8 Radiological Dose Assessment

The radiological dose assessment assures stakeholders that BNL facilities and operations are in compliance with federal, state, and local regulations and the public is protected. The potential radiological dose to members of the public is calculated at the site boundary as the maximum dose that could be received by a hypothetical individual defined as the "maximally exposed individual" (MEI). Based on the MEI dose calculation criteria, any individual member of the public will receive a dose less than the MEI under all circumstances. The dose to the MEI is the sum total from direct and indirect dose pathways to the individual via air immersion, inhalation of particulates and gases, and ingestion of local fish and deer meat. The 2010 Total Effective Dose Equivalent (TEDE) from Laboratory operations was well below the EPA and DOE regulatory dose limits for the public, workers, and the environment.

The average annual on-site external dose from ambient sources was 66 ± 12 mrem (660 ± 120 µSv) and 61 ± 11 mrem (610 ± 110 µSv) at off-site locations. Both on- and off-site dose measurements include the contribution from natural terrestrial and cosmic background radiation. A statistical comparison of the average doses measured using 49 on-site thermoluminescent dosimeters (TLDs) and 14 off-site TLDs showed that there was no external dose contribution from BNL operations distinguishable from the natural background radiation level. An additional nine TLDs were used to measure on-site areas known to have radiation dose slightly above the natural background radiation. The results of these measurements are described in Section 8.1.2.

The effective dose equivalent (EDE) from air emissions was estimated as 9.20E-01 mrem (9.2 µSv) to the MEI. The dose from the ingestion pathway was estimated as 4.9 mrem (49 µSv) from the consumption of deer meat, and 0.11 mrem (1.1 µSv) from the consumption of fish caught in the vicinity of the Laboratory. The total annual dose to the MEI from all the pathways was estimated as 5.93 mrem (59 µSv). The BNL dose from the inhalation pathway was less than 10 percent of EPA's annual regulatory dose limit of 10 mrem (100 µSv). The total dose from all environmental pathways was less than 6 percent of DOE's annual dose limit of 100 mrem (1,000 µSv). The population dose was 23 person-rem for approximately 5 million persons residing in the 50 mile radius of the Laboratory.

Doses to aquatic and terrestrial biota were also evaluated and found to be well below DOE regulatory limits. Other short-term projects, such as remediation work and waste management disposal activities, were assessed for radiological emissions; the potential dose from each of these activities was below regulatory limits, and thus, there was no radiological risk to the public, workers, or the environment. In summary, the overall dose impact from all Laboratory activities in 2010 was comparable to natural background radiation levels.

8.0 INTRODUCTION

This chapter discusses the dose risk consequences from research activities, radiation generating devices, facilities, and minor bench-top radiation sources at the Laboratory. It is important to understand the health impacts of radiation to the public, workers, and visitors, along with radiation effects to the environment, fauna, and flora. The Laboratory's routine operations, scientific experiments, and any proposed new research projects are evaluated for their radiological dose risk. The dose risks from decommissioned facilities and decontamination work are also evaluated for dose impact. All environmental pathway scenarios that can give a dose to humans, aquatic life, plants, and animals are evaluated to calculate the dose risks at the Laboratory. Because all research reactors at the Laboratory have been shut down, there is no dose risk from these facilities. The laboratory's current radiological risks are from very small quantities of radionuclides used in the small sciences, radiopharmaceuticals produced at the Brookhaven Linear Isotope Facility (BLIP), and the BNL accelerators: Alternating Gradient Synchrotron (AGS), Relativistic Heavy Ion Collider (RHIC), and the future National Synchrotron Light Source II (NSLS-II), which will begin start-up operations in Fiscal Year 2015. The radiological dose assessments are performed to make sure that dose risks from all Laboratory operations remain "As Low As Reasonably Achievable" (ALARA) to members of the public, workers, and the environment.

8.1 DIRECT RADIATION MONITORING

A direct radiation-monitoring program is used to measure the external dose contribution to the public and workers from radiation sources at BNL. This is achieved by measuring direct penetrating radiation exposures at both on- and off-site locations. The direct measurements taken at the off-site locations are with the premise that off-site exposures represent true natural background radiation (with contribution from both cosmic and terrestrial sources) and represent no contribution from Laboratory operations. On- and off-site external dose measurements were averaged and then compared using the statistical t-test to measure any variations in the averages and thus the contribution, if any, from BNL operations.

8.1.1 Ambient Radiation Monitoring

To assess the dose impact of direct radiation from BNL operations, TLDs are deployed on site and in the surrounding communities. On-site TLD locations are determined based on the potential for exposure to gaseous plumes, atmospheric particulates, scattered radiation, and the location of radiation-generating devices. The Laboratory perimeter is also posted with TLDs to assess the dose impact, if any, beyond the site's boundaries. On- and off-site locations are divided into grids, and each TLD is assigned an identification code based on the grids.

In 2010, a total of 58 environmental TLDs were deployed on site, of which nine were placed in known radiation areas. Another 14 TLDs were deployed at off-site locations (see Figures 8-1 and 8-2 for locations). An additional 30 TLDs were stored in a lead-shielded container for use as reference and control TLDs for comparison purposes. The average of the control TLD values, reported as "075-TLD4" in Tables 8-1 and 8-2, is 36 ± 5 mrem. This dose also accounts for any small "residual" dose on the control TLDs when they were annealed, because it is impossible to completely remove residual dose and shield the TLDs from all natural background and cosmic radiation sources. The on- and off-site TLDs were collected and read quarterly to determine the external radiation dose measured.

Table 8-1 shows the quarterly and yearly on-site radiation dose measurements for 2010. The on-site average external doses for the first through fourth quarters were 18.3 ± 5.6, 14.8 ± 3.3, 15.8 ± 3.5, and 16.7 ± 3.3 mrem, respectively. The on-site average annual external dose from all potential environmental sources, including cosmic and terrestrial radiation sources, was 66 ± 12 mrem (660 ± 120 µSv).

Table 8-2 shows the quarterly and yearly off-site radiation dose measurements for 2010. The off-site average external doses for the first through fourth quarters were 15.2 ± 4.1, 13.6 ± 2.3, 15.2 ± 4.1, and 15.2 ± 2.1 mrem, respec-

