Draft

ADVISORY BOARD ON
RADIATION AND WORKER HEALTH

National Institute for Occupational Safety and Health

REVIEW OF ORAUT-RPRT-0079, REVISION 00, "EVALUATION OF AIRBORNE EFFLUENT RELEASES FROM INITIAL ENGINE TEST NO. 10 AT THE IDAHO NATIONAL LABORATORY"

Contract No. 211-2014-58081
SCA-TR-2017-PR010, Revision 0

Prepared by

John Mauro, PhD, CHP
Steve Marschke

SC&A, Inc.
2200 Wilson Boulevard, Suite 300
Arlington, Virginia, 22201

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

October 2017

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

DOCUMENT TITLE:	Review of ORAUT-RPRT-0079, Revision 00, "Evaluation of Airborne Effluent Releases from Initial Engine Test No. 10 at the Idaho National Laboratory"
DOCUMENT NUMBER/ DESCRIPTION:	SCA-TR-2017-PR010
REVISION NO.:	0 (Draft)
SUPERSEDES:	N/A
EFFECTIVE DATE:	October 9, 2017
TASK MANAGER:	John Stiver, MS, CHP [signature on file]
PROJECT MANAGER:	John Stiver, MS, CHP [signature on file]
DOCUMENT REVIEWER(S):	Kathleen Behling [signature on file] Stephen L. Ostrow, PhD [signature on file] John Stiver, MS, CHP [signature on file]

Record of Revisions

Revision Number	Effective Date	Description of Revision
0 (Draft)	10/9/2017	Initial issue

TABLE OF CONTENTS

ABBREVIATIONS AND ACRONYMS

ABRWH	Advisory Board on Radiation and Worker Health
ANL-W	Argonne National Laboratory–West
ANP	Aircraft Nuclear Propulsion
ARA	Auxiliary Reactor Area
CDC	Centers for Disease Control and Prevention
CFA	Central Facilities Area
Ci	curie
Cs	cesium
DOE	U.S. Department of Energy
EBR-I	Experimental Breeder Reactor-I
GCRE	Gas Cooled Reactor Experiment
H-CL	horizontal centerline
HDE	Historical Dose Evaluation
ICPP	Idaho Chemical Processing Plant
ICRP	International Commission on Radiological Protection
IET	Initial Engine Test
INEL	Idaho National Engineering Laboratory
INL	Idaho National Laboratory
INL-HDE	Idaho National Laboratory Historical Dose Evaluation
NIOSH	National Institute for Occupational Safety and Health
NOAA	National Oceanic and Atmospheric Administration
NRC	U.S. Nuclear Regulatory Commission
ORAU	Oak Ridge Associated Universities
ORAUT	Oak Ridge Associated Universities Team
PNL	Pacific Northwest Laboratory
PNNL	Pacific Northwest National Laboratory
RSB	Radiation Studies Branch
RWMC	Radioactive Waste Management Complex
SPERT	Special Power Excursion Reactor Test
Sr	strontium
SRDB	Site Research Database

TAN	Test Area North
TRA	Test Reactor Area
TREAT	Transient Reactor Test Facility
U	uranium
X/Q	atmospheric dispersion factor

1.0 INTRODUCTION

This report fulfills the June 5, 2017, request by the Advisory Board on Radiation and Worker Health (the Board) that SC&A review the National Institute for Occupational Safety and Health (NIOSH) report, ORAUT-RPRT-0079, Revision 00, *Evaluation of Airborne Effluent Releases from Initial Engine Test No. 10 at the Idaho National Laboratory* (hereafter referred to as "RPRT-0079").

RPRT-0079 addresses Issue 2 originally raised by SC&A in *Review of the NIOSH Site Profile for the Idaho National Laboratory, Idaho* (SC&A 2005), which dealt with internal doses associated with episodic airborne emissions from the Aircraft Nuclear Propulsion (ANP) Program at the Test Area North (TAN) facilities at the Idaho National Laboratory (INL). The issue was discussed during the Argonne National Laboratory-West (ANL-W)/INL Work Group meeting held on November 10, 2015, where NIOSH committed to provide the Work Group with a white paper on this subject.

Detailed descriptions of the ANP Program and specific Initial Engine Test No. 10 (IET 10) experiments are provided in RPRT-0079, DOE 1991a, DOE 1991b, DOE 1991c, and SC&A & SENES 2005. This report is organized in two major sections, one dealing with estimates of the releases of radionuclides from IET 10 experiments (also referred to as runs), and the other dealing with the models and assumptions used to derive the outdoor doses to workers at INL due to those releases.

2.0 ATMOSPHERIC RELEASE ESTIMATES FROM IET 10 EXPERIMENTS

The estimates and subsequent review of the airborne emission and associated doses from IET 10 experiments have a long and complex history, which are described in DOE 1991a, DOE 1991b, SC&A & SENES 2005, SC&A 2005, and RPRT-0079, and are not repeated here in detail. However, as part of the review of this issue, it is instructive to briefly describe the major investigations performed by the U.S. Department of Energy (DOE), SC&A (for the Radiation Studies Branch [RSB] of the Centers for Disease Control and Prevention [CDC]), and now NIOSH (by the Oak Ridge Associated Universities Team [ORAUT]). In particular, this section reviews the purpose of each investigation, the type and magnitude of the differences in the source terms and doses, and the reasons for these differences.

The first investigation was performed by the Idaho National Engineering Laboratory Historical Dose Evaluation (INEL-HDE, or HDE) Task Group formed by DOE in December 1988, which published its findings in 1991 (DOE 1991a, b). These investigations were part of the historical dose reconstruction evaluation initiated over concern that weapons complex facilities might have released large amounts of radionuclides to the atmosphere, which could have had adverse impacts on public health at many locations throughout the United States. INL[1] was only one of many facilities for which these types of offsite dose reconstructions were performed. The primary goal of these dose reconstructions was to determine whether follow-up radioepidemiological investigations of the populations near the various weapons complex facilities were warranted considering the atmospheric releases that occurred over the many decades of operation.

The HDE Task Group, and later SC&A as a consultant to the CDC RSB, concluded that the atmospheric releases from the IET 10 series of experiments had a substantial potential for large offsite population doses. The releases from the IET 10 experiments were estimated by DOE to be 130,000 curies (Ci) from IET 10A and 140,000 Ci from IET 10B (see Table 5 of SC&A 2015, as well as SC&A & SENES 2005, where the respective releases are reported as 1.28×10^5 Ci and 1.36×10^5 Ci). The radionuclides identified in the DOE HDE reports are noble gases (xenon and krypton isotopes), which have little potential for internal dose, fission products (strontium-90 [Sr-90] and cesium-137 [Cs-137], among others), and uranium (U) isotopes (e.g., U-234, U-235, and U-238).

The second major assessment of the atmospheric releases from INL, performed by SC&A for the CDC (SC&A & SENES 2005), was initiated as a result of uncertainties in the estimates of the atmospheric releases and associated offsite doses at INL. SC&A's initial screening determined that atmospheric releases from IET experiments 3, 4, and 10 had the greatest potential for offsite exposure of all the INL releases, as well as the largest uncertainties in both releases and offsite doses. SC&A then investigated these releases and associated offsite doses in more detail in a 2005 report, *A Critical Review of Source Terms for Select Initial Engine Tests Associated with the Aircraft Nuclear Propulsion Program at INEL* (SC&A & SENES 2005). With respect to IET

[1] The laboratory is currently named the Idaho National Laboratory (INL) but went by several other names in previous time periods.

10 experiments, SC&A estimated atmospheric releases of 2×10^6 Ci, about 10-fold higher than those estimated by DOE in the HDE Task Group investigations.

SC&A's review of the INL site profile (SC&A 2005) noted that NIOSH had employed the DOE HDE Task Group estimates of the atmospheric releases from IET 10 experiments as the bases for its onsite dose calculations (not just for offsite doses). As a result, SC&A reported that these values were underestimated by about a factor of 10 based on the investigations SC&A had previously performed for the CDC in 2005.

The latest IET 10 study, NIOSH's RPRT-0079, responds to SC&A's Issue 2 in its site profile review regarding the IET 10 release estimates and constitutes the third attempt (after DOE and CDC/SC&A) to place a reasonable but bounding estimate on these atmospheric releases.

Table 4-2 of RPRT-0079 provides an estimate 1.77×10^3 Ci of the total fission product releases (it does not include noble gases) from the IET 10 experiments. Based on SC&A's review of the NIOSH spreadsheets in the Site Research Database (SRDB) in support of RPRT-0079, SC&A believes that Table 4-2 contains several typographical errors, as follows:

1) The list of IET 10 runs that were included in the RPRT-0079 calculation is given as 12, 13, 15, 17, 21, 24, 25, 28, 29, 37, 42, 43, 45, 46, 47, 52, 53, 54, 55, and 56. However, the IET 10 runs that were included in the Excel calculations differ slightly: 12, 13, 15, 17, 21, 24, 25, 28, 29, 37, 42, 43, 45, 46, **47A&B**, **48A**, 52, 53, 54, 55, and **56A&B**.

