-1), room sizes and ventilation rates to derive RFs.
Healy (1971)	1E-3 to 1E-8/m (includes indoors and outdoors)	Cites a wide range of values reported by other researchers.
Gibson and Wrixom (1979)	2E-6–4E-5 m^{-1}	Refers to studies performed by others. The lower value was used in original calculation of derived working limits (DWL) for active area surfaces and might be inappropriate for widespread contamination on dusty surfaces. The higher value was obtained from measurements in a confined space and is suggested for general use.
IAEA (1970)	2E-6–3E-3 m^{-1} 5E-5 m^{-1} (recommended)	Recommended value is suggested as appropriate for general conditions of contamination on surfaces. Because of confounding factors, this effectively reduces the recommended value by 2.5H for use in calculating DWL values.
Kennedy et al. (1981)	2.5E-5 m^{-1} (derived)	This value is calculated using the equation for airborne concentration, assuming ventilation rate of an open transport truck and resuspension rate for a 28 m^2 room.
Kennedy and Strenge (1992)	1E-6 m^{-1} (recommended)	Based on a review of resuspension literature. Recommended as a reasonably conservative default value to be applied to total surface concentration.
IAEA (1992)	1E-6 m^{-1} (recommended)	This value is recommended for use in assessing reuse of tools and equipment. Used a transfer factor of 0.01 to account for the fraction of the residual surface radioactivity that is available for resuspension.
Chen (1993)	1 E-6 m^{-1}	No justification given (based on use in Kennedy and Strenge 1992).
Draft NUREG-1720 (NRC 2002)	Lognormal distribution with mean of 3.7 E-7 m^{-1} and 90th percentile of 9.6 E-7 m^{-1}	NRC staff analyzed literature and recent field data considering realistic assumptions about decommissioned facilities and building occupancy for the DandD code. Resuspension factor values best represent cleaned and aged surfaces.

* Many of the reports cited in this table include a review of other reports and also the results of measurements and experiments performed by the authors. In many cases, large numbers of resuspension factors are cited for a broad range of operational, post-operational, D&D, and experimental conditions. SC&A selected the results that we believe best apply to the issues of interest to this report.

The use of RFs near the high end is likely conservative (even when adjusted for removable contamination) based on consideration of the respirable fraction of resuspended contamination. In one of the few studies where particle size has been measured, Jones and Pond (1964) reported that measurements of air concentration were often biased by a few highly active large particles. In their study on resuspension of plutonium, they concluded that only 10% to 20% of the total airborne radioactivity would be respirable. In theory, this factor tends to counterbalance the adjustment needed to account for the removable fraction discussed above.

Another complicating factor is that the residual surface radioactivity is probably not uniform. Several studies (Dunster 1967; IAEA 1970; Healy 1971) discuss how this issue relates to resuspension values. Healy (1971) points out that in most cases, resuspension has been measured for uniformly contaminated surfaces and uniformly applied resuspension forces. Healy suggests that air concentrations are more strongly related to the total amount of surface contamination present, rather than the amount on any one limited area, and that basing allowable surface contamination limits on the highest surface levels may be too conservative.

There are many other factors that contribute to the uncertainty in resuspension that are not addressed here because of lack of information. These include temperature, humidity, type and roughness of surface material, degree and effectiveness of mechanical disturbance, weathering processes, and the chemical state of the contamination and substrate to which it adheres. The effect of changes in many of these factors on resuspended air particle concentrations is intuitive (e.g., an increase in the size of the contaminated area would likely result in an increase in the resuspended air concentration); however, the degree and direction of the effect of other factors (e.g., specific surface conditions) is not so clear.

Based on this relatively brief review of the literature, it is apparent that the variabilities and uncertainties in resuspension factors are enormous. In addition, one could raise questions regarding whether the data upon which the RFs in the reported literature apply to metal tritides (i.e., none of the data cited above are based on metal tritide measurements). Notwithstanding these issues, SC&A believes that, given adequate swipe sample data, the RF approach can be used to predict average annual airborne concentrations using swipe sample data. However, the value selected by NIOSH's contractors of 5E-5/m should be increased by about a factor of 5 to 2.5E-4/m to account for the fact that the starting point for this calculation is swipe data and not total surface contamination. In addition, we recommend that the RF approach be limited to time periods when there was no possibility of direct leakage of tritides to the atmosphere associated with tritide operations; i.e., an RF of 2.5E-4/m should be used only during the residual period.

4.4 REVIEW OF DOSE CONVERSION FACTORS

According to NIOSH 2012, dose conversion factors (DCFs) for use in deriving annual organ dose commitments from intakes of SMTs were calculated using the Integrated Modules for Bioassay Analysis (IMBA) code. IMBA was developed to meet the NIOSH requirements under EEOICPA, and implements the biokinetic models in International Commission on Radiological Protection (ICRP) Publications 68 (ICRP 1994b) and 71 (ICRP 1995). NIOSH uses guidance for calculating intake and dose from SMTs in ORAUT-OTIB-0066 (ORAUT 2007), which implements the recommendations for SMT aerosols in ICRP 1995. Because intakes were calculated based on air concentrations rather than urine bioassay, however, the modifications to the urine bioassay model discussed in ORAUT-OTIB-0066 were not necessary for this application. IMBA was used to generate a table of annual dose equivalents (rem) per unit activity intake [microcuries (μCi)] for Type S, 5-μm AMAD SMTs for 9 target organs. DCFs were calculated for the 9 organs from the respiratory and GI tracts that were projected to receive the highest total doses over an extended period (50 years). Table 19 lists the 9 organs and is taken from Table 4 of NIOSH (2012). According to NIOSH, the IMBA calculations can be

extended to any modeled organ or for any period. Table 5 of NIOSH 2012 provides annual DCFs for each of the 9 organs out to 50 years post-intake, as well as the 50-year CDE.

Table 19. Target Organ Designations and Descriptions

Organ	Description
SI	Small intestine
ULI	Upper large intestine
LLI	Lower large intestine
ET	Extrathoracic region
Lung	Lung
Colon	Colon
LN(ET)	Lymphatics and lymph nodes that drain the ET region
AI	Alveolar interstitial region
LN(TH)	Lymphatics and lymph nodes that drain the thoracic region

Source: NIOSH 2012, Table 4

As part of this review, SC&A attempted to replicate the NIOSH DCFs in units of rem per µCi inhaled for Type S, 5-µm AMAD SMTs for the 9 organs in Table 19, implementing ICRP 1994 and 1995. SC&A used an ingestion absorption (f1) value of 0.01 for Type S tritiated particulates in adults, in accordance with Table 5.1.1b of ICRP Publication 71 (ICRP 1995). For this task, SC&A employed AIDE (Activity and Internal Dose Estimates, Version 7), a preferred code for calculating activities in compartments and committed doses due to occupational exposures, and for performing intake and dose estimates using bioassay data. AIDE Version 7 is used by ICRP and has several advantages over IMBA, including the option to select independent kinetics for parent-progeny relationships. Additionally, it has all the latest updates from ICRP and is the only software that has the National Council on Radiation Protection and Measurements (NCRP) wound model. Using AIDE, SC&A was able to replicate the NIOSH DCFs to within 99.4% and concludes that the NIOSH DCFs were developed correctly. The SC&A DCFs are presented in Table 20. In summary, we have no findings related to NIOSH's development of the DCFs for use in deriving annual organ doses from intakes of SMTs.

Table 20. Dose (rem) from 1 µCi Intake

Year	SI AIDE	ULI AIDE	LLI AIDE	ET AIDE	Lung AIDE	Colon AIDE	LN(ET)AIDE	AI AIDE	LN(TH) AIDE
1	2.75E-05	1.65E-04	4.82E-04	8.30E-07	1.05E-03	3.01E-04	2.16E-04	3.16E-03	5.59E-04
2	4.22E-07	2.27E-06	6.55E-06	7.01E-07	6.64E-04	4.11E-06	5.12E-04	1.99E-03	7.88E-04
3	2.72E-07	1.45E-06	4.18E-06	7.89E-07	4.55E-04	2.62E-06	6.67E-04	1.36E-03	8.22E-04
4	1.76E-07	9.32E-07	2.68E-06	8.14E-07	3.19E-04	1.68E-06	7.34E-04	9.55E-04	8.37E-04
5	1.16E-07	6.02E-07	1.73E-06	8.02E-07	2.29E-04	1.09E-06	7.49E-04	6.84E-04	8.39E-04
6	7.67E-08	3.92E-07	1.12E-06	7.69E-07	1.69E-04	7.07E-07	7.33E-04	5.04E-04	8.31E-04
7	5.16E-08	2.58E-07	7.36E-07	7.25E-07	1.28E-04	4.63E-07	7.00E-04	3.81E-04	8.15E-04
8	3.54E-08	1.72E-07	4.88E-07	6.75E-07	9.91E-05	3.07E-07	6.58E-04	2.95E-04	7.93E-04
9	2.48E-08	1.16E-07	3.28E-07	6.25E-07	7.89E-05	2.07E-07	6.13E-04	2.35E-04	7.67E-04
10	1.78E-08	8.00E-08	2.24E-07	5.76E-07	6.42E-05	1.42E-07	5.67E-04	1.90E-04	7.38E-04
11	1.31E-08	5.63E-08	1.56E-07	5.28E-07	5.31E-05	9.93E-08	5.22E-04	1.57E-04	7.06E-04
12	9.95E-09	4.06E-08	1.12E-07	4.84E-07	4.46E-05	7.12E-08	4.79E-04	1.32E-04	6.73E-04
13	7.76E-09	3.01E-08	8.21E-08	4.43E-07	3.80E-05	5.25E-08	4.38E-04	1.12E-04	6.39E-04
14	6.17E-09	2.29E-08	6.16E-08	4.04E-07	3.26E-05	3.95E-08	4.01E-04	9.59E-05	6.04E-04
15	5.02E-09	1.78E-08	4.75E-08	3.69E-07	2.81E-05	3.06E-08	3.66E-04	8.27E-05	5.70E-04
16	4.17E-09	1.42E-08	3.75E-08	3.37E-07	2.44E-05	2.42E-08	3.34E-04	7.17E-05	5.37E-04
17	3.51E-09	1.16E-08	3.02E-08	3.07E-07	2.13E-05	1.96E-08	3.05E-04	6.25E-05	5.04E-04
18	2.99E-09	9.57E-09	2.48E-08	2.80E-07	1.86E-05	1.61E-08	2.78E-04	5.45E-05	4.72E-04
19	2.57E-09	8.03E-09	2.06E-08	2.55E-07	1.63E-05	1.35E-08	2.54E-04	4.77E-05	4.42E-04
20	2.22E-09	6.80E-09	1.75E-08	2.33E-07	1.44E-05	1.14E-08	2.31E-04	4.19E-05	4.12E-04
21	1.93E-09	5.83E-09	1.48E-08	2.12E-07	1.26E-05	9.70E-09	2.11E-04	3.68E-05	3.84E-04
22	1.69E-09	5.00E-09	1.27E-08	1.93E-07	1.11E-05	8.31E-09	1.92E-04	3.23E-05	3.58E-04
23	1.48E-09	4.33E-09	1.10E-08	1.76E-07	9.80E-06	7.18E-09	1.75E-04	2.84E-05	3.33E-04
24	1.30E-09	3.75E-09	9.37E-09	1.61E-07	8.64E-06	6.17E-09	1.60E-04	2.50E-05	3.09E-04
25	1.15E-09	3.26E-09	8.19E-09	1.46E-07	7.63E-06	5.38E-09	1.46E-04	2.21E-05	2.87E-04
26	1.01E-09	2.86E-09	7.23E-09	1.33E-07	6.74E-06	4.74E-09	1.33E-04	1.94E-05	2.66E-04
27	8.90E-10	2.48E-09	6.14E-09	1.22E-07	5.96E-06	4.05E-09	1.21E-04	1.71E-05	2.46E-04
28	7.87E-10	2.18E-09	5.41E-09	1.11E-07	5.27E-06	3.57E-09	1.10E-04	1.51E-05	2.27E-04

