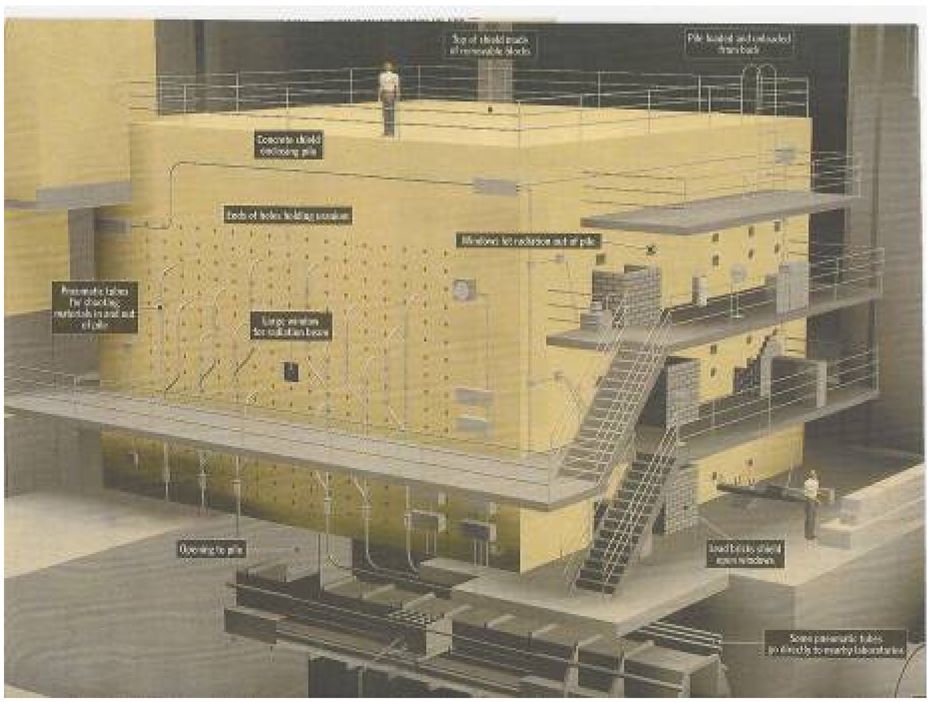
Final
CLOSEOUT REPORT

Brookhaven Graphite Research Reactor
Biological Shield Removal
Area of Concern 9
Brookhaven National Laboratory
Upton, New York



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Executive Summary

The Brookhaven Graphite Research Reactor (BGRR) biological shield is associated with Area of Concern (AOC) 9 at Brookhaven National Laboratory (BNL). Removal of the biological shield and related structures, and the completion of the associated preparation activities and as-left survey, referred to herein as the “BGRR Biological Shield Removal Project,” are part of the remedial actions described in the *Record of Decision for AOC 9, Brookhaven Graphite Research Reactor* (BGRR ROD) (BNL, 2005a). This Closeout Report addresses specifically the BGRR biological shield removal and how it was completed in accordance with the BGRR ROD and the *Explanation of Significant Differences for the Brookhaven Graphite Research Reactor, Area of Concern 9* (BNL, 2012b) (ESD). Other closeout reports for the BGRR, such as the engineered cap, and graphite removal address how they also meet the requirements of the BGRR ROD. All remedial actions described in the BGRR ROD and ESD have been implemented.

The project was completed in part with funding under the American Recovery and Reinvestment Act (ARRA) and in accordance with Closeout Procedures for National Priorities List Sites, Environmental Protection Agency (EPA) Office of Solid Waste and Emergency Response (OSWER) Directive 9320.2-22 (EPA, 2011) and the *Final Remedial Design/Remedial Action Work Plan for the Biological Shield Removal* (BNL, 2008) (RD/RA Work Plan). Modifications to the scope of work specified in the BGRR ROD and the project RD/RA Work Plan are documented in this report and in the following:

- *Remedial Design Implementation Report, Differences in the Scope of Removal of the Brookhaven Graphite Research Reactor (BGRR) Biological Shield* (BNL, 2011e) (RDIR),
- *Explanation of Significant Differences for the Brookhaven Graphite Research Reactor, Area of Concern 9* (BNL, 2012b) (ESD); and

The ESD describes and justifies one instance where the completed end state is different than described in the BGRR ROD. The BGRR ROD anticipated removal of the biological shield walls from the top of the bioshield to its base, which is three feet below the floor level. Per the ESD, the portion of the biological shield below the floor level was not removed and was left in place (this portion of the biological shield contains activation products). This change results in “reductions in radiation doses to workers who would otherwise be removing the lowermost section of the biological shield” while preserving the ROD’s radiological end state and without affecting the planned long-term surveillance and maintenance activities for Building 701. The RDIR describes and justifies the actions described in the BGRR ROD and the RD/RA Work Plan which were not executed as originally planned. These were: the removal of many of the experimental balconies in their entirety instead of only portions; the removal of the Chemo-Nuclear System in its entirety instead of just the lead wall around it; and the abandonment of the upper bed plates in place, rather than their removal. The first two changes were driven by

operational considerations and resulted in the removal of more material from the BGRR than anticipated. The last was driven by As Low As Reasonably Achievable (ALARA) concerns. A detailed listing of these differences is found in Table 3-1.

Work activities associated with the BGRR Biological Shield Removal Project commenced in June 2010 and were completed in May 2012, and included the following scope of work:

- Removal of the two uppermost balconies (located at elevation 136'-0") and the single north balcony, two west balconies and lower east balcony in their entirety;
- Removal of the Chemo-Nuclear System within the high bay area, including the lead walls;
- Removal of the asbestos containing material (ACM) floor tiles on the balcony areas;
- Removal of the pile upper sliding rails;
- Placement of 3-inch steel plates over the upper pile bedplates to provide radiological shielding for workers. The plates were secured in place with concrete grout;
- Filling of void areas (West Animal and Instrument Tunnels, and the North Pipe Trench) beneath the Building 701 high bay area outside of the biological shield footprint with cementious grout, and the placement of steel plates atop this floor surface to evenly spread the load of the excavator/hammer unit used to break up the biological shield;
- Filling of the north and south outlet air plenums with reinforced concrete to elevation 109'-0" to support the excavator/hammer unit and provide additional radiological shielding for workers;
- Re-supporting one east elevation 123'-0" balcony;
- Extending the previously constructed Contamination Control Enclosure (CCE) on the west side;
- Removal of the biological shield outer steel walls, inner steel walls and concrete structure down to the Building 701 floor level (elevation 110'-0");
- Sealing of all plenums, chutes and experimental openings;
- Removal of all visible loose debris and removal and/or stabilization of loose radiological contamination in the Building 701 area associated with the removal of the biological shield, including the remaining pile support structure within the biological shield footprint;
- Placement of reinforced concrete from elevation 109'-0" to elevation 110'-0";
- Completion of a final as-left radiological survey of Building 701 interior, including independent verification (IV) performed by the Oak Ridge Institute for Science and Education (ORISE);

- Completion of a final as-left survey for the remaining BGRR Outside Areas, including IV performed by ORISE; and
- Packaging, transportation and disposal of all project wastes.

There was no ROD-required cleanup criterion for the BGRR complex. Therefore, the as-left survey data for the remaining BGRR Outside Areas were compared to the site cleanup criteria specified in the *Record of Decision, Operable Unit I and Radiologically Contaminated Soils* (BNL 1999) (OU I ROD) for cesium (Cs)-137, radium (Ra)-226 and strontium (Sr)-90. The OU I ROD cleanup goals for these radionuclides were calculated using the Residual Radioactivity Computer Code (RESRAD), based on a total dose limit of 15 millirem per year (mrem/yr) above background to a future resident (non-farmer) after 50 years of institutional controls.

The following summarizes the as-left conditions for surficial soils in the remaining BGRR outside areas:

- The maximum Cs-137 and Ra-226 concentrations remaining in the soils are 0.25 pico-Curies per gram (pCi/g), and 0.40 pCi/g, respectively. Sr-90 was not detected in soil above its minimum detectable concentration. The as-left average and maximum concentrations are well below the cleanup goals (Cs-137 = 23 pCi/g, Sr-90 = 15 pCi/g and Ra-226 = 5 pCi/g).

- The as-left average concentrations of the chemical contaminants of concern detected in soils samples are below the site cleanup goals (lead = 400 milligrams per kilogram [mg/kg], mercury = 0.7 mg/kg, nickel = 130 mg/kg, zinc = 2,200 mg/kg, copper = 270 mg/kg, beryllium = 0.43 mg/kg). The maximum concentrations of lead, mercury, nickel, zinc, copper and beryllium detected in soil samples were 35.2 mg/kg, 0.0365 mg/kg, 5.52 mg/kg, 36.9 mg/kg, 18.6 mg/kg, and 0.201 mg/kg, respectively.

