# Radiological Dose Assessment 8

*BNL's annual radiological dose assessment assures stakeholders that on-site facilities and Laboratory 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 sum total from direct and indirect dose pathways via air immersion, inhalation of particulates and gases, and ingestion of local fish and deer meat. In 2015, the total effective dose (TED) of 3.15 mrem (32 µSv) from Laboratory operations was well below the EPA and DOE regulatory dose limits for the public, workers, and the environment.*

*The dose estimates for 2015 at BNL were calculated using an updated version of the dose modeling software promulgated by EPA. As such, the effective dose equivalent (EDE) from air emissions in 2015 was estimated at 2.84E-01 mrem (2.8 µSv) to the MEOSI. The dose level from the inhalation pathway was less than 3 percent of EPA's annual regulatory dose limit of 10 mrem (100 µSv). In addition, the dose from the ingestion pathway was estimated as 2.78 mrem (27.8 µSv) from the consumption of deer meat and 8.75E-2 mrem (0.88 µSv) from the consumption of fish caught in the vicinity of the Laboratory. In summary, the total annual dose to the MEOSI from all pathways was estimated at 3.15 mrem (32 µSv), which is less than 4 percent of DOE's 100-mrem limit. The aggregate population dose was 0.419 person-rem among approximately 6 million persons residing within a 50-mile radius of the Laboratory. On average, this is equivalent to a fraction of an airport whole body scan.*

*Dose to the maximally exposed individual (MEI) on site and outside of controlled areas, calculated from thermoluminescent dosimeter (TLD) monitoring records, was 10 mrem above natural background radiation levels. The average annual external dose from ambient sources on site was 64 ± 9 mrem (640 ± 90 µSv) and 59 ± 6 mrem (590 ± 60 µSv) from off-site ambient sources. Both on- and off-site external dose measurements include the contribution from natural terrestrial and cosmic background radiation. A statistical comparison of the average doses measured using 49 on-site TLDs and 18 off-site TLDs showed that there was no external dose contribution from BNL operations distinguishable from the natural background radiation level. An additional nine TLDs were used to measure on-site areas known to have radiation dose slightly above the natural background radiation.*

*Doses to aquatic and terrestrial biota were also evaluated and found to be well below DOE regulatory limits. One demolition project, which was assessed for radiological emissions prior to 2015, was carried out; the potential dose from this activity was below regulatory limits and there was minimal radiological risk to the public, workers, or the environment. In summary, the overall dose impact from all Laboratory activities in 2015 was comparable to that of natural background radiation levels.*

## 8.0 INTRODUCTION

This chapter 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 on site have been shut down, defueled, and partly or fully decommissioned, there was no dose risk from these facilities in 2015. 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 (with contribution from both cosmic and terrestrial sources) and represent no contribution from Laboratory operations. On- and off-site external dose measurements are averaged and then compared using 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 the grids.

In 2015, to measure direct radiation from Laboratory operations, 58 environmental thermoluminescent dosimeters (TLDs) were deployed on site, of which 9 were placed in known radiation areas. Eighteen TLDs were deployed at off-site locations (see Figures 8-1 and 8-2). Over the year, two off-site TLD locations were discontinued and five locations were added. All 16 wind sectors around the Laboratory had TLDs located in them by the fourth quarter, with the exception of sectors 7 and 12. An additional 30 TLDs were stored in a lead-shielded container for use as reference and control TLDs for comparison purposes. The average of the control TLD values, reported as "075-TLD4" (see Tables 8-1 and 8-2), was 32 ± 1 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 2015. The on-site average external doses for the first through fourth quarters were 16.6 ± 2.9, 15.6 ± 2.8, 14.7 ± 2.8, and 16.6 ± 2.7 mrem, respectively. The on-site average annual external dose from all potential environmental sources, including cosmic and terrestrial radiation sources, was 64 ± 9 mrem (640 ± 90 µSv).

