Radiological Dose Assessment

8

Brookhaven National Laboratory routinely evaluates site operations and new projects to ensure that the overall radiological dose impact to members of the public, BNL workers, and the environment is "As Low As Reasonably Achievable." All scientific and operational processes that can in any way impact the health and safety or may contribute to radiological dose are reviewed for their individual impacts on the people and environment. The potential radiological dose to the public is calculated as the maximum dose to a hypothetical Maximally Exposed Individual (MEI) at the BNL site boundary. Doses are calculated for all direct and indirect pathways, such as air immersion dose, inhalation of particulates and gases, ingestion of deer meat and fish, and any immersion dose. In 2006, the radiation dose calculations showed that the total Effective Dose Equivalent (EDE) from Laboratory activities was well below the EPA and DOE regulatory dose limits for the public, workers, and the environment.

The average annual external dose from all potential ambient sources was 68 ± 11 mrem (680 ± 110 µSv) on site and 63 ± 9 mrem (630 ± 90 µSv) at off-site locations. Both measurements include the contribution from natural background and cosmic radiation. A statistical comparison of the average doses measured at 47 on-site and 15 off-site locations using thermoluminescent dosimeters (TLDs) showed that there was no additional external dose contribution from BNL operations above the natural background radiation dose. Additionally, nine TLDs were used to measure areas with slightly elevated radiation dose on the BNL site. The results of these measurements are described in Section 8.1.2.

The EDE from air emissions was calculated as 8.14E-02 mrem (0.81 µSv) to the MEI. The ingestion pathway dose was estimated as 2.96 mrem (30 µSv) from consumption of deer meat and 0.07 mrem (0.7 µSv) from consumption of fish caught in the vicinity of the BNL site. The total annual dose to the MEI from all pathways was estimated as 3.11 mrem (31 µSv). The BNL dose from the air inhalation pathway was less than 1 percent of EPA's annual regulatory dose limit of 10 mrem (100 µSv), and the total dose was less than 4 percent of DOE's annual dose limit of 100 mrem (1,000 µSv) from all pathways.

Doses to aquatic and terrestrial biota were also evaluated and found to be well below the DOE regulatory limits. Other short-term projects conducted in 2006, such as remediation work and waste management disposal activities, were evaluated for radiological emissions and their potential dose impact; there was no radiological risk to the public, BNL employees, or the environment from these activities. In conclusion, the overall dose impact from all Laboratory activities in 2006 was indistinguishable from the natural background radiation levels.

8.1 DIRECT RADIATION MONITORING

Direct, penetrating beta and gamma radiation is measured using thermoluminescent dosimeters. The principle of TLD operation 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), the 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. BNL participates in the inter-comparison proficiency testing programs sponsored by DOE, as a check of its ability to measure radiation doses accurately.

A direct radiation-monitoring program is used to measure the external dose contribution to members of the public and workers from radiation sources at BNL. This is achieved by measuring direct penetrating radiation exposures both on and off site. The direct measurements taken at the off-site locations are with the premise that off-site exposures are true natural background radiation (contribution from cosmic and terrestrial) exposures and represent no contribution from Laboratory operations. On- and off-site external dose measurements were averaged, then compared with each other 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 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 air plumes, atmospheric particulates, scattered radiation, and the location of radiation-generating facilities. 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 these grids.

In 2006, 47 TLDs were deployed on site; nine were placed in known radiation areas (i.e., they were facility area monitors, FAMs). Another 15 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 as the reference and