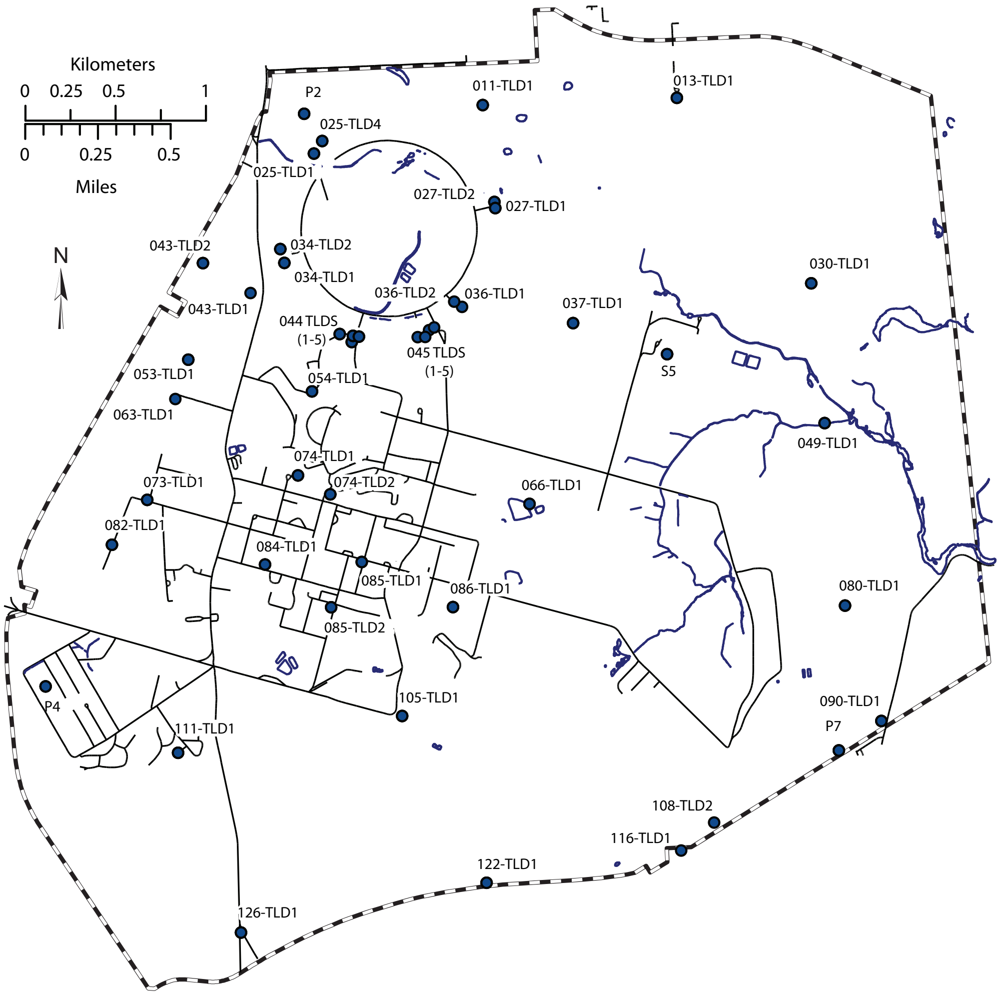

Figure 8-1. On-Site TLD Locations.

tively. The off-site average annual ambient dose from all potential environmental sources, including cosmic and terrestrial radiation sources, was 61 ± 11 mrem (610 ± 110 µSv).

To determine the BNL contribution to the external direct radiation dose, a statistical t-test between the measured on- and off-site external dose averages was conducted. The t-test showed no significant difference between the off-site dose (66 ± 12 mrem) and on-site dose (61 ± 11 mrem) at the 95 percent confidence level. From the measured TLD doses, it can be safely concluded that there was no measurable external dose contribution to on- and off-site locations from Laboratory operations in 2010.

8.1.2 Facility Area Monitoring

Nine on-site TLDs were designated as facility-area monitors (FAMs) because they were posted in known radiation areas (near "facilities"). Table 8-3 shows the external doses measured with the FAM-TLDs. The environmental TLDs 088-TLD1 through 088-TLD4 are posted at the S-6 blockhouse location and on the fence of the former Hazardous Waste Management Facility (HWMF). These TLDs measured external doses that were slightly elevated compared to the normal natural background radiation doses measured from other areas of BNL. The elevated external dose measured at the former HWMF can be attributed to the presence of

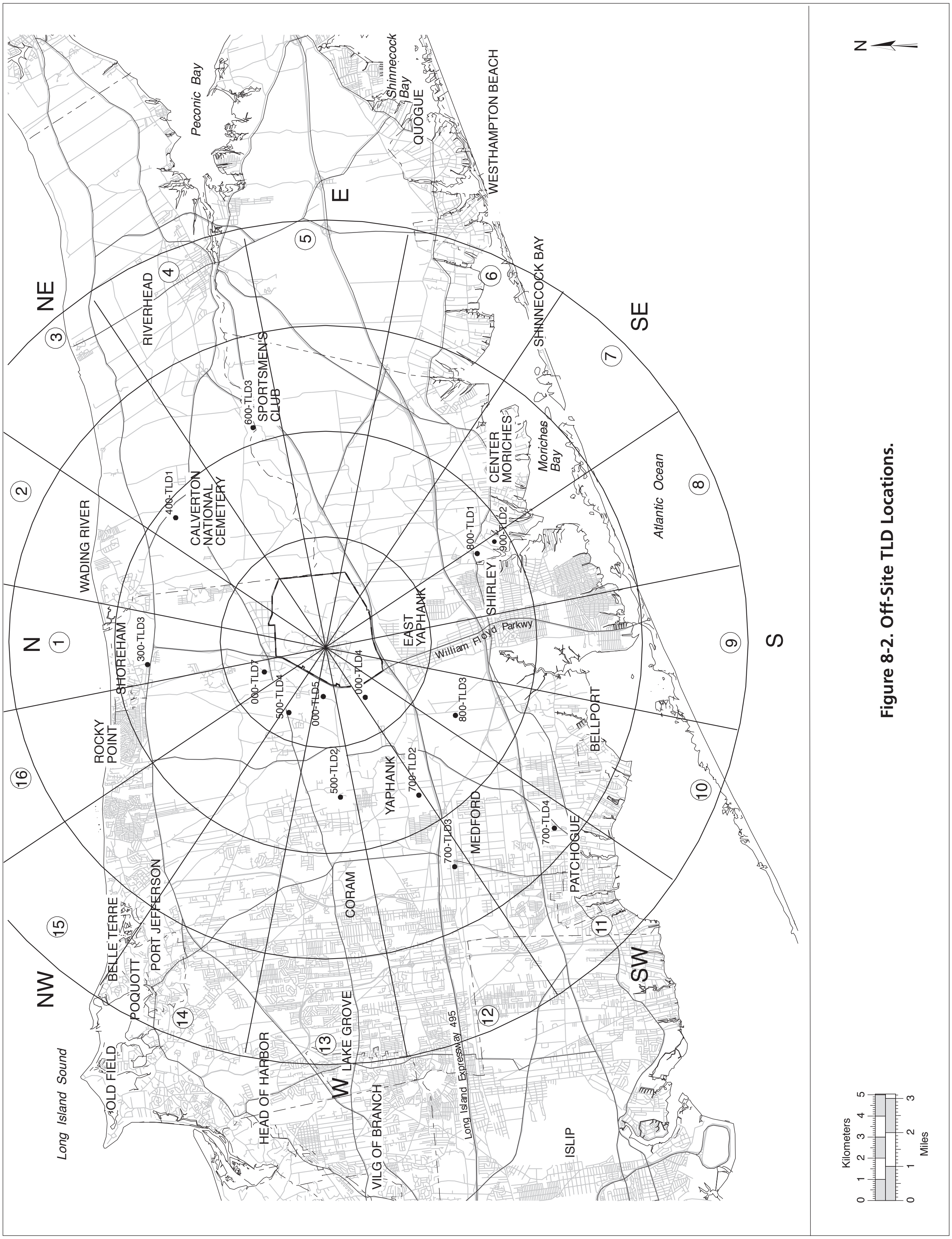

Figure 8-2. Off-Site TLD Locations.