Table 8-2 shows the quarterly and yearly

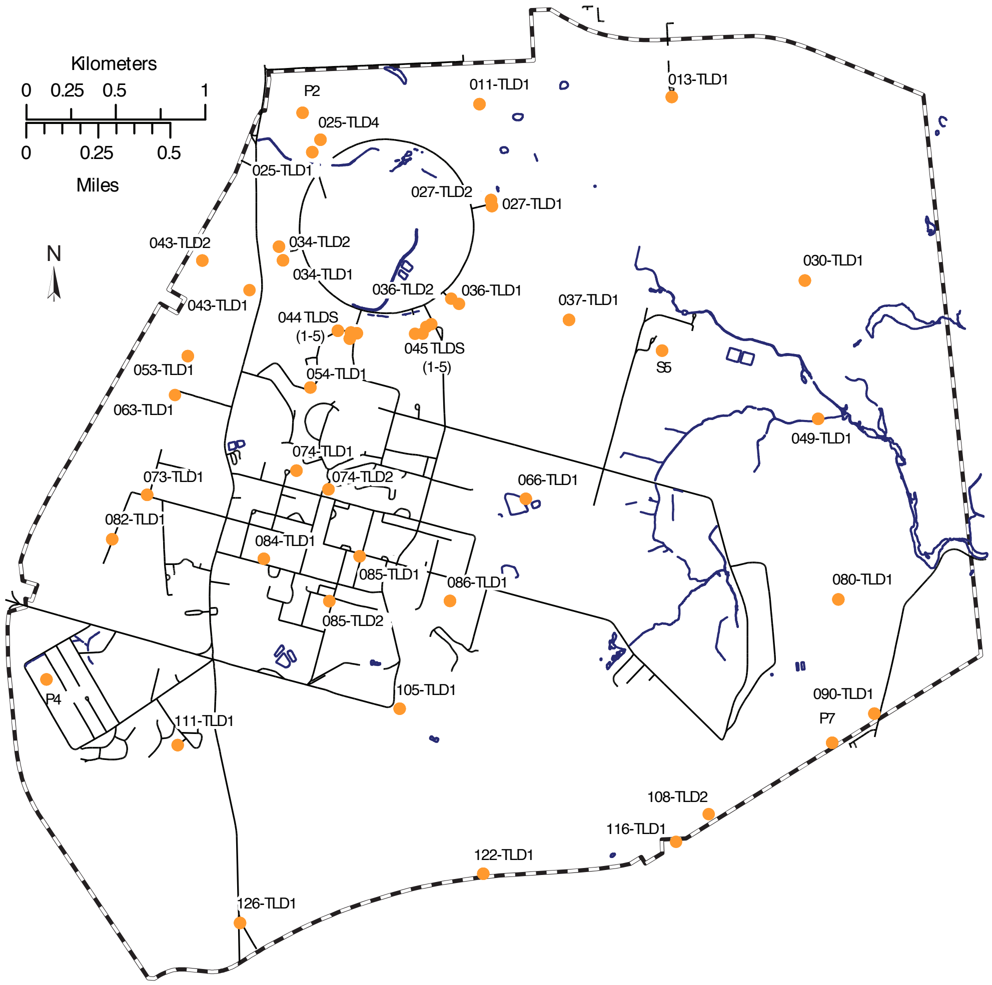


**Figure 8-1. On-Site TLD Locations.**

off-site radiation dose measurements for 2015. The off-site average external doses for the first through fourth quarters were 15.4± 2.6, 15.1 ± 3.0, 14.0 ± 3.4, and 15.4± 3.3 mrem, respectively. The off-site average annual ambient dose from all potential environmental sources, including cosmic and terrestrial radiation sources, was 59 ± 6 mrem (590 ± 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 dose averages was conducted. The t-test showed no significant difference between the off-site dose (59 ± 6 mrem) and on-site dose (64 ± 9 mrem) at the 95 percent confidence level. From the measured TLD doses, it can be safely concluded that there was no measurable external dose contribution to on- and off-site locations from Laboratory operations in 2015. The dose to the MEI on site and outside of controlled areas (in the vicinity of Building 356) was measured at 2 mrem (first quarter), 4 mrem (second quarter), 0 mrem (third quarter), and 4 mrem (fourth quarter) for 2015. The total dose to the on-site MEI was 10 mrem, which is less than the dose received from three round-trip flights from Los Angeles, California to New York, New York.

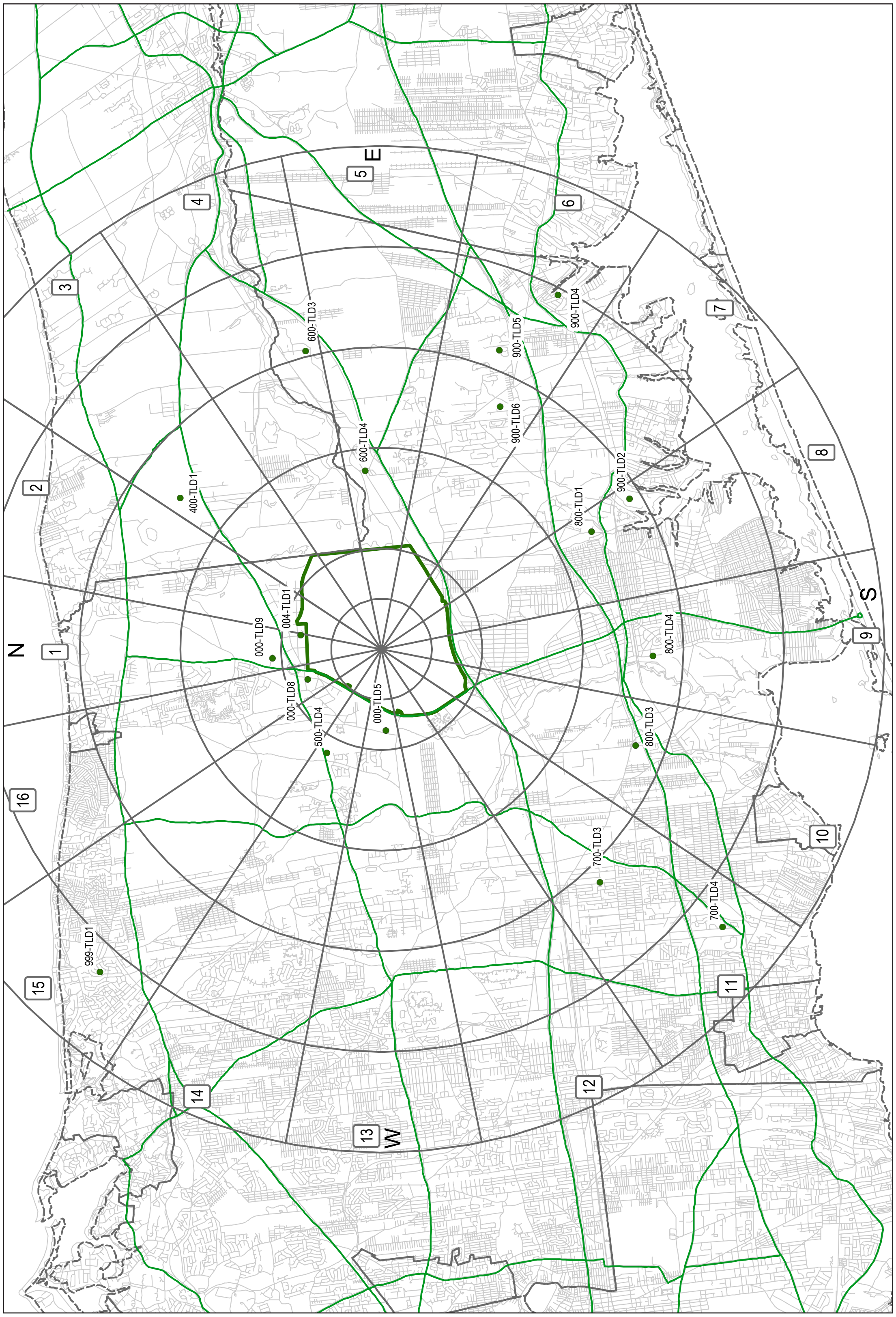


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**Figure 8-2. Off-Site TLD Locations.**

