Radiological Dose Assessment 8

Brookhaven National Lab's (BNL) 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 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 total dose from direct and indirect dose pathways via air immersion, inhalation of particulates and gases, and ingestion of local fish and deer meat. In 2018, the total effective dose (TED) of 5.0 mrem (50 µSv) from Laboratory operations was well below the U. S. Environmental Protection Agency (EPA) and U.S. Department of Energy (DOE) regulatory dose limits for the public, workers, and the environment.

The dose estimates for 2018 were calculated using the latest version of the dose modeling software promulgated by EPA. All data in this chapter are reported with uncertainties at the 95 percent (2-sigma) confidence level. As such, the effective dose equivalent (EDE) from air emissions in 2018 was estimated at 1.6 mrem (16 µSv) to the MEOSI. This BNL dose level from the inhalation pathway was less than 17 percent of the EPA's annual regulatory dose limit of 10 mrem (100 µSv). In addition, the dose from the ingestion pathway was estimated as 3.3 mrem (33 µSv) from the consumption of deer meat and 8.8E- 2 mrem (0.88 µSv) from the consumption of fish caught near the Laboratory. In summary, the total annual dose to the MEOSI from all pathways was estimated at 5.0 mrem (50 µSv), which is five percent of DOE's 100-mrem limit. The aggregate population dose was 2.6 person-rem among approximately six million people residing within a 50-mile radius of the Laboratory. On average, this is equivalent to a fraction of an airport whole body scan per person.

Dose to the maximally exposed individual (MEI) on site and outside of controlled areas, calculated from thermo-luminescent dosimeter (TLD) monitoring records, was 14 mrem above natural background radiation levels. The average annual external dose from ambient sources on site was 66 ± 11 mrem (660 ± 110 µSv), while the dose from off-site ambient sources was 64 ± 10 mrem (640 ± 110 µSv). 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 50 on-site TLDs and 17 off-site TLDs showed that there was no external dose contribution from BNL operations distinguishable from the natural background radiation level. An additional ten TLDs were used to measure on-site areas known to receive radiation dose slightly above the natural background radiation.

Doses to aquatic and terrestrial biota were also found to be well below DOE regulatory limits. In summary, the overall dose impact from all Laboratory activities in 2018 was comparable to that of 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. 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 for several years, the dose risk from these facilities was trivial in 2018. The Laboratory's current radiological risks are from very small quantities of radionuclides used in science experiments, production of radiopharmaceuticals at the Brookhaven LINAC Isotope Producer (BLIP), and small amounts of air activation produced at the BNL accelerators: Alternating Gradient Synchrotron (AGS), Relativistic Heavy Ion Collider (RHIC), and the National Synchrotron Light Source II (NSLS-II). 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 based on the premise that off-site exposures represent true natural background radiation levels (with contribution from both cosmic and terrestrial sources) with no contribution from Laboratory operations.

On- and off-site external dose measurements are averaged separately and then compared using standard statistical methods 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 those grids (See Photo 8-1 below).

Photo 8-1. TLD at P-4 Perimeter Station

In 2018, a total of 60 environmental TLDs were deployed on site, ten of which were placed in known radiation areas. During the year, three environmental TLDs were relocated and two neutron TLDs at a single location were converted to environmental TLDs and relocated. A total of 17 environmental TLDs were deployed at off-site locations (see Figures 8-1 and 8-2). In 2018, all 16 wind sectors around the Laboratory