Table 8-1. On-Site Direct Ambient Radiation Measurements.

TLD#	Location	1st Quarter	2nd Quarter	3rd Quarter	4th Quarter	Avg./Qtr. ±2σ (95%)	Annual Dose ±2σ (95%)
		(mrem)					
011-TLD1	North firebreak	15.8	12.8	16.2	14.7	15 ± 3	60 ± 12
013-TLD1	North firebreak	20.0	14.9	15.8	15.4	17 ± 5	66 ± 18
025-TLD1	Bldg. 1010, beam stop 1	17.7	12.6	14.0	14.3	15 ± 4	59 ± 17
025-TLD4	Bldg. 1010, beam stop 4	13.5	13.6	13.7	15.3	14 ± 2	56 ± 7
027-TLD1	Bldg. 1002A South	15.5	12.6	13.7	14.1	14 ± 2	56 ± 9
027-TLD2	Bldg. 1002D East	15.0	10.2	12.8	13.9	13 ± 4	52 ± 16
030-TLD1	NE Firebreak	17.3	14.8	17.6	16.2	16 ± 2	66 ± 10
034-TLD1	Bldg. 1008, collimator 2	18.3	16.6	14.4	16.5	16 ± 3	66 ± 13
034-TLD2	Bldg. 1008, collimator 4	22.3	16.5	18.4	16.3	18 ± 5	74 ± 22
036-TLD1	Bldg. 1004B, East	19.6	13.4	12.5	14.6	15 ± 6	60 ± 25
036-TLD2	Bldg. 1004, East	29.8	14.4	17.4	17.7	20 ± 13	79 ± 53
037-TLD1	S-13	17.5	15.0	15.5	14.5	16 ± 3	63 ± 10
043-TLD1	North access road	18.7	14.3	16.5	17.4	17 ± 4	67 ± 15
043-TLD2	North of Meteorology Tower	19.4	15.1	17.8	16.6	17 ± 4	69 ± 14
044-TLD1	Bldg. 1006	16.6	13.5	16.0	15.7	15 ± 3	62 ± 11
044-TLD2	South of Bldg. 1000E	16.7	14.7	15.7	14.9	16 ± 2	62 ± 7
044-TLD3	South of Bldg. 1000P	16.1	13.5	14.7	15.1	15 ± 2	59 ± 8
044-TLD4	NE of Bldg. 1000P	19.4	17.1	16.3	17.6	18 ± 3	70 ± 10
044-TLD5	N of Bldg. 1000P	18.4	16.9	15.4	16.7	17 ± 2	67 ± 10
045-TLD1	Bldg. 1005S	16.4	16.1	17.7	L	17 ± 2	67 ± 7
045-TLD2	E of Bldg. 1005S	18.3	15.8	17.1	17.0	17 ± 2	68 ± 8
045-TLD3	SE of Bldg. 1005S	19.9	13.4	16.1	17.7	17 ± 5	67 ± 21
045-TLD4	SW of Bldg. 1005S	16.4	14.1	15.2	15.4	15 ± 2	61 ± 7
045-TLD5	WSW of Bldg. 1005S	15.0	14.5	13.0	15.2	14 ± 2	58 ± 8
049-TLD1	East firebreak	20.0	14.5	14.4	17.4	17 ± 5	66 ± 21
053-TLD1	West firebreak	18.2	14.9	17.1	18.1	17 ± 3	68 ± 12
054- TLD1	Bldg. 914	22.7	18.1	15.5	18.0	19 ± 6	74 ± 24
063-TLD1	West firebreak	20.1	16.2	17.4	17.3	18 ± 3	71 ± 13
066-TLD1	Waste Management Facility	16.5	13.2	13.1	14.9	14 ± 3	58 ± 13
073-TLD1	Meteorology Twr. /Bldg. 51	16.4	16.9	18.6	17.7	17 ± 2	70 ± 8
074-TLD1	Bldg. 560	21.2	13.8	16.7	19.9	18 ± 7	72 ± 26
074-TLD2	Bldg. 907	18.5	17.3	16.8	19.0	18 ± 2	72 ± 8
080-TDL1	East firebreak	24.2	15.8	18.4	18.3	19 ± 7	77 ± 28
082-TLD1	West firebreak	21.5	15.6	17.9	19.1	19 ± 5	74 ± 19
084-TLD1	Tennis courts	16.7	15.7	13.1	16.6	16 ± 3	62 ± 13
085-TDL2	Upton gas station	L	14.6	16.8	20.6	17 ± 6	69 ± 24
085-TLD1	Diversity Office	19.7	14.0	15.1	19.2	17 ± 6	68 ± 23
086-TLD1	Baseball fields	18.7	13.7	14.6	18.1	16 ± 5	65 ± 20
090-TLD1	North St. Gate	16.8	15.8	14.5	NP	16 ± 2	63 ± 9
105-TLD1	South firebreak	20.5	16.9	17.1	18.3	18 ± 3	73 ± 13

(continued on next page)

Table 8-1. On-Site Direct Ambient Radiation Measurements *(concluded).*

TLD#	Location	1st Quarter	2nd Quarter	3rd Quarter	4th Quarter	Avg./Qtr. ±2σ (95%)	Annual Dose ±2σ (95%)
		(mrem)					
108-TLD1	Water tower	16.1	14.2	16.2	15.4	15 ± 2	62 ± 7
108-TLD2	Tritium pole	20.6	19.3	20.5	19.5	20 ± 1	80 ± 5
111-TLD1	Trailer park	18.6	13.2	16.0	18.6	17 ± 5	66 ± 20
122-TLD1	South firebreak	17.0	13.2	14.8	17.2	16 ± 4	62 ± 15
126-TLD1	South gate	19.0	16.8	17.9	17.3	18 ± 2	71 ± 7
P2		13.6	13.2	13.7	14.2	14 ± 1	55 ± 3
P4		16.3	14.9	16.3	15.4	16 ± 1	63 ± 5
P7		16.9	14.3	16.0	16.3	16 ± 2	64 ± 9
S5		16.4	14.4	14.3	16.1	15 ± 2	61 ± 9
On-site average		**18.3**	**14.8**	**15.8**	**16.7**	**16 ± 3**	**66 ± 12**
Std. dev. (2 σ)		**5.6**	**3.3**	**3.5**	**3.3**		
075-TLD4 Control TLD average		**9.4**	**8.0**	**9.3**	**9.2**	**9.0 ± 1**	**36 ± 5**

Notes:
See Figure 8-1 for TLD locations.
L = TLD lost
NP = TLD not posted

small amounts of contamination in soil. However, a comparison of the current ambient dose rates to doses from previous years shows that the dose rates have declined significantly since the removal of the contaminated soil within the former HWMF. As recorded in Table 8-3, the 2010 dose is just slightly above natural background levels. The former HWMF is fenced, access is controlled, and only radiologically trained employees are allowed inside the fenced area.