The as-left radiological survey of the Building 701 interior was conducted following the completion of all the work, the removal of equipment and the stabilizing of dispersible radioactive materials. All radiation/contamination areas are identified and appropriately posted and controlled per the BNL Radiation Control Program. The as-left radiological survey concludes the following:

- Office spaces within Building 701 are free of removable contamination and are at background radiation levels.
- Areas within the reactor high bay indicate areas of fixed contamination, including the steel plates on the 110’ elevation. Currently the external whole body radiation levels within the reactor high bay are at background levels with the exception of the biological shield concrete cap, which is 0.01 to 0.08 millirem per hour (mrem/hr) at a distance of three feet from the floor. Maximum dose rate on contact with the floor is 0.2 mrem/hr.
- Building 701 is predominantly free of loose radiological contamination with the

exception of the inaccessible areas (above six feet).

- Radiological surveys of the Fuel Chute, Canal Deep Pit and remaining portions of the Fuel Canal indicate the remaining contamination exists primarily within the Canal Deep Pit. Existing contamination levels are approximately 1,000 to 5,000 disintegrations per minute per 100 square centimeters (dpm/100cm^2) beta and <100 dpm/100cm^2 alpha. General area external whole body radiation dose rates while standing at the base of the pit range from 8 to 15 mrem/hr with a one foot radiation level of 80 mrem/hr at the drain strainer located in the northeast corner of the pit.
- The external surfaces of the top of the biological shield cap contained no removable contamination above normal operational release limits.
- Isolated areas of removable contamination were identified on the interior surface of the reactor building roof, "I" beams, and catwalks. Discrete locations exhibited fixed beta contamination levels up to 1,000 dpm/100 cm^2.

Based on measured levels of contamination and residual dose rates, a conservative summary of calculated radiological content remaining in the BGRR biological shield and pile bedplates is 1.1 Curies and 11.2 Curies, respectively, for a total of 12.3 Curies. As noted in the "Evaluation of Total Remaining Curie Content of the BGRR Complex vs. ROD Commitments" December 2011 paper, which is included in the RDIR, the end state of the BGRR reflects removal of 99.8% of the total Curie content. The residual radioactivity in the BGRR itself is in the form of activated steel and concrete, surrounded and contained by the building and its foundation. The residual radioactivity in the soil is below the BGRR and protected by the building and the cap, which extends up to 120 feet beyond the edge of the building and prevents rainfall from causing migration of the contamination. The distance from the bottom of the foundation of the building to groundwater is approximately 40 feet.

A pre-final inspection was conducted among DOE, Brookhaven Science Associates (BSA) and their contractors during the Exit Readiness Review walkthroughs on April 9th, 16th, 24th and 25th 2012. The EPA Remedial Project Manager also performed a site visit of the BGRR on July 12, 2012.

The BGRR Biological Shield Removal Project meets all the completion requirements as specified in OSWER Directive 9320.2-22, May 2011 *Closeout Procedures for National Priorities List Sites.* The remedy was constructed in accordance with the remedial design plans and specifications, as modified by RDIR (BNL, 2011e) and the ESD (BNL, 2012b).

The *Long-Term Surveillance and Maintenance Manual for the Brookhaven Graphite Research Reactor* (BNL, 2012c) includes monitoring, maintenance, and inspection activities and frequencies for Building 701 and the remaining BGRR Outside Areas. The monitoring and inspection frequencies vary depending on the activity being performed and include quarterly, semi-annual, annual, every five years, or as conditions require after major natural events. These activities include:

- Inspections and maintenance of Building 701 exterior, including the roof, perimeter walls and doors, and associated transformers and circuit breakers;
- Inspection and maintenance of the Building 701 interior (i.e., high bay, canal, deep pit, office spaces and sample room).
- Testing, maintenance and monitoring of the BGRR Water Infiltration Detection System;
- Inspections and maintenance of the engineered cap asphalt, concrete pads and coatings;
- Inspection and maintenance of the Below Ground Ducts, and monitoring of the Below Ground Duct Water Infiltration Detection System;
- Annual certification to the regulators that the Institutional and Engineering Controls are in place and functioning; and
- Institutional controls (land use controls, notifications and restrictions, such as no parking or vehicular traffic within 10 feet of the cap geomembrane anchor points, work planning controls such as digging permits, and government ownership).

Brookhaven Science Associates (BSA) will perform surveillance and maintenance activities. In addition to maintaining institutional controls, BSA will ensure that that routine maintenance/inspections are performed. The U.S. Department of Energy (DOE) will ensure enforcement of all institutional controls.

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Acronym List

ACM	Asbestos Containing Material
ALARA	As Low As Reasonably Achievable
Am	Americium
AOC	Area of Concern
ARRA	American Recovery and Reinvestment Act
ATM	Air Tight Membrane
BER	Brookhaven Executive Round Table
BGD	Below Ground Duct
BGRR	Brookhaven Graphite Research Reactor
BNL	Brookhaven National Laboratory
BSA	Brookhaven Science Associates
C	Carbon
CAC	Community Advisory Council
CAM	Continuous Air Monitor
CCE	Contamination Control Enclosure
CERCLA	Comprehensive Environmental Response, Compensation & Liability Act
Ci	Curies
cpm	Counts Per Minute
Co	Cobalt
Cs	Cesium
DOE	Department Of Energy
$dpm/100cm^2$	Disintegrations Per Minute Per 100 Square Centimeters
EPA	Environmental Protection Agency
EPD	Environmental Protection Division
ERP	Environmental Restoration Projects
ESD	Explanation of Significant Differences
ES&H	Environmental, Safety and Health
Eu	Europium
F&O	Facilities and Operations
Fe	Iron
FS	Feasibility Study
GPS	Global Positioning System
HFBR	High Flux Beam Reactor
IAG	Interagency Agreement
IBC	Intermediate Bulk Container
IP-1	Industrial Package Type 1
IV	Independent Verification
JSA	Job Safety Analysis
LLRW	Low-Level Radioactive Waste
MARSSIM	EPA Multi-Agency Radiation Survey and Site Investigation Manual
MDA	Minimum Detectable Activity
mg/kg	Milligrams Per Kilogram
mrem/hr	Millirem Per Hour
mrem/yr	Millirem Per Year

NaI	Sodium Iodide
NEPA	National Environmental Policy Act
Ni	Nickel
NNSS	Nevada National Security Site
NYCRR	New York Code of Rules and Regulations
NYSDEC	New York State Department of Environmental Conservation
ORISE	Oak Ridge Institute for Science and Education
OSWER	EPA Office of Solid Waste and Emergency Response
OU	Operable Unit
pCi/g	Pico-Curie Per Gram
PCM	Personnel Contamination Monitor
Pu	Plutonium
PRAP	Proposed Remedial Action Plan
Psi	Pounds Per Square Inch
QA/QC	Quality Assurance/Quality Control
Ra	Radium
RCD	Radiological Controls Division
RDIP	Remedial Design Implementation Plan
RD/RA	Remedial Design/Remedial Action
RESRAD	Residual Radioactivity Computer Code
ROD	Record of Decision
SOP	Standard Operating Procedure
SPRU	Separations Process Research Unit
Sr	Strontium
SU	Survey Unit
TAGM	Technical and Administrative Guidance Memorandum
U	Uranium
WP	Work Procedure

1.0 INTRODUCTION

1.1 Purpose

The purpose of this Closeout Report is to document the removal of Brookhaven Graphite Research Reactor (BGRR) biological shield, as well as the completion of the associated preparation activities, the as-left radiological survey of Building 701 and the remaining BGRR Outside Areas, at Brookhaven National Laboratory (BNL). This work is referred to as the “BGRR Biological Shield Removal Project.” The BGRR Biological Shield Removal Project is part of the remedial actions described in the *Record of Decision for AOC 9, Brookhaven Graphite Research Reactor* (BGRR ROD) (BNL, 2005a). This Closeout Report addresses specifically the BGRR biological shield removal and how it was completed in accordance with the BGRR ROD and the *Explanation of Significant Differences for the Brookhaven Graphite Research Reactor, Area of Concern 9* (BNL, 2012b) (ESD). Other closeout reports for the BGRR, such as the engineered cap, and graphite removal address how they also meet the requirements of the BGRR ROD. All remedial actions described in the BGRR ROD and ESD have been implemented. The project was completed with funding under the American Recovery and Reinvestment Act (ARRA) and in accordance with Closeout Procedures at National Priority List Sites, Environmental Protection Agency (EPA) Office of Solid Waste and Emergency Response (OSWER) Directive 9320.2-22 (EPA 2011).