Table 20. Dose (rem) from 1 µCi Intake

Year	SI AIDE	ULI AIDE	LLI AIDE	ET AIDE	Lung AIDE	Colon AIDE	LN(ET)AIDE	AI AIDE	LN(TH) AIDE
29	6.96E-10	1.91E-09	4.73E-09	1.01E-07	4.66E-06	3.12E-09	1.01E-04	1.34E-05	2.10E-04
30	6.14E-10	1.68E-09	4.09E-09	9.21E-08	4.12E-06	2.72E-09	9.17E-05	1.18E-05	1.94E-04
31	5.46E-10	1.47E-09	3.55E-09	8.39E-08	3.65E-06	2.36E-09	8.35E-05	1.04E-05	1.79E-04
32	4.86E-10	1.26E-09	3.18E-09	7.65E-08	3.23E-06	2.09E-09	7.62E-05	9.22E-06	1.65E-04
33	4.23E-10	1.14E-09	2.77E-09	6.97E-08	2.87E-06	1.84E-09	6.94E-05	8.15E-06	1.52E-04
34	3.81E-10	9.89E-10	2.32E-09	6.35E-08	2.54E-06	1.56E-09	6.33E-05	7.21E-06	1.40E-04
35	3.35E-10	8.64E-10	2.14E-09	5.79E-08	2.25E-06	1.41E-09	5.77E-05	6.38E-06	1.29E-04
36	2.98E-10	7.62E-10	1.86E-09	5.28E-08	2.00E-06	1.24E-09	5.26E-05	5.65E-06	1.19E-04
37	2.67E-10	6.59E-10	1.59E-09	4.81E-08	1.78E-06	1.06E-09	4.79E-05	5.01E-06	1.09E-04
38	2.36E-10	5.91E-10	1.41E-09	4.38E-08	1.58E-06	9.43E-10	4.37E-05	4.44E-06	1.00E-04
39	2.07E-10	5.23E-10	1.23E-09	4.00E-08	1.40E-06	8.26E-10	3.98E-05	3.93E-06	9.21E-05
40	1.88E-10	4.66E-10	1.05E-09	3.64E-08	1.25E-06	7.15E-10	3.63E-05	3.49E-06	8.46E-05
41	1.65E-10	3.98E-10	9.55E-10	3.32E-08	1.11E-06	6.37E-10	3.31E-05	3.10E-06	7.77E-05
42	1.45E-10	3.41E-10	8.64E-10	3.02E-08	9.87E-07	5.66E-10	3.01E-05	2.75E-06	7.13E-05
43	1.31E-10	3.07E-10	6.82E-10	2.76E-08	8.79E-07	4.68E-10	2.75E-05	2.44E-06	6.54E-05
44	1.19E-10	2.73E-10	6.37E-10	2.51E-08	7.83E-07	4.29E-10	2.50E-05	2.17E-06	6.00E-05
45	1.05E-10	2.39E-10	5.91E-10	2.29E-08	6.98E-07	3.90E-10	2.28E-05	1.93E-06	5.50E-05
46	9.38E-11	2.05E-10	4.55E-10	2.09E-08	6.22E-07	3.12E-10	2.08E-05	1.72E-06	5.04E-05
47	7.96E-11	2.05E-10	4.09E-10	1.90E-08	5.55E-07	2.93E-10	1.90E-05	1.53E-06	4.62E-05
48	7.39E-11	1.71E-10	3.64E-10	1.73E-08	4.96E-07	2.54E-10	1.73E-05	1.36E-06	4.23E-05
49	6.54E-11	1.36E-10	3.64E-10	1.58E-08	4.42E-07	2.34E-10	1.58E-05	1.21E-06	3.88E-05
50	6.25E-11	1.25E-10	2.73E-10	1.44E-08	3.95E-07	1.89E-10	1.44E-05	1.08E-06	3.55E-05
	SI AIDE	**ULI AIDE**	**LLI AIDE**	**ET AIDE**	**Lung AIDE**	**Colon AIDE**	**LN(ET)AIDE**	**AI AIDE**	**LN(TH) AIDE**
CDE	2.88E-05	1.72E-04	5.01E-04	1.32E-05	3.65E-03	3.13E-04	1.20E-02	1.09E-02	1.80E-02

4.5 REVIEW OF ORIGINAL EXCEL SPREADSHEET

This section presents a comprehensive review of the spreadsheet, "SMT exposures in R-108 SW-8 10-6 in 1980s.xls," which was presented and discussed at the November 7, 2011, work group meeting. Subsequent to that meeting, an additional spreadsheet was produced titled, "SMT exposures in R-108 SW-8 10-6 pre 1980.xls," which complemented the NIOSH 2011a white paper analysis. This spreadsheet presented additional data and analysis for years prior to 1985. With the release of NIOSH 2012 in March of 2012, a third spreadsheet was produced which contained data for rooms SW-13 and SW-150 titled, "SW-13 SW-150 1960s-1990s 3-12.xls." The two previous spreadsheets were also updated to reflect the changes in dose parameters presented in NIOSH 2012.

Although this section focuses on the first spreadsheet produced, the subsequent calculation spreadsheets produced had the similar structure and analysis; many of the findings related to annual dose calculations are also applicable to these later spreadsheets.

4.5.1 Sheet 'CDE Summary'

Equation 2-3 presented the methodology used to calculate the annual dose from the monthly calculated tritide intake. Equation 2-3 assumes that there are sufficient swipe data to allow for tritide intakes to be calculated for every month of the year. Unfortunately, with the exception of 1985 for both SW-8 and R-108, there are insufficient swipe data for some of the months. Thus, an adjustment to equation 2-3 is needed in order to calculate an annual dose using data from less than 12 months. Equation 4.5-1 is a proposed adjustment; it simply multiplies the sum of the tritide intakes for the months with swipe data by the ratio of 12 to the number of months with data. There are other adjustments that could be used, but equation 4.5-1 is used for this study.

$$D = DCF\ 1000 \frac{12}{N_m} \sum_{m=1}^{N_m} I_m \qquad (4.5\text{-}1)$$

Where:

D	=	Annual tritide dose (mrem)
DCF	=	Tritide inhalation dose factor (rem/µCi)
1,000	=	Conversion factor (mrem/rem)
12	=	Number of months in a year
N_m	=	Number of months with swipe data
I_m	=	Tritide intake for month, m (µCi/month)

Table 21 illustrates the effect that equation 4.5-1 would have on the NIOSH-calculated annual dose for LN(TH). The top third of Table 21 simply repeats the NIOSH-calculated annual LN(TH) CDE for 1985 through 1989 for SW-8 and R-108. The middle third of Table 21 shows the number of months for which swipe data are available and were used by NIOSH in the calculation of the annual dose. The bottom third of Table 21 shows the annual LN(TH) CDE for 1985 through 1989 for SW-8 and R-108 revised using equation 4.5-1.

Table 21. Annual Dose Adjusted for the Number of Months with Swipe Data

NIOSH Reported Dose LN(TH) CDE (mrem/yr)		
Years	**R-108**	**SW-8**
1985	64.1	103.7
1986	34.6	53.4
1987	0.0	116.8
1988	38.7	40.2
1989	45.9	36.4
Number of Months with Swipe Data		
Years	**R-108**	**SW-8**
1985	12	12
1986	5	5
1987	0	8
1988	6	6
1989	6	6
SC&A Adjusted Dose LN(TH) CDE (mrem/yr)		
Years	**R-108**	**SW-8**
1985	64.1	103.7
1986	83.0	128.2
1987	0.0	175.3
1988	77.5	80.5
1989	91.8	72.8

4.5.2 Sheet 'SRDB Search Summary'

The data contained in columns C and F of this sheet are incorrect. The correct data are given in columns U and AI of sheet 'CDE Summary.' Columns C and F of sheet 'SRDB Search Summary' should be changed to link back to columns U and AI of sheet 'CDE Summary.' However, since the data in columns C and F of sheet 'SRDB Search Summary' are only used to generate the chart shown on the sheet, this does not affect any of the results.

4.5.3 Sheets 'R108 1985,' 'R108 1986,' 'R108 1988,' 'R108 1989,' 'SW8 1985,' 'SW8 1986,' 'SW8 1987,' 'SW8 1988,' and 'SW8 1989'

These sheets calculate the 95th percentile air concentration using the equations described in Section 3.0, and the data from sheets 'Raw Data R-108' and 'Raw Data SW-8,' described in Sections 4.1.2 and 4.1.5, and assuming a lognormal data distribution. Rather than check every calculation performed on each of these sheets, SC&A has used the Excel "Percentile" function and the data from sheets 'Raw Data R-108' and 'Raw Data SW-8' to calculate the 95th percentile air concentration. Rather than make any assumption regarding the form of the data distribution, the Excel "Percentile" function simply finds the datum that has 5% higher values and 95% lower values. Thus, it is not expected that the Excel "Percentile" function-calculated 95th percentile air concentrations would *exactly* match the NIOSH-calculated values using an assumed lognormal distribution, but agreement should be within a factor of 2. Any results that differ by more than a

factor of 2 would indicate that something was wrong with the 95th percentile air concentration calculation.

Table 22 shows the results of this check. The top third of Table 22 simply reproduces the NIOSH-calculated 95th percentile air concentrations from the spreadsheets for both the SW-8 and R-108 rooms from 1985 to 1989. The middle third of Table 22 shows the 95th percentile air concentrations calculated using the Excel "Percentile" function, while the bottom third shows the ratio of the two derived air concentrations (NIOSH/Excel) as a function of percentage.