Two TLDs (075-TLD3 and 075-TLD5) near Building 356 showed much higher than normal quarterly averages: 22 ± 6 mrem (220 ± 60 µSv) and 74 ± 20 mrem (740 ± 200 µSv), respectively. The yearly doses were measured at 89 ± 25 mrem (890 ± 250 µSv) for 075-TLD3, and 295 ± 81 mrem (2950 ± 810 µSv) for 075-TLD5. The direct doses are higher than the on-site annual average because Building 356 houses a cobalt-60 (Co-60) source, which is used to irradiate materials, parts, and electronic circuit boards. The elevated dose from Building 356 is attributed to the “sky-shine” phenomenon. Although it is conceivable that individuals who use the parking lot adjacent to Building 356 could receive a dose from this source, the dose would be small due to the partial occupancy factor.

Two FAM-TLDs placed on fence sections northeast and northwest of Building 913-B (the AGS tunnel access) showed slightly higher than average ambient external dose. The first-quarter dose at that site was measured at 22.7 mrem for 054-TLD2 and 26.4 mrem for 054-TLD3 (compared to the site-wide first-quarter dose of 18.3 ± 5.6 and off-site dose of 15.2 ± 4.1 mrem). For the remaining quarters, both TLDs showed dose comparable to the natural background radiation.

The AGS accelerates protons to energies up to 30 GeV and heavy ion beams to 15 GeV/amu. RHIC has two beams circulating in opposite directions and is capable of accepting either protons or heavy ions up to gold. At the RHIC, protons and heavy ions received from the AGS are further accelerated up to final energies of 250 GeV for protons and 100 GeV per nucleon for gold ions. Under these high-energy conditions, facilities such as AGS and RHIC have the potential to generate high-energy neutrons

Table 8-2. Off-Site Direct Radiation Measurements.

TLD#	Location	1st Quarter	2nd Quarter	3rd Quarter	4th Quarter	Avg./Qtr. ± 2 σ (95%)	Annual Dose ± 2 σ (95%)
		(mrem)					
000-TLD4	Private property	13.6	12.2	12.9	13.8	13 ± 1	68 ± 13
000-TLD5	Longwood Estate	13.1	14.6	14.8	14.6	15 ± 0	62 ± 5
000-TLD7	Mid-Island Game Farm	L	L	16.0	15.3	16 ± 1	68 ± 20
300-TLD3	Private property	NP	NP	NP	NP		70 ± 0
400-TLD1	Calverton Nat. Cemetary	19.7	13.7	18.4	L	17 ± 6	74 ± 13
500-TLD2	Private property	15.0	14.1	14.4	15.0	15 ± 1	60 ± 8
500-TLD4	Private property	NP	NP	15.3	15.1	15 ± 0	64 ± 20
600-TLD3	Sportsmen’s Club	L	L	17.6	L	18	60 ± 10
700-TLD2	Private property	NP	NP	NP	NP		62 ± 19
700-TLD3	Private property	14.3	13.4	13.2	15.0	14 ± 2	65 ± 17
700-TLD4	Private property	16.4	14.2	14.7	14.9	15 ± 2	66 ± 15
800-TLD1	Private property	NP	12.0	15.5	17.7	15 ± 6	64 ± 6
800-TLD3	Suffolk County CD	15.2	15.6	18.2	16.1	16 ± 3	67 ± 10
900-TLD2	Private property	14.4	12.6	11.7	14.2	13 ± 0	63 ± 22
Off-site average		**15.2**	**13.6**	**15.2**	**15.2**	**15 ± 3**	**61 ± 11**
Std. dev. (2 σ)		**4.1**	**2.3**	**4.1**	**2.1**		
075-TLD4	**Control TLD average**	**9.4**	**8.0**	**9.3**	**9.2**	**9.0 ± 1**	**36 ± 5**

Notes:
See Figure 8-2 for TLD locations.
CD = Correctional Department
NP = TLD not posted for the quarter
L = TLD Lost

Table 8-3. Facility Area Monitoring.

TLD#	Location	1st Quarter	2nd Quarter	3rd Quarter	4th Quarter	Average ± 2σ (95%)	Annual Dose ± 2σ (95%)
		(mrem)					
054-TLD2	NE of Bldg. 913B	22.7	20.1	16.4	20.6	20 ± 5	80 ± 21
054-TLD3	N/W of Bldg. 913B	26.4	18.5	14.9	19.2	20 ± 9	79 ± 38
S6		18.6	17.0	17.7	20.0	18 ± 3	73 ± 10
088-TLD1	FWMF, 50' East of S-6	17.5	16.9	19.2	17.0	18 ± 2	71 ± 8
088-TLD2	FWMF, 50' West of S-6	23.0	18.3	19.5	20.2	20 ± 4	81 ± 16
088-TLD3	FWMF, 100' West of S-6	21.6	16.7	19.2	21.0	20 ± 4	79 ± 17
088-TLD4	FWMF, 150' West of S-6	17.9	15.2	15.5	17.9	17 ± 3	67 ± 12
075-TLD3	Bldg. 356	26.2	21.1	18.6	23.4	22 ± 6	89 ± 25
075-TLD5	North Corner of Bldg. 356	60.9	69.8	83.4	80.8	74 ± 20	295 ± 81

Notes:
See Figure 8-1 for TLD locations.
FWMF = Former Waste Management Facility

when the charged particles leave the confines of the accelerator and produce nuclear fragments along their path or when they collide with matter. A passive monitoring TLD device provides dose information from the neutron interactions when placed at strategic locations. In 2010, 12 neutron-monitoring TLDs (Harshaw Badge 8814) were posted at these strategic locations to measure the dose contribution from the high-energy neutrons (see Figure 8-3 for locations). The technical criteria used for the placement of the neutron TLDs is based on design aspects such as the thickness of the berm shielding, location of soil activation areas, beam stop areas and beam collimators, and proximity to the site boundary. A passive monitor for the neutron dose, 054-TLD-N2 in the vicinity of BLIP facility, showed 1 mrem neutron dose in the first and fourth quarter of 2010. A second neutron TLD (034-TLD-N1) at the collimator of Building 1008 also showed neutron dose of 1 mrem in the second and fourth quarter of 2010.