**Table 8-1. On-Site Direct Ambient Radiation Measurements for 2015.**

| TLD# | Location | 1st Quarter | 2nd Quarter | 3rd Quarter | 4th Quarter | Avg./Qtr. ±2σ (95%) | Annual Dose ±2σ (95%) |
|---|---|---|---|---|---|---|---|
| | | (mrem) | | | | | |
| 011-TLD1 | North Firebreak | 13.4 | 12.7 | 12.3 | 15.3 | 13±2 | 54±9 |
| 013-TLD1 | North Firebreak | 15.4 | 15.4 | 13.8 | 16.0 | 15±2 | 61±7 |
| 025-TLD1 | Bldg. 1010, Beam Stop 1 | 16.2 | 14.0 | 13.3 | 15.6 | 15±2 | 59±9 |
| 025-TLD4 | Bldg. 1010, Beam Stop 4 | 16.9 | 15.5 | 14.2 | 16.2 | 16±2 | 63±8 |
| 027-TLD1 | Bldg. 1002A South | 15.1 | 12.9 | 12.6 | 14.7 | 14±2 | 55±9 |
| 027-TLD2 | Bldg. 1002D East | 15.7 | 13.7 | 12.5 | 14.2 | 14±2 | 56±9 |
| 030-TLD1 | Northeast Firebreak | 15.2 | 15.4 | 14.3 | 16.5 | 15±2 | 61±6 |
| 034-TLD1 | Bldg. 1008, Collimator 2 | 15.3 | 16.0 | 14.1 | 16.4 | 15±2 | 62±7 |
| 034-TLD2 | Bldg. 1008, Collimator 4 | 15.9 | 15.2 | 15.0 | 16.3 | 16±1 | 62±4 |
| 036-TLD1 | Bldg. 1004B, East | 17.7 | 15.9 | 12.9 | 15.0 | 15±3 | 61±14 |
| 036-TLD2 | Bldg. 1004, East | 17.0 | 17.0 | 14.7 | 15.1 | 16±2 | 64±9 |
| 037-TLD1 | S-13 | 15.3 | 14.4 | 14.3 | 19.8 | 16±5 | 64±18 |
| 043-TLD1 | North Access Road | 17.3 | 16.7 | 16.7 | 16.7 | 17±1 | 67±2 |
| 043-TLD2 | North of Meteorology Tower | 15.4 | 16.4 | 15.9 | 16.7 | 16±1 | 64±4 |
| 044-TLD1 | Bldg. 1006 | 16.6 | 15.6 | 13.8 | 17.2 | 16±3 | 63±10 |
| 044-TLD2 | South of Bldg. 1000E | 16.3 | 15.0 | 15.9 | 15.8 | 16±1 | 63±4 |
| 044-TLD3 | South of Bldg. 1000P | 16.8 | 14.9 | 13.8 | 15.8 | 15±2 | 61±9 |
| 044-TLD4 | Northeast of Bldg. 1000P | 18.7 | 16.0 | 15.1 | 17.3 | 17±3 | 67±11 |
| 044-TLD5 | North of Bldg. 1000P | 17.9 | 15.1 | 14.7 | 15.7 | 16±2 | 63±10 |
| 045-TLD1 | Bldg. 1005S | 17.2 | 13.8 | 14.2 | 15.0 | 15±3 | 60±11 |
| 045-TLD2 | East of Bldg. 1005S | 16.1 | 16.8 | 14.3 | 15.9 | 16±2 | 63±7 |
| 045-TLD3 | Southeast of Bldg. 1005S | 18.2 | 15.5 | 14.3 | 16.1 | 16±3 | 64±11 |
| 045-TLD4 | Southwest of Bldg. 1005S | 17.2 | 15.2 | 13.5 | 16.1 | 16±3 | 62±11 |
| 045-TLD5 | West-Southwest of Bldg. 1005S | 16.8 | 14.8 | 14.4 | 17.3 | 16±2 | 63±10 |
| 049-TLD1 | East Firebreak | 15.8 | 15.2 | 15.3 | 19.2 | 16±3 | 66±13 |
| 053-TLD1 | West Firebreak | 16.5 | 16.1 | 15.9 | 19.2 | 17±3 | 68±11 |
| 054-TLD1 | Bldg. 914 | 21.6 | 19.1 | 14.0 | 17.7 | 18±6 | 72±22 |
| 063-TLD1 | West Firebreak | 17.6 | 17.3 | 16.8 | 17.7 | 17±1 | 69±3 |
| 066-TLD1 | Waste Management Facility | 14.6 | 13.2 | 13.0 | 14.8 | 14±2 | 56±6 |
| 073-TLD1 | Meteorology Tower | 15.7 | 16.3 | 16.9 | 17.2 | 17±1 | 66±5 |
| 074-TLD1 | Bldg. 560 | 16.9 | 17.5 | 16.6 | 17.4 | 17±1 | 68±3 |
| 074-TLD2 | Bldg. 907 | 18.8 | 14.6 | 13.2 | 15.7 | 16±4 | 62±16 |
| 080-TLD1 | East Firebreak | 17.9 | 16.1 | 16.1 | 19.0 | 17±2 | 69±10 |
| 082-TLD1 | West Firebreak | 19.3 | 17.1 | 17.1 | 19.0 | 18±2 | 73±8 |
| 084-TLD1 | Tennis courts | 16.1 | 15.2 | 14.4 | 17.0 | 16±2 | 63±8 |
| 085-TLD1 | TFCU Bank | 15.2 | 15.8 | 16.6 | 16.7 | 16±1 | 64±5 |
| 085-TLD2 | Upton Gas Station | 17.7 | 15.7 | 14.1 | 16.5 | 16±3 | 64±11 |
| 086-TLD1 | Baseball Fields | 16.8 | 15.7 | 14.3 | 18.1 | 16±3 | 65±11 |
| 090-TLD1 | North St. Gate | 15.7 | 15.2 | 13.9 | 17.3 | 16±2 | 62±10 |
| 105-TLD1 | South Firebreak | 16.7 | 15.5 | 16.7 | 18.4 | 17±2 | 67±8 |