Activities associated with the BGRR Biological Shield Removal Project were performed by Brookhaven Science Associates (BSA) Environmental Restoration Projects (ERP), ERP- seconded and task order subcontractors, BSA’s Radiological Control Division (RCD), and Environmental Protection Division (EPD) personnel. Independent verification activities were performed by Oak Ridge Institute for Science and Education (ORISE), DOE’s independent subcontractor.

Work was performed in accordance with the BGRR ROD and the *Final Remedial Design/Remedial Action Work Plan for the Biological Shield Removal* (BNL, 2008) (RD/RA Work Plan). Modifications to the scope of work specified in the BGRR ROD and the project RD/RA Work Plan, which are summarized in Table 3.1, were documented in this report and in the following:

- *Remedial Design Implementation Report, Differences in the Scope of Removal of the Brookhaven Graphite Research Reactor (BGRR) Biological Shield* (BNL, 2011e) (RDIR),
- *Explanation of Significant Differences for the Brookhaven Graphite Research Reactor, Area of Concern 9* (BNL, 2012b) (ESD); and

The ESD describes and justifies one instance where the completed end state is different than described in the BGRR ROD. The BGRR ROD anticipated removal of the biological shield walls from the top of the bioshield to its base, which is three feet below the floor level. Per the ESD, the portion of the biological shield below the floor level was not removed and was left in place (this portion of the biological shield contains activation products). This change results in “reductions in radiation doses to workers who would otherwise be removing the lowermost section of the biological shield” while preserving the ROD’s radiological end state and without affecting the planned long-term surveillance and maintenance activities for Building 701. The RDIR describes and justifies the actions described in the BGRR ROD and the RD/RA Work Plan which were not executed as originally planned. These were: the removal of many of the experimental balconies in their entirety instead of only portions; the removal of the Chemo-Nuclear System in its entirety instead of just the lead wall around it; and the abandonment of the upper bed plates in place, rather than their removal. The first two changes were driven by operational considerations and resulted in the removal of more material from the BGRR than anticipated. The last was driven by As Low As Reasonably Achievable (ALARA) concerns. A detailed listing of these differences is found in Table 3-1.

The as-left radiological surveys of Building 701 and the remaining BGRR Outside Areas were performed in accordance with the Work Procedure (WP)-314-35, *As-Left Survey for the BGRR*, *Rev. 2* (BNL, 2012a).

The scope of work for the BGRR Biological Shield Removal Project included the following:

- Removal of the pile upper sliding rails;
- Removal of the asbestos containing material (ACM) floor tiles on the balcony areas;
- Removal of the two uppermost balconies (located at elevation 136’-0”), the single north balcony, two west balconies and lower east balcony in their entirety;
- Removal of the Chemo-Nuclear System within the high bay area, including the lead walls;
- Placement of 3-inch steel plates over the upper pile bedplates to provide radiological shielding for workers. The plates were secured in place with concrete grout;
- Filling of void areas (West Animal and Instrument Tunnels, and the North Pipe Trench) beneath the Building 701 high bay area outside of the biological shield footprint with cementious grout, and the placement of steel plates atop this floor surface to evenly spread the load of the excavator/hammer unit used to break up the biological shield;
- Filling of the north and south outlet air plenums with reinforced concrete to elevation 109’-0” to support the excavator/hammer unit and provide additional radiological shielding for workers;
- Re-supporting the east elevation 123’-0” balcony;
- Extending the previously constructed Contamination Control Enclosure (CCE) on the west side;

- Removal of the biological shield outer steel walls, inner steel walls and concrete structure down to the Building 701 floor level (elevation 109’-0”);
- Sealing of all plenums, chutes and experimental openings;
- Removal of all visible loose debris and removal and/or stabilization of loose radiological contamination in the Building 701 area associated with the removal of the biological shield, including the remaining pile support structure within the biological shield footprint;
- Placement of reinforced concrete from elevation 109’-0” to elevation 110’-0”;
- Completion of a final as-left radiological survey of Building 701 interior, including independent verification (IV) performed by the Oak Ridge Institute for Science and Education (ORISE);
- Completion of a final as-left survey for the remaining BGRR Outside Areas, including IV performed by ORISE; and
- Packaging, transportation and disposal of all project wastes.

A pre-final inspection was conducted among DOE, BSA and their contractors during the Exit Readiness Review walkthroughs on April 9th, 16th, 24th and 25th 2012. The EPA Remedial Project Manager also performed a site visit of the BGRR on July 12, 2012.

The remedy was constructed in accordance with the remedial design plans and specifications, as modified by RDIR (BNL, 2011e) and the ESD (BNL, 2012b).

1.2 Site Description and Operational History

The U.S. Army occupied the BNL Site, formerly Camp Upton, during World Wars I and II. Between the wars, the Civilian Conservation Corps operated the BNL Site. It was transferred to the Atomic Energy Commission in 1947, to the Energy Research and Development Administration in 1975, and to Department of Energy (DOE) in 1977. Brookhaven Science Associates (BSA) operates BNL under a contract with DOE.

The BNL site covers almost 5,300 acres, much of which is wooded. It is an irregular polygon, and each side is approximately 2.5 miles long. The developed portion of the BNL site includes the principal facilities, which are located near the center of the BNL site on relatively high ground. The developed portion is approximately 1,650 acres, 500 acres of which were originally developed for U.S. Army use. Large, specialized research facilities occupy 200 acres and another 400 acres are occupied by roads, parking lots and connecting areas. The remaining 550 acres are occupied by outlying facilities including an apartment area, the Long Island Solar Farm, Former Hazardous Waste Management Area, Sewage Treatment Plant, firebreaks, and the Former Landfill Area. The terrain is gently rolling, with elevations varying from 40 to 120 feet above mean sea level. The land lies on the western rim of the shallow Peconic River watershed, with a tributary of the Peconic River rising in marshy areas in the northern section of the tract. The sole-source aquifer beneath BNL comprises three water-bearing units: the upper glacial deposits, the Magothy Formation, and the Lloyd Sand Member of the Raritan Formation. These units are hydraulically connected and make up a single zone of saturation with varying physical properties extending from a depth of 5 to 1,500 feet below the land surface. These three water-bearing units are designated as a “sole source aquifer” by the U.S. Environmental Protection Agency (EPA) and serve as the primary source of drinking water for Nassau and Suffolk counties.

A map illustrating the location of the BNL site is presented as Figure 1-1.