8.2 DOSE MODELING

EPA regulates radiological emissions from DOE facilities under the requirements set forth in 40 CFR 61, Subpart H, National Emission Standards for Hazardous Air Pollutants (NESHAPs). This regulation specifies the compliance and monitoring requirements for reporting radiation doses received by members of the public from airborne radionuclides. The regulation mandates that no member of the public shall receive a dose from DOE operations that is greater than 10 mrem (100 µSv) in a year. The emission monitoring requirements are set forth in Subpart H, Section 61.93(b) and include the use of a reference method for continuous monitoring at major release points (defined as those with a potential to exceed 1 percent of the 10 mrem standard), and a periodic confirmatory measurement for all other release points. The regulations also require DOE facilities to submit an annual NESHAPs report to EPA that describes the major and minor emission sources

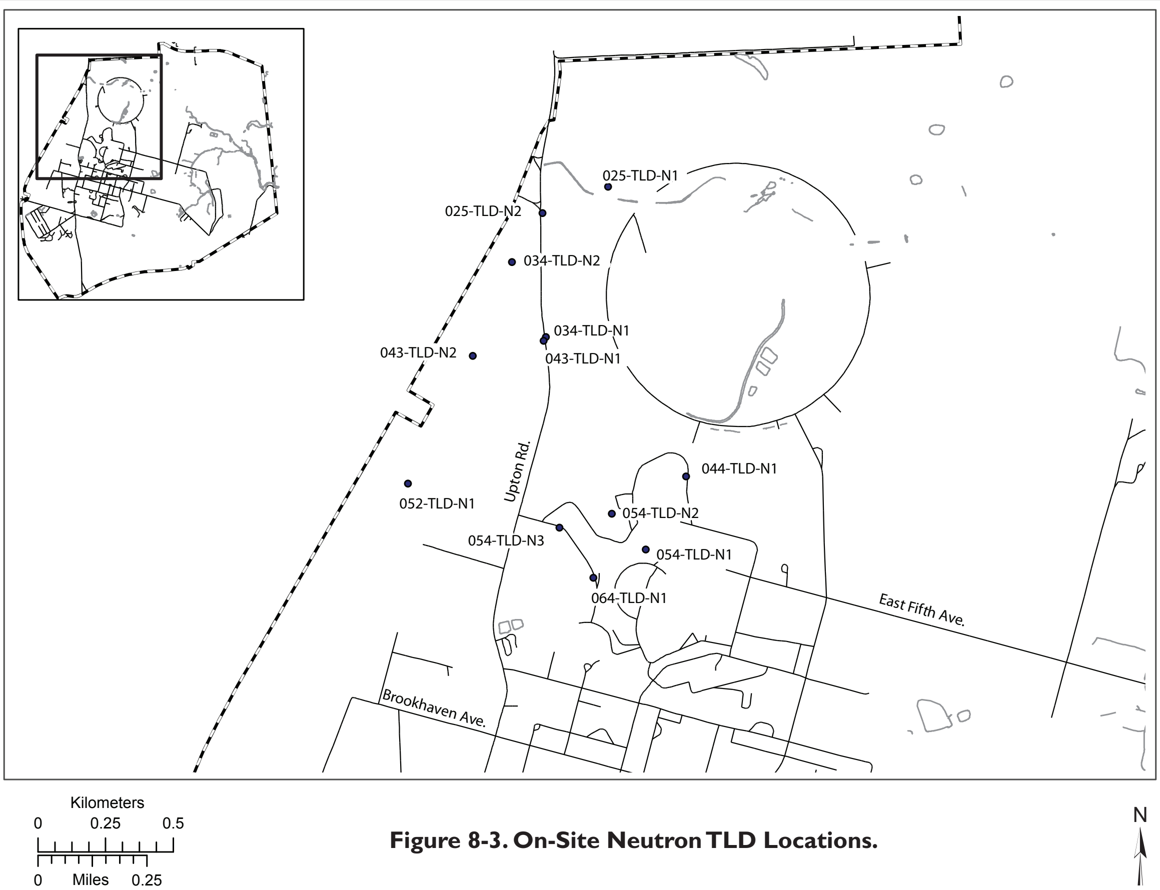

Figure 8-3. On-Site Neutron TLD Locations.

and dose to the MEI. The dose estimates from various facilities are given in Table 8-4, and the actual air emissions for 2010 are discussed in detail in Chapter 4.

As a part of the NESHAPs review process at BNL, any source that has the potential to emit radioactive materials is evaluated for regulatory compliance. Although the activities conducted by the Environmental Restoration Group are exempt under the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA), these activities are also monitored and assessed for any potential to release radioactive materials, and to determine their dose contribution, if any, to the environment. Any new processes or activities are also evaluated for compliance with NESHAPs regulations using EPA's approved dose modeling software (see Section 8.2.1 for details). Because this model was designed to treat radioactive emission

Table 8-4. Maximally Exposed Individual Effective Dose Equivalent From Facilities or Routine Processes.

Building No.	Facility or Process	Construction Permit No.	MEI Dose (mrem) (a)	Notes
348	Radiation Protection	None	ND	(g)
463	Biology Facility	None	1.79E-09	(b)
490	Medical Research	BNL-489-01	ND	(d)
490A	Energy and Environment National Security	None	5.27E-07	(b)
491	Brookhaven Medical Research Reactor	None	ND	(h)
510	Calorimeter Enclosure	BNL-689-01	ND	(d)
510A	Physics	None	ND	(g)
535	Instrumentation	None	ND	(g)
555	Chemistry Facility	None	ND	(g)
725	National Synchrotron Light Source	None	ND	(b)
750	High Flux Beam Reactor	None	4.55E-04	(c)
801	Target Processing Lab	None	1.35E-04	(b)(c)
802B	Evaporator Facility	BNL-288-01	ND	(d)(e)
820	Accelerator Test Facility	BNL-589-01	ND	(h)
830	Environmental Science Department	None	ND	(h)
865	Waste Management Facility	None	ND	(h)
906	Medical-Chemistry	None	ND	(h)
925	Accelerator Department	None	ND	(h)
931	Brookhaven Linac Isotope Producer	None	9.19E-01	(c)
938	REF/NBTF	BNL-789-01	ND	(d)
942	Alternate Gradient Syncrotron Booster	BNL-188-01	ND	(f)
—	Relativistic Heavy Ion Collider	BNL-389-01	ND	(h)
Total Potential Dose from BNL Operations			**9.20E-01**	
EPA Limit			**10.0 mrem**	

Notes:
Diffuse, Fugitive, and Other sources are not included in this table since they are short-term emissions.
NBTF = Neutron Beam Test Facility
REF = Radiation Effects Facility
ND = No Dose from the emission sources in 2010.
(a) "Dose" in this table means effective dose equivalent to MEI.
(b) Dose is based on emissions calculated using 40 CFR 61, Appendix D methodology.
(c) Emissions are monitored at the facility.
(d) This facility was decommissioned and is a zero emission facility.
(e) This facility is decontaminated and demolished.
(f) Booster ventilation system prevents air release through continuous air recirculation.
(g) No radiological dispersible material inventory in 2010.
(h) No detectable emissions from the facility in 2010.

sources as continuous over the course of a year, it is not well suited for estimating short-term or acute releases. Consequently, it overestimates potential dose contributions from short-term projects and area sources. For that reason, the results are considered to be "conservative"—that is, erring on the side of caution.