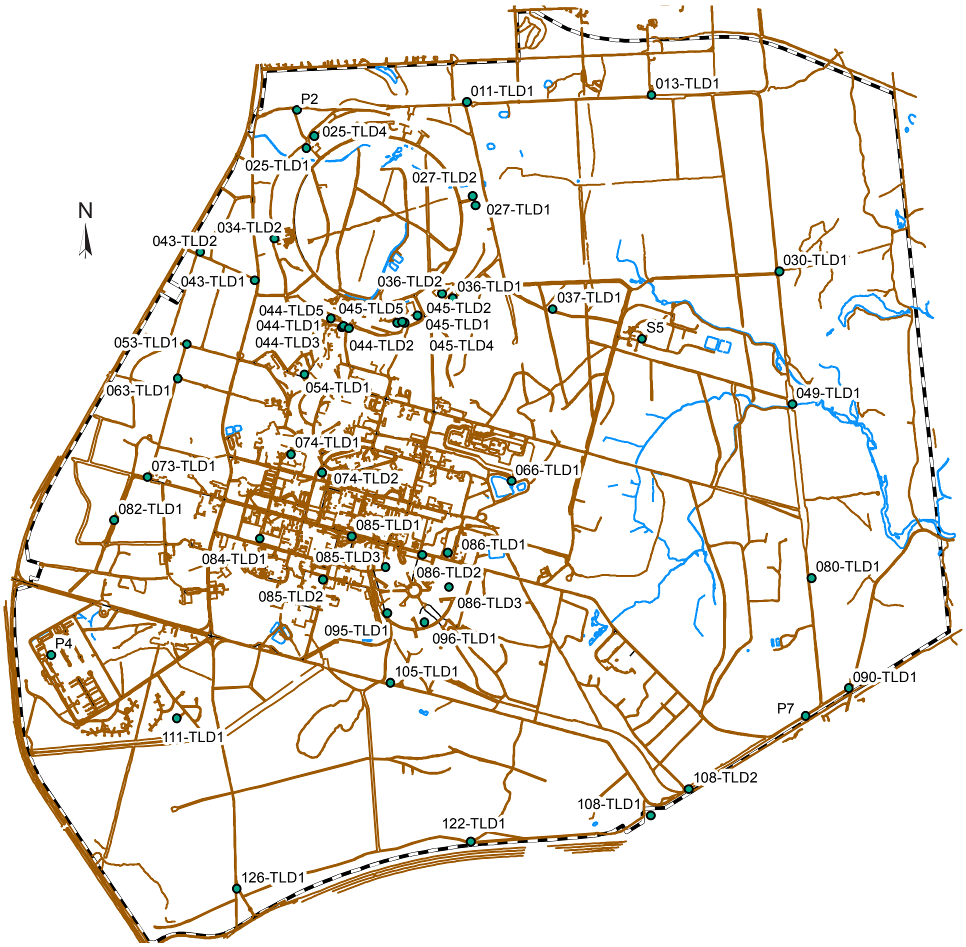

Figure 8-1. On-Site TLD Locations.

had TLDs located in them. An additional 30 TLDs were stored in a lead-shielded container for use as reference and control TLDs for comparison purposes. The total of the control TLD dose values for 2018, reported as 075-TLD4 in Tables 8-1 and 8-2, was 30± 4 mrem. This dose accounts for any small residual dose not removed from TLDs 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 2018. The on-site average external doses for the first through fourth quarters were 18 ± 3.3, 16 ± 2.7, 15 ± 2.8, and 17 ± 3.1 mrem, respectively. The on-site average annual external dose from all potential environmental sources, including cosmic and terrestrial radiation sources, was 66 ± 11 mrem (660 ± 110 µSv). Table 8-2 shows the quarterly and yearly off-site radiation dose measurements for 2018. The off-site average external doses for the first through fourth quarters were 17± 3.3, 16 ± 3.3, 15 ± 2.9, and 17± 2.7 mrem, respectively. The off-site average annual ambient dose from all potential environmental sources,

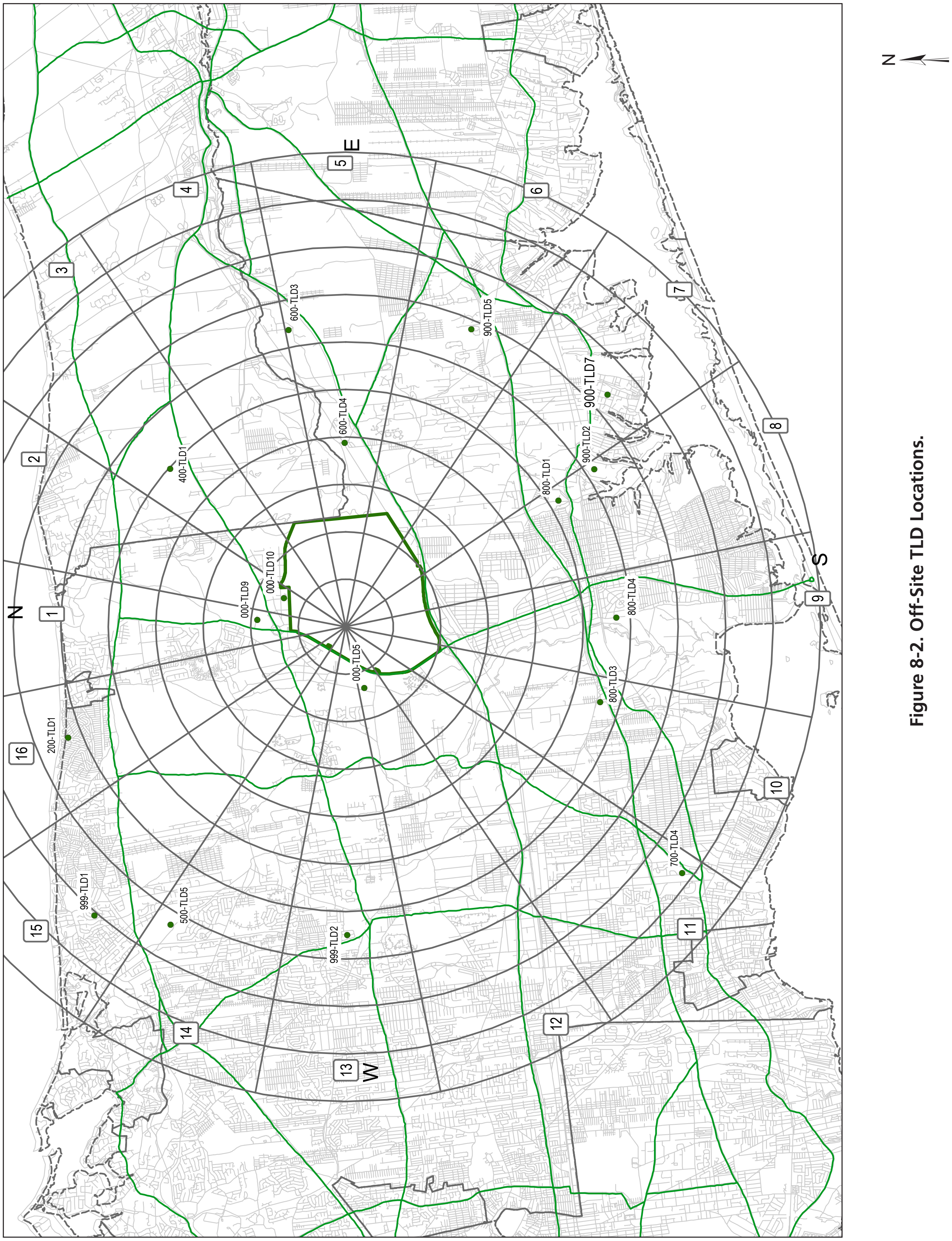

Figure 8-2. Off-Site TLD Locations.

