8 Radiological Dose Assessment

Brookhaven National Laboratory'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. 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 2022, the total effective dose (TED) to the MEOSI from Laboratory operations was five percent of the dose limit of 100 mrem in a year required by DOE Order 458.1 and well below 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.

The dose estimates for 2022 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 2022 was estimated at 1.19 mrem (11.9 uSv) to the MEOSI. This BNL dose level from the inhalation pathway was 11.9 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 3.82 mrem (38.2 µSv) from the consumption of deer meat. The on-site 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 Cesium-137 levels in fish in the Peconic River. In summary, the total annual dose to the MEOSI from all pathways was estimated at 5.01 mrem (50.1 µSv), which is five percent of DOE's 100-mrem limit. The aggregate population dose was 5.6 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.

Five years of measurement data are shown in the data tables to present the recent history of measured ambient radiation dose at BNL. In 2022, the ambient dose remained indistinguishable from background.

Dose to the maximally exposed individual (MEI) on site and outside of controlled areas, calculated from thermo-luminescent dosimeter (TLD) monitoring records, was 26 ± 8 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 61 ± 7 mrem (610 ± 70 µSv), while the dose from off-site ambient sources was 58 ± 6 mrem (580 ± 60 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 53 on-site TLDs and 16 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 2022 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 2022. The Laboratory's current radiological risks are from very small quantities of radionuclides used in science experiments, production of radiopharmaceuticals at the Brookhaven Linear Accelerator (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 evaluations 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 2022, a total of 63 environmental TLDs were deployed on-site, ten of which were placed in known radiation areas (Figure 8-3). A total of 16 environmental TLDs were deployed at off-site locations (see 8-2). In 2022, all 16 wind sectors around the Laboratory, except one, had at least one TLD location. An additional 30 TLDs were stored on-site in a lead-shielded container for use as reference and control TLDs for comparison

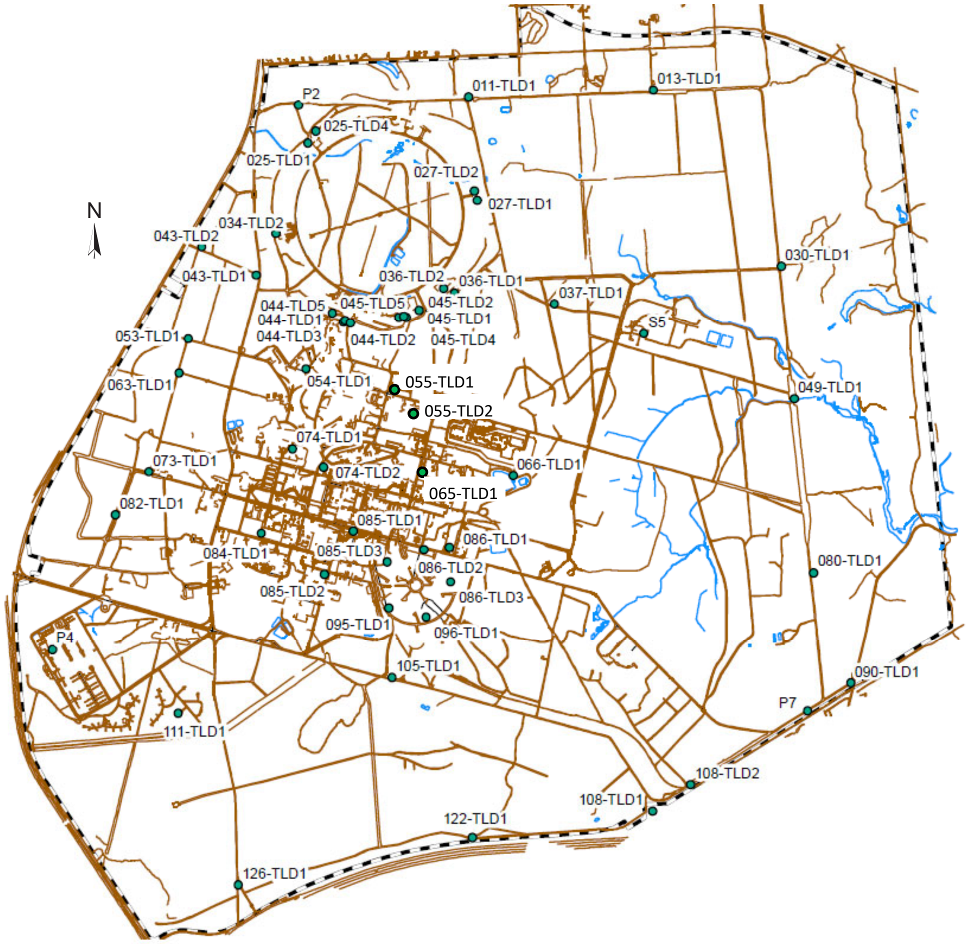

Figure 8-1. On-Site TLD Locations.