8.2.1 Dose Modeling Program

Compliance with NESHAPs regulations is demonstrated through the use of EPA dose modeling software and the Clean Air Act Assessment Package 1988 (CAP88-PC), Version 3.0. This computer program uses a Gaussian plume model to estimate the average dispersion of radionuclides released from elevated stacks or diffuse sources. It calculates a final value of the projected dose at the specified distance from the release point by computing dispersed radionuclide concentrations in air, rate of deposition on ground surfaces, and intake via the food pathway (where applicable). CAP88-PC calculates both the EDE to the MEI and the collective population dose within a 50-mile radius of the emission source. In most cases, the CAP88-PC model provides conservative doses. For the purpose of modeling the dose to the MEI, all emission points are located at the center of the developed portion of the Laboratory site. The dose calculations are based on very low concentrations of environmental releases and on chronic, continuous intakes in a year. The input parameters used in the model include radionuclide type, emission rate in curies (Ci) per year, stack parameters such as height and diameter, and emission exhaust velocity. Site-specific weather and population data are factored into the dose assessment. Weather data are supplied by measurements from the Laboratory's meteorological tower. These measurements include wind speed, direction, frequency, and air temperature (see Chapter 1 for details). A population of 5 million (5,053,192) people, based on the Long Island Power Authority population survey (LIPA 2000), was used in the model. The population variation on Long Island during the 2010 census was not much different from the LIPA survey. Because visiting researchers and their families may reside at the BNL on-site apartment area for extended periods, these residents are included in the population file used for dose assessment.

8.2.2 Dose Calculation Methods and Pathways

8.2.2.1 Maximally Exposed Individual

The MEI is defined as a hypothetical person who resides at the site boundary and has a lifestyle such that no other member of the public could receive a higher dose than the MEI. This person is assumed to reside 24 hours a day, 365 days a year at the BNL site boundary in the downwind direction, and to consume significant amounts of fish and deer containing radioactivity attributable to Laboratory operations based on projections from the New York State Department of Health (NYSDOH). In reality, it is highly unlikely that such a combination of "maximized dose" to any single individual would occur, but the concept is useful for evaluating maximum potential risk and dose to members of the public.

8.2.2.2 Effective Dose Equivalent

The EDE to the MEI for low levels of radioactive materials dispersed into the environment was calculated using the CAP88-PC dose modeling program, Version 3.0. Site meteorology data were used to calculate annual dispersions for the midpoint of a given wind sector and distance. Facility-specific radionuclide release rates (Ci/yr) were used for continuously monitored facilities. For small sources, the emissions were calculated using the method set forth in 40 CFR 61, Appendix D. The Gaussian dispersion model calculated the EDE at the site boundary and the collective population dose values from immersion, inhalation, and ingestion pathways. These dose and risk calculations to the MEI are based on low emissions and chronic intakes.

8.2.2.3 Dose Calculation: Fish Ingestion

To calculate the EDE from the fish consumption pathway, the intake is estimated. Intake is the average amount of fish consumed by a person engaged in recreational fishing in the Peconic River. Based on a NYSDOH study, the consumption rate is estimated at 15 pounds (7 kg) per year (NYSDOH 1996). For each radionuclide of concern for fish samples, the dry weight activity concentration was converted to picocuries per gram (pCi/g) wet weight, since "wet weight" is the form in which fish are caught and consumed. A dose conversion factor was used for each radionuclide to convert the activity concentration into the EDE. For example, the committed dose equivalent conversion factor for cesium-137 (Cs-137) is 5.0E-02 rem/µCi, as set forth in DOE/EH-0071. The dose was calculated as: dose (rem/yr) = intake (kg/yr) × activity in flesh (µCi/kg) × dose factor (rem/µCi).

8.2.2.4 Dose Calculation: Deer Meat Ingestion

The dose calculation for the deer meat ingestion pathway is similar to that for fish consumption. The Cs-137 radionuclide dose conversion factor was used to estimate dose, based on the U.S. Environmental Protection Agency Exposure Factors Handbook (EPA 1996). The total quantity of deer meat ingested during the course of a year was estimated as 64 pounds (29 kg) (NYSDOH 1999).

8.3 SOURCES: DIFFUSE, FUGITIVE, "OTHER"

Diffuse sources, also known as nonpoint or area sources, are described as releases of radioactive contaminants to the atmosphere that do not have well-defined emission points. Fugitive sources include leaks through window and door frames, and unintended releases to the air through vents or stacks when they are supposedly inactive (i.e., leaks from vents are fugitive sources). As a part of the NESHAPs review process, in addition to stack emissions, any fugitive or diffuse emission source that could potentially emit radioactive materials to the environment is evaluated. Although CERCLA-prompted actions such as remediation projects are exempt from the procedural requirements to obtain federal, state, or local permits, any BNL activity or process with the potential to emit radioactive material must be evaluated and assessed for dose impact to members of the public. The following radiological sources were evaluated in 2010 for potential contribution to the overall site dose.

8.3.1 Remediation Work at Buildings 704 and 802

A record of decision (ROD) for Area of Concern (AOC) 31 included the removal of ancillary Buildings 704 and 802. Building 704 was a radiologically controlled building which housed the five primary fans that discharged air through a below-grade exhaust duct. Building 802 was utilized as an evaporator facility for tritiated water. Building 802 is an EPA NESHAP-approved facility under permit BNL-288-01, which requires official "delisting" of structures that are no longer needed for their current purpose. Remediation work for the two buildings included dismantling and removing structures, systems, components, ducts, filter house inlets (above and below), resin beds, plenums, pipes, asphalt, and the soil below the overall footprint of the two buildings.

The source term for both facilities was calculated to determine the quantities of radioactive material that potentially could be released for the purpose of estimating dose consequences to an off-site MEI. The radionuclides of concern were: tritium, Co-60, nickel-63 (Ni-63), strontium-90 (Sr-90), Cs-137, and americium-241 (Am-241). The effective dose equivalent to the MEI from Building 704 and 802 remedial work was estimated to be 1.68-E02 mrem in a year. The potential dose is well below the 0.1 mrem/yr annual limit as specified in 40 CFR 61, subpart H. A continuous air monitoring station for the particulate matter was set up in the downwind direction to record any radioactivity released during the remediation work. The filter sample results showed no measureable activity above the natural background radiation.

8.3.2 Demolition of Building 705 Stack

The large, 98-meter Building 705 stack was constructed in the late 1940s to discharge effluents from the Brookhaven Graphite Research Reactor (BGRR) and to ventilate equipment and rooms in Building 801. Over the years, other BNL facilities such as Buildings 750, 811, 815, 830, and 901A were connected to the large stack via underground duct work. In April 2009, the ROD that was finalized for AOC 31 included the demolition of the stack and silencer, and removal of underground utilities and contaminated soil associated with the High Flux Beam Reactor (HFBR).

The stack was constructed using an isometric wire frame and fabricated with poured-in reinforced concrete. The original design drawing of the overall stack height is 320 ft. (97.54 m) above grade, with a conical shape that varies in wall thickness from 14 inches at the base to 7 inches at the top. The interior of the stack contains several components, including a large baffle plate, two metal ducts, and a series of three drains.

Prior to demolition, the area around the base of the stack will be coated with 2 inches of bituminous concrete to prevent the spread of contamination. The stack's exterior components, such as the lightening protection system, strobe lights, steel platforms, and ladders, will be removed and properly disposed. A mast climber will be anchored to the stack; a hoist system to move supplies and personnel will be engineered adjacent to the decontamination unit and at the base of the stack; and demolition of the stack will be accomplished using a hydraulic shear, working from the top of the stack and progressing downward toward the base. A moveable trolley and trolley beam will allow the mechanical pulverizer to be positioned around the circumference of the stack as demolition progresses from top to bottom. Herculite® or poly will be placed on the deck of the platform to protect the deck surface from contamination. The device will shear the stack concrete into small pieces approximately the size of a baseball. The pulverized concrete rubble will be knocked inside, allowing it to freefall to the bottom. A fixative applied to the inside of the stack before the demolition work will control dust and suppress particulate matter from becoming airborne. The base of the stack and silencer will be demolished with excavators equipped with hammers, pulverizers, grapples, and buckets. A skid steer loader will be used to load the concrete rubble and debris into Department of Transportation (DOT)-approved waste containers for proper off-site disposal.

