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Evaluation of Airborne Effluent Releases from Initial Engine Test No. 10 at the Idaho National Laboratory

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PUBLICATION RECORD

EFFECTIVE DATE	REVISION NUMBER	DESCRIPTION
04/28/2017	00	New document initiated to evaluate airborne effluent releases from Initial Engine Test #10 at the Idaho National Laboratory. Incorporates formal internal and NIOSH review comments. Training required: As determined by the Objective Manager. Initiated by Brian P. Gleckler.

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ACRONYMS AND ABBREVIATIONS

A&M	Assembly & Maintenance (Area)
ANL-W	Argonne National Laboratory-West
ANP	aircraft nuclear propulsion
ARA	Army (later Auxiliary) Reactor Area
Bq	becquerel
CFA	Central Facilities Area
Ci	curie
cm	centimeter
CTF	Core Test Facility
DOE	U.S. Department of Energy
EBR-I	Experimental Breeder Reactor No. 1
ft	foot
g	gram
GCRE	Gas-Cooled Reactor Experiment
GE	General Electric Company
HDE	*Idaho National Engineering Laboratory Historical Dose Evaluation*
HTRE	Heat Transfer Reactor Experiment
ICPP	Idaho Chemical Processing Plant
ICRP	International Commission on Radiological Protection
IET	Initial Engine Test
IMBA	Integrated Modules for Bioassay Analysis
INL	Idaho National Laboratory
in.	inch
lb	pound
m	meter
mi	mile
min	minute
mph	miles per hour
NIOSH	National Institute for Occupational Safety and Health
ORAU	Oak Ridge Associated Universities
RaLa	radioactive lanthanum
rpm	revolutions per minute
RSAC	Radiological Safety Analysis Computer (Program)
RWMC	Radioactive Waste Management Complex
s	second
SPERT	Special Power Excursion Reactor Test
SRDB Ref ID	Site Research Database Reference Identification (number)
TAN	Test Area North

TBD	technical basis document
TRA	Test Reactor Area
TREAT	Transient Reactor Experiment and Test (facility)
°C	degrees Celsius
°F	degrees Fahrenheit

1.0 PURPOSE

The purpose of this document is to evaluate the airborne effluent releases from the Initial Engine Test No. 10 (IET #10) and determine if the Idaho National Laboratory (INL) workers were potentially exposed to that airborne radioactivity. The results of this evaluation are intended to assist the National Institute for Occupational Safety and Health (NIOSH) with its response to Comment 2 in SCA-TR-TASK1-0005, *Review of the NIOSH Site Profile for the Idaho National Laboratory, Idaho* (SC&A and Salient 2006).

2.0 BACKGROUND

It should be noted that INL has been known by several names throughout its history. It has been the National Reactor Testing Station (1949 to 1973), Idaho National Engineering Laboratory (1974 to 1996), Idaho National Engineering and Environmental Laboratory (1997 to 2004), and now INL (2005 to present). For convenience, this document uses INL.

2.1 ORIGIN AND APPLICABILITY OF COMMENT

Comment 2 in SCA-TR-TASK1-0005 (SC&A and Salient 2006) was made about the information in Revision 00 of the ORAUT-TKBS-0007-4, *Technical Basis Document for the Idaho National Engineering and Environmental Laboratory (INEEL) – Occupational Environmental Dose* (ORAUT 2004a). Even though the current version of this document is Revision 02, Comment 2 is still considered valid because no significant changes have been made to this document in relation to how episodic releases should be addressed in dose reconstructions (ORAUT 2004a, 2010a). However, it should be noted that the title of this technical basis document (TBD) changed to *Idaho National Laboratory and Argonne National Laboratory-West – Occupational Environmental Dose* for Revision 02 (ORAUT 2010a; henceforth environmental TBD).

2.2 SUMMARY OF THE ISSUE

Comment 2 as stated in the INL Issue Resolution Matrix for Findings and Key Observations of SC&A and Salient (2006, Attachment 5) is:

> *Issue 2: (5.1.1.2) Episodic Airborne Release - The airborne releases associated with several of the Initial Engine Tests of the Aircraft Nuclear Propulsion (ANP) Program were likely to have been underestimated by factors ranging from **2 to 7**. Also, NIOSH did not evaluate the uncertainties associated with the deficiencies in air monitoring equipment* [emphasis added].

The sections relevant to Comment 2 in the main body of the SC&A and Salient (2006) are:

> *5.1.1.2.1 Completeness and Quality of Episodic Releases Data*
>
> *The airborne releases associated with several of the Initial Engine Tests (IETs 3, 4, and 10) of the Aircraft Nuclear Propulsion (ANP) Program, as estimated by the INELHDE* [Idaho National Engineering Laboratory Historical Dose Evaluation (HDE)]*, were likely to have been underestimated as follows:*
>
> - *IET 3 – underestimate of total radionuclide release by up to a factor of about 3*
> - *IET 4 – underestimate of noble gases by up to a factor of about 16, halogens by up to a factor of about 7, and solids by a factor of up to about 2*

- *IET 10 – underestimate of total radionuclide releases by up to a factor of about 7*

These concerns were also cited in *A Critical Review of Source Term for Select Initial Engine Tests Associated with the Aircraft Nuclear Propulsion Program at INEL*, which states the following (SC&A and SENES 2005, p. 62):

> *The HDE Task Group acknowledged the absence of available raw effluent data as well as the deficiencies/limitations of summary data contained in the report by Thornton et al. (1962b). The HDE Task Group, therefore, modeled release estimates that were principally based on historical operating records and photographic evidence, which characterized the extent of fuel damage to the HTRE No. 1 reactor core. … Embedded in the HDE Task Group model of radioactive releases are several assumptions that potentially may have underestimated the true release quantities of fission products. To estimate realistic but near maximum release values, SC&A identified four key model parameters whose values differed significantly from those assumed by the HDE Task Group….*

3.0 OVERVIEW OF THE AIRCRAFT NUCLEAR PROPULSION PROGRAM AND INITIAL ENGINE TEST NO. 10

IET #10 was part of (HTRE-2), which was part of the ANP Program in the Test Area North (TAN) portion of the INL site operated by the General Electric Company (GE). Figure 3-1 shows where TAN was located in relation to the other operating areas on the INL site. The ANP Program facilities at the INL site were in TAN and consisted of an Administration Area, an Assembly & Maintenance (A&M) Area, and the IET Facility. The Administration Area consisted of a guardhouse, office building, service building, warehouse, fuel oil storage, water supply, cafeteria, and first aid services. Figure 3-2 is a more detailed map of the facilities associated with the ANP Program. The following subsections describe the reactor and facilities associated with the IET #10 effluent releases.

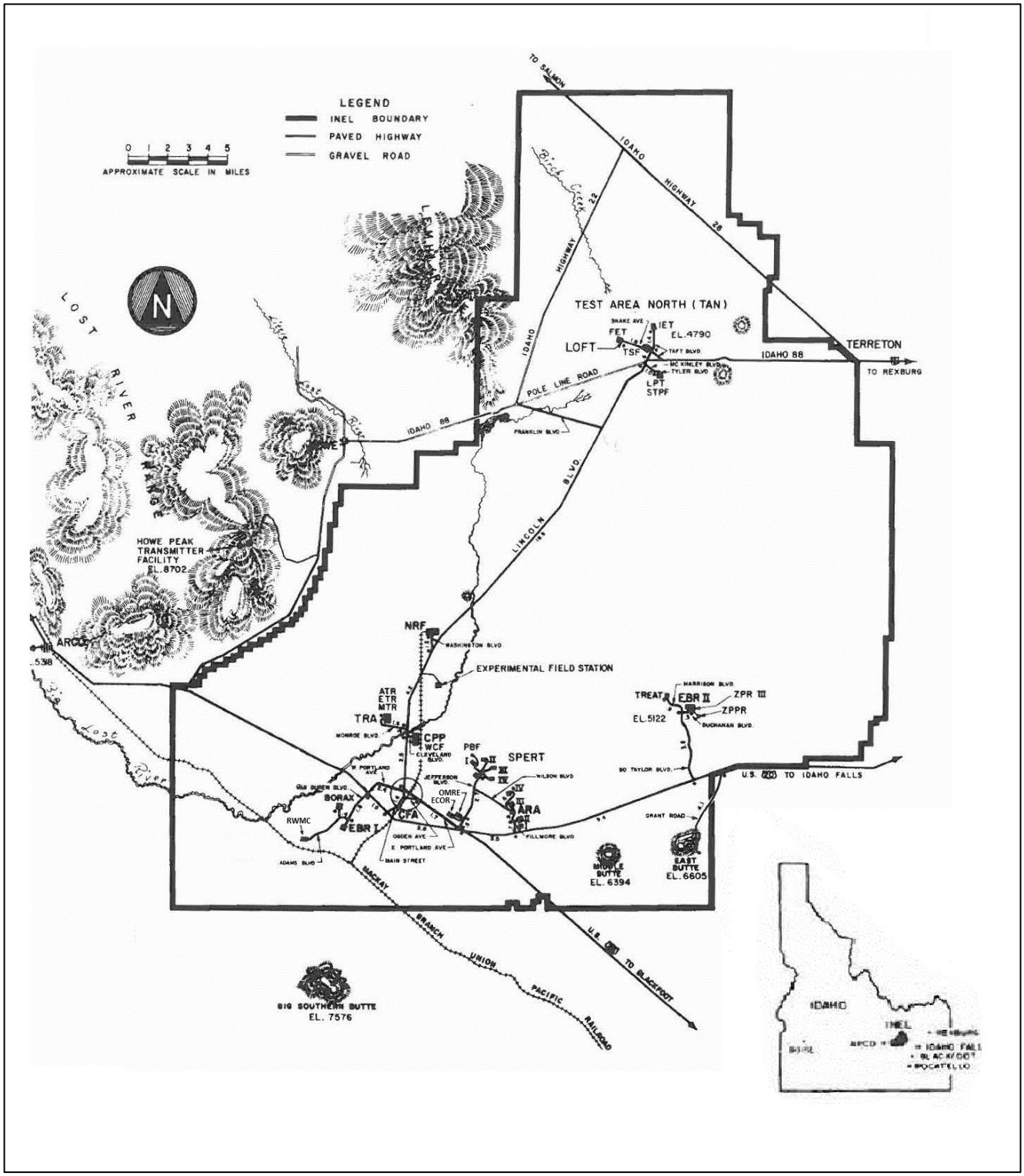

Figure 3-1. Map of INL site (ERDA 1975).

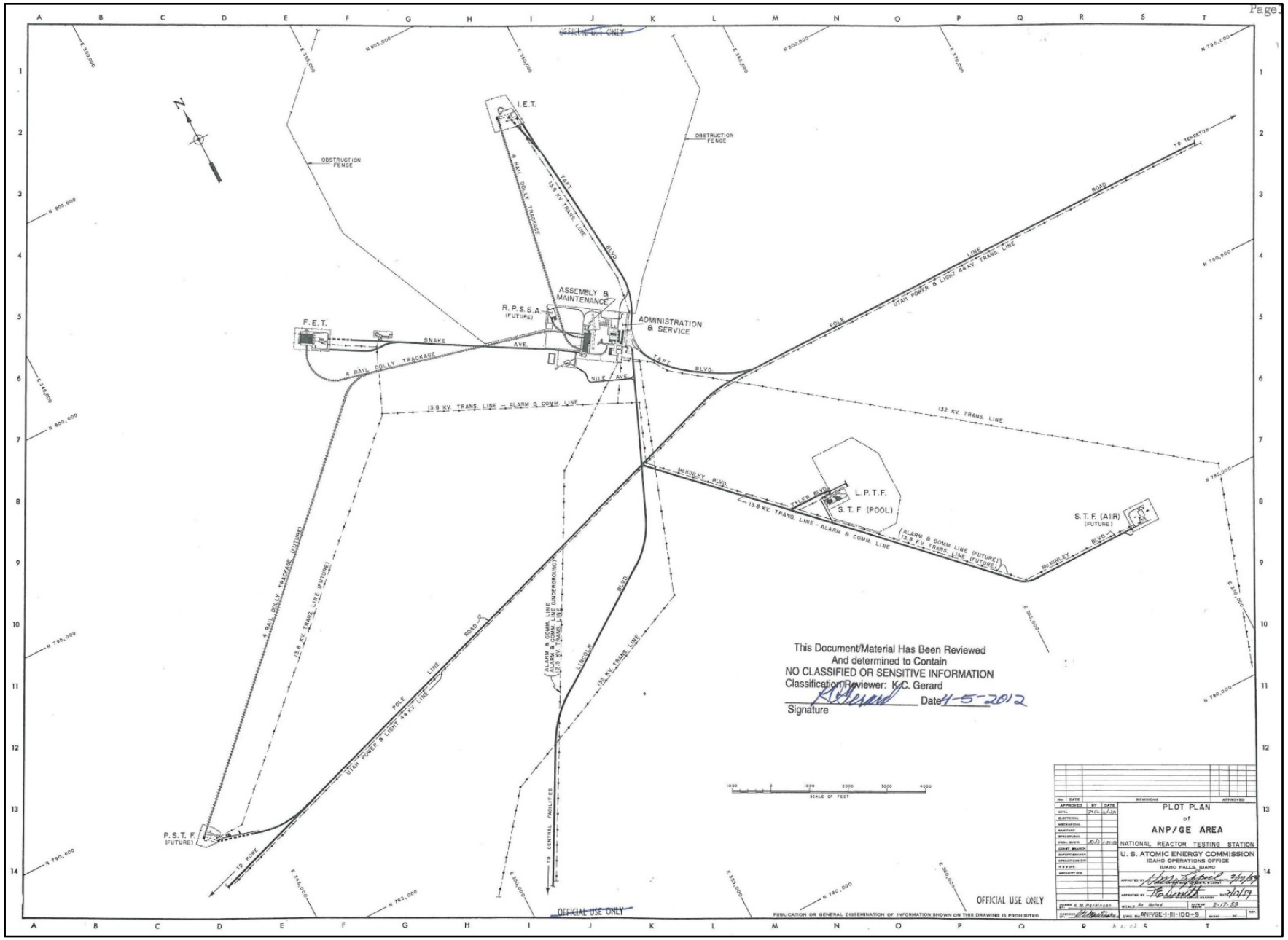

Figure 3-2. Facilities associated with the ANP Program (AEC 1954–1960).

3.1 INITIAL ENGINE TEST FACILITY

The IET Facility was approximately 6,000 ft (1,828 m) from the Administration and A&M Areas. It included shielded underground control and equipment rooms, jet engine fuel storage, water cooling facilities, and an effluent exhaust gas system. The facility was unique among other reactor installations in that the radiation shielding enclosed the personnel rather than the reactor, which made the facility very flexible for adapting to testing and operating power plants of varying size. The power plant could be viewed directly from the control room through either of two periscope eyepieces. Personnel could be dropped off or picked up within 100 ft of the power plant by a shielded locomotive. The locomotive was equipped with a shielded retractable hatchway in the floor of the cab that would mate with a hatch that was between the two center rails. Personnel could then travel to and from the control room via an underground tunnel (GE 1953). Figure 3-3 shows the layout of the IET Facility.

The effluent exhaust gas system was designed to handle the disposal of about 250 lb of air per second with provisions for expansion to 600 lb/s (GE 1953). The system consists of stainless-steel ductwork that leads from a coupling station to a 150-ft (45.7-m) exhaust stack with a 15.5-ft (4.72-m) inside diameter at the top of the stack (GE 1953; Parsons 1955). The reactor coolant air travels through approximately 200 ft of 76-in. diameter ductwork before reaching the exhaust stack (GE 1953; Parsons 1963). In addition to the reactor coolant air, ambient air enters the exhaust stack through the porous firebrick liner, which dilutes the effluent air coming from the 76-in. duct (Boone, Lofthouse, and VanVleck 1959; Parsons 1955). During IET #4, an augmentation factor of 1.25 was calculated for this dilution (Boone, Lofthouse, and VanVleck 1959). Figure 3-4 is a drawing of the IET exhaust system. Figure 3-5 is a picture of the IET Facility that shows the underground control room, the building that housed the power plant, a portion of the exhaust system, and the stack.

3.2 CORE TEST FACILITY

To provide a test vehicle for the HTREs, a Core Test Facility (CTF) was built in which various experimental reactor types could be tested. The CTF consisted of two turbojet engines, a large shield tank, and accessory equipment, all of which was mounted on a mobile platform. The experimental reactors and shield plug were then inserted into the shield tank to become an integral unit. All principal elements of a nuclear propulsion system – reactor, engine, and controls – were thus incorporated into the test assembly. The entire assembly could then be delivered to the test stand on a special flatcar or dolly by a shielded locomotive. The dolly and locomotive operated on a four-rail track system. After operation, the CTF dolly was returned to the Hot Shop for inspection (GE 1953; Thornton and Rothstein 1962). Figure 3-6 is an airflow diagram of the CTF for HTRE-2. Figure 3-7 is a picture of the HTRE-2 CTF on display at the Experimental Breeder Reactor No. 1 (EBR-I) site.

3.3 HEAT TRANSFER REACTOR EXPERIMENT NO. 2

The HTRE-2 reactor consisted of a “parent core” and an insert cartridge (a.k.a. an insert). The purpose of this configuration was to allow sections of advanced reactors (i.e., the various inserts) to be inserted into the parent core without requiring the removal of the entire core from the shield (Thornton and Rothstein 1962). Inserts were designed specifically for obtaining experimental data (Flagella 1962). When an insert was combined with the parent core, the two formed a critical assembly, which was designated as the D 101 D2 core (Flagella 1962; Foster et al. 1958).

