8 Radiological Dose Assessment

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 where models indicate a site-emission source could result in the maximum dose to 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 2020, the total effective dose (TED) to the MEOSI of 0.913 mrem (9.3 µSv) from Laboratory operations was well below the dose limit of 100 mrem in a year required by DOE Order 458.1, as well as all other U.S. Environmental Protection Agency (EPA) and U.S. Department of Energy (DOE) regulatory dose limits for the public, workers, and the environment.

Five years of measurement data are shown in the data tables of this chapter to present and describe trends in measured ambient radiation dose at BNL. In general, the radiological footprint at BNL continues to slowly grow, with a recent peak in 2018, as testing for Ac-225 production occurred. The ambient dose decreased slightly in 2020 as readiness reviews took place in preparation for ramping up production testing for that same process.

The dose estimates for 2020 were calculated using a recent version of the dose modeling software promulgated by the 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 2020 was estimated at 5.6E-5 mrem (5.6E-4 uSv) to the MEOSI. This BNL dose level from the inhalation pathway was less than one 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 0.913 mrem (9.13 µSv) from the consumption of deer meat. The onsite portions of the Peconic River did not have sufficient water to support fish populations of sufficient size for surveillance monitoring, therefore there was no dose attributable to BNL legacy Cs-137 levels in fish in the Peconic River. In summary, the total annual dose to the MEOSI from all pathways was estimated at 0.913 mrem (9.3 µSv), which is less than 1.0 percent of DOE's 100-mrem limit. The aggregate population dose was 2.05E-3 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 thermoluminescent dosimeter (TLD) monitoring records, was 27 mrem above natural background radiation levels, also well below the 100-mrem DOE limit on dose. The average annual external dose from ambient sources on site was 64 ± 9 mrem (640 ± 90 µSv), while the dose from off-site ambient sources was 61 ± 14 mrem (610 ± 140 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. Additional 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 2020 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. To this end, the Laboratory's routine operations, scientific experiments, and new research projects are evaluated for their radiological dose risk. The dose risks from demolishing decommissioned facilities and decontamination work are also evaluated. All environmental pathway scenarios with potential for dose to humans, aquatic life, plants, and animals are evaluated to estimate 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 2020. 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). These 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 contributions from cosmic and terrestrial sources, and with no contributions 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 (See Photo 8-1). On- and off-site land areas are divided into grids, and each TLD is assigned a unique identification code based on those grids.

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

In 2020, a total of 60 environmental TLDs were deployed on site, ten of which were placed in known radiation areas. A total of 17 environmental TLDs were deployed at off-site locations (see Figures 8-1 and 8-2). In 2020, all 16 wind sectors around the Laboratory had TLD locations. 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 2020, reported as 075-TLD4

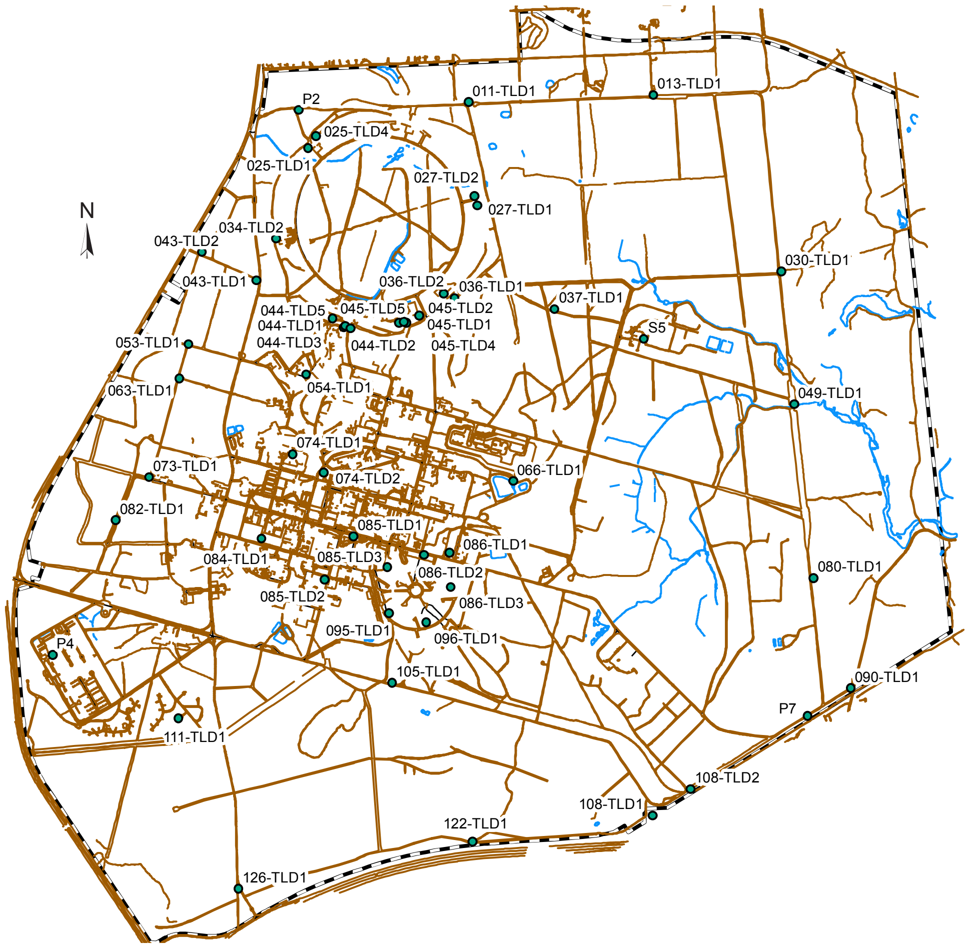

Figure 8-1. On-Site TLD Locations.