2) Table 4-2 only gives the IET 10 releases associated with Phase I of the IET 10 experiments, i.e., runs 12, 13, 15, 17, and 21. It should be revised to include the releases from Phases II and III, as shown below in Table 1. Note that the Phase I column matches exactly the RPRT-0079 Table 4-2 releases and that the Phase I releases are about two orders of magnitude less that the total releases. Table 1 provides the full set of releases from IET 10 as provided by ORAUT in the SRDB spreadsheets provided in support of RPRT-0079.

Table 1. IET 10 Releases from RPRT-0079 SRDB Spreadsheets (ORAUT 2017a, b, c), Ci

Nuclide	Phase I Runs: 12, 13, 15, 17, & 21	Phase II Runs: 24, 25, 28, & 29	Phase III Runs: 37, 42, 43, 45, 46, 47A, 47B, 48A, 52, 53, 54, 55, 56A, & 56B	Total All 23 runs
Br-84	3.03E+00	2.63E+01	5.58E+01	8.52E+01
Rb-89	6.15E+01	6.67E+02	3.44E+03	4.17E+03
Sr-89	5.82E-01	5.70E+00	9.87E+01	1.05E+02
Sr-90	1.84E-04	3.17E-03	1.30E-01	1.33E-01
Sr-91	3.99E+00	5.46E+01	6.79E+02	7.38E+02
Sr-92	4.22E+00	5.50E+01	6.19E+02	6.78E+02
Y-91	1.95E-02	1.01E+00	5.89E+01	5.99E+01
Y-92	2.23E+00	5.49E+01	7.12E+02	7.69E+02
Y-93	2.01E+00	4.08E+01	5.65E+02	6.08E+02

Nuclide	Phase I Runs: 12, 13, 15, 17, & 21	Phase II Runs: 24, 25, 28, & 29	Phase III Runs: 37, 42, 43, 45, 46, 47A, 47B, 48A, 52, 53, 54, 55, 56A, & 56B	Total All 23 runs
Zr-95	3.12E-02	1.27E+00	6.33E+01	6.46E+01
Zr-97	1.32E+00	2.85E+01	4.28E+02	4.57E+02
Nb-96	1.06E-04	2.38E-03	3.72E-02	3.97E-02
Mo-99	5.08E-01	1.41E+01	2.80E+02	2.95E+02
Ru-103	2.45E-02	9.79E-01	4.53E+01	4.63E+01
Ru-105	5.36E-01	9.10E+00	1.11E+02	1.20E+02
Ru-106	3.55E-04	1.47E-02	8.32E-01	8.47E-01
Sb-129	3.51E-01	5.94E+00	7.22E+01	7.85E+01
Te-131	1.55E+00	1.17E+01	1.05E+02	1.18E+02
Te-131m	5.57E-02	1.30E+00	2.11E+01	2.25E+01
Te-132	3.21E-01	9.30E+00	1.96E+02	2.05E+02
Te-133m	1.73E+00	1.46E+01	1.44E+02	1.61E+02
Te-134	3.02E+00	2.38E+01	2.20E+02	2.47E+02
I-131	6.49E-01	3.24E+01	2.43E+02	2.77E+02
I-132	1.28E-01	3.76E+00	3.34E+01	3.73E+01
I-133	8.46E+00	2.47E+02	9.78E+02	1.23E+03
I-134	2.70E+00	3.29E+01	1.13E+02	1.48E+02
I-135	2.16E+00	4.63E+01	1.50E+02	1.98E+02
Cs-137	4.34E-03	4.17E-02	7.42E-01	7.88E-01
Cs-138	1.61E+03	1.07E+04	9.90E+04	1.11E+05
Ba-139	5.86E+01	3.93E+02	4.06E+03	4.51E+03
Ba-140	2.68E-01	6.29E+00	1.89E+02	1.96E+02
Ba-141	7.17E-01	6.88E+00	4.13E+01	4.89E+01
Ba-142	6.28E-02	1.02E+00	3.35E+00	4.43E+00
La-141	3.67E+00	5.73E+01	6.82E+02	7.43E+02
La-142	4.70E+00	4.93E+01	5.26E+02	5.80E+02
Ce-141	3.87E-02	1.92E+00	9.46E+01	9.66E+01
Ce-143	8.52E-01	2.02E+01	3.33E+02	3.54E+02
Ce-144	5.97E-03	2.48E-01	1.38E+01	1.41E+01
Pr-143	4.60E-02	2.99E+00	1.46E+02	1.49E+02
Pr-144	5.96E-03	2.48E-01	1.38E+01	1.41E+01
U-234	9.07E-05	2.39E-04	1.58E-03	1.91E-03
U-235	2.89E-06	7.76E-06	5.02E-05	6.09E-05
U-238	2.69E-08	7.08E-08	4.68E-07	5.65E-07

It appears that the doses derived in RPRT-0079 are based on the total releases provided in ORAUT 2017a and not the values in Table 4-2. However, as discussed below, the releases used in RPRT-0079 to derive the outdoor internal exposures to workers at INL are in total about a factor 1.6 lower than those estimated in SC&A & SENES 2005.

To investigate the reasons for these differences, SC&A prepared Table 2, which uses the radionuclide releases in the spreadsheet in ORAUT 2017a (SRDB Ref. ID 166017) as the starting point, and compares those releases to the releases for the radionuclides reported by SC&A and the DOE HDE Task Group. Table 2 does not include noble gases because they do not contribute substantially to the internal doses. In total, SC&A's estimates are about 1.6 times higher than those NIOSH estimated in support of RPRT-0079 and about 7.6 times higher than those estimated by the DOE HDE Task Group. However, for many individual radionuclides, such as radioiodines, the SC&A & SENES 2005 estimates are 2 to 3 times higher.

Table 2. Estimates of the Total Atmospheric Releases from all IET Runs (Excluding Noble Gases) as Derived by DOE, SC&A, and ORAUT, Ci

Nuclide	Half-life	DOE HDE (DOE 1991)	SC&A (SC&A & SENES 2005)	RPRT-0079 (ORAUT 2017a)	Ratio (SC&A/ ORAUT)
Br-84	6.0 m	2.06E+01	2.26E+02	8.52E+01	2.65E+00
Rb-89	15.4 m	1.04E+03	8.11E+03	4.17E+03	1.94E+00
Sr-89	52.7 d	1.87E+01	1.46E+02	1.05E+02	1.39E+00
Sr-90+D	29 y	2.33E-02	1.82E-01	1.33E-01	1.37E+00
Sr-91+D	9.5 h	1.52E+02	1.19E+03	7.38E+02	1.61E+00
Sr-92	2.71 h	1.35E+02	1.05E+03	6.78E+02	1.55E+00
Y-91	58.8 d	1.02E+01	7.95E+01	5.99E+01	1.33E+00
Y-92	3.53 h	1.56E+02	1.21E+03	7.69E+02	1.57E+00
Y-93	10.3 h	1.29E+02	1.01E+03	6.08E+02	1.66E+00
Zr-95+D	64 d	1.12E+01	8.70E+01	6.46E+01	1.35E+00
Zr-97	17 h	1.01E+02	7.85E+02	4.57E+02	1.72E+00
Nb-96	23.35 h	8.82E-03	6.88E-02	3.97E-02	1.73E+00
Mo-99	66 h	5.98E+01	4.66E+02	2.95E+02	1.58E+00
Ru-103 +D	39 d	8.02E+00	6.26E+01	4.63E+01	1.35E+00
Ru-105	4.4 h	2.43E+01	1.90E+02	1.20E+02	1.58E+00
Ru-106+D	368 d	1.46E-01	1.13E+00	8.47E-01	1.33E+00
Sb-129	4.4 h	1.58E+01	1.24E+02	7.85E+01	1.58E+00
Te-131	25 m	2.42E+01	1.89E+02	1.18E+02	1.60E+00
Te-131m	30 h	4.97E+00	3.88E+01	2.25E+01	1.72E+00
Te-132+D	78 h	4.08E+01	3.18E+02	2.05E+02	1.55E+00
Te-133m	55 m	3.24E+01	2.53E+02	1.61E+02	1.57E+00
Te-134	42 m	5.04E+01	3.93E+02	2.47E+02	1.59E+00
I-131	8.05 d	5.49E+01	5.87E+02	2.77E+02	2.12E+00

