Draft

ADVISORY BOARD ON
RADIATION AND WORKER HEALTH

National Institute for Occupational Safety and Health

RESPONSE TO NIOSH'S REVIEW OF SC&A'S NEVADA TEST SITE RESUSPENSION ISSUES STATUS REPORT

Contract No. 211-2014-58081
SCA-TR-2016-SP010, Revision 0

Prepared by

Lynn Anspaugh, PhD

SC&A, Inc.
1608 Spring Hill Road, Suite 400
Vienna, Virginia, 22182

Saliant, Inc.
5579 Catholic Church Road
Jefferson, Maryland 21755

December 2016

SC&A, INC.: ***Technical Support for the Advisory Board on Radiation and Worker Health Review of NIOSH Dose Reconstruction Program***

DOCUMENT TITLE:	Response to NIOSH's Review of SC&A's Nevada Test Site Resuspension Issues Status Report
DOCUMENT NUMBER/ DESCRIPTION:	SCA-TR-2016-SP010
REVISION NO.:	0 (Draft)
SUPERSEDES:	N/A
EFFECTIVE DATE:	December 21, 2016
TASK MANAGER:	Arjun Makhijani, PhD [signature on file]
PROJECT MANAGER:	John Stiver, MS, CHP [signature on file]
DOCUMENT REVIEWER(S):	John Mauro, PhD, CHP [signature on file] John Stiver, MS, CHP [signature on file]

Record of Revisions

Revision Number	Effective Date	Description of Revision
0 (Draft)	12/21/2016	Initial issue

TABLE OF CONTENTS

ABBREVIATIONS AND ACRONYMS

ABRWH	Advisory Board on Radiation and Worker Health
Am	americium
Be	beryllium
Bq	becquerel
CF	correction factor
Ci	curie
Co	cobalt
Cs	cesium
DOE	U.S. Department of Energy
ER	evaluation report
ET	extra-thoracic region
Eu	europium
HHS	U.S. Department of Health and Human Services
IMBA	Integrated Modules for Bioassay Analysis
LN	lymph node
MDA	minimum detectable activity
MeV	mega-electron volt
mR	milliroentgen
NIOSH	National Institute for Occupational Safety and Health
NRDS	Nuclear Rocket Development Station
NTS	Nevada Test Site
ORAUT	Oak Ridge Associated Universities Team
ORERP	Off-Site Radiation Exposure Review Project
OTIB	ORAUT technical information bulletin
pCi	picocurie
Pu	plutonium
RIDP	Radionuclide Inventory and Distribution Program
SEC	Special Exposure Cohort
Sr	strontium
SRDB	Site Research Database
TBD	technical basis document

TH	thoracic
U	uranium
WG	Work Group

1.0 INTRODUCTION

SC&A, Inc., has had an ongoing task to assist the Advisory Board on Radiation and Worker Health (ABRWH) and its Nevada Test Site (NTS) Work Group (WG) in evaluating site-profile (also known as technical basis documents [TBDs]) and other issues related to the NTS. This process began with SC&A's (2005) review of the initial (2004) versions of the National Institute for Occupational Safety and Health (NIOSH)/Oak Ridge Associated Universities Team (ORAUT) six-part TBD. The many issues discussed by SC&A (2005) were summarized in an issue-resolution matrix (SC&A 2006).

Over the years, many of the original issues have been resolved through the addition of two classes of employees to the Special Exposure Cohort (SEC) and by improvements in the NTS site-profile documents (or TBDs). SEC Petition No. 55 was approved and became effective on July 26, 2006, for NTS workers from January 27, 1951, through December 31, 1962, who worked an aggregate of at least 250 work days (HHS 2006). SEC Petition No. 84 was approved and became effective on May 5, 2010, for NTS workers from January 1, 1963, through December 31, 1992, who worked an aggregate of at least 250 work days (HHS 2010). SEC Petition No. 84 did not have an easy path to approval. The *initial* petition evaluation report (NIOSH 2007) was against approval. After extensive discussions among persons from the NTS WG, NIOSH, ORAUT, and SC&A, the NTS WG (ABRWH 2009b) voted to recommend that the ABRWH approve SEC Petition No. 84. The *final* NIOSH evaluation report was in favor of approval (NIOSH 2010) and was forwarded to the members of the ABRWH. The members of the ABRWH unanimously approved SEC Petition No. 84 (ABRWH (2010).

The technical volumes of the NTS site profile (TBDs) have undergone as many as three revisions. At the June 2012 meeting of the ABRWH, SC&A was tasked with updating the NTS issue resolution matrix. The matrix, along with extensive discussion, was published as SC&A (2012). Twenty-six issues were identified in this update; some, but by no means all, of the issues were noted to have been closed by the granting of the SEC petitions or by other means. One outstanding issue was Issue 5 related to resuspension, and it was noted that several other matrix issues depended on resolution of Issue 5.

The most recent meeting of the NTS WG (ABRWH 2014) was held on December 3, 2014, with the goal of resolving the matrix issues. Several of the issues were closed, but Issue 5 on resuspension could not be closed satisfactorily and it was again noted that several issues depended on the resolution of Issue 5. SC&A was tasked with reviewing the resuspension issue and the information on that subject contained in Revision 03 to the occupational environmental dose volume of the NTS site profile, ORAUT-TKBS-0008-4 (ORAUT 2012). A general conclusion has been that it is not possible to consider resuspension issues related to persons actively working in dust-enhancing conditions (such as running a bulldozer), but it would be necessary to concentrate only on general dust loading in the absence of worker-specific activities. It was also concluded that these general resuspension issues could be treated only for the time period after the cessation of atmospheric testing.

The continuing concern about resuspension and other issues remains despite the approval of SEC Petitions 55 and 84. But it is understood that any procedures of dose reconstruction are meant to apply only to claimants who do not meet the criteria for inclusion in the SEC. The primary area of application would be for claimants who do not have presumptive diseases that would automatically enroll them in the SEC.

SC&A published its latest status report on resuspension issues in July 2015 (SC&A 2015). Eight comments (issues) were identified, which are discussed in detail below. NIOSH (2016) responded with replies to the eight comments; further, NIOSH produced “white papers” on Comment 5 (Strenge 2016) and Comment 8 (Rollins 2016).

The purpose of this current report is to discuss the responses received from NIOSH and its contractors with a goal of finding a clear path to closure of the resuspension issue. SC&A will conclude the discussion of each comment with a clear recommendation to the members of the NTS WG.

Finally, SC&A notes that there are several other issues in the NTS issue matrix that have not been resolved (ABRWH 2014) and will not be resolved with the closure of the resuspension issue. SC&A has not been tasked to consider any issue other than resuspension.

2.0 SC&A COMMENTS ON NEVADA TEST SITE RESUSPENSION ISSUES

2.1 COMMENT 1

2.1.1 SC&A (2015) Original Statement as Taken from the Executive Summary, Part 1, page 7

On Page 12, Section 4.1.2 of the TBD (ORAUT 2012), the following statement is made:

> *"Therefore, dose reconstructions for individuals employed at NTS during the period from 1951 through December 31, 1992, but who do not qualify for inclusion in the SEC, can be performed using these data as appropriate."*

We have concern with this statement because the TBD actually provides a protocol for reconstructing the internal doses from resuspension of radionuclides from January 1, 1963, through December 31, 1992. This statement should be corrected.

2.1.2 NIOSH (2016) Response, Part 1, page 1

NIOSH agrees that additional clarification should be added to ORAUT-TKBS-0008-4 (the NTS environmental TBD) to instruct dose reconstructors to include environmental inhalation and ingestion intakes as prescribed in Sections 4.2.1.2 and 4.2.2, respectively, beginning on January 1, 1963.

2.1.3 SC&A Resolution Comments, Part 1

It is clear that occupational environmental dose cannot be reconstructed back to 1951, although that might have been the original intent. A more important question (also addressed below for Comments 2 and 5) is whether occupational environmental dose should be extrapolated back to July 1962. The method specified in ORAUT (2012) is based on measurements of concentration of plutonium in air starting in 1971 and measurements of radionuclides in soil in the 1980s with extrapolation of air concentrations back to January 1, 1963, based on a time-dependent resuspension model. A stated goal has been to calculate occupational environmental dose back to the end of atmospheric testing, which ended on July 17, 1962 (DOE 2000). Thus, there is no reason why this method cannot be applied back to the period when atmospheric testing ended.

2.1.4 SC&A (2015) Original Statement as Taken from the Executive Summary, Part 2, pages 7–8

We also have a concern with the following statement made in Appendix A of the TBD:

> *"If an internal exposure was suspected, bioassay was performed. Managing radioactive material in the form of devices was episodic*

> *and limited to a few workers (e.g., radiation safety and industrial hygiene personnel, miners, and experimenters). These workers are identified on the rosters that were published before the event, and these workers are likely to have bioassay results in the DOE records."*

It is our understanding that an SEC was granted in part because there were inadequate bioassay data and many employees were exposed in situations where there were no rosters, thereby precluding the ability to develop a co-worker model. This topic was discussed thoroughly during the NTS WG meetings on October 29, 2008 (ABRWH 2008); April 23, 2009 (ABRWH 2009a); and December 15, 2009 (ABRWH 2009b).

2.1.5 NIOSH (2016) Response, Part 2, page 1

NIOSH agrees and will make the following change to the Attachment A text:

"These workers are usually identified on the rosters that were published before the event, and these workers are likely to have bioassay results in the DOE records."

2.1.6 SC&A Resolution Comments, Part 2

The NIOSH response about workers on rosters being likely to have bioassay results in the U.S. Department of Energy (DOE) records is directly contradicted by NIOSH's own *final* analysis of SEC Petition No. 84 (NIOSH 2010, page 68):

> *Upon completion of this review, there are still remaining data gaps and concerns associated with NTS internal monitoring data that bring into question NIOSH's ability to bound all NTS internal exposures. NIOSH believes that there is insufficient information to adequately support bounding internal dose (reconstructing internal dose with sufficient accuracy) for the portion of the SEC-00084 NTS class who worked during the period of testing from 1963 through 1992.*

2.1.7 SC&A Recommendations to the Nevada Test Site Work Group

1. Change the time period for the reconstruction of occupational environmental dose to July 17, 1962, through December 31, 1992. The same method can be used as NIOSH is now doing for a start period of January 1, 1963. Such a change would be substantively more claimant favorable and can be performed using scientifically valid methodologies for time periods that extend back to the latter half of 1962.

2. Change the statement about rosters and bioassay results to a more valid statement:

   > "These workers may have been identified on the rosters that were published before the event, and these workers may have had bioassay results in the DOE records."