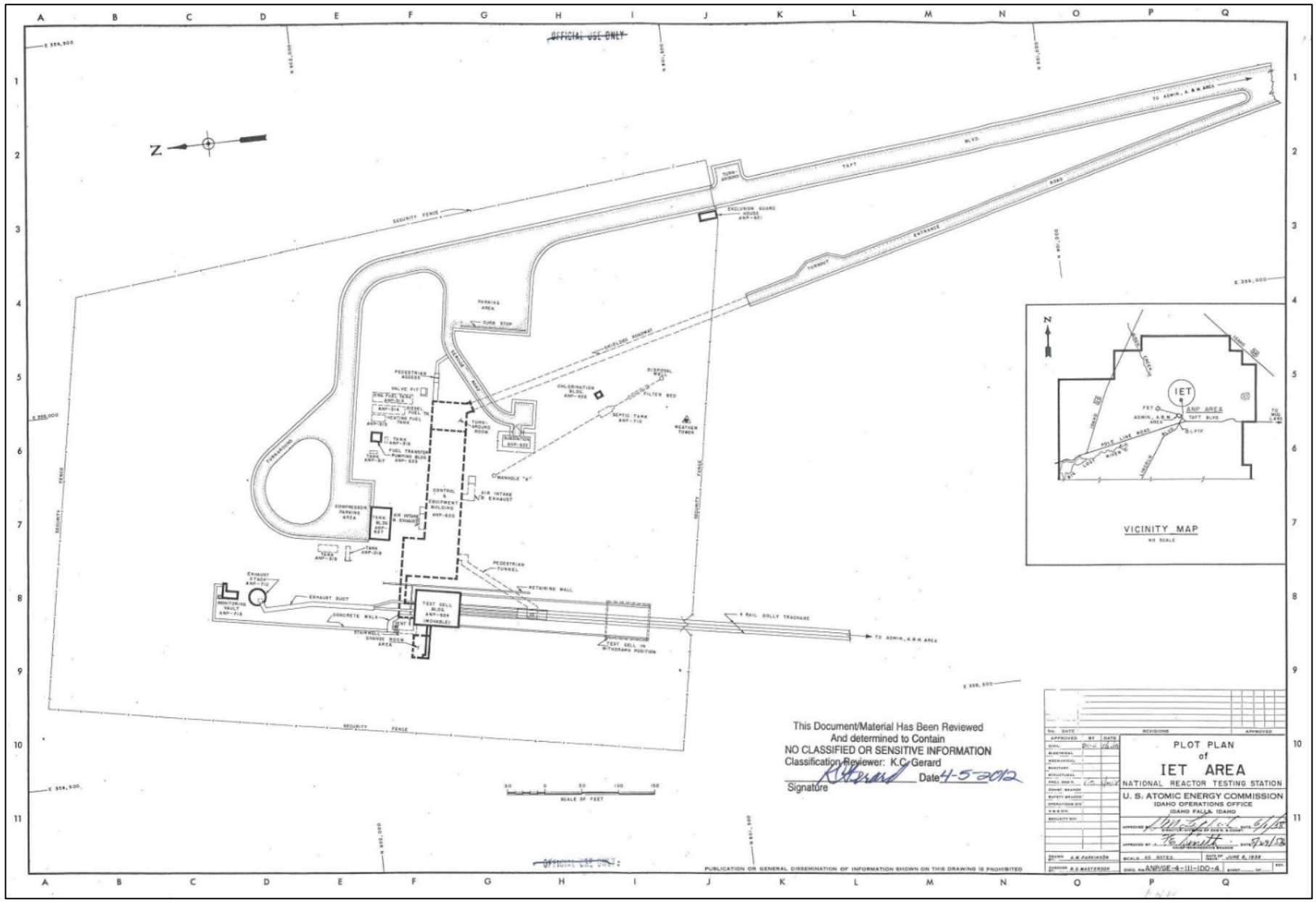

Figure 3-3. IET Facility site layout (AEC 1954–1960).

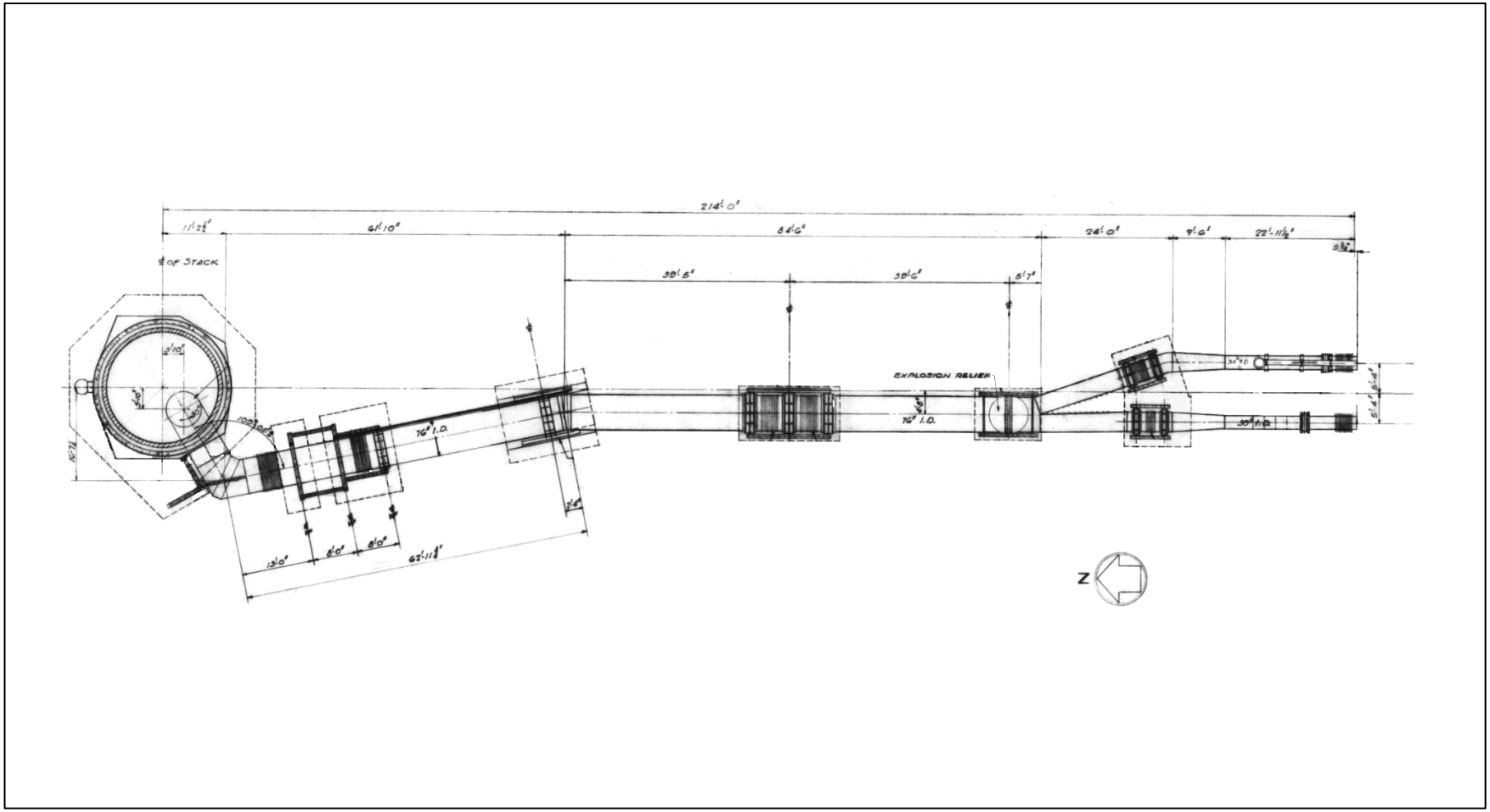

Figure 3-4. IET Facility exhaust system during IET #10 runs (Parsons 1963).

Figure 3-5. IET Facility (Stacey 2000).

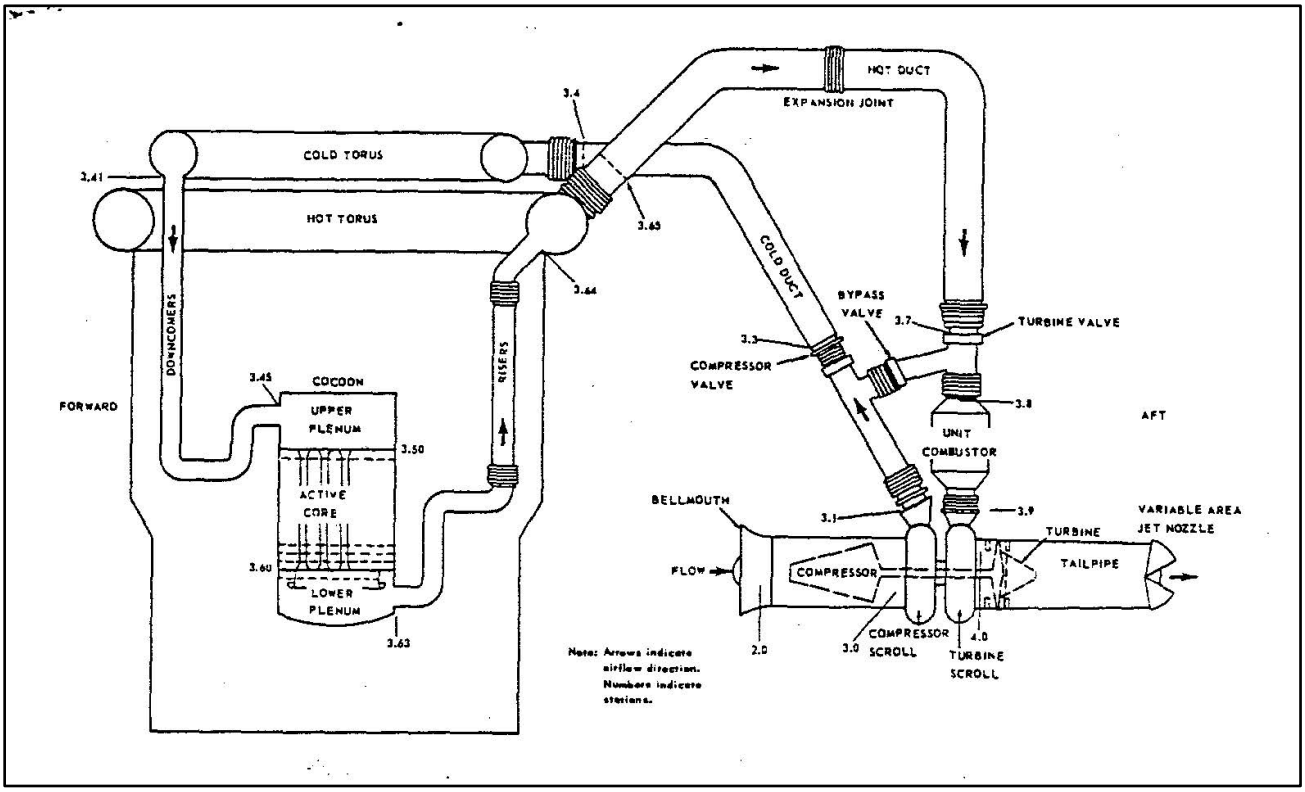

Figure 3-6. Airflow diagram of CTF for HTRE-2 (Flagella 1962).

Figure 3-7. CTF for the HTRE-2 (TexAgs 2017).

3.3.1 Parent Core

The HTRE-2 parent core used a water moderator and air-cooled metallic fuel elements. The parent core was a 30-tube bank in a hexagonal array with radially varying tube spacing. The active portion of the parent core formed a regular hexagonal cylinder 29.758 in. across the flats and 29.125 in. long (Flagella 1962). Figures 3-8 and 3-9 show what the parent core configuration looked like.

The 30 parent core fuel cartridges were made up of 18 stacked fuel element stages, with stage consisting of 14 to 16 concentric fuel rings. Each of the concentric rings consisted of a sandwich of uranium oxide mixed with a special 80Ni-20Cr (80% nickel and 20% chromium) alloy to form the "meat," which was clad with 0.004 in. of 80Ni-20Cr alloy (Flagella 1962).

After their final use, the fuel elements in the parent core were inspected and determined to be metallurgically and mechanically in good condition (Thornton and Rothstein 1962). Therefore, the parent core did not contribute to the IET #10 effluent releases.

3.3.2 Insert 2B

Insert 2B (also notated as Insert-2B and Insert 2-B) was the first of the ceramic inserts that were tested as part of the HTRE-2 and was the insert for IET #10 testing. It was devised to evaluate the use of ceramics as reactor core components adaptable to nuclear propulsion aircraft and designed to fit into the hexagonal test hole of the HTRE-2 parent core (Flagella 1962).

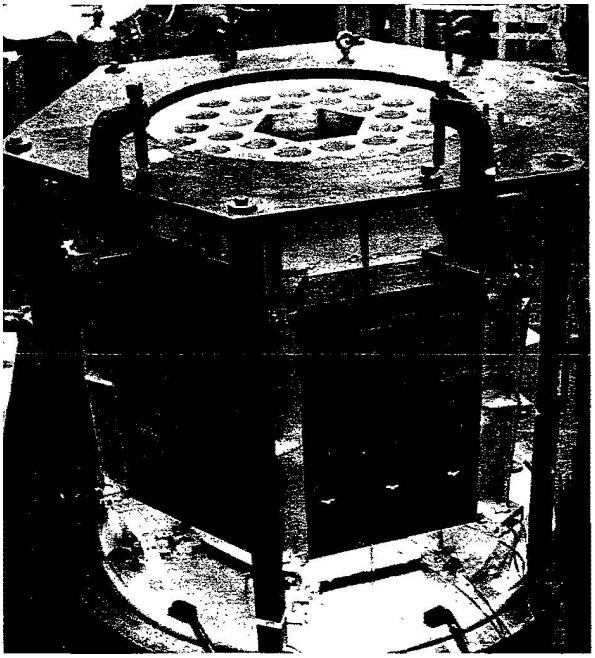

Figure 3-8. Parent core during construction (Thornton and Rothstein 1962).

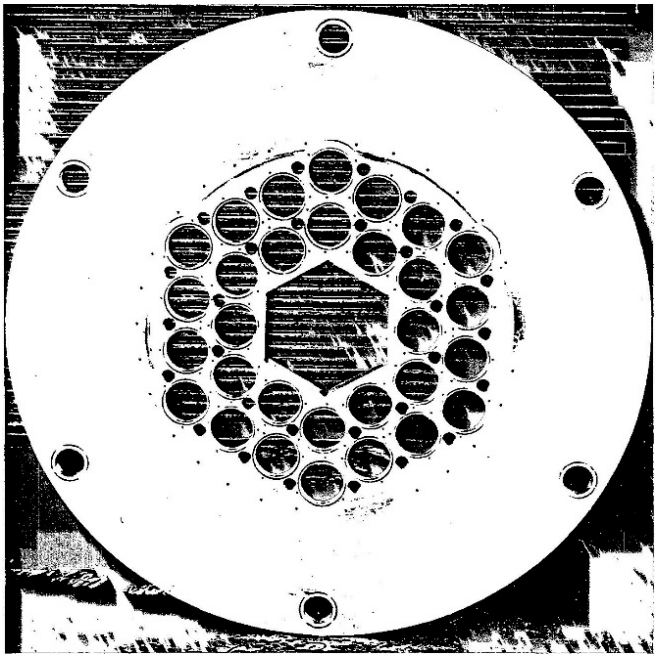

Figure 3-9. Top tube sheet for parent core (Flagella 1962).

The fuel for Insert 2B fuel consisted of unclad ceramic tubes of beryllium oxide (BeO), uranium dioxide (UO_2), and yttrium oxide (Y_2O_3). The composition by weight of the BeO-UO_2-Y_2O_3 fuel tubes was 85% BeO, 6% UO_2, and 9% Y_2O_3. The Y_2O_3 was added to stabilize the ceramic against the loss of the UO_2. The actual density of the tubes was 3.237 g/cm^3. The unfueled tubes and moderator slabs were made of 100% BeO, excluding impurities, and had an actual density of 2.904 g/cm^3 (Evans 1958a).

The hexagonal Insert 2B measured 10.75 in. across the flats and had an overall length of 45.34 in. The active portion of Insert 2B, from top to bottom, was 30.00 in. plus 7.5 in. of reflector at each end (Evans 1958a). This equates to a total of 12 stacked stages of 3.75-in.-long tubes (8 stages of fueled BeO-UO_2-Y_2O_3 tubes sandwiched between 2 stages of unfueled BeO tubes on either end for a total of 4 stages of unfueled BeO tubes) (Evans 1958a, 1960). Insert 2B further included 11 stacked layers of 4.10-in.-long BeO moderator slabs (Evans 1958a, 1960). The moderator slabs made up the inner and outer walls of the equilateral triangular cells (a.k.a. sections and/or banks). With this configuration, the tube stages and moderator slab layers did not line up, which was likely intended to help increase the structural integrity of the insert. Figure 3-10 provides a drawing of Insert 2B.

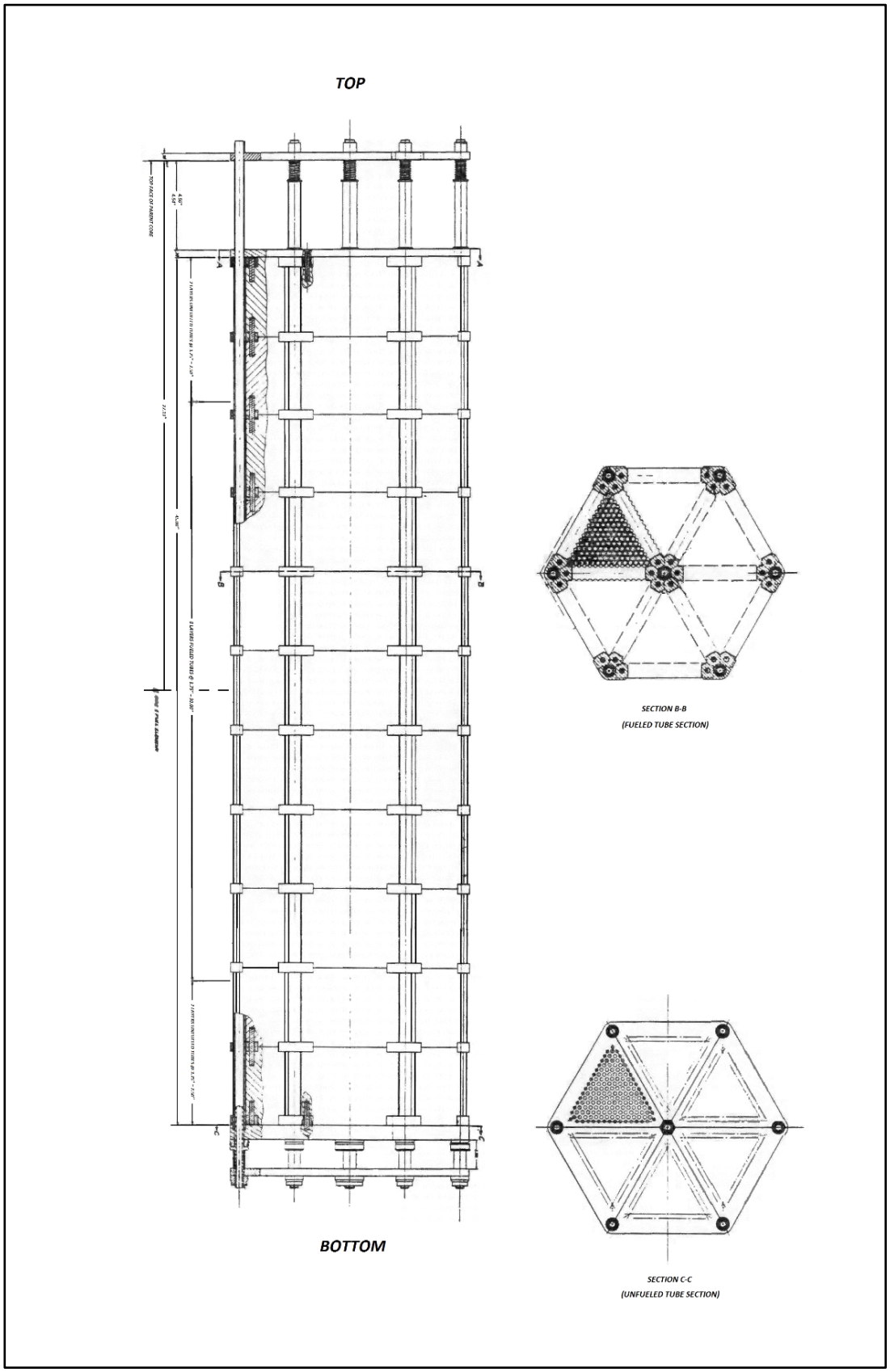

Figure 3-10. Drawing of Insert 2B (Evans 1958a, 1960).

