Draft

ADVISORY BOARD ON
RADIATION AND WORKER HEALTH

National Institute for Occupational Safety and Health

SC&A RESPONSE TO NIOSH WHITE PAPER: "FOLLOW-UP EFFORTS ON SEC-00192 ROCKY FLATS PLANT TRITIUM ISSUES," DATED MAY 30, 2014

Contract No. 211-2014-58081

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September 2014

S. COHEN & ASSOCIATES: *Technical Support for the Advisory Board on Radiation & Worker Health Review of NIOSH Dose Reconstruction Program*	Document No. Response to NIOSH White Paper Effective Date: Draft – September 18, 2014
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Task Manager: _________________________________ Joseph Fitzgerald, MS, MPH Date	Supersedes: N/A
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Record of Revisions

Revision Number	Effective Date	Description of Revision
0 (Draft)	09/18/2014	Initial issue

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ABBREVIATIONS AND ACRONYMS

ABRWH, Board or Advisory Board	Advisory Board on Radiation and Worker Health
AEC	Atomic Energy Commission
BNWL	Battelle Northwest Laboratory
Bq	Becquerel
Ci	curie
d	day
dis/sec	disintegrations per second
DOE	(U.S.) Department of Energy
dpm	disintegrations per minute
EEOICPA	Energy Employees Occupational Illness Compensation Act of 2000
g	gram
GI	gastro-intestinal
h or hr	hour
HTO	tritium oxide
ICRP	International Commission on Radiation Protection
IMBA	Integrated Modules for Bioassay Analysis
keV	kilo electron volt, 1,000 electronvolts
kg	kilogram
L or l	liter
LANL	Los Alamos National Laboratory
LLL	Lawrence Livermore Laboratory
LLNL	Lawrence Livermore National Laboratory
LSD	Liquid Scintillation Detector
m^3	cubic meter
MDL	minimum detectable limit
MeV	million electron volt
ml	milliliter
mrad	millirad
mrem	millirem
µCi	microcurie

NIOSH	National Institute for Occupational Safety and Health
NOCTS	NIOSH/OCAS Claims Tracking System
OBT	organically bound tritium
ORAUT	Oak Ridge Associated Universities Team
pCi	picocuries
PER	Petition Evaluation Report
QC	quality control
rad	radiation absorbed dose
RFAO	Rocky Flats Area Office
RFP	Rocky Flats Plant
SRS	Savannah River Site
SS	"Source and Special" [nuclear material]
SC&A	S. Cohen and Associates (SC&A, Inc.)
SEC	Special Exposure Cohort
SRDB	Site Research Database
Sv	Sievert
y or yr	year

EXECUTIVE SUMMARY

This SC&A white paper is being provided to the Advisory Board on Radiation and Worker Health (ABRWH or Advisory Board) and the National Institute for Occupational Safety and Health (NIOSH) in response to NIOSH's May 30, 2014, white paper titled, *Response: Rocky Flats Plant Surveillance Document Review* (Bogard et al. 2014). NIOSH's white paper represents the latest exchange of white papers and discussions performed under the direction of the RFP Work Group designed to resolve issues associated with the reconstruction of tritium doses to RFP workers. NIOSH sought to revisit its 2013 assessment (Bogard et al. 2013) based on additional document data captures and personnel interviews that were performed to (1) clarify the existence of tritium on site and associated personnel exposures; (2) expand the investigation on tritium bubbler sampling; (3) confirm the existence of shipping container tritium surveys; and (4) confirm the type and amount of sampling analysis performed in Building 123. NIOSH's additional investigations did not lead to any changes in its conclusions regarding the validity of the tritium bounding method for the SEC-00192 evaluation report for RFP.

The tritium exposures of primary concern are those to workers who opened containers received by RFP that, at times, may have been contaminated with tritium. Reviews of the various white papers that were prepared by NIOSH and SC&A, discussions of tritium issues at various work group meetings, worker interviews, and the review of documents captured during site visits and placed in the Site Research Database (SRDB) reveal that prior to an incident that occurred in April 1973, it was the general belief that material shipped to RFP for processing did not contain tritium, because the tritium was monitored and removed prior to shipment. As a result, RFP's radiological controls before 1973 included very little in-plant tritium air monitoring and no routine tritium bioassay monitoring of workers. The incident was discovered as part of a routine environmental surveillance program being performed by the State of Colorado.

Subsequent to the April 1973 incident, actions were taken by the Department of Energy (DOE) and its contractors to determine the cause of the incident, the impacts of the incident, and take corrective actions to avoid such incidents in the future. In addition, as more was learned about the incident, DOE and its contractors began to put in place and expand upon certain tritium monitoring programs, which included air samplers using bubblers and scintillation counters, tritium swipe samples, effluent and environmental monitoring, and bioassay programs.

The data and process knowledge that NIOSH proposes to use to reconstruct the tritium doses to workers associated with the April 1973 tritium incident are described in the various white papers. In addition, research related to the 1973 incident uncovered information associated with other incidents of lesser impact than the 1973 incident that expanded NIOSH's investigations into tritium exposures. Investigations into tritium exposures were, therefore, divided into three time categories; the 1973 incident, exposures post-1973, and exposures pre-1973. NIOSH's investigations concluded that (1) the highest tritium dose associated with the 1973 incident was 84 mrem; (2) the coworker model for post-1973 exposures is assumed to be zero mrem/yr, except for known exposures to workers specifically exposed in the 1974 incident; and (3) pre-1973 exposures to tritium are assumed to be 37.5 mrem/yr, assuming one incident per day at 0.15 mrem (largest reported bioassay result from the 1974 release) for 250 work days per year.

SC&A's investigation into these matters found that a plausible upper bound for the exposures associated with the 1973 incident may be as high as 6,000 mrem. The reasons for the differences between the NIOSH and SC&A estimates of the tritium dose are that SC&A assumed a different date when the acute intakes occurred for some workers and also used a tritium retention model that is being developed by the International Commission on Radiation Protection (ICRP) that is applicable to circumstances where urine samples are first collected more than 100 days following an acute exposure. SC&A used this model, because the current ICRP model is only applicable to reconstructing acute doses that occurred less than 100 days before the first urine sample is collected. SC&A, while acknowledging NIOSH's response that it is not, as a matter of internal policy, able to use pending ICRP methods, points out that NIOSH did not use the current recommended ICRP intake-excretion function for deriving the bounding intakes for tritium, but an Integrated Modules for Bioassay Analysis (IMBA) modification of the model, which was not approved by the ICRP.

With respect to NIOSH's conclusions regarding post-1973 exposures, SC&A concludes that post-1973 data cannot be used with confidence to reconstruct post-1973 exposures. In our judgment, based on the original 1974 investigation, there is considerable uncertainty regarding the locations of the bubblers in relation to the locations where workers might have been exposed during and following the 1974 incident, and perhaps other unidentified incidents. As a result, SC&A questions data adequacy with respect to reconstructing post-1973 exposures. In addition, the post-1973 urine sampling data were collected too infrequently to be used with confidence for the purpose of building a coworker model.

With respect to pre-1973 exposures, SC&A finds that radiological control protocols for tritium contamination changed substantially following the 1973 incident, and that both the operations and the circumstances of tritium releases associated with routine pit returns and the 1974 pressure cooker container release, respectively, were sufficiently different to make the 1974 releases not representative of these earlier ones. Therefore, the retrospective application of this source term would not be supportable.

1.0 INTRODUCTION

Under the direction of the Rocky Flats Plant (RFP) Work Group, NIOSH and its contractors [Oak Ridge Associated Universities Team (ORAUT)] and the Advisory Board and its contractor (SC&A) have been investigating strategies for reconstructing tritium doses to workers at RFP. The investigations began with Special Exposure Cohort (SEC) Petition Evaluation Report (PER) for Petition SEC-00192 dated September 30, 2013 (NIOSH 2013). Revision 0 of the SEC-00192 (NIOSH 2012) petition evaluation report addressed:

> *All employees of the Department of Energy, its predecessor agencies, and their contractors and subcontractors with the potential for tritium exposures while working at the Rocky Flats Plant in Golden, Colorado, during the period from April 1, 1952 through December 31, 2005.*

In addition, Revision 1 of the report (NIOSH 2013) was expanded to evaluate:

> *All employees of the Department of Energy, its predecessor agencies, and their contractors and subcontractors with the potential for tritium, thorium, uranium-233 and associated progeny, and/or neptunium-237 exposures while working at the Rocky Flats Plant in Golden, Colorado, during the period from April 1, 1952 through December 31, 2005.*

In Revision 1 of its petition evaluation report, dated September 30, 2013, NIOSH concluded that:

> *…it has access to sufficient information to: (1) estimate the maximum radiation dose, for every type of cancer for which radiation doses are reconstructed, that could have been incurred in plausible circumstances by any member of the class; or (2) estimate radiation doses more precisely than an estimate of maximum dose. Information available from the site profile and additional resources is sufficient to document or estimate the maximum internal and external potential exposure to members of the evaluated class under plausible circumstances during the specified period (January 1, 1984 through December 31, 2005).*

Revision 1 of the SEC PER provided the technical basis for concluding that tritium exposures could be reconstructed with sufficient accuracy.