purposes. The total of the control TLD dose values for 2022, reported as 075-TLD4 in Tables 8-1 and 8-2, was 26 ± 3 (260 +/- 30 uSv). 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 2018 to 2022. For 2022, the on-site external dose from all potential environmental sources, including cosmic and terrestrial radiation sources, was 61 ± 7 mrem (610 ± 70 µSv). The on-site 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 2018 to 2022. The off-site ambient dose in 2022 from all potential environmental sources, including cosmic and terrestrial radiation sources, was 58 ± 6 mrem (580 ± 60 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

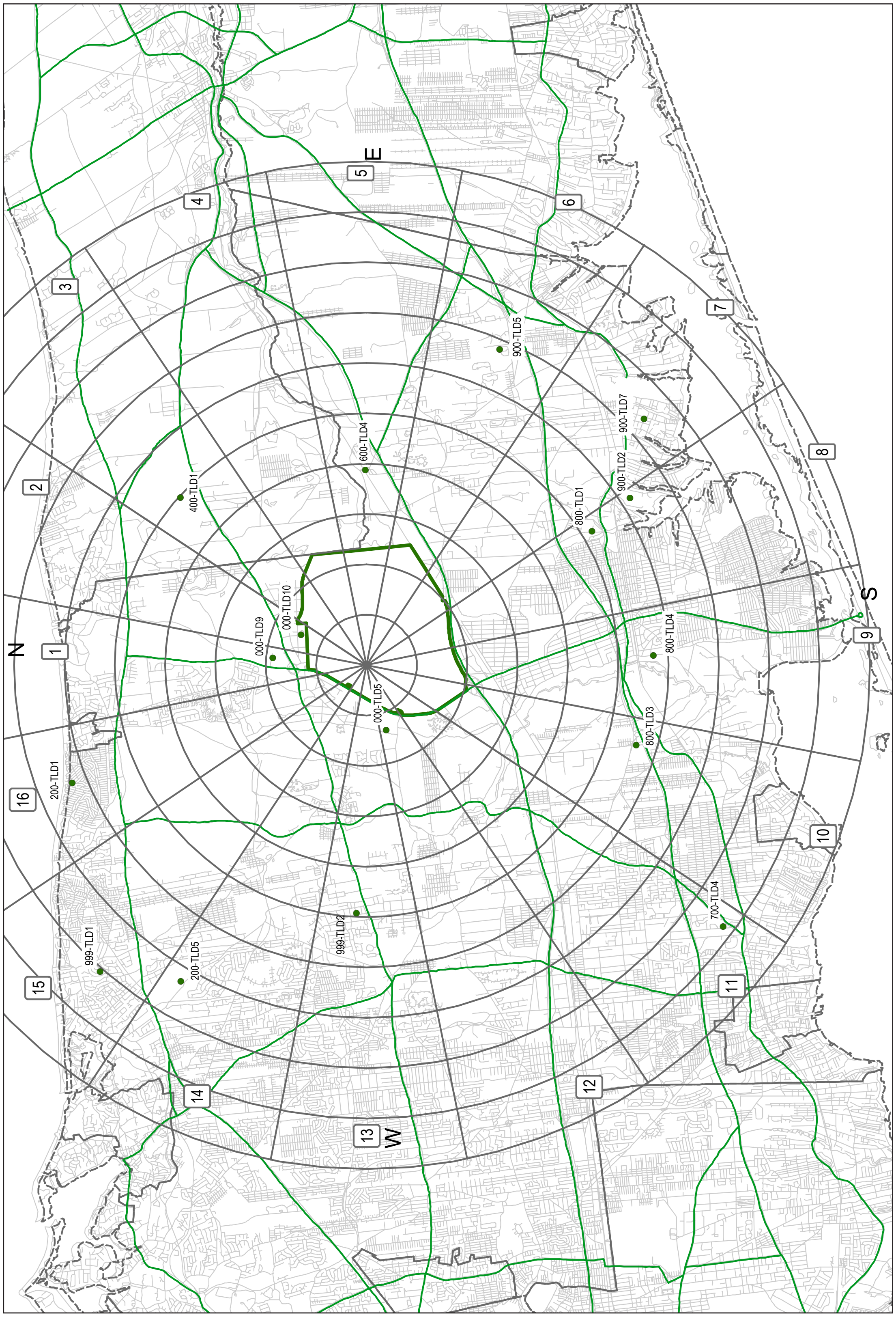

Figure 8-2. Off-Site TLD Locations.