in Tables 8-1 and 8-2, was 29 ± 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 annual total external radiation dose measured. Table 8-1 shows the annual on-site radiation dose measurements from 2016 to 2020. For 2020, the on-site external dose from all potential environmental sources, including cosmic and terrestrial radiation sources, was 64 ± 9 mrem (640 ± 90 µSv). The onsite measurements in this table generally exhibit year-to-year variation within ten percent or less of the average. The same can be said about the off-site measured doses in Table 8-2, which shows the annual off-site radiation dose measurements from 2016 to 2020. The off-site ambient dose in 2020 from all potential environmental sources, including cosmic and terrestrial radiation sources, was 61 ± 14 mrem (610 ± 140 µSv).

To determine the BNL contribution to the external direct radiation dose, a statistical t-test between the measured on- and off-site external doses was conducted. The test showed no significant difference between the off-site dose (61 ± 14 mrem) and on-site dose (64 ± 9 mrem) at the

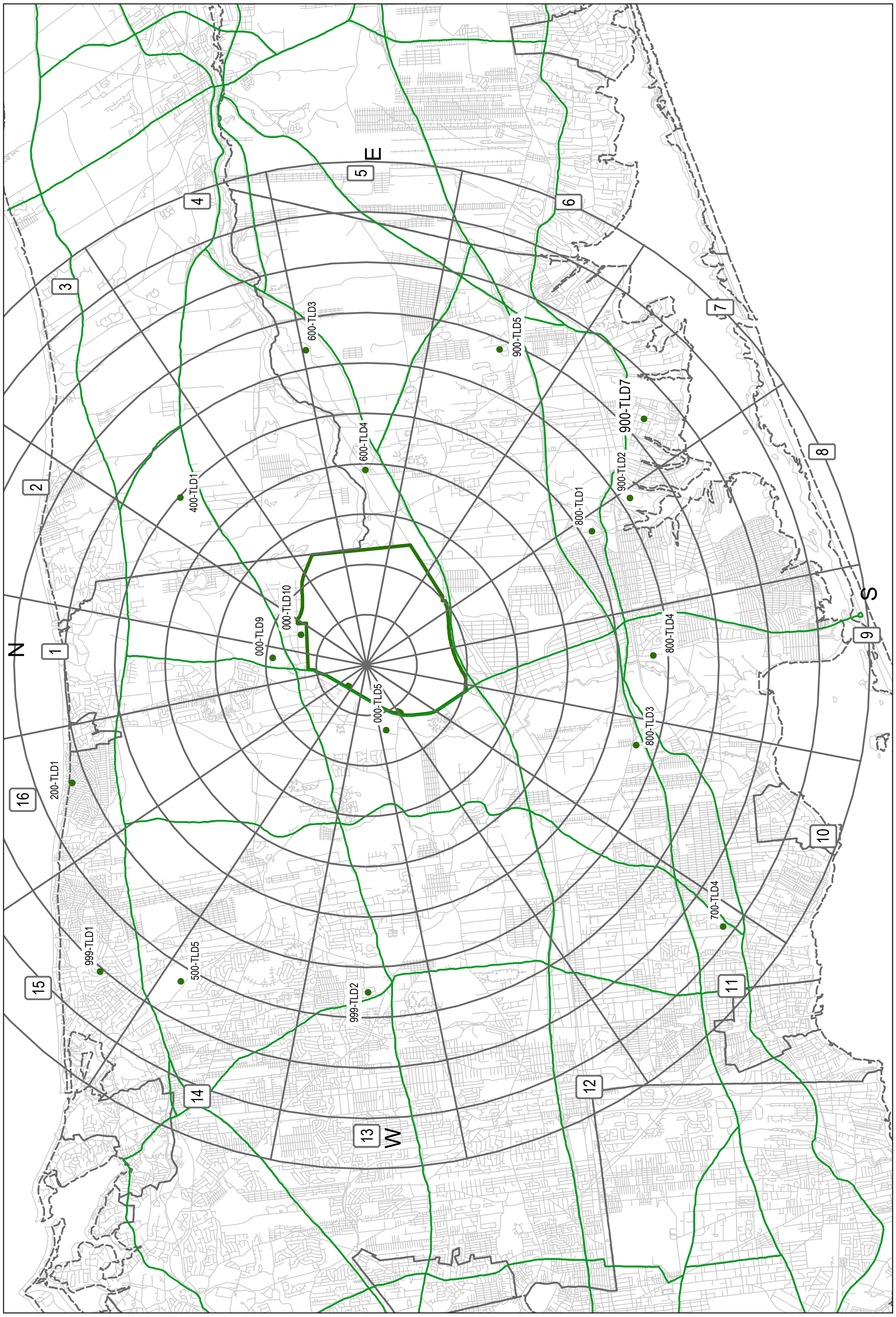

Figure 8-2. Off-Site TLD Locations.

