8 Radiological Dose Assessment

The Laboratory's routine operations, scientific experiments, and proposed new research projects are all evaluated for safety and radiological dose impact to workers and the environment. Radiological assessments are also performed as necessary, to ensure that radiological dose impact from non-routine activities remain "As Low As Reasonably Achievable" (ALARA) to members of the public, BNL workers, visitors, and the environment. These assessments ensure that facilities and operations are in compliance with federal, state, and local regulations. 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). Therefore, all other individual members of the public will receive dose less than the MEI. The dose to the MEI is the sum total from direct and indirect dose pathways to an individual via air immersion, inhalation of particulates and gases, and ingestion of local fish and deer meat. The 2009 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 71 ± 10 mrem (710 ± 100 µSv) and 65 ± 7 mrem (650 ± 70 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 thermoluminescent dosimeters (TLDs) on-site and 14 TLDs off-site 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 elevated 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 calculated as 7.20E-02 mrem (0.72 µSv) to the MEI. The dose from the ingestion pathway was estimated as 7.10 mrem (71 µSv) from the consumption of deer meat, and 0.17 mrem (1.7 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 7.34 mrem (73 µSv). The BNL dose from the inhalation pathway was less than 1 percent of EPA's annual regulatory dose limit of 10 mrem (100 µSv). The total dose was less than 8 percent of DOE's annual dose limit of 100 mrem (1,000 µSv) from all environmental pathways.

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 impacts from these activities were below regulatory limits and there was no radiological risk to the public, BNL employees, visitors, or the environment. In summary, the overall dose impact from all Laboratory activities in 2009 was comparable to natural background radiation levels.

8.1 DIRECT RADIATION MONITORING

Direct, penetrating beta and gamma radiation is measured using TLDs. The principle of TLD function is that when certain crystals are exposed to radiation, impurities in the crystals' low-temperature trapping sites are excited to higher energy states. These electrons remain in a high-energy state at normal ambient temperature. When the TLDs are heated (annealed), electrons return to the lower energy state, emitting photon energy (light), which is measured with a photomultiplier tube; the light intensity is directly proportional to the absorbed radiation dose. The environmental TLDs used at the Laboratory are composed of calcium fluoride and lithium fluoride crystals. Accuracy is verified by exposing the TLD to a known and characterized radiation source.

A direct radiation-monitoring program is used to measure the external dose contribution to members of the public and workers from radiation sources at the Laboratory. 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 BNL operations. On- and off-site external dose measurements were averaged, and then compared with each other using the statistical t-test to measure any variations in the averages and thus the contribution, if any, from Laboratory 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 2009, 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 in Building 490 for use as reference and control TLDs for comparison purposes. The average of the control TLD values was reported as

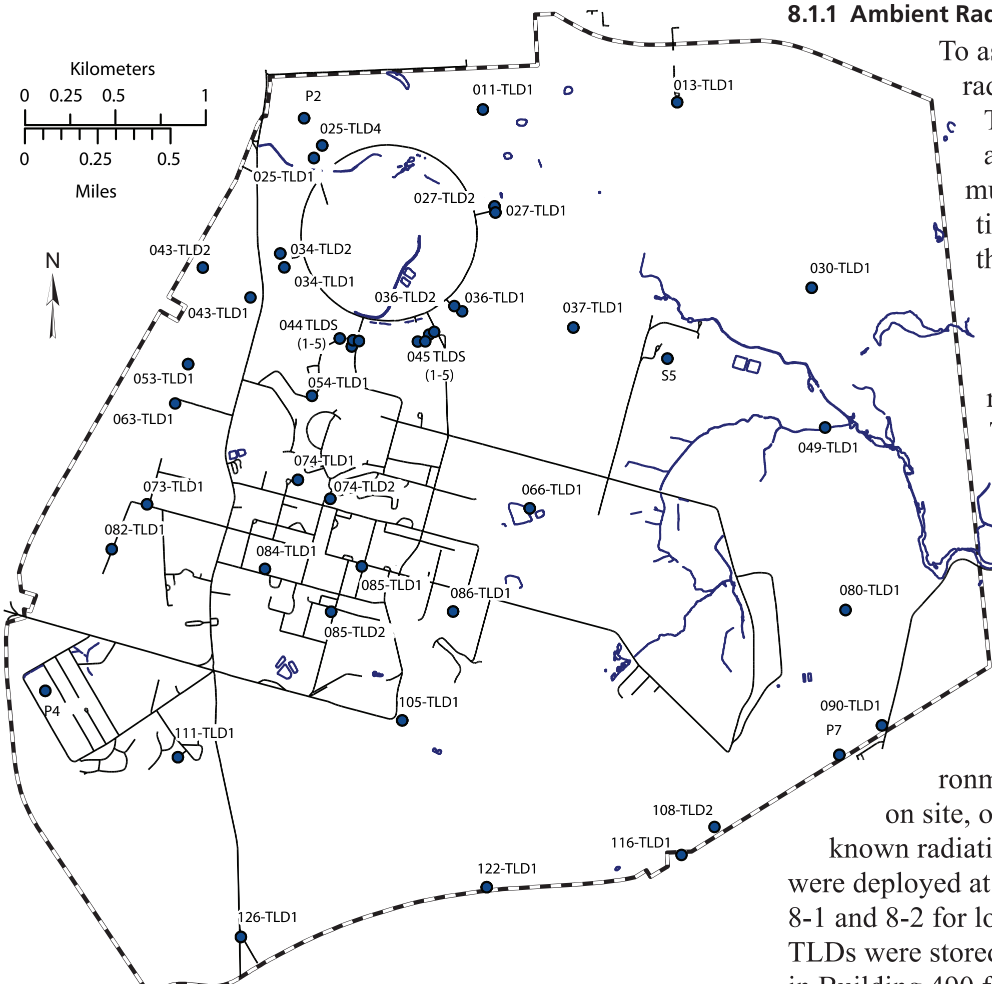

Figure 8-1. On-Site TLD Locations.