*(continued on next page)*

**Table 8-1. On-Site Direct Ambient Radiation Measurements for 2015** *(concluded).*

| TLD# | Location | 1st Quarter | 2nd Quarter | 3rd Quarter | 4th Quarter | Avg./Qtr. ±2σ (95%) | Annual Dose ±2σ (95%) |
|---|---|---|---|---|---|---|---|
| | | (mrem) | | | | | |
| 108-TLD1 | Water Tower | 16.2 | 17.2 | 15.5 | 17.1 | 16±1 | 66±6 |
| 108-TLD2 | Tritium Pole | 19.4 | 19.4 | 18.3 | 19.9 | 19±1 | 77±5 |
| 111-TLD1 | Trailer Park | 17.2 | 17.0 | 15.5 | 16.8 | 17±1 | 66±5 |
| 122-TLD1 | South Firebreak | 16.2 | 15.0 | 15.5 | 16.2 | 16±1 | 63±4 |
| 126-TLD1 | South Gate | 17.6 | 17.5 | 16.1 | 18.6 | 17±2 | 70±7 |
| P2 | | 14.0 | 14.8 | 12.6 | 14.2 | 14±2 | 56±6 |
| P4 | | 15.7 | 13.3 | 14.7 | 15.7 | 15±2 | 59±8 |
| P7 | | 17.2 | 15.5 | 14.3 | 16.4 | 16±2 | 63±9 |
| S5 | | 15.2 | 16.5 | 13.2 | 15.7 | 15±2 | 61±10 |
| **On-Site Average** | | **16.6** | **15.6** | **14.7** | **16.7** | **16±2** | **64±9** |
| **Std. Dev. (2s)** | | **2.9** | **2.8** | **2.8** | **2.8** | | **17 ± 3** |
| **075-TLD4: Control TLD Average** | | **7.29** | **6.92** | **7.27** | **7.27** | **7.2±0.3** | **29±1.2** |

Notes :
See Figure 8-1 for TLD locations.
L = TLD lost
NP = TLD not posted

### 8.1.2 Facility Area Monitoring

Nine on-site TLDs were designated as facility-area monitors (FAMs) because they were posted in known radiation areas (near “facilities”). Table 8-3 shows the external doses measured with the FAM-TLDs. Environmental TLDs 088-TLD1 through 088-TLD4 are posted at the S-6 blockhouse location and near S6 on the fence of the Former Hazardous Waste Management Facility (FHWMF). The TLDs measured external doses that were slightly elevated compared to the normal natural background radiation doses measured in other areas on site. This can be attributed to the presence of small amounts of contamination in soil. All TLD readings in this area were within 9 percent (of each other), except for 088-TLD1, which was approximately 15 percent higher. The elevated reading was most likely due to the nearby short-term storage of waste (e.g., building debris, remediated soil) from the Building 811 demolition project. However, a comparison of the current ambient dose rates to doses from previous years shows that the dose rates have significantly declined since the removal of contaminated soil within the FHWMF. As shown in Table 8-3, the 2015 dose is just 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 slightly higher quarterly averages of 20 ± 4 mrem (200 ± 40 µSv) and 19±2 mrem (190±20 µSv), respectively, which are just above the normal ambient background radiation. The yearly doses were measured at 81 ± 15 mrem (810 ± 150 µSv) for 075-TLD3 and 76 ± 10 mrem (760 ± 100 µSv) for 075-TLD5. The direct doses are higher than the on-site annual average because Building 356 houses a cobalt-60 (Co-60) source, which is used to irradiate materials, parts, and electronic circuit boards. The slightly elevated dose from Building 356 on 075-TLD3 is attributed to the “sky-shine” phenomenon. This building also contains several californium-252 (Cf-252) neutron sources in a cask near the corner of the building where 075-TLD5 is located. Although it is conceivable that individuals who use the parking lot adjacent to Building 356 could receive a dose from these sources, the dose would be small due to the low occupancy factor.

Two FAM-TLDs placed on fence sections northeast and northwest of Building 913B (the AGS tunnel access) showed slightly elevated

**Table 8-2. Off-Site Direct Radiation Measurements for 2015.**

| TLD# | Location | 1st Quarter | 2nd Quarter | 3rd Quarter | 4th Quarter | Avg./Qtr. ± 2 σ (95%) | Annual Dose ± 2 σ (95%) |
|---|---|---|---|---|---|---|---|
| | | | | | (mrem) | | |
| 000-TLD4 | Private property | 13.9 | NP | NP | NP | 14±0 | 56±0 |
| 000-TLD5 | Longwood Estate | 15.4 | 13.5 | 13.0 | 14.4 | 14±2 | 56±7 |
| 000-TLD7 | Mid-Island Game Farm | 15.4 | 14.7 | 14.7 | 15.3 | 15±1 | 60±3 |
| 000-TLD8 | Private property | NP | NP | NP | 13.6 | 14±0 | 54±0 |
| 000-TLD9 | Private property | 14.4 | 13.1 | 12.9 | 14.8 | 14±2 | 55±6 |
| 004-TLD1 | Private property** | 14.7 | 15.6 | 16.2 | 16.5 | 16±1 | 63±5 |
| 400-TLD1 | Calverton Nat. Cemetery | 18.7 | 16.9 | 16.6 | 17.3 | 17±2 | 69±7 |
| 500-TLD4 | Private property | 14.0 | 15.5 | 13.3 | 19.5 | 17±2 | 62±19 |
| 600-TLD3 | Sportsmen's Club | 14.6 | 13.5 | 12.8 | NP | 14±2 | 55±6 |
| 700-TLD3 | Private property | 14.3 | 14.2 | 13.1 | 14.5 | 14±1 | 56±4 |
| 700-TLD4 | Private property | 15.2 | 14.8 | 14.8 | 15.4 | 15±1 | 60±2 |
| 800-TLD1 | Private property | 15.3 | 14.4 | 14.8 | 14.3 | 15±1 | 59±3 |
| 800-TLD3 | Suffolk County CD | 16.8 | 14.8 | 15.3 | 16.0 | 16±1 | 63±6 |
| 900-TLD2 | Private property | 14.9 | 15.3 | 11.0 | 14.5 | 14±3 | 56±14 |
| 900-TLD4 | Private property | 17.6 | 19.3 | 14.7 | 15.8 | 17±4 | 67±14 |
| 900-TLD5 | Private property | NP | NP | NP | 13.5 | 13±0 | 54±0 |
| 900-TLD6 | Private property | NP | NP | NP | 14.4 | 14±0 | 58±0 |
| 999-TLD1 | Private property | 15.5 | 16.1 | 10.9 | 16.3 | 15±4 | 59±18 |
| Off-Site Average | | 15.4 | 15.1 | 13.9 | 15.4 | 15±2 | 59±6 |
| Std. Dev. (2s) | | 2.6 | 3.1 | 3.3 | 3.0 | | |
| **075-TLD4: Control TLD Average** | | **7.3** | **6.9** | **7.3** | **7.3** | **7.2±0.3** | **29±1** |
| **Std. Dev. (2σ)** | | **3.3** | **11.0** | **2.8** | **1.8** | | |
| **075-TLD4: Control TLD Average** | | **8.2** | **7.6** | **7.4** | **7.2** | **7.6±1** | **30±3** |