Table 8-1. Five-Year Annual On-Site Direct Ambient Radiation Measurements (2016-2020).

		Annual Total Dose, mrem (±2σ, 95% conf. interval)				
TLD#	Location	2016	2017	2018	2019	2020
011-TLD1	North Firebreak	53±3	56±12	58±8	55±13	58±3
013-TLD1	North Firebreak	59±6	61±8	61±11	62±12	61±4
025-TLD1	Bldg. 1010, Beam Stop 1	63±9	61±12	63±7	58±14	63±19
025-TLD4	Bldg. 1010, Beam Stop 4	63±10	67±22	62±10	59±9	60±11
027-TLD1	Bldg. 1002A South	58±10	58±9	60±9	58±14	57±9
027-TLD2	Bldg. 1002D East	59±12	58±12	62±18	55±13	56±9
030-TLD1	Northeast Firebreak	62±3	64±11	64±11	59±7	64±9
034-TLD1	Bldg. 1008, Collimator 2	64±7	NLP	NLP	NLP	NLP
034-TLD2	Bldg. 1008, Collimator 4	66±11	66±9	67±12	65±11	66±10
036-TLD1	Bldg. 1004B, East	57±8	58±14	57±9	58±12	56±12
036-TLD2	Bldg. 1004, East	61±9	61±12	62±10	58±11	58±4
037-TLD1	S-13	59±6	60±11	59±7	58±12	62±7
043-TLD1	North Access Road	68±8	66±6	69±11	68±14	66±10
043-TLD2	North of Meteorology Tower	66±5	67±11	66±10	65±15	67±6
044-TLD1	Bldg. 1006	65±10	67±11	69±13	61±10	61±8
044-TLD2	South of Bldg. 1000E	67±11	67±8	67±11	64±6	62±9
044-TLD3	South of Bldg. 1000P	62±15	65±10	66±20	60±10	59±8
044-TLD4	Northeast of Bldg. 1000P	68±14	NLP	NLP	NLP	NLP
044-TLD5	North of Bldg. 1000P	68±14	67±18	67±14	59±9	63±7
045-TLD1	Bldg. 1005S	59±9	62±10	63±14	62±9	61±10
045-TLD2	East of Bldg. 1005S	62±5	62±10	67±10	59±10	63±16
045-TLD3	Southeast of Bldg. 1005S	65±7	NLP	NLP	NLP	NLP
045-TLD4	Southwest of Bldg. 1005S	65±13	64±13	69±21	61±13	62±6
045-TLD5	West-Southwest of Bldg. 1005S	63±8	60±11	66±14	64±12	61±5
049-TLD1	East Firebreak	64±6	65±11	70±11	62±10	66±16
053-TLD1	West Firebreak	69±6	66±7	71±11	71±22	72±6
063-TLD1	West Firebreak	69±8	70±13	72±6	68±14	71±4
066-TLD1	Waste Management Facility	54±6	57±12	60±9	52±11	55±5
073-TLD1	Meteorology Tower	66±6	66±12	66±11	63±6	69±10
074-TLD1	Bldg. 560	69±8	72±21	73±15	67±13	65±10
074-TLD2	Bldg. 907	63±9	63±10	66±14	61±19	62±9
080-TLD1	East Firebreak	73±6	70±10	72±6	70±18	66±5
082-TLD1	West Firebreak	73±10	71±13	73±7	71±13	74±9
084-TLD1	Tennis courts	65±4	63±7	72±19	63±12	65±8
085-TLD1	Bldg. 735	64±8	66±16	68±11	65±15	65±12
085-TLD2	Upton Gas Station	65±7	67±7	66±9	66±17	67±9
085-TLD3	NSLS-II LOB 745	NYP	64±4	71±13	68±20	66±6
086-TLD1	Baseball Fields	62±7	64±7	66±8	61±11	66±8
086-TLD2	NSLS-II LOB 741	NYP	59±3	64±14	56±11	61±17
086-TLD3	NSLS-II LOB 742	NYP	55±4	59±11	60±16	62±12
090-TLD1	North St. Gate	66±8	66±7	64±9	62±11	61±8

(continued on next page)

Table 8-1. Five-Year Annual On-Site Direct Ambient Radiation Measurements (2016-2020). *(concluded).*