Table 22. Check of 95th Percentile Air Concentration

	SW-8 NIOSH Calculated					R-108 NIOSH Calculated			
	1985	**1986**	**1987**	**1988**	**1989**	**1985**	**1986**	**1988**	**1989**
Jan	1.75E-03	3.73E-03	3.33E-03	N.D.	N.D.	5.19E-04	1.80E-03	N.D.	N.D.
Feb	2.02E-03	2.47E-03	5.26E-03	N.D.	N.D.	1.36E-03	1.65E-03	N.D.	N.D.
Mar	2.01E-03	N.D.	4.23E-03	N.D.	N.D.	1.28E-03	N.D.	N.D.	N.D.
Apr	3.24E-03	4.31E-03	4.74E-03	N.D.	N.D.	1.75E-03	2.62E-03	N.D.	N.D.
May	2.26E-03	1.70E-03	3.14E-03	N.D.	N.D.	1.76E-03	1.96E-03	N.D.	N.D.
Jun	1.56E-03	2.57E-03	5.24E-03	N.D.	N.D.	1.17E-03	1.54E-03	N.D.	N.D.
Jul	1.59E-03	N.D.	3.39E-03	1.65E-03	1.34E-03	1.19E-03	N.D.	1.84E-03	2.23E-03
Aug	2.56E-03	N.D.	3.01E-03	4.48E-03	1.70E-03	1.98E-03	N.D.	2.42E-03	2.55E-03
Sep	3.96E-03	N.D.	N.D.	1.62E-03	1.21E-03	2.19E-03	N.D.	2.08E-03	1.24E-03
Oct	3.04E-03	N.D.	N.D.	1.42E-03	1.86E-03	1.89E-03	N.D.	1.54E-03	2.53E-03
Nov	3.33E-03	N.D.	N.D.	1.04E-03	1.63E-03	1.65E-03	N.D.	1.46E-03	2.02E-03
Dec	1.37E-03	N.D.	N.D.	9.12E-04	1.94E-03	9.98E-04	N.D.	1.36E-03	2.14E-03
Total	2.87E-02	1.48E-02	3.23E-02	1.11E-02	9.67E-03	1.77E-02	9.57E-03	1.07E-02	1.27E-02
	SW-8 Excel Calculated					**R-108 Excel Calculated**			
	1985	**1986**	**1987**	**1988**	**1989**	**1985**	**1986**	**1988**	**1989**
Jan	1.49E-03	2.74E-03	2.79E-03	N.D.	N.D.	4.72E-04	1.25E-03	N.D.	N.D.
Feb	1.57E-03	2.12E-03	4.67E-03	N.D.	N.D.	1.54E-03	1.08E-03	N.D.	N.D.
Mar	2.10E-03	N.D.	4.05E-03	N.D.	N.D.	1.07E-03	N.D.	N.D.	N.D.
Apr	2.95E-03	5.07E-03	4.58E-03	N.D.	N.D.	1.48E-03	2.28E-03	N.D.	N.D.
May	1.88E-03	1.58E-03	3.25E-03	N.D.	N.D.	1.44E-03	1.66E-03	N.D.	N.D.
Jun	1.50E-03	2.53E-03	4.55E-03	N.D.	N.D.	9.66E-04	1.21E-03	N.D.	N.D.
Jul	1.54E-03	N.D.	3.69E-03	1.85E-03	1.26E-03	9.68E-04	N.D.	1.62E-03	2.13E-03
Aug	2.77E-03	N.D.	3.17E-03	4.17E-03	1.64E-03	1.81E-03	N.D.	1.99E-03	2.68E-03
Sep	3.86E-03	N.D.	N.D.	1.83E-03	1.31E-03	2.39E-03	N.D.	1.71E-03	1.25E-03
Oct	2.95E-03	N.D.	N.D.	1.44E-03	1.78E-03	1.69E-03	N.D.	1.73E-03	2.99E-03
Nov	2.78E-03	N.D.	N.D.	1.02E-03	1.30E-03	1.26E-03	N.D.	1.15E-03	1.87E-03
Dec	1.21E-03	N.D.	N.D.	7.47E-04	1.29E-03	8.78E-04	N.D.	1.01E-03	1.81E-03
Total	2.66E-02	1.40E-02	3.08E-02	1.11E-02	8.58E-03	1.60E-02	7.47E-03	9.22E-03	1.27E-02

Table 22. Check of 95th Percentile Air Concentration

	SW-8 NIOSH to Excel Ratio					R-108 NIOSH to Excel Ratio			
	1985	**1986**	**1987**	**1988**	**1989**	**1985**	**1986**	**1988**	**1989**
Jan	117%	136%	119%	N.D.	N.D.	110%	144%	N.D.	N.D.
Feb	129%	116%	112%	N.D.	N.D.	88%	152%	N.D.	N.D.
Mar	96%	N.D.	104%	N.D.	N.D.	120%	N.D.	N.D.	N.D.
Apr	110%	85%	103%	N.D.	N.D.	118%	115%	N.D.	N.D.
May	120%	108%	97%	N.D.	N.D.	122%	118%	N.D.	N.D.
Jun	104%	102%	115%	N.D.	N.D.	121%	128%	N.D.	N.D.
Jul	103%	N.D.	92%	89%	106%	123%	N.D.	114%	105%
Aug	93%	N.D.	95%	107%	103%	110%	N.D.	122%	95%
Sep	102%	N.D.	N.D.	88%	92%	92%	N.D.	122%	100%
Oct	103%	N.D.	N.D.	99%	104%	112%	N.D.	89%	85%
Nov	120%	N.D.	N.D.	102%	125%	130%	N.D.	127%	108%
Dec	113%	N.D.	N.D.	122%	151%	114%	N.D.	134%	118%
Total	108%	105%	105%	101%	113%	111%	128%	116%	100%

5.0 EVALUATION OF VARIABLES AND UNCERTAINTIES USED ON MOUND LABORATORY SMT DOSE ESTIMATIONS

5.1 INTRODUCTION

While NIOSH's first white paper (NIOSH 2011a) presents an upper limit to the potential organ dose from SMT at the ML, the second white paper (NIOSH 2012) presents what NIOSH considers a best-estimate approach. The two papers obviously derive results that are very different (i.e., several hundred mrem to the maximally exposed organ [LN(TH)] in the first paper and about 1 mrem to the lung in the second paper, a difference of 2 orders of magnitude). Therefore, SC&A was concerned with the dependence of the results obtained on the parameters/variables selected in deriving the estimated doses from SMT at the ML. To address this issue, SC&A performed a brief qualitative evaluation of the impact of selecting certain parameter/variable values out of a range of values for use in deriving estimated doses from SMT at the ML. This analysis does not include uncertainties in the stated values, such as count rates, constants, statistical analyses, etc., as these would be secondary to the wide range of possible values for the major parameters evaluated here.

5.2 SC&A'S EVALUATION OF PARAMETERS/VARIABLES USED IN ESTIMATING SMT DOSES

Annual Organ Dose Estimate

The basic equation used for deriving the estimated annual SMT dose is provided on page 3 of NIOSH 2011a and page 12 of NIOSH 2012:

$$D = \{[(C_{PC-5} \times (Eff_{PC-5})^{-1}) \times CF] \times 100 \times RF\} \times Br \times T \times DCF$$

where:
D is the internal organ annual dose (mrem/y); C_{PC-5} is the contamination swipe data as counted by a PC-5 proportional counter (cpm/100 cm^2); Eff_{PC-5} is the counter efficiency (cpm/dpm); CF is the conversion factor equal to 4.505×10^{-7} µCi/dpm; the constant, 100, converts 100 cm^2 to m^2; RF is the resuspension factor defined as the ratio between the airborne concentration of a pollutant per cubic meter directly over a contaminated surface and the areal pollutant surface contamination (m^{-1}); Br is the worker's breathing rate equal to 1.2 m^3/hr (ICRP 1994a); T is the exposure time equal to 2,000 working hr/yr; and DCF is the dose conversion factor for Type S, 5-µm activity median aerodynamic diameter (AMAD) SMT for the target organ (mrem/µCi).

As can be seen from analyzing this equation, the resulting annual dose depends linearly, either proportionally or inversely proportionally, on several variables; the rest of the components are simply standard conversion factors. The items of interest for this evaluation are listed below. Also listed is the possible range of their values that will be considered.

1. **C_{pc-5} – per 100 cm^2** – The recorded count rate (cpm) of the counter used to count the tritium swipes, with the assumption that an area of 100 cm^2 was swiped using a consistent method. However, the persons swiping the surface may vary their area/pressure, and the swipes obtained may not be representative of the wider area of concern. Therefore, a reasonable assumption is that these variations could cause the results to change by a factor of 2 less up to a factor of 2 greater than normal during the routine activity of taking many swipes over time; hence, the recorded results (normalized to a preset pressure and 100 cm^2) may be a factor of 0.5x or 2.0x the true value.

2. **Eff_{pc-5}** – The efficiency of the PC-5 counter (dpm/cpm). NIOSH determined this factor by comparing 292 swipe values that were counted at ML using both the PC-5 counter and the liquid scintillation counter (LSC), and incorporates an average energy self-absorption factor (SAFe) for the LSC activity determination. As shown in Figure A-13, page 29, of NIOSH 2012, this variable has a range of 0.001 to 0.05, with a mean value of 0.011 and a GSD of 2.2 (NIOSH used a rounded value of 1% in their dose estimates). A reasonable range for this variable would be to use the GSD of 2.2, which would result in an efficiency range of 0.005% to 2.2%.

3. **RF** – The Resuspension Factor defined as the ratio between the airborne concentration of a pollutant per cubic meter directly over a contaminated surface and the areal pollutant surface contamination (unit = m^{-1}). This variable could have a wide range of values; from 1E-6/m recommended by the NRC (NIOSH 2012, page 30), to 5E-5/m used by NIOSH in the second paper (NIOSH 2012), to 3E-3/m used by NIOSH in the first paper (NIOSH 2011a). However, the variance of this parameter in a given situation (e.g., in a given room over a 1-year time period) would most likely not vary throughout this large range, but instead vary about a mean value. Considering the discussion in Section 4.3 of this report concerning the use of the RF factor, a reasonable range would be a factor of 5 below and a factor of 5 above the value recommend by NIOSH of 5E-5/m (NIOSH 2012).

4. **Br** - Worker's breathing rate of 1.2 m^3/hr. This value is fairly constant and could vary between 1.0 m^3/hr to 1.25 m^3/hr. NIOSH used a value of 1.2 m^3/hr in the SMT dose estimations.

5. **T** - Exposure time of 2,000 working hr/yr. These values could range from 40 hr/wk at 50 wk/y (2,000 hr/y) at the lower end to 50 hr/wk at 52 wk/y (2,600 hr/y) at the upper end for workers constantly exposed.

6. **DCF** - Dose Conversion Factor for Type S, 5-μm AMAD SMT for the target organ in units of mrem/μCi. Although NIOSH assumes an AMAD of 5 μm, the DCF is highly dependent on the particle size. Table E.5-11 of DOE (2008, pdf pg. 195) demonstrates that the DCFs for a given SMT compound can vary by about a factor of 10 over a range of particles sizes of 0.5 to 10 μm AMAD. Based on Table E.5-11 of DOE 2008, and the discussion in Section 6.0 of this report, it can be assumed that an adjustment factor could range from 0.2x to 5x the median value.

These are the items of most interest in this evaluation and are those that could have different values, depending on the values selected by the person performing the dose estimate. Table 23 provides a summary of these items, their possible range of values, and their potential impact on the resulting estimated SMT dose.