Prior to and following the issuance of Revision 1 to SEC Petition Evaluation Report for SEC-00192, white papers were issued to discuss NIOSH's conclusions provided in Revision 1 of the SEC PER that:

> *…the potential for tritium exposures existed from the beginning to the end of RFP operations, and was associated with, and the result of, the receipt and reprocessing of tritium-contaminated weapons components returned to the site. Based on the assessment presented in this evaluation, NIOSH concludes that there are sufficient data and knowledge of processes and operations to support*

bounding the associated tritium dose using the methods and information presented in this evaluation.

On June 25, 2013, a white paper was issued by J.S. Bogard, E.M. Brackett, Mutty Shafi, and Dan Stempfley titled, *White Paper: Follow-up Efforts on SEC-00192 Tritium Issues* (Bogard et al. 2013), which expands upon the technical basis for concluding that tritium doses at RFP could be reconstructed with sufficient accuracy. Noteworthy are Appendix 1, Parts 1 and 2, and Attachment A to the white paper that provide extensive information, data, and analyses that establish the technical underpinning for the conclusion that tritium exposures for pre-1973, 1973, and post-1973 time periods can be reconstructed with sufficient accuracy. The reconstruction of tritium exposures at RFP were divided into these three time periods because of the nature of tritium monitoring and discrete tritium "events" that took place at RFP, especially in 1973.

In response to the June 25, 2013, white paper, SC&A delivered two white papers to NIOSH and the Board, one on September 10, 2013, and a second one on December 11, 2013, as follows:

- Draft White Paper, *Focused Review of "White Paper: Followup Efforts on SEC-00192 RFP Tritium Issues*," Contract Number 200-2009-28555, Prepared by John Mauro, PhD, CHP, and Joseph Fitzgerald. September 2013. (SC&A 2013a)

- Draft *SC&A Review of Part II, Rocky Flats Tritium Dose Assignment for 1973, Attachment A*, Contract No. 200-2009-28555, Revision 0, Prepared by Joyce Lipsztein, December 2013. (SC&A 2013b).

These SC&A white papers raised a number of concerns regarding the technical information, analyses, and conclusions regarding tritium dose reconstruction as provided in NIOSH's June 25, 2013, white paper. In response to the SC&A white papers, NIOSH issued a report dated May 30, 2014 titled:

- *Follow-up Efforts on SEC-00192, Rocky Flats Plant Tritium Issues, White Paper, Rev. 1*, National Institute for Occupational Safety and Health, May 30, 2014, by J.S. Bogard, E.M. Brackett, Mutty Sharfi, and Dan Stempfley, Oak Ridge Associated Universities Team. Reviewed by Dr. James W. Neton and LaVon B. Rutherford, CHP, Division of Compensation Analysis and Support. (Bogard et al. 2014).

This SC&A white paper is provided in response to this May 30, 2014, white paper prepared by NIOSH and its contractors. As a preface to this white paper, SC&A would like to point out a number of overarching issues that might be useful to the Advisory Board in its deliberations with respect to this matter, as follows:

Under SEC-00030, SEC status was granted for eligible RFP workers for April 1, 1952, through December 31, 1966. Under Petition 00192, SEC status was expanded through December 31, 1983. Accordingly, the tritium issues addressed in this report are eclipsed to a certain degree by the SECs that have been granted, because the covered period encompasses the time periods when the tritium issues are of concern. The implications of these SECs are that, should the tritium issues be resolved in accordance with NIOSH's position on these matters, tritium doses would be reconstructed as part of partial dose reconstructions for workers not covered by the SEC. Should it be determined that tritium doses cannot be reconstructed with sufficient accuracy, partial dose reconstructions, to the extent that they can be performed, would not include reconstructed tritium doses. It is also noteworthy that, notwithstanding how this issue is resolved, we believe that the tritium exposures are quite small (i.e., in the mrem/yr range). However, judgments made regarding the ability to reconstruct doses with sufficient accuracy that emerge from these deliberations will help to advance ongoing inquiries by the Board with respect to what constitutes "sufficient accuracy."

2.0 COMMENTARY ON THE NIOSH WHITE PAPER ADDRESSING TRITIUM ISSUES DATED MAY 30, 2014

The introduction to the NIOSH May 30, 2014, white paper explains that, in response to concerns expressed by the RFP Work Group and questions raised by the SC&A white papers dated September 2013 and December 2013, NIOSH revisited its existing records and initiated a number of follow-on investigations that included additional worker interviews and focused records retrieval.

Our concerns are with respect to interpreting the relevant data and their dosimetric implications. As discussed at great depth in the previous white papers, issues related to reconstructing tritium exposures can be conveniently divided between pre-1973, 1973, and post-1973 exposures. The year 1973 is a watershed year because of the tritium incident that occurred in April 1973, which alerted all concerned that tritium exposures could have been occurring prior to 1973, a time when it was generally believed that the potential for tritium exposures was minimal. As a result of the 1973 incident, considerable attention was given to the potential for chronic and possibly additional acute exposures to tritium associated with the receipt and processing of material from other weapons complex facilities after the 1973 incident.

Because the 1973 incident is central to understanding all issues related to tritium exposures at RFP, we begin by first discussing the May 30th NIOSH white paper with respect to this incident (addressed in Appendix 1, Part II), followed by a discussion of whether post-1973 tritium exposure data can be applied retrospectively to pre-1973 historic exposures.

2.1 THE 1973 INCIDENT AND ASSOCIATED EXPOSURES (APPENDIX 1, PART II)

2.1.1 Overview

A review of the full set of white papers with respect to this issue reveals that our concerns are a mix of policy issues related to applying ICRP guidance as well as issues related to data interpretation by time of exposure. In its June 25, 2013, white paper and in the more recent May 2014 white paper, NIOSH contends that the methods used to reconstruct plausible upper bound doses to workers due to the April 1973 tritium incident are scientifically sound, because they follow current ICRP guidance. In brief, NIOSH was able to obtain bioassay data from two workers about 140–180 days after the incident, and then using IMBA, reconstructed the acute intakes and associated doses due to the April 1973 incident for the two workers. The outcome of the NIOSH analysis is that the upper bound exposure from the incident was 84 mrem from an intake equal to 1,240 µCi. In reality, the NIOSH bounding intake was not calculated using the current ICRP model.

The current ICRP model for tritium after intake of tritiated water is the one described in ICRP Publication 78 (1997), with a clarification published in ICRP 88 (2002). The model assumes that for bioassay, the concentration in urine is the same as in body water and recommends that, “the activity concentration in urine should be calculated by dividing the whole body activity by the volume of body water, 42 l [liters].”

SC&A contends that the biokinetic models recommended by ICRP are only applicable to reconstructing doses if the bioassay samples were collected up to about 50 to 60 days after an acute exposure to tritiated water.

Based on SC&A's review of the data, we believe that it is not plausible for NIOSH to place an upper bound on these exposures unless a model is employed that accommodates reconstruction of tritium intakes well beyond 100 days after intake, e.g., the most-recent ICRP model, which is pending. Using this approach, SC&A believes that a plausible upper bound for the tritium exposures associated with the April 1973 incident can be assigned by using this newer ICRP model or similar models.

The following table taken from SC&A's December 2013 white paper reiterates the differences in the bounding doses as derived using NIOSH's approach (current ICRP model) and SC&A's approach (pending ICRP model).

Table 1. Summary of Intake and Dose Assessments for Five Workers that had the Highest H-3 Bioassay Results among the Samples Collected in September and October 1973

(Highest possible intakes are displayed)

Case	*NIOSH Intake Date*	*NIOSH Intake (µCi)*	*NIOSH Dose (mrem)*	*SC&A Intake Date*	*SC&A Intake (rounded) (µCi)*	*SC&A Dose (rounded) (mrem)*
A	*9/19/73*	*38.7*	*2.6*	*04/21/73*	*9.0E4*	*6000*
B	*7/1/73 thru 9/25/73*	*28.1*	*1.9*	*7/1/73*	*1.6E3*	*100*
C	*8/27/73*	*21.3*	*1.4*	*8/27/73*	*21*	*1.4*
D	*4/10/73–4/25/73*	*1070*	*72*	*4/10/73–4/25/73*	*5.0E3*	*300*
H	*4/6/73*	*1240*	*84*	*4/6/73*	*5.4E3*	*360*

The differences between NIOSH and SC&A assessments of intake and doses are caused by:

- *For Cases A and B: Different dates were assigned for the intake and New Model for HTO was used by SC&A;*
- *For cases D and H, the same dates were assigned but new model for HTO was used.*

For case C, the same dates and same intakes and doses were assigned, because the current ICRP 78 (ICRP 1997) model for HTO gives similar predictions for the H-3 excretion rates as the new one, for about 30 days after exposure.

As explained in SC&A's December 2013 paper, when a worker is exposed to HTO in several incidents, the HTO excretion rate will be dominated by the worker's most recent exposure. Sampling just after the last incident will reflect mostly the most recent exposure, hiding the ones that occurred months before the sampling. This could have happened, for example, with the exposure from Worker A, for which three different scenarios were assumed in SC&A's 2013 paper: exposure in September, mixed exposure in April and September, and exposure in the April incident. All three scenarios could be reasonably fitted with the excretion results, but the differences in doses between the worst case scenario and lower dose scenario were above three orders of magnitude.