		Annual Total Dose, mrem (±2σ, 95% conf. interval)				
TLD#	**Location**	**2016**	**2017**	**2018**	**2019**	**2020**
095-TLD1	NSLS-II LOB 744	NYP	68±2	70±8	68±19	70±13
096-TLD1	NSLS-II LOB 743	NYP	58±3	62±10	59±12	58±8
105-TLD1	South Firebreak	70±7	70±8	68±14	73±24	69±10
108-TLD1	Water Tower	65±5	73±25	65±11	62±12	64±5
108-TLD2	Tritium Pole	79±4	77±14	82±16	82±9	78±9
111-TLD1	Trailer Park	66±1	65±7	72±6	69±10	66±9
122-TLD1	South Firebreak	65±13	64±16	62±11	60±12	61±6
126-TLD1	South Gate	72±4	72±16	75±17	68±9	72±13
P2	NW Corner Site Perimeter Station	57±8	56±9	58±8	55±10	56±5
P4	SW Corner Site Perimeter Station	62±5	64±16	64±11	60±12	59±10
P7	SE Corner Site Perimeter Station	63±9	66±12	66±9	64±10	66±10
S5	Sewage Treatment Plant	60±3	58±11	61±11	57±13	61±9
On-Site Average		**64±8**	**65±11**	**66±11**	**62±12**	**64±9**
Off-site average (Table 8-2)		**60±8**	**61±11**	**64±10**	**59±11**	**61±14**
075-TLD4: Control TLD Average		**27±3**	**29±3**	**30±2**	**27±3**	**29±4**

Notes :
See Fig. 8-1 for TLD Locations
Note: Beginning with the 2017 calendar year, a handful of stable-dose-level TLDs were moved from other locations onsite to the NSLS-II locations.
NLP = No Longer Posted. TLDs were removed from these locations to be posted at NSLS-II.
NYP = The NSLS-II locations had not yet been posted with EM TLDs in 2015 and 2016.

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 2020.

8.1.2 Facility Area Monitoring

Ten on-site TLDs are designated as facility area monitors (FAMs) because they are posted in known radiation areas (i.e., near facilities). Table 8-3 shows the external doses measured with the FAM TLDs from 2016 to 2020. Environmental TLDs 088-TLD1 through 088-TLD4 are posted at and near the S-6 blockhouse location on the fence of the Former Waste Management Facility (FWMF). Except for the doses at 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. The 088-TLD1 had the highest dose reading of the four, which can be attributed to waste-loading activities at the nearby rail spur in recent years. As shown in Table 8-3, overall dose levels near the FWMF have been fairly consistent. Access to the FWMF is controlled by fencing.

Two TLDs (075-TLD3 and 075-TLD5) near Building 356 showed a higher annual dose of 99 ± 9 mrem (990± 90 µSv) for 075-TLD3 and 107 ± 14 mrem (1070 ± 140 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 printed circuit boards. Higher doses are to be expected there as the source collimators were removed in 2018 to allow for objects to be placed closer to the source due to declining dose rates resulting from source decay. In addition, the source is left up for longer periods, sometimes overnight, and generates "sky-shine." Finally, this building also contains several Californium-252 (Cf-252) neutron sources in a cask near the corner

Table 8-2. Five-Year Annual Off-Site Direct Ambient Radiation Measurements (2016-2020).

TLD#	Location	Annual Total, mrem (±2σ, 95% Conf. Interval)				
		2016	2017	2018	2019	2020
000-TLD4	Private property	NLP	NLP	NLP	NLP	NLP
000-TLD5	Longwood Estate	55±3	58±8	59±11	58±15	58±7
000-TLD7	Mid-Island Game Farm	NLP	NLP	NLP	NLP	NLP
000-TLD8	Private property	52±30	NLP	NLP	NLP	NLP
000-TLD9	Private property	60±11	56±7	58±9	53±10	61±13
000-TLD10	Private property	63±6	65±7	66±10	62±8	61±16
004-TLD1	Private property**	NLP	NLP	NLP	NLP	NLP
200-TLD1	Private property	NYP	NYP	71±14	66±12	70±20
200-TLD5	Private property	NYP	NYP	78±10	74±21	69±38
400-TLD1	Calverton Nat. Cemetery	69±5	68±14	71±10	61±9	67±8
500-TLD4	Private property	63±9	58±2	NLP	NLP	NLP
600-TLD3	Private property	64±14	62±8	68±12	59±2	65±10
600-TLD4	Maples B&G	59±2	57±9	59±7	57±11	59±10
700-TLD3	Private property	58±7	58±12	NLP	NLP	NLP
700-TLD4	Private property	60±5	60±7	61±10	57±6	56±9
800-TLD1	Private property	62±5	65±21	65±14	56±9	63±11
800-TLD3	Suffolk County CD	64±2	62±5	62±8	61±16	63±12
800-TLD4	LI Nat'l Wildlife Refuge	64±6	58±12	63±4	56±12	59±10
900-TLD2	Private property	57±0	62±26	62±18	57±15	56±14
900-TLD4	Private property	60±13	72±26	NLP	NLP	NLP
900-TLD5	Private property	56±7	54±5	59±7	50±3	49±8
900-TLD6	Private property	54±10	NLP	NLP	NLP	NLP
900-TLD7	Private property	NYP	NYP	67±8	61±13	64±18
999-TLD1	Private property	61±10	61±7	64±7	58±12	64±18
999-TLD2	Private property	NYP	NYP	73±2	52±12	61±13
Off-site average		**60±8**	**61±11**	**64±10**	**59±11**	**61±14**
075-TLD4 : Control TLD Average		**27±3**	**29±3**	**30±4**	**27±3**	**29±4**

Notes:
See Fig. 8-2 for TLD Locations
Note: TLDs are placed by volunteers or other entities.
Year-to-year, willingness to participate varies among owners at these locations.
NLP = No Longer Posted. TLDs were removed from these locations.
NYP = Not Yet Posted with TLDs.
**TLD designator 004-TLD1 was changed to 000-TLD10 to align its designator with the naming convention.