Table 8-1. Five-Year Annual On-Site Direct Ambient Radiation Measurements (2018-2022).

		Annual Total Dose, mrem (±2σ, 95% conf. interval)				
TLD#	**Location**	**2018**	**2019**	**2020**	**2021**	**2022**
011-TLD1	North Firebreak	58±8	55±13	58±3	61±8	52±4
013-TLD1	North Firebreak	61±11	62±12	61±4	68±10	59±7
025-TLD1	Bldg. 1010, Beam Stop 1	63±7	58±14	63±19	70±12	56±8
025-TLD4	Bldg. 1010, Beam Stop 4	62±10	59±9	60±11	64±11	57±6
027-TLD1	Bldg. 1002A South	60±9	58±14	57±9	62±13	55±7
027-TLD2	Bldg. 1002D East	62±18	55±13	56±9	62±14	53±3
030-TLD1	Northeast Firebreak	64±11	59±7	64±9	65±13	61±6
034-TLD2	Bldg. 1008, Collimator 4	67±12	65±11	66±10	71±10	59±9
036-TLD1	Bldg. 1004B, East	57±9	58±12	56±12	62±8	54±6
036-TLD2	Bldg. 1004, East	62±10	58±11	58±4	66±12	56±6
037-TLD1	S-13	59±7	58±12	62±7	67±12	58±3
043-TLD1	North Access Road	69±11	68±14	66±10	72±15	66±4
043-TLD2	North of Meteorology Tower	66±10	65±15	67±6	71±12	63±3
044-TLD1	Bldg. 1006	69±13	61±10	61±8	67±10	61±4
044-TLD2	South of Bldg. 1000E	67±11	64±6	62±9	70±10	62±6
044-TLD3	South of Bldg. 1000P	66±20	60±10	59±8	64±10	59±4
044-TLD5	North of Bldg. 1000P	67±14	59±9	63±7	66±19	62±8
045-TLD1	Bldg. 1005S	63±14	62±9	61±10	69±10	57±3
045-TLD2	East of Bldg. 1005S	67±10	59±10	63±16	67±11	61±7
045-TLD4	Southwest of Bldg. 1005S	69±21	61±13	62±6	68±7	58±5
045-TLD5	West-Southwest of Bldg. 1005S	66±14	64±12	61±5	70±11	60±7
049-TLD1	East Firebreak	70±11	62±10	66±16	55±13	62±2
053-TLD1	West Firebreak	71±11	71±22	72±6	74±17	65±9
055-TLD1	Thomson and Fifth	NYP	NYP	NYP	NYP	59±8
055-TLD2	Building 935	NYP	NYP	NYP	NYP	59±8
063-TLD1	West Firebreak	72±6	68±14	71±4	74±9	65±6
065-TLD1	Building 820	NYP	NYP	NYP	NYP	63±7
066-TLD1	Waste Management Facility	60±9	52±11	55±5	64±13	58±14
073-TLD1	Meteorology Tower	66±11	63±6	69±10	68±11	64±3
074-TLD1	Bldg. 560	73±15	67±13	65±10	73±13	69±5
074-TLD2	Bldg. 907	66±14	61±19	62±9	69±12	58±6
080-TLD1	East Firebreak	72±6	70±18	66±5	75±11	67±7
082-TLD1	West Firebreak	73±7	71±13	74±9	82±8	68±4
084-TLD1	Tennis Courts	72±19	63±12	65±8	70±7	66±6
085-TLD1	Bldg. 735	68±11	65±15	65±12	69±14	63±10
085-TLD2	Upton Gas Station	66±9	66±17	67±9	69±10	63±6
085-TLD3	NSLS-II LOB 745	71±13	68±20	66±6	72±7	64±12
086-TLD1	Baseball Fields	66±8	61±11	66±8	69±9	62±13
086-TLD2	NSLS-II LOB 741	64±14	56±11	61±17	65±9	58±8
086-TLD3	NSLS-II LOB 742	59±11	60±16	62±12	66±12	56±10
090-TLD1	North St. Gate	64±9	62±11	61±8	49±7	59±7

(continued on next page)

Table 8-1. Five-Year Annual On-Site Direct Ambient Radiation Measurements (2018-2022). *(concluded).*