SC&A's estimated bounding dose, assumed to be the highest possible dose, was 6,000 mrem, assigned based on an acute intake of tritium in April 2013. NIOSH's estimate of the bounding dose is 84 mrem. Some of the differences in these respective estimates are due to differences in the assumed time of intake and some of the differences are due to SC&A's use of the new tritium biokinetic model being developed by ICRP for these types of situations. Some of the large differences between these two dose estimates may be resolvable if we can reconcile the differences in the date of exposure for Case A. However, we are still left with significant differences in the doses for this case and other cases due to differences in the retention models applied by NIOSH and SC&A, given the assumed timing of the initial intakes.

With respect to retention models, we have been in a similar situation in the past when we were confronted with the issue of high-fired plutonium at RFP. At that time, ICRP had not yet developed clearance models for high-fired plutonium, and NIOSH employed the standard Type S clearance model for slowly cleared plutonium for the purpose of reconstructing doses. However, all participants involved in the analyses agreed that high-fired plutonium existed at RFP and was cleared from the lung more slowly than typical Type S plutonium, indicating that the lung doses, as reconstructed using urine analysis data and approved ICRP models, would substantially underestimate the lung doses. As a result, NIOSH developed a protocol that addresses this issue (i.e., ORAUT-OTIB-0049) to the satisfaction of all concerned. We have a similar situation here. We believe that NIOSH should adopt the new models currently under development by ICRP and apparently widely accepted by the scientific community or, alternatively, determine that these doses cannot be reconstructed with sufficient accuracy at this time. It is important to note that NIOSH did not use the current recommended ICRP intake excretion function for deriving the bounding intakes for tritium, but an IMBA modification of the model, which does not follow the currently approved ICRP model.

NIOSH states that the bounding dose is based on the bioassay results taken on September 1973, from intakes that were assumed to have occurred in April 1973:

- *…follow-up efforts were performed to validate the tritium bounding method for the SEC-00192 RFP ER (which uses information from the 1973 tritium incident as the maximum exposure scenario).*

- *ORAUT finds no evidence disputing the use of the 1973 incident data as the bounding estimate for tritium at RFP, as presented in the SEC-00192 RFP ER.*

- *The potential for tritium exposure to Rocky Flats personnel was not considered significant until an unexpected release occurred in April 1973. Because tritium monitoring was not rigorous before this event, NIOSH requested that ORAUT perform a follow-up effort to validate the tritium bounding method for the SEC-00192 RFP ER, which uses information from the 1973 tritium incident as the maximum exposure scenario.*

In reality, only the activity excreted in urine by two workers were used by NIOSH to calculate bounding intakes and doses. One of the workers submitted samples on only 3 days, with large uncertainties on those results. The second worker submitted six samples, but NIOSH used only two samples to calculate the bounding dose. The uncertainties on the results from this worker are large, because the results do not follow the expected pattern of decrease with time for both distilled and non-distilled results.

In addition, NIOSH points out on page 41 of its white paper that they have reason to believe that the date of acute intake of tritium for Case A was September 19, 1973, as opposed to April 21, 1973, as used by SC&A (see Table 1 above). NIOSH contends that this is the best estimate of the date of intake, because other cases where intakes were in April 1973 did not exhibit similar excretion rates. These intake dates are a matter of judgment that we were not able to verify. Case D, for example, worked with Case A, and NIOSH assumed in its intake assumptions that it occurred in April 1973. Hence, we are left with a situation where it is difficult to reconstruct intakes that might have occurred because of the April 1973 incident unless we can agree on intake dates and, for some of the cases, take advantage of the new biokinetic models being developed by ICRP.

2.1.2 SC&A Response to Specific NIOSH Comments

1st NIOSH Issue: The primary NIOSH response to the SC&A review is that the SC&A analysis uses a draft model that is clearly identified as not for use at this time, which is acknowledged in the SC&A response. The policy governing this program explicitly requires the use of currently approved ICRP models for the purpose of assessments and use of unapproved models is outside of the scope of the NIOSH methodology. As such, NIOSH has not performed a detailed analysis of the model as it relates to EEOICPA dose reconstruction or of the results provided by SC&A from its assessment. The general observation is that it should have very little impact on situations outside of the RFP, because it only affects cases where urine samples are collected more than 100 days after intake, which should be a rare occurrence for tritium. It is noted that the SC&A paper matched the NIOSH White Paper values when the bioassay was collected 50 or 60 days after the assumed intake. If the model is approved and issued by the ICRP, it will be reviewed for incorporation into the EEOICPA dose reconstruction program.

SC&A Response: SC&A agrees with NIOSH that the draft model published on the ICRP web for public consultation was not released yet for official use.

Notwithstanding the standing policy, NIOSH has used a model for tritium that is not the current ICRP recommendation for bioassay analysis. NIOSH's bounding intake was obtained using the concentration of tritium in urine for case H. The intake derived by NIOSH is different from the intake obtained when the current ICRP model is applied.

The current ICRP model is the one described in ICRP Publication 78 (1997), with a clarification published in ICRP 88 (2002, pg. 517), as reproduced below:

BIOKINETIC MODEL FOR TRITIUM—A CLARIFICATION

It has become apparent that there is some lack of clarity in the description of the retention and excretion of tritium in the forms of tritiated water (HTO) and

> *organically bound tritium (OBT) in Publications 56, 67, and 78 (ICRP, 1990 1993, and 1997, respectively). The following paragraphs are intended to rectify the position.*
>
> *Ingested and inhaled HTO is assumed to be translocated directly and instantaneously from the site of intake to blood without consideration of nuclear transformations in either the respiratory or gastro-intestinal tracts. From the blood activity is taken to be transferred, with a biological half-time of 0.25 days, to two whole body compartments which have biological half-times of 10 days (97%) and 40 days (3%). For bioassay purposes the activity concentration in urine is calculated by dividing the whole body activity (the activity in blood and both whole body compartments) by the volume of body water, 42 l. For dosimetric purposes, however, the activity is taken to be distributed throughout the whole body (excluding the lumen of the GI tract) which has a mass of 68.8 kg (ICRP, 1993).* [Emphasis added to highlight the bioassay model).

Table 2, reproduced from SC&A's December 2013 white paper, shows the predicted activities of tritium excreted per liter of urine for a unit activity intake of tritiated water (inhalation, injection or ingestion). It is important to note that the values in this table are the same as the ones published in the IAEA 1999 (only the first 100 days were published in the IAEA document). In addition, the values in Table 2 reproduce the ones published by C.A. Potter (2004).

Table 2. Predicted Values (Bq/L per Bq intake) for Ingestion, Injection and Inhalation of Tritiated Water, using Current ICRP Model for Tritiated Water

Time after Intake	**Activity Concentration**	**Time after Intake**	**Activity Concentration**
days	in Urine (Bq/L)		
1	2.3E-02	80	2.7E-04
2	2.1E-02	90	1.9E-04
3	2.0E-02	100	1.5E-04
4	1.9E-02	110	1.2E-04
5	1.7E-02	120	9.4E-05
6	1.6E-02	130	7.7E-05
7	1.5E-02	140	6.4E-05
8	1.4E-02	150	5.3E-05
9	1.3E-02	160	4.4E-05
10	1.2E-02	170	3.7E-05
20	6.4E-03	177	3.32E-5
30	3.4E-03	178	3.25E-5
40	1.8E-03	180	3.1E-05
50	1.0E-03	190	2.6E-05
60	6.2E-04	200	2.2E-05
70	3.9E-04		

The outcome of the NIOSH analysis is that the upper bound exposure from the incident was an intake of 1,240 µCi, calculated using the activities excreted by case H worker, 18,800 pCi/L on September 30, 1973, 177 days after the exposure date assumed by NIOSH, and 23,600 pCi/L on October 1st, 1973, 178 days after intake. Using Table 2 values above, the predicted activities excreted per liter at 177 days and 178 days after an intake of 1,240 µCi are, respectively, 41,200 pCi/L and 40,300 pCi/L. Those predicted values are much higher than the real activities excreted by the worker; i.e., 18,800 pCi/L and 23,600 pCi/L.

In conclusion, NIOSH's bounding intake calculations were not obtained using the current ICRP-recommended bioassay model for tritiated water.

The recommendation that, "**the activity concentration in urine is calculated by dividing the whole body activity (the activity in blood and both whole body compartments) by the volume of body water, 42 l [liters]**," is only valid for the activity equilibrated with body water which is retained with a half-life of 10 days. As seen in Table A.1.9 from ICRP 78 (1997), the maximum recommended monitoring interval for exposures to tritium after intakes of tritiated water is 30 days.

In addition to the recommendations on interpretation of bioassay urine activity results , the ICRP has issued a biokinetic model for tritiated water to calculate doses from occupational exposure, described in Publications 30 (1979), 54 (1989), 56 (1990) and 78 (1997), and a clarification in Publication 88 (2002). All those models are based on ICRP Publication 30 (1979).

ICRP Publication 30 (1979) and ICRP Publication 54 (1989) recommend the use of the three-component exponential function to represent the whole body retention of tritium after intakes of tritiated water, with the half-life of the 3rd component in the range of 250–550 days. Both publications suggest the simplification to a single exponential function, with a half-life of 10 days, and assuming the concentration in urine is the same as in total body water:

$$\text{Concentration in urine } Cu(t) = 1/(4200 \exp(-0.693t/10)$$

ICRP 56 (1990) recommended that the whole body retention of tritium after intakes of tritiated water could be represented by a three-component exponential function:

$$R(t)=Ae^{-0.693t/T1}+ B\, e^{-0.693/T2}+ C\, e^{-0.693/T3}$$

where T1 closely approximates to the turnover of body water in component A with a half-life of about 10 days; and components B and C represent tritium incorporated into tissue. The latter two components contribute to about 10% of the dose. For calculating the dose from tritium that entered the body as tritiated water, the three-term equation was simplified to a two-component exponential function, and T1 was calculated from the daily water balance (10 d) and T2 was calculated from the daily carbon balance (40 d).