2.2 COMMENT 2

2.2.1 SC&A (2015) Original Statement as Taken from the Executive Summary, Part 1, page 8

A method for analyzing chronic environmental exposures associated with resuspension processes is provided for the time period beginning in January 1, 1963, approximately 6 months after the "last above ground test."[3] *Inspection of the Anspaugh et al. (2002) resuspension-factor equation reveals that by 180 days after deposition, the resuspension factor drops down to about 5×10^{-9}/m. For earlier times, closer to the end of above ground testing, the resuspension factors, according to the Anspaugh model, are orders of magnitude greater. SC&A believes that it is possible to back extrapolate the dose reconstruction to mid-1962, at the end of above ground testing. Such calculations would be more complete and will likely reveal substantially higher doses from resuspension during that 6-month period. The intended time period of coverage for these calculations should be discussed and agreed upon with the members of the NTS WG. There is no reason that the important time period of July 1962 to December 31, 1962, is not included in the material in the TBD….*

[3] ORAUT (2012) repeatedly refers to Small Boy (July 14, 1962, "low" yield) as the last above ground test. Actually, the last above ground test was Little Feller I (July 17, 1962, "low" yield). Other above ground, surface, or cratering tests during the month of July 1962 were Sedan (July 6, 1962, 104 kt, fission yield less than 30%); Little Feller II (July 7, 1962, "low" yield), and Johnnie Boy (July 11, 1962, 500 t). Sedan and Johnnie Boy were cratering events. The Sedan event was the most important event in terms of release of radionuclides. The event data are taken from DOE (2000).

2.2.2 NIOSH (2016) Response, Part 1, page 2

The evaluation report for SEC-00055 (SRDB Ref ID: 150574) [NIOSH 2006], which covers the time period of 1/27/51 – 12/31/62, specifically discusses the inability to reconstruct doses between the cessation of testing in July of 1962 and the end of that year. The last paragraph of section 4.5 states:

> *"Above-ground testing at the NTS began on January 27, 1951, and concluded on July 17, 1962. NIOSH considers reconstruction of internal doses at the NTS feasible for periods after cessation of atmospheric testing beginning on January 1, 1963. During the period of atmospheric testing, the source term to which workers were exposed changed with each detonation, due mainly to re-suspension and mixing of fallout caused by the blast waves. After the final above-ground test, NIOSH considers the radiological source term to be sufficiently stable so as to allow assumptions adequate for dose reconstruction. The extension of the SEC period through December 31, 1962, approximately six months after the last atmospheric test, allows time for the stabilization of*

the source term and for decay of the shorter-lived radionuclides associated with the final atmospheric tests."

In addition, the ER for SEC-0084 (SRDB Ref ID: 77699) [NIOSH 2007] describes a model for the reconstruction of environmental internal doses beginning on 1/1/63. Thus, the ERs for the SECs are clear on the time period for which environmental doses can be reconstructed.

2.2.3 SC&A Resolution Comments, Part 1

In the comments above, NIOSH has relied on the evaluation report (NIOSH 2006) for SEC Petition 55 and the *initial* evaluation report (NIOSH 2007) for SEC Petition 84. Each of these two reports indicated that NIOSH had the ability to reconstruct internal dose beginning from January 1, 1963, through December 31, 1992. However, the *final* evaluation report (NIOSH 2010) found that NIOSH could not reconstruct internal dose from January 1, 1963, through December 31, 1992, and SEC Petition 84 was approved. Thus, the conclusion that internal dose could not be reconstructed was valid for January 27, 1951, through December 31, 1992, and there is no longer a dividing line at January 1, 1963. The real question then becomes, "Where is the logical dividing line for the reconstruction of occupational environmental dose?" It seems clear that this dividing line should be the end of atmospheric testing, as frequently suggested in ORAUT (2012).

As the method in ORAUT (2012) <u>is just as applicable back to July 1962 as it is back to January 1, 1963</u>, failure to calculate occupational environmental dose back to July 1962 would be unfair to claimants who worked during the latter half of 1962.

2.2.4 SC&A (2015) Original Statement as Taken from the Executive Summary, Part 2, page 8

Further confusion on this point arises from the following statement on Page 42 of the TBD under Instruction to Dose Reconstructors:

> *"With the exception of cases that can be worked using the bounding assumption in ORAUT-OTIB-0018 (ORAUT 2005* ["OTIB-0018"]*), environmental inhalation and ingestion intakes listed in Tables 4-7 and 4-11, respectively, shall be applied starting in 1964."*

OTIB-0018 seems to be an inappropriate reference within the context of outdoor chronic exposures at the NTS. OTIB-0018 is more appropriately employed indoors at sites that have a comprehensive health physics and airborne monitoring program, which is not the case for the NTS.

2.2.5 NIOSH (2016) Response, Part 2, page 3

The referenced exception does not infer that OTIB-0018 intakes would be applied instead of environmental intakes. OTIB-0018 intakes are typically applied as an efficiency method to obviate the need to assess negative (less than MDA) bioassay

> *data for non-compensable cases. When OTIB-0018 intakes are applied, the addition of environmental intakes is unnecessary because the OTIB-0018 intakes envelope the environmental intakes.*

NIOSH also recently provided two white papers on this subject. Strenge (2016) addresses Comment 5 (discussed in Section 2.5 below) but also includes the same information as above as to why the start time for the reconstruction of occupational environment dose should be January 1, 1963. Rollins (2016) addresses Comment 8 (addressed by SC&A in a memorandum dated December 16, 2016) and includes NIOSH's justification for using OTIB-0018.

2.2.6 SC&A Recommendations to the Nevada Test Site Work Group

The recommendation to extend the period of reconstruction of occupational environmental dose to July 17, 1962, is already Recommendation 1 under Comment 1.

Comments and recommendations about the use of OTIB-0018 are addressed in SC&A's (2016) memorandum about Comment 8.

2.3 COMMENT 3

2.3.1 SC&A (2015) Original Statement as Taken from the Executive Summary, Part 1, page 8

> *It is important that the time period to be covered be carefully considered by the members of the NTS WG. SC&A believes that the logical time period to be covered is July 1962 through December 31, 1992.*

2.3.2 NIOSH (2016) Response, Part 1, pages 3–4

> *See response to Issue 2 above.* [Regarding the July 1962 start date]

2.3.3 SC&A (2015) Original Statement as Taken from the Executive Summary, Part 2, pages 8–9

> *The method of environmental occupational dose reconstruction is strongly based upon measurements of the concentrations of Pu-239/240 in air samples starting in 1971. SC&A was originally concerned that the air-sampling locations were not representative of the locations where workers were exposed. We originally detailed these concerns in the Anspaugh report dated October 21, 2008 (Anspaugh 2008). At that time, these concerns were based on the assumption that our interest was in "active environments" where operational activities were ongoing. However, within the context of using these air-sampling data as a means to characterize airborne Pu-239/240 concentrations during relatively quiescent conditions, referred to as chronic environmental exposure, these concerns are greatly diminished. It is important to note that the current scope of dose estimation from residual radioactivity is limited to environmental dose not associated with work activities. Exposure during work-related activities that disturb soil is not included within the scope of the TBD.*

2.3.4 NIOSH (2016) Response, Part 1, page 3

NIOSH agrees with this observation.

2.3.5 SC&A Recommendations to the Nevada Test Site Work Group

The recommendation to extend the period of reconstruction of occupational environmental dose to July 17, 1962, is already Recommendation 1 under Comment 1.

2.4 COMMENT 4

2.4.1 SC&A (2015) Original Statement as Taken from the Executive Summary, page 9

The soil radionuclide inventory data collected in the 1980s by the Radionuclide Inventory and Distribution Program (RIDP) (Kordas and Anspaugh 1982; McArthur 1991) characterized soil contamination at the site during the 1980s. However, the TBD extrapolates back in time to derive the soil contamination levels that were present on January 1, 1963,[4] so that doses could be reconstructed from the resuspension process during early years following the end of aboveground testing. One of the limitations of the back extrapolation process used in the TBD is there is evidence that some areas were decontaminated (McArthur 1991, p. 34) before the RIDP measurements were made. Also, significant contamination occurred in Areas 20 and 30 from Plowshare activities after 1963, and the Baneberry event in 1970 produced major contamination in Areas 8 and 12. These concerns need to be addressed in terms of the degree to which the TBD remains scientifically sound and claimant favorable, notwithstanding these events….

[4] SC&A believes that this back extrapolation should be to July 1962.

2.4.2 NIOSH (2016) Response, pages 4–6

In order to assure that intakes and resultant doses from environmental intakes was not underestimated, NIOSH used the highest measurement of airborne plutonium to calculate reasonable intakes for all other years and all other areas. The highest measured airborne concentration measured in any area was in 1972 in Area 9 of 4.3×10^{-3} pCi/m^3. To determine the intake, exposure to this concentration was assumed to be 2,400 m^3 per year which resulted in a calculated intake of 0.381 Bq/yr. To determine bounding intakes for other radionuclides measured in the NTS soils but not measured by air sampling (e.g., Am-241, Pu-238, Co-60, Cs-137, Sr-90 and Eu-152, 154, and 155), the maximum ratio of these radionuclides to Pu-239 for all areas was used. These methods would mitigate the effects of decontamination venting in later years. In section 3.1 of the Resuspension Issue Status Report (Status Report on Resuspension Issues at the Nevada Test Site, Contract No. 211-2014-58081, Rev, S.Cohen & Associates, Vienna, VA, July 2015), on page 19, the following statement is made:

> *"For example, by selecting the location and year with the highest annual average airborne plutonium concentration for the purposes of partial dose reconstruction, there is a level of assurance that reconstructed internal exposures are claimant favorable for all workers during those time periods, and also for earlier time periods where back-extrapolation was required. One could also argue that this strategy would be reasonable for earlier time periods and locations, even for locations that were cleaned-up prior to the commencement of the air-sampling program."*

In Section 3.1, on page 21 of the Resuspension Issue Status Report, the following statements appear:

> *"The TBD acknowledges that the portion of the NTS where the RIDP data are provided is limited to only about one-third of the entire area of the NTS. However, the areas selected for the RIDP were those with measurable levels of contamination in soil above ubiquitous background. Hence, it certainly appears that a combination of the air-sampling data and the RIDP soil-inventory data can be used to assign chronic intakes of these nine radionuclides to workers. In addition, if high-end air-sampling and soil-inventory data are used, reconstructed doses associated with the chronic inhalation of these nine radionuclides would seem to be reasonably bounding. As presented in Table 4-6 of the TBD, this is, in fact, the approach adopted in the TBD to reconstruct radionuclide intake rates."*

For these reasons, NIOSH believes the maximum intakes provided in Table 4-6 of the NTS environmental TBD to be scientifically sound and claimant favorable even if specific consideration is given to decontamination activities and loss of containment incidents.

