



Radiological Dose Assessment

BNL's annual radiological dose assessment assures stakeholders that on-site facilities and BNL operations are in compliance with federal, state, and local regulations, and that the public is protected. The potential radiological dose to members of the public is calculated at an off-site location (residence, school, or an office) closest to an emission source as the maximum dose that could be received by an off-site individual, defined as the "maximally exposed off-site individual" (MEOSI). Based on MEOSI dose calculation criteria, members of the public will receive a dose less than the MEOSI under all circumstances. The dose to the MEOSI is the sum total from direct and indirect dose pathways via air immersion, inhalation of particulates and gases, and ingestion of local fish and deer meat. In 2014, the total effective dose (TED) of 3.15 mrem (32 μ Sv) from Laboratory operations was well below the EPA and DOE regulatory dose limits for the public, workers, and the environment.

The effective dose equivalent (EDE) from air emissions in 2014 was estimated at 2.85E-01 mrem (2.9 μ Sv) to the MEOSI. The BNL dose from the inhalation pathway was less than three percent of the EPA's annual regulatory dose limit of 10 mrem (100 μ Sv). In addition, the dose from the ingestion pathway was estimated as 2.80 mrem (28 μ Sv) from the consumption of deer meat and 6.3E-2 mrem (0.63 μ Sv) from the consumption of fish caught in the vicinity of the Laboratory. In summary, the total annual dose to the MEOSI from all pathways was estimated at 3.15 mrem (32 μ Sv), which is less than 4 percent of DOE's 100-mrem limit. The aggregate population dose was 0.563 person-rem among approximately 6 million persons residing within a 50-mile radius of the Laboratory. On average, this is equivalent to a fraction of an airport whole body scan.

Dose to the maximally exposed individual (MEI) on-site and outside of controlled areas, calculated from TLD thermoluminescent dosimeter (TLD) monitoring records, was 8 mrem above natural background radiation levels in 2014. The average annual external dose from ambient sources on-site was 69 ± 9 mrem (690 ± 90 μ Sv) and 69 ± 8 mrem (690 ± 80 μ Sv) from off-site ambient sources. Both on- and off-site external dose measurements include the contribution from natural terrestrial and cosmic background radiation. A statistical comparison of the average doses measured using 58 on-site TLDs and 15 off-site TLDs showed that there was no external dose contribution from BNL operations distinguishable from the natural background radiation level.

Doses to aquatic and terrestrial biota were also evaluated and found to be well below DOE regulatory limits. Other short-term projects, such as remediation work and waste management disposal activities, were assessed for radiological emissions; the potential dose from each of these activities was below regulatory limits and there was minimal radiological risk to the public, workers, or the environment. In summary, the overall dose impact from all Laboratory activities in 2014 was comparable to natural background radiation levels.

8.0 INTRODUCTION

Chapter 8 discusses the dose risk consequences from research activities, radiation generating devices, facilities, and minor bench-top radiation sources at BNL. It is important to understand the health impacts of radiation to the public and workers, as well as radiation effects to the environment, fauna, and flora. The Laboratory's routine operations, scientific experiments, and new research projects are evaluated for their radiological dose risk. The dose risks from decommissioned facilities and decontamination work are also evaluated for dose impact. All environmental pathway scenarios that can cause a dose to humans, aquatic life, plants, and animals are evaluated to calculate the dose risks on site. Because all research reactors at BNL have been shut down, defueled, and partly or fully decommissioned, there was no dose risk from these facilities in 2014. The Laboratory's current radiological risks are from very small quantities of radionuclides used in the small sciences, radiopharmaceuticals produced at the Brookhaven Linac Isotope Producer (BLIP), and small amounts of air activation at the BNL accelerators: Alternating Gradient Synchrotron (AGS), Relativistic Heavy Ion Collider (RHIC), National Synchrotron Light Source (NSLS), and the future National Synchrotron Light Source II (NSLS-II), which began low-power testing in 2014. The radiological dose assessments are performed to ensure that dose risks from all Laboratory operations meet regulatory requirements and remain "As Low As Reasonably Achievable" (ALARA) to members of the public, workers, and the environment.

8.1 DIRECT RADIATION MONITORING

A direct radiation-monitoring program is used to measure the external dose contribution to the public and workers from radiation sources at BNL. This is achieved by measuring direct penetrating radiation exposures at both on- and off-site locations. The direct measurements taken at the off-site locations are with the premise that off-site exposures represent true natural background radiation (with contribution from both cosmic and terrestrial sources) and represent no contribution from Laboratory operations.

On- and off-site external dose measurements are averaged and then compared using the statistical t-test to assess 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 a unique identification code based on the grids.

In 2014, a total of 58 environmental TLDs were deployed on site, of which 9 were placed in known radiation areas and 15 were deployed at off-site locations (see Figures 8-1 and 8-2). Fourteen off-site TLDs are listed, but three were retired during the first quarter. Six off-site TLDs were added in the last quarter, of which four reported dose. An additional 30 TLDs were stored in a lead-shielded container for use as reference and control TLDs for comparison purposes. The average of the control TLD values, reported as "075-TLD4" in Tables 8-1 and 8-2, was 30 ± 3 mrem. This dose accounts for any small "residual" dose not removed during the annealing process and the natural background and cosmic radiation sources that are not completely shielded. 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 2014. The on-site average external doses for the first through fourth quarters were 17.1 ± 3.4 , 17.7 ± 3.8 , 16 ± 3.4 , and 18 ± 2.6 mrem, respectively. The on-site average annual external dose from all potential environmental sources, including cosmic and terrestrial radiation sources, was 69 ± 9 mrem (690 ± 90 μ Sv).