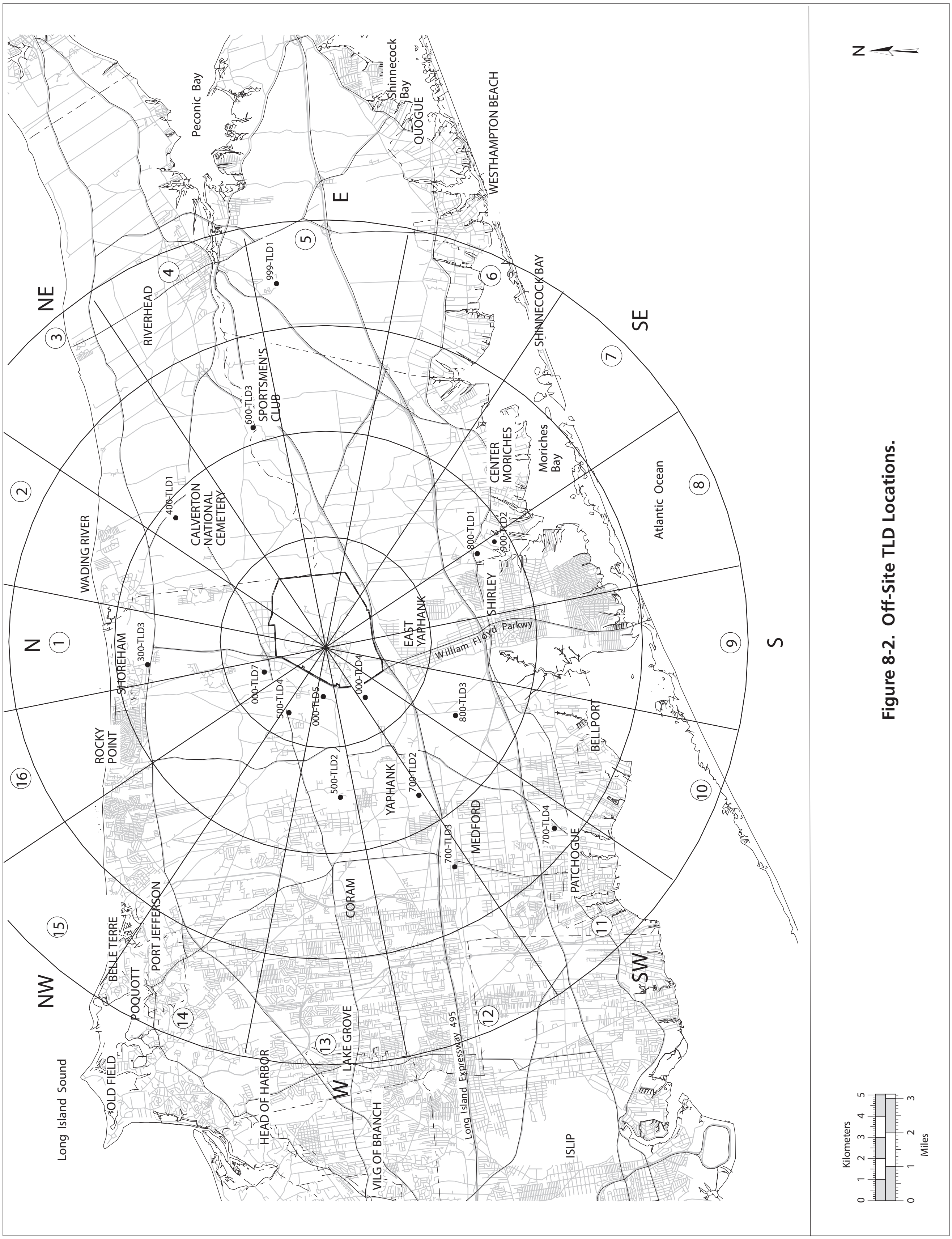

Figure 8-2. Off-Site TLD Locations.

"075-TLD4" in Tables 8-1 and 8-2. Note that a small "residual" dose was reported for the control TLDs when they were annealed, because it is not possible to completely anneal 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 2009. The on-site average external doses for the first, second, third, and fourth quarters were 18.6 ± 3.5, 18.1 ± 3.6, 15.5 ± 3.0, and 18.3 ± 3.5 mrem, respectively. The on-site average annual external dose from all potential environmental sources, including cosmic and terrestrial radiation sources, was 71 ± 10 mrem (710 ± 100 µSv).

Table 8-2 shows the quarterly and yearly off-site radiation dose measurements for 2009. The off-site average external doses for the first, second, third, and fourth quarters were 16.7 ± 2.8, 16.2 ± 2.9, 14.6 ± 2.3, and 18.1 ± 2.7 mrem, respectively. The off-site average annual ambient dose from all potential environmental sources, including cosmic and terrestrial radiation sources, was 65 ± 7 mrem (650 ± 70 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 (71 ± 10 mrem) and on-site dose (65 ± 7 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 2009.