Summary of Insert 2B tube specifications (Evans 1958a, 1960):

- 12 stacked hexagonal stages of fueled tubes,
- 6 equilateral triangular cells/sections/banks per tube stage,
- 120 tubes per triangular cell in a given tube stage,
- 15 tubes lined the outer rows of each triangular cell,
- 720 tubes per tube stage (i.e., 6 triangular cells times 120 tubes per cell),
- 8 fueled tube stages containing a total of 5,760 BeO-UO_2-Y_2O_3 tubes, and
- 4 unfueled tube stages containing a total of 2,880 BeO tubes.

Summary of Insert 2B moderator slab specifications (Evans 1958a, 1960):

- 11 stacked hexagonal layers of moderator slabs,
- 12 moderator slabs per layer, and
- 132 total moderator slabs in insert.

Calculated mass composition values for an Insert 2B fuel tube (see Note 1):

- BeO-UO_2-Y_2O_3 : 5.999 – 6.078 g,
- BeO: 5.099 – 5.166 g,
- Y_2O_3: 0.540 – 0.547 g,
- UO_2: 0.360 – 0.365 g, and
- Uranium: 0.317 – 0.321 g.

Note 1: The first values in each range were calculated from the density and tube dimension information above, and the second values were calculated by dividing the total BeO-UO_2-Y_2O_3 mass in Insert 2B from Evans (1958a, 1960) by the 5,760 total fuel tubes. The total BeO-UO_2-Y_2O_3 mass for Insert 2B in Evans (1958a, 1960) was 77.189 lb (35,012 g).

Calculated mass composition values for an unfueled tube in Insert 2B:

- BeO: 5.382 g, and
- Beryllium: 1.939 g.

Calculated total mass values for the fuel tubes in Insert 2B (see Note 2):

- BeO-UO_2-Y_2O_3: 34,556–35,012 g (76.182–77.188 lb)
- BeO: 29,373–29,760 g (64.756–65.610 lb)
- Beryllium: 10,584–10,723 g (23.333–23.640 lb)
- Y_2O_3: 3,110–3,151 g (6.856–6.947 lb)
- UO_2: 2,073–2,101 g (4.570–4.632 lb)
- Uranium: 1,825–1,849 g (4.023–4.076 lb)

Note 2: Based the information in Evans (1960), three different values for the total amount of BeO-UO_2-Y_2O_3 ceramic in the insert could be obtained, with the lower bound being the most likely value. Evans (1960) reported a value of 77.189 lb (35,012 g) of total BeO-UO_2-Y_2O_3 ceramic in the insert. However, based on volume and density information where that value is reported in Evans (1960), there was a total of 76.213 lb (34,570 g) of BeO-UO_2-Y_2O_3 ceramic in the insert. Also, based on the fuel tube dimensions, fuel tube density, and total number of tubes information in Evans (1960), there was a total of 76.182 lb (34,556 g) of BeO-UO2-Y2O3 ceramic in the insert.

Calculated total mass values for the unfueled tubes in Insert 2B:

- BeO: 15,500 g, and
- Beryllium: 4,747 g.

Calculated total mass values for the moderator slabs in Insert 2B:

- BeO: 92,909 g, and
- Beryllium: 33,477 g.

3.4 INITIAL ENGINE TEST NO. 10

IET #10 operations at the IET Facility took place during the period of December 12, 1957, through March 6, 1958.

3.4.1 Operations

IET #10 involved the power testing of ceramic Insert 2B in the A-4 Reactor (Foster et al. 1958). Testing commenced on December 12, 1957, with the delivery of the ceramic insert 2B and A-4 reactor combination, which was designated as the D 101 D2 core (Foster et al. 1958). After 32 reactor test runs, IET #10 testing was terminated on March 6, 1958, after an endurance test of 100 hours (Foster et al. 1958; DOE 1991c). During the testing, modifications were made to the insert orifice plate on two occasions to alter the peak insert-to-parent core temperature ratio (Foster et al. 1958). Phase I, II, and III testing refers to the testing with the original, first modification, and second modification of the orifice plate, respectively (Foster et al. 1958). Phase I involved 10 runs between December 20, 1957, and January 14, 1958. Phase II involved 6 runs between January 19, 1958, and January 30, 1958. Phase III involved 16 runs between February 8, 1958, and March 6, 1958. Table 3-1 provides a list of the IET #10 runs and their operating periods (Foster et al. 1958; DOE 1991c).

3.4.2 Effluent Monitoring

To collect information about the rate of release of fission products from the insert during the IET #10 testing, sampling and monitoring devices were established at various points throughout the reactor loop and IET Facility exhaust system. These included the use of chilled activated-carbon traps, electrostatic precipitators, particulate air filters, a multiple sampler capable of holding various types of fission product absorbers, as well as a continuous stack monitor, rupture detector system, and Jordan system, which were permanently installed in the facility for continuous monitoring during power operation. The primary sampling locations for calculating the releases were the sampling point in the main exhaust duct (i.e., the 76-in. duct) and the sampling point at the 80-ft level of the stack. In the 76-in. duct, effluent from a sampling probe was directed through a carbon trap or an electrostatic precipitator, and a multiple sampler was connected in series (Foster et al. 1958). The effluent samples from the 80-ft level on the stack were collected inside a shielded vault, which allowed personnel to collect and change out samples during the IET runs. As a result, the samples collected from the 80-ft level on the stack were often referred to as “vault samples.” The sampling points at the 80-ft level on the stack were located at the point where the maximum effluent velocity occurs, as determined by velocity profile measurements (Boone, Lofthouse, and VanVleck 1959). Samples from one probe were collected on a filter paper and samples from a second probe were collected using a chilled carbon trap (DOE 1991c). During Phase III testing, a second carbon trap was installed in the vault in series with the original. This second trap was immersed in a dry ice acetone bath that kept it at a temperature of about –100°F. The purpose of this trap was to collect data indicating the amounts of iodine and barium isotopes and beryllium that might have escaped the first carbon trap (Foster et al. 1958).

Table 3-1. Runs (Foster et al. 1958).

IET #10 Run	Start Date	Start Time	End Date	End Time	Operating Time (hr)	Elapsed Time (hr)
			Phase I Testing			
5	12/20/57	11:30	12/20/57	14:25	2.92	2.92
9a	12/26/57	10:22	12/26/57	10:34	0.20	0.20
9b	12/26/57	11:05	12/26/57	14:11	3.10	3.10
11	12/30/57	11:41	12/30/57	12:42	1.02	1.02
12	01/04/58	14:09	01/04/58	15:08	0.98	0.98
13	01/05/58	13:07	01/05/58	14:51	1.73	1.73
15	01/07/58	11:38	01/07/58	13:06	1.47	1.47
17	01/10/58	12:57	01/10/58	14:25	1.47	1.47
19	01/12/58	13:03	01/12/58	14:54	1.85	1.85
20	01/13/58	15:46	01/13/58	17:15	1.48	1.48
21	01/14/58	13:34	01/14/58	15:20	1.77	1.77
			Phase II Testing			
24	01/19/58	13:03	01/19/58	16:33	3.50	3.50
25	01/21/58	12:36	01/21/58	19:45	6.15	7.15
26	01/22/58	12:13	01/22/58	19:46	7.55	7.55
28	01/25/58	12:13	01/25/58	19:13	7.00	7.00
29	01/26/58	12:00	01/26/58	14:54	2.90	2.90
32	01/29/58	16:00	01/30/58	00:47	8.79	8.78
			Phase III Testing			
37	02/08/58	14:08	02/08/58	15:39		1.52
38	02/09/58	13:08	02/09/58	19:30	6.37	6.37
40	02/13/58	15:50	02/13/58	18:13	2.38	2.38
42	02/15/58	13:25	02/15/58	13:39		0.23
43	02/16/58	13:44	02/16/58	14:59		1.25
45	02/19/58	18:38	02/19/58	19:50	1.20	1.20
46	02/20/58	16:29	02/20/58	19:52	3.38	3.38
47a	02/22/58	10:26	02/22/58	11:21	0.92	0.92
47b	02/22/58	12:44	02/22/58	19:30	6.77	6.77
48a	02/23/58	10:20	02/23/58	11:40	1.33	1.33
48b	02/23/58	18:28	02/25/58	01:21	30.88	30.88
49	02/25/58	10:57	02/25/58	23:20	12.39	12.38
52	03/01/58	20:15	03/01/58	22:39	2.40	2.40
53	03/02/58	10:03	03/02/58	19:33	9.50	9.50
54	03/03/58	18:22	03/03/58	20:50	2.47	2.47
55	03/04/58	20:02	03/05/58	01:58	5.93	5.93
56a	03/05/58	10:58	03/05/58	12:45	1.78	1.78
56b	03/05/58	13:36	03/06/58	02:35	12.99	12.98
57a	03/06/58	18:52	03/06/58	19:27	0.58	0.58
57b	03/06/58	20:05	03/06/58	20:39	0.57	0.57
				Total Times:	**155.72**	**159.70**

3.4.3 Post-Test Examinations

Post-test examination of Insert 2B showed that considerable deposits of BeO were built up inside some of the ceramic fuel elements. This probably reduced the airflow in those tubes, which would have resulted in a higher temperature at the same nuclear power level. Visual examination of the fuel tubes as Insert 2B was dismantled revealed that some of the tubes in the center of the triangular stage sections at the lower end of the insert were bleached almost completely white. This, in

conjunction with the fact that some of the tubes in the same section of the insert were fused together, suggested that temperatures considerably above those reported had been attained in portions of Insert 2B (Foster et al. 1958).

As Insert 2B was unstacked in the TAN-607 Hot Shop, a white substance was observed on the inner diameter of the unclad ceramic fuel tubes. The deposits were caused by BeO hydrolysis, which was produced by the interaction of water vapor in the air stream with the BeO in the fueled tubes. The hydrolysis of the BeO and deposition of the BeO crystals was not anticipated in preoperational predictions. The white BeO crystal deposits appeared in the largest quantity at the leading and trailing edges of the tubes and were observed first on the trailing edge of Stage 6. It increased slightly in quantity as the insert was unstacked, with a large increase occurring at the trailing edge of Stage 10, where deposits apparently completely blocked flow passage in some tubes. Approximately 50% of the Stage 10 tubes of the insert showed large deposits with each of the six cells exhibiting the same uniformity of deposit (Flagella 1962).

The hydrolysis of the BeO was also an indication that some of the UO_2 in the fuel had diffused out of the fuel tubes (Flagella 1962). However, no immediate investigation was performed to assess the amount of amount of UO_2 that might have been lost.

On March 12, 1958, IET #11 began. IET #11 involved the power test series for Insert 1C. After the first 10 minutes of testing, the effluent release rate reached an unexpectedly high level of 14 Ci/hr. It was suspected that the unexpected release rate was due to the fissioning of UO_2 that was deposited in the lower cocoon of the CTF during Insert 2B operations. Because the current release rate was above the permissible limit, the CTF was returned to the TAN-607 Hot Shop for examination and cleaning, to verify that the Insert 1C had not ruptured. The CTF cocoon was flushed with nitric acid and water, which recovered a total of 8.4 g of ^{235}U (9.0 g U). It was confirmed that the Insert 1C fuel had not ruptured (Evans 1958b). Therefore, the recovered uranium was from the Insert 2B and the IET #10 operations (Flagella 1962; Evans 1958b).

4.0 AIRBORNE EFFLUENT RELEASES

This section provides the basis for the airborne effluent releases that were used to calculate the environmental intakes attributable to IET #10. Releases were previously calculated for *the HDE* (DOE 1991 a, 1991b) and as part of a critical review of the HDE (SC&A and SENES 2005). Even though there are issues associated with each of these sets of release estimates, no attempt was made to create a set of revised effluent releases for IET #10. Because all of the necessary information was not available and because the available information contains a number of discrepancies, it would be impossible to create a more accurate or defensible estimate of the effluent releases for IET #10. Fortunately, most of the issues with the two sets of release estimates result in biases that overestimate the releases.

The releases that were previously calculated for the HDE (DOE 1991 a, 1991b) and as part of a critical review of the HDE (SC&A and SENES 2005) were largely dependent on the reported leakage rates for beryllium, radioactive iodine, and radioactive barium. For the ANP Program, leakage rate was defined as the fraction of fission products, produced in the reactor insert during a given time, that escaped via the effluents (Foster et al. 1958).

4.1 MECHANISMS THAT CAUSED BERYLLIUM RELEASES

Because some of the IET #10 radionuclide releases were based on the measured releases of nonradioactive beryllium, it is important to understand the mechanical and chemical processes that caused the beryllium releases from Insert 2B. For the IET #10 runs, the two main processes were (1) the mechanical process of erosion and (2) the chemical process of hydrolysis.

4.1.1 BeO Erosion

The erosion process is straightforward. The mechanical actions caused by the high-velocity, high-temperature, turbulent air stream passing through Insert 2B eroded some of the BeO from the tubes and moderator slabs. Further, dust particles in the ambient air that were sucked into the CTF air intake could significantly contribute to the erosion process. This process likely eroded the BeO in Insert 2B at a relatively constant rate throughout each of the three IET #10 operating phases. The beryllium release rates during the Phase I testing are representative of the contribution to the total release rate attributable to this process, because the temperatures during Phase I testing were too low for the process of hydrolysis.

4.1.2 BeO Hydrolysis

The hydrolysis of BeO is a much less known and more complicated process. Most chemistry texts and documents indicate that BeO does not react with water. However, the hydrolysis of BeO can occur at temperatures that are normally only encountered in certain types of nuclear reactors. At high temperatures, the volatility of BeO is greatly increased by the presence of water vapor (Grossweiner and Seifert 1951). The following chemical reaction shows how gaseous water vapor interacts with solid BeO to form gaseous beryllium hydroxide [$Be(OH)_2$] (Grossweiner and Seifert 1951; Lapides et al. 1956; Maimoni 1964). This process is also considered to be a corrosion process, so hydrolysis and corrosion are often used interchangeably in the literature (Grossweiner and Seifert 1951; Lapides et al. 1956; Maimoni 1964).

$$BeO\ (solid) + H_2O\ (vapor) \rightarrow Be(OH)_2\ (vapor)$$

The threshold temperature for BeO hydrolysis is above 2,192°F (1,200°C) (SCB undated; Grossweiner and Seifert 1951). In addition, the newly formed $Be(OH)_2$ can be dehydrated at temperatures ≥752°F (400°C) and converted back into BeO via the following:

$$Be(OH)_2\ (vapor) \rightarrow BeO\ (solid) + H_2O\ (vapor)$$

The following is the process of BeO corrosion and deposition from Maimoni (1964). Water vapor diffuses from the main gas stream into the BeO wall, where it reacts. The reaction product, $Be(OH)_2$, diffuses out of the BeO and into the main gas stream. There is no nucleation of solid BeO in the gas stream when it becomes supersaturated with $Be(OH)_2$. Qualitative experimental results show that BeO deposition does not occur uniformly, but rather takes place by growth of isolated crystals from the BeO surfaces and extending into the gas stream (Maimoni 1964).

4.1.3 Beryllium Release Processes in Relation to Operations

The tube and moderator temperature profile information indicates that BeO hydrolysis was not possible during Phase I testing (Foster et al. 1958). This is also supported by the summarized results from the postoperation inspection of Insert 2B after Phase I testing, which did not report any sign of BeO hydrolysis (Foster et al. 1958). Based on the temperature profile data and the postoperation inspection results, the beryllium release rates during the Phase I testing would have only been attributable to the erosion process.

The tube and moderator temperature profile information indicates that BeO hydrolysis was possible in the fueled and unfueled tubes during Phase II testing (Foster et al. 1958). However, the summarized results from the postoperation inspection of Insert 2B after Phase II testing reported no indication of BeO hydrolysis (Foster et al. 1958). Therefore, if hydrolysis took place during Phase II testing, it was likely minimal.

Based on the IET #10 power testing results and postoperation inspections of Insert 2B after Phase III operations, it was confirmed that a significant amount of BeO hydrolysis took place during Phase III operations (Evans 1960). Based on temperature profile information for Phase III in Foster et al. (1958) and the maximum fuel and moderator temperatures in Evans (1960), BeO hydrolysis was possible in Stages 6 to 10 of the fuel tubes, Stages 11 and 12 of the unfueled tubes, and some of the lower moderator slabs. Figure 4-1 provides the excerpted the paragraphs from the Power Testing section of Evans (1960) that summarize the extent of BeO hydrolysis. Figures 4-2 and 4-3 are pictures of the downstream ends of fuel tube Stages 9 and 10, which show the extent of BeO hydrolysis.

Since we were primarily concerned with the observations made on the BeO tubes after testing the evaluation of the test data and observations will be concentrated in this area. As the insert was unstacked in the Hot Shop two observations were made, one being the appearance of white substance on the ID of the BeO tubes. This substance occurred in the largest quantity at the leading and trailing edges of the tubes and was observed first on the trailing edge of the 6th stage. And slightly increased in quantity as the insert was unstacked with a large increase in amount occuring at the trailing edge of stage ten, where deposits apparently completely blocked flow passage in some tubes. See figure 2.26, and 2.27. . . Approximately 50 percent of the tenth stage tubes of the insert showed large deposits with each of the six cells exhibiting the same uniformity of deposit. In addition to the deposits of BeO it was found that a large fraction of the fueled tubes in the tenth stage were white in appearance indicating that UO_2 fuel had been lost from the tube (it is estimated that a temperature of the order of 3000 to 3200°F is required to accomplish this bleaching). The examination of unfueled tubes in the 11 and 12 stages showed BeO deposits but to a much smaller degree than in the tenth stage.

The deposit observed in the tenth stage and other stages of the 2-B was identified as BeO crystals. This deposit and the extent of the deposit was completely unexpected in pre-operational predictions. Prior to the operations of the 2-B no similar observations were made on fuel tubes tested in LITR and MTR under similar temperature conditions. The deposits observed in the 2-B was subsequently identified as being caused by a BeO hydrolysis which is produced by the action of water vapor in the air stream and BeO in the fueled tubes. In essence the water air vapor picks up BeO in the cooler regions of the insert carries it into the hot regions of the insert where it is deposited in cool sections of the fuel tubes which here we can conclude were at the ends of the tube. Why the tube ends were cooler than other portions of the tubes can probably be attributed to some flow pattern existing at the ends of the tubes either flow down the backside and through the ends or some other cooling phenomena which may be caused by a tube edges projecting into the air stream (misalignment).

Figure 4-1. Excerpt from Power Testing section of Evans (1960).

In Evans (1960), the “whitening” of the fuel tubes was initially thought to have been caused by loss of black UO_2 from the fueled tube, which would leave behind white molecules of BeO and Y_3O_8. It was also estimated that fuel tube temperatures of 3,000°F to 3,200°F (1,649°C to 1,760°C) were needed for that “bleaching” process to happen. However, it was later determined that the whitening or bleaching of the fuel tubes was actually caused by the hydrolysis of BeO and the deposition of BeO on those tubes. Based on that information and the maximum fuel temperature for IET #10 in Evans (1960), the maximum fuel tube temperature was 2,750°F (1,510°C).