Nuclide	Half-life	DOE HDE (DOE 1991)	SC&A (SC&A & SENES 2005)	RPRT-0079 (ORAUT 2017a)	Ratio (SC&A/ ORAUT)
I-132	2.3 h	9.18E+01	9.18E+01	3.73E+01	2.46E+00
I-133	20.3 h	3.86E+02	3.80E+03	1.23E+03	3.09E+00
I-134	52.0 m	3.43E+02	3.43E+02	1.48E+02	2.32E+00
I-135	6.68 h	5.31E+02	5.31E+02	1.98E+02	2.68E+00
Cs-137+D	30 y	1.40E-01	1.09E+00	7.88E-01	1.38E+00
Cs-138	32.2 m	2.23E+04	1.74E+05	1.11E+05	1.57E+00
Ba-139	82.9 m	8.86E+02	6.91E+03	4.51E+03	1.53E+00
Ba-140+D	13 d	3.48E+01	2.71E+02	1.96E+02	1.38E+00
Ba-141	18 m	1.14E+01	8.86E+01	4.89E+01	1.81E+00
Ba-142	11 m	1.50E+00	1.17E+01	4.43E+00	2.64E+00
La-141	3.87 h	1.49E+02	1.16E+03	7.43E+02	1.56E+00
La-142	92.5 m	1.16E+02	9.03E+02	5.80E+02	1.56E+00
Ce-141	32.5 d	1.67E+01	1.30E+02	9.66E+01	1.35E+00
Ce-143	33 h	7.77E+01	6.06E+02	3.54E+02	1.71E+00
Ce-144	284 d	2.42E+00	1.89E+01	1.41E+01	1.34E+00
Pr-143	13.59 d	2.48E+01	1.94E+02	1.49E+02	1.30E+00
Pr-144	17 m	2.42E+00	1.89E+01	1.41E+01	1.34E+00
U-234	2.47×10^5 y	4.29E-04	3.86E-03	1.91E-03	2.02E+00
U-235	7×10^8 y	1.37E-05	1.23E-04	6.09E-05	2.02E+00
U-238	2.5×10^9 y	1.27E-07	1.14E-06	5.65E-07	2.02E+00
Total	—	2.71E+04	2.06E+05	1.29E+05	1.60E+00

Table 4-1 of RPRT-0079 provides a convenient summary of the multiplication factors that adjust (i.e., correct) the release rates for the IET experiments provided by the DOE HDE Task Group. Table 3 is a reproduction of that table.

Table 3. SC&A and SENES (2005) Adjustment Factors

Nuclides	Adjustment factor
Br-84	11.0
I-131	10.7
I-133	9.8
U-234, U-235, U-238	9.0
Sr-90	2.2
Ar-41, I-132, I-134, I-135	1.0
Remaining 40 nuclides	7.8

Source: Reproduced from RPRT-0079, Table 4-1.

The differences between the total fission product releases estimated by SC&A as compared to those derived by DOE are due to the following reasons:

- SC&A believes that an additional 1.37 fuel cartridges were severely damaged.
- SC&A believes that there was 25% higher fuel burnup among the severely damaged fuel.
- SC&A used a higher release fraction for iodines released from severely damaged fuel (0.8 versus 0.5).
- SC&A used a release fraction of 0.006 for halogens and 0.002 for fission products for undamaged fuel, while DOE did not provide release estimates for undamaged fuel.

SC&A & SENES 2005 provides a detailed description of the bases for the differences between the SC&A and DOE HDE Task Group estimates. These differences were discussed extensively with representatives of DOE and the CDC, and DOE representatives stated that they had no objections to the methods and assumptions used by SC&A to derive the releases from IET 10. (There is no information available online attesting to this conclusion, but it can be attested to by the participants, including C.M. Wood (the CDC project manager), and John Mauro and Hans Behling, the contractors providing technical support to the CDC).

The differences between the release estimates derived by SC&A and those derived by NIOSH in RPRT-0079 (as provided in the spreadsheets supporting the report) are relatively small (a factor of 1.6 in total) but are worth exploring. Based upon the RPRT-0079 excerpts below and SC&A's review of the "166017_INEL – IET 10 Releases and Worker Intakes Spreadsheet.xlsx" Excel file (ORAUT 2017a), SC&A concludes that NIOSH did not recalculate the release for any of the IET 10 runs. Rather, NIOSH used the releases that were calculated by the DOE HDE Task Group and adjusted them by the factors developed by SC&A & SENES 2005, as summarized in Table 4-1 of RPRT-0079 (Table 3 above). Section 4.4 of RPRT-0079 (page 31) also provides the following description of the approach used by NIOSH to derive the releases:

> *Because of the complexity associated with reconstructing the IET #10 releases and because not all of the necessary information to calculate more accurate or defensible release estimates is available, the ORAU Team has relied on the work that was previously completed and reported.… The ORAU Team still considers the original fission product releases for IET #10 in the HDE documentation (DOE 1991c) to be the best values that are consistent with the available information. However, there is a reasonable chance that the original uranium releases in the HDE were underestimated. Therefore, to ensure that none of the IET #10 releases were underestimated, the adjusted release values were retabulated based on the information in SC&A and SENES (2005).*

Section 5.1 of RPRT-0079 (page 33) also states the following:

> *Of the 32 runs, 12 of the runs (5, 9, 11, 19, 20, 26, 32, 38, 40, 48, 49, and 57) had air concentrations of zero for all four downwind locations, and therefore did not have the potential to contribute to the internal doses of the INL workers. Therefore, the releases from these runs were excluded from the calculations for this report.*

It appears that, by using the SC&A & SENES 2005 adjustment factors as applied to the releases estimated by the DOE HDE Task Group, the NIOSH estimates adopt the basic approach used by

SC&A. However, NIOSH made some adjustments that SC&A believes account for the differences in the releases between those estimated in SC&A & SENES 2005 and those used by NIOSH to derive the doses in RPRT-0079. The first difference appears to be the elimination of 12 of the releases identified in Section 5.1 of RPRT-0079 for the reasons described above. To confirm that the rationale for excluding selected releases from IET 10 runs is reasonable, SC&A reviewed the spreadsheets used by NIOSH to derive the releases and onsite doses. The results of our investigations, as described in Appendix A, reveal that NIOSH appropriately eliminated the releases from those 12 runs because, at the time of those runs, the wind was blowing in a direction that could not have resulted in onsite doses. Attachment A also found that NIOSH incorrectly eliminated the releases from certain runs. However, this is a minor point that is more than accommodated by the other assumptions used by NIOSH to derive the doses. Therefore, the rationale for the differences between the releases as in SC&A & SENES 2005 and those derived by NIOSH in support of RPRT-0079 appear reasonable.

In addition, starting on page 30 RPRT-0079 provides seven significant points regarding the releases estimated in SC&A & SENES 2005. In summary, these seven points explain that:

1) The SC&A & SENES 2005 report does not provide sufficient detail about the basis for the estimated releases.

2) There is new evidence that the peak temperature of the fuel never reached 3,200 degrees Fahrenheit (which would imply that the releases were lower than those estimated by both DOE and SC&A).

3) NIOSH has a different interpretation of the degree of fuel damage and associated isotopic releases as implied by inspection of the residue associated with the damaged fuel.

SC&A believes these points might be important, and, if they are correct, the releases as estimated in SC&A & SENES 2005 and by the DOE HDE Task Group may have been substantially overestimated. However, it appears that the releases, as estimated by NIOSH in deriving the doses reported in RPRT-0079, do not take into account these seven points, but the points are discussed in RPRT-0079 to demonstrate the conservatism inherent in the release estimates that are used in RPRT-0079. These seven points are quite complex, and SC&A has no basis for disputing these points and did not investigate these issues further because they were not incorporated into the analyses in RPRT-0079.

The above review reveals that the release estimates appear to be reasonable, taking the following into consideration:

1) the relatively small differences between those derived by SC&A (SC&A & SENES 2005) and those derived by NIOSH (RPRT-0079)
2) the uncertainties in the estimates
3) our confirmation that the differences between the release estimates as derived by SC&A in SC&A & SENES 2005 and those derived by NIOSH in RPRT-0079 are justified based on inspection of the wind direction at the time of each release

3.0 ATMOSPHERIC DISPERSION FACTORS AND ASSOCIATED INTERNAL DOSE TO WORKERS OUTDOORS ON SITE

Section 5.0 of RPRT-0079 presents a detailed discussion of the models and assumptions used by NIOSH to derive the internal doses to onsite workers outdoors. A realistic estimate of the internal doses to workers due to atmospheric releases from the IET 10 runs would require information on the location of workers outdoors at the time of each episodic release associated with the 32 IET 10 runs tabulated in Table 3-1 of RPRT-0079.[2] In addition, meteorological conditions (wind speed, direction, and stability class; i.e., joint frequency data) would be required for the time periods associated with each run. Though this latter information is available, the overall calculation would require a significant level of effort and, in the end, would be a futile exercise because the actual time and location of the workers outdoors is not known. Instead, RPRT-0079 adopts a simple and extremely claimant-favorable approach to place an upper bound on the internal doses to onsite workers outdoors.