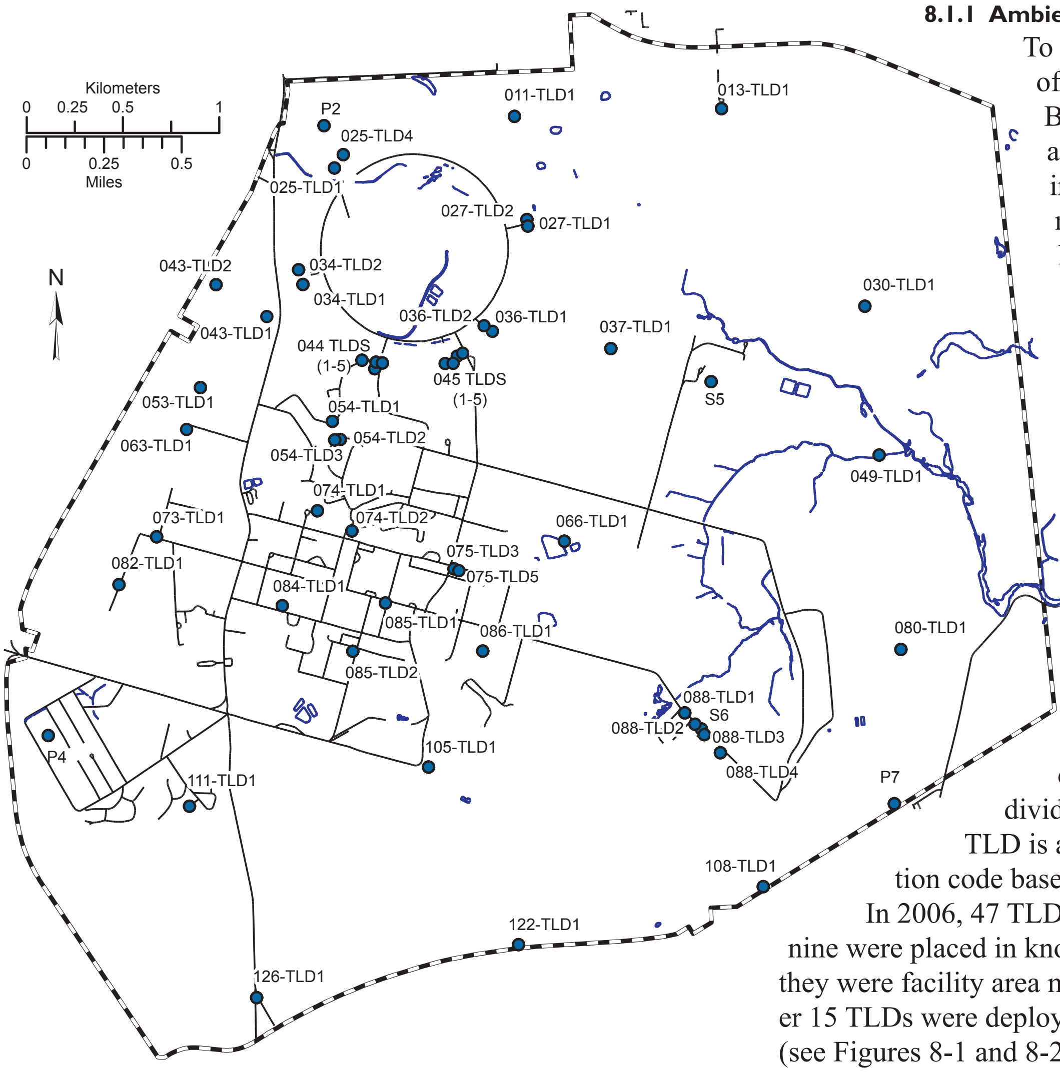

Figure 8-1. On-Site TLD Locations.