The ICRP Publication 88 (2002) model for retention of tritium after intakes of tritiated water states that:

Ingested and inhaled HTO is assumed to be translocated directly and instantaneously from the site of intake to blood without consideration of nuclear transformations in either the respiratory or gastro-intestinal tracts. From the blood activity is taken to be transferred, with a biological half-time of 0.25 days, to two whole body compartments which have biological half-times of 10 days (97%) and 40 days (3%).

The model for tritiated water described in ORAUT-OTIB-0011 (ORAUT 2004) is very similar to the retention model from ICRP Publication 78 (1997)/88 (2002), complemented by the ICRP 78 (1997) assumption that about ½ of the total body water is excreted via urine. It is important to notice that the ICRP does not recommend the use of this model to interpret excretion rates. SC&A calculated predicted 24h excretion rates of tritium as a function of time after intake of tritiated water using this model. The model predicts that at 177 days after intake, the 24h activity of tritium excreted in urine should be 1.21E-5 of the intake, and at 178 days after the intake, 1.19 E-5 of the intake. NIOSH calculated an intake of 1,240 µCi, which corresponds to 24h excretion of 15,004 pCi at 177 days after intake and 14,756 pCi at 178 days after intake. The worker's 24h excretion was 26,320 pCi (18,800 × 1.4) and 33,040 pCi (23,600 × 1.4), respectively, assuming 1.4 L as the daily excretion of urine. Thus, NIOSH did not use the model described in ORAUT-OTIB-0011 (2004).

NIOSH has used a modification of the ICRP model for tritium by using the IMBA model for inorganic H-3, as described in *Guidance on Use of IMBA Software for DOE Safety Applications* (DOE 2006). The IMBA model is a modification of the ICRP recommended model, and there is no citation in DOE (2006) of peer-reviewed papers, using human or animal results, attesting that it is correct.

On the other hand, the draft ICRP publication contains many published references that show how well the model fits real data.

On several occasions, for example, in the derivation of doses for strongly retained plutonium in the lungs (high-fired plutonium) for RFP, when the ICRP model could not be applied, NIOSH has used alternative methods for estimating bounding doses (ORAUT 2010).

In addition to issues related to the long-term biokinetics of tritium, NIOSH calculated the bounding dose and intake using data from two workers. The tritium concentrations in urine from those two workers are not reliable for use as a reference for exposures to the tritium incident in April 1973, because of the high uncertainties on those results. The uncertainty in the results of one of the workers was recognized by NIOSH:

Case D submitted samples on only three days, although there are two results on two of those days. In one instance, one of the samples was distilled; on the other day, there is a note stating "repeated with sample channel ratio." On the latter day, the results differ by a factor of almost two;

NIOSH based the bounding intake and dose on two non-distilled samples collected from worker H. The uncertainties in the results from this worker are large, because the results do not follow the expected pattern of decrease with time for both distilled and non-distilled results.

The current ICRP model cannot be used to derive doses based on urine bioassay samples taken in September related to intakes in April. There are only two alternatives:

1. It is not possible to calculate bounding doses based on the April 1973 incident, as NIOSH claims.

2. An alternative model needs to be provided to calculate those bounding doses, using peer-reviewed literature. In addition, more reliable results from tritium activity excreted in urine are needed to calculate the bounding dose.

2nd NIOSH Issue: One of the focuses in the SC&A assessment of the NIOSH Tritium White Paper was the analysis of Case A (from the RFP evaluation of the five highest exposed individuals from the 1973 tritium release incident). It appears that the SC&A assessment results are approximately the same as the results presented in the NIOSH White Paper for Case A when the same intake assumptions are used. The similar results occur when assessing the exposures based on the ‘best fit’ of the data in the model—the best fit scenario is not disputed by SC&A; rather, the SC&A assessment offers other possible exposure situations that were not considered plausible based on NIOSH’s review.

The earlier intake date assumed by SC&A had been ruled out in the NIOSH analysis, because Case A worked with Cases [redacted for privacy] in April and they did not exhibit similar excretion levels, and Case A’s elimination pattern exhibited a less-than-10-day half-time, which is indicative of a relatively recent intake. In its review, the SC&A assessment concurs with the NIOSH assessment of Case D. However, as it relates to Case A, SC&A does not address that workers [redacted for privacy] worked together in April 1973 on the same project. When considered, there is no support for the use of the SC&A assumptions for Case A that results in the significantly higher dose totals. Further explained, the likelihood of [fewer than 9] receiving an intake of 92 mCi when co-located workers received no intake, is not plausible. NIOSH concludes that the nature of the exposure scenario does not support large differences in personnel exposure; rather, it supports the use of the NIOSH best-fit analysis.

SC&A Response: As NIOSH has stated before, Case A worked with Case D in April. NIOSH recognizes that the Case D worker was exposed in April, as NIOSH has calculated its intake based on the April exposure. Thus, as NIOSH stated before, the Case A worker was involved in the [redacted] from April 11, 1973, until April 25, 1973, along with Cases D and P. It follows that it is plausible that the Case A worker was exposed in the 1973 incident. The fact that workers exposed in the same room presented different excretion rates and had different intakes is not unusual. As NIOSH already pointed out, the Case P worker was in the same room and this worker’s excretion rate was below the action level.

In Appendix II, page 23, it is stated:

> *The report,* Investigation of the Tritium Release Occurrence at the Rocky Flats Plant *(SRDB 24165, pdf p. 16), describes a 1973 incident that prompted the site to sample a number of workers for tritium exposure. A shipment of scrap plutonium from LLNL was discovered to have been contaminated with tritium. This material was processed at the Rocky Flats Plant from April 9 to 25, 1973 in Building 779A. Because it was not immediately identified as being contaminated, monitoring of potentially-exposed individuals did not begin until late September 1973. … The five most-exposed individuals were identified and details of their potential exposures, including bioassay results, are included in the investigation report.*

On page 24, it is stated:

> *The best estimates for the five cases reviewed in Attachment A are summarized in Table A-5 below. Tritium contamination was associated with plutonium scrap material; therefore, H-3 doses will be assigned to all individuals who were monitored for plutonium in 1973. Because monitoring began several months after the potential start of exposure, the largest assessed dose (84 mrem) will be assigned.*

Table A-5: Summary of Intake Assessments for the RFP 1973 Incident

Case	*Intake Date*	*Intake (µCi)*	*Dose (mrem)*
A	*9/19/73*	*38.7*	*2.6*
B	*7/1 thru 9/25/73*	*28.1*	*1.9*
C	*8/27/73*	*21.3*	*1.4*
D	*4/10 thru 4/25/73*	*1070*	*72*
H	*4/6/73*	*1240*	*84*

As seen in Table A-5, NIOSH calculated intake and doses for Case D, considering that Case D was exposed in the April accident, when working with Case A.

In addition, the uncertainties of the bioassay results from the Case D worker are high. NIOSH points out on page 33:

> *Case D submitted samples on only three days, although there are two results on two of those days. In one instance, one of the samples was distilled; on the other day, there is a note stating "repeated with sample channel ratio." On the latter day, the results differ by a factor of almost two; the larger of these results is assumed to be the pre-distilled analysis and is used for the intake assessment.*

Also, the following is stated on page 31: "…because there are few samples and the results follow no specific pattern, there is little difference between the fits." In conclusion, Case D excretion rate results carry high uncertainties and cannot be used as proof that Case A was not exposed in the April incident.

SC&A has calculated doses from three possible exposure scenarios for the Case A worker. The differences in the assigned doses to the worker are huge: 2.7 mrem, 670 mrem, and 6,000 mrem. The uncertainties are quite high. The reason for this large uncertainty is the large delay between sample collection and the possible involvement of the worker in the April accident. As stated before by SC&A, when a worker is exposed to HTO in several incidents, the HTO excretion rate will be dominated by the worker's most-recent exposure. Thus, sampling just after the last incident will reflect mostly the most recent exposure, hiding the ones that occurred months before the sampling. This could have happened, for example, with the exposure from Case A worker. As shown by SC&A, the urine excretion rate from Case A worker fitted equally well an exposure scenario of contamination in the September bubbler accident and a scenario of high intake in the April 1973 accident, followed by additional contamination in the September incident. Other scenarios could equally fit the urinary excretion rates results. In conclusion, SC&A does not agree to rule out the April exposure from Case A worker, especially when NIOSH's proposal is to calculate bounding intakes.

SC&A reaffirms that it is not possible to rule out Case A worker's exposure in the April 1973 incident.

In view of the great uncertainties in the calculation of bounding doses, aggravated by the lack of a correct internationally accepted model for tritium workers, SC&A cannot accept that the bounding doses calculated by NIOSH are applicable to RFP tritium workers.