Table 8-1. On-Site Direct Ambient Radiation Measurements for 2018.

TLD#	Location	1st Quarter	2nd Quarter	3rd Quarter	4th Quarter	Avg./Qtr. ±2σ (95%)	Annual Dose ±2σ (95%)
		(mrem)					
011-TLD1	North Firebreak	16.1	13.9	13.6	14.7	15±2	58±8
013-TLD1	North Firebreak	16.8	15.3	13.2	16.1	15±3	61±11
025-TLD1	Bldg. 1010, Beam Stop 1	17.1	15.4	14.6	15.6	16±2	63±7
025-TLD4	Bldg. 1010, Beam Stop 4	16.4	16.4	13.3	15.7	15±3	62±10
027-TLD1	Bldg. 1002A South	15.9	13.5	14.5	16.2	15±2	60±9
027-TLD2	Bldg. 1002D East	15.6	14.4	12.9	19.1	16±5	62±18
030-TLD1	Northeast Firebreak	17.5	15.4	14.0	16.9	16±3	64±11
034-TLD2	Bldg. 1008, Collimator 4	18.5	15.9	14.7	17.9	17±3	67±12
036-TLD1	Bldg. 1004B, East	15.1	13.8	12.5	15.5	14±2	57±9
036-TLD2	Bldg. 1004, East	17.2	15.6	13.7	15.5	16±2	62±10
037-TLD1	S-13	16.3	14.0	14.4	14.6	15±2	59±7
043-TLD1	North Access Road	18.9	16.6	15.1	18.0	17±3	69±11
043-TLD2	North of Meteorology Tower	18.3	17.0	15.0	16.0	17±2	66±10
044-TLD1	Bldg. 1006	19.1	16.8	14.7	18.4	17±3	69±13
044-TLD2	South of Bldg. 1000E	18.5	15.9	14.8	17.6	17±3	67±11
044-TLD3	South of Bldg. 1000P	19.6	15.4	13.2	18.0	17±5	66±20
044-TLD5	North of Bldg. 1000P	19.6	16.6	14.9	15.9	17±3	67±14
045-TLD1	Bldg. 1005S	17.5	14.4	13.8	17.4	16±3	63±14
045-TLD2	East of Bldg. 1005S	18.2	15.6	15.3	17.6	17±2	67±10
045-TLD4	Southwest of Bldg. 1005S	21.0	16.3	13.7	17.7	17±5	69±21
045-TLD5	West-Southwest of Bldg. 1005S	17.1	16.6	13.7	18.5	16±3	66±14
049-TLD1	East Firebreak	17.6	15.4	18.3	19.0	18±3	70±11
053-TLD1	West Firebreak	19.3	17.3	15.7	18.9	18±3	71±11
063-TLD1	West Firebreak	18.9	17.2	17.5	18.9	18±2	72±6
066-TLD1	Waste Management Facility	16.1	14.7	13.3	16.0	15±2	60±9
073-TLD1	Meteorology Tower	18.9	16.1	15.0	16.1	17±3	66±11
074-TLD1	Bldg. 560	21.4	17.7	16.4	17.9	18±4	73±15
074-TLD2	Bldg. 907	18.9	17.0	14.1	16.2	17±3	66±14
080-TLD1	East Firebreak	19.2	18.0	17.0	18.2	18±2	72±6
082-TLD1	West Firebreak	19.6	18.4	17.0	18.2	18±2	73±7
084-TLD1	Tennis courts	19.8	16.2	15.2	20.9	18±5	72±19
085-TLD1	Bldg. 735	18.7	16.0	15.5	18.1	17±3	68±11
085-TLD2	Upton Gas Station	17.2	15.7	15.1	17.9	16±2	66±9
085-TLD3	NSLS-II LOB 745	19.9	16.3	16.2	18.6	18±3	71±13
086-TLD1	Baseball Fields	18.1	15.7	15.5	16.5	16±2	66±8
086-TLD2	NSLS-II LOB 741	17.6	17.1	13.1	16.0	16±3	64±14
086-TLD3	NSLS-II LOB 742	16.8	14.5	12.8	14.6	15±3	59±11
090-TLD1	North St. Gate	17.4	15.6	14.6	16.8	16±2	64±9
095-TLD1	NSLS-II LOB 744	18.1	16.5	16.4	18.9	17±2	70±8
096-TLD1	NSLS-II LOB 743	16.5	15.3	13.4	16.6	15±3	62±10

(continued on next page)

Table 8-1. On-Site Direct Ambient Radiation Measurements for 2018. *(concluded).*