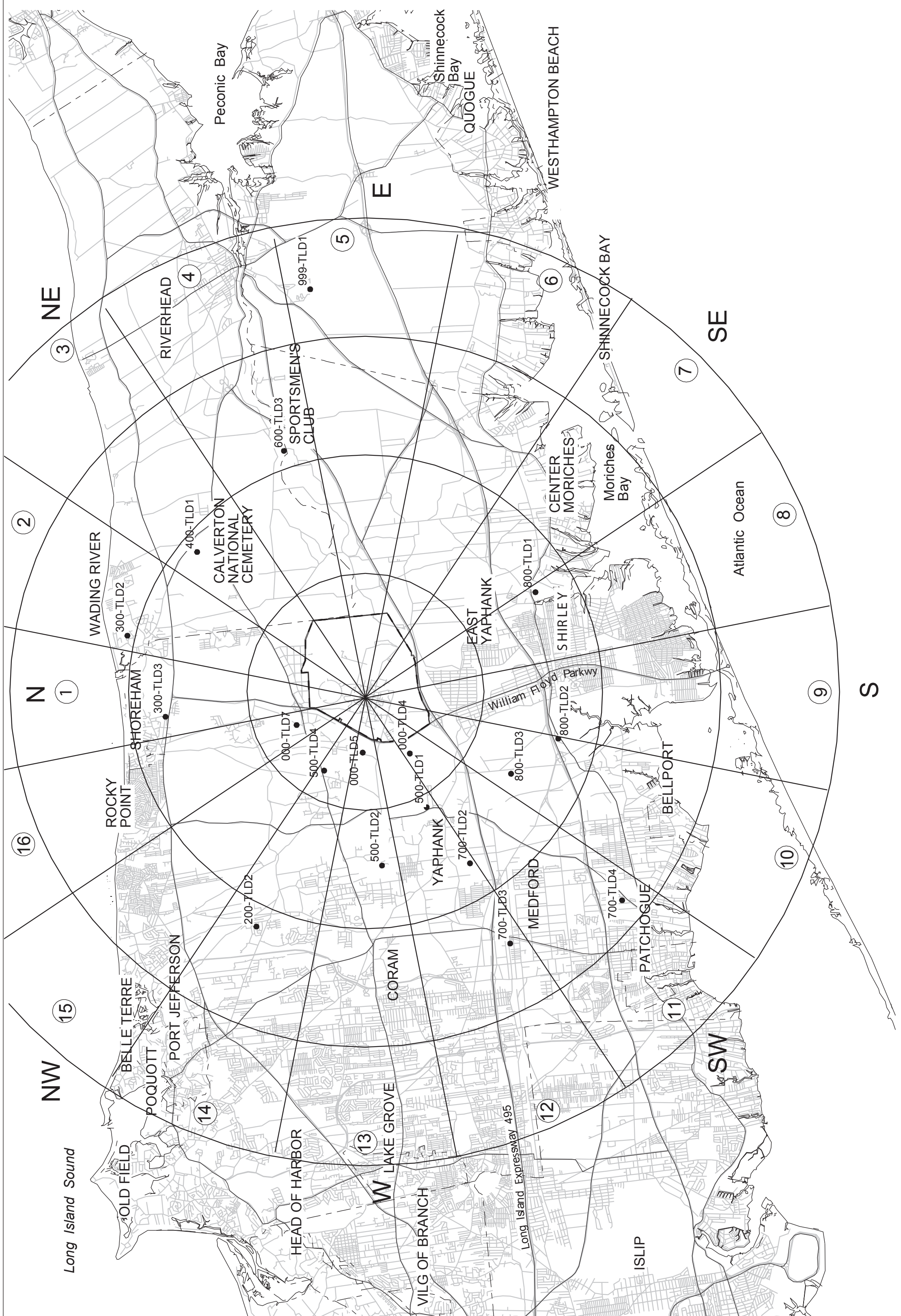

Figure 8-2. Off-Site TLD Locations.

control TLDs for comparison purposes. The average of the control TLD values was reported as "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 shield 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 2006. The on-site average external doses for the first, second, third, and fourth quarters were 18.4 ± 3.6, 16.0 ± 3.0, 15.6 ± 3.3, and 18.0 ± 3.0 mrem, respectively. The on-site average annual external dose from all potential environmental sources, including cosmic and terrestrial radiation sources, was 68 ± 11 mrem (680 ± 110 µSv).

Table 8-2 shows the quarterly and yearly off-site radiation dose measurements. The off-site average external doses for the first, second, third, and fourth quarters were 17.1 ± 2.4, 14.9 ± 2.5, 14.6 ± 3.6, and 16.2 ± 2.5 mrem, respectively. The off-site average annual ambient dose from all potential environmental sources, including cosmic and terrestrial radiation sources, was 63 ± 9 mrem (630 ± 90 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 (63 ± 9 mrem) and on-site dose (68 ± 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 2006.

8.1.2 Facility Area Monitoring

Nine on-site TLDs were designated as facility area monitors because they were posted in known radiation areas. 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 slightly higher external doses than the normal natural background radiation doses measured in other areas of BNL. The elevated ex-

Table 8-1. On-Site Direct 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	16.3	12.6	12.8	15.5	14 ± 4	57 ± 15
013-TLD1	North firebreak	17.1	14.4	14.7	16.7	16 ± 3	63 ± 11
025-TLD1	Bldg. 1010 beam stop 1	17.6	15.7	13.7	16.8	16 ± 3	64 ± 13
025-TLD4	Bldg. 1010 beam stop 4	19.8	14.2	14.6	17.2	16 ± 5	66 ± 20
027-TLD1	Bldg. 1002A South	14.8	15.0	14.1	16.5	15 ± 2	60 ± 8
027-TLD2	Bldg. 1002D East	17.7	14.5	13.2	17.0	16 ± 4	62 ± 17
030-TLD1	NE Firebreak	18.4	16.5	15.6	17.5	17 ± 2	68 ± 10
034-TLD1	Bldg. 1008 collimator 2	18.6	16.2	15.7	17.7	17 ± 3	68 ± 10
034-TLD2	Bldg. 1008 collimator 4	18.5	15.1	15.6	17.6	17 ± 3	67 ± 13
036-TLD1	Bldg. 1004B East	16.8	13.5	13.5	15.7	15 ± 3	60 ± 13
036-TLD2	Bldg. 1004 East	18.6	16.1	17.3	19.5	18 ± 3	72 ± 12
037-TLD1	S-13	17.3	14.6	15.2	19.2	17 ± 4	66 ± 16
043-TLD1	North access road	19.0	18.1	18.2	18.6	18 ± 1	74 ± 3
043-TLD2	North of Meteorology Tower	18.4	16.3	16.4	17.7	17 ± 2	69 ± 8

(continued on next page)