Table 8-2 shows the quarterly and yearly off-site radiation dose measurements for 2014. The off-site average external doses for the first

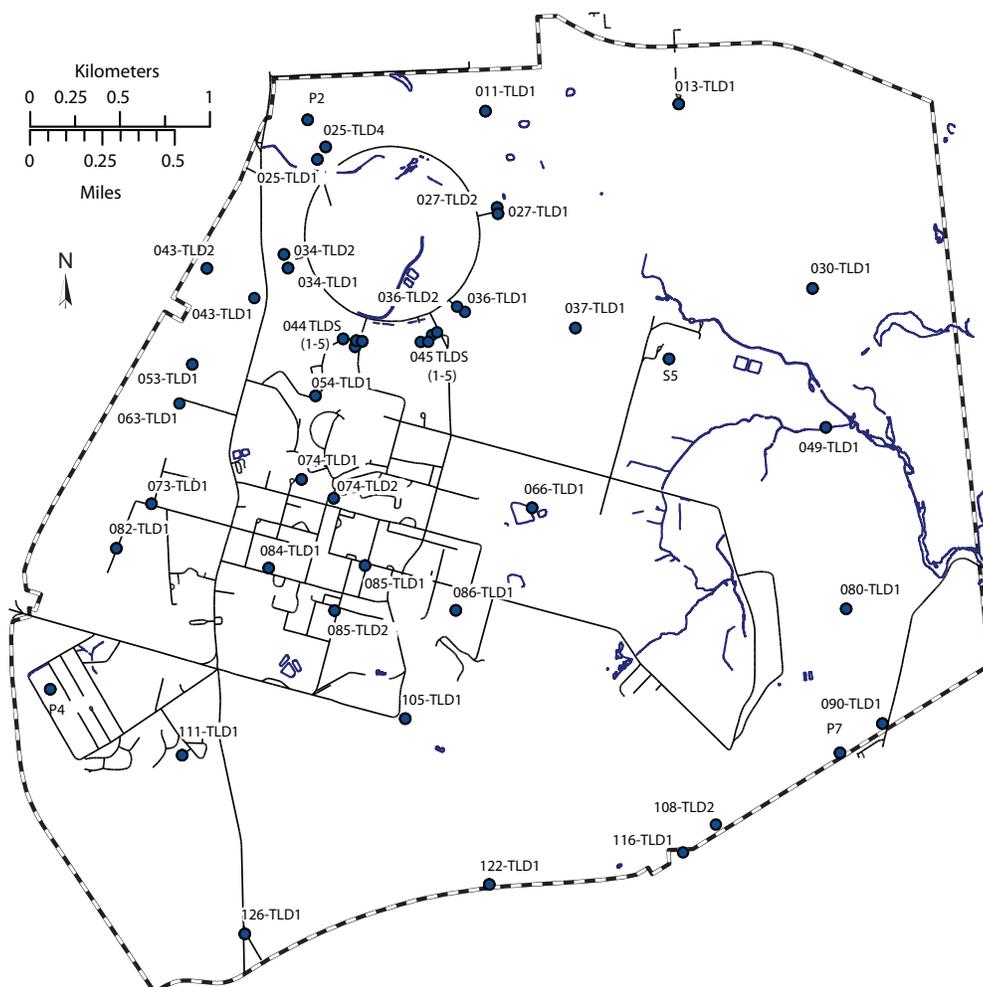


Figure 8-1. On-Site TLD Locations.

through fourth quarters were 16.6 ± 3.3 , 15.5 ± 11 , 15.1 ± 2.8 , and 16.6 ± 1.8 mrem, respectively. The off-site average annual ambient dose from all potential environmental sources, including cosmic and terrestrial radiation sources, was 69 ± 8 mrem ($690 \pm 80 \mu\text{Sv}$). Based upon a reevaluation of the TLD program, six new TLD locations were added, and three existing TLD locations were removed during the last quarter of 2014. The changes were made to cover all wind sector areas on the grid map for dose calculations.

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 (69 ± 9 mrem) and on-site dose (69 ± 8 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 2014. The dose to the maximally exposed individual (MEI) on site and outside of controlled areas (in the vicinity of Building 356) was measured at 0 mrem (first quarter), 4 mrem (second quarter), 1 mrem (third quarter), and 3 mrem (fourth quarter) for 2014. The total dose to the on-site MEI was 8