Notes:
See Figure 8-2 for TLD locations.
** TLD # changed to 000-TLD10 in fourth quarter
CD = Correctional Department
NP = TLD not posted
L = TLD lost

**Table 8-3. Facility Monitoring Area for 2015.**

| TLD# | Location | 1st Quarter | 2nd Quarter | 3rd Quarter | 4th Quarter | Average ± 2σ (95%) | Annual Dose ± 2σ (95%) |
|---|---|---|---|---|---|---|---|
| | | | | | (mrem) | | |
| 054-TLD2 | NE of Bldg. 913B | 25.6 | 23.5 | 14.9 | 18.5 | 21±8 | 82±34 |
| 054-TLD3 | NW of Bldg. 913B | 22.2 | 23.0 | 14.6 | 16.8 | 17±7 | 77±28 |
| S6 | | 18.6 | 14.2 | 16.1 | 17.9 | 17±3 | 67±14 |
| 088-TLD1 | FHWMF, 50' East of S6 | 21.4 | 20.6 | 19.2 | 21.0 | 21±2 | 82±7 |
| 088-TLD2 | FHWMF, 50' West of S6 | 19.5 | 17.4 | 18.0 | 19.0 | 18±2 | 74±7 |
| 088-TLD3 | FHWMF, 100' West of S6 | 19.4 | 18.7 | 17.8 | 19.3 | 19±1 | 75±5 |
| 088-TLD4 | FHWMF, 150' West of S6 | 16.6 | 15.7 | 15.8 | 17.0 | 16±1 | 65±5 |
| 075-TLD3 | Building 356 | 22.9 | 19.6 | 17.9 | 20.9 | 20±4 | 81±15 |
| 075-TLD5 | North Corner of Bldg. 356 | 20.1 | 17.5 | 18.2 | 20.3 | 19±2 | 76±10 |

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

above-average ambient external dose. The first-quarter dose at these sites was measured at 25.6 mrem for 054-TLD2 and 22.2 mrem for 054-TLD3 (compared to the site-wide first-quarter dose of 16.6 ± 2.9 and off-site dose of 15.4 ± 2.6 mrem). The second-quarter dose at these sites was measured at 23.5 mrem for 054-TLD2 and 23.0 mrem for 054-TLD3 (compared to the site-wide second-quarter dose of 15.6 ± 2.8 mrem and off-site dose of 15.1 ± 3.0 mrem). During the third quarter, both TLDs showed dose comparable to natural background radiation. In the fourth quarter, the 054-TLD2 site showed an elevated dose of 18.5 mrem, while the other was closer to background, although still elevated. The slightly higher levels of the first and second quarters are expected because the operating period for the AGS is typically in the first half of the calendar year.

The AGS accelerates protons to energies up to 30 GeV and heavy ions up to 15 GeV/amu. RHIC has two beams circulating in opposite directions and is capable of accepting either protons or heavy ions up to gold. At the RHIC, protons and heavy ions received from the AGS are further accelerated up to final energies of 250 GeV for protons and 100 GeV per nucleon for gold ions. Under these high-energy conditions, facilities such as AGS and RHIC have the potential to generate high-energy neutrons when the charged particles leave the confines of the accelerator and produce nuclear fragments along their path or when they collide with matter. In 2015, twelve 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

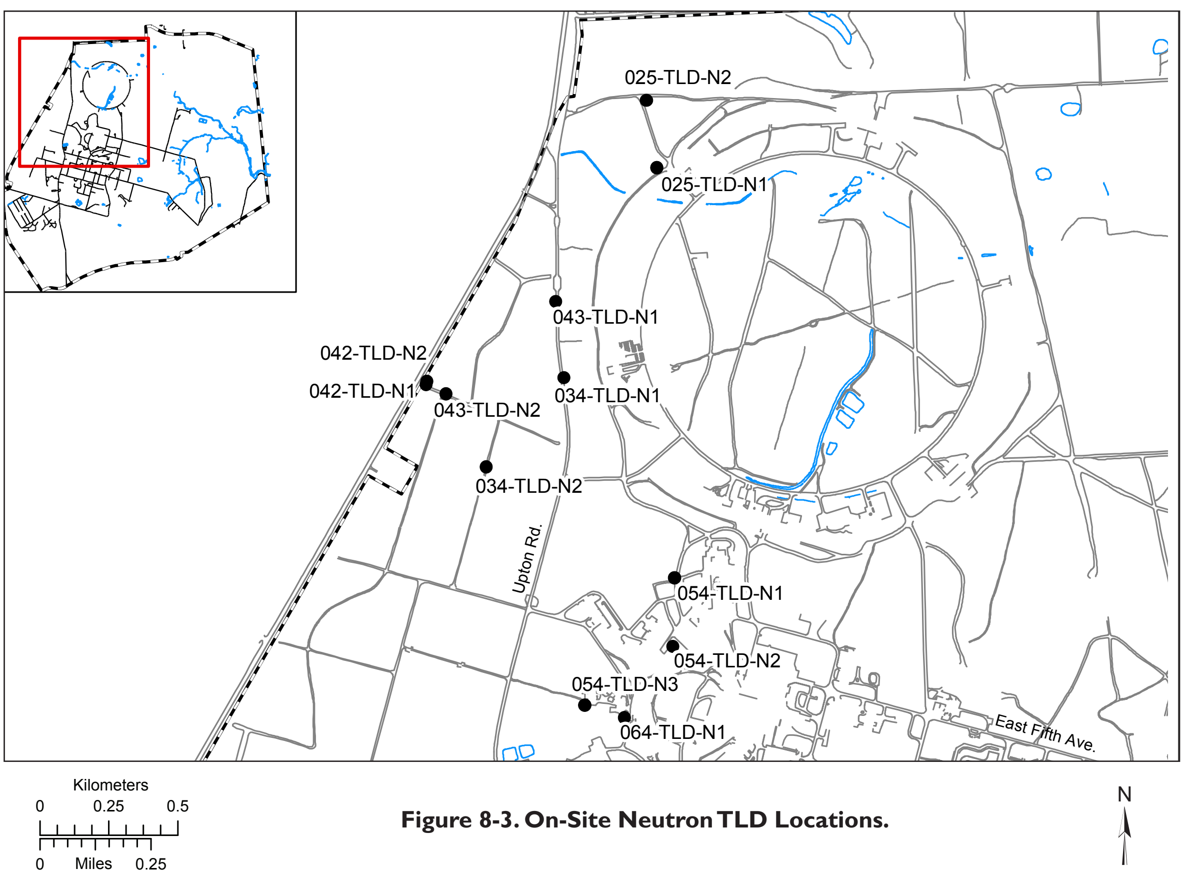


**Figure 8-3. On-Site Neutron TLD Locations.**

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 a measure of 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. Only the neutron TLDs are mounted 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. This allows the incident neutrons to be counted when reflected back out.