Given the wind trajectories depicted in Figure 5-1 of RPRT-0079, NIOSH identified eight locations on site where workers might have been outdoors during the IET 10 runs (see Table 5-1 of RPRT-0079). Given the releases associated with each run (Table 2 provides the total releases from all IET runs combined) and the designated downwind receptor locations, RPRT-0079 derives the atmospheric dispersion factors at each hypothetical receptor location for each run using a conventional Gaussian dispersion model. In applying this model, the report uses realistic meteorological data collected on site at the time of the releases and several simplifying, but highly conservative, assumptions to derive the atmospheric dispersion factors at each receptor location for each IET 10 release. Table A-1 of RPRT-0079 presents the hourly meteorological data at the time of each test (Tests 28, 29, 37, 42, 43, 45, 46, 47a and b, 52, 53, 54, 55, and 56a and b) considered applicable to this analysis (i.e., because they had the potential to cause internal doses to workers on site outdoors, as discussed above). The data in Table A-1 include the wind direction, wind speed, and the lower level (20 feet) and upper level (150 feet) temperatures that were prevalent at the beginning of each hour during each IET 10 run.

NIOSH could have run a puff advection model to derive the atmospheric dispersion factors at any location as a function of time. However, such an elaborate analysis would be an overreach because we do not have real information about the actual locations of the workers outdoors during the releases. Instead, ORAUT used a conventional centerline Gaussian dispersion model to derive the atmospheric dispersion factors at each of the eight locations for each of the IET 10 releases. In performing these calculations, ORAUT found that the highest atmospheric dispersion factors were obtained by assuming Stability Class E.[3] In reality, the actual stability class associated with each hour of each release and each location likely varied among the six stability classes (A through E) and probably overestimates the real atmospheric dispersion factors experienced at each location during all IET 10 runs by several-fold. (See Figure 5-4 and

[2] Note that Section 5.1 of RPRT-0079 provides a sound basis for excluding 12 of those runs based on information about the direction of the wind (see Figure 5-1 of RPRT-0079, which was excerpted from DOE-1991a, and which was based on a puff advection model [MESODIF] described in DOE 1991a, b, and c, which was used for offsite dose reconstruction by DOE).

[3] SC&A independently reviewed the X/Q calculations provided in the NIOSH spreadsheets cited in RPRT-0079 and confirmed the validity of the derived values (see Attachment A).

Table 5-4 of RPRT-0079, which shows the spread in sigma z [a measure of vertical atmospheric dispersion as a function of receptor location] and atmospheric dispersion factors, respectively; also see Attachment A to this report.) In addition, inherent in the approach adopted by NIOSH is the assumption that the outdoor worker at each location was located directly under the plume centerline for the duration of each run. **This assumption (i.e., that the worker is located beneath the centerline of the plume during all releases) makes the NIOSH dose calculation extremely conservative.** Another conservative assumption is that, in derivation of the atmospheric dispersion factors, no credit was taken to account for plume rise associated with the temperature of the gaseous effluents from the elevated stack.

The results of these calculations are provided in Table 7-1 of RPRT-0079, reproduced here as Table 4.

Table 4. IET 10 Internal Doses for Selected Organs (rem)

Organ	Total dose
Bone	7.81E–03
ET1[a]	1.22E+01
Lung	2.35E–02
Kidney	1.56E–03
Liver	3.19E–03
Lower Large Intestine	1.85E–02
Upper Large Intestine	1.30E–02
Red Bone Marrow	3.31E–03
Skin	8.48E–04
Thyroid	2.11E–01

[a] ET1 – Extrathoracic Region 1 in the ICRP's human respiratory model (ICRP 1994b).
Source: Reproduced from RPRT-0079, Table 7-1.

Section 8 of RPRT-0079 provides additional discussion of the uncertainties and conservatism inherent in these dose calculations.

SC&A concludes that, although NIOSH derives releases that are a factor of about 1.6 lower than those derived in SC&A & SENES 2005, the differences are small, considering the uncertainties in the assumptions used to derive the releases. In addition, our independent check of the wind direction during each test confirmed that NIOSH has a sound basis for excluding the releases from several tests (i.e., at the time of those tests, the wind was blowing in a direction that could not have exposed workers on site). **SC&A concludes that the dose reconstruction data, methods, and assumptions in RPRT-0079 are scientifically sound and claimant favorable.**

4.0 REFERENCES

DOE 1991a. *Idaho National Engineering Laboratory Historical Dose Evaluation, Volume 1*, DOE/ID-12119, U.S. Department of Energy, Idaho Operations Office, Idaho Falls, Idaho. August 1991. [SRDB Ref. ID 1107]

DOE 1991b. *Idaho National Engineering Laboratory Historical Dose Evaluation, Volume 2: Appendices*, DOE/ID-12119, U.S. Department of Energy, Idaho Operations Office, Idaho Falls, Idaho. August 1991. [SRDB Ref. ID 1109]

DOE 1991c. *Idaho National Engineering Laboratory Historical Dose Evaluation Quality Assurance Files – Source Term Quality Control Tasks (Episodic Releases) – IET #10 Source Term Characterization*, DOE/ID-12119-QAF-026, U.S. Department of Energy, Idaho Operations Office, Idaho Falls, Idaho. March 1991. [SRDB Ref. ID 88731]

ICRP 1994. *Dose Coefficients for Intakes of Radionuclides by Workers*, Publication 68, International Commission on Radiological Protection, Pergamon Press, Oxford, England. July 1994. [SRDB Ref. ID 22731]

NOAA 2017. "Pasquill Stability Classes," Web page, Air Resources Laboratory, National Oceanic and Atmospheric Administration. Accessed September 2017 at https://www.ready.noaa.gov/READYpgclass.php

NRC 1977. *Methods for Estimating Atmospheric Transport and Dispersion of Gaseous Effluents in Routine Releases from Light-Water-Cooled Reactors*, Regulatory Guide 1.111, Revision 1, U.S. Nuclear Regulatory Commission, Washington, DC. July 1977.

ORAUT 2017a. "166017_INEL – IET 10 Releases and Worker Intakes Spreadsheet.xlsx," Revision 0 [Excel spreadsheet], Oak Ridge Associated Universities Team, Oak Ridge, Tennessee. March 13, 2017. [SRDB Ref. ID 166017]

ORAUT 2017b. "166018_INEL - Dose Summary for IET 10 Releases Spreadsheet.xlsx," Revision 0 spreadsheet, Oak Ridge Associated Universities Team, Oak Ridge, Tennessee. March 21, 2017. [SRDB Ref. ID 166018]

ORAUT 2017c. "165830_INEL - IET 10 Releases from INEL-HDE Rev 0.xlsx," Rev. 0 spreadsheet, Oak Ridge Associated Universities Team, Oak Ridge, Tennessee. February 19, 2017. [SRDB Ref. ID 165830]

ORAUT-RPRT-0079. 2017. *Evaluation of Airborne Effluent Releases from Initial Engine Test No. 10 at the Idaho National Laboratory*, Revision 00, National Institute of Occupational Safety and Health, Cincinnati, Ohio. April 28, 2017.

PNL 1995. *Environmental Settings for Selected U.S. Department of Energy Installations—Support Information for the Programmatic Environmental Impact Statement and the Baseline Environmental Management Report*, PNL-10550, Pacific Northwest Laboratory. May 1995. [SRDB upload pending]

SC&A & SENES 2005. *A Critical Review of Source Terms for Select Initial Engine Tests Associated with the Aircraft Nuclear Propulsion Program at INEL*, SC&A, Inc. McLean, VA, and SENES Oak Ridge, Inc., Oak Ridge, Tennessee. July 2005. [SRDB Ref. ID 103215]

SC&A 2005. *Review of the NIOSH Site Profile for the Idaho National Laboratory, Idaho*, SCA-TR-TASK1-0005, Revision 0, SC&A, Inc. McLean, VA, September 23, 2005.

SC&A 2015. *Review of NIOSH Strategy for Reconstructing Internal Doses to Workers at Test Area North*, SCA-TR-2015-SEC0074A, SC&A, Inc. Vienna, VA, September 28, 2015.