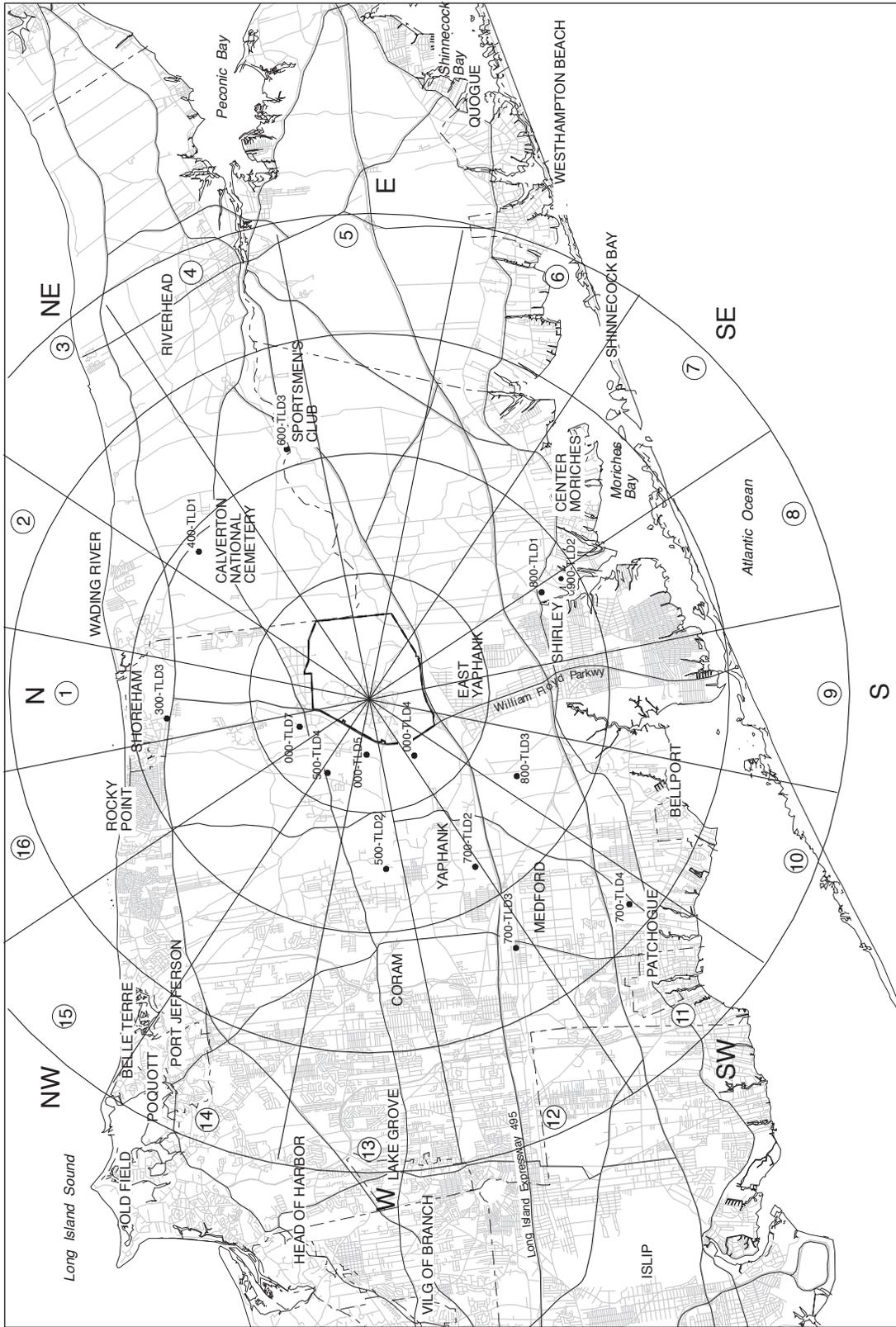


Figure 8-2. Off-Site TLD Locations.

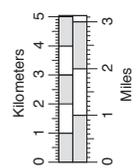


Table 8-1. On-Site Direct Ambient Radiation Measurements for 2014.

TLD#	Location	1st Quarter	2nd Quarter	3rd Quarter	4th Quarter	Avg./Qtr. $\pm 2\sigma$ (95%)	Annual Dose $\pm 2\sigma$ (95%)
		(mrem)					
011-TLD1	North Firebreak	14.0	14.2	12.6	17.8	15 \pm 4	58 \pm 15
013-TLD1	North Firebreak	16.7	16.732	15.8	16.5	16 \pm 1	66 \pm 3
025-TLD1	Bldg. 1010, Beam Stop 1	16.9	16.0	14.3	17.1	16 \pm 2	64 \pm 9
025-TLD4	Bldg. 1010, Beam Stop 4	14.7	16.7	15.6	16.9	16 \pm 2	64 \pm 7
027-TLD1	Bldg. 1002A South	14.1	15.5	13.4	15.3	15 \pm 2	58 \pm 7
027-TLD2	Bldg. 1002D East	15.5	15.7	12.7	17.7	15 \pm 4	62 \pm 14
030-TLD1	Northeast Firebreak	16.0	16.6	16.2	17.9	17 \pm 2	67 \pm 6
034-TLD1	Bldg. 1008, Collimator 2	16.7	17.6	15.3	17.2	17 \pm 2	67 \pm 7
034-TLD2	Bldg. 1008, Collimator 4	17.2	18.9	15.8	17.4	17 \pm 2	69 \pm 9
036-TLD1	Bldg. 1004B, East	15.2	16.1	13.5	15.6	15 \pm 2	60 \pm 8
036-TLD2	Bldg. 1004, East	19.8	23.7	15.3	18.7	19 \pm 6	77 \pm 24
037-TLD1	S-13	15.2	16.4	17.6	18.0	17 \pm 2	67 \pm 9
043-TLD1	North Access Road	21.4	18.2	16.9	20.0	19 \pm 3	77 \pm 14
043-TLD2	North of Meteorology Tower	17.0	18.1	17.5	17.4	18 \pm 1	70 \pm 3
044-TLD1	Bldg. 1006	17.4	17.7	14.9	17.2	17 \pm 2	67 \pm 9
044-TLD2	South of Bldg. 1000E	16.9	18.6	16.1	19.0	18 \pm 2	71 \pm 9
044-TLD3	South of Bldg. 1000P	15.6	16.5	14.3	15.9	16 \pm 2	62 \pm 6
044-TLD4	Northeast of Bldg. 1000P	17.6	18.1	16.4	18.0	18 \pm 1	70 \pm 5
044-TLD5	North of Bldg. 1000P	17.6	17.8	16.0	19.1	18 \pm 2	70 \pm 9
045-TLD1	Bldg. 1005S	15.7	15.4	14.6	18.2	16 \pm 3	64 \pm 11
045-TLD2	East of Bldg. 1005S	15.6	17.1	15.0	19.6	17 \pm 4	67 \pm 14
045-TLD3	Southeast of Bldg. 1005S	16.9	17.4	17.3	18.4	17 \pm 1	70 \pm 4
045-TLD4	Southwest of Bldg. 1005S	19.1	18.6	15.8	19.0	18 \pm 3	72 \pm 11
045-TLD5	West-Southwest of Bldg. 1005S	18.8	16.9	15.4	18.1	17 \pm 3	69 \pm 10
049-TLD1	East Firebreak	17.0	17.4	15.3	17.2	17 \pm 2	67 \pm 7
053-TLD1	West Firebreak	17.4	18.5	18.2	19.2	18 \pm 1	73 \pm 5
054-TLD1	Bldg. 914	21.9	21.8	15.8	18.1	19 \pm 5	78 \pm 21
063-TLD1	West Firebreak	19.3	19.2	18.5	19.4	19 \pm 1	76 \pm 3
066-TLD1	Waste Management Facility	15.3	14.7	14.0	17.3	15 \pm 2	61 \pm 10
073-TLD1	Meteorology Tower	17.5	17.8	16.7	18.6	18 \pm 1	71 \pm 5
074-TLD1	Bldg. 560	17.6	19.0	16.7	19.1	18 \pm 2	73 \pm 8
074-TLD2	Bldg. 907	19.1	16.5	16.1	17.2	17 \pm 2	69 \pm 9
080-TLD1	East Firebreak	18.5	19.9	17.2	20.5	19 \pm 3	76 \pm 11
082-TLD1	West Firebreak	20.2	18.8	19.8	20.1	20 \pm 1	79 \pm 4
084-TLD1	Tennis Courts	16.8	17.7	16.5	17.2	17 \pm 1	68 \pm 3
085-TLD1	TFCU	16.1	17.3	16.5	18.2	17 \pm 2	68 \pm 7
085-TLD2	Upton Gas Station	16.2	18.2	16.4	18.7	17 \pm 2	69 \pm 9
086-TLD1	Baseball Fields	17.6	18.3	18.2	16.8	18 \pm 1	71 \pm 5
090-TLD1	North St. Gate	16.2	16.2	15.3	18.7	17 \pm 3	66 \pm 10
105-TLD1	South Firebreak	16.5	18.3	17.1	18.9	18 \pm 2	71 \pm 8