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

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	14.9	16.0	12.8	16.7	15 ± 3	60 ± 13
013-TLD1	North firebreak	20.6	17.7	14.5	15.5	17 ± 5	68 ± 21
025-TLD1	Bldg. 1010, beam stop 1	16.6	19.0	15.1	16.6	17 ± 3	67 ± 13
025-TLD4	Bldg. 1010, beam stop 4	16.5	17.7	15.1	16.5	16 ± 2	66 ± 8
027-TLD1	Bldg. 1002A S	16.8	18.1	13.2	16.6	16 ± 4	65 ± 16
027-TLD2	Bldg. 1002D E	16.5	16.8	13.7	14.8	15 ± 3	62 ± 11
030-TLD1	NE firebreak	18.2	18.8	14.8	17.6	17 ± 3	69 ± 14
034-TLD1	Bldg. 1008, collimator 2	18.2	18.2	15.9	17.1	17 ± 2	69 ± 9
034-TLD2	Bldg. 1008, collimator 4	21.3	19.3	16.7	16.9	19 ± 4	74 ± 17
036-TLD1	Bldg. 1004B, E	19.8	15.6	13.6	17.0	17 ± 5	66 ± 20
036-TLD2	Bldg. 1004, E	19.4	19.4	15.0	19.0	18 ± 4	73 ± 17
037-TLD1	S-13	16.2	17.6	15.5	16.8	17 ± 2	66 ± 7
043-TLD1	N access road	18.4	20.2	16.7	17.7	18 ± 3	73 ± 12
043-TLD2	N of Meteorology Tower	17.0	18.2	16.5	17.3	17 ± 1	69 ± 6
044-TLD1	Bldg. 1006	19.0	16.2	15.5	18.0	17 ± 3	69 ± 13
044-TLD2	S of Bldg. 1000E	19.4	17.7	15.4	16.0	17 ± 4	69 ± 14

(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)					
044-TLD3	S of Bldg. 1000P	16.1	15.1	14.4	19.5	16 ± 4	65 ± 18
044-TLD4	NE of Bldg. 1000P	19.2	16.4	14.3	18.4	17 ± 4	68 ± 17
044-TLD5	N of Bldg. 1000P	17.9	16.7	15.6	18.4	17 ± 2	69 ± 10
045-TLD1	Bldg. 1005S	17.7	17.9	17.5	19.0	18 ± 1	72 ± 5
045-TLD2	E of Bldg. 1005S	18.7	18.7	15.0	20.4	18 ± 4	73 ± 18
045-TLD3	SE of Bldg. 1005 S	20.8	16.3	15.3	17.2	17 ± 5	70 ± 19
045-TLD4	SW of Bldg. 1005 S	18.3	16.4	15.1	17.9	17 ± 3	68 ± 11
045-TLD5	WSW of Bldg. 1005 S	16.7	15.2	14.4	16.1	16 ± 2	62 ± 8
049-TLD1	E firebreak	20.5	19.6	14.4	18.1	18 ± 5	73 ± 21
053-TLD1	W firebreak	20.2	17.8	17.0	20.8	19 ± 4	76 ± 14
054- TLD1	Bldg. 914	20.9	20.6	15.0	15.5	18 ± 6	72 ± 25
063-TLD1	W firebreak	19.7	22.3	18.0	19.7	20 ± 3	80 ± 14
066-TLD1	Waste Management Facility	15.2	15.6	15.5	18.6	16 ± 3	65 ± 12
073-TLD1	Meteorology Tower / Bldg. 51	18.4	18.5	18.8	19.4	19 ± 1	75 ± 4
074-TLD1	Bldg. 560	20.0	20.4	15.0	21.1	19 ± 5	77 ± 22
074-TLD2	Bldg. 907	18.6	19.5	15.8	19.7	18 ± 4	74 ± 14
080-TDL1	E firebreak	20.9	20.5	16.1	21.8	20 ± 5	79 ± 20
082-TLD1	W firebreak	19.0	18.7	16.9	18.7	18 ± 2	73 ± 8
084-TLD1	Tennis courts	20.4	16.8	14.7	19.1	18 ± 5	71 ± 20
085-TDL2	Upton gas station	18.3	21.4	16.8	20.4	19 ± 4	77 ± 16
085-TLD1	Diversity Office	20.7	19.6	17.0	18.4	19 ± 3	76 ± 12
086-TLD1	Baseball fields	21.5	15.9	18.3	19.2	19 ± 5	75 ± 18
090-TLD1	North St. gate	17.1	17.6	15.3	19.8	17 ± 4	70 ± 15
105-TLD1	S firebreak	19.3	20.1	13.9	21.7	19 ± 7	75 ± 27
108-TLD1	Water tower	18.4	20.1	15.7	16.8	18 ± 4	71 ± 15
108-TLD2	Tritium pole	23.2	22.5	19.0	22.1	22 ± 4	87 ± 15
111-TLD1	Trailer park	19.1	18.6	16.2	19.1	18 ± 3	73 ± 11
122-TLD1	S firebreak	17.2	17.9	15.3	19.2	17 ± 3	70 ± 13
126-TLD1	S gate	19.8	19.2	19.4	20.7	20 ± 1	79 ± 5
P2		16.9	15.9	12.8	16.2	15 ± 4	62 ± 14
P4		16.8	16.0	14.1	19.0	16 ± 4	66 ± 16
P7		17.3	18.6	15.5	18.4	17 ± 3	70 ± 11
S5		17.7	16.0	13.4	15.6	16 ± 3	63 ± 14
On-site average		**18.6**	**18.1**	**15.5**	**18.3**	**18 ± 3**	**71 ± 10**
Std. dev. (2 σ)		**3.5**	**3.6**	**3.0**	**3.5**		
075-TLD4 Control TLD average		**9.0**	**8.6**	**9.3**	**8.9**	**8.9 ± 1**	**36 ± 2**