2.4.3 SC&A Resolution Comments

As stated in SC&A (2015), SC&A agrees with NIOSH that the RIDP data have been used as well as possible, and that the prior cleanup of a few areas has generally been compensated for by the application method. There are, however, lingering concerns about the data for the Nuclear Rocket Development Station (NRDS). These areas had been extensively cleaned up before the RIDP program made measurements. There are other issues about the NRDS that have not been resolved; these issues were highlighted in the December 14, 2012, version of the NTS issue matrix (SC&A 2012).

Also, there are still concerns about subsequent heavily contaminating events that occurred in Areas 20 and 30 from Plowshare activities after 1963 and the Baneberry event in 1970 that produced major contamination in Areas 8 and 12. Baneberry remains one of the unresolved issues from the December 2012 NTS matrix (SC&A 2012).

2.4.4 SC&A Recommendations to the Nevada Test Site Work Group

None regarding resuspension issues.

2.5 COMMENT 5

This is one of the more complex issues and goes well beyond the brief statement given in the Executive Summary of SC&A (2015). Generally, this issue encompasses the method of correction for the presence of short-lived radionuclides that were not measured by the RIDP and includes the method of calculation of dose from inhalation. The discussion here about Comment 5 spills over into the discussion about Comments 6 and 7, but Comments 6 and 7 will also be discussed separately below.

First, the original SC&A Comment 5 is presented below (Section 2.5.1), as well as the matrix reply from NIOSH (Section 2.5.2). NIOSH also provided a white paper (Strenge 2016) that addresses the issues within Comment 5. The NIOSH response and the Strenge report are addressed in the SC&A resolution comments in Section 2.5.3 below.

2.5.1 SC&A (2015) Original Statement as Taken from the Executive Summary, page 9

> *Derivation of the concentration of relatively short-lived radionuclides in soil for January 1, 1963, employed the Hicks' tables (Hicks 1982) for the Small Boy event that occurred on July 14, 1962. In fact, the contamination in soil on January 1, 1963, reflects fallout from numerous tests that resulted in surface contamination, such as the Sedan test on July 6, 1962, and Little Feller II on July 7, 1962, which occurred shortly before Small Boy, and Little Feller I that occurred after Small Boy on July 17, 1962. As such, NIOSH should address whether tests shortly before and after Small Boy on July 14, 1962, could also have contributed substantively to the fallout levels in soil derived for January 1, 1963. In a related matter, the protocol used in the TBD to account for fractionation is overly simplistic and appears to rely primarily on the Small Boy event. NIOSH will need to demonstrate that the approach used to account for fractionation does not substantively underestimate doses.*

2.5.2 NIOSH (2016) Response, pages 6–8

> *Soil radionuclide concentrations corrected to 1963 (see Table 4-5 of the NTS environmental TBD)* [ORAUT 2012] *only included radionuclides that are persistent in the environment (e.g., Am-241, Pu-238, Co-60, Cs-137, Sr-90 and Eu-152, 154, and 155).*[1] *These radionuclides would include those deposited as a result of all atmospheric test and loss of containment incidents prior to the 1980s. The persistent radionuclides deposited after January 1, 1963 were still decay corrected back to January 1, 1963 so their contribution to the soil concentrations corrected to January 1, 1963 would have been overestimated since these incident related radionuclides would not have existed in the environment on January 1, 1963. The same overestimate would occur for any persistent radionuclides*

[1] SC&A notes that Pu-239/240 is the only other radionuclide on that list.

deposited as a result of the Plowshare program. Thus the soil radionuclide concentrations corrected to January 1, 1963 likely represent overestimates of the actual soil concentrations present at the time.

In Section 3.4, page 25, of the NTS resuspension issues report, the following statement was made:

> *"The Hicks' tables that were used by NIOSH to support the reconstruction of environmental exposures onsite were actually originally derived for the purpose of evaluating offsite exposures. As a result, the Hicks' tables understate the relative abundance of refractory elements onsite and overstate the presence of volatile elements."*

In Section A.6, page 68, of the NTS environmental TBD [ORAUT 2012], *the process of adding the refractories back into the mix is discussed in some detail. The discussion also includes a description of how the nearfield (i.e., NTS soils) was enriched with the refractories. Specifically, the NTS TBD* [ORAUT 2012] *states the following:*

> *"Because the Hicks data were developed to estimate offsite levels of fallout and resultant dose, fractionation effects were simulated in these data by the removal of a fraction of the refractory nuclides from the calculated abundances. In general, air drops were assumed to be unfractionated and offsite fallout from surface and cratering tests was assumed to have 0.4 of the refractory elements. For all other types of tests, offsite fallout was assumed to have 0.5 of the refractory elements present. Therefore, the refractory elements in the Hicks data must be adjusted to produce the best estimate of their enriched abundances in the onsite environment to which workers could have been exposed. Adjustment factors for each radionuclide were determined from data in Hicks (1984); this report provided relative abundances of radionuclides assuming no fraction, 50% fraction, and 90%*[2] *fraction of refractory elements. From these data, ratios were developed for the 50% fractionation case (Table A-8). These ratios were used to deplete the refractory elements in the far-field (i.e., offsite) environment to estimate doses to offsite individuals. Therefore, to enrich the near-field (i.e., onsite) environment, the inverse of these ratios was applied to the Hicks SMALL BOY data (see below). These inverse ratios were applied twice because the Hicks SMALL BOY data were provided to estimate fallout in the offsite environment. The first application results in the data that represent no fractionation while the second*

[2] SC&A notes that this is an error. Hicks (1984) gives values for 100%, 50%, and 10% presence of refractories.

application results in data that are enriched with refractory elements.'

NIOSH believes that the methods described above represent a reasonable treatment of refractories in the nearfield environment. However, NIOSH is continuing to research the methods used in the Hicks (1984) report for appropriateness for use in the NTS environmental TBD to assure that these methods are claimant favorable.

2.5.3 SC&A Resolution Comments

NIOSH also provided a white paper (Strenge 2016) related to "short-lived radionuclide issues raised in Comment 5." According to Strenge (2016, page 2), "This white paper describes the analysis method used to estimate the environmental dose from short-lived radionuclides during the period 1963 to 1972 at the Nevada Test Site (NTS). Results of the analysis method are presented to illustrate the impact of various assumptions."

Strenge (2016) starts by again stating that the occupational environmental dose cannot be calculated for the time period from the cessation of atmospheric testing (July 1962) to the end of that year. The usual arguments related to obsolete statements given in the evaluation report for SEC Petition 55 (NIOSH 2006) and the *initial* evaluation report for SEC Petition 84 (NIOSH 2007) are the only reasons given. No mention is made of the *final* evaluation report for SEC Petition 84 (NIOSH 2010), and no scientific reason is provided why such doses cannot be calculated. The lack of the extension to July 1962 is unfair to any claimant who worked at the NTS during the latter half of 1962.

ORAUT (2012) made use primarily of the Hicks' tables for the Small Boy shot that occurred on July 14, 1962, and which had a "low" yield, and was "slightly above ground" (DOE 2000). Strenge (2016) also made additional calculations related to Little Feller I, which was the last atmospheric test at the NTS. Little Feller I occurred on July 17, 1962, had a "low" yield, and was also "slightly above ground." SC&A (2015) had recommended examination of data for the Sedan event that occurred on July 6, 1962. The Sedan device was emplaced underground, but the depth of burial was not designed for containment of fallout. By design, the Sedan event produced a crater, which was 1,280 feet in diameter and 300 feet deep (DOE 2000). Sedan was also unique in that it had a large yield of 104 kt with at least 70% of that yield from fusion. In that regard Sedan was quite different from the other "atmospheric" shots at NTS, and that is why SC&A had recommended a specific look at the Sedan event. As an example, the normalized amount of some radioisotopes of tungsten was five orders of magnitude greater for Sedan than for Small Boy (Hicks 1981a).

The calculations in ORAUT (2012) depend upon measured concentrations in air of plutonium-239/240 (Pu-239/240) beginning in 1971 with samplers in 15 locations and with six additional stations added in 1978. The calculations in ORAUT (2012) proceed with use of the maximum measured concentration of Pu-239/240 of 4.29×10^{-3} pCi m^{-3} recorded in Area 9 in 1972. This is a very conservative assumption. With the assumption of 2,400 m^3 year^{-1}, that leads to an intake of Pu-239/240 of 0.381 becquerel (Bq) year^{-1}. The next step in ORAUT (2012) was to obtain ratios of Pu-239/240 to other radionuclides that had been measured by the RIDP in the

1980s and decay corrected to 1963. This was possible as the RIDP measured not only Pu-239/240, but also americium-241 (Am-241), Pu-238, cobalt-60 (Co-60), cesium-137 (Cs-137), strontium-90 (Sr-90), europium-152 (Eu-152), Eu-154, and Eu-155.[3] These ratios allowed for the inference of the maximum airborne concentration of nine radionuclides based on the measurement of airborne Pu-239/240 and the ratios of the other eight radionuclides based on the ratios in soil. The remaining question was how to account for the short-lived radionuclides that were no longer present in soil in the 1980s. This is where the Hicks (1981a) tables come in. The Hicks tables do not tabulate the amount of Pu-239/240 created or spilled, but they do have values of Sr-90 for all tests. Thus, the RIDP soil data are used to infer airborne concentrations of Sr-90 based on the ratio in soil of Pu-239/240 to Sr-90, and the Hicks tables are then used to infer the airborne concentrations of many short-lived radionuclides based on the ratio of Sr-90 to other radionuclides.

The Hicks tables were not created by or for NIOSH. They were created for DOE's Off-Site Radiation Exposure Review Project (ORERP) (Church et al. 1990). Hicks' (1982) calculations used the ORIGEN code (RSIC 1979) and Lawrence Livermore National Laboratory's tabulated fission yields (Nethaway and Barton 1973) for fission spectrum or 14 MeV neutrons to calculate 152 products from fission of uranium-233 (U-233), U-235, U-238 and/or Pu-239/240 depending on the specific features of a given device. Hicks also used data on device characteristics to calculate 25 activation products from device materials or other nearby material masses. These basic calculations were for unfractionated debris and are given as a function of time post detonation.[4] "The phenomenon of fractionation is due to both chemical and physical separation of the radionuclides" (Hicks 1982). It is well known that fractionation of volatile (at 1,500 °C) versus refractory elements does occur, and fallout debris downwind of a surface or near surface explosion is enriched in volatile elements.