(continued on next page)

Table 8-1. On-Site Direct Ambient Radiation Measurements for 2014 (concluded).

TLD#	Location	1st	2nd	3rd	4th	Avg./Qtr. ±2σ (95%)	Annual Dose ±2σ (95%)
		Quarter	Quarter	Quarter	Quarter		
108-TLD1	Water Tower	17.4	18.2	15.8	18.0	17±2	69±8
108-TLD2	Tritium Pole	19.2	24.2	19.7	21.4	21±4	84±16
111-TLD1	Trailer Park	18.2	18.7	18.5	18.3	18±0	74±1
122-TLD1	South Firebreak	15.7	17.3	18.7	18.6	18±2	70±10
126-TLD1	South Gate	18.1	18.7	18.8	20.0	19±1	76±5
P2		15.2	14.3	13.7	14.7	14±1	58±4
P4		16.2	18.8	15.8	16.1	17±2	67±10
P7		16.2	18.1	14.9	18.2	17±3	67±11
S5		16.0	16.1	14.0	17.8	16±3	64±11
On-site average		17.1	17.7	16.0	18.0	17±2	69±9
Std. Dev. (2s)		3.4	3.8	3.4	2.6		17 ± 3
075-TLD4: Control TLD Average		8.19	7.64	7.36	7.18	7.6±1	30±3

Notes :

See Figure 8-1 for TLD locations.

TLD = thermoluminescent dosimeter

mrem, which is less than the dose received from three round-trip flights from Los Angeles, California to New York, New York.

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. Environmental TLDs 088-TLD1 through 088-TLD4 are posted at the S-6 block-house location on the fence of the Former Hazardous Waste Management Facility (FHWMF). The TLDs measured external doses that were slightly elevated compared to the normal natural background radiation doses measured from other areas on site. This can be attributed to the presence of small amounts of contamination in soil. All TLD readings in this area were within 4 percent, except for 088-TLD1, which was approximately 14 percent higher, most likely due to Phase III soil remediation activities. However, a comparison of the current ambient dose rates to doses from previous years shows that the dose rates have significantly declined since the removal of contaminated soil within the FHWMF. The

FHWMF is fenced, access to it is controlled, and only trained radiological employees are allowed access to this area.

Two TLDs (075-TLD3 and 075-TLD5) near Building 356 showed slightly higher quarterly averages of 21.75 ± 2 mrem (218 ± 20 μSv) and 21 ± 7 mrem (210 ± 70 μSv), respectively, which are just above the normal ambient background radiation. The yearly doses were measured at 87 ± 8 mrem (870 ± 80 μSv) for 075-TLD3 and 84 ± 18 mrem (840 ± 180 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 slightly elevated dose from Building 356 on 075-TLD3 is attributed to the “sky-shine” phenomenon. This building also contains several Californium -252 (Cf-252) neutron sources in a cask near the corner of the building where 075-TLD5 is located. Although it is conceivable that individuals who use the parking lot adjacent to Building 356 could receive a dose from these sources, the dose would be small due to the low occupancy factor.

Two FAM-TLDs placed on fence sections

Table 8-2. Off-Site Direct Radiation Measurements for 2014.

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	14.0	22.5	14.2	16.0	17±7	67±28
000-TLD5	Longwood Estate	14.0	17.0	14.3	17.8	16±3	63±13
000-TLD7	Mid-Island Game Farm	16.8	15.4	16.0	16.5	16±1	65±5
000-TLD8	Private property	NP	NP	NP	NP	0±0	0±0
000-TLD9	Private property	NP	NP	NP	28.7	29±0	115±0
004-TLD1	Private property	NP	NP	NP	17.5	18±0	70±0
300-TLD3	Private property	NP	NP	NP	NP	0±0	0±0
400-TLD1	Calverton National Cemetery	18.4	21.2	18.4	18.2	19±2	76±10
500-TLD2	Private property	NP	0.0	NP	NP	0±0	0±0
500-TLD4	Private property	NP	NP	16.2	18.6	17±2	70±9
600-TLD3	Sportsmen's Club	17.2	16.5	15.9	16.1	16±1	66±4
700-TLD2	Private property	NP	NP	NP	NP	0±0	0±0
700-TLD3	Private property	16.0	14.4	13.6	15.2	15±2	59±7
700-TLD4	Private property	19.3	15.4	16.4	17.1	17±3	68±11
800-TLD1	Private property	15.9	15.6	15.5	16.9	16±1	64±4
800-TLD3	Suffolk County CD	16.2	17.0	14.5	17.1	16±2	65±8
900-TLD2	Private property	18.2	15.0	13.7	15.5	16±3	62±13
900-TLD4	Private property	NP	NP	NP	14.8	15±0	59±0
900-TLD5	Private property	NP	NP	NP	NP	0±0	0±0
999-TLD1	Private property	NP	NP	NP	17.2	17±0	69±0
Off-site average		16.6	15.5	15.1	16.6	17±2	69±8
Std. Dev. (2σ)		3.3	11.0	2.8	1.8		
075-TLD4: Control TLD Average		8.2	7.6	7.4	7.2	7.6±1	30±3

Notes:
See Figure 8-2 for TLD locations.
CD = Correctional Department

NP = TLD not posted
TLD = thermoluminescent dosimeter

Table 8-3. Facility Area Monitoring, 2014.