2.2 POST-1973 EXPOSURES

In its May 30, 2014, white paper, NIOSH contends that there is no evidence that there were any acute releases larger than that which occurred in April 1973. NIOSH cites interviews and SRDB documents (by Ref ID: 8265, 8790, 24164, 24165, 24167, 110900, 110901, and 110903) as the basis for this conclusion. The following presents a summary of the material contained in these SRDB files, focusing on that material that we believe is directly pertinent to reconstructing doses to workers associated with tritium releases that might have occurred subsequent to the large release that occurred in April 1973. Issues related to tritium releases and associated doses prior to the April 1973 incident are addressed in a separate section of this report.

There are a large number of reports presenting the results of tritium swipes, bubbler air sampling, and urine analyses, along with engineering design descriptions, that are analyzed here to the extent needed to evaluate NIOSH's conclusions with respect to this matter and also to determine the availability of data that would allow the reconstruction of tritium doses associated with releases that might have occurred following the April 1973 incident. We summarize the material contained in each SRDB folder in the order that they are cited in the NIOSH white paper, but cross-referenced between SRDB reports as required to evaluate the material and conclusions provided in NIOSH's May 30, 2014, white paper with respect to post-1973 tritium exposures. In addition, some of the material is also relevant to pre-1973 releases and the 1973 incident, and is included for completeness of our review of each SRDB document. Some of the SRDB reports cited in NIOSH's May 30, 2014, white paper are not summarized here, because they are not especially relevant to post-1973 exposures or they refer to material that has been designated as "controlled" and is not provided in the SRDB. Following the descriptions of the material provided in each SRDB folder, we present a set of itemized findings and concerns with respect to reconstructing post-1973 exposures in accordance with the recommendations provided in NIOSH's May 30, 2014, white paper.

SRDB 8265

This SRDB folder contains handwritten notes related to the 1968 incident (which were apparently captured during an interview) and a newspaper article from the Rocky Mountain News dated December 21, 1973. The article is critical of Dow Chemical Company for not reporting two tritium releases that occurred post-1968, making specific reference to an unreported tritium release at the plant effluent release point that occurred in the spring of 1973, which the article reported as between 500 and 2,000 curies. Other material in the SRDB folder cites information stating that a tritium release that had previously occurred in 1968 was about $1/400^{th}$ of the amount of tritium that is required to be reported when such releases occur.

The material in the folder also refers to a 1974 and a 1977 release of tritium, stating that the 1968 release involved several hundred curies of tritium. Also, the material indicates that for the 1973 release, it was estimated that 500 to 2,000 curies were involved, and that about 56 curies were released to liquid effluents, 100 to 500 curies were retained in tanks and ponds on the site, and the rest was released to the atmosphere via gaseous effluents.

SRDB 8790

This is an important folder with respect to pre- and post-1973 tritium releases and exposures, because it contains a report titled, "Investigation of a Tritium Release Occurring in Building 777 on September 3–4, 1974." The report explains that elevated tritium concentrations were observed in Room 452 of Building 777 and in the plenum exhaust. Normal tritium concentrations were < 1E-8 µCi/ml of air, and values of 37.7 E-6 and 1.1E-6 µCi/ml (37.7 and 1.1 $\mu Ci/m^3$) of air were observed on August 30, 1974, and September 3, 1974, respectively. The report describes follow-up investigations to determine the source of the elevated tritium levels, explaining that the investigations revealed that the release likely occurred at a downdraft table in Room 452 adjacent to a glovebox serviced by plenum 205 when a shipping container, referred to as a pressure cooker, containing tritium-contaminated plutonium was opened. The pressure cooker containing the contaminated plutonium was received at RFP on July 17, 1974, and opened on August 30, 1974. However, the report also acknowledges that the contamination might have been the result of more than one tritium-contaminated object and/or residual tritium contamination already within the glovebox system.

Exhibit 13 of the report presents tritium air sampling data collected from Room 452 beginning on June 3, 1974, and continuing on an almost daily basis until September 11, 1974 (these data are reproduced in Table A-2 of the NIOSH May 30, 2014, report). The pattern of tritium air concentrations in the room is very informative and useful for evaluating the nature of the incident. Specifically, the airborne tritium concentrations in the room are reported as about

5,000 to 20,000 pCi/m^3 up to August 29, 1973, and then on August 30, 1974, the tritium concentration in the room jumps to 37,676,609 pCi/m^3 and by September 4, 1974, is back down to the normal range. This is useful information because it can be used to estimate potential worker exposures prior to the event, as a result of the event, and after the event ended. For example, the effective dose commitment for the inhalation of tritiated water by adults is 1.83E-11 Sv/Bq inhaled, and for elemental tritium, it is 1.83E-15 Sv/Bq [See *Federal Guidance Report No. 13* (EPA 1999)]. Workers were clearly exposed to tritium, but it is not apparent how much of that tritium was tritiated water and how much was elemental tritium; the difference in the dose conversion factors between these two different forms of tritium is large (a 10,000-fold difference). The magnitude of the doses can be illustrated with the following simple hand calculations. Assuming <u>chronic</u> exposure to 10,000 pCi/m^3 of tritiated water (i.e., a typical higher end value <u>before</u> the August 1974 incident), the effective dose rate would be as follows:

10,000 pCi/m^3 × 1.2 m^3/hr × 2,000 hr/yr × 1.8E-11 Sv/Bq × 1E5 mrem/Sv × 0.037 Bq/pCi = 1.6 mrem/yr

Using the bubbler data, and the assumption that workers were exposed to the observed peak tritium concentration for 2 days, the doses can be estimated as follows:

37,676,609 pCi/m^3 × 1.2 m^3/hr × 16 hr × 1.8E-11 Sv/Bq × 1E5 mrem/Sv × 0.037 Bq/pCi = 48 mrem

In both cases, the actual exposures to workers from tritium could have been orders of magnitude smaller if most of the tritium was elemental.

Exhibit 14 in the report also presents the results of the routine bioassay program. As discussed below, in a memo dated September 12, 1974, titled "Tritium Monitoring," a tritium bioassay program was initiated that required a screening program where 1/10th of randomly selected Pu/Am urine samples will be tested for tritium. We will refer to as the 1/10 program. A review of the data reveals that the concentration of tritium in the urine of workers was above the normal "background" levels in Denver, reported as 470 pCi/L. The reported values for workers under the 1/10 program were approximately 20,000 pCi/L (ranging from 13,700 to 32,320 pCi/L) for the 10 samples provided in Exhibit 14 of the report (these values are consistent with the bioassay results provided in Table A-3 of the NIOSH May 30, 2014, white paper). The doses associated with this chronic level of tritium in urine can be approximated as follows:

20,000 pCi/L × 0.037 dis/sec-pCi × 6 keV/dis × 0.01 rad-g/erg × 1.6E-6 erg/MeV × 0.001 MeV/keV × 0.001 L/g × 1000 mrad/rad × 3.15E7 sec/yr = 2.2 mrad/yr [1]

[1] After the 1974 incident, a routine bioassay program was implemented where 10% of all workers sampled for Pu/Am were also analyzed for tritium. Table A-3 of the NIOSH white paper gives the results of that program and shows that random workers had tritium concentrations ranging from 13,700 to 32,320 pCi/L. It can be assumed that this is representative of all workers. Hence, it can be assumed that all workers experienced annual tritium doses of a few mrad/yr. As used here, we assume an mrad is equal to an mrem when dealing with internal exposure to tritium.

The report explains that, following the 1973 incident, a number of steps were taken to avoid receipt of material from other facilities contaminated with unacceptably high levels of tritium. It had evidently become apparent that material from other facilities sent to RFP for processing often contained some tritium contamination, and criteria were established for checking the material for tritium contamination, establishing acceptance criteria, and performing bioassays on at least some workers.

The report provides considerable detail describing the measurements and other investigations taken to better understand the levels of contamination, the conditions under which the contamination occurred, and the exposures experienced by the workers.

The most important part of the report, as applicable to dose reconstruction, is a description of the air sampling and bioassay programs that were in place at the time of the incident and implemented after the incident was discovered. Daily air sampling records reveal that the concentration of tritium in Room 452 remained relatively low (the concentration guideline was 5E-6 µCi/ml) and spiked for a short period of time on August 30, 1974 (37.7 $\mu Ci/m^3$, see above analysis), and on September 3, 1974 (1.1 $\mu Ci/m^3$). Urine samples were also collected from workers in Building 777 at the time, with the highest concentration being 0.3 µCi/L. The report also explains that 1 out of 10 urine samples collected from workers throughout the plant for plutonium analysis were analyzed for tritium (i.e., 1/10 screening program described above). The results of these analyses revealed that workers in other areas had tritium concentrations in urine of less than 0.01 µCi/L (i.e., 10,000 pCi/L, which corresponds to about 1.6 mrad/yr; see the above calculation).[2]

The report also summarizes the results of routine exhaust air sampling, analyses of onsite and offsite water samples for tritium, and also outdoor air sampling for tritium using silica gel. One of the important findings is that the total release to the environment from the August 1974 incident was about 1.5 Ci.

The report concludes with a number of recommendations designed to detect the possible presence of tritium before packages are opened and expand tritium surveys.

Based on its review of this document, SC&A concurs with NIOSH's conclusion that the August 1974 incident was of substantially lesser radiological consequence than the April 1973 incident. Our investigations are also consistent with the data and analyses provided in the section of the NIOSH May 30, 2014, white paper describing the events and data characterizing worker exposures to tritium post-1973 at RFP. We also find that it is likely that incidents similar to the August 1974 incident could have occurred before and after the 1973 incident and gone unnoticed. However, we note that, if the recommendations provided in the report (i.e., "Investigation of a Tritium Release Occurring in Building 777 on September 3–4, 1974") were faithfully implemented, the frequency of future incidents of this nature would likely have been substantially reduced.