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

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	15.5	17.5	15.6	19.1	17 ± 3	68 ± 13
000-TLD5	Longwood Estate	16.1	15.2	15.3	16.3	16 ± 1	62 ± 5
000-TLD7	Mid-Island Game Farm	17.4	19.1	14.2	17.5	17 ± 5	68 ± 20
300-TLD3	Private property	17.6	NP	NP	NP	18 ± 0	70 ± 0
400-TLD1	Calverton Nat. Cemetary	19.6	18.3	16.2	19.6	18 ± 3	74 ± 13
500-TLD2	Private property	15.1	14.9	14.0	16.4	15 ± 2	60 ± 8
500-TLD4	Private property	15.3	15.0	14.1	19.9	16 ± 5	64 ± 20
600-TLD3	Sportsmen's Club	16.3	15.3	13.7	NP	15 ± 3	60 ± 10
700-TLD2	Private property	17.3	13.9	NP	NP	16 ± 5	62 ± 19
700-TLD3	Private property	18.5	15.8	13.4	17.4	16 ± 4	65 ± 17
700-TLD4	Private property	16.2	16.8	14.3	18.9	17 ± 4	66 ± 15
800-TLD1	Private property	16.1	15.2	16.7	NP	16 ± 1	64 ± 6
800-TLD3	Suffolk County CD	18.4	16.7	15.4	16.6	17 ± 2	67 ± 10
900-TLD2	Private property	14.7	16.8	12.7	19.2	16 ± 5	63 ± 22
999-TLD1	Private property	NP	NP	NP	NP		
Off-site average		**16.7**	**16.2**	**14.6**	**18.1**	**16 ± 2**	**65 ± 7**
Std. dev. (2 σ)		**2.8**	**2.9**	**2.3**	**2.7**		
075-TLD4	**Control TLD average**	**9.6**	**9.6**	**9.6**	**9.8**	**9.6 ± 0**	**39 ± 1**

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

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 small amounts of contamination in soil. However, a comparison of the 2009 dose rates to doses from previous years show that the dose rates have declined significantly since the removal of most of the contaminated soil within the former HWMF. As recorded in Table 8-3, the dose is currently just slightly above natural background levels. The former HWMF is fenced; access is controlled and only radiologically trained BNL employees are allowed inside the fenced area.

Two TLDs (075-TLD3 and 075-TLD5) near Building 356 showed much higher than normal quarterly averages: 25 ± 14 mrem (250 ± 140 µSv) and 25 ± 4 mrem (250 ± 40 µSv), respectively. The yearly doses were measured at 101 ± 56 mrem (1010 ± 560 µSv) for 075-TLD3, and 100 ± 17 mrem (1000 ± 170 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 minimal due to the limited time an individual spends in the parking lot.

Two FAM-TLDs placed on the fence northeast and northwest of Building 913-B (the Alternating Gradient Synchrotron tunnel access) showed slightly higher than average ambient external dose. The first-quarter dose at that site was measured at 22.9 mrem for 054-TLD2 and 21.2 mrem for 054-TLD3 (compared to the site-wide first-quarter dose of 18.6 ± 3.5). The

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. 913-B	22.9	22.3	16.4	20.6	20 ± 6	82 ± 23
054-TLD3	NW of Bldg. 913-B	21.2	18.1	14.5	16.1	17 ± 6	70 ± 23
S6		18.7	18.7	17.9	20.8	19 ± 2	76 ± 10
088-TLD1	FWMF, 50', E of S-6	18.9	19.3	17.2	18.6	19 ± 2	74 ± 7
088-TLD2	FWMF, 50', W of S-6	21.6	23.5	17.7	20.9	20 ± 5	84 ± 19
088-TLD3	FWMF, 100', W of S-6	21.3	20.5	17.0	26.2	21 ± 7	85 ± 30
088-TLD4	FWMF, 150', W of S-6	18.2	20.4	17.1	20.0	19 ± 3	76 ± 12
075-TLD3	Bldg. 356	23.8	20.3	21.5	35.8	25 ± 14	101 ± 56
075-TLD5	N corner of Bldg. 356	24.7	23.5	24.0	28.2	25 ± 4	100 ± 17

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

second quarter reading for 054-TLD2 was 22.3 mrem, which was slightly elevated. For the remaining quarters, both TLDs showed dose comparable to the natural background radiation.

The Alternating Gradient Synchrotron (AGS) accelerates protons to energies up to 30 GeV and heavy ion beams to 15 GeV/amu. The Relavistic Heavy Ion Collider (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 when the charged particles leave the confines of the accelerator and produce nuclear fragments along its 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 2009, 12 neutron monitoring TLDs (Harshaw Badge 8814) were posted at such 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 was based on such aspects as the thickness of the berm shielding, location of soil activation areas, beam stop areas and beam collimators, and the proximity to the site boundary. In 2009, the neutron 025-TLD-N2 in the vicinity of building 1010 and 034-TLD-N1 in the vicinity of Building 1008 showed neutron doses of 1 mrem and 2 mrem, respectively.