The goal of the ORERP was to calculate external and internal dose downwind of explosions that occurred at the NTS. A major set of data available for these calculations was measured values of external gamma-exposure rate in the nearby states. The purpose of the Hicks data was to convert these exposure-rate measurements into the ground deposition of up to 177 fission and activation products. To converge the two sets of data, it was necessary to know the external gamma-exposure rate per unit areal deposition for each of the 177 fission or activation products. The latter data were supplied by Beck (1980).

The final form of the Hicks tables for unfractionated debris was in the form of the ground deposition for up to 177 radionuclides *normalized to an external gamma-exposure rate of 1 mR hour^{-1} at 12 hours post deposition* (commonly referred to as mR hour^{-1} at H+12).

To account to fractionation downwind, Hicks assumed that 50% of refractory elements for tower shots were present, 40% for surface or near-surface events, and 100% for shots on balloons or air drops. For the Small Boy event, which was slightly above ground and with a low yield, the Hicks tables indicate clearly that the assumption was that 40% of refractories were considered for the downwind areas. After Hicks had removed 60% of the refractory elements, he then normalized

[3] ORAUT (2012) states that McArthur (1991) provided values for these radionuclides in soil as of 1991. This is a minor error, as McArthur clearly states that the values were decay corrected to January 1, 1990.

[4] Hicks gives three sets of tables for each explosion: values for 0–21 hours; 1–300 days, and 1–50 years.

the data to an external gamma-exposure rate of 1 mR hour^{-1} at H+12. This renormalization is important in order to give the proper relationships among the radionuclides.

To accomplish the wish of NIOSH to use the Hicks tables for Small Boy, the following steps are necessary

a. Starting with the calculation for 40% of refractors present in Hicks (1981a), add back in the 60% of refractory radionuclides missing to create an unfractionated source term.

b. Renormalize the unfractionated source term to 1 mR hour^{-1} at H+12.

c. Starting with the now unfractionated source term, add in the 60% of refractory radionuclides that are presumed to have been left behind on the NTS.

d. Renormalize the refractory-enriched source term to an external gamma-exposure rate of 1 mR hour^{-1} at H+12.

These renormalizations cannot be done with the information provided in the Hicks tables alone. It is necessary, as done by Hicks, to use the Beck (1980) data, or some more recent compilation of exposure rate per unit deposition, in conjunction with the Hicks tables. There is no indication this was done by either ORAUT (2012) or Strenge (2016).

Strenge (2016, page 5) remarks of the Hicks tables that "Application of the refractory fraction is the only treatment of deposition of activity as the analysis did not include any atmospheric transport or deposition calculation." This statement indicates that Strenge missed the key point that *no calculations* of atmospheric transport or deposition are needed for the ORERP, as the measured values of external gamma-exposure rate made along the downwind path of fallout *have already defined* both the atmospheric transport and deposition of radionuclides. Examples of how the Hicks tables fit into the calculation of internal doses from ingestion for the ORERP are given in Ng et al. (1990); examples for the calculation of external doses are given in Henderson and Smale (1990).

ORAUT (2012, page 68) indicates that NIOSH calculated correction factors (Steps a and c above), but for the case of 50% (rather than the correct 40%) missing refractories based on Hicks (1984). However, Hicks (1984) deals with very large thermonuclear tests of up to 15,000 kt fired in the Pacific Islands. There can be no assurance that very large thermonuclear tests would provide the same mix of radionuclides as that from a small, presumably fission, test. And the use of the wrong value of missing refractories is significant. There is no reason why the data from large thermonuclear test should have been used. The correction factors derived in ORAUT (2012) are provided in Table A-8.[5]

Strenge (2016) takes a different approach; his Table 1 simply lists the far field "Refractory Fraction Ratio" as either 0.4, 1.0, or other values for a few radionuclides that behave as a mixture of refractory and volatile elements. Strenge (2016) states that the data in table A-8 of ORAUT (2012) are shown in his Table 1. This is clearly not the case. For example, the value for beryllium-7 (Be-7) in Table A-8 is given as 0.68, but it is 0.4 in Table 1. In fact, the bases of the

[5] ORAUT (2012), p. 69.

two tables are not the same; if Table A-8 had been expressed in the same manner as Table 1, Be-7 would have had a value of 0.5. As noted above, the correct value should be 0.4—the value stated by Strenge.

Strenge corrected *for the missing refractories* by dividing the values for refractory elements in Hicks' tables for Small Boy and Little Feller I by 0.4 twice.[6] However, there is no indication that Strenge renormalized the values, and he does not provide the reader with his new version of the "Hicks' tables." This is not an enormous task. Hicks' original tables were provided for 0 to 21 hours in five pages; 1 to 300 days in four pages; and 1 to 50 years in one page.

From this point on, the description of how doses were calculated is murky in both ORAUT (2012) and Strenge (2016), and not enough intermediate information is provided in either document so that the reader (in this case, SC&A) can follow and verify the calculations.

The central idea in both documents is that there is a measured air concentration of Pu-239/240 starting in 1971. Then the RIDP data can be used to derive a "maximum scaling factor" of Sr-90 to Pu-239/240, and then scaling factors of short-lived radionuclides to Sr-90 based on Hicks' tables. Time-dependent corrections can be made using the Anspaugh et al. (2002) resuspension model.[7] This straightforward idea becomes very complex in its application, when the process gets to the point of calculating doses from the shorter-lived radionuclides.

Both documents indicate that it is necessary to calculate the dose from the inhalation (and subsequently ingestion) of Sr-90 as a function of time following deposition. Then, the relative (to Sr-90) dose for the up to 176 other radionuclides is calculated. Strenge (2016) states,

> *The relative activity of each radionuclide for a specific time (from five days to 10 years) is entered into a spreadsheet that evaluates the relative dose from each radionuclide using inhalation or ingestion dose factors. The list of radionuclides excludes the radionuclides included in Table 4-7*[8] *(Am-241, Pu-238, Pu-239/240, Co-60, Cs-137, Sr-90, Eu-152, Eu-154, and Eu-155, except for strontium-90, because the dose from these radionuclides is included in other parts of the dose evaluation and assignment.*
>
> *The relative dose from strontium-90 is evaluated for times from 5 days to 3650 days (10 years) for all internal organs of interest (and for which dose-conversion factors are available.) The array of relative dose values is entered into a spreadsheet that evaluates the correction factors for specific organs for each year of the 10-year period. The starting time is January 1, 1963, using the data offset from the time of the shot to the end of 1962, as in Table 2.* [pages 13–14]

What is not clear from the above two paragraphs is the meaning of the evaluation time of "from five days" to 10 years. Does the five days start from the time of deposition? Or from January 1, 1963, which is implied by the paragraph immediately above? If so, why should there be a lag

[6] Mass chains 91, 140, and 141 are treated specially, as they have both refractory and volatile elements. Values for volatile elements were not changed from those in Hicks (1981a).
[7] An improved "modified Anspaugh model" is given in Maxwell and Anspaugh (2011).
[8] From ORAUT (2012), p. 27.

time of five days? It does not make much of a difference if the start date is January 1, 1963, but this is confusing regarding what was really done. Strenge (2016, pages 14–15) continues,

> *The curve of relative dose from strontium-90 is integrated for each annual period, using the curve fit by Excel as either linear or polynomial (quadratic). The integral value is averaged over a 365-day period. The inverse of this integral is the correction factor to be used to estimate the dose from strontium-90 and associated short-lived fission and activation products.*
>
> *The correction factors are next used to estimate the internal dose from the short-lived fission and activation products. The IMBA program was used to calculate the internal dose to each organ from the intake of 1 Bq of strontium-90 type F material during a 1-year period. The dose from just the short-lived radionuclides is then calculated as shown in Equation 1.*
>
> ***Equation 1. Annual dose from short-lived radionuclides based on Sr-90 intake rates.***
>
> $$Dose_{sl}(year,i) = DCF_i * [CF(year,i)-1] * Intake_{Sr\text{-}90}(year)$$
>
> *Where,*
>
> $Dose_{sl}(year,i)$ *= dose to organ i from short-lived radionuclides during a given year based on intake of strontium-90, rem,*
>
> DCF_i *= strontium-90 dose conversion factor for 1-year intake of 1 Bq, to organ i, rem/Bq,*
>
> *CF(year,i) = factor giving the dose from strontium-90 and short-lived radionuclides to organ i during a specific year, and*
>
> $Intake_{Sr90}(year)$ *= intake of strontium-90 for a specific year from Table 4-7, Bq/year.*
>
> *Note that the correction factor, CF(year,i) includes the dose from strontium-90 and is always greater than or equal to 1.0. The subtraction of 1 in the equation removes the strontium-90 dose. The dose from strontium-90 is included when the intakes of Table 4-7 of the NTS TBD are applied in a dose reconstruction.*
>
> *This evaluation of dose is different from the method used in the previous analysis. Previously, the correction factors were applied to the dose commitment from strontium-90 in years after the first year. However, the dose factors for the short-lived radionuclides are 50-year dose commitments and include all possible dose from each radionuclide for the year of intake. The correction factors are developed for the year of intake.*

Unfortunately, Strenge does not provide results of the intermediate steps in these calculations and goes directly to his Table 3, which contains his "Dose Correction Factors for Various Organs

Based on Deposition from Event Small Boy." These values are CF(year,i) as defined above and are given for each year from 1963–1972. More details were given in ORAUT (2012), which Strenge says in the paragraph above have been superseded.

Nevertheless, it is useful to consider some of the material from ORAUT (2012) to help understand this complicated process. Figure 1 is a copy of Figure A-2 from ORAUT (2012). NIOSH states that it gives the fraction of the total dose to the lungs from Sr-90 at various times after detonation.