Table 23. SMT Dose Parameters and Ranges

Parameter	Dependence	Lower Value	NIOSH 2012 Value	Upper Value	Impact on Resulting Dose Value
C_{pc-5} factor	Inversely Prop	2.0	1.0	0.5	0.5x to 2.0x
Eff_{pc-5}	Inversely Prop.	0.022	0.01	0.005	0.46x to 2.2x
RF	Proportional	1E-05/m	5E-5/m	2.5E-04/m	0.2x to 5.0x
Br	Proportional	1.00 m^3/hr	1.2 m^3hr	1.25 m^3/hr	0.83x to 1.04x
T	Proportional	2000 hr/y	2000 hr/y	2600 hr/y	1.0x to 1.30x
DCF adj.	Proportional	0.2	1.0	5	0.2x to 5.0x
Total impact using lower and upper values =					**0.008x to 149x**
Total impact using lower and upper values w/constant RF or DCF =					**0.04x to 30x**

Committed Organ Dose Estimate

NIOSH's Case Study – NIOSH used a case study (see pages 5–6 of NIOSH 2012) to illustrate the committed organ dose to the lung, one of the organs that receive the greater dose from SMT. This case study consisted of a 2-year exposure period using the larger of the potential SMT intakes (both location and years) and deriving the committed organ dose after a 10-year latent period. The 95th and 50th percentile annual doses (for 50 years) are listed in Table 6, pages 38–39, and are summarized for a 10-year latent period in Table 1, page 6, of NIOSH 2012. For the lung, the maximum (Room SW-8) committed dose for a 2-year exposure and 10-year latent period was 0.48 mrem at the 95th percentile level and 0.12 mrem at the 50th percentile level. (Note: The text on page 2 of NIOSH 2012 that states, "The bounding and best estimate **annual** dose equivalents to the lung associated with intakes of the SMT are 0.48 mrem and 0.12 mrem, respectively" appears to be incorrect in that it should read "committed" instead of "annual" according to Table 1, page 6 of NIOSH 2012).

Changes in Exposure Period – Changes in the exposure period would change the committed dose to an organ approximately as a linear function for a given intake scenario (derived 95th percentile concentration for a room/year combination). In other words, if the exposure period was 1 year instead of 2 years, the dose would be approximately one-half the stated dose; if the exposure was 4 years instead of 2 years, the dose would be approximately twice the stated dose.

Changes in Latent Period – Changes in the latent period would have a smaller impact on the committed dose; i.e., a shorter latent period would decrease the committed dose, and a longer latent period would increase the committed dose, but not substantially. The annual organ dose values decrease steadily as a function of time (as illustrated in the vertical column of Table 6, page 38, of NIOSH 2012; therefore, an additional 10-year latent period does not add an equal amount of committed dose.

This qualitative analysis of the impact of exposure and latent periods on SMT doses will be further evaluated quantitatively in the next section.

5.3 SC&A'S EVALUATION OF VARIABILITY IN THE DERIVED CASE STUDY DOSE BASED ON EXPOSURE DURATION AND LATENCY TIME AFTER THE EXPOSURE

NIOSH 2012 presented a case study example that calculated the lung dose to a worker 10 years after a 2-year exposure. The intakes for the 2-year exposure were based on the years with the highest observed contamination by room. Of the four rooms with data compiled by NIOSH, room SW-150 had the highest observed contamination values. These derived doses[14] for all the target organs identified in NIOSH 2012 are shown in Table 24. It is worth noting that the "lung" dose was not the limiting target organ in the case study example, but rather "Al," the alveolar/interstitial region of the lung, at approximately 93 mrem. The dose to the lower large intestine (LLI) was also higher than the derived lung dose.

Table 24. Calculated Doses based on NIOSH Case Study for Room SW-150

Target Organ	95th Percentile Dose (mrem)	50th Percentile Dose (mrem)
Lung	3.72[1]	0.95[1]
SI	0.27	0.07
ULI	1.58	0.41
LLI	4.63	1.19
ET	0.07	0.02
Colon	2.90	0.74
LN(ET)	64.30	16.47
Al	92.88	23.80
LN(TH)	82.19	21.05

In order to quantify the variability in the derived doses based on the case study example, SC&A performed similar calculations while varying the exposure duration and latency time after the exposure. Similar to the NIOSH case study example, the years with the highest contamination/intake values were used for each exposure duration example. The results for the calculated lung dose are shown in Table 25 which presents the respective dose values along with the ratio to the original case study value (shown in parenthesis). As seen in Table 25, the lung dose increases by as much as a factor of 4 if the exposure duration and latency time for the case study were increased to 10 years and 20 years, respectively.

[14] Note: the lung dose values in Table 24 for SW-150 differ from the values presented in NIOSH 2012 Table 1 due to an error in the original calculation that did not extrapolate intakes to a full year. The doses presented in Table 1 have been extrapolated to a full year of exposure. Refer to Section 4.1.5 for further discussion.

Table 25. Calculated Lung Dose (mrem) as a Function of Exposure Duration and Latency Time for Room SW-150

(Ratio with base case shown in parenthesis)

Intake Percentile	Years of Latency After Exposure	Exposure Duration in Years			
		2	3	5	10
95th	10	3.72* (1.00)	5.58 (1.50)	8.66 (2.33)	14.43 (3.88)
	15	3.90 (1.05)	5.90 (1.58)	9.06 (2.43)	14.87 (4.00)
	20	3.98 (1.07)	5.94 (1.60)	9.15 (2.46)	14.99 (4.03)
50th	10	0.95* (1.00)	1.39 (1.45)	2.08 (2.18)	3.45 (3.62)
	15	1.00 (1.05)	1.44 (1.52)	2.16 (2.26)	3.54 (3.71)
	20	1.02 (1.07)	1.47 (1.55)	2.19 (2.30)	3.59 (3.76)

*NIOSH base case values

Tables 26 and 27 present the ratio of the calculated dose for the remaining organs versus the NIOSH case study example. Table 26 presents the ratio of doses based on the 95th percentile intake values, and Table 27 is based on the 50th percentile intake values.

Table 26. Ratio of Remaining Target Organ Doses to NIOSH Base Case Values by Exposure Duration and Latency after Exposure based on 95th Percentile Contamination

Years of Latency After Exposure	Target Organ	Exposure Duration in Years			
		2	3	5	10
10	S. I.	1.00*	1.49	2.29	3.73
	U. L. I.	1.00*	1.49	2.29	3.73
	L. L. I.	1.00*	1.49	2.29	3.73
	E. T.	1.00*	1.53	2.50	4.57
	Colon	1.00*	1.49	2.29	3.73
	LN(ET)	1.00*	1.54	2.52	4.66
	Al	1.00*	1.50	2.33	3.87
	LN(TH)	1.00*	1.54	2.55	4.85
15	S. I.	1.00	1.49	2.29	3.73
	U. L. I.	1.00	1.49	2.29	3.73
	L. L. I.	1.00	1.49	2.29	3.73
	E. T.	1.25	1.89	3.00	5.20
	Colon	1.00	1.49	2.29	3.73
	LN(ET)	1.28	1.94	3.07	5.35
	Al	1.05	1.56	2.41	3.97
	LN(TH)	1.33	2.03	3.24	5.78

Table 26. Ratio of Remaining Target Organ Doses to NIOSH Base Case Values by Exposure Duration and Latency after Exposure based on 95th Percentile Contamination

Years of Latency After Exposure	Target Organ	Exposure Duration in Years			
		2	3	5	10
20	S. I.	1.00	1.49	2.29	3.73
	U. L. I.	1.00	1.49	2.29	3.73
	L. L. I.	1.00	1.49	2.29	3.73
	E. T.	1.41	2.12	3.31	5.60
	Colon	1.00	1.49	2.29	3.73
	LN(ET)	1.46	2.19	3.42	5.79
	Al	1.07	1.59	2.45	4.02
	LN(TH)	1.57	2.37	3.74	6.43

*NIOSH base case values

Table 27. Ratio of Remaining Target Organ Doses to NIOSH Base Case Values by Exposure Duration and Latency after Exposure based on 50th Percentile Contamination

Years of Latency After Exposure	Target Organ	Exposure Duration in Years			
		2	3	5	10
10	S. I.	1.00*	1.44	2.14	3.48
	U. L. I.	1.00*	1.44	2.14	3.48
	L. L. I.	1.00*	1.44	2.14	3.48
	E. T.	1.00*	1.49	2.35	4.27
	Colon	1.00*	1.44	2.14	3.48
	LN(ET)	1.00*	1.49	2.37	4.35
	Al	1.00*	1.45	2.18	3.62
	LN(TH)	1.00*	1.50	2.40	4.54
15	S. I.	1.00	1.44	2.14	3.48
	U. L. I.	1.00	1.44	2.14	3.48
	L. L. I.	1.00	1.44	2.14	3.48
	E. T.	1.25	1.84	2.81	4.86
	Colon	1.00	1.44	2.14	3.48
	LN(ET)	1.28	1.88	2.88	5.01
	Al	1.05	1.51	2.26	3.71
	LN(TH)	1.33	1.97	3.04	5.40
20	S. I.	1.00	1.45	2.14	3.49
	U. L. I.	1.00	1.44	2.14	3.48
	L. L. I.	1.00	1.44	2.14	3.48
	E. T.	1.41	2.06	3.11	5.23
	Colon	1.00	1.44	2.14	3.48
	LN(ET)	1.46	2.12	3.21	5.42
	Al	1.07	1.54	2.30	3.76
	LN(TH)	1.58	2.30	3.51	6.01

*NIOSH base case values

5.4 SUMMARY

As can be seen from Table 23, the impact on the estimated SMT annual dose is most pronounced by the choice of the value of the resuspension factor and the DCF (which is dependent on the AMAD value selected). The selected values of the other parameters have a lesser impact on the estimated SMT annual dose. While SC&A does not advocate that all the parameters would be at one extreme or the other at the same time (or that the results need to be adjusted accordingly), this qualitative analysis illustrates that the resulting estimated SMT annual dose can vary by several orders of magnitude, depending on the values of the parameters selected, while using a model that has no site-specific or source term characterization data to bench-mark the results.

When considering committed dose to an organ (as NIOSH did in their 2-year exposure and 10-year latent period case study to illustrate that the committed lung dose was projected to be less than 1 mrem), an increase or decrease in the exposure time would increase or decrease the corresponding committed dose somewhat linearly, as illustrated in Tables 25 through 27 above; and a longer or shorter latent period would not generally have a large impact on the committed dose after the initial 5 to 10 years of a latent period. However, the important issue is that, as shown in Table 24 above, the lung (which NIOSH used in their 2012 paper) is not the organ that receives the greater dose from SMTs; the LLI, LN(ET), LN(TH), and Al all receive greater doses.