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 and dose to the MEI. The dose estimates from various facilities are given in Table 8-4, and the actual emissions for 2009 are discussed in detail in Chapter 4.

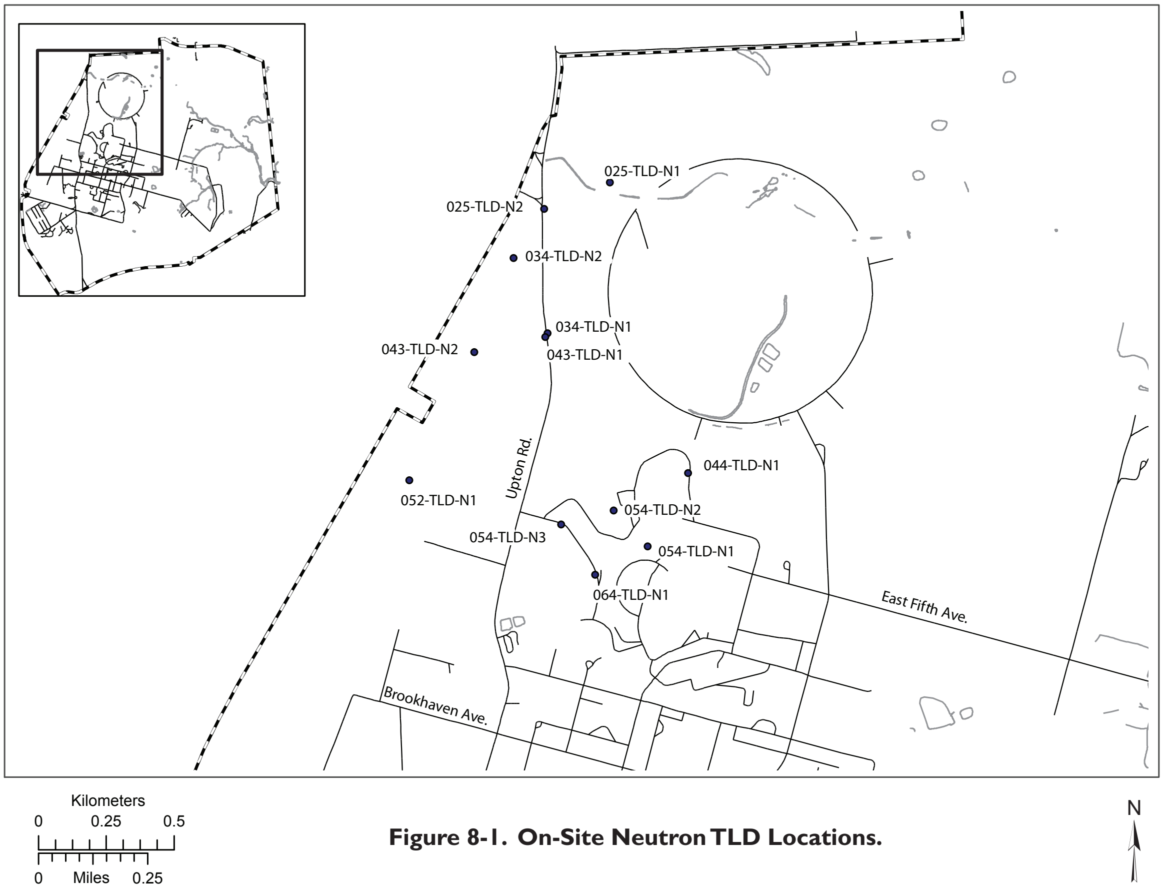

Figure 8-1. On-Site Neutron TLD Locations.

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 under the Environmental Restoration (ER) Program 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 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 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

Table 8-4. Maximally Exposed Individial 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	(b)
463	Biology Facility	None	ND	(b)
490	Medical Research	BNL-489-01	2.94E-12	(b)
490A	Energy and Environment National Security	None	ND	(b)
491	Brookhaven Medical Research Reactor	None	ND	(e)
510	Calorimeter Enclosure	BNL-689-01	ND	(f)
510A	Physics	None	ND	(b)
535	Instrumentation	None	ND	(b)
555	Chemistry Facility	None	ND	(b)
725	National Synchrotron Light Source	None	ND	(b)
750	High Flux Beam Reactor	None	1.92E-4	(c)
801	Target Processing Lab	None	6.10E-8	(b), (c)
802B	Evaporator Facility	BNL-288-01	NO	(e)
820	Accelerator Test Facility	BNL-589-01	ND	(d)
830	Environmental Science Department	None	ND	(d)
865	Reclamation Building	None	ND	(c)
906	Medical-Chemistry	None	ND	
925	Accelerator Department	None	ND	(b)
931	Brookhaven Linac Isotope Producer	None	7.20E-2	(c)
938	REF/NBTF	BNL-789-01	ND	(g)
942	Alternate Gradient Syncrotron Booster	BNL-188-01	ND	(h)
–	Relativistic Heavy Ion Collider	BNL-389-01	ND	(d)
Total Potential Dose from BNL Operations			**7.22E-2**	
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
(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) ND = No dose from emissions source in 2009.
(e) NO = Not operational in 2009.
(f) This has become a zero-release facility since original permit application.
(g) This facility is no longer in use; it produces no radioactive emissions.
(h) Booster ventilation system prevents air release through continuous air recirculation.

emission points are located at the center of the developed portion of the BNL 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). Population data used in the model are based on the Long Island Power Authority population survey (LIPA 2000). 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 are described as releases of radioactive contaminants to the atmosphere that do not have a well-defined emission point such as a stack or vent. Such sources are also known as nonpoint or area sources. Fugitive sources include releases to the air not through an actively ventilated air stream (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 2009 for potential contribution to the overall site dose.