Table 8-3. Five-Year Annual Facility Area Monitoring Results (2016-2020).

TLD#	Location	Annual Total, mrem (±2σ, 95% Conf. Interval)				
		2016	2017	2018	2019	2020
054-TLD1	Bldg. 914	82±34	83±44	91±48	75±33	65±12
054-TLD2	NE of Bldg. 913B	89±45	85±53	86±49	76±30	66±13
054-TLD3	NW of Bldg. 913B	77±32	76±43	81±47	72±24	66±13
S6	FWMF blockhouse	71±2	70±13	71±11	69±17	69±11
088-TLD1	FWMF, 50' East of S6	79±2	82±5	84±12	77±12	79±7
088-TLD2	FWMF, 50' West of S6	73±5	73±11	74±12	72±13	77±14
088-TLD3	FWMF, 100' West of S6	76±5	77±12	75±7	74±8	74±11
088-TLD4	FWMF, 150' West of S6	66±6	65±7	67±8	69±13	66±11
075-TLD3	Building 356	80±9	85±22	80±18	100±17	99±9
075-TLD5	North Corner of Bldg. 356	79±14	86±24	80±22	109±20	107±14

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

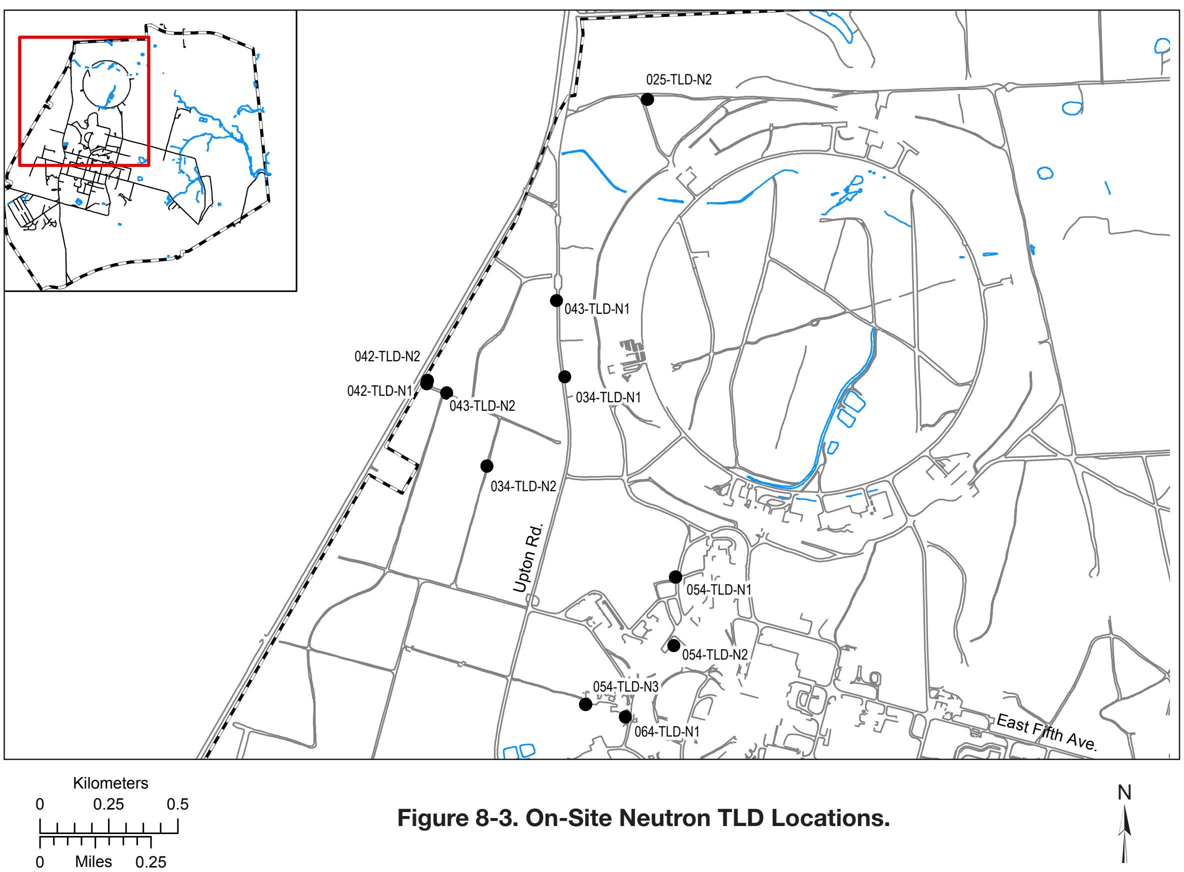

Figure 8-3. On-Site Neutron TLD Locations.