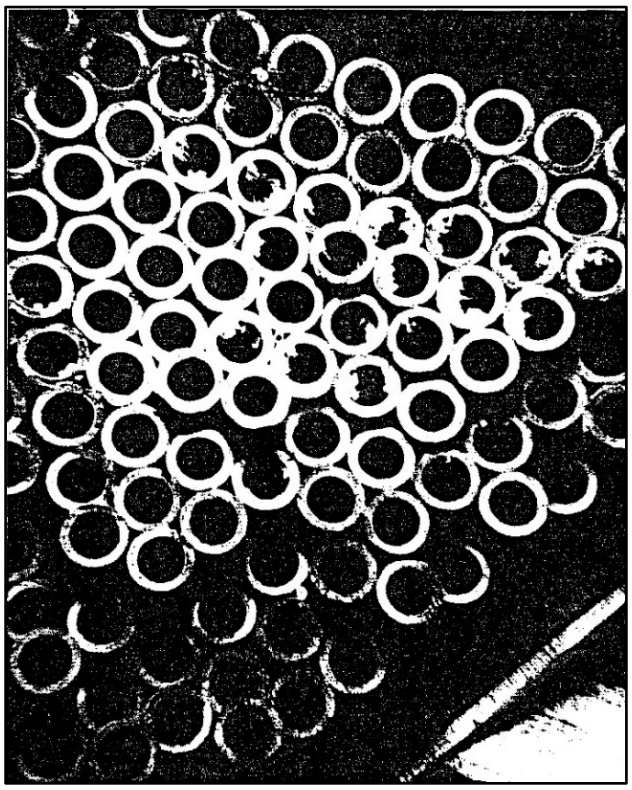

Figure 4-2. Downstream end of fuel tube Stage 9 (Evans 1960).

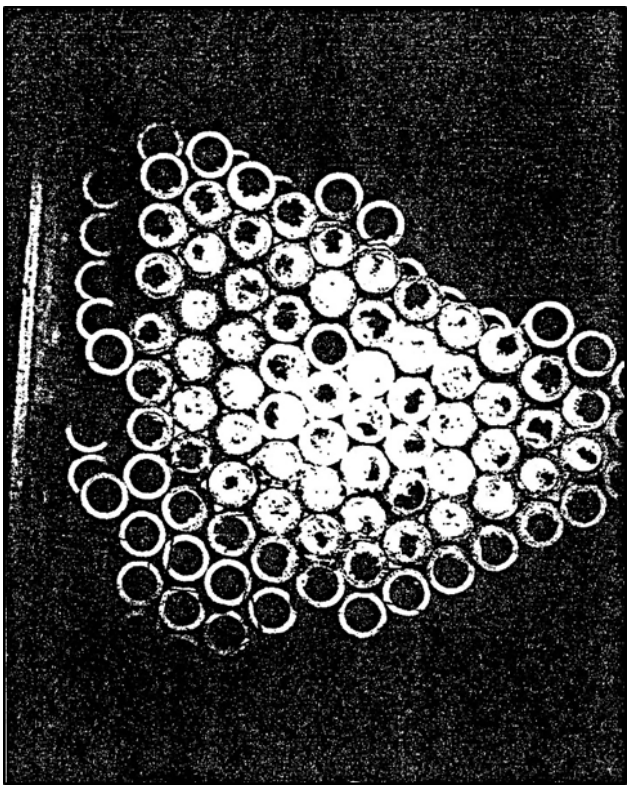

Figure 4-3. Downstream end of fuel tube Stage 10 (Evans 1960).

4.2 MECHANISMS THAT CAUSED URANIUM RELEASES

To understand the basis for the IET #10 release estimates, it is important to understand the primary mechanisms that could have caused the uranium releases. Both mechanical and chemical processes likely caused the uranium releases from Insert 2B. For the IET #10 runs, the three main processes were likely (1) the mechanical process of erosion, (2) the chemical process of UO_2 oxidation, and (3) the chemical process of triuranium octoxide (U_3O_8) decomposition. In reality, the two chemical processes simply enhance the effect of the erosion process by further weakening the crystalline structure of the fuel tubes and weakening the bonds between the uranium molecules.

4.2.1 Uranium Dioxide Erosion

As with the erosion of the BeO, the mechanical actions caused by the high velocity, high temperature, and turbulent air stream passing through Insert 2B eroded some of the UO_2 from the fuel tubes. Further, dust particles in the ambient air that were sucked into air intake of the CTF could have significantly contributed to the erosion process. Another significant contribution to this process would be from the weakening of the BeO-UO_2-Y_3O_8 tube structure due to BeO (solid) conversion to $Be(OH)_2$ (vapor), which diffused out of the crystalline structure of the fuel tubes.

4.2.2 Uranium Dioxide Oxidation

When in the presences of oxygen (O_2), UO_2 can oxidize into U_3O_8 at a temperature of 1,292°F (700°C). This reaction is depicted in the following:

$$3UO_2 \text{ (solid)} + O_2 \text{ (gas)} \rightarrow U_3O_8 \text{ (solid)}$$

This chemical process likely weakened the $BeO\text{-}UO_2\text{-}Y_3O_8$ tube structure further and contributed to the loss due to the conversion of BeO (solid) to $Be(OH)_2$ (vapor), which diffused out of the crystalline structure of the fuel tubes.

4.2.3 Triuranium Octoxide Decomposition

At temperatures of 2,370°F (1,300°C) or greater, the newly formed U_3O_8 can decompose back into UO_2.

4.2.4 Relationship of Uranium Releases to Beryllium Releases

The relationship of the uranium releases to the beryllium releases is more complex than the HDE assumed (DOE 1991a, 1991b, 1991c). In the HDE, the release of uranium was assumed to be proportional to the release of beryllium, and that proportionality value was based solely on the ratio of uranium mass to beryllium mass in the fuel tubes. That proportionality assumption does not account for the $Be(OH)_2$ vapor being much more mobile than the UO_2 and U_3O_8 compounds, which would have resulted in much larger fractions of beryllium being released from the fuel tubes than uranium. Another variable that would cause a larger fraction of beryllium to be released than a mass-proportional amount of uranium would be the attributed to the fraction of $Be(OH)_2$ vapor that does not convert back into BeO. Differences between particle size distributions, particle densities, and tendencies for the compounds to plate out on surfaces would also affect the fractions of the compounds being released from the IET Facility stack.

In SC&A and SENES (2005), the uranium releases appear to be based on the remaining uranium content reported in Table 2.3 of Evans (1960), which provides measurement results for UO_2 remaining in three tubes. However, it could not be determined how the total uranium releases in Table 4-13 of SC&A and SENES (2005) were derived. The total uranium releases in that table are equivalent to a release of 60.9 g of uranium, which appears to have been derived from their estimate of 267.48 g of UO_2 (equivalent to 235.38 g U) being lost from the fuel tubes. Because of the lack of information on how those releases were derived, this analysis could not determine if the relationship of uranium to beryllium affected the uranium release estimates in SC&A and SENES (2005). Further, there is no indication of whether or not the 8.4 g of ^{235}U (9.0 g U) that was removed from the CTF cocoon after IET #10 testing was accounted for in the SC&A and SENES (2005) estimates (see Section 3.4.3). However, the following paragraphs discuss some issues with the information that was used to estimate that 267.48 g of UO_2 were lost from the fuel tubes.

Figure 4-4 is an excerpt of the Material Analyses section in Evans (1960). The uranium release estimates in SC&A and SENES (2005) appear to be based on this information. However, there are some significant issues with this information.

MATERIALS ANALYSES

Remote analytical work including densities, leaching and uranium analysis were performed by radiochemistry laboratory personnel at the RML (remote materials laboratory).

Weight measurements of tubes #104 from stage 6 and 9 were obtained first by weighing the tube and then cleaning with ultrasonic bath and drying and re-weighing. This was done to evaluate materials lost particularly uranium. The densities were determined by weighing each tube suspended in air and then in water. The densities of the tubes were determined by the following calculations.

Density equals: weight in air x density in water at temperature; divided by weight in air minus in water. These weights and densities are recorded in Table 2.3.

TABLE 2.3

DEFINITION	TUBE 104 Stage 6	TUBE 104 Stage 9	TUBE 41 Stage 10
Weight of Crystal removed	-	-	0.032 gms.
Weight before cleaning	6.039 gms	5.9058 gms	5.449 gms.
Weight after cleaning	6.0293 gms.	5.8972 gms.	5.4473 gms.
Density in grams/cc.	3.31	3.14	-
Total UO_2 mg	342 ± 1%	302 ± 1%	64.1 ± 10%

It is seen from the table that tube #41 stage 10 lost slightly over 80% of its fuel.

Figure 4-4. Excerpt from Materials Analyses section of Evans (1960).

The following are the more significant issues associated with the information in Figure 4-4.

1. It is uncertain why only one fuel tube from Stages 6, 9, and 10 was evaluated. One tube out of 720 fuel tubes per stage is far from a representative sample. No information is available on why these tubes were selected or why no tubes from fueled Stages 7 through 8 were selected. Three tubes is far from a representative sample of the fuel tubes affected by BeO hydrolysis. Therefore, it is difficult if not impossible to make any determinations from the data in Figure 5-4.

2. The uranium analyses and their results are very uncertain, and are not likely reliable data for use as a basis for estimating the uranium losses. Again, three tubes is far too small a sample to be representative of the fuel tubes affected by BeO hydrolysis to estimate uranium losses for Insert 2B. No information is provided on the type of uranium analysis that was performed or when the analyses were performed (e.g., before or after cleaning the fuel tubes). Given that most analyses to determine the total uranium content of the fuel tubes likely involved a destructive analysis, the uranium measurements were most likely performed after cleaning the tubes and all other measurements.

3. The remaining UO_2 mass results for the Stage 10 fuel tube make no sense, because they imply that the solid uranium was more likely to diffuse out of the fuel tubes than the vaporous form of beryllium being formed by the BeO hydrolysis. Other than neutron fission and capture reactions, which were insignificant for the IET #10 testing, there aren't any known mechanisms that would yield a higher UO_2 loss rate than the BeO loss rate. If 80% of the UO_2 fuel was lost, 80% or more of the BeO should have also been lost from the tube, which would mean that virtually none of the tube was left. The picture of the Stage 10 fuel tubes in Figure 4-3 indicates that those tubes were completely intact. Based on the reported weights for the

Stage 10 fuel tube, only 9% to 10% of its total mass was lost. For some unknown reason, no density measurement result was provided for this tube. The density measurement result could have shed some light on some of the other numbers for this tube. If there was a process that would yield a higher UO_2 loss rate than the BeO loss rate, determining that would have been an extremely important part of the IET #10 testing and would have warranted evaluating more than three fuel tubes. The use of Y_2O_3 as part of the fuel was to help stabilize the final product against the loss of UO_2 (Evans 1958a), so it is possible that there could have been some mechanism that could have caused a higher UO_2 loss rate than the BeO loss rate. No further details on why Y_2O_3 was added to the fuel have been found.

4. It is unknown why there was no uranium analysis performed on the cleaning solution when they were interested in determining the uranium losses in the tubes. Cleaning the tubes in an ultrasonic bath of an unknown solution would have likely removed some of the uranium, even if the solution was just water. The more the crystalline structure of the fuel tubes was damaged by BeO hydrolysis, the more uranium was likely removed by the cleaning process. If the uranium measurements were performed before cleaning the tubes, an analysis of the cleaning solution would have provided information on how much more uranium was close to being lost. If the uranium measurements were performed after cleaning the tubes, which is the more likely scenario, most of the "lost" uranium could have been lost from the cleaning process, which would invalidate their uranium measurements. The analysis of the cleaning solution for uranium would have provided useful information for this scenario also.

5. No explanation is provided for the increase in fuel tube density for the Stage 6 tube. As reported in Table 2.1 of Evans (1960), the actual fuel tube density was 3.237 g/cm^3 and the theoretical fuel tube density was 3.27 g/cm^3. Even though the remaining UO_2 mass for that fuel tube indicates some UO_2 was lost from the tubes, the increase in the density value suggests that BeO was lost at a higher rate than UO_2, which is what one would expect based on the information provided above.

4.3 EVALUATION OF PREVIOUSLY CALCULATED RELEASES

The various radioactive airborne effluent releases from the INL site that have been used in the environmental TBD are from the HDE (DOE 1991 a, 1991b) and its supporting documentation. The radioactive airborne effluent releases from IET #10 and the bases for those releases are documented in *Idaho National Engineering Laboratory Historical Dose Evaluation Quality Assurance File – IET #10 Source Term Characterization*, which is part of the supporting documentation for the HDE (DOE 1991c). The primary source of information for that document was *Power Testing Results from D 101 D2 Core (IET # 10)* (Foster et al. 1958).

In addition to the airborne effluent releases for IET #10 in DOE (1991c), the document *Critical Review of Source Terms for Select Initial Engine Tests Associated with the Aircraft Nuclear Propulsion Program at INEL* (SC&A and SENES 2005) indicates that the HDE, "…may have underestimated the release of radioiodines and other fission products by as much as 10 fold" and provides a set of adjusted releases.

4.3.1 Evaluation of Releases in the Historical Dose Evaluation

The HDE Task Group expended a substantial amount of effort in reconstructing the episodic releases for the INL site. As an indication of the level of effort that went into the HDE and its complexity, the HDE and its 82 supporting documents (document numbers DOE/ID-12119-QAF-001 through DOE/ID-12119-QAF-082) include over 4,200 pages of documented information.

After the publication of the HDE, a U.S. Department of Energy (DOE) review committee recommended a more detailed study using source documents and incorporating public involvement. The Governor of Idaho asked the Centers for Disease Control and Prevention to perform a technical review of the methodology for the analyses for the HDE report. As a result of that technical review, minor changes were recommended in some of the airborne source terms. Those minor changes did not change the total released curies, but it added small amounts of other radionuclides and respective quantities to earlier years when detection had not been as "low-level" as in more recent years. In the course of the review, the Radiological Assessment Corporation examined the RSAC-4 program that defined the radiological doses for each of the releases (Till et al. 2002). That review stated, "The [National Council on Radiological Protection and Measurements] and Radiological Safety Analysis Computer (RSAC) Program results agreed very well, confirming that the [Council] methodology is an acceptable method to rank releases of radionuclides" (Till et al. 2002).

As indicated above, the IET #10 airborne effluent releases in the HDE were based on a significant amount of information in *Power Testing Results from D 101 D2 Core (IET # 10)* (Foster et al. 1958). However, the original historical data were critically reviewed before use. That review of the referenced data and analysis techniques indicated that some inappropriate simplifying assumptions had been used in the original analyses, which led to some of the reported discrepancies in the release data. The discussions in *Idaho National Engineering Laboratory Historical Dose Evaluation Quality Assurance File - IET #10 Source Term Characterization* point out these inappropriate assumptions and outline how the referenced data were used to determine the amounts of radioactive material that were assumed to be released to the environment for that analysis (DOE 1991c). However, not all of the details necessary to reconstruct the calculations were documented. The ORAU Team review of the IET #10 information confirmed that the available effluent monitoring data for IET #10 consists of summary data that are incomplete, inconsistent, and difficult to interpret, which was already indicated in Section 4.7 of SC&A and SENES (2005). Therefore, a number of parameters and calculations that were used to estimate the airborne effluent releases from IET #10 cannot be reconstructed or verified.

One of the things that makes the calculations in DOE (1991c) difficult to interpret is that a number of calculated parameter values were not used for the release calculations. Some of the unused calculations were used only for comparison of the different methods to estimate the effluent releases to determine which one was best. However, that was not the case for all of the unused calculations. A prime example is the total release values in Attachment VII of that document. Those values are significantly different from the sums of the individual radionuclide releases that were used for the HDE, which are the release values near the end of DOE (1991c). No explanation for the different releases is provided in the HDE documentation, and the values in Attachment VII do not appear to have been used for anything. Another example is the beryllium release fractions reported in the Uranium Release section of DOE (1991c). The reported beryllium release fraction for Phase III operations is incorrect, which was already indicated in Section 4.6.2 of SC&A and SENES (2005). However, based on the calculations in Attachment VI, neither of the reported beryllium release fractions were used for calculating the uranium releases, so the purpose of reporting them in DOE (1991c) is unknown.

The following is a summary of the more significant points, issues, and concerns about the effluent releases in DOE (1991c):

1. As indicated above in Section 3.5.3, 8.4 g of ^{235}U (9.0 g U) from Insert 2B was recovered from the lower cocoon of the CTF shortly after the start of IET #11. Even though DOE (1991c) makes no mention of this uranium, the approach for the uranium release estimates was not affected by it. That approach relied on the total beryllium and uranium in Insert 2B and the amount of beryllium in the effluent. That approach also assumed releases of UO_2 were linearly proportional to the releases of BeO (DOE 1991c). Therefore, a proportional amount of BeO would have also been trapped in lower cocoon of the CTF, based on that approach.

2. The uranium releases were based on the release rate for beryllium and a ratio of the total uranium and beryllium mass in the Insert 2Bs fuel tubes. However, during the periods when BeO temperatures were high enough for hydrolysis to occur, only half of those fuel tubes were potentially affected and both of the lower two unfueled stages could have been affected. Adjusting the beryllium inventory for that yields a significantly higher uranium release. Therefore, the uranium releases in the HDE are likely underestimates.

4.3.2 Evaluation of Releases in SC&A and SENES (2005)

Section 4.7 of *Critical Review of Source Terms for Select Initial Engine Tests Associated with the Aircraft Nuclear Propulsion Program at INEL* provides the conclusions that were made from this review (SC&A and SENES 2005). The following is an excerpt of the last paragraph of Section 4.7:

> *Our review of available information for IET #10 and its interpretation by the Task Group suggests that the HDE Task Group model may have underestimated the release of radioiodines and other fission products by as much as 10 fold. Support for this conclusion comes from empirical data that include (1) an alternative interpretation of "leakage rate," (2) data associated with the release of beryllium from Insert 2-B of IET #10, and (3) data associated with the release of uranium oxide from Insert 2-B of IET #10. Table 4-13 provides summary release data derived by the HDE Task Group and compares these data to revised estimates derived by SC&A. As noted in Table 4-13, SC&A did not attempt to divide the* IET #10 *releases into two time periods A and B, which correspond to winter and spring planting. It is SC&A's opinion, however, that the majority of releases coincided with fuel failure, which progressively increased in latter test runs of Phase III (i.e., February 15 through March 6, 1956).*

In the above excerpt, SC&A and SENES (2005) indicate that the adjusted releases are supported by empirical data about three specific issues. However, the document does not explain how those issues and data affected their adjustments to the original releases in DOE (1991a).

Adjustment factors were calculated in *INEL – IET 10 Releases & Worker Intakes* (ORAUT 2017b), based on a comparison of the release estimates in Table 4-13 of SC&A and SENES (2005) and the ones in DOE (1991c). Table 4-1 provides a summary of what the calculated adjustment factors were.

Table 4-1. 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

The following is a summary of the more significant points, issues, and concerns about the adjusted effluent releases in SC&A and SENES (2005):

1. In general, SC&A and SENES (2005) do not provide sufficient details about the basis for the adjusted releases, and additional information does not appear to be provided in any other document. In most cases, no information was provided for the basis of release adjustments.

2. Section 4.6.2 of SC&A and SENES (2005) argues that the total fission products releases were underestimated based on the "the fact that fuel temperatures in Insert 2-B were estimated between 3,000°F and 3,200°F at the time of fuel degradation". Those fuel temperatures were estimated in Evans (1960) before GE confirmed that the whitening or bleaching of the fuel was due to BeO hydrolysis. The maximum reported fuel temperature in Evans (1960) was 2,750°F (1,510°C), which has a much lower release rate for fission products than 3,000°F (1,649°C). Based on Figure 4-16 in SC&A and SENES (2005), the fission product release rate at 2,750°F (1,510°C) is more than an order of magnitude lower than the release rate at 3,000°F (1,649°C).