TLD#	Location	1st Quarter	2nd Quarter	3rd Quarter	4th Quarter	Average ± 2σ (95%)	Annual Dose ± 2σ (95%)
		(mrem)					
054-TLD2	Northeast of Bldg. 913B	24.9	25.3	15.8	20.9	22±8	87±31
054-TLD3	Northwest of Bldg. 913B	19.6	20.2	15.3	17.0	18±4	72±16
S6	FHWMF	18.1	17.7	18.1	19.2	18±1	73±4
088-TLD1	FHWMF, 50' East of S6	20.0	21.4	21.9	21.1	21±1	84±6
088-TLD2	FHWMF, 50' West of S6	19.4	19.2	19.1	20.0	19±1	78±3
088-TLD3	FHWMF, 100' West of S6	19.4	21.0	19.5	21.4	20±2	81±7
088-TLD4	FHWMF, 150' West of S6	16.9	18.7	16.8	18.7	18±2	71±7
075-TLD3	Bldg, 356	20.3	22.1	21.4	23.2	22±2	87±8
075-TLD5	North Corner of Bldg. 356	19.0	18.8	22.8	23.7	21±4	84±18

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

TLD = thermoluminescent dosimeter

northeast and northwest of Building 913B (the AGS tunnel access) showed slightly elevated above-average ambient external dose. The first-quarter dose at these sites was measured at 24.9 mrem for 054-TLD2 and 19.6 mrem for 054-TLD3 (compared to the site-wide first-quarter dose of 17.1 ± 3.4 and off-site dose of 16.6 ± 3.3 mrem). The second-quarter dose at these sites was measured at 25.3 mrem for 054-TLD2 and 20.2 mrem for 054-TLD3 (compared to the site-wide second-quarter dose of 17.7 ± 3.8 mrem and off-site dose of 15.5 ± 11 mrem). During the third quarter, both TLDs showed dose comparable to natural background radiation. In the fourth quarter, the 054-TLD2 site showed elevated dose of 20.9 mrem, while the other was at or below background. While the slightly higher levels of the first and second quarters are expected because the operating period for the AGS is typically in the first half of the calendar year, these dose levels are comparable to recent

years overall.

The AGS accelerates protons to energies up to 30 GeV and heavy ions up to 15 GeV/amu. RHIC has two beams circulating in opposite directions and is capable of accepting either protons or heavy ions up to gold. At the RHIC, protons and heavy ions received from the AGS are further accelerated up to final energies of 250 GeV for protons and 100 GeV per nucleon for gold ions. Under these high-energy conditions, facilities such as AGS and RHIC have the potential to generate high-energy neutrons when the charged particles leave the confines of the accelerator and produce nuclear fragments along their path or when they collide with matter. A passive monitoring TLD provides dose information from the neutron interactions when placed at strategic locations. In 2014, 12 neutron-monitoring TLDs (Harshaw Badge 8814) were posted at these strategic locations to measure the dose contribution from the high-energy neutrons (see Figure

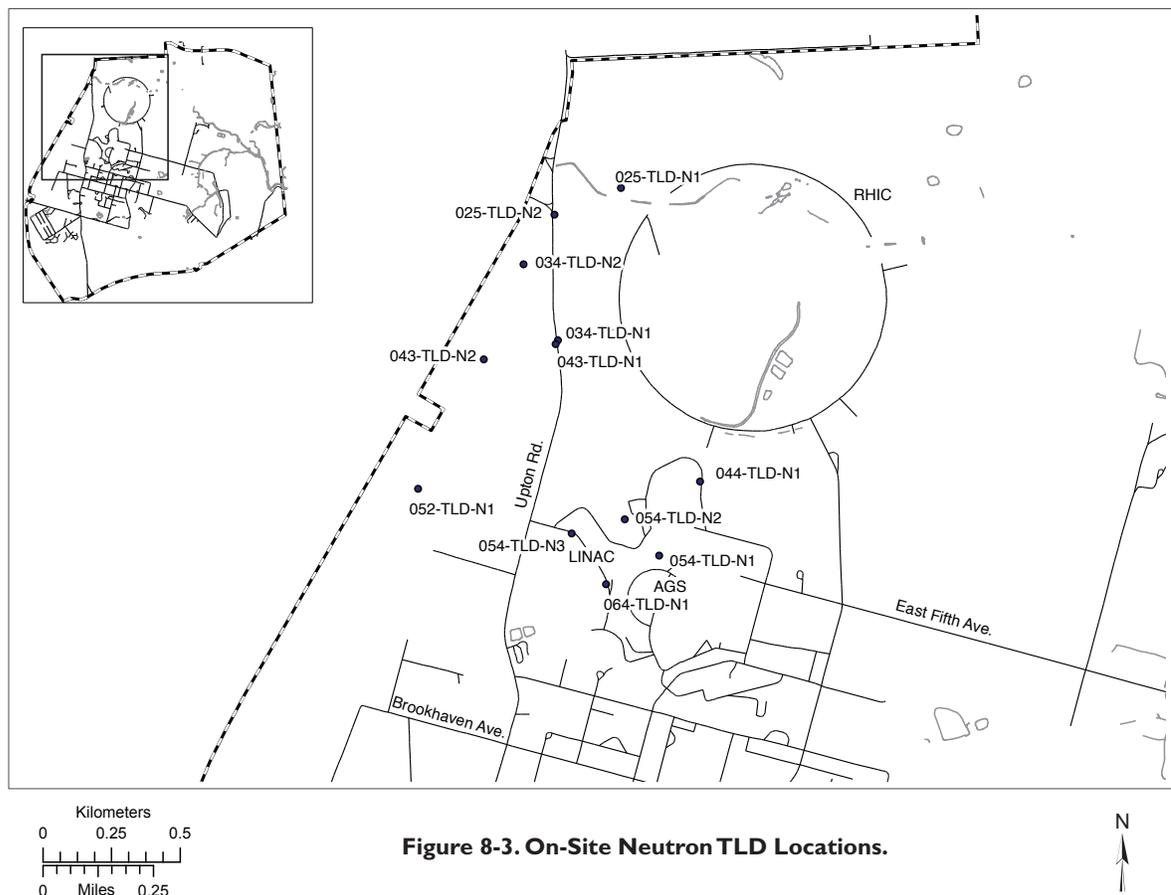


Figure 8-3. On-Site Neutron TLD Locations.