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

TLD#	Location	1st Quarter	2nd Quarter	3rd Quarter	4th Quarter	Avg./Qtr. ± 2σ (95%)	Annual Dose ± 2σ (95%)
		(mrem)					
044-TLD1	Bldg. 1006	17.4	17.2	16.4	17.4	17 ± 1	68 ± 4
044-TLD2	South of Bldg. 1000E	18.0	17.6	14.7	17.2	17 ± 3	68 ± 12
044-TLD3	South of Bldg. 1000P	16.8	15.2	13.7	19.8	16 ± 5	66 ± 20
044-TLD4	NE of Bldg. 1000P	20.1	17.0	15.6	18.1	18 ± 4	71 ± 15
044-TLD5	N of Bldg. 1000P	17.2	16.7	15.2	18.5	17 ± 3	68 ± 11
045-TLD1	Bldg. 1005S	20.4	15.9	16.2	17.5	18 ± 4	70 ± 16
045-TLD2	East of Bldg. 1005S	21.2	18.2	16.8	17.1	18 ± 4	73 ± 16
045-TLD3	SE of Bldg. 1005 S	18.0	16.2	14.8	17.3	17 ± 3	66 ± 11
045-TLD4	SW of Bldg. 1005 S	17.4	15.5	16.4	16.9	17 ± 2	66 ± 6
045-TLD5	WSW of Bldg. 1005 S	14.4	13.7	13.5	15.2	14 ± 2	57 ± 6
049-TLD1	East firebreak	16.3	16.2	14.6	17.1	16 ± 2	64 ± 8
053-TLD1	West firebreak	22.6	17.2	18.3	20.7	20 ± 5	79 ± 19
054- TLD1	Bldg. 914	19.7	14.6	13.0	16.0	16 ± 6	63 ± 22
063-TLD1	West firebreak	20.2	18.4	18.4	20.4	19 ± 2	77 ± 9
066-TLD1	Waste Management Facility	16.5	14.0	14.2	15.7	15 ± 2	60 ± 9
073-TLD1	Meteorology Twr. /Bldg. 51	19.5	17.1	17.6	19.0	18 ± 2	73 ± 9
074-TLD1	Bldg. 560	18.7	18.3	18.5	19.2	19 ± 1	75 ± 3
074-TLD2	Bldg. 907	17.6	15.8	16.3	19.5	17 ± 3	69 ± 13
080-TDL1	East firebreak	20.9	17.5	16.1	20.0	19 ± 4	75 ± 17
082-TLD1	West firebreak	22.6	18.4	17.3	20.9	20 ± 5	79 ± 19
084-TLD1	Tennis courts	NP	16.4	15.2	18.0	17 ± 3	66 ± 11
085-TDL2	Upton gas station	19.0	17.1	17.0	19.4	18 ± 2	73 ± 10
085-TLD1	Diversity Office	19.9	17.8	15.9	19.3	18 ± 3	73 ± 14
086-TLD1	Baseball fields	20.9	19.3	19.3	20.6	20 ± 2	80 ± 7
105-TLD1	South firebreak	19.0	15.5	16.5	19.1	18 ± 4	70 ± 14
108-TLD1	Water tower	16.1	15.3	14.7	16.8	16 ± 2	63 ± 7
111-TLD1	Trailer park	18.7	16.5	17.2	18.5	18 ± 2	71 ± 8
122-TLD1	South firebreak	17.7	15.2	14.9	17.9	16 ± 3	66 ± 13
126-TLD1	South gate	21.0	16.9	18.0	20.4	19 ± 4	76 ± 15
P2		16.3	12.8	13.0	15.2	14 ± 3	57 ± 13
P4		16.6	15.2	14.4	16.7	16 ± 2	63 ± 9
P7		17.9	16.1	16.2	17.3	17 ± 2	68 ± 7
S5		16.7	15.1	14.0	17.8	16 ± 3	64 ± 13
On-site average		**18.4**	**16.0**	**15.6**	**18.0**	**17 ± 3**	**68 ± 11**
Standard Deviation (2 σ)		**3.6**	**3.0**	**3.3**	**3.0**		
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.
NP = TLD not posted

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

TLD#	Location	1st Quarter	2nd Quarter	3rd Quarter	4th Quarter	Avg./Qtr. ± 2σ (95%)	Annual Dose ± 2σ (95%)
		(mrem)					
000-TLD4	Private property	15.7	13.7	13.5	15.6	15 ± 2	59 ± 9
000-TLD5	Longwood Estate	17.2	15.9	L	16.2	16 +/- 1	66 ± 5
000-TLD7	Mid-Island Game Farm	17.2	15.1	15.6	16.4	16 ± 2	64 ± 7
300-TLD3	Private property	17.2	NP	14.8	14.8	16 ± 3	62 ± 11
400-TLD1	Calverton Nat. Cemetary	19.1	17.8	19.2	19.7	19 ± 2	76 ± 6
500-TLD2	Private property	16.7	13.7	12.7	15.4	15 ± 3	59 ± 14
500-TLD4	Private property	17.2	14.5	14.5	17.2	16 ± 3	63 ± 12
600-TLD3	Sportsmen's Club	16.1	14.9	15.2	16.2	16 ± 1	62 ± 5
700-TLD2	Private property	15.7	13.0	12.7	16.2	14 ± 0	58 ± 0
700-TLD3	Private property	19.2	15.6	13.1	15.4	16 ± 5	63 ± 20
700-TLD4	Private property	17.2	14.8	14.1	16.8	16 ± 3	63 ± 12
800-TLD1	Private property	18.8	14.4	15.3	15.6	16 ± 4	64 ± 15
800-TLD3	Suffolk County CD	17.4	16.2	16.3	17.5	17 ± 1	67 ± 5
900-TLD2	Private property	NP	NP	NP	14.8	15 ± 0	59 ± 0
999-TLD1	Private property	15.2	14.0	13.0	15.2	14 ± 2	57 ± 8
Off-site average		**17.1**	**14.9**	**14.6**	**16.2**	**16 ± 2**	**63 ± 9**
Standard Deviation (2 σ)		**2.4**	**2.5**	**3.6**	**2.5**		
075-TLD4	**Control TLD average**	**10.1**	**9.2**	**9.3**	**9.1**	**9.4 ± 1**	**38 ± 4**