		Annual Total Dose, mrem (±2σ, 95% conf. interval)				
TLD#	**Location**	**2018**	**2019**	**2020**	**2021**	**2022**
095-TLD1	NSLS-II LOB 744	70±8	68±19	70±13	77±19	69±8
096-TLD1	NSLS-II LOB 743	62±10	59±12	58±8	64±15	56±7
105-TLD1	South Firebreak	68±14	73±24	69±10	73±10	66±6
108-TLD1	Water Tower	65±11	62±12	64±5	68±9	64±5
108-TLD2	Tritium Pole	82±16	82±9	78±9	85±5	78±8
111-TLD1	Trailer Park	72±6	69±10	66±9	73±6	64±7
122-TLD1	South Firebreak	62±11	60±12	61±6	68±12	55±2
126-TLD1	South Gate	75±17	68±9	72±13	76±10	68±2
P2	NW Corner Site Perimeter Station	58±8	55±10	56±5	60±10	50±5
P4	SW Corner Site Perimeter Station	64±11	60±12	59±10	68±9	57±5
P7	SE Corner Site Perimeter Station	66±9	64±10	66±10	71±15	62±11
S5	Sewage Treatment Plant	61±11	57±13	61±9	67±11	60±6
On-Site Average		**66±11**	**62±12**	**64±9**	**68±11**	**61±7**
Off-site average (Table 8-2)		**64±10**	**59±11**	**61±14**	**68±11**	**58±6**
075-TLD4: Control TLD Average		**30±2**	**27±3**	**29±4**	**35±12**	**26±3**

Notes :
See Fig. 8-1 for TLD Locations
NYP = Not Yet Posted. TLDs were added at these locations for additional major facility emissions monitoring in the vicinity

significant difference between the off-site dose (58 ± 6 mrem) and on-site dose (61 ± 7 mrem) at the 95 percent confidence level. From the measured TLD doses, it can be safely concluded that there was no measurable external dose contribution to on- or off-site locations from Laboratory operations in 2022.

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 2018 to 2022. Environmental TLDs 088-TLD1 through 088-TLD4 are posted at and near the S6 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 of low-level radioactive waste. 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 an annual dose of 84 ± 26 mrem (840 ± 260 µSv) for 075-TLD3 and 92 ± 34 mrem (920 ± 340 µSv) for 075-TLD5. These doses are higher than the on-site annual average because Building 356 houses a cobalt-60 source which is used to irradiate materials, parts, and printed circuit boards, and its collimators were removed in 2018 to allow targets to be placed closer to the source due to source decay. In addition, the source is exposed for longer periods, sometimes overnight, and generates “skyshine.” However, in 2022 the doses were once again lower due to a pandemic-related drop in usage.

Table 8-2. Five-Year Annual Off-Site Direct Ambient Radiation Measurements (2018-2022).

TLD#	Location	Annual Total, mrem (±2σ, 95% Conf. Interval)				
		2018	2019	2020	2021	2022
000-TLD5	Longwood Estate	59±11	58±15	58±7	60±14	50±4
000-TLD9	Private property	58±9	53±10	61±13	74±21	60±18
000-TLD10	Private property	66±10	62±8	61±16	69±8	60±3
200-TLD1	Private property	71±14	66±12	70±20	78±25	60±8
200-TLD5	Private property	78±10	74±21	69±38	80±14	74±6
400-TLD1	Calverton National Cemetery	71±10	61±9	67±8	72±6	64±6
600-TLD3	Private property	68±12	59±2	65±10	69±7	NLP
600-TLD4	Maples B&G	59±7	57±11	59±10	64±5	58±4
700-TLD4	Private property	61±10	57±6	56±9	65±7	57±9
800-TLD1	Private property	65±14	56±9	63±11	69±11	58±5
800-TLD3	Suffolk County CD	62±8	61±16	63±12	62±6	57±6
800-TLD4	Long Island National Wildlife Refuge	63±4	56±12	59±10	64±12	54±7
900-TLD2	Private property	62±18	57±15	56±14	64±11	55±9
900-TLD5	Private property	59±7	50±3	49±8	55±14	41±5
900-TLD7	Private property	67±8	61±13	64±18	72±12	56±3
999-TLD1	Private property	64±7	58±12	64±18	65±14	59±1
999-TLD2	Private property	73±2	52±12	61±13	73±7	64±8
Off-Site Average		**64±10**	**59±11**	**61±14**	**68±11**	**58±6**
075-TLD4 : Control TLD Average		**30±4**	**27±3**	**29±4**	**35±12**	**26±3**

Notes:
See Fig. 8-2 for TLD Locations
TLDs are placed by volunteers or other entities. Year-to-year, willingness to participate varies among owners at these locations.
NLP = No Longer Posted with TLD.