8-3 for locations). The technical criteria used for the placement of the neutron TLDs is based on design aspects such as the thickness of the berm shielding, location of soil activation areas, beam stop areas and beam collimators, and proximity to the site boundary. In the first quarter of 2014, passive monitors for neutron dose showed no dose. In the second quarter, neutron TLDs at 025-TLD-N2, 043-TLD-N2, and 054-TLD-N2 showed neutron doses of 1 mrem, 1 mrem, and 2 mrem, respectively. Finally, four neutron TLDs 025-TLD-N2, 042-TLD-N1, 043-TLD-N1, and 043-TLD-N2, all showed neutron doses of 1 mrem in the third quarter. No neutron dose was found on neutron TLDs in the fourth quarter. The RHIC/BLIP runs at slightly higher current and energy during the beginning of the third quarter for approximately one month, but is turned off for the remainder of the third quarter. In the fourth quarter, the RHIC/BLIP runs for a two-week period at the end of the calendar year. These low-level neutron doses indicate that engineering controls (i.e. berm shielding) in place at AGS and RHIC are effective.

8.2 DOSE MODELING

EPA regulates radiological emissions from DOE facilities under the requirements set forth in 40 CFR 61, Subpart H, entitled, “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 that is greater than 10 mrem (100 μ Sv) in a year from airborne emissions. 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 MEOSI. The dose estimates from various facilities are given in Table 8-4,

and the actual air emissions for 2014 are discussed in detail in Chapter 4.

As a part of the NESHAPs review process at BNL, any source that has the potential to emit radioactive materials is evaluated for regulatory compliance. Although the activities conducted by the Laboratory’s Environmental Restoration Programs 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. Currently, any new radiological processes or activities are also evaluated for compliance with NESHAPs regulations using EPA’s approved dose modeling software (see Section 8.2.1 for details). Because this model is 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, dose model 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). 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 MEOSI 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 MEOSI, all emission points are co-located at the BLIP Facility located in the developed portion of the 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

Table 8-4. Maximally Exposed Off-site Individual Effective Dose Equivalent From Facilities or Routine Processes, 2014.

Building No.	Facility or Process	Construction Permit No.	MEOSI Dose (mrem) (a)	Notes
197	Nonproliferation & Nuclear Safety	None	1.57E-12	(b)
197B	Nonproliferation & Nuclear Safety	None	2.65E-08	(b)
348	Instrumentation & Calibration	None	ND	(d)
463	Biology	None	1.03E-08	(b)
480	Condensed Matter Physics	None	ND	(d)
490	Radiation Therapy Facility	BNL-489-01	ND	(e)
490/490A	Medical Research	None	5.60E-06	(b)
491	Brookhaven Medical Research Reactor	None	ND	(e)
510	Calorimeter Enclosure	BNL-689-01	ND	(f)
510A	Physics	None	5.49E-14	(b)
535	Instrumentation	None	4.10E-14	(b)
555	Chemistry Facility	None	ND	(i), (k)
725	National Synchrotron Light Source	None	2.30E-08	(b)
734	Interdisciplinary Science Building	None	1.75E-16	(b)
750	High Flux Beam Reactor	None	6.73E-05	(c)
801	Target Processing lab	None	5.19E-04	(b), (c)
802B	Evaporator Facility	BNL-288-01	ND	(e)
815	Environmental Chemistry	None	2.64E-07	(b)
820	Accelerator Test Facility	BNL-589-01	ND	(d)
830	Environmental Science Department	None	ND	(d)
865	Waste Management Facility	None	ND	(j)
901	BioSciences Department	None	1.49E-08	(b)
902	Superconducting Magnet Division	None	1.41E-11	(b)
906	Medical-Chemistry	None	ND	(i)
911	Alternating Gradient Synchrotron	None	ND	(d)
925	Accelerator Department	None	ND	(i)
931	Brookhaven Linac Isotope Producer	BNL-2009-01	2.84E-01	(c)
938	REF/NBTF	BNL-789-01	ND	(f), (g)
942	Alternating Gradient Synchrotron Booster	BNL-188-01	ND	(h)
---	Relativistic Heavy Ion Collider	BNL-389-01	ND	(d)
Total Potential Dose from BNL Operations			2.85E-01	
EPA Limit (Air Emissions)			10	

Notes:
 MEOSI = Maximally Exposed Off-site Individual
 ND = No dose
 (a) "Dose" in this table means effective dose equivalent to MEOSI.
 (b) Dose is based on emissions calculated using 40CFR61, Appendix D methodology.
 (c) Emissions are periodically monitored at the facility.
 (d) No Dose from emissions source in 2014.
 (e) NO = Not Operational in 2014.

(f) This facility was decommissioned and has been a zero-emission facility.
 (g) This facility is no longer in use; it produces no radioactive emissions.
 (h) Booster ventilation system prevents air release through continuous air recirculation.
 (i) No radiological dispersible material inventory in 2014.
 (j) No detectable emissions from the Waste Management Facility in 2014.
 (k) Sealed sources were excluded from this inventory--no emission.

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 towers. These measurements include wind speed, direction, and frequency, as well as air temperature and precipitation amounts (see Chapter 1 for details). A population of 6 million (6,031,539) people, based on the Geographical Information System design population survey performed by Oak Ridge National Laboratory for BNL, was used in the model (ORNL 2012).