In the first quarter of 2015, passive monitors for neutron dose showed 3 mrem neutron dose at 042-TLD-N1 and 2 mrem at 054-TLD-N2. In the second quarter, neutron TLDs at 034-TLD-N2, 043-TLD-N2, and 054-TLD-N2 (both TLDs) showed neutron doses of 1 mrem, 1 mrem, and 3 mrem and 2 mrem, respectively. In the third quarter, TLDs at 043-TLD-N2 and 042-TLD-N1 showed 1 mrem. Finally, a TLD at 042-TLD-N1 showed a neutron dose of 1 mrem in the fourth quarter (see Table 8-4). The RHIC/BLIP run at slightly higher current and energy during the beginning of the third quarter for approximately 1 month, but is turned off for the remainder of the third quarter. In the fourth quarter, the RHIC/BLIP run for a 2-week period at the end of the calendar year. These low-level neutron doses indicate that engineering controls (i.e. berm shielding) in place at AGS and RHIC are effective.

## 8.2 DOSE MODELING

The EPA regulates radiological emissions from DOE facilities under the requirements set forth in 40 CFR 61, Sub-part H, entitled, "National Emission Standards for Hazardous Air Pollutants (NESHAPs)." This regulation specifies the compliance and monitoring requirements for reporting radiation doses received by members of the public from airborne radionuclides. The regulation mandates that no member of the public shall receive a dose 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 1 percent of the 10 mrem standard) and a periodic confirmatory measurement for all other release points. The regulations also require DOE facilities to submit an annual NESHAPs report to EPA that describes the major and minor emission sources and dose to the MEOSI. The dose estimates from various facilities are given in Table 8-5, and the actual air emissions for 2015 are discussed in detail in Chapter 4.

As a part of the NESHAPs review process at BNL, any source that has the potential to emit radioactive materials is evaluated for regulatory compliance. Under the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA), certain restoration activities are also monitored and assessed for any potential to release 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 considered to be conservative.

### 8.2.1 Dose Modeling Program

Compliance with NESHAPs regulations is demonstrated through the use of EPA dose modeling software and the Clean Air Act Assessment Package 1988 (CAP88-PC). This computer program uses a Gaussian plume model to estimate the average dispersion of radionuclides released from elevated stacks or diffuse sources. It calculates a final value of the projected dose at the specified distance from the release point by computing dispersed radionuclide concentrations in 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

Table 8-4. Neutron Dose Report for 2015.

| Location ID No. | 1st Quarter | 2nd Quarter | 3rd Quarter | 4th Quarter | Annual Neutron Dose |
|---|---|---|---|---|---|
| | (mrem neutron)) | | | | |
| 025-TLD-N1 | 0 | 0 | 0 | 0 | 0 |
| " | 0 | 0 | 0 | 0 | 0 |
| 025-TLD-N2 | 0 | 0 | 0 | 0 | 0 |
| " | 0 | 0 | 0 | 0 | 0 |
| 034-TLD-N1 | 0 | 0 | 0 | 0 | 0 |
| " | 0 | 0 | 0 | 0 | 0 |
| 034-TLD-N2 | 0 | 0 | 0 | 0 | 0 |
| " | 0 | 1 | 0 | 0 | 1 |
| 043-TLD-N1 | 0 | 0 | 0 | 0 | 0 |
| " | 0 | 0 | 0 | 0 | 0 |
| 043-TLD-N2 | 0 | 0 | 0 | 0 | 0 |
| " | 0 | 1 | 1 | 0 | 2 |
| 042-TLD-N1 | 0 | 0 | 0 | 1 | 1 |
| " | 3 | 0 | 1 | 0 | 4 |
| 042-TLD-N2 | 0 | 0 | 0 | 0 | 0 |
| " | 0 | 0 | 0 | 0 | 0 |
| 054-TLD-N1 | 0 | 0 | 0 | 0 | 0 |
| " | 0 | 0 | 0 | 0 | 0 |
| 054-TLD-N2 | 2 | 3 | 0 | 0 | 5 |
| " | 2 | 2 | 0 | 0 | 4 |
| 054-TLD-N3 | 0 | 0 | 0 | 0 | 0 |
| " | 0 | 0 | 0 | 0 | 0 |
| 064-TLD-N1 | 0 | 0 | 0 | 0 | 0 |
| " | 0 | 0 | 0 | 0 | 0 |
| Total Annual On-Site Neutron Dose | | | | | 17 |
| PM-bkg * | 0 | 1 | 1 | 0 | 2 |

Note:
* Personal Monitoring of measured natural background neutron dose.

population dose within a 50-mile radius of the emission source. In most cases, the CAP88-PC model provides conservative doses. For the purpose of modeling the dose to the MEOSI, all emission points are co-located at the BLIP Facility 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 amounts (see Chapter 1 for details). A population of 6 million (6,031,539) people, based on the Geographical Information System design population survey