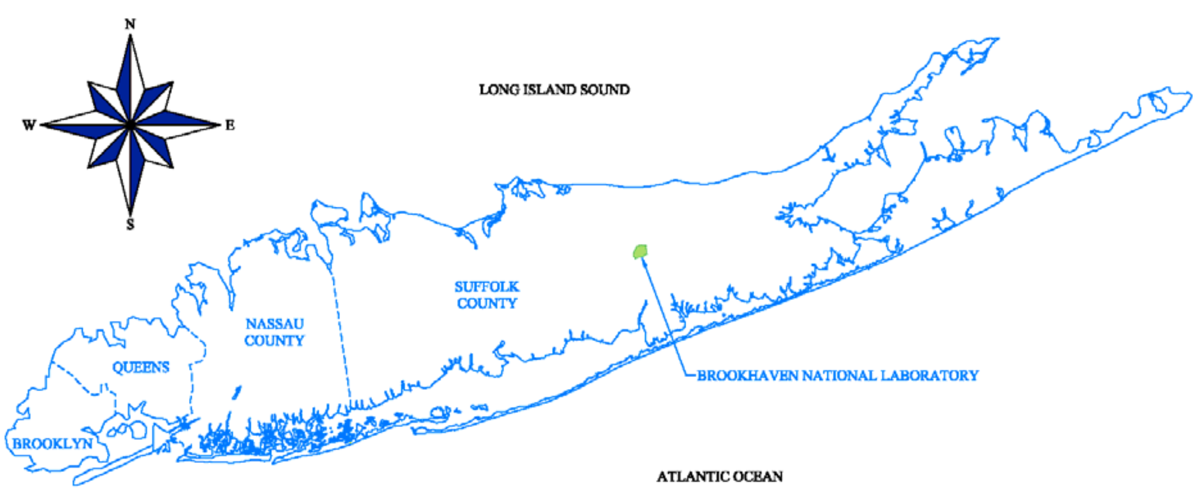


Figure 1-1. Location of Brookhaven National Laboratory

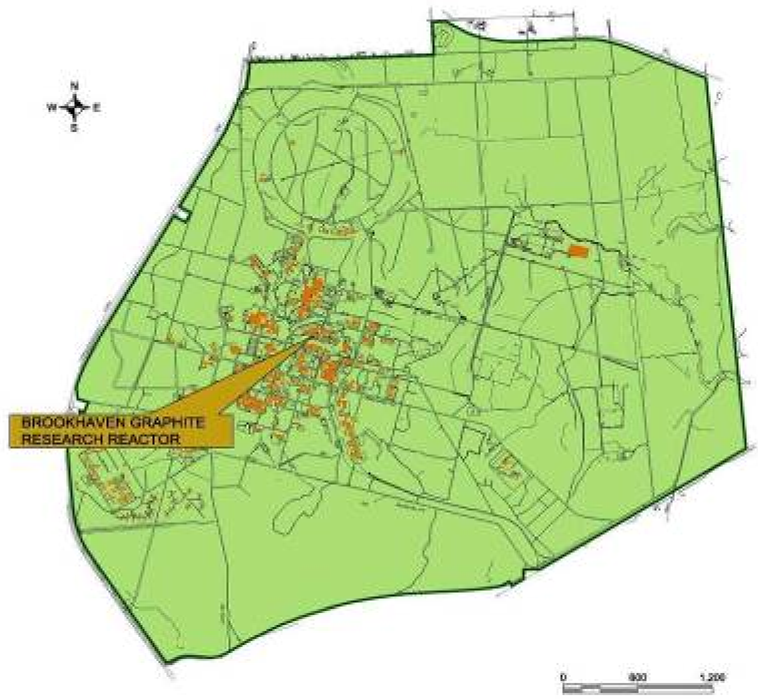


Figure 1-2. Location of the BGRR on BNL Site

The BGRR is centrally located within the BNL site (Figure 1-2). It operated from 1950 to 1968 and was the first reactor in the world designed and built strictly for peaceful research purposes. The BGRR was an air-cooled, graphite-moderated reactor. Deactivation of the facility was initiated in September 1969. In March 1972, the last fuel element was removed from the reactor and shipment of the fuel to the DOE Savannah River Site was completed shortly thereafter. Portions of the BGRR facility were used as the BNL Science Museum from 1977 through 1997. Figure 1-3 illustrates the BGRR complex.

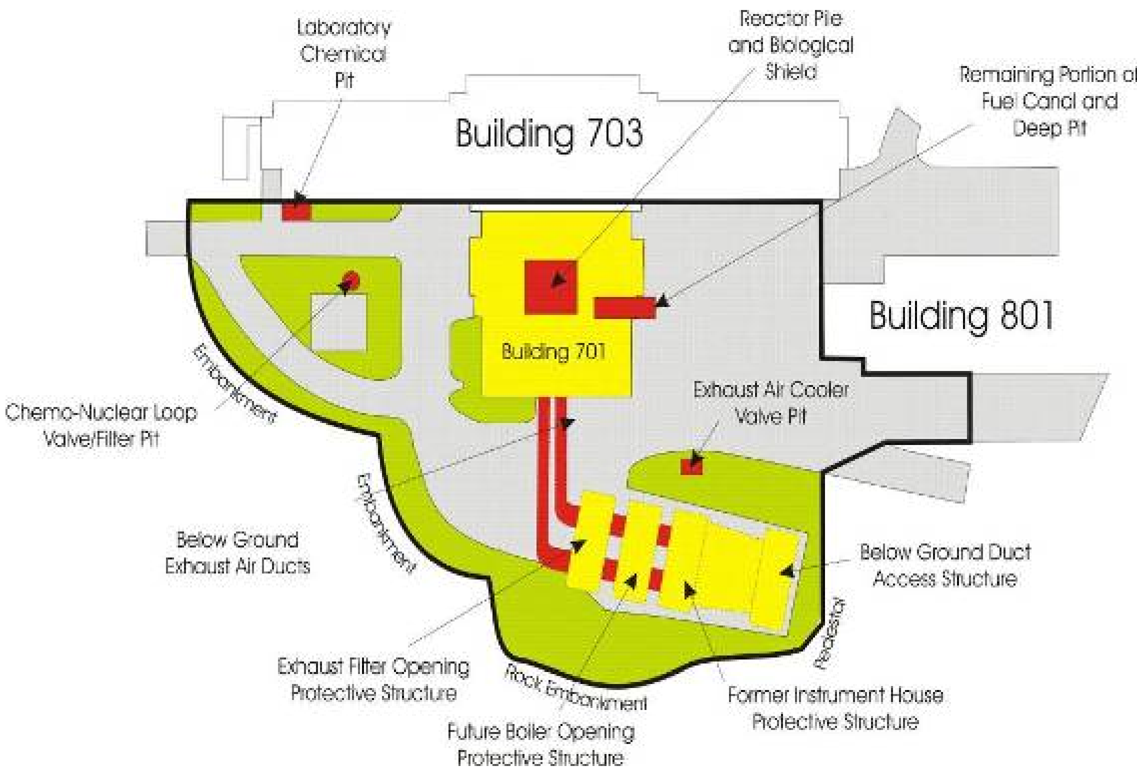


Figure 1-3. BGRR Complex

In 2005, the BGRR ROD was signed by the EPA and DOE, with concurrence provide by the New York State Department of Environmental Conservation (NYSDEC). This agreement requires the removal of the graphite pile, biological shield, canal structure, reasonably accessible contaminated soils, and the installation of a water infiltration control engineered cap and monitoring system for the remaining structures and subsurface contaminated soils. This closeout report addresses the removal and disposal of the BGRR biological shield.

1.2.1 Biological Shield

The BGRR biological shield and associated components were the structures that shielded personnel from radiation during reactor operation, and provided physical support and an airtight membrane around the BGRR graphite pile. The biological shield was constructed of steel and high density concrete and surrounded the graphite pile and air plenum chambers. The biological shield was 55'-0" long and 37'-6" wide by 33'-7" high as measured from elevation 106'-9". The biological shield walls were set 3'-3" lower than the building floor at elevation 110'-0".

The graphite pile and plenum chambers were surrounded by the biological shield. The thickness of the biological shield walls varied by location, from 4'-3" to 5'-6". The outer walls consisted of 3" thick steel. The east and west inner walls were 6" thick (two 3" thick plates adjoined) in the area immediately adjacent to the graphite pile location and 3" thick elsewhere. Biological shield components also included two 3" thick steel neutron shields, as well as the thermal shielding and binding plates in the exhaust plenums. The biological shield is illustrated below in Figures 1-4 through 1-6.

The following descriptions are provided for the key components included in Figures 1-5 and 1-6:

- North and South Air Plenums – The two plenums are contained within the biological shield and were part of the primary air cooling system. Air was drawn through the fuel channels and around the face of the graphite and exited through the air plenums into the below-ground ducts.
- Thermal Shield – This protected the concrete from becoming dehydrated from the hot primary air exiting into the air plenums.
- Neutron Shield – These 3" steel plates were designed to structurally restrain accidental outward movement of the two pile halves and to serve as a neutron shield for the north and south faces.
- Bed Plate – The pile is supported by the upper of two steel bed plates which in turn are supported on a set of thirteen I-beams. The lower bed plate is keyed to the I-beams which are anchored to the concrete foundation. Graphite lubricated steel runners are between the two layers of bedplates to allow movement of the pile.
- Locking Mechanism – The upper steel bed plate was designed to be moved to adjust the diameter of the air gap between the two pile halves. To ensure inadvertent movement of the pile does not occur, two similar locking devices are located on the east and west sides of the pile. They consist of steel bars that fit into a recessed portion of the upper bed plate and is held in place by three adjustable shafts.