Table 8-3. Facility Area Monitoring Measurements of Direct Ambient Radiation (2018-2022).

TLD#	Location	Annual Total, mrem (±2σ, 95% Conf. Interval)				
		2018	2019	2020	2021	2022
054-TLD1	Bldg. 914	91±48	75±33	65±12	79±25	87±12
054-TLD2	NE of Bldg. 913B	86±49	76±30	66±13	77±26	84±6
054-TLD3	NW of Bldg. 913B	81±47	72±24	66±13	77±30	79±9
S6	FWMF	71±11	69±17	69±11	73±10	64±6
088-TLD1	FWMF, 50' East of S6	84±12	77±12	79±7	87±12	73±1
088-TLD2	FWMF, 50' West of S6	74±12	72±13	77±14	76±14	68±2
088-TLD3	FWMF, 100' West of S6	75±7	74±8	74±11	80±11	70±7
088-TLD4	FWMF, 150' West of S6	67±8	69±13	66±11	71±12	62±2
075-TLD3	Bldg. 356	80±18	100±17	99±9	83±11	84±26
075-TLD5	North Corner of Bldg. 356	80±22	109±20	107±14	92±23	92±34

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

Although it is conceivable for individuals who use the parking lot adjacent to Building 356 to 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 levels. The full-year dose at these sites was measured at 87±12 mrem (870+/-120 uSv) for 054-TLD1, 84 ± 6 mrem (840+/-60 uSv) for 054-TLD2, and 79 ± 9 mrem (790+/-90 uSv) for 054-TLD3 (compared to the on-site dose of 61 ± 7 mrem and off-site dose of 58 ± 6 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 2022, 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