For the last several years, Version 3 of the dose modeling software CAP88-PC has been used to estimate dose due to the air immersion pathway from BNL operations. The 2014 effective dose equivalents were estimated using Version 4, which was released via a notice in the Federal Register on February 10, 2015. It has been noted that calculated dose values have generally decreased from those calculated using the last version of CAP88-PC, Version 3. The Federal Register notice attributes this primarily to intake factors in Version 4 that were updated "to be consistent with the latest version of the EPA Exposure Factors Handbook".

8.2.2 Dose Calculation Methods and Pathways

8.2.2.1 Maximally Exposed Off-site and On-site Individual

The MEOSI is defined as a person who resides at a residence, office, or school beyond the BNL site boundary such that no other member of the public could receive a higher dose than the MEOSI. This person is assumed to reside 24 hours a day, 365 days a year, off site, and close to the nearest emission point of the BNL site boundary. This person is also assumed to consume significant amounts of fish and deer containing radioactivity assumed to be 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. The on-site maximally exposed individual

who could receive any dose outside of BNL's controlled areas was determined by and monitored with TLD measurements.

8.2.2.2 Effective Dose Equivalent

The EDE to the MEOSI from low levels of radioactive materials dispersed into the environment was calculated using the CAP88-PC dose modeling program, Version 4. Site meteorology data were used to calculate annual dispersions for the midpoint of a given wind sector and distance. Facility-specific radionuclide emission 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 the immersion, inhalation, and ingestion pathways. As stated above, these dose and risk calculations to the MEOSI 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. The term "Intake" is defined as the average amount of fish consumed by a person engaged in recreational fishing on 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 $5.0E-02 \text{ rem}/\mu\text{Ci}$, as set forth in DOE/EH-0071 (DOE 1988). The dose was calculated as: $\text{dose (rem/yr)} = \text{intake (kg/yr)} \times \text{activity in flesh } (\mu\text{Ci/kg}) \times \text{dose conversion factor (rem}/\mu\text{Ci})$.

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). No other radionuclides associated with Laboratory operations have been detected in deer meat. The total quantity of deer meat ingested during the course of a year was estimated at 64 pounds (29 kg) (NYSDOH 1999).

8.3 SOURCES: DIFFUSE, FUGITIVE, "OTHER"

Diffuse sources, also known as nonpoint or area sources, are described as sources of radioactive contaminants which diffuse into the atmosphere but do not have well-defined emission points. Fugitive sources include leaks through window and door frames, as well as unintended releases to the air through vents or stacks which are supposedly inactive (i.e., leaks from vents are fugitive sources). As 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 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 2014 for potential contribution to the overall site dose: Building 801, Building 750 complex (HFBR), and Building 906 (Scanner Rooms 5 & 6).

8.3.1 Remediation Work

At the site of the FHWMF, Phase Three of the perimeter soil remediation component of the project was performed. During previous phases of the project, the area designated for soil remediation was sub-divided into a grid of 16 zones. Each zone was plotted on a grid map, then surveyed to locate discrete spots of elevated Cs-137 activity in the soil. The goal of Phase Three was to use the grid map, with its discrete spots, to mark, remove, survey, isolate, and dispose of contaminated soil in Supersaks on a nearby rail car. All soil that contained contamination above 21,000 cpm (the equivalent of 23 pCi/g Cs-137)

was removed. When the amount and activity of soil had been removed such that soil activity did not exceed 15,000 cpm, the remediation work was considered complete. Some 64-cubic yards of contaminated soil were removed and sent off site for disposal.

8.4 DOSE FROM POINT SOURCES

8.4.1 Brookhaven LINAC Isotope Producer

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

In 2014, the BLIP facility operated over a period of 32 weeks. During the year, 2,511 Ci of C-11 (half-life: 20 minutes) and 5,023 Ci of O-15 (half-life: 122 seconds) were released from the BLIP facility. A small quantity (3.25E-02 Ci) of tritiated water vapor from activation of the targets' cooling water was also released. The EDE to the MEOSI was calculated to be 2.84-01 mrem (2.8 μ Sv) in a year from BLIP operations.

8.4.2 High Flux Beam Reactor

In 2014, the residual tritium emissions from the HFBR Facility were measured at 0.487 Ci, and the estimated dose attributed was 6.73E-5 mrem (0.67 nSv) in a year.

8.4.3 Brookhaven Medical Research Reactor

In 2014, the Brookhaven Medical Research Reactor (BMRR) facility remained in a cold-shutdown mode as a radiological facility with

institutional controls in place. There was no dose contribution from the BMRR in 2014.

8.4.4 Brookhaven Graphite Research Reactor

In 2014, long-term surveillance of the BGRR continued, as well as the maintenance and periodic refurbishment of structures, systems, and components. This will continue throughout the period of radioactive decay. There was no dose contribution from the BGRR during 2014.

8.4.5 Waste Management Facility

In 2014, there were no detectable levels of emissions from the Waste Management Facility.

8.4.6 Unplanned Releases

There were no reported unplanned releases in 2014.

8.5 DOSE FROM INGESTION

Radionuclides in the environment bio-accumulate in deer and fish tissues, bones, and organs; consequently, samples from deer and fish are 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 MEOSI for 2014. The maximum tissue concentration in the deer meat (flesh) collected “off site” was used to calculate the potential dose to the MEOSI. 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 2014, the maximum Cs-137 concentrations were 1.93 ± 0.04 pCi/g (wet weight) in the flesh (off site < 1 mile) and 1.07 ± 0.03 pCi/g (wet weight) in the liver (off site < 1 mile) (see Table 6-2). The average Cs-137 concentration from all samples was calculated at 0.46 ± 0.13 pCi/g; however, the maximum concentration of 1.93 pCi/g was used for the purpose of MEOSI dose calculations. The maximum estimated dose to humans from consuming deer meat containing the maximum Cs-137 concentration was estimated to be 2.8 mrem (28 μ Sv) in a year. This dose is below the health advisory limit of 10 mrem (100 μ Sv) established by NYSDOH.