6.0 COMPARISON BETWEEN NIOSH AND DOE DOSE ESTIMATION METHODS FOR STCS

6.1 PURPOSE

The purpose of this section is to present a comparison between the methods to evaluate lung dose for "Insoluble Tritiated Particles" (ITP) presented in *Doe Handbook – Tritium Handling and Safe Storage* (DOE 2008) and the current NIOSH white paper, *Potential Stable Metal Tritide Exposures at the Mound Laboratory* (NIOSH 2012). Of particular focus is the characterization of dose to tissues of the respiratory tract (i.e., lung dose) in the context of the effect of self absorption on both the measurement technique and the radiation dose delivered to the lung. Comparison of the respective intake models will not be discussed, as both methods rely on adequate characterization of the airborne contamination. DOE 2008 relies on adequate direct air sampling (preferably breathing zone sampling) during operations with insoluble tritiated compounds. NIOSH 2012 relies on a resuspension model based on area surface contamination as measured by swipe data. Air monitoring for insoluble tritiated particles is not available for Mound during the period of interest; therefore, intake values derived from the resuspension of surface contamination are necessitated.

6.2 COMPARISON OF DOE 2008 INSOLUBLE TRITIATED PARTICLE DOSE CHARACTERIZATION

Self absorption occurs when the low-energy beta emissions from tritium deposit all of their energy within the particle and are not able to escape the particle surface. Self absorption of low energy beta emissions (nominally 6 keV) in particulate tritides affects both the ability to measure the contamination present in the particle and the amount of radiation dose that can be delivered to the lung from the particle.

DOE 2008 presents adjustment factors, or "self absorption factors" (SAF), that can be used to adjust for the dose delivered to the lung, as well as adjustment to counting results. The most common detection system employed in tritium measurement is liquid scintillation counting (LSC). These two correction factors are labeled as the SAFe (adjustment to account for the fraction of energy available to impart dose to the lung) and SAFβ (adjustment to account for the fraction of betas emitted that escape the particle surface and are counted in the LSC system) and are derived based on the methods described in Kropf 1998. Self absorption of tritium beta emissions in ITP is strongly correlated with particle size. Self-absorption factors (SAFs) vary as a function of respirable (<10 μm AMAD) particulate size and material by a factor of approximately 10.

These two correction factors SAFe and SAFβ are shown in Tables 28 and 29, respectively, for selected ITP compounds, and are used in DOE 2008 to adjust the DCFs applied in a typical effective dose calculation. Unadjusted committed equivalent lung DCFs for the example ITP compounds are presented in Table 30.

Table 28. SAFe Various ITP Materials and Polydisperse (σg = 2.5) Particle Size Distributions (in AMAD)

Base Material*	SAFe vs. Particle Size [AMAD(μm), σ_g=2.5]				
	10	5	2	1	0.5
Organic [~$(CH_2)_n$]	0.305	0.474	0.707	0.841	0.925
Rust [~FeO(OH)]	0.231	0.381	0.614	0.768	0.879
Ti H_2	0.215	0.362	0.594	0.753	0.871
Zr H_2	0.180	0.312	0.541	0.714	0.852
Hf H_2	0.142	0.260	0.490	0.680	0.842

* Variable amounts of elemental hydrogen are isotopically tritium.
Source: DOE 2008, Table E.5-9

Table 29. SAFβ for Various ITP Materials and Polydisperse (σg = 2.5) Particle Size Distributions (in AMAD)

Base Material*	SAFβ vs. Particle Size [AMAD(μm), σ_g=2.5]				
	10	5	2	1	0.5
Organic [~$(CH_2)_n$]	0.205	0.333	0.535	0.677	0.789
Rust [~FeO(OH)]	0.140	0.244	0.439	0.602	0.745
Ti H_2	0.133	0.231	0.423	0.590	0.739
Zr H_2	0.104	0.191	0.380	0.555	0.719
Hf H_2	0.077	0.154	0.343	0.529	0.707

* Variable amounts of elemental hydrogen are isotopically tritium.
Source: DOE 2008, Table E.5-10

Table 30. Unadjusted Lung Committed Equivalent Dose DCFs (Sv/Bq) for Various ITPs and Particle Sizes (AMAD, σg = 2.5), Absorption Type S Assumed

Base Material*	Lung DCF vs. Particle Size [AMAD (μm), σ_g = 2.5]				
	10	5	2	1	0.5
Organic [~$(CH_2)_n$]	4.50×10^{-10}	9.90×10^{-10}	1.65×10^{-9}	1.74×10^{-9}	1.64×10^{-9}
Rust [~FeO(OH)]	4.51×10^{-10}	1.00×10^{-9}	1.71×10^{-9}	1.98×10^{-9}	2.29×10^{-9}
Ti H_2	4.51×10^{-10}	1.00×10^{-9}	1.74×10^{-9}	2.07×10^{-9}	2.52×10^{-9}
Zr H_2	4.53×10^{-10}	1.01×10^{-9}	1.81×10^{-9}	2.30×10^{-9}	3.07×10^{-9}
Hf H_2	4.56×10^{-10}	1.03×10^{-9}	1.94×10^{-9}	2.70×10^{-9}	3.87×10^{-9}

* Variable amounts of elemental hydrogen are isotopically tritium.
** DCF values calculated in DOE 2008 using the LuDEP software (NRPB 1999) which make no adjustment for self absorption.
Source: DOE 2008, Table E.5-11

A DCF adjusted for self absorption in the lung can be obtained simply by multiplying the committed dose equivalent DCF_{lung} shown in Table 30 by the SAFe shown in Table 28. These adjustments to the DCF due to self absorption in the lung are displayed in Table 31. The DCFs developed for 5 AMAD particles are highlighted for comparison with the NIOSH-developed DCF values for a similar sized particle, as described below.

The approach described in NIOSH 2012 also accounts for self absorption as it affects measurement results and lung dose, though NIOSH relies exclusively on an energy correction factor ($SAFe_e$), as indicated on page 24 of NIOSH 2012:

> *The SAF_e is a better quantity for correction of LS counting efficiency because almost any amount of beta energy deposited in the LS cocktail will result in a count being recorded in the tritium "window." The SAF_e is also appropriate for dosimetry calculations because almost any amount of ionization from a beta decay that reaches living tissue can impart dose.*

NIOSH accounts for the effect of self absorption on measurements by deriving a detector efficiency that incorporates an LSC energy self absorption correction factor (SAFe). The detector efficiency distribution is described by a lognormal distribution with a geometric mean (GM) of 0.011 and a geometric standard deviation (GSD) of 2.2 and is applied to the 95th percentile swipe count rates to yield an estimate of total activity intake in accordance with Equation A-1 of NIOSH 2012.

NIOSH accounts for the effect of self absorption on lung dose by applying the GM of their SAFe distribution (0.12) to the lung DCF (NIOSH 2012, Table A-4). Equation A-8 of NIOSH 2012 is used to derive SAFe; the SAFe distribution is depicted in Figure A-10 of that document. The adjusted 50-year DCF for the lung in Table A-4 is 4.41×10^{-4} rem/µCi (1.19×10^{-10} Sv/Bq). A comparison of the lung DCF values in Table A-4 of NIOSH 2012 to those presented in NIOSH 2011a confirms that the 2012 values were adjusted as stated. For example, the 50-year DCF for the lung in NIOSH 2011a is 3.68×10^{-3} rem/µCi. Multiplying this value by 0.12 yields the adjusted 50-year value of 4.41×10^{-4} rem/µCi from Table A-4.

The values in Table 31 do not address the self absorption effect on the detector. It is important to remember that for comparison with the NIOSH 2012 method, the values in Table 31 would be used in conjunction with the "total activity" of tritium in the source particles, so adjustments would have to be made to account for self absorption in the measurement of the contamination. In NIOSH 2012, the detector efficiency is estimated to be 1% (0.011) to account for the self absorption effect in LSC measurement. Thus, the derived DCF values in Table 31 can be directly compared to the 50-year lung DCF value in Table A-4 of NIOSH 2012 [1.19×10^{-10} Sv/Bq (4.41×10^{-4} rem/µCi)].

Table 31. Lung Committed Equivalent Dose DCFs (Sv/Bq) for Various ITPs and Particle Sizes (AMAD, σ_g = 2.5), Absorption Type S Assumed with SAFe Corrections Applied

Base Material*	Lung DCF (w/ SAFe) vs. Particle Size [AMAD (µm), σ_g = 2.5]				
	10	5	2	1	0.5
Organic [~$(CH_2)_n$]	1.37×10^{-10}	4.69×10^{-10}	1.17×10^{-09}	1.46×10^{-09}	1.52×10^{-09}
Rust [~FeO(OH)]	1.04×10^{-10}	3.81×10^{-10}	1.05×10^{-09}	1.52×10^{-09}	2.01×10^{-09}
Ti H_2	9.70×10^{-11}	3.62×10^{-10}	1.03×10^{-09}	1.56×10^{-09}	2.19×10^{-09}
Zr H_2	8.15×10^{-11}	3.15×10^{-10}	9.79×10^{-10}	1.64×10^{-09}	2.62×10^{-09}
Hf H_2	6.48×10^{-11}	2.68×10^{-10}	9.51×10^{-10}	1.84×10^{-09}	3.26×10^{-09}

* Variable amounts of elemental hydrogen are isotopically tritium.

As can be seen, the adjusted lung DCF value used in NIOSH 2012 is bounded by the corresponding DCF for HfH_2 developed for 5µm AMAD ITPs in DOE 2008. The ratio of the DOE to NIOSH values for HfH_2 is 2.25 and is largely explained by the ratio of the corresponding SAFe values derived for each (0.26/0.12).

At this point, there is a major divergence in the DOE and NIOSH approaches as applied to dose assessment. It is important to note that the approach taken in DOE 2008 is applied to effective dose (E_{50}), while the NIOSH approach is concerned with equivalent organ dose.
The effective dose (E) introduced in ICRP Publication 60 (ICRP 1991) is defined by a weighted sum of tissue equivalent doses:

$$E = \sum_T w_T H_T = \sum_T w_T \sum_R w_R D_{T,R} \qquad (4.4)$$

where w_T is the tissue weighting factor for tissue T and $\Sigma\, w_T = 1$. The sum is performed over all organs and tissues of the human body considered to be sensitive to the induction of stochastic effects. These w_T values are chosen to represent the contributions of individual organs and tissues to overall radiation detriment from stochastic effects. DOE accounts for the combined effects of self absorption on measurement (observed activity) and lung dose from particulates in their effective dose DCFs (Table E.5-14 of DOE 2008). In contrast, to fulfill the requirements of EEOICPA, the NIOSH approach addresses individual annual organ doses summed from the onset of intake through the date of cancer diagnosis. Thus only the lung DCF is adjusted for SAFe in the NIOSH model; the effects of self absorption on measurement results are treated at the "front end" in equation A-1 to yield total activity intake to be applied to all organs and tissues of concern.