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

ternal dose measured at the former HWMF can be attributed to the presence of small amounts of soil contamination. However, a comparison of the 2006 dose rates to doses from previous years show that the dose rates have declined significantly since the removal of most of the radioactive soil. As Table 8-3 shows, the dose is currently just slightly above natural background levels. The former HWMF is fenced, access is controlled, and only qualified staff members are allowed inside the facility.

Two TLDs (075-TLD3 and 075-TLD5) near Building 356 showed higher than normal quarterly averages: 22 ± 4 mrem (220 ± 40 µSv) and 25 ± 4 mrem (250 ± 40 µSv), respectively. The yearly doses were measured at 89 ± 14 mrem (890 ± 140 µSv) for 075-TLD3, and 101 ± 16 mrem (1010 ± 160 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.

In previous years, two FAM-TLDs placed on the fence northeast and northwest of Building 913-B (the Alternating Gradient Synchrotron tunnel access) showed higher than normal ambient external dose. In 2006, the dose was just barely above normal background radiation.

8.2 DOSE MODELING

EPA regulates radiological emissions from

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	N/E of Bldg. 913-B	19.7	17.5	15.6	17.9	18 ± 3	71 ± 13
054-TLD3	N/W of Bldg. 913-B	21.4	18.0	13.7	16.4	17 ± 6	70 ± 25
S6		20.9	17.6	17.6	18.8	19 ± 3	75 ± 12
088-TLD1	FWMF-50' East of S-6	19.9	16.6	17.3	18.9	18 ± 3	73 ± 12
088-TLD2	FWMF-50' West of S-6	21.8	19.2	19.6	21.5	21 ± 3	82 ± 10
088-TLD3	FWMF-100' West of S-6	20.8	18.1	18.0	20.3	19 ± 3	77 ± 11
088-TLD4	FWMF-150' West of S-6	19.8	17.8	18.5	19.4	19 ± 2	76 ± 7
075-TLD3	Bldg. 356	21.0	20.3	24.2	23.2	22 ± 4	89 ± 14
075-TLD5	North Corner of Bldg. 356	25.0	22.5	25.8	27.5	25 ± 4	101 ± 16

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

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 the 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 emissions 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 under the Environmental Restoration (ER) Program are exempt under the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA), these activities are monitored and assessed for any potential to release radioactive materials, and to determine their dose contribution, if any, to the environment. In 2006, any new processes or activities were 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 all 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, the Clean Air Act Assessment Package-1988 (CAP88-PC), Versions 2.1 and 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 path-

Table 8-4. MEI 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	1.59E-11	(b)
490	Medical Research	BNL-489-01	8.46E-9	(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	5.57E-10	(b)
750	High Flux Beam Reactor	None	2.61E-5	(c)
801	Target Processing Lab	None	3.47E-5	(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	8.13E-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			**8.14E-2**	
EPA Limit			**10.0 mrem**	

Notes:
Diffuse, Fugitive, and Other sources are not included in this table since they are short-term emissions.
MEI = Maximally Exposed Individual
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 2006.
(e) NO = Not operational in 2006.
(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.

way (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 BNL site. The dose calculations are based on very low concentrations of the 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, which include the 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 also 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. 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.

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, Versions 2.1 and 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, Subpart H, 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 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). 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 2006 for potential contribution to the overall site dose.

8.3.1 Brookhaven Graphite Research Reactor

The decontamination activities for removal of the Brookhaven Graphite Research Reactor (BGRR) belowground duct (BGD) liner and graphite pile were continued in 2006. The BGRR facility was shut down in 1969 and all fuel was removed from the site by June of 1972. As a result of previous operations at the BGRR, the BGD liner and graphite pile were both activated and contaminated. The following radionuclides were identified as potential contaminants: Am-241, C-14, Co-60, Cs-137, Eu-152, Eu-154, H-3, I-129, Ni-63, Pu-238, Pu-239, Pu-240, Sr-90, and Th-232.