[2] Note that these simple hand calculations are estimates of the doses to body water. The whole body doses would be closer to 1.0 mrem/yr if consideration is given to the fact that about 70% of the body is water, ranging from a low of 45% to a high of 75% (see Guyton 1991).

Other documents also contained in this folder include the Atomic Energy Commission (AEC) report on this incident and newspaper articles published at the time of the incident. An additional document in the package that is noteworthy is titled, *Procedure for Completing Form "Authorization to Ship SS Material."* That form establishes requirements, as of October 1973, that are to be used by facilities that ship non-routine source and special (SS) nuclear material to RFP. The form requires a thorough documentation of the source and composition of the material, including any impurities.

Another document in this SRDB folder worth noting is a memo to Mr. W.M. Lamb, Manager, Rocky Flats Area Office (RFAO), USAEC, from H.E. Bowman, General Manager, dated September 12, 1974, and titled "Tritium Monitoring" (Bowman 1974). The memo establishes requirements for tritium monitoring and action levels for follow-up investigations and decontamination. Among other requirements, this is the memo that resulted in the tritium screening program, where 1/10th of randomly selected Pu/Am urine samples will be tested for tritium.

SRDB 24164

This SRDB folder contains tritium effluent inventory reports for the 1980s. Since this information has limited applicability to worker dose reconstruction, the material was not evaluated in detail, except to note the concentration of tritium in the exhaust. For example, for a limited number of effluent samples collected in 1981, the concentrations ranged from less than the minimum detectable limit (MDL) of 50 pCi/m^3 to 216,670 pCi/m^3. The implications are that the potential for tritium exposures of workers appears to be highly variable if one assumes that the concentrations of tritium in the exhaust lines are related to the concentrations of tritium in the air where workers are located. Judgments on the significance of these concentrations can be made by using the relationship described above, where chronic exposure to a tritiated water airborne concentration of 10,000 pCi/m^3 is associated with a worker annual effective dose of about 1.6 mrem.

This SRDB folder also contains a 1976 report titled, *Estimates of Maximum Tritium Releases to the Atmosphere from Operations at Rocky Flats* (March 1976). The introduction of the report explains that routine effluent monitoring was triggered in part because of the large release of tritium (500 to 2,000 Ci) that occurred in 1973. The report explains that the total tritium released in 1975 was 1.5 Ci. The report concludes that, with the controls implemented subsequent to the 1973 incident, operations may be easily controlled to a release of less than 10 Ci/yr.

The March 1976 report certainly provides evidence that the 1973 release was an unusual one-of-a-kind release, at least subsequent to the 1973 release. In addition, it appears that considerable data are available to place a plausible upper bound on the incident that occurred in August 1974, if the data are representative of the locations of workers that opened shipping containers. One could also argue that the programs implemented in accordance with the September 12, 1974, memo likely reduced the intensity and frequency of tritium incidents, such as the one that occurred in August 1974.

SRDB 24165

This SRDB folder contains material that is duplicative of the material provided in SRDB 24164.

SRDB 24167

This SRDB folder does not contain any material, but refers the reader to controlled documents.

SRDB 110900

This SRDB folder does not contain any material, but refers the reader to controlled documents.

SRDB 110901

This SRDB folder includes a report addressing the 1973 incident and provides no new information pertinent to either the incident or post-1973 exposures to tritium.

SRDB 110903

This SRDB folder contains a report investigating elevated tritium releases that occurred in Room 154 in 1977. This is an interesting report, because it refers to a fire in a glovebox that was being used in hydride-oxidation runs. Reference is made to effluent tritium concentrations in exhaust air of 1,500 µCi/m^3. For reasons discussed above, this concentration of elemental tritium or tritiated water is of little dosimetric significance. However, the fact that RFP was handling metal tritides is of interest, because the doses associated with the inhalation of metal tritides is much greater than for tritiated water.

SRDB 111095

This SRDB file contains, among other information, what we believe is tritium bubbler air sample data collected from 1977 to 1981 for different buildings. It is difficult to determine specifically where each sample was taken, but it also appears that through further research, we should be able to determine the sample locations. We believe that this could be an important issue, because we do need assurance that the airborne tritium concentrations, as determined using the bubbler data, are representative of the airborne tritium concentration in the breathing zone of workers, especially workers involved in opening packages at the downdraft tables.

The samples appear to be taken continuously over an approximate 3-day period before the water in the bubbler is analyzed for tritium. We suspect that the analytical method employed liquid scintillation detection. The tables are simply a series of columns as exemplified by the following first row on the first readily legible page of the file:

Date On	Date off	Sample #	Volume m^3	Water	Analysis
527	5-30	201 203	8.74	125	L=10 pCi/m^3

From the headings of the tables, this example is from a sample taken in 1977 and the standard procedure was to collect the samples on Monday, Wednesday, and Friday. It appears that a total volume of air sampled over the approximate 2 or 3 day period was 8.74 m^3, the total volume of water in the bubbler was 125 ml, and the result of this analysis was less than 10 pCi/m^3 of tritium in the air over the time period and at the location where the sample was taken.

Scanning through a large number of tables (there appear to be over 1,000 pages, with some pages containing about 70 data points and others with only 15 data points), 1,490 pCi/m^3 between February 6, 1978, and February 8, 1978, was the highest observed value (we did not look at every table), with most values below 100 pCi/m^3. Again, the dosimetric significance of these concentrations is minimal, as exemplified by the above example calculations, as long as the data are representative of the concentrations of tritium in the breathing zone of workers.

SRDB 122466

There are handwritten notes in this folder from a February 5, 2013, interview with a worker (who first worked at RFP for [redacted] and then again [redacted]), indicating that tritium analysis was performed using liquid scintillation detection, because reference is made to a "scintillation cocktail" that was used to analyze for tritium in 1979 and later.

SRDB 122712

This SRDB folder contains a lab analysis report for 57 tritium bubbler samples analyzed for tritium in 1997 using liquid scintillation detection (LSD). The report presents a detailed description of the analytical methods and QC program. The results appear to indicate that all the samples were below or occasionally slightly above the detection limit of about 0.8 dpm/ml. We suspect that the 0.8 dpm/ml value refers to a ml of water in the bubbler. We are not sure how to convert this concentration in the bubbler water to airborne tritium concentration from the information provided in the file.

SRDB 111301 and SRDB 122907

These SRDB files contain similar information. Memos are provided dated October 21, 1974, stating that swipe surveys of shipping containers revealed many containers with tritium contamination. On this basis, the memo in SRDB 111301 requires that additional requirements be established with respect to non-routine SS and non-SS material. The memo requires that the shipper not only verify the tritium level of the material sent, but must also check the tritium level of the shipping container, and a statement to that effect must be affixed to the shipping form. The memo also states that this protocol must be followed until RFP develops facilities for handling tritium-contaminated shipments, which is stated as expected to be available in 1975.

SRDB 122550

This SRDB folder presents a summary of an interview with a worker who worked at RFP from [redacted]. The worker had many jobs at RFP and was able to describe operations related to opening packages where tritium exposures could have occurred. The worker explained that packages arrived as two pits in a 10-gallon drum, and both were inside a 55-gallon drum. The worker explained that two large outer drums were opened per shift, i.e., six drums per day, and that bubblers were used when the drums were opened. The worker also states that bubblers were used beginning in 1965 and no tritium measurements were made before 1965. Each 55-gallon drum was opened in a tent next to the room exhaust, and there was a bubbler positioned in front of the intake plenum of the exhaust system. The smaller drums were opened in another room, and no bubblers were used when opening the smaller drums and removing the pits and placing them in a glovebox for processing. The interviewee explained that the opening of the inner box and its transfer to the glovebox was the time when unmonitored tritium exposures could have occurred. Also, the interviewee said that no urine analyses were performed. However, bubblers were used for monitoring tritium off-gas in Room 123 of Building 777. The worker mentioned that one or two times a year, elevated tritium was observed during off-gassing. This description is consistent with the information provided on page 36 of the NIOSH May 30, 2014, white paper.

SRDB 111267

This SRDB folder contains a memo dated September 12, 1974, to Mr. M.W. Lamb, Manager, RFAO, USAEC from H.E. Bowman, General Manager, titled "Tritium Monitoring." This memo is described above under SRDB 8790.

SRDB 111288

This SRDB folder contains a memo dated September 16, 1974, from Dow Chemical personnel to R.D. Forest. The memo describes the people responsible for minimizing the potential for carrying tritium contamination from inside a line into a room. A separate memo in this SRDB folder dated September 12, 1974, presents specific action levels and protocols for handling tritium contaminated lines. These memos are only marginally applicable to the issues at hand, because they address primarily the handling of contaminated lines after the contaminating event occurred. However, the second memo also provides instructions for additional tritium monitoring in areas where employees are working. Also, action levels were set at 50,000 pCi/m^3 (5E-8 µCi/m^3). The memo also provides instructions regarding the 1/10 bioassay program described above and action levels for tritium swipe samples. This is an important memo, because it reveals that specific direction was given after the August 1974 incident to augment tritium sampling with the objective of monitoring workers, and not just assessing tritium that might have been released via effluent lines.