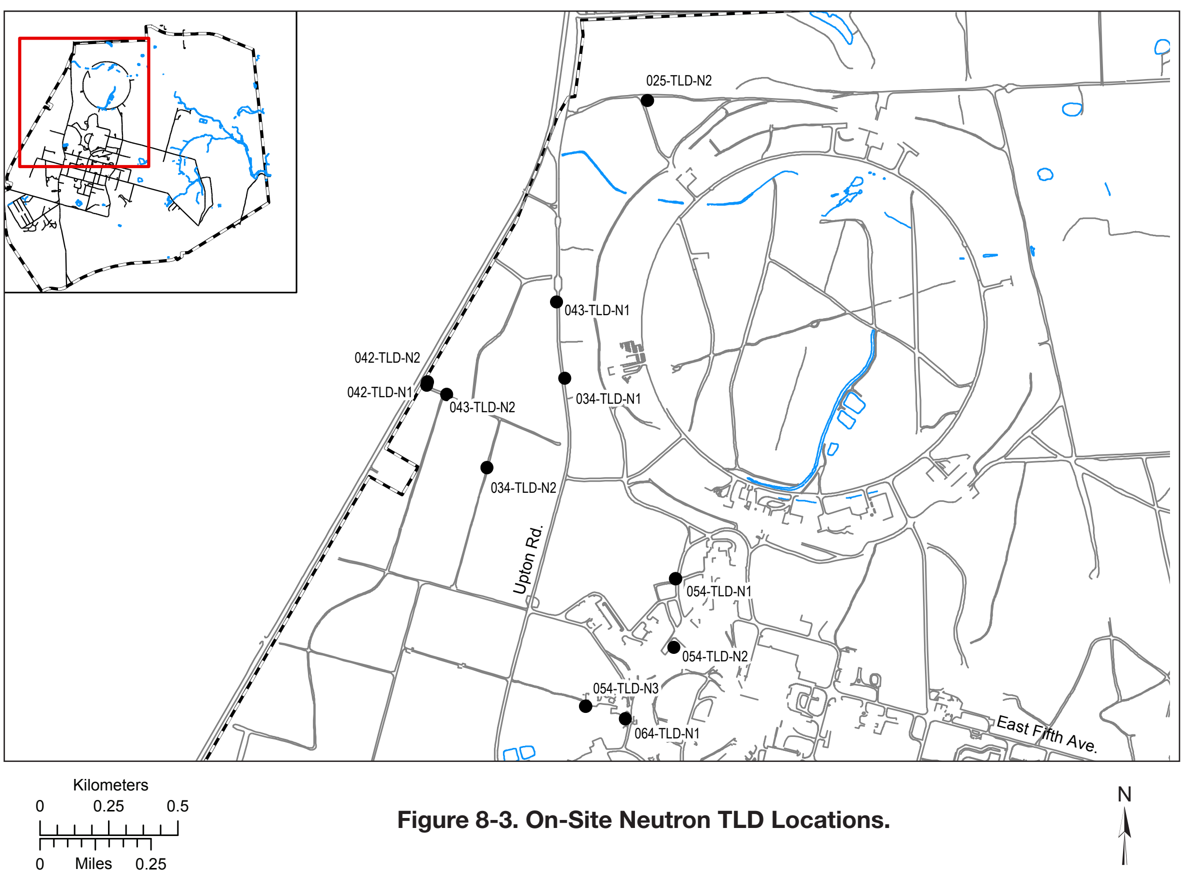

Figure 8-3. On-Site Neutron TLD Locations.

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 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 2018 to 2022. In 2022, seven neutron TLDs showed 1 mrem, eight showed 2 mrem, and one showed 3 mrem. Six neutron TLDs showed no dose. All of 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 Emissions of Radionuclides Other than Radon from Department of Energy Facilities. 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 MEOSI. The dose estimates from various facilities are provided in Table 8-5, and the actual air emissions for 2022 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

Photo 8-2. Neutron TLDs in Monitored Area

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 the dose from short-term or acute releases. Consequently, the modeling software overestimates potential dose contributions from short-term projects and area sources. For that reason, such 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 characterize the average dispersion of airborne radionuclides released from elevated stacks or diffuse sources. CAP88-PC then calculates the EDE to the MEOSI from 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

Table 8-4. Five-Year Annual Neutron Monitoring Results (2018-2022).

Neutron TLD #	Location ID No.	Annual Total, mrem neutron				
		2018	2019	2020	2021	2022
TK277	025-TLD-N2	0	0	2	2	3
TK278	"	2	0	0	1	1
TK279	034-TLD-N1	0	1	1	0	2
TK280	"	1	0	0	2	1
TK281	034-TLD-N2	0	0	0	0	2
TK282	"	1	0	0	1	2
TK283	043-TLD-N1	0	0	1	2	2
TK284	"	0	0	0	1	1
TK285	043-TLD-N2	0	0	0	1	1
TK286	"	1	2	0	1	0
TK287	042-TLD-N1	0	1	1	1	1
TK288	"	0	1	0	2	2
TK289	042-TLD-N2	0	0	0	1	1
TK290	"	0	0	0	1	2
TK291	054-TLD-N1	0	0	2	0	0
TK292	"	0	0	0	0	2
TK293	054-TLD-N2	0	0	0	3	2
TK294	"	0	0	0	3	0
TK295	054-TLD-N3	0	0	0	1	1
TK296	"	0	1	2	1	0
TK297	064-TLD-N1	0	0	0	0	0
TK298	"	1	0	1	0	0
PM-bkg		1	1	1	2	2

"PM-bkg" = The background dose-rate levels in the Personnel Monitoring (PM) counting room where the TLDs are stored and prepared for issue.

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.

These dose and risk calculations to the MEOSI are based on low-level 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 except those from Building 801 are treated as having been released from the BLIP Facility (Fig. 4-1), 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

Table 8-5. Maximally Exposed Off-Site Individual Effective Dose Equivalent From Facilities or Routine Processes, 2022.

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	5.83E-10	(b)
480	Condensed Matter Physics	None	ND	(f)
490/490A	Personnel Monitoring	None	1.96E-08	(b)
490	DJ/EBNN	None	3.86E-10	(b)
510	Condensed Matter Physics	None	1.19E-11	(b)
535	Instrumentation	None	ND	(f)
555	Chemistry Facility	None	1.00E-03	(b)
734	Interdisciplinary Science Building - CMP	None	1.41E-11	(b)
735	Center for Functional Nanomaterials	None	ND	(f)
745	NSLS-II	None	1.01E-03	(b)
750	HFBR	None	7.48E-05	(c)
801	RRPL	BNL-2022-01	1.34E-05	(c)
815	Nonproliferation & Nuclear Safety	None	6.21E-11	(b)
817	Nuclear Science & Technology	None	7.77E-11	(b)
820	Accelerator Test Facility	BNL-589-01	ND	(f)
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	1.19E+00	(c)
942	AGS Booster	BNL-188-01	ND	(e)
---	RHIC	BNL-389-01	ND	(d)
Total Potential Dose from BNL Operations			**1.19E+00**	
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 2022.
(e) Booster ventilation system prevents air release through continuous air recirculation.
(f) No radiological dispersible material inventory in 2022.
(g) Sealed sources were excluded from this inventory - no emission.

population of six million people surrounding BNL, based on the 2020 US Census and the Geographical Information System design population survey performed in 2021 by Oak Ridge National Laboratory for BNL, was used in the model.