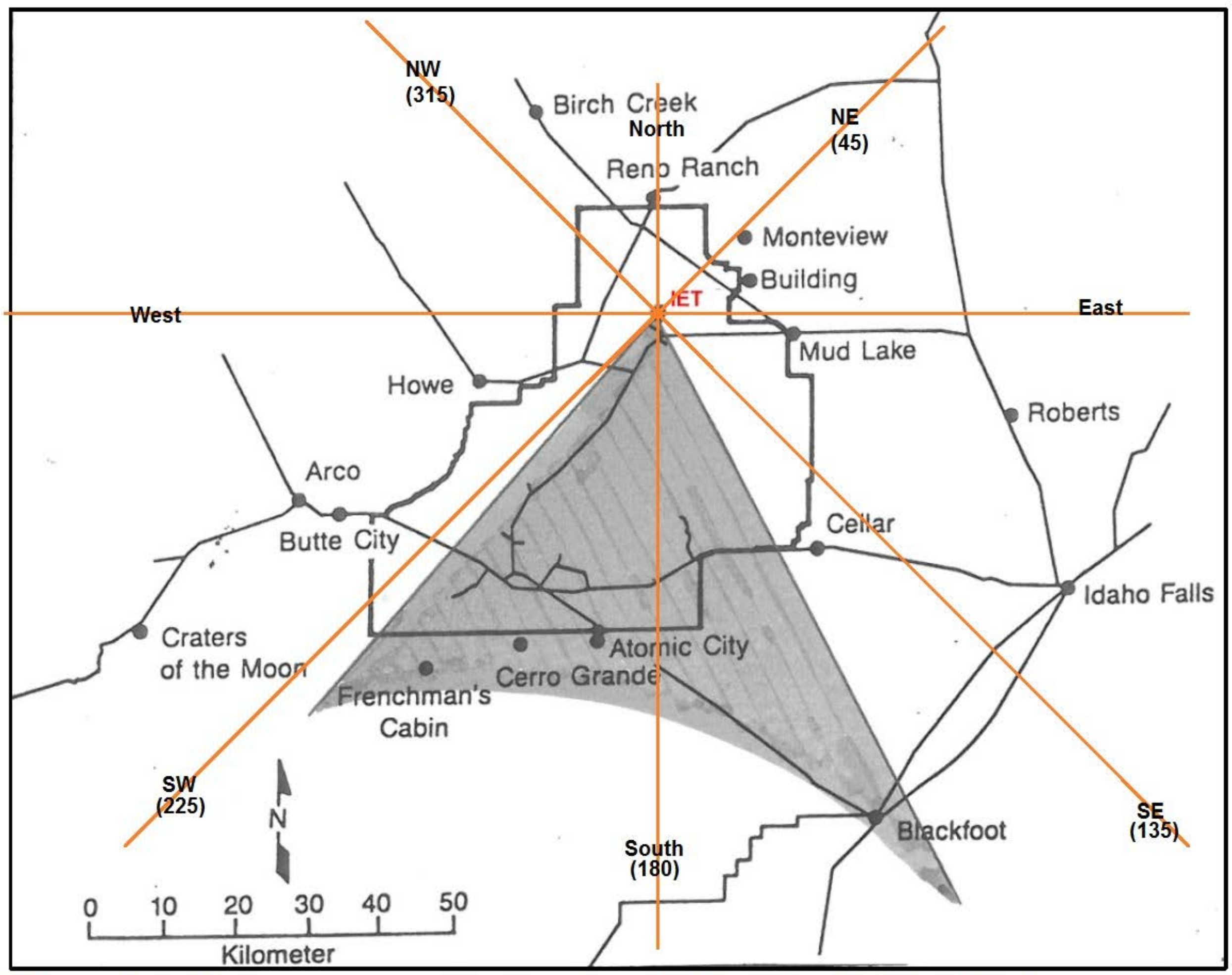
SRNL-STI-2012-00055. 2012. *A Recommended Pasquill-Gifford Stability Classification Method for Safety Basis Atmospheric Dispersion Modeling at SRS*, Revision 0, C. H. Hunter, Savannah River National Laboratory, Aiken, South Carolina. March 2012. [SRDB upload pending.]

APPENDIX A: CRITIQUE OF ORAUT-RPRT-0079 SUPPORTING CALCULATIONS

A.1. IET 10 RADIONUCLIDE RELEASE ADJUSTMENT

In this section, SC&A reviews the approach NIOSH used to limit the number of IET 10 runs included in their analysis. To perform the review, SC&A obtained the IET 10 run dates from RPRT-0079, Table 3-1, and the meteorological data from RPRT-0079, Attachment A. Not accounting for wind speed, SC&A included any IET 10 run that blew toward the SE (135°) to SW (225°) (See Figure A-1). Thus, if the recorded wind direction was between 0° and 45° or between 315° and 360° at any time during the run, then SC&A included that run's release.

Figure A-1. INL Site and Surrounding Areas; Modified by SC&A from ORAUT-RPRT-0079, Figure 5-1



With this simple approach, SC&A agrees with NIOSH on including or excluding 25 of the 37 IET #10 runs. Of the 12 runs for which we disagreed, SC&A's simplified analysis excluded 10 runs that NIOSH included. This is likely due to the fact that NIOSH accounted for travel time; i.e., if the recorded wind blew toward the four receptor points at any time during the release or during the travel time, then NIOSH included that run's release in their analysis. Extending the period of interest by 2 hours would move 7 of the 10 previously excluded runs to being included, and in agreement with NIOSH. Extending the period of interest by 3, 4, and 13 hours would include the remaining 3 previously excluded runs, in agreement with NIOSH.

Of more concern are the 2 runs that NIOSH excluded but that the SC&A analysis suggests should be included, namely, runs 48b and 57b. For run 48b, there are 3 hours of meteorological data (i.e., 03, 04, and 05 hours on February 24, 1958) showing 0.0° wind direction—blowing directly toward the South. Thus, by NIOSH's ground rules these hours should be included in the analysis. For run 57b, there is only a single hour of meteorological data, showing a 22.5° wind direction—blowing directly towards the SSW. By NIOSH's ground rules, this hour should likewise be included in the analysis. Run 57b is not a significant contributor to the radionuclide releases (<1% to the total release); however, run 48b is a significant contributor, about an addition third to the total release.

Table A-1. Results of SC&A Review of NIOSH IET 10 Release Modifications

Phase – Run	SC&A Review Result	Agree
I – 5	SC&A and NIOSH agree to Exclude	Yes
I – 9a	SC&A and NIOSH agree to Exclude	Yes
I – 9b	SC&A and NIOSH agree to Exclude	Yes
I – 11	SC&A and NIOSH agree to Exclude	Yes
I – 12	SC&A and NIOSH agree to Exclude	Yes
I – 13	SC&A and NIOSH agree to Exclude	Yes
I – 15	SC&A and NIOSH agree to Exclude	Yes
I – 17	SC&A and NIOSH agree to Exclude	Yes
I – 19	SC&A and NIOSH agree to Exclude	Yes
I – 20	SC&A and NIOSH agree to Exclude	Yes
I – 21	SC&A and NIOSH agree to Exclude	Yes
II – 24	Agree to Include, when time extended by 4 hrs	Yes
II – 25	Agree to Include, when time extended by 2 hrs	Yes
II – 26	SC&A and NIOSH agree to Exclude	Yes
II – 28	SC&A and NIOSH agree to Exclude	Yes
II – 29	SC&A and NIOSH agree to Exclude	Yes
II – 32	SC&A and NIOSH agree to Exclude	Yes
III – 37	SC&A and NIOSH agree to Exclude	Yes
III – 38	SC&A and NIOSH agree to Exclude	Yes
III – 40	SC&A and NIOSH agree to Exclude	Yes
III – 42	Agree to Include, when time extended by 1 hr	Yes
III – 43	Agree to Include, when time extended by 2 hrs	Yes
III – 45	Agree to Include, when time extended by 1 hr	Yes
III – 46	Agree to Include, when time extended by 1 hr	Yes

Phase – Run	SC&A Review Result	Agree
III – 47a	SC&A and NIOSH agree to Exclude	Yes
III – 47b	Agree to Include, when time extended by 1 hr	Yes
III – 48a	SC&A and NIOSH agree to Exclude	Yes
III – 48b	SC&A Included, NIOSH Excluded	No
III – 49	SC&A and NIOSH agree to Exclude	Yes
III – 52	SC&A and NIOSH agree to Exclude	Yes
III –53	SC&A and NIOSH agree to Exclude	Yes
III – 54	Agree to Include, when time extended by 1 hr	Yes
III – 55	Agree to Include, when time extended by 3 hrs	Yes
III – 56a	Agree to Include, when time extended by 13 hrs	Yes*
III – 56b	SC&A and NIOSH agree to Exclude	Yes
III – 57a	SC&A and NIOSH agree to Exclude	Yes
III – 57b	SC&A Included, NIOSH Excluded	No

Table A-2 summarizes the wind direction analysis and shows that most of the IET 10 runs were made when the wind was blowing out of the NE or North sectors.