Figure 1. Reproduction of Figure A-2 from ORAUT (2012), p. 70

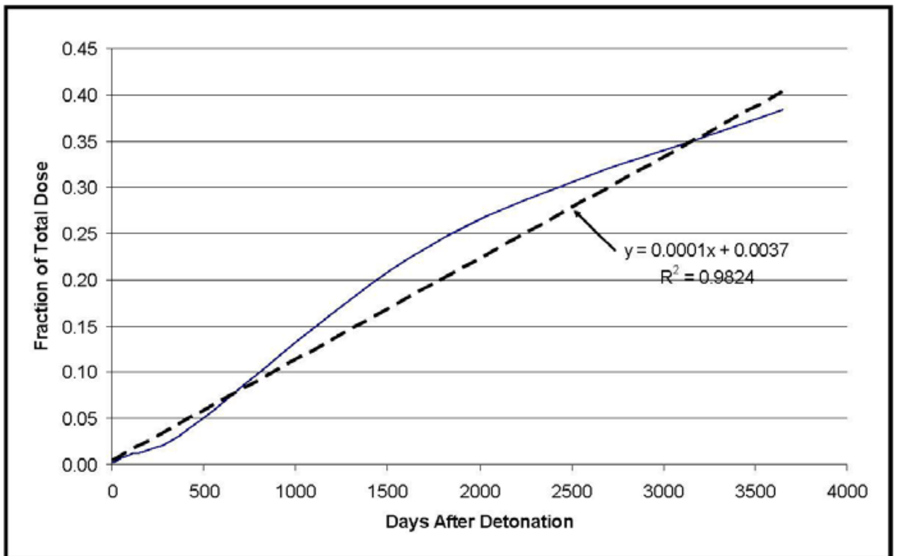

Figure A-2. SMALL BOY – ^{90}Sr fraction of total dose lungs.

It also shows the linear fit to the data as discussed by Strenge and ORAUT. From the information presented, it is difficult to know whether this curve really starts at time zero, or if it has an offset of 172 days as suggested in Strenge's Table 2 (not reproduced here). As one might expect, the dose from Sr-90 becomes an increasingly larger fraction of dose as the short-lived radionuclides decay. SC&A's understanding is that similar curves were constructed for 26 organs/tissues, and that necessitated Integrated Modules for Bioassay Analysis (IMBA) runs for up to 177 radionuclides for several time periods from five minutes to 10 years. If that is what was done in a spreadsheet format, this was an enormous undertaking—almost incomprehensible.

Another important question is how the dose correction factors were calculated. A passage from Strenge quoted above states that yearly correction factors were calculated by integrating the curve fits as shown in Figure 1 and then averaging the integral over 365 days. This does not seem logical. Further confusion comes from statements within ORAUT (2012). There, the equation for Sr-90 fraction of dose to the lung is given as

$$y = 0.0001x + 0.0074,$$

which does not quite match the equation shown in Figure 1. ORAUT (2012) goes on to say,

> *Integrating Equation A-2 [the equation shown in the paragraph above] for SMALL BOY from 0 to 365 days and dividing the result by 365 (the value that represents the integrated total dose for 1 year), it was determined that for the first year after detonation the lung dose from ^{90}Sr represented 0.0000738 or about 0.00738% of the dose from all 177 radionuclides.* [page 70]

There are two problems with this.[9] The first is the implication that time zero is the time of the last detonation (i.e., July 1962), but this appears to be impossible, given that the authors show in their Table A-9[10] that the relative dose to the thyroid is the same as for 17 other organs. Due to the affinity of the thyroid for short-lived radioiodines, this cannot be correct.

The second problem is the integration. The following equation is a reproduction of what the authors *said* they did:

$$\frac{\int_0^{365}(0.0001x + 0.0074)\mathrm{d}x}{365} = \frac{\left.\frac{0.0001x^2}{2} + 0.0074x\right|_0^{365}}{365} = 0.026$$

The calculated value of 0.026 is obviously very different from 0.0000738. The above equation is, in fact, the classic definition of an average of the function over the 365-day period, and according to the authors' Figure A-2, which is reproduced here as Figure 1, the average value has to be about midway between 0.00 and 0.05. The authors' contention that they have calculated an integrated total dose does not match the reproduction of what they said they did.

In a response to Comment No. 7, NIOSH (2016) stated that

> *The difference between these numbers is a factor of 365. The factor of 0.0000738 is actually the average dose for one day—not one year as stated in the NTS environmental TBD. This will be corrected in the next TBD revision.* [page 11]

This response is wrong, as the value of 0.026 is clearly the average dose for one day, and not the integral dose it should be. Dividing again by 365 simply means that the calculations are wrong by a factor of 365^2 = 133,225. However large this error is, it does not matter if the doses from Sr-90 and other short-lived radionuclides are calculated in the same way; the mistaken values of 365 or 365^2 simply cancel out. It would be much less confusing to the reader if such distractions were not in the NIOSH contractor's reports. Strenge (2016, page 14) simply states that "The integral value is averaged over a 365-day period."

The results of ORAUT's calculations of the correction factors are shown in Table 1. Strenge's calculations, which he states have avoided double counting the doses from Am-241, Pu-238, Pu-239/240, Co-60, Cs-137, Sr-90, Eu-152, Eu-154, and Eu-155, are shown in Table 2.

---

[9] The discussion in this and the following two paragraphs was first presented in SC&A (2015), p. 26.
[10] ORAUT (2012), Table A-9, is reproduced in this document as Table 1.

Comparison of Tables 1 and 2 indicates that Strenge's calculations are higher than those from ORAUT for 1963 and 1964 but then become lower. Strenge's values are a factor of 16 lower for 1972.

Table 1. Reproduction of Table A-9 from ORAUT (2012) (inhalation "correction factors" calculated from event Small Boy)

Organ	Fission and activation product correction factor									
Year	1963	1964	1965	1966	1967	1968	1969	1970	1971	1972
Skin Adrenals Thymus SI Spleen Skin Muscle Uterus Pancreas Kidneys Breast Testes Esophagus Ovaries Brain Stomach Thyroid Gall bladder	730	364	242	182	145	121	104	90.7	80.6	72.5
ULI	458	179	99.2	64.0	45.0	33.4	25.9	20.6	16.8	14.0
Urinary bladder	335	149	91.3	63.6	47.5	37.2	30.1	24.9	21.0	18.0
Lungs	34,900	14,200	7,960	5,150	3,630	2,700	2,100	1,660	1,360	1,130
ET ET1 ET2 LN(TH) LN(ET)	1,570	827	598	492	438	412	412	412	412	412
LLI	420	142	70.8	42.4	28.2	20.1	15.1	11.7	9.4	7.6
Colon	390	148	79.4	50.0	34.5	25.2	19.3	15.2	12.3	10.2
Liver	9,260	4,620	1,540	1,190	988	858	769	706	661	629
Red bone marrow	37.9	18.2	12.8	10.4	10.4	10.4	10.4	10.4	10.4	10.4
Bone surfaces	78.5	40.1	28.1	22.4	22.4	22.4	22.4	22.4	22.4	22.4

Source: Reproduced from ORAUT (2012), p. 72, Table A-9, "Organ-Specific Inhalation Dose Fission and Activation Product Correction Factors."

Table 2. Reproduction of Table 3 from Strenge (2016) (inhalation "correction factors" calculated from event Small Boy)

Organ	1963	1964	1965	1966	1967	1968	1969	1970	1971	1972
Skin, Adrenals, Thymus, Small Intestine, Spleen, Muscle, Uterus, Pancreas, Kidneys, Breast, Testes, Esophagus, Ovaries, Brain, Stomach, Thyroid, Gall Bladder	1,500	477	231	136	79	26	14	8.8	6.2	4.5
Upper Large Intestine	784	250	120	70	46	19	12	8.8	6.6	5.1
Urinary Bladder	499	170	84	50	33	23	6.0	3.9	2.8	2.1
Lungs	54,201	16,814	7,865	4,515	2,920	2,041	482	322	232	175
Extra Thoracic Regions	1,258	428	214	151	87	57	40	29	23	18
Lower Large Intestine	439	144	70	41	27	13	8.3	5.9	4.4	3.4
Colon	525	173	85	50	33	31	18	12	8.4	6.3
Liver	13,459	6,631	4,399	3,292	2,630	1,660	626	350	228	162
Red Bone Marrow	82	23	12	7.8	5.4	3.9	3.0	2.3	1.9	1.6
Bone Surface	192	78	43	28	19	14	11	8.8	7.1	5.9

Source: Reproduced from Strenge (2016), p. 17, Table 3, "Annual Inhalation Dose Correction Factors for Various Organs Based on Deposition from Event Small Boy."

Of more interest are the calculated doses from inhalation with use of the source term from the Small Boy event. The results of calculations from ORAUT (2012) are reproduced in Table 3.

Most of the doses are very low, except for the liver, bone surface, lower large intestine, extra-thoracic region (ET), and ET1.

Similar values as given by Strenge are shown in Table 4. Strenge only gives values for doses above 5×10^{-4} rem.

All doses, whether from ORAUT (2012) or Strenge (2016), are very low, except for ET1. Unfortunately, neither ORAUT nor Strenge give intermediate values of their calculations so that the dose values could be verified. Of course, if this evaluation process were extended to include the last half of 1962, the doses would be much higher by factors of several hundred.

Table 3. Reproduction of Doses from Inhalation Calculated with the Use of the Small Boy Source Term, as Given in Table A-10 from ORAUT (2012)