8.3.1 Brookhaven Graphite Research Reactor (BGRR)

The BGRR was the first reactor built in 1950 for the sole purpose of providing neutrons for research projects. The BGRR was an air-cooled, graphite-moderated research reactor. During reactor operations, filtered outside air was drawn through the reactor pile, cooled in the ductwork, filtered, and then exhausted back out through a 100-meter stack. Until 1958, the reactor was fueled with natural uranium. It was then fueled with enriched uranium; the enriched fuel produced a higher neutron flux and reduced the fuel failure rate. The reactor was shut down in 1969, and all fuel was removed from the BNL site by June 1972.

The BGRR has been identified as Area of Concern (AOC) 9, under an Interagency Agreement and Record of Decision (ROD) among DOE, EPA, and the New York State Department of Environmental Conservation (NYSDEC) under the Federal Facility Agreement of the CERCLA of 1980. There are several BGRR structures that must be removed under this ROD and disposed of at an off-site licensed facility.

The graphite pile and biological shield that surrounds the graphite pile were called out for removal in the ROD and a NESHAP evaluation was performed. The graphite pile, which acted as a neutron moderator for the research reactor, is housed within the biological shield. The graphite pile is a 25-foot cube, made up of 60,000 graphite blocks of various shapes and sizes. There is some debris remaining within the air passages and at the base of the pile. The debris is contaminated with activation products and fission products as a result of past fuel failures. The amount of loose surface contamination on the biological shield is limited to the inner surfaces exposed to the reactor cooling air. The Environmental Remediation Project group analyzed graphite samples and swipes to identify the radiological constituents in the graphite pile. The following radionuclides were identified as major contamination components: H-3, C-14, Co-60, Ni-63, I-129, Cs-137, Sr-90, Eu-152, Eu-154, Am-241, Th-232, Pu-238, Pu-239, and Pu-240.

The removal of the graphite pile and the biological shield is expected to be completed by the end of 2011. Approximately 1.4 million pounds of activated graphite blocks and 5,000 tons of activated concrete and steel from the biological shield will be removed from Building 701 and then packaged, transported, and disposed of at an off-site location. The graphite pile removal work will be performed within a contamination containment enclosure (CCE) with a remotely controlled Gradall manipulator. The remote manipulator will be used to remove the graphite pile blocks starting from the top layer and continuing down to the pile bedplates. The remote manipulator will be fitted with a specially designed end effecter and clamshell bucket to load the graphite blocks into "super sacks" located inside the biological shield cavity. Once a super sack is full, it will be lifted out of the biological shield with a 5-ton crane and transferred to a 144 ft^3 Industrial Package Type 1 (IP-1) box. The IP-1 box will be staged and decontaminated inside the CCE to control the spread of contamination.

Due to the many fuel failures during the operational phase of the reactor and the presence of activation and fission products, multiple barriers to control contamination will be implemented during the remediation to prevent the generation and spread of dispersible contaminants. Special tools will be used with the manipulator and administrative controls will be implemented to restrict the airborne concentrations of radionuclides, both inside the CCE and within Building 701. Continuous air monitors will also be installed to measure air concentrations and any spread of contamination inside Building 701 and adjacent to the biological shield.

The source term was based on the results of waste characterization studies, smear results, and the radiological inventory of the graphite pile and biological shield. The inventory is predominantly composed of activation products resulting from neutron activation of the graphite pile and biological shield materials. Fission products from fuel leakage are present on graphite surfaces and on the innermost section of the biological shield. The effective dose equivalent to the MEI from the graphite pile and biological shield removal project was estimated to be 1.33E-02 mrem/year.

8.3.2 Waste Transfer Lines, Buildings 801 to 811

Underground waste lines were used to transfer radioactive liquid waste from the Hot Laboratory in Building 801 to the Waste Concentration Facility, Building 811. These underground radioactive waste transfer lines (A, B, D, and a non-acid off-gas pipe) were installed in 1949, modified in 1952, and completely abandoned in-place in 1961. A steam line in the area was also abandoned in 2001. The radioactive waste transfer lines A and B were 2″-diameter shielded stainless steel pipes, which were used to transfer Class A uranium and other fissionable material, and Class B non-fissionable waste materials. The D waste line was a 4″-diameter mild steel pipe used to transfer other radioactive liquid waste. The liquid radioactive waste was generated from the operation of the BGRR, the HFBR, and the Hot Laboratory. A concrete culvert, approximately 700′ long and 3′-8 ½″ wide, was used as a secondary containment for the radioactive waste transfer pipes. The waste lines lead to six waste storage tanks in the Building 811 Waste Concentration Facility, which were removed and documented in 2005 Closeout Report, Operable Unit I, and Area of Concern 10 (AOC 10).