TLD#	Location	1st Quarter	2nd Quarter	3rd Quarter	4th Quarter	Avg./Qtr. ±2σ (95%)	Annual Dose ±2σ (95%)
		(mrem)					
105-TLD1	South Firebreak	18.2	16.1	14.7	19.4	17±4	68±14
108-TLD1	Water Tower	16.2	18.1	14.3	16.7	16±3	65±11
108-TLD2	Tritium Pole	23.7	20.0	18.1	20.5	21±4	82±16
111-TLD1	Trailer Park	18.0	16.6	18.4	18.7	18±2	72±6
122-TLD1	South Firebreak	17.5	15.2	13.8	15.8	16±3	62±11
126-TLD1	South Gate	21.8	18.0	16.1	18.9	19±4	75±17
P2		15.9	13.2	14.3	14.4	14±2	58±8
P4		16.9	15.1	14.2	17.5	16±3	64±11
P7		17.6	16.6	14.7	17.0	16±2	66±9
S5		17.3	14.1	13.9	15.8	15±3	61±11
On-Site Average		**18.1**	**16.0**	**14.8**	**17.2**	**17±3**	**66±11**
Std. Dev. (2σ)		**3.3**	**2.7**	**2.8**	**3.1**		
075-TLD4: Control TLD Average		**8.3**	**7.1**	**7.1**	**7.5**	**7.5±1**	**30±4**

Notes :
See Figure 8-1 for TLD locations.

including cosmic and terrestrial radiation sources, was 64 ± 10 mrem (640 ± 100 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 test showed no significant difference between the off-site dose (64 ± 10 mrem) and on-site dose (66 ± 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- or off-site locations from Laboratory operations in 2018. The dose to the MEI on site and outside of controlled areas (near Building 356) was measured at 0 mrem for the first quarter, 1 mrem for the second quarter, 0 mrem for the third quarter, and 13 mrem for the fourth quarter of 2018. The increase in MEI dose in the fourth quarter was due to nearly continuous research irradiations being conducted using a Cobalt-60 (Co-60) source in Building 356 during the quarter. The total dose to the on-site MEI was 14 mrem, which is less than the dose received from four round-trip flights from Los Angeles, California to New York, New York.

8.1.2 Facility Area Monitoring

Ten on-site TLDs were designated as facility-area monitors (FAMs) because they were posted in known radiation areas (i.e., near facilities). Table 8-3 shows the external doses measured with the FAM-TLDs. Environmental TLDs 088-TLD1 through 088-TLD4 were posted at the S-6 blockhouse location and near S6 on the fence of the Former Hazardous Waste Management Facility (FHWMF). Except for S6 and 088-TLD4, which were consistent with the site average dose, the TLDs measured external doses that were slightly elevated compared to the normal natural background radiation doses measured in other areas on site. This can be attributed to the presence of small amounts of contamination in the soil. 088-TLD1 had the highest dose reading of the four, which can be attributed to waste-loading activities at the rail spur in recent years. 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. As shown in Table 8-3, the 2018 dose is

Table 8-2. Off-Site Direct Radiation Measurements for 2018.

TLD#	Location	1st Quarter	2nd Quarter	3rd Quarter	4th Quarter	Avg./Qtr. ± 2 σ (95%)	Annual Dose ± 2 σ (95%)
		(mrem)					
000-TLD5	Longwood Estate	16.8	14.8	13.1	14.5	15±3	59±11
000-TLD9	Private property	15.9	13.5	13.1	15.4	14±2	58±9
000-TLD10	Private Property	15.8	17.8	14.9	17.6	17±2	66±10
200-TLD1	Private property	19.8	15.6	D	17.9	18±3	71±14
200-TLD5	Private property	21.4	19.3	18.0	19.0	19±2	78±10
400-TLD1	Calverton Nat. Cemetery	18.5	18.1	15.6	18.4	18±2	71±10
600-TLD3	Private property	18.7	17.6	14.7	17.0	17±3	68±12
600-TLD4	Maples B&G	16.2	14.1	13.9	14.9	15±2	59±7
700-TLD4	Private property	16.3	15.3	13.2	16.4	15±3	61±10
800-TLD1	Private property	17.8	14.9	14.0	18.2	16±4	65±14
800-TLD3	Suffolk County CD	16.8	15.1	14.0	15.8	15±2	62±8
800-TLD4	LI Nat'l Wildlife Refuge	16.5	15.6	15.1	15.7	16±1	63±4
900-TLD2	Private property	18.8	14.3	12.8	15.9	15±4	62±18
900-TLD5	Private property	14.8	13.8	NP	15.8	15±2	59±7
900-TLD7	Private property	17.1	17.0	15.0	17.6	17±2	67±8
999-TLD1	Private property	17.4	15.5	15.2	15.4	16±2	64±7
999-TLD2	Private property	18.2	18.5	NP	17.8	18±1	73±2
Off-site average		**17.4**	**15.8**	**14.7**	**16.6**	**16±2**	**64±10**
Std. Dev. (2σ)		**3.3**	**3.3**	**2.9**	**2.7**		
075-TLD4 : Control TLD Average		**8.3**	**7.1**	**7.1**	**7.5**	**7.5±1**	**30±4**

Notes:
See Figure 8-2 for TLD locations.
CD = Correctional Department
NP = TLD not posted.
D = Damaged; no reading

Table 8-3. Facility Monitoring Area for 2018.