Year	1963	1964	1965	1966	1967	1968	1969	1970	1971	1972
Adrenals	1.52E-04	6.76E-05	3.92E-05	2.89E-05	2.47E-05	2.17E-05	1.94E-05	1.74E-05	1.57E-05	1.42E-05
Bladder	1.86E-04	6.99E-05	3.45E-05	2.26E-05	1.81E-05	1.51E-05	1.29E-05	1.12E-05	9.73E-06	8.53E-06
Brain	1.52E-04	6.76E-05	3.92E-05	2.89E-05	2.47E-05	2.17E-05	1.94E-05	1.74E-05	1.57E-05	1.42E-05
Breast	2.08E-07	3.57E-08	1.65E-08	1.37E-08	1.18E-08	1.01E-08	8.70E-09	7.50E-09	6.49E-09	5.58E-09
Gall bladder	2.08E-07	3.57E-08	1.65E-08	1.37E-08	1.18E-08	1.01E-08	8.70E-09	7.50E-09	6.49E-09	5.58E-09
Heart wall	1.52E-04	6.76E-05	3.92E-05	2.89E-05	2.47E-05	2.17E-05	1.94E-05	1.74E-05	1.57E-05	1.42E-05
Kidney	1.52E-04	6.76E-05	3.92E-05	2.89E-05	2.47E-05	2.17E-05	1.94E-05	1.74E-05	1.57E-05	1.42E-05
Liver	1.93E-03	8.57E-04	3.71E-04	2.70E-04	2.33E-04	2.07E-04	1.85E-04	1.67E-04	1.52E-04	1.39E-04
Muscle	1.52E-04	6.76E-05	3.92E-05	2.89E-05	2.47E-05	2.17E-05	1.94E-05	1.74E-05	1.57E-05	1.42E-05
Ovaries	1.52E-04	6.76E-05	3.92E-05	2.89E-05	2.47E-05	2.17E-05	1.94E-05	1.74E-05	1.57E-05	1.42E-05
Pancreas	1.52E-04	6.76E-05	3.92E-05	2.89E-05	2.47E-05	2.17E-05	1.94E-05	1.74E-05	1.57E-05	1.42E-05
Testes	1.52E-04	6.76E-05	3.92E-05	2.89E-05	2.47E-05	2.17E-05	1.94E-05	1.74E-05	1.57E-05	1.42E-05
Thyroid	1.52E-04	6.76E-05	3.92E-05	2.89E-05	2.47E-05	2.17E-05	1.94E-05	1.74E-05	1.57E-05	1.42E-05
RBM	4.08E-04	7.00E-04	6.65E-04	6.09E-04	5.59E-04	5.18E-04	4.84E-04	4.57E-04	4.35E-04	4.16E-04
Bone surface	1.23E-03	2.03E-03	2.00E-03	1.91E-03	1.83E-03	1.77E-03	1.72E-03	1.69E-03	1.66E-03	1.64E-03
Stomach	1.69E-04	7.22E-05	4.14E-05	3.02E-05	2.57E-05	2.26E-05	2.01E-05	1.81E-05	1.63E-05	1.47E-05
SI	1.85E-04	7.67E-05	4.36E-05	3.15E-05	2.68E-05	2.35E-05	2.09E-05	1.87E-05	1.69E-05	1.53E-05
ULI	4.70E-04	1.36E-04	5.98E-05	3.59E-05	2.73E-05	2.19E-05	1.81E-05	1.52E-05	1.29E-05	1.11E-05
LLI	1.38E-03	3.26E-04	1.24E-04	6.66E-05	4.74E-05	3.63E-05	2.90E-05	2.37E-05	1.98E-05	1.67E-05
Skin	1.52E-04	6.76E-05	3.92E-05	2.89E-05	2.47E-05	2.17E-05	1.94E-05	1.74E-05	1.57E-05	1.42E-05
Spleen	1.52E-04	6.76E-05	3.92E-05	2.89E-05	2.47E-05	2.17E-05	1.94E-05	1.74E-05	1.57E-05	1.42E-05
Thymus	1.52E-04	6.76E-05	3.92E-05	2.89E-05	2.47E-05	2.17E-05	1.94E-05	1.74E-05	1.57E-05	1.42E-05
Uterus	1.52E-04	6.76E-05	3.92E-05	2.89E-05	2.47E-05	2.17E-05	1.94E-05	1.74E-05	1.57E-05	1.42E-05
ET	2.22E-03	6.97E-04	3.78E-04	2.60E-04	2.32E-04	2.19E-04	2.17E-04	2.15E-04	2.14E-04	2.13E-04
Lung	7.67E-03	2.96E-03	1.55E-03	1.08E-03	8.84E-04	7.46E-04	6.40E-04	5.52E-04	4.80E-04	4.18E-04
Colon	7.82E-04	2.08E-04	8.57E-05	4.85E-05	3.57E-05	2.78E-05	2.26E-05	1.86E-05	1.57E-05	1.34E-05
ET1	1.63E+00	4.74E-01	2.48E-01	1.64E-01	1.46E-01	1.38E-01	1.38E-01	1.38E-01	1.38E-01	1.38E-01
ET2	5.83E-04	2.24E-04	1.30E-04	9.60E-05	8.63E-05	8.10E-05	7.92E-05	7.78E-05	7.66E-05	7.55E-05
LN(ET)	3.27E-04	1.50E-04	9.15E-05	7.03E-05	6.34E-05	5.95E-05	5.77E-05	5.63E-05	5.51E-05	5.40E-05
LN(TH)	3.27E-04	1.50E-04	9.15E-05	7.03E-05	6.34E-05	5.95E-05	5.77E-05	5.63E-05	5.51E-05	5.40E-05
Esophagus	1.52E-04	6.76E-05	3.92E-05	2.89E-05	2.47E-05	2.17E-05	1.94E-05	1.74E-05	1.57E-05	1.42E-05

Source: Reproduced from ORAUT (2012), p. 76, Table A-10, "Inhalation Dose from Short-Lived Fission and Activation Products (rem)."

Table 4. A Reproduction of Doses from Inhalation Calculated with the Use of the Small Boy Source Term, as Given in Table 4 of Strenge (2016)

Organ	1963	1964	1965	1966	1967	1968	1969	1970	1971	1972
Liver	0.003	0.001	Negl[a]	Negl	Negl	Negl	Negl	Negl	Negl	Negl
Bone Surface	0.003	0.001	Negl	Negl	Negl	Negl	Negl	Negl	Negl	Negl
Lower Large Intestine	0.001	Negl	Negl	Negl	Negl	Negl	Negl	Negl	Negl	Negl
ET[b](ET2), LN[c](ET), LN(TH[d])	0.002	Negl	Negl	Negl	Negl	Negl	Negl	Negl	Negl	Negl
Lung	0.012	0.002	0.001	Negl	Negl	Negl	Negl	Negl	Negl	Negl
ET1	1.305	0.243	0.088	0.050	0.029	0.018	0.013	0.009	0.007	0.006

[a] Negl means the dose is less than 0.0005 rem and is negligible.
[b] ET=extra-thoracic region.
[c] LN=lymph node.
[d] TH=thoracic.
Source: Reproduced from Strenge (2016), p. 18, Table 4, "Annual Inhalation Dose (Rem) from Short-Lived Activity from Event Small Boy."

Strenge (2016) compared correction factors and doses that are calculated using the source term from Little Feller I, which was the last atmospheric test, to those calculated using the source term from the Small Boy event. The results for Little Feller I are shown in Tables 5 and 6. There is a substantial difference between the values calculated with the Little Feller I source term and those using that of Small Boy. SC&A (2015) had suggested that NIOSH should examine the results from tests other than Small Boy, as each event is different.[11] SC&A continues to recommend that calculations also be performed with the source term from Sedan, which was a cratering event just eight days before Small Boy. Sedan was a quite large thermonuclear event and was quite different from Small Boy or Little Feller I.

SC&A has not attempted to follow the calculations for ingestion. Virtually the same problems exist in that it is impossible to follow the calculations without the provision of intermediate results.

[11] Hicks (1982, 1990) pointedly made separate calculations for every atmospheric test at the NTS. Many devices were one-of-a-kind experiments.

Table 5. Reproduction of Table 5 from Strenge (2016) (values shown are inhalation correction factors as computed with the Little Feller I source term)

Organ	1963	1964	1965	1966	1967	1968	1969	1970	1971	1972
Skin, Adrenals, Thymus, Small Intestine, Spleen, Muscle, Uterus, Pancreas, Kidneys, Breast, Testes, Esophagus, Ovaries, Brain, Stomach, Thyroid, Gall Bladder	432	159	77	45	29	20	6.5	4.8	3.7	2.9
Upper Large Intestine	165	58	30	18	12	8.7	6.6	5.1	4.1	3.4
Urinary Bladder	646	176	56	26	15	5.2	3.4	2.4	1.8	1.4
Lungs	15,794	4,801	2,175	1,223	780	171	105	71	52	39
Extra Thoracic Regions	500	160	76	44	29	13	9.5	7.1	5.5	4.4
Lower Large Intestine	108	41	22	14	9.8	7.2	5.6	4.4	3.6	3.0
Colon	105	41	22	14	9.8	7.2	5.6	4.4	3.6	3.0
Liver	3,804	1,866	1236	297	108	58	37	25	19	14
Red Bone Marrow	25	19	4.8	3.5	2.8	2.3	2.0	1.7	1.5	1.3
Bone Surface	29	13	7.8	5.4	4.1	3.2	2.6	2.2	1.9	1.6

Source: Reproduced from Strenge (2016), p. 19, "Annual Inhalation Dose Correction Factors for Various Organs Based on Deposition from Event Little Feller I."

Table 6. A Reproduction of Doses from Inhalation Calculated with the Use of the Little Feller I Source Term, as Given in Table 6 from Strenge (2016)

Organ	1963	1964	1965	1966	1967	1968	1969	1970	1971	1972
Liver	0.001	Negl	Negl	Negl	Negl	Negl	Negl	Negl	Negl	Negl
Bone Surface/Red Bone Marrow	Negl	Negl	Negl	Negl	Negl	Negl	Negl	Negl	Negl	Negl
Lower Large Intestine	Negl	Negl	Negl	Negl	Negl	Negl	Negl	Negl	Negl	Negl
ET[a](ET2), LN[b](ET), LN(TH[c])	0.001	Negl	Negl	Negl	Negl	Negl	Negl	Negl	Negl	Negl
Lung	0.003	0.001	Negl	Negl	Negl	Negl	Negl	Negl	Negl	Negl
ET1	0.519	0.090	0.031	0.014	0.009	0.004	0.003	0.002	0.001	0.001

[a] ET=extra-thoracic region.
[b] LN=lymph node.
[c] TH=thoracic.
Source: Reproduced from Strenge (2016), p. 20, Table 6, "Annual Inhalation Dose (Rem) from Short-Lived Activity from Event Little Feller I."

2.5.4 SC&A Recommendations to the Nevada Test Site Work Group

SC&A's Recommendation 1 (above) is to change the time period for the reconstruction of the occupational environmental dose to July 17, 1962, through December 31, 1992. Additional recommendations are as follows:

3. NIOSH and contractors should redo the calculations for correction of fractionation to include all steps a through d given above. This essentially requires the additional steps of renormalizing the source term after each addition of refractory elements.

4. NIOSH and contractors should be very specific about how their calculations were made and provide the results of all intermediate calculations so that SC&A can verify the

calculations. This may require that one or more DVDs be provided, as the intermediate data are likely too voluminous to be inserted into a report or spreadsheets may be much too large to fit on a page.

5. NIOSH and contractors should also consider the source term for the Sedan event, which was a relatively large thermonuclear event.

2.6 COMMENT 6

Much of the material regarding Comments 6 and 7 has been covered above in the material on Comment 5. Nevertheless, the procedure followed above for other comments is followed here.

2.6.1 SC&A (2015) Original Statement as Taken from the Executive Summary, Part 1, pages 9–10

The levels of contamination observed in soil by the RIDP performed in the 1980s captured some contamination that occurred many years subsequent to the termination of aboveground testing. This is a concern that needs to be addressed, because the TBD is based on the assumption that all radionuclides observed in soil in the 1980s were as a result of aboveground testing that occurred in July 1962. However, some of the contamination was deposited many years later. NIOSH should explain how this affects the dose reconstruction process.