Two remote manipulators were used for the liner removal work. One manipulator was fitted with standard demolition tools, while the other manipulator had a clamshell bucket for loading the liner waste into a transport cart. When the transport cart was full, it was moved to the filter access opening and the liner waste was removed with a gantry crane, for placement into sealant-type waste transport containers. Once the primary liner was removed, the secondary liner was exposed; this was left in place until final disposition of the BGRR is determined. Debris and loose surface contamination were removed via vacuuming or other physical or mechanical means. After loose surface contamination was removed, a light-colored industrial coating of paint was applied to affix any remaining contamination. The newly painted surface also is more visible during inspections. The primary liner radionuclides concentration was used for development of the source term were based on BGRR-SE-04-03 document During the primary liner removal operation, the BGD was connected with Building 708-T, the Duct Service Building (DSB), to minimize the potential for any airborne contamination. Both buildings were maintained at a slightly negative pressure with respect to the outside atmosphere. Two self-contained, skid-mounted 6,000-cfm HEPA-filtered ventilation units were tested and installed in the DSB. They exhausted to the outside via a single, 26-inch diameter duct.

A NESHAPs evaluation showed that the total dose to the MEI resulting from the BGRR BGD primary liner removal operation was estimated to be 1.5E-05 mrem/yr. The potential dose was below the 10 mrem/yr annual limit as specified in 40 CFR 61, subpart H, and below the 0.1mrem/yr limit that triggers the NESHAPs continuous monitoring requirements. Although continuous monitoring was not required, a sampling probe was installed in the HEPA-filtered ventilation system of the DSB to ensure that the nearby environment was not exposed to levels of radioactive materials exceeding the established regulatory limits, and also to verify that the engineering controls were effective. In addition, emissions monitoring was implemented to assess non-routine incident consequences, and specify appropriate corrective action that might be needed if such an event were to happen. The monitoring was performed in accordance with ANSI/HPS N13.1-1999 standards. The samples collected from the ducts were routinely analyzed for gross alpha/beta, gamma, and other radiological parameters, when deemed necessary. The results showed that there was no radioactivity released above the detection limit.

8.3.2 Former Hazardous Waste Management Facility

The objective of the dose assessment was to evaluate the potential dose impact to the MEI (in this case, a firefighter) in the event of an accidental fire at the former HWMF (Area of Concern I). The former HWMF covers about 12 acres; two acres are radiologically controlled and will be used to support planned Waste Loading Area operations for the BGRR and HFBR remediation projects. The main portion of the former HWMF was cleaned up under the Operable Unit I technical specifications and applicable design criteria for soil removal and remediation. The remedial cleanup goal was based on 15 mrem/yr dose above natural background after 50 years of institutional control of the site. However, if there were a fire in the controlled area, firefighters and other personnel could receive radiation dose from residual radionuclide contamination in the soils and via airborne particulates. There is no dose modeling program specifically for an accidental fire incident; the RESRAD dose modeling program

(Version 6.3) was deemed more appropriate for the scenario being evaluated than CAP88-PC.

For the dose assessment, it was assumed that firefighting equipment, water trucks, fire retardants, and shovels were used to control and mitigate the accidental fire. This assessment did not evaluate access to certain contaminated areas, the availability of fire hydrants, the use of firebreaks to control the fire, and the potential for fire to spread to other vulnerable buildings. Also, structural hazard factors, slope hazard, and fuel type and loading were not assigned values. The radiological contamination beneath paved roads/surfaces was not considered in the dose assessment, because fixed contamination underneath the asphalt has a low probability of becoming airborne. Additionally, engineering controls such as containment structures and HEPA filters were not used as mitigating measures in the dose assessment.

The highest residual contamination present in the hotspot areas was assumed to be the concentrations of radionuclides distributed evenly throughout the former HWMF. The concentrations were taken from Appendix A of the closeout report prepared by Envirocon, Inc., dated September 29, 2005. The Multi Agency Radiation Survey and Site Investigation Manual (MARSSIM) suggests using the Derived Concentration Guideline Level (DCGL) as the investigation level. However, if the residual activity appears as small areas of elevated activity within a larger area, MARSSIMS considers the results of individual measurements. In a worst-case scenario, the highest likely concentrations of the radionuclides in unit K-4 for Cs-137 (96 pCi/g), unit D-4 for Sr-90 (81.10 pCi/g), and unit A for Ra-226 (1.27 pCi/g) were taken as the source terms. The concentration of the radionuclides present in the vegetation, plants, and grass was assumed to be in equilibrium with the remediation radioactivity present in the soil. In the model, air pollutant emissions are directly related to the intensity and direction (relative to wind) of the accidental fire. An assumption for this study was that fire personnel and equipment would be upwind of the fire scene. The dose evaluation did not consider factors that affect the spread of fire such as weather conditions, fuel type, fuel array, and topography. The particle size was also not taken into consideration in the dose assessment. The fugitive dust source was assumed to be controlled by watering the contaminated area. Also, the quantities of natural primordial radionuclides present in the air and soil from nuclear tests fallout were not taken into consideration, because the quantities were treated as natural background radiation. Another assumption was that the accidental fire was a surface fire, which favors the grassy "available fuel" (i.e., loose, combustible material), rather than a crown fire, which causes sufficient heat to burn the deep soil. Therefore, the modeling factor for the intensity of fires greater than 400 degrees Celsius, which could affect the volatility of cesium-137, was not included in the dose assessment.