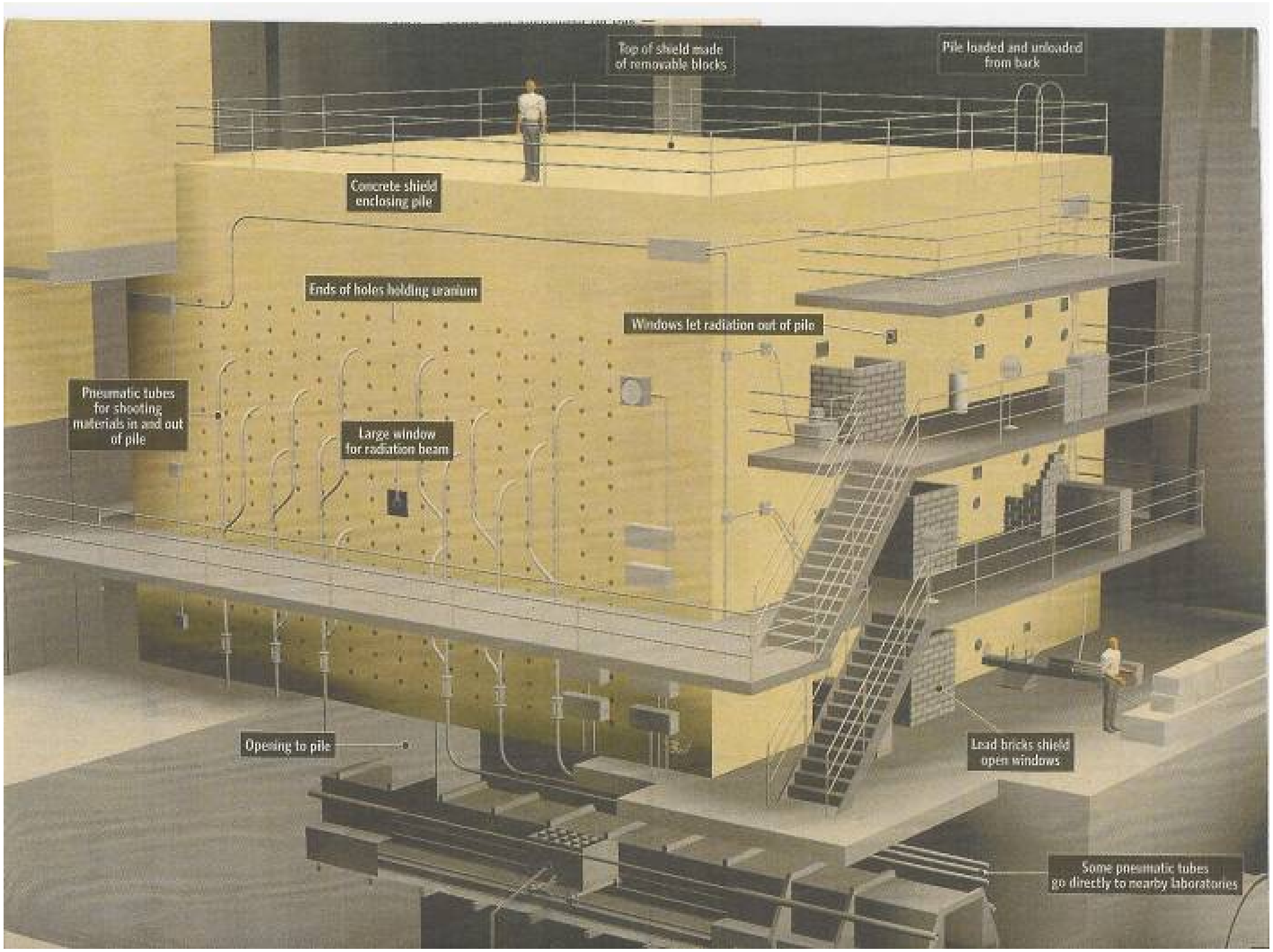


Figure 1-4. BGRR Biological Shield and Experimental Facilities

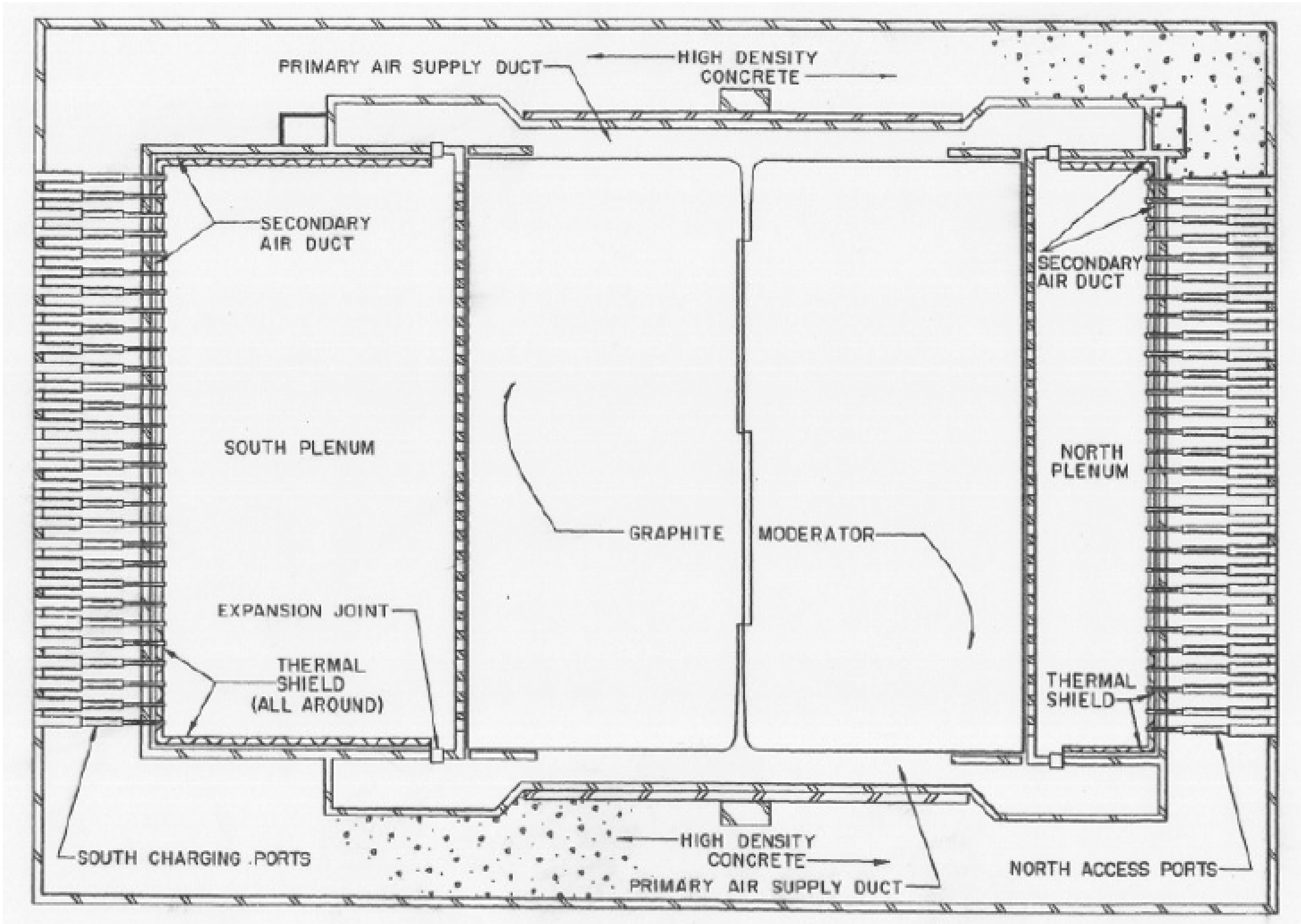


Figure 1-5. BGRR Biological Shield and Graphite Pile Plan View

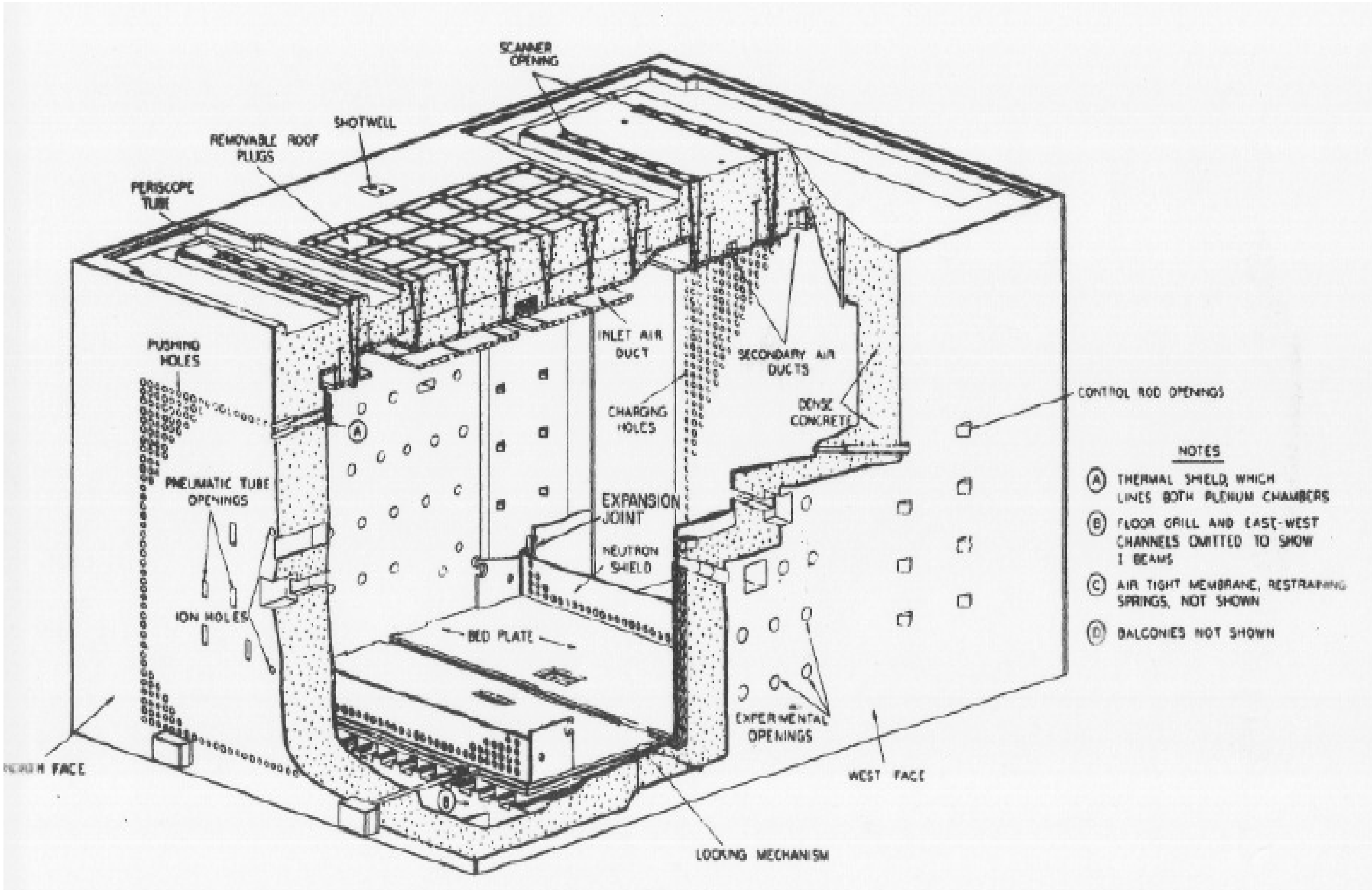


Figure 1-6. BGRR Biological Shield Isometric Cutaway View

1.2.1 Remaining BGRR Outside Areas

The remaining BGRR Outside Areas include the outside areas within the BGRR complex boundaries that were not included in the final as-left radiological survey that was performed as part of the BGRR Engineered Cap Project. This area is further defined in Section 3.4.

1.3 Regulatory and Enforcement History

In 1980, the BNL site was placed on the NYSDEC list of Inactive Hazardous Waste Sites. On December 21, 1989, the BNL site was included on the EPA National Priorities List because of soil and groundwater contamination that resulted from BNL's past operations. Subsequently, EPA, NYSDEC, and DOE entered into a Federal Facilities Agreement (herein referred to as the Interagency Agreement; [IAG]) that became effective in 1992 (Administrative Docket Number: II- Comprehensive Environmental Response, Compensation & Liability Act [CERCLA]-FFA-00201) to coordinate the cleanup.

The IAG identified AOCs to be evaluated for response actions. The BGRR is subject to the provisions of Section X – Areas of Concern of the IAG and is identified as AOC 9. The remediation of the BGRR complex is divided into four sub-AOCs. These include AOC 9A, the Canal; AOC 9B, Underground Ductwork; AOC 9C, Spill Sites; and, AOC 9D, the Pile Fan Sump. Additional areas of remedial action outside the scope of the AOC subdivisions include removal of the above-ground ductwork, graphite pile, and biological shield. Interim measures were authorized through issuance of Action Memoranda or National Environmental Policy Act (NEPA) Categorical Exclusions. The remaining cleanup activities for the BGRR were addressed in the BGRR ROD.

A Feasibility Study (FS) for the BGRR complex was prepared to evaluate the alternatives for remediation of the BGRR. Upon completion and review of the results of a FS for the BGRR and public review of the Brookhaven Graphite Research Reactor Proposed Remedial Action Plan (PRAP) the BGRR ROD was signed in March 2005. It documented the remedial action for the BGRR selected in accordance with the CERCLA consistent with the National Oil and Hazardous Substances Pollution Contingency Plan ("National Contingency Plan").

The final remedy was developed in collaboration with regulators using the Core Team Process. The BGRR ROD requirements were incorporated into the RD/RA Work Plan. Modifications to the scope of work specified in the RD/RA Work Plan were presented to the regulators in the RDIP and ESD discussed in Section 1.1.

1.4 Site Investigation

The BGRR pile was characterized in 2000, and as part of that effort, gamma surveys of the south face neutron shield were performed. In 2002, eight core bores were taken, two through the east face, three from the west face, two from the north face, and one core bore from the top, of concrete only. The results of these surveys were documented in the *BGRR Characterization Report for the 701 Below-Ground Structures, 702 Pile, and Remaining Soils* (BNL, 2003) and a summary of the seven steel sample results are presented in Table 1-1. The characterization data from 2000 and 2002 were used to help develop potential conceptual decommissioning scenarios; therefore conservative assumptions were made in developing the activity estimate. The total activity calculated for the biological shield and associated components at that time were 4,805 Curies. Following signature of the BGRR ROD in 2005, additional sampling was performed to eliminate any over-conservative bias inherent in previous bounding radiological inventory