TLD#	Location	1st Quarter	2nd Quarter	3rd Quarter	4th Quarter	Average ± 2σ (95%)	Annual Dose ± 2σ (95%)
		(mrem)					
054-TLD1	Bldg. 914	31.4	23.4	14.6	21.6	23±12	91±48
054-TLD2	NE of Bldg. 913B	31.5	20.9	15.0	18.3	21±12	86±49
054-TLD3	NW of Bldg. 913B	28.8	21.7	13.1	16.9	20±12	81±47
S6		19.7	17.8	15.9	17.6	18±3	71±11
088-TLD1	FWMF, 50' East of S6	23.2	21.3	18.8	20.7	21±3	84±12
088-TLD2	FWMF, 50' West of S6	20.5	18.8	16.4	18.2	18±3	74±12
088-TLD3	FWMF, 100' West of S6	19.9	18.9	17.5	19.1	19±2	75±7
088-TLD4	FWMF, 150' West of S6	17.9	17.5	15.8	15.6	17±2	67±8
075-TLD3	Building 356	20.8	17.2	18.8	23.1	20±4	80±18
075-TLD5	North Corner of Bldg. 356	20.2	16.4	19.1	24.0	20±5	80±22

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

slightly above natural background levels. The FHWMF is fenced, so access to it is controlled. Two TLDs (075-TLD3 and 075- TLD5) near Building 356 showed a slightly higher quarterly average of 20 mrem, which is just above the normal ambient background radiation. The yearly doses were measured at 80 ± 18 mrem (800 ± 180 µSv) for 075-TLD3 and 80 ± 22 mrem (800 ± 220 µSv) for 075-TLD5.

These direct doses are higher than the on-site annual average because Building 356 houses a Co-60 source which is used to irradiate materials, parts, and electronic circuit boards. The elevated dose from Building 356 measured 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.

Three FAM-TLDs near Building 914 and placed on fence sections 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 31 mrem for 054-TLD1, 32 mrem for 054-TLD2, and 29 mrem for 054-TLD3 (compared to the first-quarter site-wide dose of 18 ± 3.3 mrem and off-site dose of 17 ± 3.3 mrem). The second-quarter dose at these sites was measured at 23 mrem for 054-TLD1, 21 mrem for 054-TLD2, and 22 mrem for 054-TLD3 (compared to the second quarter site-wide dose of 16.0± 2.7 mrem and off-site dose of 16 ± 3.3 mrem). During the third and fourth quarters, both TLDs showed dose comparable to natural background radiation, though 054-TLD1 was still elevated at 22 mrem. The slightly higher levels of the first and second quarters are expected because

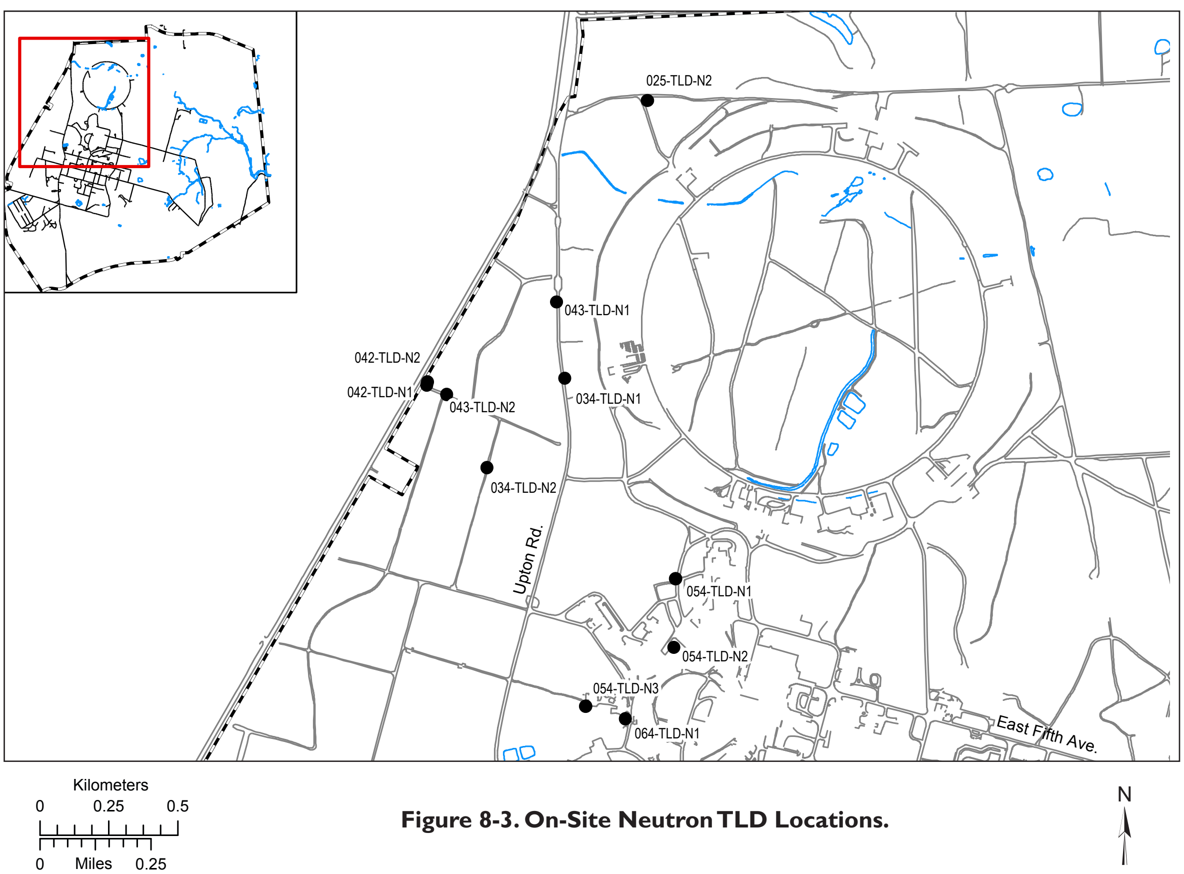

Figure 8-3. On-Site Neutron TLD Locations.

the operating period for the AGS is typically in the first half of the calendar year.