Table A-2. Summary of Wind Direction Analysis

Affected Sector	# of IET 10 Runs – SC&A	# of IET 10 Runs – NIOSH	Total Non-Noble Gas Release (Ci) – SC&A*	Total Non-Noble Gas Release (Ci) – NIOSH
SE	0	0	0.00E+00	0.00E+00
SSE	1	1	2.80E+03	2.80E+03
S	9	9	1.85E+05	1.85E+05
SSW	5	4	4.28E+03	3.63E+03
SW	10	9	8.44E+04	3.27E+04
Totals	25	23	2.76E+05	2.24E+05

* The SC&A releases include IET 10 runs 48b and 57b, while the NIOSH releases do not include these two runs.

Table A-3 presents a breakdown by sectors of the IET 10 runs. This table can be used to determine which runs are the most significant contributors to the total IET 10 release, as well as the releases toward a particular downwind sector.

Table A-3. IET 10 Releases as a Function of Wind Direction, Percentage of Total IET 10 Release

Wind Direction* Associated with IET 10 Release	SC&A Release Total	SC&A Release Per Sector	NIOSH Release Total	NIOSH Release Per Sector
NNW 54	1.01%	100.00%	1.25%	100.00%
NNW Sector Total	1.01%	100.00%	1.25%	100.00%
N – 13	0.01%	0.01%	0.01%	0.01%
N – 15	0.00%	0.01%	0.00%	0.01%
N – 17	0.01%	0.02%	0.02%	0.02%
N – 21	0.76%	1.14%	0.94%	1.14%
N – 48a	0.57%	0.85%	0.70%	0.85%
N – 56a	4.80%	7.18%	5.91%	7.18%
N – 55	13.98%	20.90%	17.20%	20.90%
N – 56b	41.28%	61.72%	50.79%	61.72%
N – 53	5.46%	8.16%	6.72%	8.16%
N Sector Total	66.87%	100.00%	82.29%	100.00%
NNE – 28	1.02%	65.89%	1.26%	65.98%
NNE – 42	0.00%	0.15%	Not Included	Not Included
NNE – 57b	0.23%	15.14%	0.29%	15.17%
NNE – 52	0.24%	15.37%	0.29%	15.40%
NNE – 45	0.05%	3.45%	0.07%	3.45%
NNE Sector Total	1.55%	100.00%	1.90%	100.00%
NE – 12	0.00%	0.00%	0.00%	0.00%
NE – 29	0.63%	2.05%	0.77%	5.30%
NE – 37	0.02%	0.08%	0.03%	0.19%
NE – 47a	0.34%	1.11%	0.42%	2.87%
NE – 48b	18.73%	61.28%	Not Included	Not Included
NE – 46	1.20%	3.93%	1.48%	10.15%
NE – 43	0.52%	1.70%	0.64%	4.38%
NE – 47b	3.63%	11.87%	4.46%	30.65%
NE – 25	3.85%	12.60%	4.74%	32.53%
NE – 24	1.65%	5.39%	2.03%	13.91%
NE Sector Total	30.56%	100.00%	14.56%	100.00%
IET 10 Total	100.00%	—	100.00%	—

* The affected sectors are 180 degrees from the direction from which the wind is blowing.

From Table A-3, IET 10 run 56b contributes more than any other single run. According to RPRT-0079, Table 3-1, run 56b started on March 5, 1958, at 13:36 and ended on March 6, 1958, at 2:35; in other words, run 56b ran for 14 hours. Table A-4 presents the measured meteorology that was reported in RPRT-0079 during the run 56b release. Table A-4 shows that the wind was blowing toward the onsite worker locations during only one of the 14 hours of meteorological measurements. During run 56b, NIOSH conservatively assumed that all release occurred during the one hour the wind was blowing toward the worker's location (i.e., from the North toward the South). However, the data from the hours before and after are toward the South and SSE, respectively; it seems unlikely that there would be two 180° shifts in the wind direction during a 3-hour period. Also, the measured wind speed was 0 mph during the hour that the wind was blowing toward the worker's location. Since both the wind speed and direction are recorded as zero, this may be further indication that the meteorological data for that hour are unreliable.

For the remaining hours during run 56b, the wind was generally blowing from the South, away from the worker's location. Also, the measured wind speed averaged 8 mph (including the 1 and 0 mph measurements and excluding 8.6 mph), as opposed to the 6 mph used by NIOSH. Finally, the SC&A-calculated stability class is mostly D, with a single C, throughout run 56b. Similar results are expected if other IET 10 runs were to be evaluated to this level of detail.

Table A-4. IET 10 Run 56b Meteorology

Release Date	Release Time	Wind Speed (mph)	Wind Speed (m/s)	Stability Class	Wind Direction (degrees and sector)	Worker Impacted?
3/5/1958	13	19	8.5	D	180° S	No Impact
3/5/1958	14	14	6.3	C	202.5° SSW	No Impact
3/5/1958	15	10	4.5	C	180° S	No Impact
3/5/1958	16	6	2.7	D	157.5° SSE	No Impact
3/5/1958	17	9	4.0	D	157.5° SSE	No Impact
3/5/1958	18	9	4.0	D	157.5° SSE	No Impact
3/5/1958	19	10	4.5	D	135° SE	No Impact
3/5/1958	20	7	3.1	D	135° SE	No Impact
3/5/1958	21	6	2.7	D	67.5° ENE	No Impact
3/5/1958	22	10	4.5	D	90° E	No Impact
3/5/1958	23	5	2.2	D	90° E	No Impact
3/6/1958	0	4	1.8	D	180° S	No Impact
3/6/1958	1	0	0.0	D	0° N	Impact
3/6/1958	2	3	1.3	D	157.5° SSE	No Impact

A.2. ATMOSPHERIC DISPERSION

For the RPRT-0079 analysis, NIOSH utilized a centerline atmospheric dispersion factor (X/Q) based on a single set of meteorological assumptions: i.e., a wind speed of 6 mph (2.7 m/s) and stability class E (slightly stable). In this section, SC&A examines the effects that these assumptions have on the X/Qs, and resulting radionuclide concentrations and receptor doses.

The X/Qs calculated by NIOSH are presented in RPRT-0079, Table 5-4, and have been reproduced here in Table A-5. The Class E X/Q values in Table A-5 are limiting at each location. NIOSH states that they only used the higher value (i.e., 7.68E-07 s/m^3) because the results are not "significantly different" and would result in a "slight overestimate" of some intakes, "but eliminates the need to determine where a worker was located onsite during the period for the IET #10 releases." SC&A agrees with this approach.

Table A-5. NIOSH-Calculated Atmospheric Dispersion Factors, X/Q Values by Atmospheric Stability Class (s/m^3)

Area	Class A	Class B	Class C	Class D	Class E	Class F
ANL-W (TREAT), ICPP, TRA, SPERT (SPERT II), ARA (GCRE)	8.80E-09	1.68E-08	2.18E-08	2.10E-07	7.68E-07	1.11E-07
CFA, EBR-I, RWMC	6.01E-09	1.18E-08	1.55E-08	1.07E-07	5.37E-07	1.62E-07

Technical Area North Joint Frequency Table

Meteorological data are collected and organized into "joint frequency tables" that present the fraction of time that the data fall within a particular speed, stability class, and direction. For this analysis, SC&A focused on only wind speed and stability class.

For the INL Technical Area North, PNL-10550, *Environmental Settings for Selected U.S. Department of Energy Installations*, Exhibit 6.3, provides the joint frequency distribution of atmospheric stability, wind direction, and wind speed (PNL 1995). Table A-6 summarizes the Pacific Northwest National Laboratory (PNNL) data for wind speed and direction only. Note that the joint frequency distribution should sum to 100%, but that the Table A-6 joint frequency sums to 105.1%. SC&A has checked that our transcription from Exhibit 6.3 is correct, so the problem is with PNL-10550, Exhibit 6.3. Table A-6 shows that the meteorological conditions of 2.7 m/s wind speed and stability Class E are met about 8.9% of the time. Table A-7 presents the joint frequency for the PNNL data only when the wind is blowing from the five sectors of interest for this study, i.e., NW, NNW, North, NNE, and NE. Table A-7 shows that the meteorological conditions of 2.7 m/s wind speed and stability Class E are met about 13.1% of the time.