SRDB 8789

This SRDB folder contains a memo to William A. Lamb, Area Manager, RFAO, ERDA from R.O. Williams, Jr. Vice President and General Manager dated November 12, 1975 (75-RF-0818). The memo summarizes tritium surveillance, providing information on the quantity of tritium stored at the facility at various locations (Buildings 123, 559, 779, 881, and 991). The quantities ranged from 100 mCi to 7 Ci. The memo is indicative of the quantities of tritium at the facility at the time, which were relatively small.

SRDB 111106

This SRDB folder contains a report dated December 16, 1974, describing a tritium monitoring plan, which consisted of swipe samples inside hoods and glovebox lines, different rooms and buildings, frequency of sampling, and action levels. It also provides instructions for effluent stack sampling.

2.2.1 Observations and Conclusions Regarding Post-1973 Exposures based on Review of the SRDB Folders

1. Based on the review of the above SRDB folders, SC&A concurs that there do not appear to be any incidents post-1973 where the doses to workers could have been greater than the doses that might have been associated with the April 1973 incident. In addition, there are considerable air sampling data, and a limited amount of bioassay data post-1973, that indicate that a plausible upper bound could be placed on the tritium exposures that workers might have experienced after the 1973 incident. However, one of our concerns is whether the locations of the bubblers are representative of the airborne tritium concentrations at the locations of the potentially exposed workers. Also, one of the conclusions on page 20 of the May 30, 2014, white paper states that, "a co-worker study using data from NOCTS for 1974 and 1975 resulted in an annual dose of less than 1 mrem; therefore, no dose will be assigned for unmonitored tritium after 1973*.*" This conclusion is not consistent with the material provided in SRDB 8790, where the potential doses involved in the August 1974 incident were certainly higher than 1 mrem/yr, and it is unclear whether more than one of these incidents might have occurred. This observation also applies to the conclusion on page 22 of the NIOSH white paper that the bioassay data support a conclusion that the doses to workers from tritium for 1974 and 1975 were zero for everyone.

2. In a related matter, Table A-2 of the NIOSH May 30, 2014, report and its supporting SRDB 8790 document, provide detailed air sampling data for Room 452 related to the August 1974 release. Our question is, were there other rooms where containers were opened, and if so, are there any air sampling data, swipe data, or effluent data that demonstrate that tritium releases did not occur at those locations? It appears that Item 2, under the section titled "Comment Reponses" beginning on page 36 of the NIOSH May 30, 2014, white paper provides information pertaining to this issue, but it is not clear that there is a high level of confidence that exposures to tritium associated with opening containers can be characterized and bounded.

3. The NIOSH conclusion regarding doses post-1973 being less than 1 mrem/yr is likely based on the 1/10 bioassay program, but it is not apparent that the workers included in the bioassay program were bioassayed at a frequency that would have detected an incident. In addition, there are questions regarding the locations of the bubblers with respect to the degree to which those data are representative of the airborne tritium concentrations where workers might have been exposed to tritium. There are a substantial number of smear samples, but it is not apparent that the results of smear samples could be used to validate the conclusions that exposures to workers post-1973 were less than 1 mrem/yr.

4. Another concern we have regarding the post-1973 air sampling data is we did not find any reports that used two bubblers in series to confirm the efficiency of the bubbler for collecting tritium. We note that the efficiency of bubblers can be affected by humidity, the flow rate of air through the bubbler, and how long the bubbler is on line before analysis. Some discussion of bubbler efficiency is required.

5. Drawings of the bubbler are provided in SRDB 122779 and 122791, and handwritten notes from an interview that discusses the location of the bubblers is provided in SRDB 122466. With respect to bubbler location, the notes in these SDBRs state that, "prior to 1980, bubbler contents from exhaust plenums went to 123. … In early 80's (81 or thereabouts) they put a bubbling unit where components were disassembled." The implications of these statements are that, prior to 1981, the bubblers may not have been placed in the optimum location for providing data useful for dose reconstruction. This matter requires further investigation and discussion.

6. We would also like to hear more about the handling of metal tritides at the facility and the exposures associated with incidents, such as the incident that occurred in 1977 in Room 154 where metal tritides might have been involved.

7. Table 1 of the NIOSH white paper presents a thorough summary of the reports addressing bubblers, but not bubbler efficiency. However, Table 1 of the white paper does confirm that a substantial amount of airborne tritium concentration data was collected following the 1973 incident that might be useful in reconstructing potential tritium exposures to workers post-1973 if they were located where workers might have been exposed to tritium. We would like to reiterate the need to address bubbler location.

8. Page 22 of the NIOSH white paper concludes that the doses after 1975 should be assigned as zero for the same reasons given for 1974. We are concerned with this conclusion for the same reason as given above regarding 1974 exposures.

9. Page 40 of the NIOSH May 30, 2014, white paper explains why zero dose is being used as a coworker tritium dose for workers in 1974 (provided in response to a question posed by Dr. Ziemer). For the reasons discussed previously, we believe the basis for assigning zero doses to workers in 1974 and also 1975 is not well founded because of uncertainties with respect to where the bubblers were located relative to the breathing zone of the workers, and also the very limited amount of bioassay data collected under the 1/10 program.

2.3 PRE-1973 EXPOSURES (APPENDIX 1, PART I)

As observed in the NIOSH May 30, 2014, white paper (Part I) and in the preceding June 25, 2013, paper, which it repeated:

> *Several factors single out the 1973 tritium release as bounding for the entire history of Rocky Flats operations. These factors include the large quantity of tritium involved, the chemical form of the released tritium, and the meteorological*

> *conditions at the time of release. Other documented releases involved smaller quantities of elemental tritium, having a much smaller dose conversion factor than the tritium oxide released in 1973. Bounds for personnel tritium exposures after the 1973 release can be developed based on measurement results, since personnel bioassay, air sampling, and workplace contamination monitoring for tritium became more common after that release.* ***There are only very limited tritium measurement results prior to 1973 because tritium was not perceived as a radionuclide of occupational or environmental interest at Rocky Flats. Bounding tritium exposures for the pre-1973 period are more difficult to develop as a result of this lack of measurement data.*** [Emphasis added]

Given the lack of useable tritium characterization and release data for the pre-1973 period, NIOSH has proposed to apply data from the only fully documented tritium release from a shipping container at RFP, a release that occurred on August 30, 1974, at one of the production facilities. The underlying assumption for retrospective use of this data is that the release is representative of such container releases throughout the pre-1973 RFP operating history, and can be considered bounding of all such releases in terms of source term and potential worker exposure. Based on air sampling and bioassay data collected at the time, NIOSH concludes that the resulting dose from the 1974 release would be less than 1 mrem (0.15 mrem), which translates into an annual occupational dose of 37.5 mrem/year, assuming one such incident per day for 250 days per year.

To support its use of the 1974 data in a retrospective application prior to 1973, NIOSH has highlighted six key supporting factors, which SC&A has already addressed in its 2013 white papers, and offers the following re-evaluation given the reissued June 2014 white paper.

1. **NIOSH (excerpt):** Background tritium levels immediately prior to the incident described in the RFAO report, although undoubtedly elevated since the more significant 1973 release, were well below dosimetrically-significant values and can be considered as fairly representative of typical background levels for this analysis [taken to be less than 1 mrem per year based on background measurements made prior to the 1974 event].

   SC&A Response: SC&A agrees that the background for tritium was very low at RFP, even after the 1973 event. However, it is not clear what the baseline background level would have been for tritium within the affected production facilities. For example, a contemporary assessment of the 1974 release by Boss and Hobbs (1974) notes that given that a "specific cause of the tritium release could not be absolutely determined…" it was possible that "tritium contamination residing in glovebox lines, exhaust and supply plenums from the previous major tritium incident in 1973 cannot be totally discounted as the cause or at least being contributory." It is further noted that "elevated room air concentrations of tritium were detected in the special assembly area of Building 776/777, although these elevated concentrations could not be related specifically to the time period of the effluent air releases." The authors go on to note that "cross-contaminated sampling apparatus, resulting in the loss of data, points to the extreme care that must be exercised to obtain valid sample results." These findings are supported in the RFAO investigation report (RFAO 1974), which notes that:

> *Exhaust from the Special Assembly Glovebox Line in room 452* [the one implicated in the release] *is currently handled by plenum 206. However, during the period from February 11–August 7, 1974, exhaust air from* [this line] *temporarily was exhausted through plenum 205 because of the construction of new plenum 206. Therefore, exhaust air from* [this line] *contributed to significant tritium contamination within both exhaust plenums 205 and 206.*

Under the circumstances detailed in SRDB 24165 and SRDB 8790, with confirmed tritium contamination in the facility and significant cross contamination in exhaust lines, a valid determination of background workplace tritium levels for the 1974 event is difficult to establish, although the annual background dose involved would undoubtedly remain in the lower mrem range.

2. **NIOSH (excerpt):** The quantity of tritium released (1.5 Ci) was significantly less than that released in 1973, and is probably more typical of potential undocumented releases in work areas – particularly those resulting from opening contaminated shipping containers. Because NIOSH has only identified six documented releases from 1968-1974 (an average of 1 per year), the application of a daily release would be a significant/bounding overestimate of the number of RFP tritium releases.