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 ambient external dose. The full-year dose at these sites was measured at 65 mrem for 054-TLD1, 66 mrem for 054-TLD2, and 66 mrem for 054- TLD3 (compared to the on-site dose of 64 ± 9 mrem and off-site dose of 61 ± 14 mrem). The slightly higher levels of the first and second quarters (not shown) are expected because the operating period for the AGS is typically in the first half of the calendar year.

8.1.2.1 Neutron Monitoring

The AGS accelerates protons to energies up to 30 GeV and heavy ions up to 15 GeV/amu. 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 for ions. Under these high-energy conditions, such accelerated particles have the potential to generate high-energy neutrons when the particles leave the walls of the accelerator and produce nuclear fragments along their path or as they collide with matter. In 2020, 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 placement of neutron TLDs is based on facility 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 on polyethylene cylinders 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 and reflected back out, where the TLD can detect them. The neutron TLDs are mounted 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

Photo 8-2. Neutron TLDs in Monitored Area

side-by-side decreases the potential dependence of measured dose on mounting orientation; and the reflected neutron could strike either neutron TLD and be counted (see Photo 8-2).

Table 8-4 shows the measured ambient neutron doses recorded from 2016 to 2020. In 2020, four neutron TLD locations showed 1 mrem and three showed 2 mrem, for a total of 10 mrem. 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 FOR AIRBORNE RADIONUCLIDES

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 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 periodic confirmatory measurements for all other release points. The regulations also require DOE facilities to submit an annual NESHAPs report to the EPA that describes the major and minor emission sources, their releases, and their resultant dose to the Maximally Exposed Off Site Individual (MEOSI). The dose estimates from various facilities are

Table 8-4. Five-Year Annual Neutron Monitoring Results (2016-2020).

Neutron TLD #	Location ID No.	Annual Total, mrem neutron				
		2016	2017	2018	2019	2020
TK275	025-TLD-N1	0	0	NLP	NLP	NLP
TK276	"	0	0	NLP	NLP	NLP
TK277	025-TLD-N2	0	0	0	0	2
TK278	"	0	2	2	0	0
TK279	034-TLD-N1	0	1	0	1	1
TK280	"	1	0	1	0	0
TK281	034-TLD-N2	0	0	0	0	0
TK282	"	0	1	1	0	0
TK283	043-TLD-N1	0	0	0	0	1
TK284	"	0	1	0	0	0
TK285	043-TLD-N2	0	0	0	0	0
TK286	"	0	0	1	2	0
TK287	042-TLD-N1	0	0	0	1	1
TK288	"	1	0	0	1	0
TK289	042-TLD-N2	3	0	0	0	0
TK290	"	0	0	0	0	0
TK291	054-TLD-N1	0	0	0	0	2
TK292	"	0	0	0	0	0
TK293	054-TLD-N2	0	1	0	0	0
TK294	"	0	2	0	0	0
TK295	054-TLD-N3	1	0	0	0	0
TK296	"	0	0	0	1	2
TK297	064-TLD-N1	2	1	0	0	0
TK298	"	0	0	1	0	1
PM-bkg		1	1	1	1	1

NLP = No Longer Posted. TLDs were removed from these locations to be posted at NSLS-II.

given in Table 8-5, and the actual air emissions for 2020 are discussed in detail in Chapter 4.

As a part of the NESHAPs review process at 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

Table 8-5. Maximally Exposed Off-site Individual (MEOSI) Effective Dose Equivalent From Facilities or Routine Processes, 2020.

Building No.	Facility or Process	Construction Permit No.	MEOSI Dose (mrem) (a)	Notes
120	Instrumentation & Calibration	None	ND	(f)
348	Instrumentation & Calibration	None	ND	(f)
463	Biology	None	3.19E-08	(b)
480	Condensed Matter Physics	None	2.76E-15	(b)
490	Personnel Monitoring	None	3.02E-08	(b)
510A	Physics	None	8.25E-10	(b)
535	Instrumentation	None	ND	(f)
555	Chemistry Facility	None	ND	(f)
734	Interdisciplinary Science Building	None	7.02E-09	(b)
735	Center for Functional Nanomaterials	None	ND	(f)
745	NSLS-II	None	1.42E-08	(b)
750	HFBR	None	5.19E-05	(c)
750	Nonproliferation & National Security	None	ND	(g)
801	Target Processing Lab	None	1.56E-07	(c)
815	Nonproliferation & National Security	None	1.32E-16	(b)
820	Accelerator Test Facility	BNL-589-01	4.04E-12	(b)
830	Environmental Science Department	None	ND	(f)
865	Waste Management Facility	None	ND	(d)
902	Superconducting Magnet Division	None	ND	(f)
906	Imaging Lab	None	ND	(f)
911	Collider-Accelerator	None	ND	(f)
925	RF Systems	None	ND	(f)
931	BLIP	BNL-2009-01	3.84E-06	(c)
942	AGS Booster	BNL-188-01	ND	(e)
---	RHIC	BNL-389-01	ND	(d)
Total Potential Dose from BNL Operations			**5.60E-05**	
EPA Limit (Air Emissions)			**10**	

Notes:
MEOSI = Maximally Exposed Offsite 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 2020.
(e) Booster ventilation system prevents air release through continuous air recirculation.
(f) No radiological dispersible material inventory in 2020.
(g) Sealed sources were excluded from this inventory - no emission

1988 (CAP88-PC). This computer program uses a Gaussian plume model to characterize the average dispersion of airborne radionuclides released from elevated stacks or diffuse sources. CAP88-PC then calculates the effective dose equivalent (EDE) to the MEOSI from low levels of radioactive materials released into the environment. Site-specific meteorology data was 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. CAP88-PC calculated the EDE at the MEOSI location from the immersion, inhalation, and ingestion pathways, and also calculated the collective population dose within a 50-mile radius of the emission source.