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 can accept 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. In 2018, 11 pairs of neutron-monitoring TLDs (Harshaw Badge 8814) were posted at strategic locations to measure the dose contribution from the high-energy neutrons (see Figure 8-3 for locations).

The technical criteria used for the placement of the neutron TLDs is based on design aspects such as the thickness of the berm shielding, location of soil activation areas, beam stop areas and beam collimators, and proximity to the site boundary. The neutron TLDs are placed in pairs for three reasons: The dose registered on these TLDs is low, so a matching number on the second TLD adds confidence to the dose measured by the first one; two neutron TLDs side-by-side decreases the potential dependence of measured dose on directional orientation; and only the neutron TLDs are mounted on polyethylene cylinders (see Photo 8-2 at top right) so that incident neutrons, which are at a high enough energy to pass through the TLD undetected, are thermalized by the hydrocarbons in the polyethylene. This allows the incident neutrons to be counted when reflected back out of the cylinder.

In the first quarter of 2018, passive monitors for neutron dose showed no neutron dose. In the second quarter, neutron TLDs showed no neutron dose. In the third quarter, neutron TLDs at 025-TLD-N2, 034-TLD-N2, 043-TLD-N2, and 064-TLD-N1 all showed 1 mrem. Finally, 1 mrem neutron doses were recorded in the fourth quarter at 025-TLD-N2 and 034-TLD-N1. See Table 8-4 for the neutron dose data. The RHIC/BLIP ran at slightly higher current and energy during the beginning of the third quarter for approximately one month, but it was turned off for the remainder of the third quarter. In the fourth quarter, the RHIC/BLIP ran for a two-week period at the end of the calendar year at low, startup-testing levels. These low-level neutron doses indicate that engineering controls (i.e., berm shielding) in place at AGS and RHIC are effective.

Photo 8-2. Neutron TLDs in Monitored Area

8.2 DOSE MODELING

The 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 greater than 10 mrem (100 µSv) 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 one 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 8-5, and the actual air emissions for 2018 are discussed in detail in Chapter 4.

As a part of the NESHAPs review process at

Table 8-4. Neutron Dose Report for 2018.

Neutron TLD #	Location ID No.	1st Quarter	2nd Quarter	3rd Quarter	4th Quarter	Annual Neutron Dose
		(mrem neutron)				
TK277	025-TLD-N2	0	0	0	0	0
TK278	"	0	0	1	1	2
TK279	034-TLD-N1	0	0	0	0	0
TK280	"	0	0	0	1	1
TK281	034-TLD-N2	0	0	0	0	0
TK282	"	0	0	1	0	1
TK283	043-TLD-N1	0	0	0	0	0
TK284	"	0	0	0	0	0
TK285	043-TLD-N2	0	0	0	0	0
TK286	"	0	0	1	0	1
TK287	042-TLD-N1	0	0	0	0	0
TK288	"	0	0	0	0	0
TK289	042-TLD-N2	0	0	0	0	0
TK290	"	0	0	0	0	0
TK291	054-TLD-N1	0	0	0	0	0
TK292	"	0	0	0	0	0
TK293	054-TLD-N2	0	0	0	0	0
TK294	"	0	0	0	0	0
TK295	054-TLD-N3	0	0	0	0	0
TK296	"	0	0	0	0	0
TK297	064-TLD-N1	0	0	0	0	0
TK298	"	0	0	1	0	1
PM-bkg		0	0	1	0	1

BNL, any emission source, such as a stack, that has the potential to release airborne radioactive materials is evaluated for regulatory compliance. Under the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA), certain restoration activities are also monitored and assessed for any potential to release airborne radioactive materials, and to determine their dose contribution, if any, to the environment. Any new radiological processes or activities are also evaluated for compliance with NESHAPs regulations using the 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, modeling results are conservative.

8.2.1 Dose Modeling Program

Compliance with NESHAPs regulations is demonstrated using 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

Table 8-5. Maximally Exposed Off-site Individual Effective Dose Equivalent From Facilities for 2018.

Building No.	Facility or Process	Construction Permit No.	MEOSI Dose (mrem) (a)	Notes
348	Instrumentation & Calibration	None	3.40E-12	(b)
463	Biology	None	2.10E-07	(b)
480	Condensed Matter Physics	None	ND	(f)
490/490A	Personnel Monitoring	None	2.02E-06	(b)
510A	Physics	None	ND	(f)
535	Instrumentation	None	ND	(f)
555	Chemistry Facility	None	3.66E-04	(b)
734	Interdisciplinary Science Building	None	ND	(f)
735	Center for Functional Nanomaterials	None	ND	(f)
740	Nuclear Science & Technology	None	9.58E-12	(b)
741	Nuclear Science & Technology	None	4.93E-13	(b)
743	Nuclear Science & Technology	None	9.61E-10	(b)
744	NSLS-II	None	7.08E-12	(b)
745	NSLS-II	None	1.09E-07	(b)
750	HFBR	None	9.09E-05	(c)
750	Nonproliferation & Nuclear Safety	None	ND	(g)
801	Target Processing lab	None	1.08E-02	(c)
815	Nonproliferation & Nuclear Safety	None	ND	(g)
820	Accelerator Test Facility	BNL-589-01	ND	(d)
830	Environmental Science Department	None	ND	(f)
860	Waste Managerment Facility	None	5.44E-13	(b)
901	BioSciences Department	None	ND	(f)
902	Superconducting Magnet Division	None	ND	(f)
906	Imaging Lab	None	ND	(f)
911	Collider Accelerator	None	1.48E-09	(b)
925	RF Systems	None	ND	(f)
931	BLIP	BNL-2009-01	1.62E+00	(c)
942	AGS Booster	BNL-188-01	ND	(e)
---	RHIC	BNL-389-01	ND	(d)
Total Potential Dose from BNL Operations			**1.63E+00**	
EPA Limit (Air Emissions)			**10**	