3. In the absence of more credible sampling data, SC&A and SENES (2005) derived ^{131}I source terms from the amounts of BeO and UO_2 that had been lost. However, the document neglects to identify the relationship between the vaporous ^{131}I source terms and the solid BeO and UO_2 losses. Further, the suggested ^{131}I release values (Section 4.8) do not match the values in Table 4-13 of SC&A and SENES (2005), although they are close (587 Ci versus 600 Ci).

4. Assuming that there is some relationship between the ^{131}I source terms and the amounts of BeO and UO_2 that had been lost, that relationship should be applicable to all isotopes of iodine. Therefore, it is not clear why the ^{131}I and ^{133}I releases were adjusted differently or why ^{132}I, ^{134}I, and ^{135}I releases were not adjusted (see Table 4-1).

5. It is not clear how the same adjustment (e.g., the radionuclides adjusted by a factor of 7.8) is applicable to gaseous, vaporous, and solid radionuclides with vastly different half-lives and different modes of production (e.g., nuclear fission, radioactive decay, transmutation, or a combination of the three).

6. At the end of Section 4.6.4 of SC&A and SENES (2005), it was assumed that the total effluent release rates in Foster et al. (1958) only represent particulate radionuclide releases and do not include noble gases and volatile halogens. The document then provides a new estimate for the particulate effluents based on that assumption. However, the new total release of 252,197 Ci of particulate effluent in Section 4.6.4 is significantly less than the sum of the particulate radionuclides in Table 4-13 of SC&A and SENES (2005), and no explanation is provided.

7. The uranium releases in SC&A and SENES (2005) appear to be based on an estimate of UO_2 that diffused out of the fuel due to the hydrolysis of the BeO. However, SC&A and SENES (2005) do not appear to account for the diffused uranium that was retained in the CTF. As indicated above in Section 3.4.3, 8.4 g of ^{235}U (9.0 g U) from Insert 2B was recovered from the lower cocoon of the CTF shortly after the start of IET #11.

4.4 SOURCE OF RELEASE DATA

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. Based on an evaluation of the revised releases in SC&A and SENES (2005), the revised releases do not appear to be more credible than the original releases in the HDE documentation, especially given the lack of documentation about the basis for those adjustments and the other issues and discrepancies identified above. 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).

The following sections describe how the IET #10 releases were retabulated for the purposes of this evaluation.

4.5 RADIONUCLIDES NOT USED FOR RELEASES

Because exposure to noble gases does not result in significant internal dose, no environmental releases of noble gases were used for these calculations. External exposures to the noble gases in the IET #10 effluent plumes are accounted for in dose reconstructions using dosimetry data.

4.6 RELEASES USED

Based on the information above, airborne effluent releases reported for IET #10 in the HDE were retabulated to only include the releases for IET #10 runs 12, 13, 15, 17, 21, 24, 25, 28, 29, 37, 42, 43, 45, 46, 47, 52, 53, 54, 55, and 56. The retabulated radionuclide releases were then adjusted by the factors provided above in Table 4-1. These calculations were performed in *INEL – IET 10 Releases & Worker Intakes* (ORAUT 2017a), which utilized an electronic version of the HDE release data for IET #10. A validated electronic version of the HDE release data for IET #10 is provided in *INL – IET 10 Releases from INEL-HDE* (ORAUT 2017c). Table 4-2 provides the adjusted radionuclide releases that were used for the environmental intake calculations.

Table 4-2. Adjusted IET #10 releases (Ci).

Nuclide	Release
Br-84	3.03E+00
Rb-89	6.15E+01
Sr-89	5.82E–01
Sr-90	1.84E–04
Sr-91	3.99E+00
Sr-92	4.22E+00
Y-91	1.95E–02
Y-92	2.23E+00
Y-93	2.01E+00
Zr-95	3.12E–02
Zr-97	1.32E+00
Nb-96	1.06E–04
Mo-99	5.08E–01
Ru-103	2.45E–02
Ru-105	5.36E–01
Ru-106	3.55E–04
Sb-129	3.51E–01
Te-131	1.55E+00
Te-131m	5.57E–02
Te-132	3.21E–01
Te-133m	1.73E+00
Te-134	3.02E+00
I-131	6.49E–01
I-132	1.28E–01
I-133	8.46E+00
I-134	2.70E+00
I-135	2.16E+00
Cs-137	4.34E–03
Cs-138	1.61E+03
Ba-139	5.86E+01
Ba-140	2.68E–01
Ba-141	7.17E–01

Nuclide	Release
Ba-142	6.28E–02
La-141	3.67E+00
La-142	4.70E+00
Ce-141	3.87E–02
Ce-143	8.52E–01
Ce-144	5.97E–03
Pr-143	4.60E–02
Pr-144	5.96E–03
U-234	9.07E–05
U-235	2.89E–06
U-238	2.69E–08

5.0 ATMOSPHERIC DISPERSION OF RELEASES

The releases from IET #10 were inadvertently excluded from the environmental TBD (Revisions 00, 01, and 02). By excluding any consideration of the IET #10 releases in the environmental TBD, the environmental TBD implies that those releases could not have exposed the workers at other major operating areas on the INL site to elevated environmental air concentrations. However, evaluations of the meteorological data for the IET #10 releases and the dispersion factors in the HDE indicate that the workers at other major operating areas were exposed. The original author of the environmental TBD who performed those reviews is now deceased (H. K. Peterson), and no detailed documentation of those reviews could be found. It is worth noting that Mr. Peterson was also a member of the task group that created the HDE, and that he was involved with the meteorological diffusion calculations for that document. Therefore, Mr. Peterson was intimately familiar with the information in the HDE reference and the bases for that information. Because no basis could be found for excluding the IET #10 releases from the environmental TBD, the ORAU Team has reevaluated releases to determine if they could have exposed the workers at other major operating areas on the INL site to elevated environmental air concentrations.

5.1 TRAJECTORIES OF RELEASES

The HDE does not contain release trajectories or dispersion isopleths for the IET #10 releases. However, the quality assurance documentation for the HDE does provide dispersion factors and air concentration estimates for 16 offsite locations (DOE 1991c). Those 16 offsite locations are shown in Figure 5-1. Dispersion factors and air concentration values were generated for the 32 IET #10 runs (DOE 1991c). When the dispersion factors and air concentrations for the four downwind locations in the shaded portions of Figure 5-1 are zero, the releases associated with that specific run would not have affected the INL workers. 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. The dispersion factors and air concentrations for 20 of the runs indicated that those runs had the potential to contribute to internal doses of the INL workers at varying degrees. Those 20 runs included IET #10 runs 12, 13, 15, 17, 21, 24, 25, 28, 29, 37, 42, 43, 45, 46, 47, 52, 53, 54, 55, and 56.

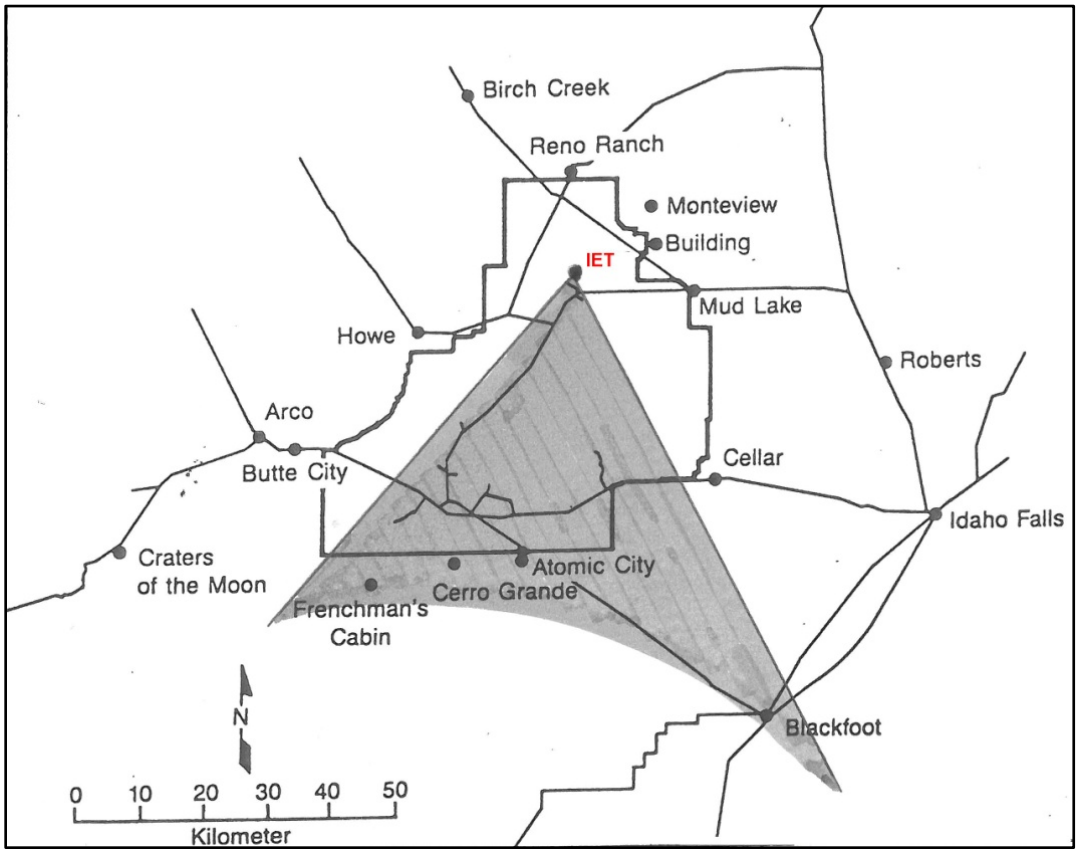

Figure 5-1. Trajectory area affecting other INL facilities (DOE 1991a).

5.2 ATMOSPHERIC DISPERSION CALCULATIONS

The MESODIF atmospheric dispersion model was used for the atmospheric dispersion calculations in the HDE (DOE 1991a, 1991b, 1991c). The model was developed for and is well suited to modeling releases from the INL site. The MESODIF computer model was a forward time-marching Gaussian plume model in which successive, small plume elements are advected throughout the computational area.

Because the MESODIF model is no longer available and because its more sophisticated replacement at the INL requires more meteorological data than was available in the late 1950s, a relatively simple Gaussian plume model was used with a number of simplifying assumptions or approaches that would result in the environmental air concentrations at the receptor locations (i.e., the other major operating areas) being overestimated. Figure 5-2 provides an illustration of how stack releases are represented by the Gaussian plume model.

The use of the Gaussian plume model is consistent with the atmospheric dispersion calculations that were performed for the other IET releases in the environmental TBD (ORAUT 2010a). For those calculations, the RSAC-6 program was used (ORAUT 2004b, 2004c). Based on the user's manual for the RSAC-6 program, a straight-line Gaussian plume model that calculates ground-level air concentrations is used for its atmospheric dispersion calculations (Wenzel and B.J. Schrader 2001).

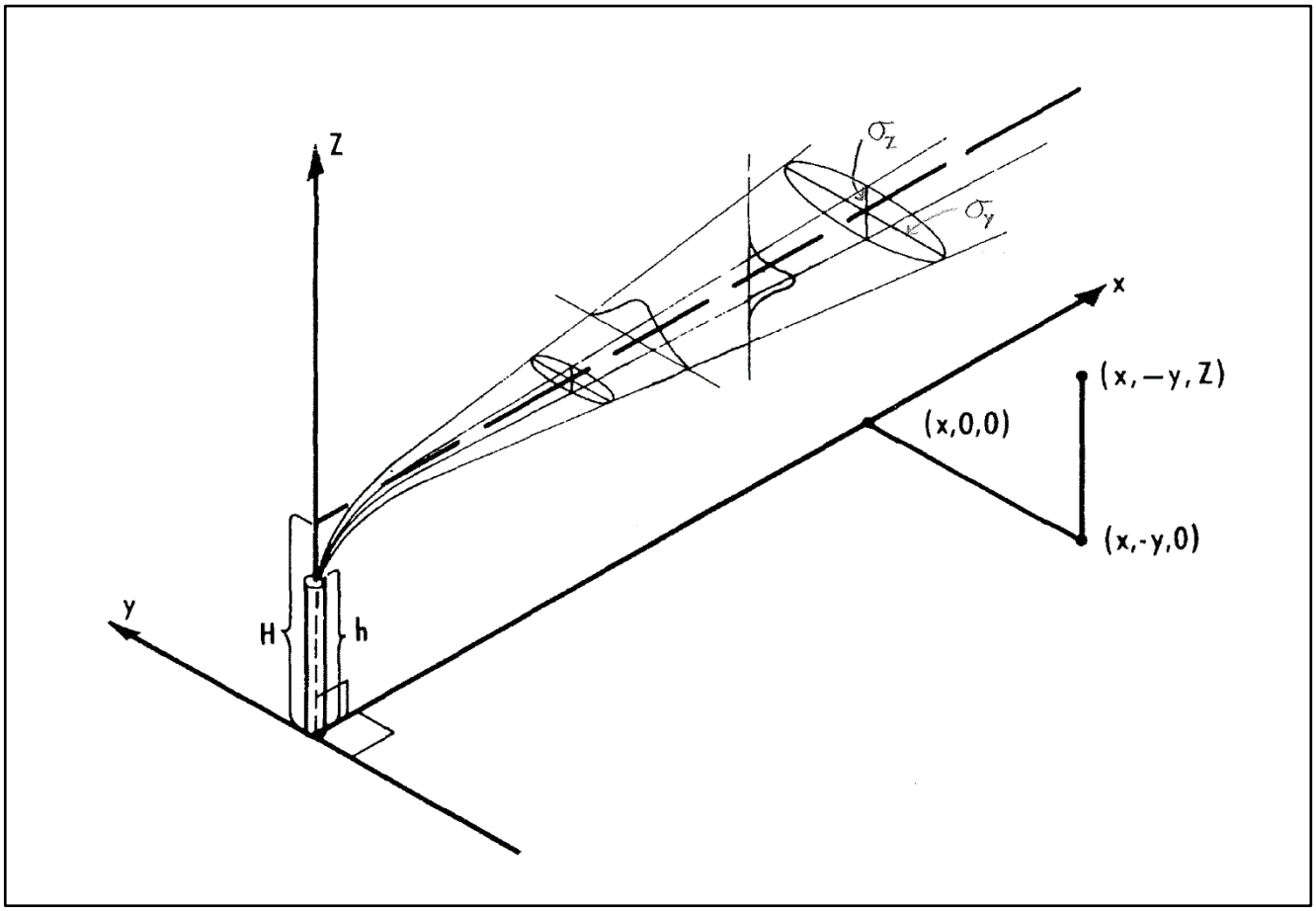

Figure 5-2. Illustration of Gaussian plume model (Turner 1970).

The Gaussian plume equation that accounts for the potential reflection of the plume off the ground was used and is shown below as Equation 5-1 (Turner 1970). This equation assumes that none of the plume is absorbed when it reaches the ground (i.e., 100% plume reflection), which results in a slight overestimate of the environmental air concentrations. Note that Equation 5-1 has been configured to calculate dispersion factors (i.e., χ/Q values) versus downwind air concentrations. All of the atmospheric dispersion calculations are contained in *INEL – IET 10 Releases & Worker Intakes* (ORAUT 2017a).

$$\frac{\chi}{Q} = \frac{1}{2\pi\sigma_y\sigma_z u}\left(e^{-\frac{1}{2}\left(\frac{y}{\sigma_y}\right)^2}\right)\left(e^{-\frac{1}{2}\left(\frac{(z-H)}{\sigma_z}\right)^2} + e^{-\frac{1}{2}\left(\frac{(z+H)}{\sigma_z}\right)^2}\right) \quad (5\text{-}1)$$

where

χ/Q = atmospheric dispersion factor (s/m^3)
χ = downwind air concentration at coordinates (x,y,z) (Ci/m^3)
Q = release rate (Ci/s)
x = downwind distance to receptor (m)
y = crosswind distance to receptor (m)
z = vertical distance to receptor (m)
σ_y = horizontal dispersion coefficient for downwind distance e (m)
σ_z = vertical dispersion coefficient for downwind distance x (m)

u = average wind speed at release point (coordinates 0,0,H) (m/s)
H = effective stack height (m)

Equation 5-2 shows the relationship between the release rate Q and the total release Q_{Tot}:

$$Q = \frac{Q_{Tot}}{t_{Tot}} \quad (5\text{-}2)$$

where

Q = release rate (Ci/s)
Q_{Tot} = total release (Ci)
t_{Tot} = total duration of release (s)

The equation for effective stack height is provided as Equation 5-3:

$$H = h_s + \Delta h \quad (5\text{-}3)$$

where

H = effective stack height (m)
h_s = physical stack height (m)
Δh = plume rise (m)

A crosswind distance of zero (i.e., y = 0 m) was used because only the maximum air concentrations at the plume's centerline were being calculated. The vertical distance to the receptor is the height of Reference Man (ICRP 1975) (i.e., z = 1.7 m). Plume rise due to momentum and buoyancy was significant for the IET Facility stack but was disregarded. Therefore, the effective stack height is equal to the physical stack height (i.e., $H = h_s$ = 45.7 m). Not accounting for the plume rise associated with the IET #10 releases results in the downwind air concentrations being overestimated.

5.2.1 Meteorological Data

Hourly wind and temperature data were obtained from the INL site for the IET #10 testing period (i.e., December 20, 1957, through March 6, 1958) (NOAA 2014). This dataset included data at the 20- and 150-ft elevations of the meteorological towers for the TAN and the Central Facilities Area (CFA). Based on the data for the 150-ft elevation on the TAN tower, an average wind speed of 6.0 mph (2.7 m/s) was calculated for the effluent release periods for IET #10 runs 12, 13, 15, 17, 21, 24, 25, 28, 29, 37, 42, 43, 45, 46, 47, 52, 53, 54, 55, and 56. Only the wind data for the periods associated with each run and the periods that it would take the last of the effluent to reach each receptor location were included in the calculation of this average. The meteorological data is provided in Appendix A.

5.2.2 Distances to Other Major Operating Areas

Distances from the IET Facility stack to the other major operating areas were determined using the Measure Distance feature in Google Maps. Table 5-1 provides a summary of those distances.

Table 5-1. Downwind distances from facility stack.

Operating area	Miles	Meters
ANL-W (TREAT)	18.29	29,440
ICPP	22.99	37,000
TRA	23.07	37,120
SPERT (SPERT II)	23.02	37,040
ARA (GCRE)	23.92	38,490
CFA	25.59	41,180
EBR-I	28.81	46,370
RWMC	30.18	48,570

5.2.3 Atmospheric Dispersion Coefficients

To retain some consistency with the previous atmospheric dispersion calculations for the environmental TBD, the atmospheric dispersion coefficients used for the short duration releases in the RSAC-6 program were used for these calculations (Wenzel and B.J. Schrader 2001). The original publication of those atmospheric dispersion coefficients was in *Climatography of the National Reactor Testing Station* (Yanskey, Markee, and Richter 1966, Start and Markee 1967). Figures 5-3 and 5-4 provide the horizontal and vertical dispersion coefficients from Yanskey, Markee, and Richter (1966). Another reason for using those atmospheric dispersion coefficients is that they are specific to the INL site and short duration releases, such as the IET #10 releases.