A Torit® dust collector will be used to control and collect the dust generated during demolition. The Torit is a 12,000 cubic feet per minute (cfm) system with a 32-filter cartridge bank that will maintain the stack under negative pressure. A 24-inch diameter duct will connect the Torit to the stack, and another 24-inch diameter duct will connect the containment tent to the Torit. A high-efficiency particulate air (HEPA) filtration system (99.7 percent efficient to 0.3 micron) will be attached downstream of the Torit exhaust. When operated simultaneously, the ventilation system will provide a complete air change approximately every 16.25 minutes (four air changes every hour) for both the stack and tent. When the stack alone is kept under negative pressure during demolition activities, there will be six air changes per hour. The capture velocity may not be sufficient to remove all dust particles; therefore, a light mist of water will be sprayed to minimize airborne dust.

A source term for the stack and pedestal remediation action was developed based on the radionuclides characterization data for 1) the concrete core samples collected at various (1/4- to 3/4-inch) depths of the stack, and 2) the plenum sediments from the silencer. The Cs-137, Sr-90, and H-3 radionuclides were measured at 1/4- to 3/4-inch depth in the concrete core samples inside the stack. The volume of material at risk was estimated using the upper and the base radii of the stack and by a straight line approximating the inner surface of the structure between the base and the upper radii of a truncated cone. The inner cone has the inside radius of the stack opening throughout its length. The outer cone has a radius of 1 inch (0.0833 ft.) greater than the inner cone radii. The height of each cone is the same (298.5 ft., height or distance apothem). The volume of the outer cone minus the volume of the inner cone provides an estimate of the potentially contaminated concrete in the stack.

The effective dose to the MEI resulting from demolition of the stack, silencer, and other structures was estimated to be 5.35E-05 mrem/yr. This potential dose is below the 10 mrem/yr annual limit specified in 40 CFR 61, subpart H, and below the EPA 0.1 mrem/yr limit. BNL's policy of keeping the dose-risk as low as reasonably achievable (ALARA) shall be implemented during the stack demolition work activities.

Although the NESHAP evaluation was completed in 2010, the stack remediation work was postponed by DOE until a later date, most likely prior to 2020. A new method of stack demolition will be proposed and reviewed under the NESHAP program at that time.

8.3.3 National Synchrotron Light Source II

The NSLS-II facility will be a 3.0 giga electron volt (GeV) electron storage ring that is designed to operate in a top-off mode, thus providing an electron source of nearly constant current in the storage ring. The state-of-the-art facility will have the capacity to investigate materials at 1 nanometer (nm) spatial resolution and 0.1 milli-electron volt (meV) energy resolutions; this is equivalent to the spectroscopy of a single atom. After the completion of construction, NSLS-II is anticipated to operate 24 hours a day, 7 days a week for approximately 5,000 hours per year. A potential ionizing radiation hazard would be the prompt radiation (neutrons, bremsstrahlung, and x-rays) produced during normal NSLS-II accelerator operations. The electron losses inside the accelerator enclosure and photo-neutron activation reactions of the air could generate airborne radionuclides inside the accelerator enclosure. In addition, scattered radiation along the beamline from collimators, shutters, apertures, storage magnets, injection stoppers, and beam stops could become a radiation hazard inside the accelerator enclosure. The radionuclide production and their subsequent environmental losses are governed by the 3.0 GeV energy, 500 milli-amperes (mA) current in the storage ring and the top-off mode of accelerator operation. A potential radiation hazard can also result from point losses due to an error in beam tuning or beam loss from the failure of the vacuum valve or the collapse of the magnetic field. The scatter of residual gas particles can create energetic bremsstrahlung radiation. The high energy particle interactions with the ambient air will generate small amounts of air activation by spallation reaction, or photon neutron reactions from the bremsstrahlung radiation. The principal short-lived radionuclides produced by air activation are N-13 (half-life: 9.97 minutes), O-15 (half-life: 122.24 seconds), and C-11 (half-life: 20.48 minutes). The short-lived gaseous radionuclides produced inside the enclosure will reach a saturation point within 1 hour of operation and could be released into the environment by fugitive or diffusive losses through small openings.

The source term of the diffusive or fugitive losses from the NSLS-II storage ring was estimated at 2.38 Ci of N-13, 0.26 Ci of O-15, and 0.05 Ci of C-11, based on forced air circulation in the storage ring area for the entire year. The Linac energy selector, Linac beam stop, and Booster injection-extraction areas do not have forced circulation; therefore, ambient diffusive or fugitive losses mostly would be from the physical gaps between 60 doors, hinges, and other apertures in the accelerator facility. The Linac and Booster source term was estimated at 0.48 Ci of N-13, 0.05 Ci of O-15, and 0.01 Ci of C-11, based on normal ambient diffusive losses from the accelerator. The diffuse/fugitive losses estimated for NSLS-II were evaluated to demonstrate compliance with the annual limit of 10 mrem to the members of the general public from DOE facility operations. The total dose to the MEI resulting from future NSLS-II operations was estimated to be 2.32E-04 mrem/yr. The potential dose is below the 10 mrem/yr. annual limit specified in 40 CFR 61, subpart H, and well below the EPA 0.1mrem/yr. limit. The potential exposure hazard to the general public from release of these small quantities of short-lived radionuclides is negligible. However, in accordance with the 40 CFR 61.93(b) (4) (i), the NSLS-II facility will take a graded approach to periodically ascertain that the emissions remain below the EPA 0.1 mrem/yr. limit in any given year.

8.4 DOSE FROM POINT SOURCES

8.4.1 Brookhaven Linac Isotope Producer

Source term descriptions for point sources are given in Chapter 4. The BLIP facility is the only emission source with the potential to contribute dose to members of the public greater than 1 percent of the EPA limit (i.e., 0.1 mrem or 1.0 µSv). The BLIP facility is considered a major emission source in accordance with the ANSI N13.1-1999 standard's graded approach; that is, a potential impact category (PIC) of II. The emissions are directly and continuously measured in real-time with an in-line low-resolution NaI gamma spectrometer connected to the exhaust ventilation system for recording emissions. The particulate emissions are monitored on a weekly frequency using a conventional fiberglass filter and analyzed at an off-site laboratory. The tritium samples are also collected continuously using a silica gel absorbent, and are then analyzed at an off-site laboratory on a biweekly basis.