Notes:
MEOSI = Maximally Exposed Off-site Individual
(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 continuously monitored at the facility.
(d) ND = No Dose from emissions source in 2018.
(e) Booster ventilation system prevents air release through continuous air recirculation.
(f) No radiological dispersible material inventory in 2018.
(g) Sealed sources were excluded from this inventory - no emission

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 the air, the rate of deposition on ground surfaces, and the 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 dose estimates. For the purpose of modeling the dose to the MEOSI, all emission points are located at the BLIP Facility, which is used to represent 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 such as height and diameter, and emission exhaust velocity. Site-specific weather and population data are also 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 amount (see Chapter 1 for details). A population of six million people, based on the Geographical Information System design population survey performed by Oak Ridge National Laboratory for BNL, was used in the model.

The 2018 effective dose equivalents were estimated using Version 4.0.1.17 of CAP88-PC. The following approaches were taken and assumptions made in determining 2018 dose estimates for this report:

- A conservative approach is used for agricultural data put into the CAP88 modeling program, with 92 percent of vegetables, 100 percent of milk, and 99 percent of meat from the assessment area.
- The velocity of the exhaust from the BLIP facility stack was updated to reflect current operation. The average volumetric flow rate of the BLIP exhaust system in 2018 was 516.5 cfm, or 0.243 m3/sec. With an exit diameter of 0.1 m, the exit velocity was 31.04 m/sec, down slightly from last year's 31.05 m/sec.
- The method of characterizing atmospheric stability for purposes of estimating effluent dispersion was the Solar Radiation/Delta Temperature method for conservatism.

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). 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 dose and risk to members of the public. The dose to the on-site maximally exposed individual who could receive any dose outside of BNL's controlled areas was also determined by 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. Site meteorology data were used to calculate annual emission 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 annual intake is estimated which is defined as the average weight of fish consumed in a year by a person engaged in recreational fishing on the Peconic River. Based on a NYSDOH study, the annual 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 pico-Curies 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 ICRP 68. The dose was calculated as: dose in (rem/yr) = intake (kg/yr) × activity in flesh (µCi/kg) × dose conversion 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 same Cs-137 radionuclide dose conversion factor was used to estimate dose, based on the U.S. Environmental Protection Agency Exposure Factors Handbook (EPA 2011). 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 potential dose impact to members of the public. One NESHAPs review was performed in 2018.

8.3.1 Remediation Work

In 2018, a single remediation project was performed to remediate an area of soil that was contaminated with very low levels of Co60 and Cs137. The soil area was a remnant from a previous building demolition and removal project. It was located along a fenceline on one edge of the former work-site and involved 22m^3 of soil. The soil was excavated, placed into Supersacks, and subsequently shipped to Energy Solutions in Clive, Utah for disposal. The dose risk of the material being removed was well below the level requiring a NESHAPs permit; there were no anomalies during remediation efforts and all cleanup goals were achieved.

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 one percent of the EPA limit (0.1 mrem or 1.0µSv). 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 gaseous emissions are directly and continuously measured in real time with an inline, low-resolution, Sodium Iodide (NaI) gamma spectrometer. The spectrometer system is connected to a computer workstation that is used to continuously record and display emission levels. The particulate emissions are sampled for gross alpha and gross beta activity weekly using a conventional fiberglass filter, which is analyzed at an off-site contract analytical laboratory. Likewise, exhaust samples for tritium are also collected continuously using a silica gel adsorbent and are then analyzed at an off-site contract analytical laboratory on a weekly basis.

In 2018, the BLIP facility operated over a period of 26.7 weeks. During the year, 7,678 Ci of C-11 (half life: 20.4 minutes) and 15,357 Ci of O-15 (half life: 122 seconds) were released from the BLIP facility. A small quantity (3.10E-02

Table 8-6. BNL Site Dose Summary, 2018.

Pathway	Dose to Maximally Exposed Individual	Percent of DOE 100 mrem/year Limit	Estimated Population Dose per year
Inhalation			
Air	1.63 mrem	<2%	2.55 Person-rem
Ingestion			
Drinking Water	None	None	None
Fish[1]	8.80E-02	<0.1%	Not Tracked
Deer	3.32 mrem	<4%	Not Tracked
All Pathways	**5.04 mrem**	**<6%**	**2.55 Person-rem**

Note:
1 - Source River remained dried up in 2018, so 2015 fish data was used to represent magnitude since sampling was not possible in 2018.

Ci) of tritiated water vapor from activation of the targets' cooling water was also released. The EDE to the MEOSI from BLIP operations was calculated to be 1.6 mrem (16 µSv) in a year.

8.4.2 Target Processing Laboratory

In 2018, there were no detectable levels of emissions from the Target Processing Laboratory.

8.4.3 High Flux Beam Reactor

In 2018, the residual tritium emissions from the HFBR facility were measured at 0.41 Ci, and the estimated dose attributed was 9.1E-5 mrem (0.91 µSv) in a year.