**Table 8-5. Maximally Exposed Off-site Individual Effective Dose Equivalent From Facilities or Routine Processes, 2015.**

| Building No. | Facility or Process | Construction Permit No. | MEOSI Dose (mrem) (a) | Notes |
|---|---|---|---|---|
| 197 | Nonproliferation & Nuclear Safety | None | ND | (k) |
| 197B | Nonproliferation & Nuclear Safety | None | ND | (k) |
| 348 | Instrumentation & Calibration | None | ND | (d) |
| 463 | Biology | None | ND | (i) |
| 480 | Condensed Matter Physics | None | ND | (d) |
| 490 | Radiation Therapy Facility | BNL-489-01 | ND | (e) |
| 490/490A | Medical Research | None | 5.60E-06 | (b) |
| 491 | Brookhaven Medical Research Reactor | None | ND | (e) |
| 510 | Calorimeter Enclosure | BNL-689-01 | ND | (f) |
| 510A | Physics | None | 5.71E-14 | (b) |
| 535 | Instrumentation | None | ND | (i) |
| 555 | Chemistry Facility | None | ND | (i), (k) |
| 725 | National Synchrotron Light Source | None | ND | (i) |
| 734 | Interdisciplinary Science Building | None | 2.80E-15 | (b) |
| 745 | National Synchrotron Light Source II | None | 3.81E-04 | (b) |
| 750 | High Flux Beam Reactor | None | 1.16E-04 | (c) |
| 801 | Target Processing lab | None | 6.90E-04 | (c) |
| 802B | Evaporator Facility | BNL-288-01 | ND | (e) |
| 815 | Environmental Chemistry | None | ND | (k) |
| 820 | Accelerator Test Facility | BNL-589-01 | ND | (d) |
| 830 | Environmental Science Department | None | ND | (d) |
| 865 | Waste Managerment Facility | None | ND | (j) |
| 901 | BioSciences Department | None | ND | (i) |
| 902 | Superconducting Magnet Division | None | ND | (i) |
| 906 | Medical-Chemistry | None | ND | (i) |
| 911 | Alternating Gradient Synchrotron | None | ND | (d) |
| 925 | Accelerator Department | None | ND | (i) |
| 931 | Brookhaven Linac Isotope Producer | BNL-2009-01 | 2.83E-01 | (c) |
| 938 | REF/NBTF | BNL-789-01 | ND | (f), (g) |
| 942 | Alternating Gradient Synchrotorn Booster | BNL-188-01 | ND | (h) |
| --- | Relativistic Heavy Ion Collider | BNL-389-01 | ND | (d) |
| **Total Potential Dose from BNL Operations** | | | **2.84E-01** | |
| **EPA Limit (Air Emissions)** | | | **10** | |

Notes:
MEOSI = Maximally Exposed Off-site Individual
ND = No dose
(a) "Dose" in this table means effective dose equivalent to MEOSI.
(b) Dose is based on emissions calculated using 40CFR61, Appendix D methodology.
(c) Emissions are periodically monitored at the facility.
(d) No Dose from emissions source in 2015.
(e) NO = Not Operational in 2015.
(f) This facility was decommissioned and has been a zero-emission facility.
(g) This facility is no longer in use; it produces no radioactive emissions.
(h) Booster ventilation system prevents air release through continuous air recirculation.
(i) No radiological dispersible material inventory in 2015.
(j) No detectable emissions from the Waaste Managemet Facility in 2015.
(k) Sealed sources were excluded from this inventory--no emission.

performed by Oak Ridge National Laboratory for BNL, was used in the model.

The 2015 effective dose equivalents were estimated using Version 4.0 of CAP88-PC, which was released via a notice in the Federal Register on February 10, 2015. The following approaches were taken and assumptions made in determining dose estimates for this year's report:

- A conservative approach is used for agricultural data input into the CAP88 modeling program, in that 92 percent of vegetables, 100 percent of milk, and 99 percent of meat is considered to be from the assessment area.
- For this year's calculations, the velocity of the exhaust from the BLIP facility stack was updated to reflect current operations. The average volumetric flow rate of the BLIP exhaust system in 2015 was 517 cfm, or 0.244 m3/sec. With an exit diameter of 0.1 m, the exit velocity was increased to 31.06 m/sec, up from last year's 21.8 m/sec, which is the design exit velocity.
- The method of characterizing atmospheric stability for purposes of estimating effluent dispersion was changed to the sigma theta method from the lapse rate method for increased conservatism.
- Based on recent reviews, the programming for the STAR file used for development of the 2015 wind file was updated by the Environmental Sciences Department.

### 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 site boundary. This person is also assumed to consume significant amounts of fish and deer containing radioactivity assumed to be attributable to Laboratory operations based on projections from the New York State Department of Health (NYSDOH). In reality, it is highly unlikely that such a combination of "maximized dose" to any single individual would occur, but the concept is useful for evaluating maximum potential dose and risk to members of the public. The on-site maximally exposed individual who could receive any dose outside of BNL's controlled areas was determined by TLD measurements.

#### *8.2.2.2 Effective Dose Equivalent*

The EDE to the MEOSI from low levels of radioactive materials dispersed into the environment was calculated using the CAP88-PC dose modeling program, Version 4.0. Site meteorology data were used to calculate annual dispersions for the midpoint of a given wind sector and distance. Facility-specific radionuclide emission rates (Ci/yr) were used for continuously monitored facilities. For small sources, the emissions were calculated using the method set forth in 40 CFR 61, Appendix D. The Gaussian dispersion model calculated the EDE at the site boundary and the collective population dose values from the immersion, inhalation, and ingestion pathways. As stated above, these dose and risk calculations to the MEOSI are based on low emissions and chronic intakes.

#### *8.2.2.3 Dose Calculation: Fish Ingestion*

To calculate the EDE from the fish consumption pathway, the intake is estimated. The term "intake" is defined as the average amount of fish consumed by a person engaged in recreational fishing on the Peconic River. Based on a NYSDOH study, the consumption rate is estimated at 15 pounds (7 kg) per year (NYSDOH 1996). For each radionuclide of concern for fish samples, the dry weight activity concentration was converted to picoCuries per gram (pCi/g) "wet weight," since wet weight is the form in which fish are caught and consumed. A dose conversion factor was used for each radionuclide to convert the activity concentration into the EDE. For example, the committed dose equivalent conversion factor for cesium-137 (Cs-137) is 5.0E-02 rem/µCi, as set forth in DOE/EH-0071. 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 1996). No other radionuclides associated with Laboratory operations have been detected in deer meat. The total quantity of deer meat ingested during the course of a year was estimated at 64 pounds (29 kg) (NYSDOH 1999).

## 8.3 SOURCES: DIFFUSE, FUGITIVE, "OTHER"

Diffuse sources, also known as nonpoint or area sources, are described as sources of radioactive contaminants which diffuse into the atmosphere but do not have well-defined emission points. Fugitive sources include leaks through window and door frames, as well as unintended releases to the air through vents or stacks which are supposedly inactive (i.e., leaks from vents are fugitive sources). As part of the NESHAPs review process, in addition to stack emissions, any fugitive or diffuse emission source that could potentially emit radioactive materials to the environment is evaluated. Although CERCLA-prompted actions, such as remediation projects, are exempt from procedural requirements to obtain federal, state, or local permits, any BNL activity or process with the potential to emit radioactive material must be evaluated and assessed for potential dose impact to members of the public. No NESHAPs reviews were requested or performed in 2015.