It is important to note that DOE 2008 concludes that using observed measurements of contamination rather than "actual activity" may be preferable in evaluating lung doses because of the lower variability in DCFs relative to particle size. Specifically, DOE 2008 states:

> *Table [6] data indicate that the E_{50} DCF_os, based on "observed" activity of ITPs of absorption type S, are less dependent on particle size than are the E_{50} DCFs, based on "actual" activity, from Table [5]. The assumption of a single particle size distribution would result in much smaller errors than noted above; for example, when using "observed" activity, E_{50} DCFs vary only by a factor of about 5 for particles ranging in sizes from 0.5 to 10 µm AMAD. Compare this with a factor of 25 when using "actual" activity.*
> …
> *As noted above, the variability of E_{50} DCF_o with material or particle size is not great (range is factor of 5). Therefore, using a conservative assumption of material and particle size distribution (5 µm AMAD) is accurate within that factor for any material or particle size distribution; this assumption can be readily implemented when air monitoring is the method of intake assessment. A factor of dose overestimation (~ 2–10) is further applied when all captured tritiated particulates are assumed to be absorption type S and are measured by LSC.* (DOE 2008, pp. 197 and 199)

6.3 CONCLUSION

The DOE 2008 approach provides a methodology for quantifying effective dose from intakes of ITPs, whether the intake is based on the "observed activity" present in the original measurement or the "actual activity" present in the contamination. DOE 2008 concludes that a preferable method for calculating effective dose is to use the observed activity along with an appropriately modified DCF. NIOSH has adopted an approach in which the "actual activity" is quantified, and then the lung dose DCF is adjusted to account for reduced irradiation of respiratory tract tissues due to particulate self absorption. This is understandable, given the requirements under EEOICPA to calculate dose to organs and tissues associated with specified cancers, many of which are not affected by self absorption. It is noteworthy that the SAFe derived in NIOSH 2012 yields lower doses to the lung than the method presented in DOE 2008 by a factor of approximately 0.45.

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ATTACHMENT 1: EXTRAPOLATION OF INTAKES ASSUMING A FULL YEAR OF EXPOSURE

Room R-108						
Year	**Original Intake Period**	**# Samples**	**95th Percentile Air Concentration**	**NIOSH Intake**	**Corrected Intake**	**Action Taken**
1983	Jun–Aug	141	6.54E-03	1.31E+00	3.92E+00	Multiply original intake by 3
	Sep–Dec	186	3.24E-03	6.48E-01	2.59E+00	Multiply original intake by 4
	Remaining Months	N/A	N/A	N/A	4.66E+00	Average intakes from June to December, multiply by 5 to account for missing months
	Annual Totals	N/A	N/A	1.96E+00	1.12E+01	
				Ratio:	**5.71E+00**	
1984	Jan–Apr	246	2.43E-03	4.85E-01	1.94E+00	Multiply original intake by 4
	May–Aug	264	2.64E-03	5.27E-01	2.11E+00	Multiply original intake by 4
	Sep–Dec	270	7.96E-03	1.59E+00	6.37E+00	Multiply original intake by 4
	Remaining Months	N/A	N/A	N/A	N/A	
	Annual Totals	N/A	N/A	2.60E+00	1.04E+01	
				Ratio:	**4.00E+00**	
1985	Jan	292	5.19E-04	1.04E-01	1.04E-01	No action taken
	Feb	282	1.36E-03	2.73E-01	2.73E-01	No action taken
	Mar	222	1.28E-03	2.57E-01	2.57E-01	No action taken
	Apr	316	1.75E-03	3.51E-01	3.51E-01	No action taken
	May	294	1.76E-03	3.52E-01	3.52E-01	No action taken
	Jun	236	1.17E-03	2.35E-01	2.35E-01	No action taken
	Jul	252	1.19E-03	2.39E-01	2.39E-01	No action taken
	Aug	245	1.98E-03	3.98E-01	3.98E-01	No action taken
	Sep	264	2.19E-03	4.39E-01	4.39E-01	No action taken
	Oct	357	1.89E-03	3.79E-01	3.79E-01	No action taken
	Nov	292	1.65E-03	3.30E-01	3.30E-01	No action taken
	Dec	279	9.98E-04	2.00E-01	2.00E-01	No action taken
	Remaining Months	N/A	N/A	N/A	N/A	
	Annual Totals	N/A	N/A	3.56E+00	3.56E+00	
				Ratio:	**1.00E+00**	

Room R-108						
Year	**Original Intake Period**	**# Samples**	**95th Percentile Air Concentration**	**NIOSH Intake**	**Corrected Intake**	**Action Taken**
1986	Jan	349	1.80E-03	3.61E-01	3.61E-01	No action taken
	Feb	320	1.65E-03	3.30E-01	3.30E-01	No action taken
	Apr	351	2.62E-03	5.26E-01	5.26E-01	No action taken
	May	336	1.96E-03	3.92E-01	3.92E-01	No action taken
	Jun	286	1.54E-03	3.08E-01	3.08E-01	No action taken
	Remaining Months	N/A	N/A	N/A	2.68E+00	Average intakes from January to June, multiply by 7 to account for missing months
	Annual Totals	N/A	N/A	1.92E+00	4.60E+00	
				Ratio:	**2.40E+00**	
1988	Jul	326	1.84E-03	3.70E-01	3.70E-01	No action taken
	Aug	365	2.42E-03	4.86E-01	4.86E-01	No action taken
	Sep	329	2.08E-03	4.18E-01	4.18E-01	No action taken
	Oct	321	1.54E-03	3.09E-01	3.09E-01	No action taken
	Nov	297	1.46E-03	2.93E-01	2.93E-01	No action taken
	Dec	236	1.17E-03	2.35E-01	2.35E-01	No action taken
	Remaining Months	N/A	N/A	N/A	2.11E+00	Average intakes from July to December, multiply by 6 to account for missing months
	Annual Totals	N/A	N/A	2.11E+00	4.22E+00	
				Ratio:	**2.00E+00**	
1989	Jul	305	2.23E-03	4.46E-01	4.46E-01	No action taken
	Aug	334	2.55E-03	5.11E-01	5.11E-01	No action taken
	Sep	292	1.24E-03	2.49E-01	2.49E-01	No action taken
	Oct	325	2.53E-03	5.07E-01	5.07E-01	No action taken
	Nov	291	2.02E-03	4.05E-01	4.05E-01	No action taken
	Dec	236	1.17E-03	2.35E-01	2.35E-01	No action taken
	Remaining Months	N/A	N/A	N/A	2.35E+00	Average intakes from July to December, multiply by 6 to account for missing months
	Annual Totals	N/A	N/A	2.35E+00	4.70E+00	
				Ratio:	**2.00E+00**	

Room SW-8						
Year	**Original Intake Period**	**# Samples**	**95th Percentile Air Concentration**	**NIOSH Intake**	**Corrected Intake**	**Action Taken**
1969	Jan	44	4.40E-03	8.80E-01	8.80E-01	No action
	Feb	20	3.04E-03	6.09E-01	6.09E-01	No action
	Mar	306	6.18E-03	1.24E+00	1.24E+00	No action
	Apr	63	3.36E-03	6.72E-01	6.72E-01	No action
	May	81	4.29E-03	8.57E-01	8.57E-01	No action
	Jun	65	4.32E-03	8.63E-01	8.63E-01	No action
	Jul	93	1.32E-02	2.64E+00	2.64E+00	No action
	Aug	131	3.34E-03	6.68E-01	6.68E-01	No action
	Oct	46	7.92E-03	1.58E+00	1.58E+00	No action
	Nov	51	6.77E-03	1.35E+00	1.35E+00	No action
	Missing Months	N/A	N/A	N/A	2.27E+00	Average intakes from January to August and October to December, multiply by 2 to account for missing months
	Annual Totals	N/A	N/A	1.14E+01	1.36E+01	
				Ratio	**1.20E+00**	
1972	Oct	12	8.97E-03	1.79E+00	1.79E+00	No action
	Nov	75	4.27E-03	8.54E-01	8.54E-01	No action
	Missing Months	N/A	N/A	N/A	1.32E+01	Average October and November intakes and multiply by 10 to account for missing months
	Annual Totals			2.65E+00	1.59E+01	
				Ratio	**6.00E+00**	
1975	July–Aug	21	3.53E-02	7.07E+00	1.41E+01	Multiply by 2
	Missing Months	N/A	N/A	N/A	7.07E+01	Multiply original July–August intake by 10
	Annual Totals			7.07E+00	8.48E+01	
				Ratio	**1.20E+01**	

Room SW-8						
Year	**Original Intake Period**	**# Samples**	**95th Percentile Air Concentration**	**NIOSH Intake**	**Corrected Intake**	**Action Taken**
1976	Jun–July	60	1.85E-02	3.70E+00	7.40E+00	Multiply by 2
	Aug	30	8.73E-03	1.75E+00	1.75E+00	No action
	Sep	48	9.74E-03	1.95E+00	1.95E+00	No action
	Oct	51	1.62E-02	3.23E+00	3.23E+00	No action
	Nov	48	9.16E-03	1.83E+00	1.83E+00	No action
	Dec	45	5.76E-03	1.15E+00	1.15E+00	No action
	Missing Months	N/A	N/A	N/A	1.24E+01	Average intakes from June to December, multiply by 5 to account for missing months
	Annual Totals			1.36E+01	2.97E+01	
				Ratio	**2.18E+00**	
1977	Jan	54	4.86E-03	9.72E-01	9.72E-01	No action
	Feb	51	6.28E-03	1.26E+00	1.26E+00	No action
	Mar	48	1.17E-02	2.34E+00	2.34E+00	No action
	Apr	51	7.70E-03	1.54E+00	1.54E+00	No action
	May	57	8.28E-03	1.66E+00	1.66E+00	No action
	Jun	48	7.74E-03	1.55E+00	1.55E+00	No action
	Jul	54	8.17E-03	1.63E+00	1.63E+00	No action
	Missing Months	N/A	N/A	N/A	7.82E+00	Average intakes from January to July, multiply by 5 to account for missing months
	Annual Totals			1.09E+01	1.88E+01	
				Ratio	**1.71E+00**	
1978	Jan–Feb	33	2.96E-03	5.92E-01	1.18E+00	Multiply by 2
	Mar	36	4.21E-03	8.42E-01	8.42E-01	No action
	Apr	32	5.83E-03	1.17E+00	1.17E+00	No action
	May	36	7.41E-03	1.48E+00	1.48E+00	No action
	Jun	45	2.83E-03	5.67E-01	5.67E-01	No action
	July	36	9.32E-03	1.86E+00	1.86E+00	No action
	Aug	42	6.16E-03	1.23E+00	1.23E+00	No action
	SEP	42	7.34E-03	1.47E+00	1.47E+00	No action
	Oct	42	9.38E-03	1.88E+00	1.88E+00	No action
	Nov	30	6.02E-03	1.20E+00	1.20E+00	No action
	Dec	39	5.60E-03	1.12E+00	1.12E+00	No action