In 2009, remediation work included the removal of the waste transfer lines, steam line, soil below the pipes, a portion of the long concrete culvert and the non-acid off-gas pipe under the HFBR AOC 31 ROD. The pipes and concrete were disposed of as radiological material, and approximately 47 yd^3 (36 m^3) of soil were excavated from the area. Building 811 characterization data was used to estimate the potential source term during the remediation work and was based on a material-at-risk (MAR). An MAR is defined as the maximum amount of radionuclides available to be acted upon by a given physical stress (remediation activities) with certain probability for the radioactive materials to be released into the environment. The effective dose equivalent to the MEI from the underground waste transfer lines A, B, D, and acid off-gas remediation work was estimated to be 1.38E-03 mrem/year at the northwest location.

8.3.3 Waste Management Facility (Building 865)

A NESHAPs compliance review for venting of the radioactive gases used in the gallium trichloride experiment in Building 555 was performed. The residual radioactive gases were released in the fume hood (EF-108) in the Waste Management Building, 865. The source activity was estimated to be carbon dioxide in the form of C-14 at 17.42 µCi, and krypton-85 (Kr-85) at 1.4 µCi.

The source term was based on the information provided on the NESHAPs Assessment Form. Although both gases had long half-lives, their specific activity was very low. A conservative estimate of effective dose equivalent to the MEI was estimated to be 2.37E-08 mrem/year. Based on the radiological dose risk assessment, the venting of the inert gases did not have an adverse impact on the environment or members of public.

8.3.4 Brookhaven Avenue Soil Removal

The former HWMF is located south of Brookhaven Avenue in the southeast wind sector at the Laboratory. In 2005, the cleanup and remediation of the former HWMF was completed under the CERCLA program, Operable Unit (OU) I AOC I. The former HWMF is fenced and categorized as a radiological facility, currently under the surveillance and maintenance program of the Environmental Restoration Project. In 2005, a small area with residual surface contamination was left in place and designated as the Waste Loading Area (WLA) to be used for remedial activities from other facilities. A decision was later made to remediate the WLA and to remove the contaminated soil from the area. Soon after the remedial activity in November 2007, BNL prepared an investigation and characterization of Brookhaven Avenue Cs-137 contamination, which showed additional elevated levels of beta/gamma radiation north/northeast and east of the former HWMF. Due to limited funding in 2008, a few discrete spots were remediated and the remainder of the area contamination was left in place. Stimulus package funding in 2009 allowed additional removal and disposal of the remaining contaminated soil at Brookhaven Avenue.

Survey results showed elevated levels of beta/gamma radiation contamination in an area of 1,433 square meters and at 13 localized spots above natural background radiation levels. Excavation equipment (i.e., Bobcat, backhoe) were used to scrape the top layers of contaminated soil, and a front-end loader was used to load the contaminated soil into super sacks for transportation to an off-site disposal facility. The residential cleanup level for Cs-137 of 23pCi/g was chosen as the cleanup goal for remediation work. The investigation and characterization of the Brookhaven Avenue Cs-137 contamination was reviewed in order to develop the source term. The effective dose equivalent to the MEI was estimated to be 6.67E-05 mrem/year.

8.3.4 Cyclotron

A NESHAPs dose assessment was performed for the potential release of carbon-11 (half-life: 20 minutes) in an "Accident" scenario for inclusion in the Safety Analysis Report (SAR) of the cyclotron. The worse case (maximal) accident condition was seen as the rupture of a carbon-11 (C-11) gas foil target. As a result of the accident condition, the maximum radioactivity released to the environment would be 500 mCi. Therefore, the source term for the dose assessment was assumed to be 500 mCi of C-11 without decay or dispersion in the 60″ cyclotron vault. Due to the short half-life of carbon-11 and because the adiabatic dispersion of the gas would be very fast in the environment, the result would be a small impact. A conservative estimate of effective dose equivalent to the MEI was estimated to be 2.64E-04 mrem/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 Brookhaven Linac Isotope Producer (BLIP) facility is the only emission source with any 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 uses the excess beam capacity of the Linear Accelerator (Linac) to produce short-lived radioisotopes for medical diagnostic procedures, medical imaging, and scientific research. During the irradiation process, the targets are cooled continuously by recirculating water in a 16-inch-diameter shaft. The principal gaseous radionuclides produced as a result of activation of the cooling water are O-15, C-11, and trace amounts of N-13. Because the BLIP facility has the potential to exceed 1 percent of the EPA emission limit, the facility emissions are directly measured using a low-resolution gamma spectrometer with an in-line sampling system connected to the air exhaust, to measure the short-lived gaseous products that cannot be sampled and analyzed by conventional analytical methods. Particulates and radioiodine are monitored with paper and granular activated charcoal filters, which are exchanged weekly for analysis by a contract analytical laboratory. A tritium sampler also operates continuously, with samples collected weekly.

In 2009, the BLIP facility operated over a period of 24 weeks. During the year, 670 Ci of C-11 and 1,125 Ci of O-15 were released from the facility. A small quantity of tritiated water vapor from activation of the targets' cooling water was also released at 2.75E-02 Ci. The EDE to the MEI was calculated to be 7.20E-02 mrem (0.72 µSv) in a year from BLIP operations.