As stated above, these dose and risk calculations to the MEOSI are based on low emissions and chronic intakes. In most cases, the CAP88-PC model provides conservative dose estimates. For the purpose of modeling their dose to the MEOSI, all emissions are treated as having been released from 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. As mentioned earlier, weather data are supplied by measurements from the Laboratory's meteorological towers. Such measurements include wind speed, direction, and frequency, as well as air temperature and precipitation amount (see Chapter 1 for details). Solar radiation effects are also accounted for. 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 2020 effective dose equivalents were estimated using Version 4.0.1.17 of CAP88-PC. The following approaches and assumptions supported the dose estimates in this annual report:

- A conservative approach is used for agricultural data input to the CAP88 modeling program, with 92 percent of vegetables, 100 percent of milk, and 99 percent of meat assumed to originate 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 2020 was 509.2 cfm, or 0.240 m3/sec. With an exit diameter of 0.1 m, the exit velocity was 30.6 m/sec, down slightly from last year's 31.04 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 located beyond the BNL site boundary 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, off-site, and close to the emission point nearest to the BNL site boundary. The MEOSI 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 onsite maximally exposed individual (MEI) who could receive any dose outside of BNL's controlled areas was determined by TLD measurements (see Table 8-7). The dose to the MEI on site and outside of controlled areas (near Building 356) was measured at 27 mrem in 2020. The increase in MEI dose in 2020 was due to nearly continuous research irradiations conducted with a Co-60 source in Building 356 during the year, as discussed in section 8.1.2. The 27-mrem dose to the on-site MEI is less than the dose expected from seven round-trip flights from

Los Angeles, California to New York, New York, and equal to eight percent of the average annual natural background in the U.S. of 311 mrem.

8.2.2.2 Dose Calculation: Fish Ingestion

To calculate the EDE from fish consumption, the annual intake is estimated first, which is defined at BNL as the average weight of fish consumed in a year by a Reference Person engaged in recreational fishing on the Peconic River. Based on a New York State Department of Health (NYSDOH) study, that 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 is 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 for a Reference Person, as listed in DOE-STD-1196-2011, Table A-1, is used for each radionuclide to convert the activity concentration to the EDE. The dose is calculated as: dose in (rem/yr) = intake (kg/yr) × activity in flesh (µCi/kg) × dose conversion factor (rem/µCi). For BNL's case, the committed dose equivalent conversion factor for Cesium-137 (Cs-137) is 4.92E-02 rem/µCi.

8.2.2.3 Dose Calculation: Deer Meat Ingestion

The dose calculation for deer meat ingestion is like that for fish consumption. The same Cs-137 dose conversion factor was used to estimate dose. No other radionuclides associated with Laboratory operations have been detected in deer meat. The total quantity of deer meat ingested during a year has been estimated by the NYSDOH 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 radionuclides 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.

8.3.1 Remediation Work

In 2020, remediation work commenced on the HFBR stack (Building 705) in October and continued through the end of the year. A NESHAPs evaluation of the levels of stack radioactivity was previously performed and confirmed again in 2018. The estimated dose resulting from demolition was found to be below the threshold for NESHAPs authorization.

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, specifically 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 glass-fiber 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 which is then analyzed at an off-site contract analytical laboratory on a weekly basis.

In 2020, the BLIP facility did not operate with beam due to a series of readiness reviews. Therefore, typical isotopes C-11 (half life: 20.4 minutes) and O-15 (half life: 122 seconds) were not released from the BLIP facility. A small quantity (1.56E- 02 Ci) of residual tritiated water vapor from previous activation of the targets' cooling

Table 8-6. Five-Year Site Dose Summary, 2020.

	2016	2017	2018	2019	2020
Pathway	**Annual Maximally Exposed Off-Site Individual Dose, mrem**				
Inhalation					
Air	0.62	0.72	1.63	1.28	5.6E-5
Ingestion					
Drinking Water	None	None	None	None	None
Fish[1]	0.088	0.088	0.088	0.088	NS
Deer	2.45	4.8	3.32	1.4	0.913
All Pathways	**3.16**	**5.61**	**5.04**	**2.77**	**0.913**
Pathway	**Percent of DOE 100-mrem/yr Dose Limit, %**				
Inhalation					
Air	<1.0	<1.0	<2.0	<1.5	<0.001
Ingestion					
Drinking Water	None	None	None	None	None
Fish[1]	<0.1	<0.1	<0.1	<0.1	NS
Deer	<3.0	<5.0	<4.0	<1.5	<1.0
All Pathways	**<4.0**	**<6.0**	**<6.0**	**<3.0**	**<1.0**
Pathway	**Estimated Population Dose Per Year, person-rem**				
Inhalation					
Air	0.94	1.16	2.55	1.81	2.05E-03
Ingestion					
Drinking Water	None	None	None	None	None
Fish[1]	Not Tracked	Not Tracked	Not Tracked	Not Tracked	Not Tracked
Deer	Not Tracked	Not Tracked	Not Tracked	Not Tracked	Not Tracked
All Pathways	**0.94**	**1.16**	**2.55**	**1.81**	**2.05E-03**