Room SW-8						
Year	**Original Intake Period**	**# Samples**	**95th Percentile Air Concentration**	**NIOSH Intake**	**Corrected Intake**	**Action Taken**
	Missing Months	N/A	N/A	N/A	N/A	
	Annual Totals	N/A	N/A	1.34E+01	1.40E+01	
				Ratio	**1.04E+00**	
1979	Jan	24	2.12E-03	4.42E-01	4.42E-01	No action
	Feb	33	6.66E-05	1.39E-02	1.39E-02	No action
	Mar	45	5.00E-03	1.04E+00	1.04E+00	No action
	Apr	24	4.78E-03	9.95E-01	9.95E-01	No action
	May	36	6.72E-03	1.40E+00	1.40E+00	No action
	Jun	45	5.68E-03	1.18E+00	1.18E+00	No action
	July	39	2.05E-02	4.28E+00	4.28E+00	No action
	Aug	48	1.10E-02	2.29E+00	2.29E+00	No action
	Sept	33	7.47E-03	1.56E+00	1.56E+00	No action
	Oct	36	2.18E-03	4.55E-01	4.55E-01	No action
	Nov	42	2.57E-03	5.36E-01	5.36E-01	No action
	Dec	27	2.52E-03	5.25E-01	5.25E-01	No action
	Missing Months	N/A	N/A	N/A	N/A	
	Annual Totals	N/A	N/A	1.47E+01	1.47E+01	
				Ratio	**1.00E+00**	
1981	Jan	24	6.63E-03	1.33E+00	1.33E+00	No action
	Feb	24	6.35E-03	1.27E+00	1.27E+00	No action
	Mar–Jun	120	4.43E-03	8.86E-01	3.54E+00	Multiply by 4
	Jul–Oct	123	9.41E-03	1.88E+00	7.52E+00	Multiply by 4
	Nov–Dec	54	4.61E-03	9.21E-01	1.84E+00	Multiply by 2
	Missing Months	N/A	N/A	N/A	N/A	
	Annual Totals	N/A	N/A	6.28E+00	1.55E+01	
				Ratio	**2.47E+00**	

Room SW-8						
Year	**Original Intake Period**	**# Samples**	**95th Percentile Air Concentration**	**NIOSH Intake**	**Corrected Intake**	**Action Taken**
1982	Jan–Apr	129	7.81E-03	1.56E+00	6.25E+00	Multiply by 4
	May–Aug	216	1.23E-02	2.47E+00	9.86E+00	Multiply by 4
	Sep–Dec	225	9.76E-03	1.95E+00	7.81E+00	Multiply by 4
	Missing Months	N/A	N/A	N/A	N/A	
	Annual Totals	N/A	N/A	5.98E+00	2.39E+01	
				Ratio	**4.00E+00**	
1983	Jan–Apr	189	7.11E-03	1.42E+00	5.68E+00	Multiply by 4
	May–Aug	234	8.44E-03	1.69E+00	6.75E+00	Multiply by 4
	Sep–Dec	189	1.14E-02	2.28E+00	9.13E+00	Multiply by 4
	Missing Months	N/A	N/A	N/A	N/A	
	Annual Totals	N/A	N/A	5.39E+00	2.16E+01	
				Ratio	**4.00E+00**	
1984	Jan–Apr	237	1.33E-02	2.67E+00	1.07E+01	Multiply by 4
	May–Aug	261	3.69E-03	7.38E-01	2.95E+00	Multiply by 4
	Sep–Dec	270	1.19E-02	2.39E+00	9.55E+00	Multiply by 4
	Missing Months	N/A	N/A	N/A	N/A	
	Annual Totals	N/A	N/A	5.79E+00	2.32E+01	
				Ratio	**4.00E+00**	
1985	Jan	459	1.75E-03	3.50E-01	3.50E-01	No action
	Feb	516	2.02E-03	4.06E-01	4.06E-01	No action
	Mar	359	2.01E-03	4.03E-01	4.03E-01	No action
	Apr	466	3.24E-03	6.48E-01	6.48E-01	No action
	May	482	2.26E-03	4.52E-01	4.52E-01	No action
	Jun	406	1.56E-03	3.12E-01	3.12E-01	No action
	Jul	448	1.59E-03	3.20E-01	3.20E-01	No action
	Aug	450	2.56E-03	5.13E-01	5.13E-01	No action
	Sep	423	3.96E-03	7.93E-01	7.93E-01	No action
	Oct	510	3.04E-03	6.09E-01	6.09E-01	No action
	Nov	379	3.33E-03	6.66E-01	6.66E-01	No action
	Dec	335	1.37E-03	2.75E-01	2.75E-01	No action
	Missing Months	N/A	N/A	N/A	N/A	

Room SW-8						
Year	**Original Intake Period**	**# Samples**	**95th Percentile Air Concentration**	**NIOSH Intake**	**Corrected Intake**	**Action Taken**
	Annual Totals	N/A	N/A	5.75E+00	5.75E+00	
				Ratio	**1.00E+00**	
1986	Jan	483	3.73E-03	7.47E-01	7.47E-01	No action
	Feb	438	2.47E-03	4.96E-01	4.96E-01	No action
	Apr	481	4.31E-03	8.63E-01	8.63E-01	No action
	May	461	1.70E-03	3.42E-01	3.42E-01	No action
	Jun	449	2.57E-03	5.15E-01	5.15E-01	No action
	Missing Months	N/A	N/A	N/A	4.15E+00	Average intakes from January-February and April-June, multiply by 7 to account for missing months
	Annual Totals	N/A	N/A	2.96E+00	7.11E+00	
				Ratio	**2.40E+00**	
1987	Jan	449	3.33E-03	6.67E-01	6.67E-01	No action
	Feb	432	5.26E-03	1.05E+00	1.05E+00	No action
	Mar	431	4.23E-03	8.47E-01	8.47E-01	No action
	Apr	466	4.74E-03	9.50E-01	9.50E-01	No action
	May	458	3.14E-03	6.30E-01	6.30E-01	No action
	Jun	448	5.24E-03	1.05E+00	1.05E+00	No action
	Jul	407	3.39E-03	6.79E-01	6.79E-01	No action
	Aug	492	3.01E-03	6.03E-01	6.03E-01	No action
	Missing Months	N/A	N/A	N/A	3.24E+00	Average intakes from January to August, multiply by 4 to account for missing months
	Annual Totals	N/A	N/A	6.48E+00	9.72E+00	
				Ratio	**1.50E+00**	
1988	Jan	456	1.65E-03	3.30E-01	3.30E-01	No action
	Feb	300	4.48E-03	8.98E-01	8.98E-01	No action
	Mar	490	1.62E-03	3.25E-01	3.25E-01	No action
	Apr	480	1.42E-03	2.85E-01	2.85E-01	No action
	May	450	1.04E-03	2.09E-01	2.09E-01	No action
	Jun	366	9.12E-04	1.83E-01	1.83E-01	No action
	Missing Months	N/A	N/A	N/A	2.23E+00	Average intakes from January to June, multiply by 6 to account for missing months
	Annual Totals	N/A	N/A	2.23E+00	4.46E+00	

Room SW-8						
Year	**Original Intake Period**	**# Samples**	**95th Percentile Air Concentration**	**NIOSH Intake**	**Corrected Intake**	**Action Taken**
				Ratio	**2.00E+00**	
1989	Jan	449	1.34E-03	2.68E-01	2.68E-01	No action
	Feb	576	1.70E-03	3.40E-01	3.40E-01	No action
	Mar	474	1.21E-03	2.43E-01	2.43E-01	No action
	Apr	582	1.86E-03	3.72E-01	3.72E-01	No action
	May	470	1.63E-03	3.27E-01	3.27E-01	No action
	Jun	349	1.94E-03	3.89E-01	3.89E-01	No action
	Missing Months	N/A	N/A	N/A	1.94E+00	Average intakes from January to June, multiply by 6 to account for missing months
	Annual Totals	N/A	N/A	1.94E+00	3.88E+00	
				Ratio	**2.00E+00**	

ATTACHMENT 2: DESCRIPTION OF TRANSCRIPTION ERRORS, MISSED DATA AND DUPLICATE ENTRIES

QA Ref #	Description	Room	Month-Year	SRDB Ref	Page
1	Missing data: (2100, 7, 200), (152, 19, 80), (8791, 0, 649), (257, 0, 51), (199, 0, 68)	R-108	Jun-83	90092	819
2	Transcription error (720 incorrectly recorded as 7066)	R-108	Sep-83	90092	1217
3	Transcription error (299 incorrectly recorded as 65)	R-108	Nov-83	90092	1055
4	Transcription error (49 incorrectly recorded as 409)	R-108	Nov-83	90092	1090
5	Transcription error: (95 incorrectly recorded as 45)	R-108	Feb-84	90096	51
6	The following data appear to have been duplicated : (135, 0, 25), (177, 24, 60), (180, 0, 67) and (166, 24, 50)	R-108	May-84	*See Spreadsheet*	
7	Transcription error (32 incorrectly recorded as 82), (4896 incorrectly recorded as 4196)	R-108	Jun-84	90096	642
8	Transcription error (636 incorrectly recorded as 626)	R-108	Jun-84	90096	670
9	Transcription error (60 incorrectly recorded as 62)	R-108	Jul-84	90096	361
10	Transcription Error (671 incorrectly recorded as 621)	R-108	Jul-84	90096	424
11	Transcription error (134 incorrectly recorded as 1304)	R-108	Aug-84	90096	393
12	Transcription error (14 incorrectly recorded as 4)	R-108	Sep-84	90096	717
13	Missing data: (424, 0, 151) Transcription error (29 incorrectly recorded as 5), (168 incorrectly recorded as 29)	R-108	Sep-84	90096	744
14	Transcription error (22 incorrectly recorded as 0)	R-108	Oct-84	90096	793
15	Transcription error (272 incorrectly recorded as 275)	R-108	Oct-84	90096	830
16	The following data appear to have been duplicated: (55, 0, 25), (99, 0, 28), (107, 0, 54), (226, 58, 136), (433, 0, 103), (458, 0, 82), (486, 0, 81), (978, 6, 273), (1319, 28, 312), (1518, 82, 319)	R-108	Dec-84	*See Spreadsheet*	
17	Transcription error (6 incorrectly recorded as 0)	R-108	Dec-84	90096	499
18	Transcription error: (2080 incorrectly recorded as 280)	SW-8	Aug-81	90049	44
19	Three data appear to represent alpha smears not beta smears	SW-8	Oct-81	90049	66
20	Transcription error: (102 incorrectly recorded as 162)	SW-8	Dec-81	90049	357
21	Missing data: (857, 45, 215), (1577, 43, 332), (1544, 21, 208)	SW-8	Mar-82	90092	659