In addition, the differences between some of the receptor distances from Table 5-1 yielded relatively insignificant differences in the horizontal dispersion coefficients. Therefore, the various receptors were put into two groups and each group was assigned a single horizontal dispersion coefficient that was based on the shortest downwind distance to a receptor in that group. For Group 1, a single receptor distance of 29,440 m (18.29 mi) was used for all receptors between 29,440 and 38,490 m. For Group 2, a single receptor distance of 41,180 m (25.59 mi) was used for all receptors between 41,180 and 48,570 m. Based on that, Group 1 locations included Argonne National Laboratory-West (ANL-W), Idaho Chemical Processing Plant (ICPP), Test Reactor Area (TRA), Special Power Excursion Reactor Test (SPERT), and Army (later Auxiliary) Reactor Area (ARA) areas, and Group 2 locations included the CFA, EBR-I, and Radioactive Waste Management Complex (RWMC) areas. This simplification results in a slight overestimate of the environmental air concentrations for the receptor locations that were further away. Tables 5-2 and 5-3 provide the atmospheric dispersion coefficients for Groups 1 and 2.

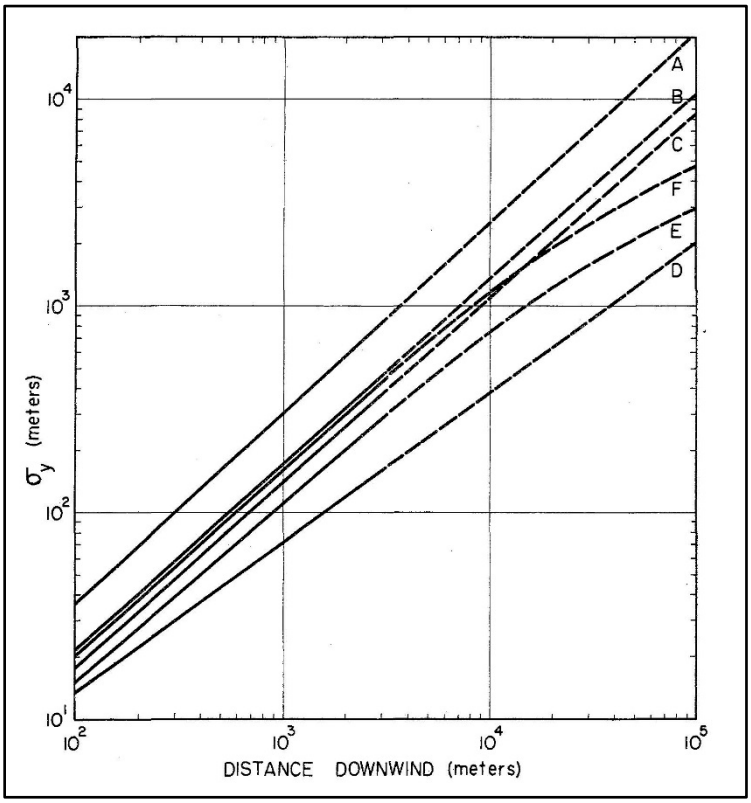

Figure 5-3. Horizontal atmospheric dispersion coefficients (Yanskey, Markee, and Richter 1966).

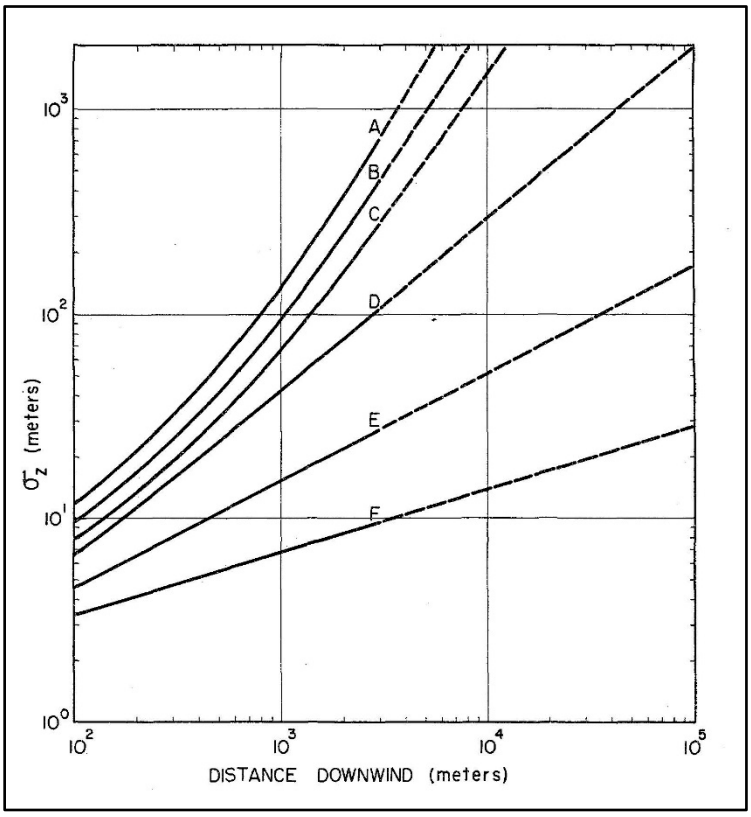

Figure 5-4. Vertical atmospheric dispersion coefficients (Yanskey, Markee, and Richter 1966).

Table 5-2. Atmospheric dispersion coefficients (m) for location Group 1.

Stability Class	σ_y	σ_z[a]
A	6,700	2,000[c]
B	3,500	2,000[c]
C	2,700	2,000[c]
D	800	700
E	1,500	90
F	2,400	18

a. The σ_z value was limited to 2,000 m, because the graph did not depict σ_z values beyond a distance of 5,500 m. This limitation results in a slight overestimate of the air concentrations.

Table 5-3. Atmospheric dispersion coefficients (m) for location Group 2.

Stability Class	σ_y	σ_z[a]
A	9,800	2,000[c]
B	5,000	2,000[c]
C	3,800	2,000[c]
D	1,100	1,000
E	1,900	105
F	3,000	21

a. The σ_z value was limited to 2,000 m, because the graph did not depict σ_z values beyond a distance of 5,500 m. This limitation results in a slight overestimate of the air concentrations.

5.2.4 Atmospheric Stability Class

The atmospheric dispersion calculations were performed for all atmospheric stability classes in Figures 5-3 and 5-4 (i.e., Classes A, B, C, D, E, and F) for the various receptor distances. However, only the atmospheric stability class that yielded the highest environmental air concentrations was used for the environmental air concentrations that are being proposed for the environmental TBD.

5.2.5 Atmospheric Dispersion Factors

Atmospheric dispersion factors (χ/Q values) were calculated for each receptor group and stability class using the equations and information above. The results of those calculations are summarized in Table 5-4. Based on the results in Table 5-4, Stability Class E yielded the highest dispersion factors and would yield the highest environmental air concentrations for the IET #10 releases. Because the atmospheric dispersion factors for Groups 1 and 2 were not significantly different, only the higher Group 1 values were used for both groups. This simplification results in a slight overestimate of the Group 2 intakes, but eliminates the need to determine where a worker was located onsite during the period for the IET #10 releases.

Table 5-4. Atmospheric dispersion factors (s/m^3).

Stability Class	Location Group 1	Location Group 2
A	8.80E–09	6.01E–09
B	1.68E–08	1.18E–08
C	2.18E–08	1.55E–08
D	2.10E–07	1.07E–07
E	**7.68E–07**	**5.37E–07**
F	1.11E–07	1.62E–07

6.0 POTENTIAL ENVIRONMENTAL INTAKES

Because INL workers who were not monitored for internal dose could have had intakes from the IET #10 effluent releases, potential environmental intakes were calculated for the unmonitored workers. All of the environmental intake calculations were performed in *INEL – IET 10 Releases & Worker Intakes* (ORAUT 2017a).

The environmental intakes were calculated using Equation 6-1:

$$I = \left(\frac{Q_{Tot}}{t_{Tot}}\right)\left(\frac{\chi}{Q}\right)\left[(BR)\left(t_{Exp}\right)\right]\left(3.7E+10\,\frac{Bq}{Ci}\right) \quad (6\text{-}1)$$

where

I = radionuclide intake for episodic release (Bq)
Q_{Tot} = total release of radioactivity for a given radionuclide (Ci)
t_{Tot} = total duration of release (s)
χ/Q = atmospheric dispersion factor (s/m^3)
BR = breathing rate (m^3/s)
t_{Exp} = total duration of exposure (s)

Because the total duration of the releases (t_{Tot}) is equivalent to exposure time (t_{Exp}), the time values cancel out and Equation 6-1 reduces to Equation 6-2:

$$I = \left(Q_{Tot}\right)\left(\frac{\chi}{Q}\right)(BR)\left(3.7E+10\,\frac{Bq}{Ci}\right) \quad (6\text{-}2)$$

A breathing rate equivalent to 9.6 m^3 over an 8-hour period was used for these calculations (i.e., BR = 3.33×10^{-4} m^3/s). This represents the breathing rate for Reference Man while performing light work (ICRP 1994a).

Environmental intakes were only calculated for Group 1 because the differences between the atmospheric dispersion factors for Group 1 and Group 2 were relatively insignificant. This simplification results in the intakes for workers at the Group 2 locations (i.e. CFA, EBR-I, and RWMC areas) to be overestimated by a factor of 1.4. However, it also eliminates the need to determine where a worker was on the INL site during the IET #10 testing period. The uranium intakes were simplified in accordance with the recommendations in ORAUT-OTIB-0060, *Internal Dose Reconstruction* (ORAUT 2014a). The radionuclide intakes for the three uranium isotopes were totaled and attributed solely to ^{234}U. The resulting environmental intakes based on the information provided above are summarized in Table 6-1.

Table 6-1. Environmental intakes from IET #10 releases (Bq).

Nuclide	IET #10 intakes
Br-84	8.06E+02
Rb-89	3.95E+04
Sr-89	9.93E+02
Sr-90	1.26E+00
Sr-91	6.98E+03
Sr-92	6.42E+03
Y-91	5.67E+02
Y-92	7.28E+03
Y-93	5.75E+03
Zr-95	6.12E+02
Zr-97	4.33E+03
Nb-96	3.76E-01
Mo-99	2.79E+03
Ru-103	4.38E+02
Ru-105	1.14E+03
Ru-106	8.02E+00
Sb-129	7.43E+02
Te-131	1.12E+03
Te-131m	2.13E+02
Te-132	1.94E+03
Te-133m	1.52E+03
Te-134	2.34E+03
I-131	2.62E+03
I-132	3.53E+02
I-133	1.17E+04
I-134	1.40E+03
I-135	1.88E+03
Cs-137	7.46E+00
Cs-138	1.05E+06
Ba-139	4.27E+04
Ba-140	1.85E+03
Ba-141	4.63E+02
Ba-142	4.20E+01
La-141	7.04E+03
La-142	5.49E+03
Ce-141	9.14E+02
Ce-143	3.35E+03
Ce-144	1.33E+02
Pr-143	1.41E+03
Pr-144	1.33E+02
U-234	1.86E-02

No adjustments were performed on the intakes in Table 6-1 to account for radioactive decay during the plume's transit time, because it was already accounted for in the releases. The release values in Table 4-2 were based on the original releases in the HDE and adjusted by the factors in Table 4-1. Based on the information in Volume II of the HDE, the episodic releases were decay corrected for a 2.9 hour transit time to the INL site boundary (DOE 1991b). Because the potential transit time for the IET #10 releases to reach an onsite receptor was reasonably close to that value (approximately 3.0 hour), no additional adjustment for radioactive decay was performed.

7.0 POTENTIAL UNMONITORED INTERNAL DOSES

To ensure that the unmonitored environmental internal doses associated with the intakes in Table 6-1 were not unreasonable, internal doses were assessed for all internal organs and tissues. With the exception of the tellurium isotopes, all doses were calculated using the Integrated Modules for Bioassay Analysis (IMBA) computer program. The doses for the tellurium isotopes were calculated using the Dose and Risk Calculation (DCAL) computer program.

The lung absorption types that were used for the internal doses calculations are based on the ICRP 68 (ICRP 1994b) lung absorption type resulting in the highest dose with the exception of strontium, iodine, and uranium isotopes. Strontium was only assessed as type F material, because the presence of strontium titanate ($SrTiO_3$) was not possible in the IET #10 releases. Because the iodine was likely in elemental form, the iodine intakes were only assessed as vapor intakes having type SR-1 lung absorption properties. The uranium intake was only assessed as material having type S lung absorption properties, because the potential uranium compounds in the IET #10 releases were limited to uranium oxides.

Because all of the IET #10 runs associated with Table 6-1 intakes occurred during a relatively short period in early 1958, the intakes in Table 6-1 were assessed as acute intakes with an intake date of January 1, 1958. The organ doses were assessed by assuming a cancer diagnosis date of December 31, 2017, for all organs. Table 7-1 provides the internal doses associated with the IET #10 releases for selected organs.

Table 7-1. 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).

8.0 QUALITATIVE EVALUATION OF UNCERTAINTIES

No quantitative uncertainty analysis was performed for this evaluation, but qualitative discussions were held concerning the associated uncertainties. This section discusses the types and levels of uncertainty to be expected in each of the major categories of calculated quantities. A number of the discussions below are based on uncertainty discussions in Volume 2 of the HDE (DOE 1991b) and IAEA-TECDOC-379 (IAEA 1986).

All measurements of physical quantities are subject to uncertainties. For measurements, there are two primary components associated with the overall uncertainty of a measurement. Because the definitions of statistical terms are highly variable throughout the reference literature on statistics, the following statistical terms have been defined for this document:

- Accuracy. The closeness of agreement between a test result and the accepted reference value. The term accuracy, when applied to a set of test results, involves a combination of random components and a common systematic error or bias component.

- Precision. Describes dispersion of measurements in relation to a measure of location or central tendency.

- Error. Difference between the correct, true, or conventionally accepted value and the measured or estimated value. Sometimes used to mean estimated uncertainty.

  – Random error. When a given measurement is repeated and the values do not agree exactly. The causes of the disagreement between the values must also be the causes of their differences from the true value.

  – Systematic error. When a given measurement is repeated and the values differ from the true value by the same amount.

- Bias. The difference between the expectation of the test results and an accepted reference value. Bias is the total systematic error as contrasted to random error. There can be one or more systematic error components contributing to the bias. A larger systematic difference from the accepted reference value is reflected by a larger bias value.

- Uncertainty. Standard deviation of the mean of a set of measurements. The standard error reduces to the standard deviation of the measurement when there is only one determination.

- Standard deviation. Square root of the variance, or the measure of spread, in a group of numbers. The sample standard deviation is the square root of the sample variance. This means that it has the same linear units as the original data values or a measure of central tendency, rather than the squared units of the sample variance.

Figure 8-1 depicts the relationship of accuracy and precision of a measurement result to its accepted reference value.

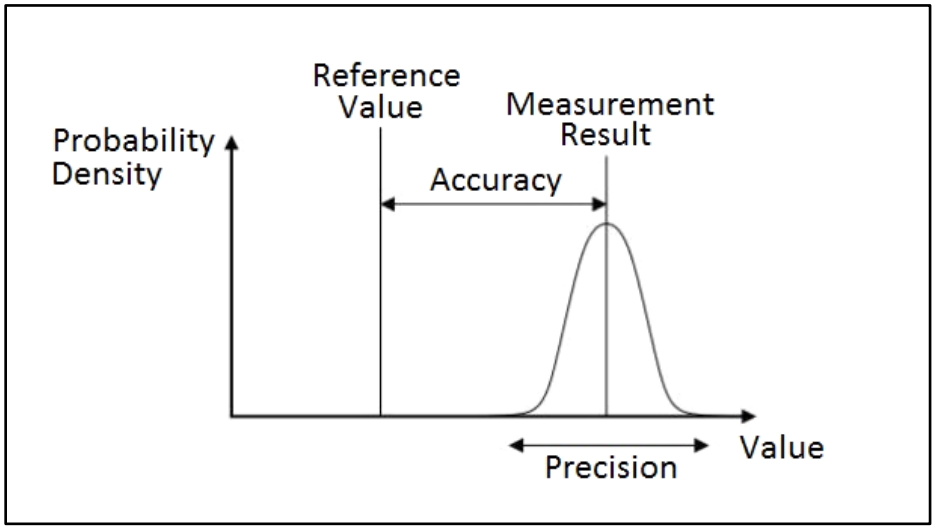

Figure 8-1. Relationship of measurement accuracy and precision to the reference value.

In addition, there are uncertainties associated with computational models that approximate complex natural and physical processes. These uncertainties are often much more difficult, if not impossible, to measure or estimate. This evaluation includes the use of three such models. The RSAC Program, version 4.03 (Wenzel 1990), was used to estimate the fission product inventory by simulating the physical processes inside the IET #10 reactor insert (Insert 2B) (DOE 1991a, 1991b, 1991c). The fission product inventory data was then used to determine the composition of the radionuclide releases from the Insert 2B testing. The Gaussian plume model was used to simulate natural atmospheric mechanisms that dispersed the IET #10 effluents. The organ doses were calculated using IMBA, which serves as a biokinetic model for the human body.

For the evaluation of the dose consequences of IET #10 airborne effluent releases, four major categories of quantities were calculated: (1) effluent releases, (2) atmospheric dispersion factors, (3) potential environmental intakes, and (4) potential internal doses. Each quantity has associated uncertainties. When those quantities are estimates rather than direct measurements, the magnitudes of their associated uncertainties can be large. Therefore, it is important to recognize that these uncertainties exist and to have some appreciation of their magnitude and how they arise. Knowledge of the uncertainties is valuable for understanding how much reliance to place on the estimated values, and for anticipating areas of potential concern.

8.1 UNCERTAINTIES IN EFFLUENT RELEASES

The accuracy and precision of the effluent releases is dependent on the degree of uncertainty in the effluent flow, effluent sample collection, sample analysis, and using surrogate releases to estimate releases of other radionuclides. Determining how these parameters affected the effluent releases in SC&A and SENES (2005) is impossible in most instances, because it is unclear how each of the radionuclide releases were calculated in that document. Therefore, only a general discussion of the uncertainties for the parameters that likely affected the SC&A and SENES (2005) release estimates is provided.

In the original reference documents effluent releases information was reported in terms of leakage rates, which is different from the current convention for reporting effluent releases. Leakage rate was defined as the fraction of fission products produced in the reactor insert during a given time that escaped via the effluents (Foster et al. 1958).

8.1.1 Uncertainty in Effluent Flow

The effluent flow rates in the IET Facility stack had a high degree of variability due to whether one or two jet engines were being operated during an IET test run and to how fast the engines were running. For IET #10, that variability was minimized by limiting all IET #10 testing to one jet engine operation and only operating that engine at 7,070 rpm (Foster et al. 1958).

The effluent stream that was fed into the IET Facility stack was augmented by fresh air that entered through the porous firebrick at the bottom of the stack. An augmentation factor of 1.25 ±0.525 (±4.2%) was reported for the effluent stream.

The IET Facility stack was too wide and too short to allow the formation of turbulent flow (i.e., uniform flow) conditions within the stack. Not achieving turbulent flow conditions within a stack often results in complex flow patterns, which make collecting a representative effluent sample difficult. A velocity profile at the 80-ft level of the stack during Operation BOOT (IET #12) confirms this, and even indicates that the flow inside the stack is reversed (i.e., a downward flow) outside of that jet stream (Devens et al. 1958).

8.1.2 Uncertainty in Effluent Sample Collection and Analysis

These uncertainties include sample line-loss, filter media collection efficiency, analyzing partial samples and aliquots of samples, counting efficiency, sample analysis, and data reproducibility.