The 2022 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 2022's operation. The average volumetric flow rate of the BLIP exhaust system in 2022 was 520 cfm, or 0.245 m^3/sec. With an exit diameter of 0.1 m, the exit velocity was 31.25 m/sec, down slightly from last year's 31.4 m/sec.
- The method of characterizing atmospheric stability for purposes of estimating effluent dispersion was the Solar Radiation/Delta Temperature method for conservatism. This is because the method takes into account the most variations in atmospheric conditions, such as solar radiation heating and cooling, and results in the highest dose in comparison to the other known methods.

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 on-site 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 26 mrem in 2022. The increase in MEI dose in 2022 was due to a sharp increase in research irradiations conducted with a Co-60 source in Building 356 during the year, as discussed in section 8.1.2, which is attributed to exiting the COVID-19 pandemic. The 26-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 about 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 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 water or milk ingested by an adult, as listed in DOE-STD-1196-2022, 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 5.03E-02 rem/µCi.

8.2.2.3 Dose Calculation: Deer Meat Ingestion

The dose calculation for deer meat ingestion is the same as 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

Table 8-6. Five-Year Site Dose Summary, (2018-2022).

	2018	2019	2020	2021	2022
Pathway	**Annual Maximally Exposed Off-Site Individual Dose, mrem**				
Inhalation					
Air	1.63	1.28	5.60E-05	0.71	1.19
Ingestion					
Drinking Water	None	None	None	None	None
Fish[1]	0.088	0.088	NS	NS	NS
Deer	3.32	1.4	0.913	2.9	3.82
All Pathways	**5.04**	**2.77**	**0.91**	**3.61**	**5.01**
Pathway	**Percent of DOE 100-mrem/yr Dose Limit, %**				
Inhalation					
Air	<2.0	<1.5	<0.001	<1.0	<1.5
Ingestion					
Drinking Water	None	None	None	None	None
Fish[1]	<0.1	<0.1	NS	NS	NS
Deer	<4.0	<1.5	<1.0	<3.0	<4
All Pathways	**<6.0**	**<3.0**	**<1.0**	**<4.0**	**<5.5**
Pathway	**Estimated Population Dose Per Year, person-rem**				
Inhalation					
Air	2.55	1.81	2.05E-03	0.773	5.6
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	**2.55**	**1.81**	**2.05E-03**	**0.773**	**5.6**

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.

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 non-point 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 (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 August 2022, the Brookhaven Medical Research Reactor (BMRR) Stack of Building 490 was demolished and removed. A NESHAPs evaluation was performed and updated with new core sample data. The estimate of potential offsite dose resulting from its demolition was less than 0.1 mrem. Therefore, no NESHAPs authorization was required.

8.4 DOSE FROM POINT SOURCES

8.4.1 Brookhaven LINAC Isotope Producer

Source term descriptions for point sources are given in Chapter 4. In 2022, the BLIP facility was 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 1.0 μSv). 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.

In the 2021 Site Environmental Report, the PIC was listed as I. However, after further review of the definition, it has been determined that the BLIP facility emissions have not reached the PIC-I threshold since the thresholds are based on fractions of the limit values rather than the thresholds themselves being dose rate values.

The gaseous emissions from BLIP 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 2022, the BLIP facility was active for 37.14 weeks. Therefore, typical isotopes Carbon-11 (C-11) (half-life: 20.4 minutes) and Oxygen-15 (O-15) (half life: 122 seconds) were released during operation. A small quantity (4.20E-02 Ci) of residual tritiated water vapor from activation of the targets' cooling water was released since the exhaust system ran continuously, as well. The EDE to the MEOSI from BLIP operations was calculated to be 1.19 mrem (11.9 μSv) in a year.

8.4.2 Radionuclide Research and Production Laboratory (RRPL) (formerly Target Processing Laboratory)

In 2022, there were no detectable levels of emissions from the RRPL.

8.4.3 High Flux Beam Reactor

In 2022, the residual tritium emissions from the HFBR facility were measured at 0.343 Ci, and the estimated dose attributed was 7.48E-5 mrem (7.48E-4 μSv) in a year.