estimates, and to estimate dose rate to workers for the planned decommissioning. The biological shield total activity in 2005 was determined to be 81.3 Curies. The 2005 samples of outside steel were taken at 13 locations, four on the east face, four on the west face, four on the north face, and one on the south face. The one location on the south face was a full core bore through the biological shield. In addition, on the west face, there were 5 locations where steel on the inner surface was sampled. The results were documented in the *Radiological and Hazardous Material Assessment of the BGRR Bioshield and Associated Components* (BNL, November 2006) and can be summarized as follows:

- The outside steel samples indicated no activation of the metal;
- The outermost 2 feet of concrete indicated no activation;
- The surveys and sample data support the assumption of essentially symmetrical activation of the biological shield walls;
- The most abundant radionuclides in the activated steel are nickel (Ni)-63 (62%), cobalt (Co)-60 (32%), iron (Fe)-55, and Ni-59 with a total inventory of 60.7 Curies; and
- The most abundant radionuclides in the activated concrete are tritium (98%), europium (Eu)-152, Ni-63, and Co-60 with a total inventory of 20.6 Curies.

Table 1-1
Inner Biological Steel Sample Summary Results (2002)

Location	Depth (ft)	Co-60 (pCi/g)	Cs-137 (pCi/g)
E-30	3.5 – 3.75	620	ND
E-30	3.75 – 4.0	1,007	ND
E-30	4.0 – 4.25	6,418	ND
E-30	4.25 – 4.5	300,900	ND
E-25	4.5 – 4.75	248	ND
E-25	4.75 – 5.0	68,300	ND
W-51	4.5 – 4.75	78.1	ND
W-51	4.75 – 5.0	15,260	ND
W-33	4.75 – 5.0	3,711	ND
W-16	4.5 – 4.75	126	ND
W-16	4.75 – 5.0	10,500	ND
B-3-3	4.75 – 5.0	22,270	ND
B-3-3	Neutron Shield	62,900	154,600
C-15-15	4.75 – 5.0	1,310	ND

Note: The depth is measured from the outer wall of the biological shield.

Hazardous materials identified in the biological shield were lead shielding in several locations, cadmium plating on control rod sleeves, cadmium coated boron shot in the shot wells, asbestos containing material (ACM) in the balcony floor tiles, and lead-cadmium alloy blocks in the helium system and fuel thermocouples.

1.5 Previous Remedial Activities

Several response actions were previously completed as interim measures (through Action Memoranda and NEPA Categorical Exclusions) to reduce or eliminate potential threats to human health or the environment. They included the removal and disposition of the following:

- Contaminated water that infiltrated and accumulated within the below-ground ducts;
- Experimental equipment and systems from the reactor building;
- Reactor exhaust fans, motors, valves and instruments;
- Pile fan sump, pipes and associated contaminated soil;
- Above-ground ducts, pipes and associated contaminated soil;
- Canal house and water treatment house, along with associated equipment, pipes, asphalt, concrete and accessible contaminated soils;

- Reactor exhaust cooling coils and filters;
- Reactor below-ground duct primary liner; and
- Portions of the fuel canal outside the structural foundation footprint of the reactor building and accessible subsurface contaminated soil in the vicinity of the fuel canal, below-ground duct expansion joint #4 and secondary cooling air bustle.

In addition, remedial activities associated with the Graphite Pile Removal Project were completed between December 2009 and May 2010. This work, documented in the *Closeout Report for the Brookhaven Graphite Research Reactor Graphite Pile Removal, Area of Concern 9* (BNL, 2010b), included the following scope of activities:

- Removal and Disposal of Control Rods;
- Removal and Disposal of Boron Shot;
- Removal and Disposal of Shield Plugs;
- Removal and Disposal of upper portion of Air Tight Membrane;
- Removal and Disposal of Invar Rods; and
- Removal and Disposal of Graphite Pile.