In order to upgrade and make the BLIP stack comply with American National Standards Institute (ANSI) standards, an authorization application was submitted to EPA to construct and modify an existing stationary stack under 40 CFR 61.07 in April 2009; authorization was approved in August 2009. The upgrade and modification required removing an existing 12-inch diameter duct (after removing the existing HEPA and charcoal filtration system) and installing a new 6-inch-diameter galvanized steel duct within the building. On the outside of the building, an 8-inch-diameter duct was installed 10 feet away from the adjacent roof to avoid eddy currents. The total physical stack height above the adjacent structure is 15 feet, and it is 39 feet above normal grade level. The exit duct nozzle size was reduced to a 4-inch-diameter with a discharge velocity of 4,295 feet per minute (fpm). The normal exhaust volume was 375 cubic fpm, variable up to 745 cubic fpm. A new emission sampling system was installed that complies with the ANSI N13.1-1999 standard for particulates, tritium, and short-lived gases. A shroud probe was installed in the 6-inch duct to extract a representative sample for particulates, and the transport lines were made of non-reactive stainless steel with the shortest distance to the filter collection system. A new sampling system for tritium and short-lived gases was also installed. The stack modifications were completed before the start of BLIP operations in 2010. The new stack sampling system will be tested during operations in 2010.

8.4.2 High Flux Beam Reactor

In 2009, the HFBR reactor vessel, primary cooling water system, and fuel canal which were filled with domestic water, were drained. The water was solidified and disposed of off site. Sixteen control rod blades and nine beam plugs were removed and shipped off site to a licensed disposal facility. The HFBR facility was downgraded to a radiological facility below the hazard category 3 after a Safety Basis Analysis. In 2009, tritium levels in the building were much higher than previous years (38.2 curies) due to the remediation work being performed. Effective dose equivalent to the MEI was calculated to be 1.92E-4 mrem (2 nSv) in a year.

8.4.3 Brookhaven Medical Research Reactor

In 2009, the Brookhaven Medical Research Reactor (BMRR) facility was in a "cold" shutdown mode. There was no dose contribution from the BMRR.

8.4.4 Unplanned Releases

There were no unplanned releases in 2009.

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 was 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 2009, the average K-40 concentrations in tissue samples (off site < 1 mile) were 3.11 ± 1.08 pCi/g (wet weight) in the flesh and 1.66 ±0.37 pCi/g (wet weight) in the liver. The maximum Cs-137 concentrations were 4.89 ± 0.47 pCi/g (wet weight) in the flesh and 0.42 ± 0.04 pCi/g (wet weight) in the liver (see Table 6-2). The average Cs-137 concentration was calculated at 1.66 ± 0.58 pCi/g; however, the maximum concentration of 4.89 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 7.10 mrem (71 μSv) in a year. The dose was below the health advisory limit of 10 mrem (100 μSv) established by NYSDOH. The maximized estimated dose would not be actualized, as no deer hunting is permitted on the BNL site.

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 2009, largemouth bass samples collected from the Peconic River on BNL site had the highest concentration of Cs-137, at 0.51 ± 0.06 pCi/g; this was used to estimate the EDE to the MEI. The potential dose from consuming 15 pounds of bass annually was calculated to be 0.17 mrem (1.7 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, terrestrial plants, and terrestrial animals, using site-specific environmental surveillance data. The RESRAD-BIOTA 1.21 biota dose level 2 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 2009, the terrestrial animal and plant doses were evaluated based on 0.27 pCi/g of Cs-137

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	0.072 mrem (0.72 µSv)	<1%	3.09 person-rem
Ingestion			
Drinking water	None	None	None
Fish	0.17 mrem (1.7µSv)	<1%	Not tracked
Deer Meat	7.10 mrem (71 µSv)	<8%	Not tracked
All Pathways	7.34 mrem (73.4 µSv)	<8%	3.09 person-rem

found in surface soils in the vicinity of the RHIC ring and a Sr-90 concentration of 0.75 pCi/L in the surface waters collected at the HM-N location. The dose to terrestrial animals was calculated to be 0.01 mGy/day, and to plants, 1.22 E-03 mGy/day. The doses to terrestrial plants and animals were 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 HM-N location and the Cs-137 in the Carmans River, Lower lake sediments were used. The Cs-137 sediment concentration was 0.48 pCi/g, and the Sr-90 concentration in surface water was 0.75 pCi/L. The calculated dose to aquatic animals was 2.36E-04 Gy/day and to riparian animals was 2.84E-03 Gy/day. Therefore, the dose to aquatic and riparian animals was 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 2009. The total dose to the MEI from air and ingestion pathways was estimated to be 7.34 mrem (73 µSv). In comparison, the EPA regulatory limit for the air pathway is 10 mrem (100 µSv) and the DOE limit from all pathways is 100 mrem (1,000 µSv). The cumulative population dose would be 3.09 person-rem (31 person-mSv) in a year. The effective dose was well below the DOE and EPA regulatory limits, and the ambient TLD dose was within normal background levels seen at the Laboratory site. The potential dose from drinking water was not estimated, because most of the 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 300 mrem (3.0E-3 µSv). A diagnostic chest x-ray would result in a 5 to 20 mrem (50–200 µSv) dose per exposure. Using natural gas in homes yields approximately a 9 mrem (90 µSv) dose per year, cosmic radiation yields 26 mrem (260 µSv), and natural potassium in the body yields approximately 39 mrem (390 µSv) of internal dose. Even with worst-case estimates of dose from the air pathway and ingestion of local deer meat and fish, the cumulative dose from BNL operations was equivalent to the dose that could be received from a single chest x-ray.

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