2.6.2 NIOSH (2016) Response, Part 1, page 8

The persistent radionuclides deposited after January 1, 1963 were still decay corrected back to January 1, 1963 so their contribution to the soil concentrations corrected to January 1, 1963 would have been overestimated since these radionuclides would not have existed in the environment on January 1, 1963. The same overestimate would occur for any persistent radionuclides deposited as a result of the Plowshare program. Thus the soil radionuclide concentrations corrected to January 1, 1963 likely represent overestimates of the actual soil concentrations present at the time.

2.6.3 SC&A Resolution Comments, Part 1

SC&A is not concerned solely with the persistent radionuclides deposited in soil. The primary concern is with the many events (for example, Baneberry [REECo 1973])[12] that deposited short-lived radionuclides on soil. These deposits of short-lived radionuclides could have produced significantly larger doses in the 1963–1970 period than those presently being calculated in ORAUT (2012) or Strenge (2016).

[12] Further information on contaminating events after 1962 is given in Anspaugh (2008).

2.6.4 SC&A (2015) Original Statement as Taken from the Executive Summary, Part 2, page 10

In a related manner, the TBD makes use of the Anspaugh equation to derive resuspension factors in order to calculate airborne mass loadings and associated intake rates after January 1, 1963. NIOSH needs to discuss how these resuspension factors might be affected if there are locations where soil contamination occurred well after January 1, 1963.

2.6.5 NIOSH (2016) Response, Part 2, pages 8–10

The resuspension factors derived from the Anspaugh equation were not used to calculate airborne mass loadings. Rather they were used to develop correction (normalization) factors that could be applied to intakes derived from the highest airborne concentration of Pu-239 measured at the NTS (i.e, Area 9, 1972).

With the exception of the Plowshare program (which was conducted at a relatively small, remote area where personnel access would have been difficult) soil contamination occurring after 1963 was primarily the result of loss of containment incidents. For each of these events, DOE attempted to identify all workers that had a potential for exposure to radioactive material. Those that were identified as having been possibly exposed were subjected to external and internal monitoring. In addition, except for operational activities, access to these newly contaminated areas was controlled. Therefore, estimating the potential exposure of individuals to airborne radioactive materials resuspended from the newly contaminated soils would involve the introduction of large uncertainties.

However, NIOSH believes the use of high-end air-sampling data (i.e. the highest air sample concentrations ever measured at the NTS) and soil-inventory data in reconstructing environmental doses associated with the chronic inhalation of radioactive material provides reasonable assurance that the assigned intakes and resultant doses are not underestimated.

Also, in section 5, page 29, of the resuspension issues report, the statement is made that "…a mass loading of 0.168 mg/m^3 gives the same dose as the resuspension method, and (3) 1 mg/m^3 is reasonable and would be more claimant favorable." Table 7-1 of OCRWM (2003) provides ranges of mass loading factors for various conditions in the Armargosa Valley where the NTS is located. For inactive outdoor conditions, the table provides a triangular distribution with a minimum of 0.025 mg/m^3, a maximum of 0.100 mg/m^3 and a mode of 0.060 mg/m^3. These data do not support a mass loading of 1 mg/m^3 but do suggest that the implied mass loading factor of 1.68 mg/m^3 [sic][13] *is sufficiently claimant favorable."*

[13] SC&A presumes that NIOSH intended to state 0.168 mg/m^3 rather than 1.68 mg/m^3.

2.6.6 SC&A Resolution Comments, Part 2

The Anspaugh resuspension equation was used by NIOSH and contractors to back-extrapolate airborne concentrations of Pu-239/240 from the measurement in 1972 back to the beginning of 1963. This is clear from material contained in ORAUT (2012) on pages 66–67.

The Plowshare program was not just conducted at a "relatively small, remote area." Plowshare activities were conducted in Areas 10, 18, 20, and 30. Four of the six Plowshare events released more than 10^6 Ci at H+12 (Schoengold et al. 1996).[14] Two of the events (Sedan and Palanquin) released more than 10^7 Ci at H+12.

There were not just a few vents at the NTS during the 1963–1970 period. According to Schoengold et al. (1996), there were 225 shots that vented, including planned and unplanned releases and plutonium dispersal tests. Twenty-six of these vents were detected off site, so it cannot be presumed that DOE identified all involved workers and controlled access to the contaminated sites.

It is sometimes forgotten that tests were also being made of nuclear rocket engines and nuclear ramjet engines. Some of these tests produced substantial local contamination, especially at the Nuclear Rocket Development Station (Areas 25 and 26). The fallout from some of these tests was detected off site.

As a matter of geography, the NTS is not located in the Armargosa Valley, as stated by NIOSH.

2.6.7 SC&A Recommendations to the NTS Work Group

6. The impacts of hundreds of releases of large quantities of short-lived radionuclides should be considered in a more serious manner so that exposures to claimants are considered fairly.

2.7 COMMENT 7

2.7.1 SC&A (2015) Original Statement as Taken from the Executive Summary, Part 1, page 10

> *In order to prepare tables of doses to each organ and from each radionuclide as a function of time [which would have required an enormous number of Integrated Modules of Bioassay Analysis (IMBA) runs], NIOSH elected to prorate all doses based on the intake rate of Sr-90 beginning on January 1, 1963, and moving forward in time as the resuspension factors decline according to the Anspaugh equation and the radionuclide concentrations decline by radioactive decay.*

[14] Many of the details concerning these events are described in more detail in Anspaugh (2008).

2.7.2 NIOSH (2016) Response, Part 1, page 10

In the NTS resuspension issues report in Section 3.5, page 26, the following statement is made:

> *"There are two problems with this. The first is the implication that time zero is the time of the last detonation (i.e., July 1962), but this appears to be impossible, given that the authors show in their Table A-9 that the relative dose to the thyroid is the same as for 17 other organs. Due to the affinity of the thyroid for short-lived radioiodines, this cannot be correct."*

It should be noted that Table A-9 does not provide relative doses. Rather, the table provides correction factor which when multiplied by the annual Sr-90 dose (to a particular organ) will account for short-lived fission and activation products. In other words, the correction factors given in Table A-9 are indicators of the relative importance of dose from Sr-90 (to a particular organ) to the total annual dose from short-lived fission and activation products. The reason the thyroid is grouped with the other 17 organs in Table A-9 is because the annual dose from the annual intakes of Sr-90 are similar for all 18 organs. The thyroid does not have an affinity for Sr-90.

2.7.3 SC&A Resolution Comments, Part 1

The above NIOSH description of Table A-9 from ORAUT (2012) is, in fact, the definition of doses relative to that from Sr-90. The major point is that NIOSH's Figure A-2, which is reproduced above as Figure 1, implies that the integration started from time zero after detonation, and not at January 1, 1963. This is also the implication given in the description in ORAUT (2012, page 70) of the integration of their equation starting at time zero. If they had integrated from time zero after detonation, then the "correction factor" for the thyroid would have been much larger than for skin, adrenals, thymus, small intestine, spleen, muscle, uterus, pancreas, kidneys, breast, testes, esophagus, ovaries, brain, stomach, and gall bladder due to the preferential incorporation of short-lived radioiodines into the thyroid.

The NIOSH comment that the thyroid does not have an affinity for Sr-90 does not help in addressing SC&A's fundamental concern. Strenge (2016) has made it clear that NIOSH does not plan to reconstruct doses during the last half of 1962. SC&A believes that doses associated with this time period can be reconstructed and should be reconstructed because these doses will be large as compared to the doses post January 1, 1963.

2.7.4 SC&A (2015) Original Statement as Taken from the Executive Summary, Part 2, page 10

A review of the methods used to perform these calculations, as provided in Appendix A of the TBD, reveals that errors have been made in its use of equation A-2, which could profoundly affect the dose fractions provided in Figures A-5 *through A-11, and the doses calculated and reported in Tables 4-9, 4-14, and A-10.*

2.7.5 NIOSH (2016) Response, Part 2, pages 10–12

In a related matter, the issues report [SC&A 2015] also stated the following:

> *"The second problem is the integration. The calculated value of 0.026 is obviously very different from 0.0000738."*

The difference between these numbers is a factor of 365. The factor of 0.0000738 is actually the average dose for one day – not one year as stated in the NTS environmental TBD. This will be corrected in the next TBD revision.

However, it should be noted that the integration of equation A-2 from Figure A-2 is not used in any way to calculate doses. The slope of the lines shown in Figures A-2, A-3 and A-4 of the NTS environmental TBD are what were used to demonstrate the relative importance of the lung dose from Sr-90 to the total dose from short-lived fission and activation products. The lower the slope, the lower the relative dose from Sr-90 when compared to the total dose from short-lived fission and activation products. The slope of the trend lines that predict the relative importance of ^{90}Sr dose was determined to be 0.0001x for STORAX SMALL BOY, 0.0002x for STORAX LITTLE FELLER I (Figure A-3) and TEAPOT TURK (see Figure A-4). Because the slope of the trend line is directly proportional to the relative importance of the Sr-90 dose to total dose (i.e., the larger the slope, the larger the relative importance of Sr-90 dose), the tests with the smallest slopes result in the highest multiplicative correction factors for fission and activation products. Therefore, to ensure the organ dose from short-lived fission and activation products is not underestimated, the Hicks (1984) data for the STORAX SMALL BOY test were selected to be used to determine the fission and activation product dose correction factor. This assumption is justified by the fact that the test was very near the last atmospheric test (i.e., STORAX LITTLE FELLER I) and would therefore have been the test most likely to produce the short-lived fission and activation product intakes for workers at NTS after 1962 (the period for which organ dose from environmental intakes is calculated).

2.7.6 SC&A Resolution Comments, Part 1

This issue has already been discussed and recommendations made above for Comment 5.

3.0 SUMMARY OF RECOMMENDATIONS TO THE NEVADA TEST SITE WORK GROUP

1. Change the time period for the reconstruction of occupational environmental dose to July 17, 1962, through December 31, 1992. The same method can be used as NIOSH is now doing for a start period of January 1, 1963. Such a change would be substantively more claimant favorable and can be performed using scientifically valid methodologies for time periods that extend back to the latter half of 1962.

2. Change the statement about rosters and bioassay results to a more valid statement:

   > "These workers may have been identified on the rosters that were published before the event, and these workers may have had bioassay results in the DOE records."