Activities associated with the BGRR Engineered Cap Project were completed between May 2010 and May 2011. This work, documented in the *Closeout Report for the Brookhaven Graphite Research Reactor Engineered Cap and Monitoring System Installation, Area of Concern 9* (BNL, 2011b), included the following scope of activities:

- Demolition of Building TR897 (Duct Service Building);
- Installation of a permanent roof ("dog house") over the below ground duct filter opening;
- Modification of BGRR utilities, including roof drains and fire protection piping;
- Removal of the two Building 701 temporary vestibules;
- Removal of electrical transformers and abatement of the associated ACM;
- Grouting the South Side Building 701 Air Plenum;
- Subgrade preparation, including removal of asphalt and soil, as well as grading and compaction of the subgrade;
- Completion of an as-left survey, including independent verification performed by ORISE;
- Installation of the engineered cap; and
- Installation of groundwater monitoring wells.

1.6 BNL Operable Units

As part of remedial efforts at BNL, 30 AOCs were identified and grouped into seven Operable Units (OUs). The seven OUs were subsequently reduced to six OUs as a result of combining OU II and OU VII. In 2009 AOC 31, comprising the High Flux Beam Reactor (HFBR) complex, Waste Loading Area and the A/B Waste Line, was established, and in 2012 AOC 32, comprising the Building 454 Freon-11 groundwater plume was established.

This report documents completion of the removal of the BGRR biological shield, which is part of AOC 9.

2.0 OPERABLE UNIT BACKGROUND

2.1 Site Cleanup Criteria

The completion criterion for this remedial action was the removal, shipment and disposal of the BGRR biological shield, modified by the ESD to reflect removal, shipment and disposal of the biological shield above floor level. Upon completion of this scope, an as-left radiological survey of Building 701 was performed in accordance with WP-314-35, *As-Left Survey for the BGRR, Rev. 2* (BNL, 2012a). The associated general area dose rates and contamination levels are presented below in Table 2-1. The BGRR ROD does not contain radiological cleanup levels for areas within Building 701.

Table 2-1
Anticipated Post-Decommissioning Radiological Conditions for Building 701

General Area Dose Rates (mrem/hr)	
Deep pit	10-30
High bay	<0.1
High bay on top of biological shield cap	<0.1
Office areas	background
Yard areas	background
Below Ground Ducts (BGD) general area	5
South BGD beyond radiation trap	30
North BGD below exhaust air plenum	100-150
General Area Contamination Levels (loose beta/gamma) (dpm/100cm^2)	
Deep pit	1,000 – 2,500
High bay – accessible areas	<1,000
High bay – remote/inaccessible areas	<3,000[1]
High bay – lower pile support plate (before concrete shielding cap installation)	To be determined after pile and biological shield removal
Office areas	background
Yard areas	background
BGD inboard of bustle	7,000[2]
North BGD below exhaust air plenum	16,000[3]

Notes:
1. Control Rod Drives area 1,000 – 3,000 dpm/100cm^2, and 1,000 dpm/100cm^2 overhead horizontal surfaces
2. Low levels of removable contamination exist on the floor of the duct inboard of the secondary cooling air bustle
3. Obtained during North BGD entry for beryllium smear

In addition, an as-left survey of the remaining BGRR Outside Areas was performed, which consisted of a complete radiological walkover survey and the collection of soil samples. In accordance with WP-314-35, *As-Left Survey for the BGRR*, *Rev. 2* (BNL, 2012a), the results for primary radiological contaminants of concern for soil within the remaining BGRR Outside Areas are compared to cleanup goals specified in the *Record of Decision, Operable Unit I and Radiologically Contaminated Soils* (BNL, 1999) (OU I ROD); specifically for cesium (Cs)-137, radium (Ra)-226 and strontium (Sr)-90. The cleanup goals for specific radionuclides were calculated using RESRAD, considering a residential scenario. The dose limit used was 15 millirem per year (mrem/yr) above background (*OSWER Directive 9200.4-1., EPA, 1997*), residential land use after 50 years of institutional control by the DOE, and industrial land use with no decay time (Year 0). In addition, the NYSDEC cleanup guideline of 10 mrem/yr, from Technical and Administrative Guidance Memorandum (TAGM) 4003, was adopted as an ALARA goal. The primary radiological isotope present at the site was Cs-137; its cleanup goal is 23 pCi/g.

The potential for radiologically contaminated soil to impact groundwater was also considered. A soil cleanup goal of 15 pCi/g was calculated for Sr-90, based on its potential to impact the groundwater. This goal is protective of both residential and industrial uses. A cleanup goal of 5 pCi/g was selected for Ra-226, based on DOE Order 5400.5, *Radiation Protection of the Environment and the Public* (DOE, 1993).

Co-60, tritium, Eu-152, Eu-154, uranium (U)-235, U-238, plutonium (Pu)-238, Pu-239/240 and americium (Am)-241 were considered as additional radiological contaminants of concern and are listed with their respective cleanup goals in Table 2-1.

The primary chemical contaminants of concern for soil within the remaining BGRR Outside Areas are the same as those for OU I chemically contaminated soils: mercury and lead. A more conservative cleanup goal for mercury, in comparison to the OU I cleanup goal (1.84 mg/kg), was established based on Article 12 of the Suffolk County Sanitary Code, Standard Operating Procedure (SOP) No. 9-95 (0.7 mg/kg). The choice of a cleanup goal of 400 mg/kg for lead, from the OU I ROD, was based on the EPA's soil screening level guidance; this level is protective of residential use. Secondary chemical contaminants of concern for soil are copper, nickel and zinc. The cleanup goals and the associated source of each cleanup goal for these chemical contaminants were specified in WP-314-35, *As-Left Survey for the BGRR*, *Rev. 2* (BNL, 2012a) and are summarized below in Table 2-2.

Table 2-2
Radionuclides and Chemical Contaminants of Concern
for the BGRR Biological Shield Removal Project

Radionuclides of Concern	Cleanup Value (pCi/g)	Source of Cleanup Goal Value
Cs-137	23	OU I ROD (BNL, 1999)(4)
Sr-90	15	OU I ROD (BNL, 1999)(4)
Ra-226	5	OU I ROD (BNL, 1999)(4)
tritium	424(2)	(1)
Co-60	1,260 (3)	(1)
Eu-152	51 (3)	(1)
Eu-154	180 (3)	(1)
U-235	4.6 (4)	(1)
U-238	4.7 (4)	(1)
Pu-238	57 (3)	(1)
Pu-239/Pu-240	35 (3)	(1)
Am-241	34 (3)	(1)
Chemical Contaminant	**Soil Cleanup Level**	**Source of Cleanup Goal Value**
Mercury	0.7 mg/kg	SOP No. 9-95 for Article 12 of the Suffolk County Sanitary Code. Appendix B
Lead	400 mg/kg	6NYCRR Part 375 Restricted Use – Soil Cleanup Objectives, Residential
Copper	270 mg/kg	6NYCRR Part 375 Restricted Use – Soil Cleanup Objectives, Residential
Nickel	130 mg/kg	SOP No. 9-95 for Article 12 of the Suffolk County Sanitary Code. Appendix B
Zinc	2,200 mg/kg	6NYCRR Part 375 Restricted Use – Soil Cleanup Objectives, Residential

Notes:

1. For those nuclides not referenced, the estimated cleanup levels were not listed in either the OU I ROD nor in other BNL remediation references. If these nuclides were detected, RESRAD was used to develop the cleanup levels that will meet the 15 mrem/yr above background criteria.
2. The value is based on a RESRAD evaluation for a residential scenario with no decay.
3. The value is based on a RESRAD evaluation for a residential scenario with 50 years of decay.
4. Values listed for uranium are based on 4 mrem/yr from groundwater consumption. The OU I ROD is not directly applicable to BGRR Outside Area Soils; however, these soil contamination concentrations are indicative of a residential user scenario, and they are considered As Low as Reasonably Achievable (ALARA) cleanup goals for this project.

2.2 Design Criteria

Technical specifications and design criteria for the BGRR Biological Shield Removal Project were established in the BGRR ROD, the RD/RA Work Plan, the RDIP and the ESD. The design criteria included:

- Removal of the pile upper sliding rails;
- Removal of the asbestos containing material (ACM) floor tiles on the balcony areas;
- Removal of the two uppermost balconies (located at elevation 136’-0”) and the single north, two west balconies and lower east balcony in their entirety;
- Removal of the Chemo-Nuclear System within the high bay area, including the lead walls;
- Placement of 3-inch steel plates over the upper pile bedplates to provide radiological shielding for workers. The plates were secured in place with concrete grout;
- Filling of void areas beneath the Building 701 high bay area outside of the biological shield footprint with cementious grout, and the placement of steel plates atop this floor surface to evenly spread the load of the excavator/hammer unit used to break up the biological shield;
- Filling of the north and south outlet air plenums with reinforced concrete to elevation 109’-0” to support the excavator/hammer unit and provide additional radiological shielding for workers;
- Re-supporting the east elevation 123’-0” balcony;
- Extending the previously constructed CCE on the west side;
- Removal of the biological shield outer steel walls, inner steel walls and concrete structure down to the Building 701 floor level (elevation 109’-0”);
- Sealing of all plenums, chutes and experimental openings;
- Removal of all visible loose debris and removal and/or stabilization of loose radiological contamination in the Building 701 area associated with the removal of the biological shield, including the remaining pile support structure within the biological shield footprint; and
- Placement of reinforced concrete from elevation 109’-0” to elevation 110’-0”.