During normal operations on March 22, 2010, the BLIP alarm sounded when irradiated targets were being removed from the hot cell. The cause of the alarm was investigated and attributed to radon flux in the building filtration system and radon surge in the building itself. However, on March 25, 2010, abnormally high radiation levels (40-70 µR/hr.) were measured in the vicinity of the BLIP facility above the natural background radiation of 10-13 µR/hr. with a survey instrument. An investigation was launched to understand why the on-site ambient radiation levels in the vicinity of the BLIP facility were higher than normal. Surveillance and monitoring data were collected in April and May 2010, along with the prevailing meteorological conditions at various times of the day. The final conclusion was that during early mornings and late evenings, a negative lapse rate significantly influences vertical motion for the parcel of air, thus preventing the complete vertical dispersion until the lapse rate changes. The on-site ambient radiation levels and the lapse rate conditions did not impact the off-site MEI dose.

In 2010, the BLIP facility operated over a period of 26 weeks. During the year, 1,741 Ci of C-11 and 4,320 Ci of O-15 were released from the BLIP facility. A small quantity (3.31E-04 Ci) of tritiated water vapor from activation of the targets' cooling water was also released. The EDE to the MEI was calculated to be 0.92 mrem (9.2 µSv) in a year from BLIP operations.

8.4.2 High Flux Beam Reactor

In 2010, a new HFBR exhaust system was installed and the residual tritium was measured at 5.43 Ci, which gave a dose of 4.55E-04 mrem (5 nSv) in a year.

8.4.3 Brookhaven Medical Research Reactor

In 2010, the Brookhaven Medical Research Reactor (BMRR) facility remained in a cold-shutdown mode as a radiological facility, and periodic inspections were conducted for the facility. There was no dose contribution from the BMRR.

8.4.4 Brookhaven Graphite Research Reactor

In 2010, the graphite was removed from the facility and 249 containers (Industrial Package) were shipped off site to a licensed disposal facility. There was no dose from the BGRR facility.

8.4.5 Waste Management Facility

In 2010, there was no dose contribution from the Waste Management Facility.

8.4.6 Unplanned Releases

There were no unplanned releases in 2010.

8.5 DOSE FROM INGESTION

Radionuclides in the environment bioaccumulate in deer and fish tissues, bones, and organs; consequently, samples from deer and fish were analyzed to evaluate the dose contribution to humans from the ingestion pathway. As discussed in Chapter 6, deer meat samples collected off site and less than 1 mile from the BNL boundary were used to assess the potential dose impact to the MEI. The maximum tissue concentration in the deer meat (flesh) collected "off site and less than 1 mile" was used to calculate the potential dose to the MEI. Potassium-40 (K-40) and Cs-137 were detected in the tissue samples. K-40 is a naturally occurring radionuclide and is not related to BNL operations. In 2010, the average K-40 concentrations in tissue samples (off site < 1 mile) were 3.31 ± 0.89 pCi/g (wet weight) in the flesh and 2.43 ±0.55 pCi/g (wet weight) in the liver. The maximum Cs-137 concentrations were 3.38 ± 0.28 pCi/g (wet weight) in the flesh and 0.29 ± 0.07 pCi/g (wet weight) in the liver (see Table 6-2). The average Cs-137 concentration was calculated at 1.51 ± 0.35 pCi/g; however, the maximum concentration of 3.38 pCi/g was used for the purpose of MEI dose calculations. The maximum estimated dose to humans from consuming deer meat containing the maximum Cs-137 concentration was estimated to be 4.9 mrem (49 µSv) in a year. This dose is below the health advisory limit of 10 mrem (100 µSv) established by NYSDOH.

In collaboration with the New York State Department of Environmental Conservation (NYSDEC) Fisheries Division, BNL maintains an ongoing program of collecting and analyzing fish from the Peconic River and surrounding freshwater bodies. In 2010, a brown bullhead sample had the highest concentration of Cs-137, at 0.32 ± 0.08 pCi/g; this was used to estimate the EDE to the MEI. The potential dose from consuming 15 pounds of such bullhead annually was calculated to be 0.11 mrem (1.1 µSv)—well below the NYSDOH health advisory limit of 10 mrem.

8.6 DOSE TO AQUATIC AND TERRESTRIAL BIOTA

DOE-STD-1153-2002, A Graded Approach for Evaluating Radiation Doses to Aquatic and Terrestrial Biota, provides the guidelines for screening methods to estimate radiological doses to aquatic animals and terrestrial plants and animals, using site-specific environmental surveillance data. The RESRAD-BIOTA 1.21 biota dose level 2 computer program was used to evaluate compliance with the requirements for protection of biota specified in DOE Order 5400.5 (1990), Radiation Protection of the Public and the Environment, and DOE Order 450.1A, General Environmental Protection Program.

In 2010, the terrestrial animal and plant doses were evaluated based on 0.37 pCi/g of Cs-137 found in surface soils in the vicinity of the Apartments area and a Sr-90 concentration of 0.76 pCi/L in the surface waters collected at the Forge Pond location. The dose to terrestrial animals was calculated to be 1.78E-02 mGy/day, and to plants, 1.68 E-03 mGy/day. The doses to terrestrial plants and animals are well below the biota dose limit of 1 mGy/day.

To calculate the dose to aquatic and riparian animals, Sr-90 radionuclide concentration values for surface water from Forge Pond and the Cs-137 in sediments found at Swan Pond were used. The Cs-137 sediment concentration was 0.54 pCi/g, and the Sr-90 concentration in surface water was 0.76 pCi/L. The calculated dose to aquatic animals was 2.50E-04 mGy/day and to riparian animals was 2.90E-03 mGy/day. Therefore, the dose to aquatic and riparian animals is also well below the 10 mGy/day limit specified by the regulations.

8.7 CUMULATIVE DOSE

Table 8-5 summarizes the potential cumulative dose from the BNL site in 2010. The total dose to the MEI from air and ingestion pathways was estimated to be 5.93 mrem (59 µSv). In comparison, the EPA regulatory limit for the air pathway is 10 mrem (0.10 mSv) and the DOE limit from all pathways is 100 mrem (1 mSv). The cumulative population dose would be 23 person-rem (0.23 person-Sv) in a year. The effective dose is well below the DOE and EPA regulatory limits, and the ambient TLD dose is within normal background levels seen at the Laboratory site. The potential dose from

Table 8-5. BNL Site Dose Summary.

Pathway	Dose to Maximally Exposed Individual	Percent of DOE 100 mrem/year Limit	Estimated Population Dose per year
Inhalation			
Air	0.92 mrem (9.2 µSv)	<1%	23.1 person-rem
Ingestion			
Drinking water	None	None	None
Fish	0.11 mrem (1.1µSv)	<1%	Not tracked
Deer Meat	4.9 mrem (49 µSv)	<5%	Not tracked
All Pathways	5.93 mrem (59.3 µSv)	<6%	23.1 person-rem

drinking water was not estimated, because most residents adjacent to the BNL site get their drinking water from the Suffolk County Water Authority rather than private wells. To put the potential dose impact into perspective, a comparison was made with other sources of radiation. The annual dose from all natural background sources and radon is approximately 311 mrem (3.11 mSv). A mammogram gives 250 mrem (2.5 mSv) dose and a dental x-ray approximately 160 mrem (1.6 mSv) dose to an individual. Therefore, the BNL dose from all environmental pathways (5.93 mrem) is a minute fraction of one routine dental x-ray.

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