QA Ref #	Description	Room	Month-Year	SRDB Ref	Page
22	Transcription error (59 incorrectly recorded as 51)	SW-8	Jul-82	90092	498
23	Transcription error (406 incorrectly recorded as 402)	SW-8	Aug-82	90092	424
24	Transcription error (3857 incorrectly recorded as 3887)	SW-8	Aug-82	90092	442
25	Transcription error (299 incorrectly recorded as 219)	SW-8	Sep-82	90092	390
26	Transcription error (147 incorrectly recorded as 128)	SW-8	Nov-82	90092	243
27	Transcription error (2928 incorrectly recorded as 2908)	SW-8	Nov-82	90092	291
28	Missing data: (3769, 0, 408) Transcription error: (175 incorrectly recorded as 875)	SW-8	Feb-83	90092	138
29	Transcription error: (878 incorrectly recorded as 866), (242 incorrectly recorded as 222)	SW-8	Feb-83	90092	120
30	Missing data: (7, 502), (349, 40, 148) Transcription error: (1595 incorrectly recorded as 595), (52 incorrectly recorded as 54), (151 incorrectly recorded as 124), and (224 incorrectly recorded as 234)	SW-8	Mar-83	90092	84
31	Transcription error: (323 incorrectly recorded as 423)	SW-8	Mar-83	90092	51
32	Transcription error: (154 incorrectly recorded as 254)	SW-8	Apr-83	90092	25
33	Missing data: (175)	SW-8	Apr-83	90092	29
34	Transcription error: (1099 incorrectly recorded as 1098)	SW-8	Apr-83	90092	948
35	Missing data (868, 13, 121) Transcription error: (30 incorrectly recorded as 306), (461 incorrectly recorded as 61)	SW-8	Aug-83	90092	1269
36	Transcription error: (185 incorrectly recorded as 189)	SW-8	Sep-83	90092	1236
37	Transcription error: (273 incorrectly recorded as 233)	SW-8	Nov-83	90092	1033
38	Transcription error (17 incorrectly recorded as 7)	SW-8	Jan-84	90096	250
39	Missing data: (543, 5,104) Transcription error: (49 incorrectly recorded as 52)	SW-8	Feb-84	90096	8
40	Missing data: (826, 3 , 145)	SW-8	Mar-84	90096	131
41	Transcription error (86 incorrectly recorded as 36)	SW-8	Apr-84	90096	149
42	The following data appear to have been duplicated: (339, 0, 66), (501, 26, 159), (568, 0, 79) and (975, 33, 189)	SW-8	May-84	*See Spreadsheet*	
43	Missing data: (413, 52, 136)	SW-8	May-84	90096	523
44	Missing data: (377, 13, 98)	SW-8	May-84	90096	597

QA Ref #	Description	Room	Month-Year	SRDB Ref	Page
45	Transcription error (48 incorrectly recorded as 44)	SW-8	Jun-84	90096	643
46	Transcription error (812 incorrectly recorded as 312), (328 incorrectly recorded as 321)	SW-8	Jun-84	90096	616
47	Transcription error (8 incorrectly recorded as 1)	SW-8	Jul-84	90096	348
48	Transcription Error (1192 incorrectly recorded as 192)	SW-8	Jul-84	90096	408
49	Transcription error (30 incorrectly recorded as 32)	SW-8	Aug-84	90096	327
50	The following data appear to have been duplicated: (320, 6, 75), (357, 23, 167), (627, 18, 211) and (725, 0, 140)	SW-8	Oct-84	*See Spreadsheet*	
51	Transcription error (1526 incorrectly recorded as 1626)	SW-8	Oct-84	90096	829
52	Transcription error (5100 incorrectly recorded as 50100)	SW-8	Nov-84	90096	874
53	Missing data (3700, 99, 735) Transcription error (332 incorrectly recorded as 231)	SW-8	Nov-84	90096	897
54	Transcription error (288 incorrectly recorded as 211)	SW-8	Nov-84	90096	443
55	The following data appear to have been duplicated: (636, 7, 156), (1236, 53, 253), (1441, 58, 241), (1605, 10, 281) and (1778, 111, 354)	SW-8	Dec-84	*See Spreadsheet*	
56	Transcription error (485 incorrectly recorded as 415), (48 incorrectly recorded as 41), (585 incorrectly recorded as 515)	SW-8	Dec-84	90096	459
57	Transcription error (2854 incorrectly recorded as 2154)	SW-8	Dec-84	90096	482
58	Transcription error (281 incorrectly recorded as 211)	SW-8	Dec-84	90096	498

ATTACHMENT 3: DESCRIPTION OF DATA, INFORMATION, AND REPORTS IN THE SRDB

Documents collected by NIOSH related to the EEOICPA dose reconstruction are contained and maintained in the Site Research Database (SRDB). SC&A performed a search of the SRDB in order to obtain background information on the metal tritide issue at Mound. In general, there are three types of documents that were searched for: (1) general information on tritides at Mound, (2) information on tritium (tritide) incidents at Mound, and (3) information on tritium contamination at Mound. There are a number of documents identified in the SRDB concerning the dose response to tritides, but since it has been decided to accept modeling tritides as Type S, those documents were not included in the present SC&A search of the SRDB. Likewise, the SRDB contains a number of documents related to tritides at other (non-Mound) sites, which were not included in the present review. Table A-1 presents a list of the Mound tritides-related SRDB documents that were identified, downloaded, and reviewed by SC&A for this background information gathering effort (additional documents were obtained by SC&A in order to perform other portions of this review, specifically for the Section 4.1 temporal and spatial data adequacy and completeness review).

Based on the search and review of the SRDB for documents related to metal tritides at the Mound site, the following points can be made:

(1) "Tritium (not tritides) came to Mound in ~1957… Didn't have a particulate program until 1959" – [**Redacted**] (Ulsh and Chew 2008 and SC&A 2006).

(2) There was research and development work with tritides (SC&A 2006).

(3) Mound published tritide research results beginning in the mid-1970s, if not before (Bowman and Attalla 1974).

(4) NIOSH interviewed three tritide site experts in 2008; [**Redacted**] – [**Redacted**] Scientist 1980–1994, contractor through 2000; [**Redacted**] – Physicist 1964–1995; [**Redacted**] – [**Redacted**] Engineer 1959–2003 (Ulsh and Chew 2008).

(5) From time to time, incidents occurred with tritium and/or tritides (Rogers et al. 1993; Ricks 1973; MORE 1964, 1965, 1973a, and 1973b; Meyer et al. 1960; Kirk 1994 and 1999.

(6) The most important incident involving tritides was a 1972 glove failure on a single box in SW-13 (SC&A 2006, Appendix 7). This is probably also the Kirk incident discussed by [**Redacted**] and [**Redacted**] (Ulsh and Chew 2008). There is a 1970 incident report that sounds very much like this incident (Madding 1970) – could there be a mix-up in the date?

(7) From these incident reports, maintenance in tritium areas was performed in protective "bubble suits."

(8) "Mound never deliberately handled unconfined particulate tritides. There were unintentional spills, but it was always doubly confined" – [**Redacted**] (Ulsh and Chew 2008).

(9) It is possible to determine if a biosample is the result of inhalation or skin adsorption of tritium or inhalation of tritides, but tritides could be masked by HTO and/or H2 (Ulsh and Chew 2008).

(10) Tritide workers identified by name (Ulsh and Chew 2008).

(11) Continuous air monitors filter the air before counting; therefore, tritides would be removed and not included in air monitoring results.

(12) No data prior to the early 1990s regarding tritide contamination levels.

(13) SW-8, SW-9, SW-13, SW-150, SW-152, SW-24, and R-108 have the potential for SMT contamination (SC&A 2006).

(14) SW-8 and R-108 last used to process tritides (recover tritium from tritides on dismantled boxes/hoods) (SC&A 2006).

General Information:

Tritium (Tritide) Incidents: The SRDB contains documentation on a number of incidents involving accidental tritium contamination and personnel exposures that have occurred at Mound. SRDB documentation for three Mound tritium incidents that specifically involved metal tritides was identified and reviewed.

Tritium Contamination: The review of the SRDB revealed that there is much tritium contamination information for the Mound plant; however, no airborne or surface contamination information specific to tritide contamination was identified for the Mound plant. Therefore, this lack of information makes it difficult to benchmark any tritide model developed by NIOSH for the Mound plant.

Table A-1. SRDB Documents Reviewed for this Review

Identifier	Comments
025502_ Accident Investigation Report No. 73-08 (Ricks 1973)	1973 tritium incident, SW-8
026908_ Mound Technical Basis Document for Stable Tritiated Particulate and Organically Bound Tritium Vol 4. (Sharfi 2001)	
026975_Radiological Controls for Work Involving Stable Tritiated Particulates and Organically Bound Tritium (Collas 1999)	
039682_ (Powers 1998)	
048319_Properties of Aged Metal Tritides (McConville et al. 1994)	
048822_ Correspondence File, Incident Reports (Environmental and Worker) (Kirk 1999)	Incidents, see pages 64 (1978 tritide) and 101 (1981 tritium)
048837_Investigation of the Contamination Tracking Incident in SW_R Tritium Complex (Rogers et al. 1993)	1993 tritium incident, referred to in Interview Notes (055962)
048857_SW-209 Contamination Incident Report (Kirk 1994)	1994 tritium incident
050849_Stable Tritiated Particulates (STPs) White Paper (Trent 1999)	

Table A-1. SRDB Documents Reviewed for this Review

Identifier	Comments
055962_Interview with [Redacted], [Redacted], and [Redacted] (Ulsh and Chew 2008)	Good background information: can identify tritides from biosample,
059275_SW Health Physics Trend Sheets, August 13, 1978 – December 28, 1978 (Ulsh 2009)	Only data, no explanation
081876_SW Building Contamination Surveys 1985 (Connell 2010a)	Only data, no explanation
081912_SW Building Contamination Surveys 1987 (Connell 2010d)	Only data, no explanation
081939_SW Health Physics Trend Sheet, Tritium Air and Wipe Results, 1977, part 2 (Weaver 2010a)	Only data, no explanation
081940_SW Health Physics Trend Sheet, Tritium Air and Wipe Results, 1977, part 1 (Weaver 2010b)	Only data, no explanation
46056_Calculation Of Tritium Dose From Insoluble Particulates (McConville and Woods 1995)	[Redacted] – Woods paper, referred to in Interview Notes (055962)
039681_Characterization of Particulate Tritium Sources (EG&G 1995)	
039716_Discussion of Hafnium Tritide Dosimetry and Proposal Path Forward for Assigning Dose with Mound (D.G. Draper), Sandia National Laboratory, Lovelace Respiratory Research Institute, Los Alamos National Laboratory - M.E. Schillaci (Connell 2008)	Comments on some report: can identify tritides from biosample, 76+1 workers exposed to tritides
Final Safety Analysis Report for the SW-R Tritium Complex (EG&G 1994)	
39891_Health Physics Technician Training Tritium Monitoring (Anderson no date)	
80159_Incidents (MORE 1973a)	1973 tritium incidents – bubble suit, skin contamination, not inhalation
039686_Information Regarding the Workplace Indicators and Bioassay Limitations When Dealing with Stable Metal Tritides (Sirois 1998)	
39690_Metal Tritide Questions – Responses (Draper 1997)	
039693_Particulate Tritium Issues at Mound – (Draper 1996)	
039721_PARTICULATE TRITIUM ISSUES AT MOUND (Sullivan 1996)	Transmittal of Draper to DOE
46475_Report of Accident Investigation of the F Column Tritium Incident in the SW-8 Area (Meyer et al. 1960)	1960 tritium incident
SiteResearch – Tritide, Mound	SRDB search results for “tritide”
SiteResearch – Tritium, Mound	SRDB search results for “tritium”
039680_Survey of SW Building for Particulate Tritium before Decontamination	
Tritium Incident in SW 142 (MORE 1973b)	1973 tritium gas incident
Tritium Incident in SW (MORE 1964)	1964 “minor” tritium incident
46949_Tritium Surface Contamination (Sienkiewicz 1985)	