The radiological dose and risk assessment to the MEI (firefighter) was estimated using RESRAD, Version 6.3. The pathways analyzed for dose assessment were the external gamma dose, inhalation along with radon, and soil particles ingested during the exposure period. The maximum dose was calculated to be 16.63 mrem for a year if the individual had resided in the former HWMF. However, because a firefighter would likely only be in the area for a number of hours, the "total equivalent dose estimate" (TEDE) was corrected using an occupancy correction factor. Taking that into account, the TEDE to the firefighter was calculated to be 1.90E-03 mrem/hr, and the dose for two hours of work would be 3.80E-3 mrem.

In summary, the TEDE from the accidental wildfire scenario to a firefighter MEI was estimated to be 1.90E-03 mrem/hr under the worst-case scenario using the highest radionuclide concentration of the hot spots in the former HWMF area.

8.3.3 High Flux Beam Reactor

Since the permanent shutdown in November 1999 of the HFBR, it has been stabilized and maintained under a surveillance and maintenance program. When the reactor operated, it used heavy water (D_2O) as a neutron moderator and fuel coolant. When D_2O was exposed to the neutron fields generated inside the reactor ves-

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	0.08 mrem (0.81 μSv)	<1%	0.30 person-rem
Ingestion			
Drinking water	None	None	None
Fish	0.07 mrem (0.7 μSv)	<1%	Not tracked
Deer Meat	2.96 mrem (30 μSv)	<3%	Not tracked
All Pathways	3.11 mrem (31 μSv)	<4%	0.30 person-rem

sel, the deuterium became activated, producing radioactive tritium (half-life: 12.3 years). While most of the liquid sources of tritium have been removed, residual tritium is present in the confinement atmosphere and in the structures and equipment; this allows the potential for a small source of tritium emissions. After 2000, a number of actions were taken to remove contaminated structures, systems, and components from the HFBR complex. Most of the reactor systems have been put into a lay-up condition; the building's heating, ventilation, and cooling (HVAC) system is one of the few that remain in service.

Planned activities include demolition of numerous HFBR ancillary structures, including demolition of the 100-meter exhaust stack used for ventilation. Due to the potential release of minor amounts of tritium from the concrete and other systems into the atmosphere within the HFBR, a best management practice was established to provide ventilation prior to routine inspection of the facility. The proposed ventilation system will consist of a 4,000-cfm centrifugal exhaust fan with inline roughing and HEPA filters. The exhaust system will be operated for up to 5 days in a calendar quarter, just prior to and during the building surveillance inspections. The ventilation will also be operated during any necessary maintenance of the building. A technically acceptable and cost-effective option for the reactor is to leave the facility in a safe storage condition. This condition has the potential to generate fugitive emissions from the presence of residual tritium and low-level contamination on structures, systems, and the floor. Comprehensive sampling and analysis and multiple surveys were performed to characterize the HFBR complex. The nature and extent of radiological contamination and residual inventory were described in a series of characterization studies performed at the reactor. Most radioactivity was determined to be within the activated structures and components, which consists of the control-rod blades, reactor internals, reactor vessel, thermal shield, and biological shield. These activated materials are not dispersible radioactive materials, under normal conditions.

The source term is defined as the amount of radioactive material in grams or curies that can be released to the environment. For the NESHAPs assessment, the source term was based on the Assessment of HFBR Airborne Tritium Test Results, which gives the residual contamination within the confinement of the building. The potential source term was based on the material-at-risk (MAR) that can become airborne due to an exchange of tritium with water vapor in the confinement. MAR is defined as the maximum amount of radionuclides available to be acted upon by a given physical stress (maintenance activities, ventilation, etc.) or any other means (exchange) with certain probability for the radioactive materials to be released to the environment. The MAR values used in the calculations represent the maximum quantity of dispersible radionuclides present in the structures, components, and systems of the HFBR that were identified as activated or contaminated during the characterization activities. For the purpose of this assessment, the source term was assumed to be 5.3E-08 Ci of Cs-137, 8.3E-10 Ci of Co-60, and 1,000 Ci of tritium.

The effective dose equivalent to the MEI as a result of safe storage condition of the HFBR was estimated to be 6.13E-05 mrem/yr at the southeast location. The potential dose was well below the 10 mrem/yr annual limit as specified in 40 CFR 61, subpart H, and was below the 0.1 mrem/yr limit that triggers the requirement for a NESHAPs permit.

Although, the dose estimates are well below the NESHAPs regulatory requirements, periodic stack emissions monitoring was recommended to record any airborne particulate activity that may get released during the inspection/maintenance periods or during an unplanned release scenario. Periodic sampling frequency will include the annual collection of a representative sample of the aerosol particulates and tritium during any one of the quarterly inspection periods.