Table A-6. Idaho National Laboratory, Technical Area North – Joint Frequency Distribution of Atmospheric Stability and Wind Speed

Speed (m/s)	Stability Class A	Stability Class B	Stability Class C	Stability Class D	Stability Class E	Stability Class F	All
0.0–<1.6	0.065	0.009	0.008	0.017	0.014	0.105	0.217
1.6–<3.4	0.068	0.026	0.029	0.145	0.089	0.109	0.467
3.4–<5.6	0.000	0.012	0.029	0.111	0.036	0.000	0.188
5.6–<8.3	0.000	0.000	0.003	0.094	0.000	0.000	0.097
8.3–<11.0	0.000	0.000	0.000	0.057	0.000	0.000	0.057
>11.0	0.000	0.000	0.000	0.026	0.000	0.000	0.026
All	0.132	0.047	0.070	0.449	0.139	0.215	1.051

Source: PNL-10550, Exhibit 6.3

Table A-7. TAN Joint Frequency Distribution of Atmospheric Stability and Wind Speed for NW, NNW, North, NNE, and NE Sectors

Speed (m/s)	Stability Class A	Stability Class B	Stability Class C	Stability Class D	Stability Class E	Stability Class F	All
0.0–<1.6	0.030	0.005	0.006	0.016	0.016	0.091	0.163
1.6–<3.4	0.025	0.014	0.025	0.190	0.131	0.124	0.508
3.4–<5.6	0.000	0.005	0.014	0.110	0.041	0.000	0.170
5.6–<8.3	0.000	0.000	0.002	0.077	0.000	0.000	0.079
8.3–<11.0	0.000	0.000	0.000	0.055	0.000	0.000	0.055
>11.0	0.000	0.000	0.000	0.025	0.000	0.000	0.025
All	0.055	0.024	0.046	0.473	0.187	0.215	1.000

SC&A utilized the NIOSH-supplied Excel file, "166017_INEL - IET 10 Releases and Worker Intakes Spreadsheet.xlsx," to calculate the dispersion factors (X/Qs) at ANL-W (Transient Reactor Test Facility [TREAT]) for combinations of wind speeds and stability classes consistent with the PNL-010550, Exhibit 6.3, joint frequency table. Table A-8 shows the results of those calculations. Table A-9 shows the result of multiplying the values in Table A-7 with the corresponding values in Table A-8.

Table A-8. Horizontal Centerline (H-CL) Dispersion Factors at ANL-W (TREAT)

Speed (m/s)	Stability Class A	Stability Class B	Stability Class C	Stability Class D	Stability Class E	Stability Class F
0.0–<1.6	2.97E-08	5.68E-08	7.37E-08	7.09E-07	2.59E-06	3.76E-07
1.6–<3.4	9.50E-09	1.82E-08	2.36E-08	2.27E-07	8.29E-07	1.20E-07
3.4–<5.6	5.28E-09	1.01E-08	1.31E-08	1.26E-07	4.61E-07	6.68E-08
5.6–<8.3	3.42E-09	6.54E-09	8.48E-09	8.16E-08	2.98E-07	4.33E-08
8.3–<11.0	2.46E-09	4.71E-09	6.11E-09	5.88E-08	2.15E-07	3.12E-08
>11.0	2.16E-09	4.13E-09	5.36E-09	5.16E-08	1.88E-07	2.73E-08

Table A-9. TAN Joint Frequency Weighted H-CL Dispersion at ANL-W (TREAT)

Speed (m/s)	Stability Class A	Stability Class B	Stability Class C	Stability Class D	Stability Class E	Stability Class F	All
0.0–<1.6	8.78E-10	2.84E-10	4.14E-10	1.12E-08	4.14E-08	3.43E-08	8.84E-08
1.6–<3.4	2.39E-10	2.55E-10	5.81E-10	4.31E-08	1.08E-07	1.49E-08	1.67E-07
3.4–<5.6	0.00E+00	5.04E-11	1.86E-10	1.38E-08	1.88E-08	0.00E+00	3.29E-08
5.6–<8.3	0.00E+00	0.00E+00	1.33E-11	6.30E-09	0.00E+00	0.00E+00	6.31E-09
8.3–<11.0	0.00E+00	0.00E+00	0.00E+00	3.23E-09	0.00E+00	0.00E+00	3.23E-09
>11.0	0.00E+00	0.00E+00	0.00E+00	1.30E-09	0.00E+00	0.00E+00	1.30E-09
All	1.12E-09	5.90E-10	1.19E-09	7.89E-08	1.68E-07	4.92E-08	2.99E-07

The NIOSH-supplied Excel file, "166017_INEL - IET 10 Releases and Worker Intakes Spreadsheet.xlsx," gives the ANL-W (TREAT) dispersion factor as 7.68E-07 sec/m^3, whereas the TAN joint frequency weighted dispersion factor is 2.99E-07 sec/m^3. Similar results are expected for the other dose receptor locations included in the NIOSH RPRT-0079 analysis.

ORAUT-RPRT-0079, Attachment A

RPRT-0079, Attachment A, provides meteorological data collected at the INL Central Facilities Area (CFA) and TAN during the IET 10 test period from December 20, 1957, to March 6, 1958. Attachment A provides wind speed and directions data and was used to determine which IET 10 runs to include in the analysis (see Section A.1). Although Attachment A does not provide stability class data, it does provide the temperature measured at two different heights, which can be used to estimate stability class (see Table A-10). This allows for an IET 10-specific joint frequency table to be formed from the Attachment A data, as shown in Table A-11. Table A-12 shows the result of multiplying the values in Table A-8 by the corresponding values in Table A-11.

Table A-10. Relationship Between Delta Temperature and Stability Class

Pasquill Class	Delta T/Delta Z (°C/100 m)
A	-1.9
B	-1.9 to -1.7
C	-1.7 to -1.5
D	-1.5 to -0.5
E	-0.5 to 1.5
F	1.5 to 4.0
G	>4.0

Source: NOAA 2017.

Table A-11. Joint Frequency Distribution of Stability Class and Wind Speed for IET 10 Runs

Speed (m/s)	Stability Class A	Stability Class B	Stability Class C	Stability Class D	Stability Class E	Stability Class F	Stability Class G	All
0.0–<1.6	0.0000	0.0000	0.0379	0.2385	0.0892	0.0546	0.0654	0.4857
1.6–<3.4	0.0005	0.0027	0.0422	0.1833	0.0568	0.0330	0.0254	0.3440
3.4–<5.6	0.0000	0.0000	0.0173	0.0481	0.0043	0.0022	0.0000	0.0719
5.6–<8.3	0.0000	0.0000	0.0103	0.0422	0.0016	0.0000	0.0000	0.0541
8.3–<11.0	0.0000	0.0000	0.0022	0.0195	0.0005	0.0000	0.0000	0.0222
>11.0	0.0000	0.0000	0.0011	0.0195	0.0011	0.0005	0.0000	0.0222
All	0.0005	0.0027	0.1109	0.5511	0.1536	0.0903	0.0909	1.0000

Table A-12. IET 10 Joint Frequency Weighted H-CL Dispersion at ANL-W (TREAT)

Speed (m/s)	Stability Class A	Stability Class B	Stability Class C	Stability Class D	Stability Class E	Stability Class F*	All
0.0–<1.6	0.00E+00	0.00E+00	2.79E-09	1.69E-07	2.31E-07	4.51E-08	4.48E-07
1.6–<3.4	5.14E-12	4.92E-11	9.94E-10	4.16E-08	4.71E-08	7.02E-09	9.67E-08
3.4–<5.6	0.00E+00	0.00E+00	2.27E-10	6.07E-09	1.99E-09	1.45E-10	8.43E-09
5.6–<8.3	0.00E+00	0.00E+00	8.71E-11	3.44E-09	4.84E-10	0.00E+00	4.01E-09
8.3–<11.0	0.00E+00	0.00E+00	1.32E-11	1.14E-09	1.16E-10	0.00E+00	1.27E-09
>11.0	0.00E+00	0.00E+00	5.79E-12	1.00E-09	2.04E-10	1.48E-11	1.23E-09
All	5.14E-12	4.92E-11	4.12E-09	2.22E-07	2.81E-07	5.23E-08	5.60E-07

* The Class G frequencies have been included with Class F, because "*the criteria for class G are approximations that do not have an explicit basis in Pasquill's methodology*" (SRNL-STI-2012-00055, page 6).

The NIOSH-supplied Excel file, "166017_INEL - IET 10 Releases and Worker Intakes Spreadsheet.xlsx," gives the ANL-W (TREAT) dispersion factor as 7.68E-07 sec/m^3, whereas the TAN joint frequency weighted dispersion factor is 5.60E-07 sec/m^3. Similar results are expected for the other dose receptor locations included in the NIOSH RPRT-0079 analysis.