In collaboration with the New York State Department of Environmental Conservation (NYSDEC) Fisheries Division, the Laboratory maintains an ongoing program of collecting and analyzing fish from the Peconic River and surrounding freshwater bodies. In 2014, a large-mouth bass species had the highest measured concentration of Cs-137 at 0.18 ± 0.03 pCi/g; this was used to estimate the EDE to the MEOSI. The potential dose from consuming 15 pounds of such fish annually was calculated to be 6.3E-2 mrem (0.63 μ Sv)—well below the NYSDOH health advisory limit of 10 mrem.

8.6 DOSE TO AQUATIC AND TERRESTRIAL BIOTA

DOE-STD-1153-2002, A Graded Approach for Evaluating Radiation Doses to Aquatic and Terrestrial Biota, provides the guidelines for screening methods to estimate radiological doses to aquatic animals and terrestrial plants and animals, using site-specific environmental surveillance data. The RESRAD-BIOTA 1.5, biota dose level 2 computer program was used to evaluate compliance with the requirements for protection of biota specified in DOE Order 458.1, Radiation Protection of the Public and the Environment.

In 2014, the terrestrial animal and plant doses were evaluated based on 0.44 pCi/g of Cs-137 (see Table 6-9) found in surface soils around the West end of Brookhaven Avenue and a strontium-90 (Sr-90) concentration of 0.61 pCi/L (see Table 5-5) in the surface waters collected at the HM-N location. The dose to terrestrial animals was calculated to be 21.2 μ Gy/day, and to plants, 1.99 μ Gy/day. The dose to terrestrial animals were well below the biota dose limit of 1 mGy/day, and below the limit for terrestrial plants.

To calculate the dose to aquatic and riparian animals, Sr-90 radionuclide concentration values for surface water from the HM-N location (see Table 5-5) and the Cs-137 in sediments found at PR-WC-06-D1-L50 were used (see Table 6-7). The Cs-137 sediment concentration at PR-WC-06-D1-L50 was 5.49 pCi/g and the Sr-90 concentration in surface water at HM-N was 0.61 pCi/L. The calculated dose to aquatic animals was 106 μ Gy/day and the dose to

Table 8-5. BNL Site Dose Summary, 2014.

Pathway	Dose to Maximally Exposed Individual	Percent of DOE 100 mrem/year Limit	Estimated Population Dose per year
Inhalation			
Air	2.85E-01	<1%	0.563 Person-rem
Ingestion			
Drinking Water	None	None	None
Fish	6.30E-02	<1%	Not Tracked
Deer	2.8	<3%	Not Tracked
All Pathways	3.15 mrem	<4%	0.563 Person-rem

riparian animals was 261 $\mu\text{Gy}/\text{day}$. 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 2014. The total dose to the MEOSI from air and ingestion pathways was estimated to be 3.15 mrem (32 μSv). In comparison, the EPA regulatory limit for the air pathway is 10 mrem (0.10 mSv) and the DOE limit from all pathways is 100 mrem (1 mSv). The cumulative population dose was 0.563 person-rem (5.6E-3 person-Sv) in a year. The effective dose is well below the DOE and EPA regulatory limits, and the ambient TLD dose is within normal background levels seen at the Laboratory site. The potential dose from drinking water was not estimated, because most residents adjacent to the BNL site get their drinking water from the Suffolk County Water Authority rather than private wells. To put the potential dose impact into perspective, a comparison was made with estimated doses from other sources of radiation. The annual dose from all natural background sources and radon is approximately 311 mrem (3.11 mSv). A mammogram gives a dose of 250 mrem (2.5 mSv) and a dental x-ray gives a dose of approximately 160 mrem (1.6 mSv) to an individual. Therefore, a dose of 3.15 mrem from all environmental pathways is a minute fraction of the dose from one routine dental x-ray.

REFERENCES AND BIBLIOGRAPHY

- 40 CFR 61, Subpart H. *National Emissions Standard for Hazardous Air Pollutants*. U.S. Environmental Protection Agency, Washington, DC. 1989.
- ANSI/HPS. 1999. *Sampling and Monitoring Releases of Airborne Radioactive Substances from the Stacks and Ducts of Nuclear Facilities*. N13.1-1999.
- DOE. 2002. *A Graded Approach for Evaluation of Radiation Doses to Aquatic and Terrestrial Biota*. DOE-STD-1153-2002. U.S. Department of Energy, Washington, DC. July 2002.
- DOE Order 458.1. 2011. *Radiation Protection of the Public and the Environment*. U.S. Department of Energy, Washington, DC. February 11, 2011.
- DOE Order 436.1. 2011. *Departmental Sustainability*. U.S. Department of Energy, Washington, DC. May 2, 2011.
- DOE, 1988. DOE/EH-0071. *Internal Dose Conversion Factors for Calculations of Dose to the Public*. July 1988.
- EPA. 2007. *User's Guide for CAP88-PC, Version 3.0*. EPA 402B92001. U.S. Environmental Protection Agency, Washington, DC.
- EPA. 1996. *Food Ingestion Factors, Exposure Factors Handbook-Volume II*. EPA600P95002FB. U.S. Environmental Protection Agency, Washington, DC.
- ORNL. 2012. *Geographical Information System Population Survey of Long Island by Oak Ridge National Laboratory*.
- NCRP. 2006. *Ionizing Radiation Exposure of the Population of the United States*. NCRP Report No. 160. National Council on Radiation Protection and Measurements, Bethesda, MD.
- NYSDOH. 1993. *Environmental Radiation in New York State*. Bureau of Environmental Radiation Protection, New York State Department of Health, Albany, NY.
- NYSDOH. 1996. *Radioactive Contamination in the Peconic River*. Bureau of Environmental Radiation Protection, New York State Department of Health, Albany, NY.
- NYSDOH. 1999. *Deer Meat Contaminated With Cs-137 at Brookhaven National Laboratory*. Bureau of Environmental Radiation Protection. New York State Department of Health, Albany, NY.