   SC&A Response: While the actual quantity of tritium released from the containers in question (versus from residual systems contamination) is seriously open to question (see SRDB 24165), the magnitude of the release is clearly less than that of the 1973 event. Whether it was "typical" of historic (pre-1973) handling of shipping containers is more conjectural, given the lack of pre-1973 radiological monitoring and controls, paucity of actual measurements and their reliability, and interview accounts of opening containers without the benefit of nearby tritium monitoring or active ventilation (see SRDB 122550). It is also clear that RFP accepted both "SS" containers from Pantex and "non-SS" containers from elsewhere in the AEC complex, and that the containers themselves arrived contaminated. For example, the 1974 event involved non-SS shipped parts from Battelle Northwest Laboratory, in which one of the containers had contamination that actually exceeded the parts contained in it, suggesting that it remained in use contaminated.

   While this may lead one to assume that 1.5 Ci could be an overestimate given this degree of uncertainty over source term, it also brings into question the validity of using the 1974 release source term as "typical" or representative of all pre-1973 tritium contamination releases from SS and non-SS containers received at RFP from a range of weapons complex sites, including Savannah River Site (SRS), Hanford, Los Alamos National Laboratory (LANL), Lawrence Livermore National Laboratory (LLNL), Pantex, and Burlington.

3. **NIOSH:** Tritium was released to the workplace environment, and not in a glovebox.

   SC&A Response: While it is true that in both cases (pre-1973 and 1974 events) tritium was released to the workplace environment, the exposure conditions were widely different. This is backed up by an interview with a knowledgeable operations worker who noted that they had followed a two-step procedure for opening pit containers at RFP (see SRDB 122550). The containers consisted of two pits apiece packed in 10-gallon cans, which were themselves packed inside of a 55-gallon drum. Two of the 55-gallon drums were opened per shift for a total of 6 drums for the 3 RFP operating shifts per day. The opening of these outer drums was apparently performed in a tent near a room tritium bubbler adjacent to an exhaust plenum. However, the inner containers were subsequently opened in another room without the benefit of an alarming bubbler with a clear exposure potential to any tritium contamination as the pits were manually moved from the inner cans to the glovebox entry port. This interviewee and other workers confirmed that no one was monitored for tritium before 1973, with smearing limited to alpha smears of surfaces, alpha monitoring of any loose contamination, and gamma and neutron monitoring of the inner cans and pits (a handheld tritium "sniffer" was available for non-routine use). It was confirmed in this and other interviews that tritium bubbler alarms occurred a few times a year, although actual breathing zone measurements or room contamination levels were never established.

   As noted in SRDB 8790, the pressure cooker containers were opened over a downdraft table with workers following a formal bag out procedure requiring that the operators wear protective clothing, a full mask respirator, and several pairs of surgeons' gloves, all of it monitored by scintillation-based air samplers located nearby. Prior to 1973, pit returns were handled without respiratory protection, without monitoring (during the second step), and without active local ventilation (second step).

4. **NIOSH:** The release involved elemental tritium (HT, T2), and not tritium oxide (HTO).

   SC&A Response: It is clear that tritium oxide (HTO) is of greater dosimetric concern, and that the circumstances of the 1973 release (involving hydriding and flame oxidation) accentuated its formation. However, the presence of the hydriding operation at RFP (it was one of two process lines involved with site returns, with the other being an acid dissolution process, during which no hydrogen was generated, therefore, obviating the need for flame oxidation), the acceptance of both SS and non-SS containers of various weapons complex origins (and therefore, tritium in both forms cannot be ruled out), and the receipt of pits, parts, and other materials that had residual tritium contamination of unknown origins, raises doubt that all contamination at RFP before 1973 only involved elemental tritium. In fact, SRDB 24165 even suggests that the shutdown of the ventilation air dryer in the RFP production facilities the week before the 1974 release, coupled with abnormally high humidity at RFP, may have contributed to the tritium contamination in the process lines, suggesting the formation of HTO.[3] It seems clear that the 1974 event involved an unknown mixture of elemental tritium gas and HTO.

One interviewee (SRDB 22629) noted that while RFP had, in the past, processed similar parts before from the Lawrence Livermore Laboratory (LLL) operation responsible for the 1973 release, the unique meteorological conditions at the time (heavy snow) may have been the difference in the environmental contamination experienced. The interviewee, a knowledgeable [redacted], offered that he believed that RFP might have had other such releases [that were not detected]. The use of the hydriding process with flame oxidation for parts contaminated with tritium would have led to the generation of HTO—it just would not have been easily detected in the environment without the meteorological inversion and participation experienced in 1973, and the offsite sampling that took place then.

5. **NIOSH:** The tritium was released from a contaminated shipping container, which was procured by RFP in 1970 and can be taken as representative of shipping containers in use prior to 1973.

   SC&A Response: As noted earlier, while the container may have been an RFP prototype, it contained assorted parts from Battelle Northwest Laboratory (BNWL), and had residual contamination (in one container) that was higher than the parts inside, suggesting a prior contamination source. The two containers in question during the 1974 release were of the "pressure cooker" variety, which were not typical of most of the containers in routine use at RFP before 1973. During that timeframe, most of the potentially contaminated materials consisted of returned pits from Pantex and Burlington, which were overpacked (as described above) in an outer 55-gallon drum and within an inner container, and were only smeared for alpha contamination prior to opening.

6. **NIOSH:** The incident occurred close enough in time to the 1973 tritium release that work practices and controls were likely more similar to those prior to 1973 than to those even a year or two later, as procedures and controls evolved with greater sensitivity to the potential for tritium contamination.

   SC&A Response: The fact that the two "pressure cooker" shipping containers were opened on a downdraft table by workers in protective clothing with full-face respirators with nearby active tritium scintillation monitoring and readily available worker bioassay clearly separates the 1974 event from the RFP operating and monitoring practices of the pre-1973 era. As noted earlier, containers with returned Pantex pits (the vast majority of containers handled) were opened by hand, with limited ventilation, in a two-step process where only the first "opening" was covered by an alarming tritium bubbler located on an exhaust plenum [and this monitoring practice, itself, only began in the late 1960s, according to expert interviews (see SRDB 122515, 122625, 122550)], with the second

[3] As pointed in the RFAO investigation report (SRDB 8790), "moisture is one known means of releasing tritium from surfaces on which it is absorbed, as it readily exchanges with the hydrogen atoms associated with water molecules."

inner can opening conducted without any monitoring and negative exhausting, as the pit was moved by the handler into the glovebox port.

The new post-1973 approach for controlling tritium at RFP is evidenced in the October 5, 1973, procedures (Putzier 1973) that were issued to "express the generalized philosophy and approach to be used by Health Physics Operations in making recommendations for tritium contaminated items." These procedures provided action levels for contamination smear results, protective clothing requirements (including supplied air hood), and work planning.

As further noted in the RFAO investigation report (SRDB 8790):

> *Following the 1973 tritium incident, procedures were established to prevent the receipt of any tritium*[-]*contaminated SS material from being sent to Rocky Flats. The procedures apply to all non-routine shipments (excludes site returns from Pantex and Burlington) and requires the shipper to provide a material history and identification of any radioactive contamination.*

Therefore, procedures were in place for the containers in question in 1974 that included shipment certification, respiratory protection, smearing, container "sniffing,"[4] air sampling, and event-driven bioassay, versus a single exhaust plenum bubbler for pre-1973. SC&A finds these work practices and controls to be dissimilar between 1974 and pre-1973.

Conclusion: SC&A concludes that use of the 1974 tritium release to bound all pre-1973 container releases is not valid for the following reasons, as previously discussed:

- The radical difference in the containers handled ("pressure cookers"), source term involved (BNWL parts), ventilation ("downdraft table"), air monitoring (room air samplers), and radiological controls (personnel monitoring, protective clothing, respiratory protection, work planning) makes the 1974 event not representative of the vast majority of pre-1973 container handling at RFP, which consisted of standard pit containers, Pantex returned pits, no local ventilation, an alarming tritium bubbler at a room exhaust plenum (only after late 1960s), and little personnel protection.

- The source and composition of the tritium released is also in doubt, given the detected presence of tritium, prior to the August 30, 1974, release in the facility glovebox lines, and exhaust and supply plenums, which pointed to cross-contamination from residual tritium sources related to the 1973 event, not solely the containers in question. Likewise, the presence of HTO outside of the 1973 event cannot be discounted, given the unusual environmental and operational conditions at the time of the 1974 release, nor can it be

[4] It is noteworthy that the pressure cooker containers involved in the 1974 event were to have been monitored by a tritium "sniffer" prior to handling, but were not because the contractor had suspended such monitoring due to increasing uptake of tritium by the radiological technician responsible for conducting it for all arriving containers.

discounted given the historic pre-1973 use of hydriding processes involving flame oxidation on previously received components.

While the 1973 release is undoubtedly the largest in RFP history, the 1974 event cannot be considered bounding of all pre-1973 container releases, given the inability to demonstrate that it is sufficiently representative of the conditions under which those releases took place. This is coupled with the source term issues and questionable sampling data that stemmed from the release, bearing on whether the parameters being used are sufficiently accurate for this critical application. The 1974 release offers a relatively substantial container release coupled with comprehensive tritium measurements and bioassay results stemming from upgrades made in the aftermath of the 1973 event. However, if it cannot be sufficiently normalized with the 15 years of prior operations involving returned pits, it becomes a “large” number for bounding purposes with insufficient relevancy to the historic operations involved.

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