No uncertainties associated with the sample analysis methods were reported for any of the IET #10 effluent data. Another effluent sample uncertainty that affected the carbon trap samples was related to the practice of analyzing partial samples and aliquots of samples. Only aliquots of the first 5 in. of the carbon traps were analyzed for beryllium, radioactive iodine, and radioactive barium (Foster et al. 1958). Based on measurements performed for previous IETs, it was believed that approximately 44% of the beryllium, 90% of the radioactive iodine, and 80% of the radioactive barium were deposited within the first 5 in. of the carbon traps (Foster et al. 1958). Those deposition fractions for the carbon traps likely have some variability from one IET run to the next, due to changes in effluent flow rate, effluent temperature, effluent particle sizes, sample flow rate, etc. Because multiple aliquots were not analyzed to confirm how well the carbon trap samples were homogenized, another source of unknown uncertainty was introduced by only analyzing aliquots of the carbon trap samples.

Even though no uncertainty measurements were made for the effluent samples during the IET #10 testing, measurements were made for several parameters during other IET tests that would be applicable to the IET #10 samples. Sample line-loss factor was 1.56 ±0.0624 (±4.0%) (Boone, Lofthouse, and VanVleck 1959). The 1.56 line-loss correction factor was applied to the reported leakage rates for IET #10 (Foster et al. 1958). Filter collection efficiency for the filter paper air samples was 44% ±4% (Boone, Lofthouse, and VanVleck 1959). However, it is uncertain whether the filter paper samples were used for the effluent release estimates. Based on the information above, the collection efficiencies for the carbon traps were effectively 44% for beryllium, 90% for radioactive iodine, and 80% for radioactive barium. Data reproducibility was determined by collecting 14 spot samples at 5-minute intervals and comparing the analytical results (Boone, Lofthouse, and VanVleck 1959). Even though some of these were determined before IET #10 testing, it could not be determined if all of them were applied to the IET #10 sample results.

8.1.3 Using Surrogate Releases to Estimate Fission Product Releases

Beryllium, radioactive iodine, and radioactive barium releases were evaluated as a means of estimating the fission product composition of the IET #10 releases. As part of this, RSAC-4 (Wenzel 1990) was used to estimate the fission product inventory by simulating the physical processes inside the IET #10 reactor insert (Insert 2B) (DOE 1991a, 1991b, 1991c). The beryllium, radioactive iodine, and radioactive barium releases could then be used as surrogates for estimating the releases of the fission products. As indicated above, assessing the uncertainties associated with computational models that approximate complex natural and physical processes is very difficult, if not impossible. However, some things can be said about the use of the surrogates that were used. Even though SC&A and SENES (2005) evaluated using beryllium, radioactive iodine, and radioactive barium releases to estimate the fission product releases for IET #10, it appears that the radioactive iodine releases were used for that document's release estimates, which is what was used in the HDE (SC&A and SENES 2005, DOE 1991c). Because radioactive iodine is much more volatile and likely to be released than other fission products, the use of the radioactive iodine releases as a surrogate for the other fission products likely results in an overestimate in the releases for the less-volatile fission products. The best demonstration of this is from releases at the ICPP from radioactive lanthanum (RaLa) runs. During those release events, large quantities of radioactive iodine and radioactive noble gases without other fission products were released into some of the work areas at the ICPP. A review of the INL bioassay data confirms that radioactive iodine intakes were normally only associated with the RaLa release events at the ICPP. This is an indication that other fission products were much less likely to be released from reactor fuel than radioactive iodine. There is no indication in the IET #10 release estimates that this was accounted for.

8.1.4 Using Surrogate Releases to Estimate Uranium Releases

The uranium releases in SC&A and SENES (2005) appear to be based on an estimate of UO_2 that diffused out of the fuel due to the hydrolysis of the BeO. In addition, those estimates are based on some questionable information in Evans (1960) (see Section 4.2.4). As indicated in Sections 4.1 and 4.2, the beryllium should have been much more likely to diffuse out than the uranium. In addition, SC&A and SENES (2005) do not appear to account for the diffused uranium that was retained in the CTF. As indicated in Section 3.4.3, 8.4 g of ^{235}U (9.0 g U) from Insert 2B was recovered from the lower cocoon of the CTF shortly after the start of IET #11. Given these factors, the uranium releases in SC&A and SENES (2005) are likely overestimated to an unknown degree.

8.2 ATMOSPHERIC DISPERSION FACTORS

There are a multitude of uncertainties, many that cannot be assessed, in the calculation of atmospheric dispersion factors. The following sections address as many of those as possible.

8.2.1 Time Increments for the Meteorological Data

The meteorological data (i.e., the wind telemetry and temperature data) for the periods of the IET #10 effluent releases is only available in hourly increments, and there is no information about the uncertainty of those measurements. If the hourly wind telemetry and temperature data was not determined from a strip chart that recorded instantaneous readings for those measurements, the uncertainties associated with that hourly data could be significant.

8.2.2 Hourly Wind Speed Data

The uncertainty of hourly wind speed data is highly dependent on the frequency of the wind speed measurements. No uncertainty information was reported with the meteorological dataset provided for the IET #10 testing periods (ORAUT 2014b). During gusty wind conditions, the random uncertainties could be very large.

Insufficient information is currently available to confirm the frequency of the recorded wind speed data (i.e., were instantaneous readings recorded or readings at some time interval). Wind data collected at the 250 ft (76.2 m) level began on June 22, 1951 for the CFA meteorological station (a.k.a. WBO) and at the 150 ft (45 7 m) level on April 15, 1956 for the TAN meteorological station (a.k.a. ANP, WXA-2, or IET) (Marrais 1958a). Sometime after the IET #10 releases and by November 1958, wind and temperature data at TAN was being collected at several levels and as high as 200 ft (61.0 m) level (Marrais 1958b). All other onsite and offsite meteorological stations limited to only recording surface level data (Marrais 1958a). *Radiological and Meteorological Telemetry System for the National Reactor Testing Station* (AEC 1973), indicates that beginning in the late-1950s a radiological and meteorological telemetry system was installed to transmit the data from the remote monitoring stations to the main station at the CFA. All of the telemetered data were recorded on punched paper tape, which were subsequently submitted for computer processing (AEC 1973). No information has been found to indicate at what frequency the wind speed data was recorded. Because it does not appear that strip charts were used to continuously record instantaneous data in the form of a wind speed trace, there is a possibility that instantaneous wind data was not recorded and that this data was recorded at a predetermined interval. However, the reporting of peak wind gusts for the period of July 1950 through December 1957 for the TAN meteorological station implies that instantaneous or near-instantaneous readings of wind speed were likely recorded (Marrais 1958b, p. 69).

8.2.3 Hourly Wind Direction Data

The uncertainty of the hourly wind direction data is highly dependent on the frequency of the wind speed measurements. No uncertainty information was reported with the meteorological dataset provided for the IET #10 testing periods (ORAUT 2014b). During gusty wind conditions, the random uncertainties could be very large.

Insufficient information is currently available to confirm what frequency the wind direction data was recorded (i.e., were instantaneous readings recorded or readings at some time interval). Therefore, the uncertainty associated with that component of the wind direction measurements could not be assessed.

In 1958, the hourly wind directions for the INL were only reported in increments of 22.5 degrees (ORAUT 2014b). This reporting limitation automatically incurs an uncertainty of ± 11.25 degrees in the reported hourly wind directions, which is equivalent to a 3.1% uncertainty (11.25 /360 degrees or 0.5/16 sectors).

During the evaluated IET #10 runs, the hourly wind directions at the 150-ft (45.7-m) level fluctuated by as much as 180 degrees from one hour to the next. The standard deviations in the hourly wind fluctuations for each of those runs ranged between 9.6 and 81.1 degrees, which indicates there was a significant amount of plume meandering.

As the IET #10 plumes approached the other INL operating areas, the wind fluctuations from the 20-ft (6.1-m) and 150-ft (45.7-m) monitoring levels at the CFA would have had an increasing influence on the dispersion of the plumes and the air concentrations at the receptor locations. On average, the hourly wind directions reported for the CFA and TAN monitoring locations varied by more than 2.6 compass sectors (>59.4 degrees).

These uncertainties are negated by assuming that the plume traveled directly from the point of release to the receptors with no meandering. This maximizing assumption results in a bias favorable to the claimant because accounting for plume meandering would further diffuse the plume due to longer travel distances and times to get to the receptors. This maximizing bias is difficult to quantify without modeling each release through a model like MESODIF (i.e., a forward time-marching Gaussian plume model in which successive, small plume elements are advected throughout the computational area) and comparing those results to the calculated values in this evaluation.

8.2.4 Atmospheric Stability Class

Sufficient information is not available to accurately determine atmospheric stability classes during the IET #10 runs. Given the length of the runs and times of day when the runs started and stopped, several runs were likely associated with more than one stability class. Therefore, only the stability class yielding the highest atmospheric dispersion factor (χ/Q value) was used for this evaluation. As a result, Stability Class E was assumed for this evaluation. By assuming the worst-case stability class for these calculations, the downwind air concentrations at the receptor locations could be overestimated by at least a factor of 3.66.

8.2.5 Effective Stack Height

To help maximize the downwind air concentrations, the calculations for this evaluation did not account for plume rise and the effective stack height was assumed to be equal to the physical stack height, which resulted in a large negative bias for the effective stack height.

Because of the excessive temperature and velocity of the exhaust gases from the IET stack during ANP Program operations, the effective stack height was actually much greater than its physical stack height of 150 ft (45.7 m). Because of those excessive temperatures and velocities of the exhaust gases, standard equations will not accurately estimate the effective stack height of the IET stack. Further, the effluent release configuration inside the stack will not allow accurate estimation of the momentum contribution to the effective stack height using standard equations. This is mostly due to the highly laminar flow in the form of a jet, which is caused by the exhaust gases being released from a 5.25-ft (1.60-m)-diameter nozzle in the within the southeast quadrant of a 20.0-ft (6.10-m)-diameter stack (diameter at the release point) (Parsons 1955, 1963). The IET Facility stack was too wide and too short to allow the formation of turbulent flow (i.e., uniform flow) conditions within the stack. A velocity profile performed at the 80-ft (24.4-m) level of the IET Facility stack during Operation BOOT (IET #12) confirms this, and even indicates that the flow inside the stack was reversed (i.e., a downward flow) outside of that jet stream (Devens et. al. 1958).

During the ANP Program's Insert II operations (i.e., during IET #10 operations), aerial radioactivity measurements were made using an aircraft to better determine the actual effective height of the IET stacks plume. Those measurements confirmed that standard equations would significantly underestimate the effective stack height for the IET stack. A popular equation at the time for calculating effective stack heights (i.e., the Bryant-Davidson equation) estimated the effective height to be 190 ft (57.9 m) for a wind speed of 5 mph (2.2 m/s) and 270 ft (82.3 m) for a wind speed of 2 mph (0.89 m/s). In contrast to those calculations, aerial measurements indicated that the effective height 0.25 mi (402 m) downwind of the stack was 300 ft (91.4 m) and 900 ft (274.3 m) 4 miles (6,437 m) downwind. The aerial measurements also determined that the top of the plume reached heights of 1,500 ft (457.2 m) above the ground. The data also indicated that the plume did not rise abruptly and level off as typically assumed. Rather, the plume rose continuously for great distances (Islitzer ca. 1958).

8.2.6 Atmospheric Mixing Depth

For assessments of atmospheric dispersion over large distances from source to receptor, such as at the INL site, the depth of the mixing layer in the atmosphere can be a significant parameter. This is often referred to as the lid-height L (Till and Meyer 1983). The downwind distance x_L occurs at $\sigma_z = 0.47L$ and is considered to be the last point that the plume has a Gaussian distribution in the vertical plane (Turner 1970). After that distance, L begins to affect the dispersion in the vertical plane. At a distance of $2x_L$, the plume is considered to be uniformly distributed within the vertical plane (i.e., the concentration no longer varies with height) and the only dispersion that is occurring is in the horizontal plane (Turner 1970). For the calculations for this evaluation, L was not accounted for because it was largely an unknown parameter for the IET #10 releases. Not accounting for L after the distance of x_L could result in an underestimate of the air concentrations at the receptor locations on the INL site. However, the atmospheric dispersion calculations limited σ_z to a maximum value of 2,000 m, which is likely the minimum value of L during the IET #10 testing due to restrictions in the meteorological conditions during those tests. In addition, the unusually high temperatures of the IET #10 plumes could have nullified the effects from a lower L caused by a temperature inversion. The significant buoyancy of the plumes due to the high effluent temperatures could have enabled the plume to rise beyond L.

8.2.7 Plume Depletion

No attempt was made to account for plume depletion. The majority of the plume depletion during the IET #10 runs was likely due to dry deposition. Not accounting for this results in a small bias that overestimates the downwind air concentrations and receptor intakes.

8.2.8 Horizontal and Vertical Dispersion Coefficients

There are many systems for estimating the horizontal and vertical dispersion coefficients (a.k.a. diffusion coefficients). Those systems are typically based on empirical data from dispersion studies and are also typically only applicable to certain terrain conditions, release durations, and downwind distances. Those systems are available in graphical representations, equations, or both. There is a significant degree of variability in the dispersion coefficients these systems generate, and it is difficult to determine the most appropriate system to use for a site and release scenario. Therefore, the selection of the dispersion coefficient system can result in some potentially significant uncertainty in the calculation of the atmospheric dispersion factors.

For this evaluation, the dispersion coefficients were obtained from Figures 3-5 and 3-6 in Yanskey, Markee, and Richter (1966). Data collected using aircraft during one or more of the IET #10 runs indicated that the amount of horizontal plume spread 4 mi (6,437 m) downwind of the releases ranged between 1.0 and 2.0 mi (1,609 and 3,219 m) (Marrais and Islitzer 1960). This is equivalent to σ_y values of 0.5 to 1.0 mi (804 to 1,609 m). Based on Figure 3-5 in *Climatography of the National Reactor Testing Station*, which contains curves for the horizontal dispersion coefficients for 15- to 60-min release times (Yanskey, Markee, and Richter 1966), a σ_y value at x = 4 mi (6,437 m) is approximately 560 m for Stability Class E, which is significantly less than those based on actual measurements. Therefore, the downwind dispersion was likely underestimated, which results in an overestimate of the downwind air concentrations.

8.2.9 Atmospheric Dispersion Model

The natural processes that affect or contribute to the transport and dispersion of material in the atmosphere are typically very complex. This complexity is amplified even more when the scale of the area being modelled is expanded. Atmospheric dispersion modeling can be performed on scales ranging from local, to meso-, to regional, and finally to global. Based on distances between the major operating areas of the INL site, atmospheric dispersion modeling on a mesoscale would normally be necessary when accurate assessments of the effect of airborne effluent releases to other operating areas on the site are necessary. Fortunately for this evaluation, only an overestimate of that effect was necessary because the 1958 meteorological data for a more accurate assessment is not available (e.g., detailed stability class data, meteorological data from multiple onsite locations, etc.).

Section 5.2 explains why the much simpler Gaussian plume model was selected over a mesoscale atmospheric dispersion model. Even though the uncertainties associated with each parameter of the Gaussian plume model can be propagated through that equation, they do not account for the much larger uncertainties inherent to that model and most other atmospheric dispersion models. All atmospheric dispersion models attempt to predict the multitude of natural processes that affect or contribute to the transport and dispersion of material in the atmosphere. However, only a relatively small number of those processes can be accounted for by even the most complex models. Because of that, the overall uncertainty in those unaccounted-for processes can be much larger than the overall uncertainty being propagated through a mathematical model. Without reliable air monitoring data at designated points of interest to compare to model output, there is no way to account for those potentially significant sources of uncertainty. This is the primary reason only a quantitative uncertainty analysis was performed for this evaluation.

8.3 POTENTIAL UNMONITORED ENVIRONMENTAL INTAKES

A worker's potential to receive an unmonitored environmental intake from the IET #10 effluent releases is highly dependent on a number of parameters and assumptions, such as (1) presence on site during each of the IET #10 runs, (2) specific locations on site during each of the IET #10 runs, and (3) breathing rate.

8.3.1 A Worker's Presence Onsite

As indicated in Section 4.6, the only IET #10 effluents that the onsite workers were potentially exposed to were from runs 12, 13, 15, 17, 21, 24, 25, 28, 29, 37, 42, 43, 45, 46, 47, 52, 53, 54, 55, and 56. Table 3-1 indicates that those IET #10 runs took place during the period of January 4, 1958, through March 5, 1958. Based on the time periods for those runs, many took place over two to three work shifts, which makes it unlikely that any given worker was present for more than half the time those runs took place. Given that, the simplifying assumption that all workers with any employment during the IET #10 runs were on site during all of the periods for those runs likely overestimates the worker intakes by at least a factor of 2.

8.3.2 A Worker's Specific Onsite Location

During the months of January, February, and March, 1958, the majority of INL workers likely spent little time outside. For unmonitored workers who were indoors during the IET#10 runs, the concentrations of indoor airborne radioactivity from those runs would have been significantly lower than the outdoor concentrations, due to the transport mechanisms (e.g., moving through intakes, ducts, filters, etc.) that would bring that radioactivity indoors as well as due to some buildings that recirculated significant fractions of indoor air. This is one of the reasons why emergency response plans for many nuclear sites have instructions to shelter the workers in place (i.e., indoors) in the event of a significant environmental release. Exceptions to this were likely the various maintenance shops and buildings with large rollup doors. For the buildings where a fraction of the indoor air was being recirculated, the low outdoor temperatures during the IET #10 runs would have likely resulted in an even bigger fraction of the indoor air than normal being recirculated, which would mean even less fresh air (i.e., outdoor air) was being brought into the various INL buildings. Because accounting for the radionuclide transport mechanisms of more than 1,000 buildings would be extremely complex and because there is no reliable way to determine if a worker was indoors or outdoors during the IET #10 releases, a simplifying assumption was made. For this evaluation, all workers were assumed to be outside during the times the IET #10 plumes intersected with their locations, which resulted in significant overestimates of the environmental intakes for the majority of the unmonitored indoor workers. Note that this assumption is even unlikely for the outdoor workers because they likely took their breaks indoors during the winter. For unmonitored outdoor workers, this overestimating simplification likely has a negligible effect on the environmental intakes. However, for unmonitored indoor workers, this simplifying assumption likely causes their intakes to be overestimated by anywhere from about a factor of 2 to more than an order of magnitude.

In addition to assuming that all unmonitored workers were outside when IET #10 plumes intersected their locations, another simplification was to initially put all of the major operating areas for the INL site into two groups. The groupings of the operating areas were based on their shortest distances from the IET stack (i.e., the IET #10 effluent release point). The two groupings were further simplified to just one group, since there was not a significant difference in the dispersion factors for the two groups. It was assumed that the workers in a given operating area were in the horizontal centerline of each plume and at the point closest to the IET stack for their grouping of operating areas. These simplifying assumptions likely caused the worker intakes to be overestimated by less than a factor of 2.

8.3.3 Breathing Rate

Table 6 in ICRP Publication 66 provides a single set of reference values for respiratory parameters for both male and female workers (ICRP 1994a). These values include recommended values to assume for the amount of air breathed for an 8-hour workday for light work and heavy work activities (ICRP 1994a). When no other information is available, which is typically the case, OCAS-IG-002, *Internal Dose Reconstruction Guideline*, directs the use of the ICRP defaults for a "reference worker" (NIOSH

2002). Even though breathing rates can be highly variable, the breathing rates for standard man in Publication 66 are typically applied as constants because neither Publication 66 nor Publication 23 (ICRP 1975) provides uncertainty information for those breathing rates.