8.4.4 Brookhaven Medical Research Reactor

In 2018, 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 2018.

8.4.5 Brookhaven Graphite Research Reactor

In 2018, long-term surveillance of the BGRR continued, as well as the maintenance and periodic refurbishment of structures, systems, and components. This status will continue throughout the period of radioactive decay. There were no radionuclides released to the environment from the complex in 2018.

8.4.6 Waste Management Facility

In 2018, there were no detectable levels of emissions from the Waste Management Facility.

8.4.7 Unplanned Releases

In 2018, there were no unplanned releases.

8.5 DOSE FROM INGESTION

Radionuclides in the environment may bioaccumulate in deer and fish tissue, bones, and organs; consequently, samples from deer and fish are analyzed to evaluate the contribution of dose to humans from the ingestion pathway. As discussed in Chapter 6, deer meat samples collected on- and off-site near the BNL boundary were used to assess the potential dose impact to the MEOSI. The maximum tissue concentration in the deer meat collected for sampling 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 2018, BNL collected samples from 18 animals and analyzed them for K-40 and Cs-137. It should be noted that since the site boundaries are not fenced, deer are able to travel short distances back and forth across the site boundary. The average K-40 concentrations in deer tissue samples (BNL Average) were 3.00 ± 0.56 pCi/g (wet weight) in the flesh and 2.26 ± 0.88 pCi/g (wet weight) in the liver. The maximum

Cs-137 concentration was 2.19 ± 0.04 pCi/g (wet weight) in the flesh on site (see Table 6-2). The average Cs-137 concentration from all deer sampled was 0.90 ± 0.13 pCi/g. However, the maximum Cs-137 concentration of 2.29 ± 0.06 pCi/g from a deer sample collected more than a mile from BNL was used for MEOSI dose calculations. Therefore, the maximum estimated dose to humans from consuming deer meat containing the maximum Cs-137 concentration was estimated to be 3.32 mrem (33.2 µSv) in a year. This dose is below the health advisory limit of 10 mrem (100 µSv) established by NYSDOH.

In collaboration with the New York State Department of Environmental Conservation Fisheries Division, the Laboratory maintains an ongoing program of collecting and analyzing fish from the Peconic River and surrounding freshwater bodies. The Peconic River is an intermittent stream, with flow occurring predominantly via groundwater discharge in the spring and fall (i.e., a "gaining" stream) and completely drying up during dry periods (i.e., a "losing" stream). In 2018, the Peconic River was completely dry for a second year, so there were no samples of fish to analyze for radioactivity.

Therefore, as a representative estimate of dose due to fish consumption from local freshwater bodies for 2018, the most recent year's measured concentration of Cs-137 at 0.25 ± 0.06 pCi/g was used to estimate the EDE to the MEOSI. Accordingly, the potential dose from consuming 15 pounds of such fish annually was estimated at 8.75E-2 mrem (0.88 µSv)—well below the NYSDOH health advisory limit of 10 mrem.

8.6 DOSE TO AQUATIC AND TERRESTRIAL BIOTA

DOE-STD-1153-2002, A Graded Approach for Evaluating Radiation Doses to Aquatic and Terrestrial Biota, provides the guidelines for screening methods to estimate radiological doses to aquatic animals and terrestrial plants and animals, using site-specific environmental surveillance data. The RESRAD-BIOTA 1.8, 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 2018, the terrestrial animal and plant doses were evaluated based on 1.36 pCi/g of Cs-137 (see Table 6-3) found in soil from the tank pond, and a Strontium-90 (Sr-90) concentration of 0.78 pCi/L in the surface water collected at the HY headwaters West of the RHIC ring. The resultant dose to terrestrial animals was calculated to be 65.5 µGy/day, and to plants as 6.16 µGy/day. The dose to terrestrial animals was well below the biota dose limit of 1 mGy/day, and the plant dose was below the limit of 10 mGy/day for terrestrial plants.

To calculate the dose to aquatic and riparian animals in 2018, the surface water Sr-90 concentration mentioned above, 0.78 pCi/L, was used along with the estimated Cs-137 concentration in vegetation at the North Firebreak East of Crescent Path, which was 0.22 pCi/g. Using these concentrations, the calculated estimate of dose to aquatic animals was 0.189 µGy/day and the dose to riparian animals was 2.87 µGy/day. Therefore, the dose to aquatic animals was well below the limit of 10 mGy/day. Finally, the dose to riparian animals was also well below the 1 mGy/day limit specified by the regulations.

8.7 CUMULATIVE DOSE

Table 8-6 summarizes the potential cumulative dose from the BNL site in 2018. The total dose to the MEOSI from the air and ingestion pathways was estimated to be 5.0 mrem (50 µSv). In comparison, the DOE limit on dose from all pathways is 100 mrem (1 mSv). Furthermore, the EPA regulatory limit for the air pathway is 10 mrem (0.10 mSv). The cumulative population dose was 2.55 person-rem (2.55E-2 person-Sv) in the year.

In conclusion, the effective dose from BNL operations in 2018 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 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 in the United States is approximately 311 mrem (3.11 mSv). A mammogram gives a dose of approximately 250 mrem (2.5 mSv) and a dental x-ray gives a dose of approximately 70 mrem (0.7 mSv) to an individual. Therefore, a dose of 5.04 mrem from all environmental pathways is a minute fraction of the dose from that of several routine diagnostic procedures as well as natural background radiation.

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