Horizontal Off-Centerline

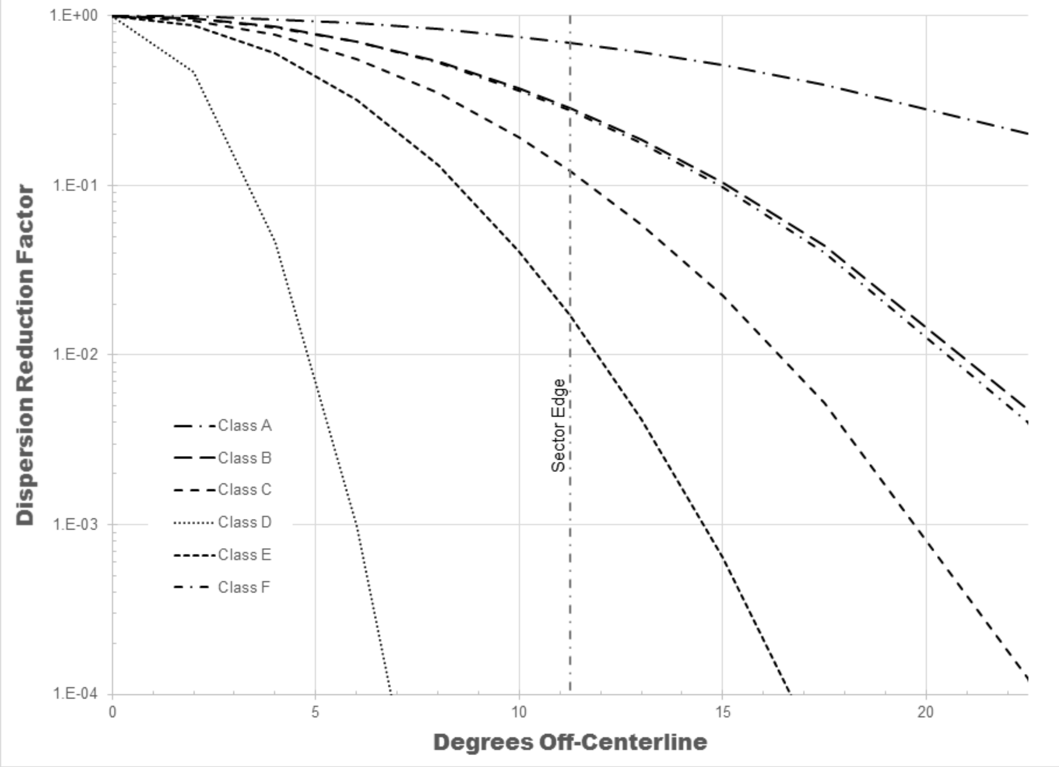
The equation used to calculate atmospheric dispersion for RPRT-0079 is given by NIOSH as:

$$X/Q = (2\ \pi\ \sigma_Y\ \sigma_Z\ u)^{-1}\ \exp[-½\ (y/\sigma_Y)^2]\ \{\exp[-½\ ((z-H)/\sigma_Z)^2] + \exp[-½\ ((z+H)/\sigma_Z)^2]\}$$

The exponential term "$\exp[-½\ (y/\sigma_Y)^2]$" accounts for the receptor being off the horizontal centerline of the plume. For all RPRT-0079 dispersion factors, NIOSH assumed that y = 0 m, i.e., that the dose receptor is located on the plume's horizontal centerline. In this section, SC&A investigates the effect of the dose receptor being located off the horizontal centerline.

Figure A-2 shows the results of solving only the exponential term $\exp[-½\ (y/\sigma_Y)^2]$ for the six stability classes.

Figure A-2. Horizontal Off-Centerline Dispersion Reduction Factor



As shown in Figure A-2, the largest dispersion factor reduction occurs for stability Classes D and E. Table A-9 shows that about 44.9% and 13.9% of the time the TAN meteorology is measured in those classes. Likewise, Table A-11 shows that about 55.1% and 15.4% of the time during the IET 10 runs, the dispersion classes were in Class D and Class E, respectively.

As discussed in Section A.1, in the release calculation NIOSH included all IET 10 releases that were directed toward the SE to SW sectors. Figure A-2 shows that it is highly unlikely that an individual located in one sector would receive exposure to a plume travelling in an adjacent (or further away) sector. What this means is that an individual continuously occupying a downwind location would only be exposed to releases that occurred when the wind was blowing toward that location, and that using the total release as calculated by NIOSH would overestimate the individual's exposure.

Table A-2 shows the SC&A-calculated wind direction IET 10 releases. It can be used to estimate the conservatism of using the entire NIOSH-calculated release for all locations.

Vertical Centerline

NIOSH gives the equation used to calculate atmospheric dispersion for RPRT-0079 as:

$$X/Q = (2\,\pi\,\sigma_Y\,\sigma_Z\,u)^{-1} \exp[-½\,(y/\sigma_Y)^2]\,\{\exp[-½\,((z-H)/\sigma_Z)^2] + \exp[-½\,((z+H)/\sigma_Z)^2]\}$$

The exponential term "$\{\exp[-½\,((z-H)/\sigma_Z)^2] + \exp[-½\,((z+H)/\sigma_Z)^2]\}$" accounts for the receptor being vertically off the centerline of the plume. In this term, H and z represent the heights of the release and dose receptor, respectively. For all RPRT-0079 dispersion factors, NIOSH assumed that the releases occurred at a height of 47.5 m (i.e., a 150-foot stack) and assumed a receptor height of 1.7 m. When these two parameters are set to zero, the resulting dispersion factors are calculated at the plume's vertical centerline. On the NIOSH-supplied Excel file, "166017_INEL - IET 10 Releases and Worker Intakes Spreadsheet.xlsx," SC&A set these parameters to zero, and the resulting X/Qs are shown in Table A-13.

Table A-13. Vertical and Horizontal Centerline Dispersion Factors, X/Q Values by Atmospheric Stability Class (s/m^3)

Area	Class A	Class B	Class C	Class D	Class E	Class F
ANL-W (TREAT), ICPP, TRA, SPERT (SPERT II), ARA (GCRE)	8.80E-09	1.68E-08	2.18E-08	2.11E-07	8.73E-07	2.70E-06
CFA, EBR-I, RWMC	6.01E-09	1.18E-08	1.55E-08	1.07E-07	5.91E-07	1.90E-06

The NIOSH-supplied Excel file, "166017_INEL - IET 10 Releases and Worker Intakes Spreadsheet.xlsx," gives the highest dispersion factor as 7.68E-07 sec/m^3 and is associated with Class E (see Table A-5), whereas the highest vertical centerline dispersion factor is 2.70E-06 sec/m^3 and is associated with Class F.

Sector Average

The equation given above is usually used to calculate dispersion of short time periods, e.g., from hours to days following an episodic release. When releases occur over long periods of time, the long-term or annual average values of X/Q is calculated via Regulatory Guide 1.111, Revision 1, *Methods for Estimating Atmospheric Transport and Dispersion of Gaseous Effluents in Routine Releases from Light-Water-Cooled Reactors*, Equation 3 (NRC 1977):

$$X/Q = 2.032\ f_{ij}\ (x\ u_i\ \sigma_{Zj})^{-1}\ \exp[-((z-H)^2/(2\sigma_{Zj}^2)]$$

The above equation assumes a continuous release and that the resulting effluent concentrations would be distributed evenly across a 22½° direction sector. Using the above equation, SC&A calculated the sector average dispersion factor for each INL area analyzed by NIOSH; Table A-4 provides the results.

Table A-14. Sector Average Dispersion Factors, X/Q Values by Atmospheric Stability Class (s/m^3)

Area	Class A	Class B	Class C	Class D	Class E	Class F
ANL-W (TREAT)	1.28E-08	1.28E-08	1.28E-08	3.64E-08	2.52E-07	7.16E-08
ICPP	1.02E-08	1.02E-08	1.02E-08	2.90E-08	2.01E-07	5.70E-08
TRA	1.01E-08	1.01E-08	1.01E-08	2.89E-08	2.00E-07	5.68E-08
SPERT (SPERT II)	1.02E-08	1.02E-08	1.02E-08	2.90E-08	2.00E-07	5.69E-08
ARA (GCRE)	9.77E-09	9.77E-09	9.77E-09	2.79E-08	1.93E-07	5.48E-08
CFA	9.14E-09	9.14E-09	9.14E-09	1.83E-08	1.59E-07	8.91E-08
EBR-I	8.11E-09	8.11E-09	8.11E-09	1.62E-08	1.42E-07	7.91E-08
RWMC	7.75E-09	7.75E-09	7.75E-09	1.55E-08	1.35E-07	7.55E-08

The first thing to notice about Table A-14 is that the dispersion factors differ for each location. This is because the distance to the location is included in the calculation (see "x" in the above equation). The second is that the sector average X/Q is the same for Classes A, B, and C. This occurs because the sigma-z value was limited to 2,000 m, and the graph did not depict sigma-z values for these classes beyond a distance of 5,500 m.

The NIOSH-supplied Excel file, "166017_INEL - IET 10 Releases and Worker Intakes Spreadsheet.xlsx," gives the highest dispersion factor as 7.68E-07 sec/m^3 and is associated with Class E (see Table A-5), whereas the highest sector average dispersion factor is 2.52E-07 sec/m^3 and is associated with Class F.

The above analyses demonstrate that overall, the approach used by NIOSH to derive atmospheric dispersion factors at potential locations of onsite workers outdoors is extremely claimant favorable.