### 8.3.1 Remediation Work

During the summer of 2015, the project to decontaminate and demolish Building 811 was largely completed. As required by NESHAPs, this demolition project was evaluated for the potential to release radioactive contaminants to the environment. A detailed demolition plan was prepared and closely followed, which included the use of a water mist spray to prevent suspension of any possible soil- or dust-borne contaminants. Monitoring for airborne radioactive materials during the demolition activities did not detect any measurable releases.

## 8.4 DOSE FROM POINT SOURCES

### 8.4.1 Brookhaven Linac Isotope Producer

Source term descriptions for point sources are given in Chapter 4. The BLIP facility is the only emission source with the potential to contribute dose to members of the public greater than 1 percent of the EPA limit (0.1 mrem or 1.0 µSv). 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 in-line, low-resolution, sodium iodide (NaI) gamma spectrometer. The spectrometer system is connected to a computer workstation that is used to display and continuously record 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 absorbent and are then analyzed at an off-site contract analytical laboratory on a biweekly basis.

In 2015, the BLIP facility operated over a period of 31 weeks. During the year, 1,517 Ci of C-11 (half life: 20 minutes) and 3,034 Ci of O-15 (half life: 122 seconds) were released from the BLIP facility. A small quantity (2.86E-02 Ci) of tritiated water vapor from activation of the targets' cooling water was also released. The EDE to the MEOSI was calculated to be 2.83-01 mrem (2.8 µSv) in a year from BLIP operations.

### 8.4.2 High Flux Beam Reactor

In 2015, the residual tritium emissions from the HFBR Facility were measured at 0.451 Ci, and the estimated dose attributed was 1.16E-4 mrem (1.16 nSv) in a year.

### 8.4.3 Brookhaven Medical Research Reactor

In 2015, 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 2015.

### 8.4.4 Brookhaven Graphite Research Reactor

In 2015, long-term surveillance of the BGRR

Table 8-6. BNL Site Dose Summary, 2015.

| Pathway | Dose to Maximally Exposed Individual | Percent of DOE 100 mrem/year Limit | Estimated Population Dose per year |
|---|---|---|---|
| **Inhalation** | | | |
| Air | 0.284 mrem | <1% | 0.419 Person-rem |
| **Ingestion** | | | |
| Drinking Water | None | None | None |
| Fish | 0.088 mrem | <1% | Not Tracked |
| Deer | 2.78 mrem | <3% | Not Tracked |
| **All Pathways** | 3.15 mrem | <4% | 0.419 Person-rem |

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 2015.

### 8.4.5 Waste Management Facility

In 2015, there were no detectable levels of emissions from the Waste Management Facility.

### 8.4.6 Unplanned Releases

There were no unplanned releases in 2015.

## 8.5 DOSE FROM INGESTION

Radionuclides in the environment may bioaccumulate in deer and fish tissues, 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-site and off-site but near the BNL boundary were used to assess the potential dose impact to the MEOSI. The maximum tissue concentration in the deer meat (flesh) 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 2015, BNL performed a managed reduction of the deer population on site. Samples from 52 animals were analyzed for K-40 and Cs-137. It should be noted that because 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 (off site < 1 mile) were 3.2 ± 0.34 pCi/g (wet weight) in the flesh and 3.41 ± 0.52 pCi/g (wet weight) in the liver. The maximum Cs-137 concentration was 0.22 ± 0.01 pCi/g (wet weight) in the flesh (off site < 1 mile) (see Table 6-2). The average Cs-137 concentration from all deer samples was 0.27 ± 0.21 pCi/g. However, the maximum Cs-137 concentration of 1.92 pCi/g, from a deer sample collected on site, was used for the purpose of MEOSI dose calculations. The maximum estimated dose to humans from consuming deer meat containing the maximum Cs-137 concentration was estimated to be 2.78 mrem (27.8 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 (NYSDEC) Fisheries Division, the Laboratory maintains an ongoing program of collecting and analyzing fish from the Peconic River and surrounding freshwater bodies. In 2015, a largemouth bass species had the highest measured concentration of Cs-137 at 0.25 ± 0.06 pCi/g; this was used to estimate the EDE to the MEOSI. The potential dose from consuming 15 pounds of such fish annually was calculated to be 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 2015, the terrestrial animal and plant doses were evaluated based on 2.84 pCi/g of Cs-137 (see Table 6-10) found in surface soils around Pond 9 and a strontium-90 (Sr-90) concentration of 0.47 pCi/L (see Table 5-5) in the surface waters collected at the HQ location. The dose to terrestrial animals was calculated to be 137 µGy/day, and to plants, 12.9 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, Sr-90 radionuclide concentration values for surface water collected from the eastern site boundary at station HQ (see Table 5-5) and the Cs-137 in sediments found near the PR-WC-06 location were used. The Cs-137 sediment concentration at PR-WC-06 was 3.71 pCi/g and the Sr-90 concentration in surface water at HQ was 0.47 pCi/L. The calculated dose to aquatic animals was 0.84 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 2015. The total dose to the MEOSI from air and ingestion pathways was estimated to be 3.15 mrem (32 µSv). In comparison, the EPA regulatory limit for the air pathway is 10 mrem (0.10 mSv) and the DOE limit from all pathways is 100 mrem (1 mSv). The cumulative population dose was 0.419 person-rem (4.2E-3 person-Sv) in a year. The effective dose is well below the DOE and EPA regulatory limits, and the ambient TLD dose is within normal background levels seen at the Laboratory site. The potential dose from drinking water was not estimated, because most residents adjacent to the BNL site get their drinking water from the Suffolk County Water Authority rather than private wells. To put the potential dose impact into perspective, a comparison was made with estimated doses from other sources of radiation. The annual dose from all natural background sources and radon is approximately 311 mrem (3.11 mSv). A mammogram gives a dose of approximately 250 mrem (2.5 mSv) and a dental x-ray gives a dose of approximately 160 mrem (1.6 mSv) to an individual. Therefore, a dose of 3.15 mrem from all environmental pathways is a minute fraction of the dose from that of several routine diagnostic procedures as well as natural background radiation.

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