3. NIOSH and contractors should redo the calculations for correction of fractionation to include all steps a through d given above. This essentially requires the additional steps of renormalizing the source term after each addition of refractory elements.

4. NIOSH and contractors should be very specific about how their calculations were made and provide the results of all intermediate calculations so that SC&A can verify the calculations. This may require that one or more DVDs be provided, as the intermediate data are likely too voluminous to be inserted into a report or spreadsheets may be much too large to fit on a page.

5. NIOSH and contractors should also consider the source term for the Sedan event, which was a relatively large thermonuclear event.

6. The impacts of hundreds of releases of large quantities of short-lived radionuclides should be considered in a more serious manner so that exposures to claimants are considered fairly.

4.0 REFERENCES

ABRWH 2008. Nevada Test Site Work Group meeting transcript, October 29, 2008. Available at http://www.cdc.gov/niosh/ocas/pdfs/abrwh/2008/wgtr102908.pdf

ABRWH 2009a. Nevada Test Site Work Group meeting transcript, April 23, 2009. Available at http://www.cdc.gov/niosh/ocas/pdfs/abrwh/2009/wgtr042309.pdf

ABRWH 2009b. Nevada Test Site Work Group meeting transcript, December 15, 2009. Available at http://www.cdc.gov/niosh/ocas/pdfs/abrwh/2009/wgtr121509.pdf

ABRWH 2010. Advisory Board on Radiation and Worker Health meeting transcript, February 10, 2010. Available at http://www.cdc.gov/niosh/ocas/pdfs/abrwh/2010/tr021010.pdf

ABRWH 2014. Nevada Test Site Work Group meeting transcript, December 3, 2014. Available at http://www.cdc.gov/niosh/ocas/pdfs/abrwh/2014/wgtr120314.pdf

Anspaugh et al. 2002. Anspaugh, L.R., S.L. Simon, K.I. Gordeev, I.A. Likhtarev, R.M. Maxwell, and S.M. Shinkarev, "Movement of Radionuclides in Terrestrial Ecosystems by Physical Processes," *Health Physics*, Vol. 82 (2002), pp. 669–679.

Anspaugh, L.R. 2008. *Comments on ORAUT-TKBS-0008-4, "Nevada Test Site–Occupational Environmental Dose*, SC&A, Inc., Vienna, Virginia. October 21, 2008.

Beck, H.L. 1980. *Exposure Rate Conversion Factors for Radionuclides Deposited on the Ground*, Report EML-378, Environmental Measurements Laboratory, Department of Energy, New York, New York. July 1980. [SRDB Ref. ID 35519]

Church et al. 1990. Church, B.W., D.L. Wheeler, C.M. Campbell, R.V. Nutley, and L.R. Anspaugh, "Overview of the Department of Energy's Off-Site Radiation Exposure Review Project (ORERP)," *Health Physics*, Vol. 59 (1990), pp. 503–510.

DOE 2000. *United States Nuclear Tests. July 1945 through September 1992*, DOE/NV-209-REV 15, Nevada Operations Office, U.S. Department of Energy, Las Vegas, Nevada. December 2000. [SRDB Ref. ID 2433]

Henderson and Smale 1990. Henderson, R.W., and R.F. Smale, "External Exposure Estimates for Individuals Near the Nevada Test Site," *Health Physics*, Vol. 59 (1990), pp. 715–722.

HHS 2006. "Final Effect of Designation of a Class of Employees for Addition to the Special Exposure Cohort," Centers for Disease Control and Prevention, U.S. Department of Health and Human Services, 71 *Federal Register* 44298. August 4, 2006.

HHS 2010. "Final Effect of Designation of a Class of Employees for Addition to the Special Exposure Cohort," National Institute for Occupational Safety and Health, U.S. Department of Health and Human Services, 75 *Federal Register* 27784. May 18, 2010.

Hicks 1981a. H.G. Hicks, *Results of Calculations of External Gamma Radiation Exposure Rates from Fallout and the Related Radionuclide Compositions. Operations Nougat through Bowline, 1962–1968*, Report UCRL-53152, Part 8, Lawrence Livermore National Laboratory, Livermore, California. July 1981. [SRDB Ref. ID 1851]

Hicks, H.G. 1981b. *Calculated Concentrations of any Radionuclide Deposited on the Ground by Release from Underground Nuclear Detonations, Tests of Nuclear Rockets, and Tests of Nuclear Ramjet Engines*, Report UCRL-53228, Lawrence Livermore National Laboratory, Livermore, California. November 1981. [SRDB Ref. ID 1828]

Hicks 1982. H.G. Hicks, "Calculation of the Concentration of Any Radionuclide Deposited on the Ground by Offsite Fallout from a Nuclear Detonation," *Health Physics*, Vol. 42 (1982), pp. 585–600.

Hicks 1984. H.G. Hicks, *Results of Calculations of External Gamma Radiation Exposure Rates from Local Fallout and the Related Radionuclide Compositions of Selected U.S. Pacific Events*, Report UCRL-53505, Lawrence Livermore National Laboratory, Livermore, California. February 1984. [SRDB Ref. ID 1856]

Hicks 1990. H.G. Hicks, "Additional Calculations of Radionuclide Production following Nuclear Explosions and Pu Isotopic Radios for Nevada Test Site Events," *Health Physics*, Vol. 59 (1990), pp. 515–523.

Kordas and Anspaugh 1982. Kordas, J.F., and L.R. Anspaugh, *Nevada Test Site Radionuclide Inventory and Distribution—Project Operations Plan*, Report UCID-19413, Lawrence Livermore National Laboratory, Livermore, California. Originally issued January 5, 1982, revised June 1, 1982.

Maxwell and Anspaugh 2011. Maxwell, R.M., and L.R. Anspaugh, "An Improved Model for Prediction of Resuspension," *Health Physics*, Vol. 101 (2011), pp. 722–730.

McArthur 1991. R.D. McArthur, *Radionuclides in Surface Soil at the Nevada Test Site*, Report DOE/NV/10845-02, Desert Research Institute, University of Nevada System, Las Vegas, Nevada. August 1991. [SRDB Ref. ID 7872]

Nethaway and Barton 1973. Nethaway, D.R., and G.W. Barton, *A Compilation of Fission Product Yields in Use at the Lawrence Livermore Laboratory*, Report UCRL-51458, Lawrence Livermore National Laboratory, Livermore, California. October 3, 1973. Available from the National Technical Reports Library, U.S. Department of Commerce, https://ntrl.ntis.gov/NTRL/dashboard/searchResults.xhtml

Ng et al. 1990. Ng, Y.C., L.R. Anspaugh, and R.T. Cederwall, "ORERP Internal Dose Estimates for Individuals," *Health Physics*, Vol. 59, No. 5 (1990), pp. 693–713.

NIOSH 2006. *SEC Petition Evaluation Report. Petition SEC-00055*, National Institute for Occupational Safety and Health, Cincinnati, Ohio. April 10, 2006. [SRDB Ref. ID 150574]

NIOSH 2007. *SEC Petition Evaluation Report. Petition SEC-00084*, National Institute for Occupational Safety and Health, Cincinnati, Ohio. September 25, 2007. [SRDB Ref. ID 77699]

NIOSH 2010. *SEC Petition Evaluation Report. Petition SEC-00084*, Revision 1, National Institute for Occupational Safety and Health, Cincinnati, Ohio. January 25, 2010.

NIOSH 2016. *NTS Resuspension Issues and Comments Matrix*, National Institute for Occupational Safety and Health, Cincinnati, Ohio. January 29, 2016.

OCRWM 2003. *Inhalation Exposure Input Parameters for the Biosphere Model*, ANL-MGR-MD-000001 RREV 2 ICN 0, Yucca Mountain Project Office, Office of Civilian Radioactive Waste Management, Las Vegas, Nevada. June 2003. [SRDB Ref. ID 35535]

ORAUT 2005. *Internal Dose Overestimates for Facilities with Air Sampling Programs*, ORAUT-OTIB-0018, Revision 01, Oak Ridge Associated Universities Team, Oak Ridge, Tennessee. August 9, 2005.

ORAUT 2012. *Nevada Test Site—Occupational Environmental Dose*, ORAUT-TKBS-0008-4, Revision 03, Oak Ridge Associated Universities Team, Oak Ridge, Tennessee. August 24, 2012.

REECo 1973. *Onsite Environmental Sciences Activities during the Baneberry Event*, Report NVO-410-29, Reynolds Electrical & Engineering Co., Las Vegas, Nevada. June 1973. [SRDB Ref. ID 8045]

Rollins 2016. E. Rollins, *NIOSH Response to Inconsistency Issues Raised in Comment 8 of SC&A's NTS Resuspension Issues Status Report*, Oak Ridge Associated Universities Team, Oak Ridge, Tennessee. June 6, 2016.

RSIC 1979. *ORIGEN-79 Isotope Generation and Depletion Code-Matrix Exponential Method*, Report CCC-217, Radiation Shielding Information Center, Oak Ridge National Laboratory, Oak Ridge, Tennessee. 1979.

SC&A 2005. *Review of the NIOSH Site Profile for the Nevada Test Site*, SC&A, Inc., Vienna, Virginia. December 13, 2005.

SC&A 2006. *Issue Resolution Matrix Based on the SC&A Review of the NIOSH Site Profile for the Nevada Test Site*, SC&A, Inc., Vienna, Virginia. January 13, 2006.

SC&A 2012. *Update of the Nevada Test Site (NTS) Issue Resolution Matrix Based on the SC&A Review of the NIOSH Site Profile for the Nevada Test Site*, SC&A, Inc., Vienna, Virginia. December 14, 2012.

SC&A 2015. *Status Report on Resuspension Issues at the Nevada Test Site*, SC&A, Inc., Vienna, Virginia. July 21, 2015.

SC&A 2016. *SC&A's Position on Comment 8 – Resuspension Issues at the Nevada Test Site*, SC&A, Inc., Vienna, Virginia. December 16, 2016.

Schoengold et al. 1996. Schoengold, C.R., M.E. DeMarre, and E.M. Kirkwood, *Radiological Effluents Released from U.S. Continental Tests 1961 through 1992*, Report DOE/NV-317, Revision 1, U.S. Department of Energy, Las Vegas, Nevada,. August 1996. [SRDB Ref ID 2435]

Strenge 2016. D. Strenge, *NIOSH Response to Short-Lived Radionuclide Issues Raised in Comment 5 of SC&A's NTS Resuspension Issues Status Report*, Revision 0-A, Oak Ridge Associated Universities Team, Oak Ridge, Tennessee. June 6, 2016.