8.3.4 National Synchrotron Light Source II

The National Synchrotron Light Source II (NSLS-II) is a newly proposed facility at BNL. A pre-NESHAPs evaluation was completed for NEPA compliance and documentation in 2006. During normal accelerator operations at the NSLS-II, it is possible to generate short-lived activation products such as C-11 (half-life: 20 minutes), N-13 (half-life: 10 minutes), and O-15 (half-life: 2.1 minutes). Theses radioactive gases would be produced within the accelerator enclosure and decay quickly, due to their short half-lives. A preliminary calculation showed that the dose impact to workers and members of the public would be less than one-tenth of the NESHAPs permit requirements (40 CFR 61.93 [b] 4[i]). A NESHAPs evaluation will be conducted prior to startup of NSLS-II operations.

8.4 Dose from Point Sources

8.4.1 Brookhaven Linac Isotope Producer

Source term descriptions for the 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 water recirculating in a 16-inch-diameter shaft. The principal gaseous radionuclides produced as a result of activation of the cooling water are O-15 and C-11. Because the BLIP facility has the potential to exceed 1 percent of the EPA emission limit (0.1 mrem/yr), 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 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 weekly sample collection and analyses.

In 2006, the BLIP facility operated over a period of 22 weeks. During the year, 1,284 Ci of C-11 and 3,122 Ci of O-15 were released from the BLIP facility. Tritiated water vapor (6.78E-02 Ci) was also released, due to activation of the targets' cooling water. The annual EDE to the MEI from BLIP operations was calculated to be 8.13E-02 mrem (0.81 µSv).

An analysis of BLIP operating data for the past four years and the real-time emissions data collected to date show that BLIP emissions have been effectively reduced by approximately 30 percent since the installation of a sealed Lucite cover to enclose the cooling water surface, which was the source of most BLIP emissions.

8.4.2 High Flux Beam Reactor

In 2006, the HFBR facility was in a cold shutdown mode and was downgraded from a nuclear facility to a radiological facility. Tritium samples were taken on a monthly frequency and the dose contribution was determined to be 2.61E-5 mrem (26 nSv) in a year.

8.4.3 Brookhaven Medical Research Reactor

In 2006, the Brookhaven Medical Research Reactor (BMRR) facility was in a cold shutdown mode. During the year, all the primary coolant was drained and the reactor internals were removed. There was no dose contribution from the BMRR.

8.4.4 Unplanned Releases

There were no unplanned releases in 2006.

8.5 DOSE FROM INGESTION

Because deer and fish bioaccumulate radionuclides in their tissues and organs, tissue samples 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. Nine samples of deer meat (flesh) were used to calculate the "off site and less than 1 mile" average for the purpose of dose calculations. Potassium-K (K-40) and Cs-137 were the two radionuclides detected in the tissue samples. K-40 is a naturally occurring radionuclide and is not related to BNL operations. The average K-40 concentrations in tissue samples were 3.7 ±1.3 pCi/g (wet weight) in the flesh and 2.6 ± 1.6 pCi/g (wet weight) in the liver. The average Cs-137 concentrations were 2.0 ± 0.3 pCi/g (wet weight) in the flesh and 0.4 ± 0.1 pCi/g (wet weight) in the liver (see Table 6-2). The potential dose from consuming deer meat with the average Cs-137 concentration was estimated as 2.96 mrem (30 µSv) in a year. This is less than 30 percent of 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 2006, brown bullhead samples collected in the Peconic River at the Manorville Road site had the highest concentration of Cs-137, at 0.21 ± 0.1 pCi/g; this was used to estimate the EDE to the MEI. The potential dose from consuming 15 pounds of these brown bullhead annually was calculated to be 0.07 mrem (0.7 µSv)—far 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 environmental surveillance data. The RESRAD-BIOTA 1.0 biota dose screening 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 proposed Rule 10 CFR 834, Subpart F (66 FR 25380). The terrestrial animal and plant doses were evaluated based on 0.25 pCi/L of strontium-90 (Sr-90) in surface waters at the Donahue Pond sampling location on the Peconic River (see Figure 5-8 for sampling stations). Soil samples were not collected this year due to a graded approach used for soil sampling (see Chapter 6 for more information). The dose was based on the surface water concentrations, and calculated to be 5.00E-09 Gy/day to terrestrial animals and 1.22E-10 Gy/day to terrestrial plants. The doses to terrestrial animals and plants were well below the biota dose limit of 1 mGy/day.

For calculating dose to aquatic animals, radionuclide concentration values from Donahue's Pond were used for both the surface water and sediment samples from the same location. The Cs-137 sediment concentration was 0.31 pCi/g, and the Sr-90 concentration in surface water was 0.25 pCi/L. The aquatic animal dose was estimated to be 2.39E-06 Gy/day and the estimated dose to riparian animals was 5.05E-06 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. The total dose to the MEI from air and ingestion pathways was estimated to be 3.11 mrem (31 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 0.30 person-rem (3 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 5 to 20 mrem (50–200 µSv) per exposure. Using natural gas in homes yields approximately 9 mrem (90 µSv) 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 well below the dose that could be received from a single chest x-ray.

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