9.0 SUMMARY OF RESULTS

The Oak Ridge Associated Universities (ORAU) Team has determined that unmonitored workers at other major operating areas on the INL site could have been exposed to the airborne effluent releases from some of the IET #10 runs and has therefore calculated estimates of the environmental intakes attributable to those episodic releases. This evaluation also determined that the workers at TAN did not likely receive significant internal exposures from the IET #10 effluent releases. Table 9-1 summarizes the environmental intakes from the IET #10 releases, as presented above in Section 4.6. These environmental intakes will be incorporated into the next revision of ORAUT-TKBS-0007-4, *Idaho National Laboratory and Argonne National Laboratory West – Occupational Environmental Dose* (currently ORAUT 2010a).

Table 9-1. Environmental intakes from IET #10 releases (Bq).

Nuclide	IET #10 intakes
Br-84	8.06E+02
Rb-89	3.95E+04
Sr-89	9.93E+02
Sr-90	1.26E+00
Sr-91	6.98E+03
Sr-92	6.42E+03
Y-91	5.67E+02
Y-92	7.28E+03
Y-93	5.75E+03
Zr-95	6.12E+02
Zr-97	4.33E+03
Nb-96	3.76E-01
Mo-99	2.79E+03
Ru-103	4.38E+02
Ru-105	1.14E+03
Ru-106	8.02E+00
Sb-129	7.43E+02
Te-131	1.12E+03
Te-131m	2.13E+02
Te-132	1.94E+03
Te-133m	1.52E+03
Te-134	2.34E+03
I-131	2.62E+03
I-132	3.53E+02
I-133	1.17E+04
I-134	1.40E+03
I-135	1.88E+03
Cs-137	7.46E+00
Cs-138	1.05E+06
Ba-139	4.27E+04
Ba-140	1.85E+03
Ba-141	4.63E+02
Ba-142	4.20E+01
La-141	7.04E+03
La-142	5.49E+03

Nuclide	IET #10 intakes
Ce-141	9.14E+02
Ce-143	3.35E+03
Ce-144	1.33E+02
Pr-143	1.41E+03
Pr-144	1.33E+02
U-234	1.86E-02

As indicated in the previous sections, there are a number of reasons that indicate that the intakes in Table 9-1 are overestimates of the potential unmonitored intakes from the IET #10 effluent releases. The following is a summary of some of the more significant items that led these conservative intake estimates.

- The HDE effluent releases for IET #10 were used, and were increased using the information from SC&A and SENES (2005).
- The effective stack height was limited to the physical stack height of 150 ft (45.7 m), and did not account for plume rise. Aerial measurements of the effluent plume indicated that the effective stack height was likely 6 times that height, based on downwind effluent measurements.
- The plumes were assumed to travel the directly to the receptor locations. In reality, most of the IET #10 plumes started out by blowing away from the other INL operating areas, and later changed course to work their way back to those locations.
- Only a single distance (i.e., the shortest distance to any of the potential receptor locations) was used for the distance to all receptor locations when some receptor locations were significantly further away.
- Only the most favorable atmospheric Stability Class was used when other Stability Classes were more probable.
- Workers were assumed to be present during all portions of all applicable IET #10 releases, even though many of those releases occurred over more than one work-shift.
- The intake estimates do not account for the fact that most workers were indoors during the Idaho winter months.

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ATTACHMENT A
METEOROLOGICAL DATA FOR ATMOSPHERIC DISPERSION CALCULATIONS

Table A-1. Meteorological data applicable to atmospheric dispersion calculations.[a,b]

IET #10 Run	Date	Time Hour	TAN 20 ft. Direction (deg.)	TAN 20 ft. Speed (MPH)	TAN 20 ft. Air Temperature (F)	TAN 150 ft. Direction (deg.)	TAN 150 ft. Speed (MPH)	TAN 150 ft. Air Temperature (F)
Phase I Testing								
12	01/04/58	14	67.5	2	18.7	67.5	4	17.2
12	01/04/58	15	45.0	3	19.3	45.0	4	18.2
	01/04/58	16	0.0	0	20.0	45.0	2	19.2
	01/04/58	17	0.0	0	16.3	45.0	1	18.2
	01/04/58	18	0.0	0	12.4	22.5	4	17.9
	01/04/58	19	337.5	3	9.5	45.0	2	17.3
	01/04/58	20	22.5	4	8.5	22.5	4	16.4
	01/04/58	21	22.5	3	7.6	45.0	4	16.3
	01/04/58	22	67.5	5	5.4	90.0	6	14.3
	01/04/58	23	22.5	3	7.4	90.0	6	11.0
13	01/05/58	13	0.0	0	18.9	0.0	0	16.3
13	01/05/58	14	247.5	2	20.6	202.5	3	19.7
	01/05/58	15	45.0	2	21.4	90.0	4	21.7
	01/05/58	16	67.5	5	21.9	67.5	8	21.6
	01/05/58	17	337.5	3	17.2	360.0	6	21.3
	01/05/58	18	337.5	5	12.7	360.0	8	21.8
	01/05/58	19	337.5	3	9.8	337.5	11	23.6
15	01/07/58	11	225.0	2	12.2	202.5	2	11.0
15	01/07/58	12	225.0	1	16.6	202.5	2	16.3
15	01/07/58	13	0.0	0	21.1	0.0	0	21.6
	01/07/58	14	0.0	0	28.0	45.0	3	27.1
	01/07/58	15	999.9	99	28.9	45.0	3	28.2
	01/07/58	16	999.9	99	28.2	0.0	0	27.8
	01/07/58	17	0.0	0	26.8	360.0	1	29.9
	01/07/58	18	315.0	3	16.5	0.0	0	27.8
	01/07/58	19	337.5	7	17.4	337.5	5	27.6
	01/07/58	20	337.5	5	17.5	337.5	17	31.5
	01/07/58	21	112.5	2	3.9	360.0	7	20.0
17	01/10/58	12	225.0	3	18.4	225.0	4	17.3
17	01/10/58	13	202.5	1	20.9	180.0	3	20.1
17	01/10/58	14	0.0	0	22.5	0.0	0	21.7
	01/10/58	15	0.0	0	23.1	67.5	2	22.5
	01/10/58	16	45.0	4	23.6	45.0	6	23.0
	01/10/58	17	45.0	3	23.0	45.0	5	23.1
	01/10/58	18	337.5	2	23.0	360.0	4	22.5
	01/10/58	19	337.5	4	23.0	337.5	8	23.6
	01/10/58	20	22.5	3	23.3	360.0	8	24.3
21	01/14/58	13	225.0	3	20.8	225.0	3	22.7
21	01/14/58	14	202.5	1	24.8	202.5	1	24.0
21	01/14/58	15	0.0	0	25.4	0.0	0	24.8
	01/14/58	16	22.5	2	26.1	22.5	1	25.1
	01/14/58	17	45.0	5	25.6	45.0	6	25.3
	01/14/58	18	67.5	4	25.3	67.5	6	25.2
	01/14/58	19	67.5	3	25.0	67.5	7	25.5
	01/14/58	20	0.0	0	25.0	90.0	3	25.0
	01/14/58	21	0.0	0	24.1	45.0	1	24.4
	01/14/58	22	315.0	2	23.7	360.0	4	23.8
	01/14/58	23	315.0	2	23.5	337.5	3	24.5
Phase II Testing								
24	01/19/58	13	247.5	7	29.1	247.5	7	27.6
24	01/19/58	14	292.5	6	30.5	292.5	4	29.9
24	01/19/58	15	247.5	6	32.8	247.5	6	30.7
24	01/19/58	16	225.0	10	29.9	225.0	12	28.8
	01/19/58	17	202.5	7	25.4	202.5	10	26.0
	01/19/58	18	180.0	4	15.8	180.0	7	22.4
	01/19/58	19	45.0	4	11.9	180.0	2	17.0
25	01/21/58	12	225.0	4	21.4	202.5	3	20.1
25	01/21/58	13	202.5	6	24.0	202.5	5	23.2
25	01/21/58	14	202.5	6	25.9	202.5	6	25.4
25	01/21/58	15	202.5	10	29.1	202.5	11	27.2
25	01/21/58	16	180.0	11	27.5	180.0	12	28.8
25	01/21/58	17	180.0	10	23.3	180.0	14	26.2
25	01/21/58	18	157.5	7	18.8	202.5	10	21.7
25	01/21/58	19	225.0	8	15.2	247.5	11	18.4
	01/21/58	20	315.0	6	8.8	315.0	7	13.3
	01/21/58	21	360.0	4	8.0	45.0	5	9.6

ATTACHMENT A
METEOROLOGICAL DATA FOR ATMOSPHERIC DISPERSION CALCULATIONS (continued)

IET #10 Run	Date	Time Hour	TAN 20 ft. Direction (deg.)	TAN 20 ft. Speed (MPH)	TAN 20 ft. Air Temperature (F)	TAN 150 ft. Direction (deg.)	TAN 150 ft. Speed (MPH)	TAN 150 ft. Air Temperature (F)
	01/21/58	22	22.5	5	5.1	22.5	5	8.7
	01/21/58	23	67.5	5	7.6	45.0	8	11.2
28	01/25/58	12	202.5	6	28.5	225.0	7	28.9
28	01/25/58	13	202.5	7	30.8	202.5	8	30.1
28	01/25/58	14	202.5	7	30.4	202.5	8	29.7
28	01/25/58	15	202.5	4	30.7	202.5	5	30.8
28	01/25/58	16	180.0	6	31.0	180.0	6	30.8
28	01/25/58	17	135.0	4	29.8	157.5	4	29.8
28	01/25/58	18	112.5	2	25.3	135.0	2	30.0
28	01/25/58	19	337.5	5	21.0	22.5	1	28.7
	01/25/58	20	360.0	3	20.9	45.0	3	28.0
	01/25/58	21	315.0	4	22.0	22.5	5	25.9
	01/25/58	22	315.0	3	23.4	360.0	7	26.3
	01/25/58	23	360.0	4	25.0	360.0	7	24.4
	01/26/58	00	360.0	4	22.9	360.0	8	25.8
29	01/26/58	12	67.5	8	30.4	67.5	9	28.6
29	01/26/58	13	45.0	9	30.8	45.0	10	29.7
29	01/26/58	14	45.0	9	31.9	45.0	10	31.2
	01/26/58	15	45.0	8	33.5	45.0	10	32.6
	01/26/58	16	22.5	8	32.8	45.0	10	32.6
Phase III Testing								
37	02/08/58	14	45.0	6	38.9	45.0	6	37.3
37	02/08/58	15	45.0	6	38.1	45.0	6	37.3
	02/08/58	16	22.5	6	35.0	22.5	7	35.0
	02/08/58	17	22.5	5	34.7	22.5	8	34.4
	02/08/58	18	45.0	3	34.5	45.0	6	34.1
	02/08/58	19	360.0	2	34.3	67.5	4	34.0
42	02/15/58	13	67.5	4	32.7	67.5	5	
	02/15/58	14	67.5	2	32.6	22.5	3	
	02/15/58	15	45.0	4	32.4	22.5	5	
	02/15/58	16	67.5	6	32.9	67.5	7	
	02/15/58	17	67.5	6	32.1	67.5	7	
	02/15/58	18	67.5	3	31.3	67.5	6	
43	02/16/58	13	67.5	7	34.5	67.5	8	
43	02/16/58	14	90.0	7	36.0	90.0	7	
	02/16/58	15	67.5	5	38.0	67.5	7	
	02/16/58	16	67.5	5	38.6	45.0	7	
	02/16/58	17	67.5	5	38.3	45.0	7	
	02/16/58	18	67.5	4	34.1	45.0	6	
45	02/19/58	18	90.0	4	44.5	67.5	8	50.0
45	02/19/58	19	67.5	3	39.5	67.5	9	48.0
	02/19/58	20	22.5	2	35.3	22.5	5	43.0
	02/19/58	21	22.5	3	33.0	22.5	5	43.1
	02/19/58	22	22.5	3	33.0	22.5	6	38.5
	02/19/58	23	45.0	2	32.6	22.5	7	38.5
46	02/20/58	16	202.5	11	54.8	202.5	15	53.0
46	02/20/58	17	45.0	8	50.8	202.5	12	50.9
46	02/20/58	18	67.5	8	44.8	67.5	14	45.5
46	02/20/58	19	45.0	3	39.0	67.5	10	43.5
	02/20/58	20	22.5	2	37.3	45.0	9	42.0
	02/20/58	21	45.0	2	34.5	22.5	5	42.6
	02/20/58	22	45.0	1	32.4	45.0	4	41.0
	02/20/58	23	360.0	1	34.0	45.0	2	38.0
47a	02/22/58	10	45.0	3	37.6	45.0	4	35.6
47a	02/22/58	11	67.5	4	42.8	67.5	5	40.8
47b	02/22/58	12	90.0	4	47.1	112.5	5	44.4
47b	02/22/58	13	90.0	4	48.4	90.0	5	46.0
47b	02/22/58	14	112.5	4	51.2	112.5	4	48.8
47b	02/22/58	15	90.0	3	52.9	90.0	4	50.3
47b	02/22/58	16	90.0	3	53.0	90.0	3	51.5
47b	02/22/58	17	67.5	4	52.4	67.5	5	51.4
47b	02/22/58	18	90.0	5	48.0	90.0	8	49.6
47b	02/22/58	19	67.5	5	41.1	67.5	12	46.8
	02/22/58	20	22.5	4	38.7	45.0	11	43.6
	02/22/58	21	22.5	4	34.9	22.5	6	39.1
	02/22/58	22	45.0	2	33.1	360.0	5	42.0
52	03/01/58	20	45.0	1	29.0	22.5	2	33.4
52	03/01/58	21	112.5	3	26.6	22.5	4	32.3

ATTACHMENT A
METEOROLOGICAL DATA FOR ATMOSPHERIC DISPERSION CALCULATIONS (continued)

IET #10 Run	Date	Time Hour	TAN 20 ft. Direction (deg.)	TAN 20 ft. Speed (MPH)	TAN 20 ft. Air Temperature (F)	TAN 150 ft. Direction (deg.)	TAN 150 ft. Speed (MPH)	TAN 150 ft. Air Temperature (F)
52	03/01/58	22	67.5	5	24.4	67.5	8	30.4
	03/01/58	23	67.5	2	23.9	45.0	5	30.0
	03/02/58	00	0.0	0	21.0	45.0	5	25.7
	03/02/58	01	247.5	2	20.4	337.5	3	24.6
	03/02/58	02	337.5	1	19.4	360.0	6	24.4
	03/02/58	03	0.0	0	17.5	360.0	2	22.5
	03/02/58	04	0.0	0	18.0	22.5	3	22.6
53	03/02/58	10	0.0	0	28.4	0.0	0	27.3
53	03/02/58	11	0.0	0	33.5	0.0	0	31.2
53	03/02/58	12	225.0	2	35.1	202.5	1	33.0
53	03/02/58	13	202.5	2	38.8	225.0	2	35.4
53	03/02/58	14	67.5	2	39.0	45.0	2	37.3
53	03/02/58	15	292.5	3	39.3	270.0	2	37.6
53	03/02/58	16	225.0	1	40.1	247.5	1	38.8
53	03/02/58	17	180.0	6	37.7	180.0	6	36.8
53	03/02/58	18	315.0	3	35.3	292.5	3	34.9
53	03/02/58	19	0.0	0	33.0	0.0	0	32.5
	03/02/58	20	22.5	6	30.6	22.5	9	30.2
	03/02/58	21	0.0	0	27.2	360.0	5	28.5
	03/02/58	22	22.5	2	27.3	22.5	6	26.5
	03/02/58	23	45.0	8	26.2	45.0	14	26.8
54	03/03/58	18	315.0	5	36.6	315.0	9	35.9
54	03/03/58	19	247.5	2	28.1	270.0	5	35.1
54	03/03/58	20	225.0	3	25.0	202.5	6	30.8
	03/03/58	21	337.5	4	29.7	337.5	7	32.4
	03/03/58	22	22.5	1	25.4	337.5	6	27.6
	03/03/58	23	45.0	3	23.0	22.5	8	26.1
	03/04/58	00	22.5	5	22.1	22.5	8	26.4
55	03/04/58	20	202.5	7	27.0	202.5	15	34.0
55	03/04/58	21	202.5	7	27.3	180.0	13	30.3
55	03/04/58	22	202.5	6	23.6	202.5	13	28.5
55	03/04/58	23	202.5	7	25.3	202.5	13	27.1
55	03/05/58	00	225.0	6	23.9	225.0	10	26.5
55	03/05/58	01	225.0	6	25.3	202.5	10	26.8
	03/05/58	02	292.5	3	23.5	247.5	6	24.5
	03/05/58	03	45.0	1	21.0	67.5	3	21.4
	03/05/58	04	0.0	0	21.3	0.0	0	25.0
	03/05/58	05	67.5	2	22.6	45.0	3	24.8
	03/05/58	06	90.0	4	23.8	67.5	3	25.3
	03/05/58	07	67.5	4	24.5	67.5	4	24.5
	03/05/58	08	202.5	3	27.3	180.0	5	26.7
56a	03/05/58	10	180.0	13	31.4	157.5	15	30.0
56a	03/05/58	11	202.5	16	34.5	180.0	17	32.8
56a	03/05/58	12	202.5	16	36.2	180.0	20	34.5
56b	03/05/58	13	202.5	16	36.0	180.0	19	35.4
56b	03/05/58	14	225.0	13	33.7	202.5	14	31.9
56b	03/05/58	15	202.5	9	33.1	180.0	10	31.5
56b	03/05/59	16	180.0	5	33.1	157.5	6	32.2
56b	03/05/58	17	180.0	7	33.6	157.5	9	33.8
56b	03/05/58	18	157.5	6	34.2	157.5	9	34.4
56b	03/05/58	19	157.5	6	34.1	135.0	10	36.2
56b	03/05/58	20	157.5	4	33.1	135.0	7	33.1
56b	03/05/58	21	67.5	5	32.2	67.5	6	34.0
56b	03/05/58	22	67.5	7	32.5	90.0	10	33.8
56b	03/05/58	23	90.0	5	32.4	90.0	5	33.4
56b	03/06/58	00	202.5	1	33.2	180.0	4	33.4
56b	03/06/58	01	0.0	0	32.9	0.0	0	32.0
56b	03/06/58	02	180.0	2	32.3	157.5	3	32.6
	03/06/58	03	45.0	3	32.0	45.0	4	31.6
	03/06/58	04	67.5	3	31.2	90.0	2	31.0
	03/06/58	05	0.0	0	32.0	157.5	1	31.5
	03/06/58	06	0.0	0	31.9	67.5	1	31.5
	03/06/58	07	0.0	0	32.3	90.0	2	31.4
	03/06/58	08	0.0	0	31.7	45.0	5	30.5
	03/06/58	09	337.5	4	29.8	337.5	10	29.9
	03/06/58	10	337.5	8	29.0	337.5	14	28.3
Averages				**5.0**	**28.2**		**6.0**	**29.5**

a. Source: NOAA (2014).
b. Time Hour in this table is assumed to be for the beginning of the sampling period based on the use of a "00" time versus "24."