8.4.4 Brookhaven Medical Research Reactor

In 2022, the BMRR facility remained in a cold shutdown mode as a radiological facility with institutional controls in place. The stack for the BMRR was demolished and removed in August 2022. There was no dose contribution from the BMRR in 2022.

8.4.5 Brookhaven Graphite Research Reactor

In 2022, 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 2022.

8.4.6 Waste Management Facility

In 2022, there were no detectable levels of emissions from the Waste Management Facility.

8.4.7 Unplanned Releases

Two target cans failed during irradiation at the BLIP facility over the Fourth of July weekend (July 2-3) in 2022. The failed cans continued to be irradiated for about 22 hours until the failure was identified. A separate target can failed a week later, but it was identified within a few hours. In both cases, the beam was shut off upon failure identification. All three targets were Rubidium Chloride (RbCl) target material used to produce Strontium-82. Effluent sample analysis determined that only Bromine-77 (Br-77), a gas, was positively detected. Due to the low reported concentration, it could not be firmly established that the target material itself was the source of the activity, and Br-77 is nominally less than 2.5 percent of the expected

Table 8-7. Five-Year Annual Maximally Exposed Onsite Individual Dose (2018-2022).

TLD #	Location	Annual Total, mrem				
		2018	2019	2020	2021	2022
TK154	2nd Floor, B120	14	25	27	3	26
TK155	1st Floor, B120	5	20	18	7	21

total Curies following RbCl target activation. Over the two-day period during which the first failure occurred, the emissions monitoring system showed a release approximately 850 Curies over the normal level of emissions expected, due to proton beam activation of the water left inside the cans following failure. Since Br-77 is the only gaseous by-product of RbCl irradiation, and the failure left water instead of target material inside the target cans, the isotopes C-11 and O-15 were released, and the annual standard dose limits under 40CFR61, Subpart H, were not challenged.

Such target failures are not operationally desirable but are anticipated to occur with low frequency and are accounted for in the BLIP safety analysis.

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 2022, BNL collected samples from 22 deer, 13 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, so the sample data is gathered from the entire aggregate of sample analyses. From Table 6-2, the average K-40 concentration in all deer tissue samples (All Samples) was 2.93 ± 0.51 pCi/g (wet weight) in the flesh (i.e., meat) and 2.17 ± 0.27 pCi/g (wet weight) in the liver. The average flesh K-40 concentration in culled deer tissue samples (Managed Cull) was 3.00 ± 0.62 pCi/g (wet weight). The average liver K-40 concentration in culled deer tissue samples (Managed Cull) was 2.20 ± 0.29 pCi/g (wet weight). The maximum Cs-137 flesh concentration in all samples (non-culled and culled) was 2.62 ± 0.06 pCi/g (wet weight). This Cs-137 flesh concentration 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 3.82 mrem (38.2 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. However, 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 2022, 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 2022, the terrestrial animal and plant doses were evaluated based on 2.29 ± 0.17 pCi/g of Cs-137 (see Table 6-3) found in soil near the Peconic River west of HM-N, and a Strontium-90 (Sr-90) concentration of 1.22 ± 0.48 pCi/L (see Table 5-5) in the surface water collected from the HV Headwaters station on site and inside the RHIC ring. The resultant dose to terrestrial animals was calculated to be 0.11 mGy/day, and to plants to be 0.010 mGy/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 2022, the surface water Sr-90 concentration mentioned above, 1.22 pCi/L, was used. Cs-137 was not detected in vegetation. Using these concentrations, the calculated estimate of dose to aquatic animals was 0.48E-3 mGy/day, and the dose to riparian animals was 4.78E-3 mGy/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 population dose to the surrounding population via the inhalation pathway from the BNL site, for the years 2018 through 2022. The total dose to the MEOSI from the inhalation and ingestion pathways in 2022 was estimated to be 5.01 mrem (50.1 µSv). In comparison, the DOE limit on dose from all pathways is 100 mrem (1 mSv). The cumulative population dose from airborne emissions was 5.6 person-rem (5.6E-2 person-Sv) in 2022. There is no current regulatory limit on cumulative population dose. However, BNL strives to maintain all dose received as low as reasonably achievable.

In conclusion, the effective dose from all pathways due to BNL operations in 2022 was well below the DOE and EPA regulatory limits, and the ambient off-site 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 310 mrem (3.10 mSv) (from the Ionizing Radiation Dose Range Chart, Department of Energy Office of Public Radiation Protection). 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 5.01 mrem from all environmental pathways from BNL is a minute fraction of the dose from that of several routine diagnostic procedures, as well as natural background radiation.

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