Note:
1 - Source River remained dried up in 2020, so no fish data was available to represent magnitude since sampling was not possible in 2020.

water was released since the exhaust system ran continuously, as normal. The EDE to the MEOSI from BLIP operations was calculated to be 3.84E-6 mrem (3.84-5 µSv) in a year.

8.4.2 Target Processing Laboratory

In 2020, there were no detectable levels of emissions from the Target Processing Laboratory.

8.4.3 High Flux Beam Reactor

In 2020, the residual tritium emissions from the HFBR facility were measured at 0.227 Ci, and the estimated dose attributed was 5.19E-5 mrem (5.19E-4 µSv) in a year.

8.4.4 Brookhaven Medical Research Reactor

In 2020, 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 2020.

8.4.5 Brookhaven Graphite Research Reactor

In 2020, 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

Table 8-7. Five-Year Annual Maximally Exposed Onsite Individual Dose (2016-2020).

TLD #	Location	Annual Total, mrem				
		2016	2017	2018	2019	2020
TK154	2nd Floor, B120	5	8	14	25	27
TK155	1st Floor, B120	3	2	5	20	18

radionuclides released to the environment from the complex in 2020.

8.4.6 Waste Management Facility

In 2020, there were no detectable levels of emissions from the Waste Management Facility.

8.4.7 Unplanned Releases

In 2020, 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 collected 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, but K-40 is a naturally occurring radionuclide unrelated to BNL operations.

In 2020, BNL collected samples from 13 deer, eight of those from a managed cull, 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 back and forth across the site boundary. From Table 6-2, the average K-40 concentration in all deer tissue samples (All Samples) was 2.95 ± 1.06 pCi/g (wet weight) in the flesh (i.e., meat) and 2.09 ± 0.67 pCi/g (wet weight) in the liver. The average K-40 flesh concentration in culled deer tissue samples (Managed Cull) was 2.77 ± 0.97 pCi/g (wet weight). The average K-40 liver concentration in culled deer tissue samples (Managed Cull) was 2.15 ± 0.53 pCi/g (wet weight). The maximum Cs-137 flesh concentration in all samples on site (non-culled and culled) was 0.24 ± 0.02pCi/g (wet weight). The maximum Cs-137 flesh concentration of 0.64 ± 0.01 pCi/g, taken from a deer sample collected less 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 0.913 mrem (9.13 µSv) in a year. This dose is below the health advisory limit of 10 mrem (100 µSv) established by NYSDOH.

The Laboratory maintains an ongoing program of collecting and analyzing fish from the on-site portions of 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 2020, the Peconic River did not have sufficient water to support fish populations, therefore there was no dose attributable to BNL legacy Cs-137 levels in fish in the Peconic River.

8.6 DOSE TO AQUATIC AND TERRESTRIAL BIOTA

DOE-STD-1153-2019, 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 2020, the terrestrial animal and plant doses were evaluated based on 0.77 pCi/g of Cs-137 (see Table 6-3) found in soil near the glass holes area, and a Strontium-90 (Sr-90) concentration of 0.75 pCi/L (see Table 5-5) in the surface water collected from the HM-S station associated with a tributary on site. The resultant dose to terrestrial animals was calculated to be 37.1 µGy/day and to plants as 3.49 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 2020, the surface water Sr-90 concentration mentioned above, 0.75 pCi/L, was used along with the estimated Cs-137 concentration in vegetation from the west side of First Street, north of East Fifth Avenue, which was 0.12 pCi/g. Using these concentrations, the calculated estimate of dose to aquatic animals was 0.163 µGy/day, and the dose to riparian animals was 2.73 µGy/day. Therefore, the dose to aquatic animals was well below the limit of 10 mGy/day, and the dose to riparian animals was also well below the 1 mGy/day limit specified by the Order.

8.7 DOSE FROM ALL PATHWAYS

Table 8-6 summarizes the estimated dose to the MEOSI from the inhalation, immersion, and ingestion pathways, the percentage of the 100-mrem annual allowable dose limit posed by the estimated MEOSI dose, by pathway, and the potential cumulative dose to the surrounding population via the inhalation pathway from the BNL site, for the years 2016 through 2020. The total dose to the MEOSI from the air and ingestion pathways was estimated to be 0.913 mrem (9.3 mSv). 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 from airborne emissions was 2.05E-3 person-rem (2.05E-2 person-Sv) in 2020.

In conclusion, the effective dose from all pathways due to BNL operations in 2020 was well below the DOE and EPA regulatory limits, and the ambient offsite TLD dose was within limits of 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 0.913 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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