2.3 Community Relations Activities

2.3.1 BNL Community Relations

The BNL Community Involvement Plan was published April 15, 1999. It is supplemented by project-specific plans. In the case of the BGRR, a BGRR Community Relations Plan was developed. In accordance with these two plans and CERCLA Sections 113 (k)(2)(B)(i-v) and 117, the community relations program focuses on informing and involving the public in the decision-making process to ensure that the views of the internal and external stakeholder communities are considered. A variety of activities are used to provide information and to seek public participation, including distribution of materials to a stakeholders' mailing list; holding community meetings, information sessions, tours, and workshops; and preparing and distributing fact sheets. The Administrative Record, which documents the basis for removal and remedial actions, was established and is maintained at the libraries listed below:

Brookhaven National Laboratory
Research Library
Bldg. 477A
Upton, NY 11973
631-344-3483 or 631-344-3489

Stony Brook University
Melville Library
Special Collections and University Archives
Room E-2320
Stony Brook, NY 11794
631-632-7119

U.S. EPA - Region II
Records Room
290 Broadway, 18th Floor
New York, New York 10007
212-637-4308

2.3.2 Community Involvement

The community involvement process for the BGRR was an integral part of making cleanup decisions. Project staff made numerous presentations to the Community Advisory Council (CAC), the Brookhaven Executive Round Table (BER), and various local civic associations.

Shortly after the 1997 decision to begin decommissioning the BGRR, possible decommissioning alternatives were developed and considered. Three roundtable meetings to elicit public comments and concerns were held in July and August of 1999.

Additionally, interested parties were invited to participate in the BGRR Working Group. Members included some local residents, representatives of several Suffolk County agencies, and representatives of the CAC. The Working Group had its initial meeting in June, 2000, and met until April, 2003. The Working Group closely followed the interim response actions and provided input on when information should be presented to the CAC.

The BGRR Proposed Remedial Action Plan (PRAP) was released for public review and comment on August 2, 2004. The Notice of Availability was published in Newsday and Suffolk Life, as were advertisements for two information sessions and a public meeting. Information sessions were held on August 17 and 19, and the public meeting was held on August 24, 2004. The public comment period closed on September 3, 2004. The Responsiveness Summary section of the BGRR ROD summarized the written and oral comments received during the public comment period and DOE's responses to these comments. Project staff continued to provide periodic updates to the CAC and the BER as the BGRR Biological Shield Removal Project entered the implementation phase. These updates included the modifications to the scope or work specified in the RD/RA Work Plan, which were documented in the RDIP and the ESD as discussed in Section 1.1.

3.0 CONSTRUCTION ACTIVITIES

The objective of the BGRR Biological Shield Removal Project was to safely complete the removal of the biological shield, as well as to complete the as-left radiological surveys of Building 701 and the remaining BGRR Outside Areas. Work was initiated in June 2010 and completed with modifications to scope as described in Table 3-1 in May 2012.

An Environmental, Safety & Health (ES&H) Plan, Job Safety Analyses (JSAs) and project-specific work procedures were developed to address hazards and work steps associated with the BGRR Biological Shield Removal Project. The information presented in the project plans was presented during a project kick-off meeting. In addition, project hazards and work steps were reviewed with site workers prior to initiating work during daily tailgate safety meetings. Copies of project plans were available onsite at all times.

As previously discussed, modifications to the scope of work specified in the BGRR ROD and the project RD/RA Work Plan are documented in the RDIP, ESD and this report. These modifications are summarized below in Table 3-1.

Table 3-1
Summary of Differences Between
Project Scope and the BGRR ROD and RD/RA Work Plan

Project Item	Reference	Delineated Removal Scope	Actual Removal Scope
Biological Shield Removal	ROD, Section 10, Selected Remedy, Removal of the Biological Shield (p. 34)	"Removal of the biological shield will include removal of the neutron shield and the steel-encase concrete walls. Loose debris will be removed and a fixative applied to the exposed surfaces."	The outer steel walls, inner steel walls and concrete were removed down to the Building 701 floor (elevation 109'-0"). Portions of the bioshield wall below floor level were left in place to minimize worker exposure.
	RD/RA Work Plan, Section 2.1.1.4.c, State of Work (p.12)	"The biological shield walls shall be removed from the top at elevation 140'-4" down to elevation 106'-9"."	
Experimental Balcony Removal	RD/RA Work Plan, Section 2.1.1.4.a, Statement of Work (p.12)	"There are seven (7) balconies attached to the outer biological shield walls. Two balconies, each located on the north and west walls at elevation 136 ft shall be removed in their entirety. The remaining five (5) balconies shall be removed to a point no greater than five feet (5'-0") from the biological shield points.	All balconies were removed in their entirety with the exception of the east balcony at elevation123'-0", which was re-supported.
Pile Bedplates Removal	RD/RA Work Plan, Section 2.1.1.4.c.vi, Statement of Work (p.12)	"Removal of the pile upper bedplates and sliding rails. The steel beams and fixed lower bedplates shall remain."	Both the upper and lower bedplates were left in place. The upper sliding rails were removed and a 3-inch thick steel plate was installed on top of the upper bedplate and grouted in place. The purpose of this was to reduce radiological dose to workers during execution of the project scope. The upper bedplate left in the building contains approximately 10.11 Curies of activation as of 2011 calculations.
As-Left Radiological Survey/Contamination Levels	RD/RA Work Plan, Section 2.1.3 (p.17)	"The final step for the biological shield removal is the installation of a permanent reinforced concrete over the footprint of the removed biological shield (Figure 2-4). Prior to the cover installation, verification that all loose and visible debris within the biological shield footprint has been removed will be conducted. BSA shall perform a final radiological survey of the top of the lower bedplates and accessible concrete surfaces around the bedplates to verify that residual contamination levels are less	Prior to the placement of the final reinforced concrete cap over the footprint of the removed biological shield on elevation 109'-0", all loose and visible debris was removed. In lieu of the surface contamination survey of the lower bedplate described in the RD/RA Work Plan, a radiological survey to document the as-left

Project Item	Reference	Delineated Removal Scope	Actual Removal Scope
		than 100,000 dpm beta gamma. The DOE will independently verify the as-left condition. Once the inspection is completed, a fixative will be applied to the internal surfaces of the biological shield footprint and the permanent reinforced concrete cover will be installed.”	status of the upper surface of the 3-inch steel plates and concrete placed during the removal of the biological shield was performed. This survey verified that residual contamination levels are less than 100,000 dpm beta/gamma and 10 mR/hr at one foot. In addition, a final as-left survey of the reinforced concrete cover at elevation 110’-0” was performed and independently verified to demonstrate that the as-left dose rate at 3 ft above the floor surface is less than 0.1 mR/hr and that all remaining contamination was fixed in place. The final concrete placement on the bioshield floor assures that all remaining contamination is bound in steel and concrete within the BGRR structure.
Chemo-Nuclear System Removal	RD/RA Work Plan, Section 2.1.1.4.a (p.12)	“The lead walls associated with the Chemo-Nuclear loop will be completely removed.”	The Chemo-Nuclear System within the Building high bay area, including the lead walls, was removed in its entirety.
Demobilization of Removal Equipment	RD/RA Work Plan, Figure 2-4	The figure, which conceptually illustrates the end state, shows no support structures.	The following were left in place after any loose contamination was removed: ▪ Gantry crane (A-frames and crosspiece) structure, minus the hoist; ▪ Excavator bridge minus the excavator; and ▪ Steel support structure for the gantry crane and excavator bridge.
	RD/RA Work Plan, Appendix A, Sections 001 01 01 (Statement of Work) and 01 71 13 (Mobilization/Demobilization)	“All temporary facilities will be dismantled, packaged and transported for off-site treatment and disposal.”	

3.1 Initial Preparation Activities

The original plan for the demolition of the biological shield was to utilize the rail-mounted Gradall excavator which had been used in the successful removal of the graphite pile. In order to demolish the 9.5 million pound biological shield structure utilizing the tools that had been installed by BSA's bioshield removal subcontractor, several preparatory activities needed to be accomplished. The first activity was the removal of structural interferences such as the north and west experimental balconies and the Chemo-Nuclear loop system. Removal of these structures was required because they were attached to the biological shield outer walls.

Initial preparation activities for the BGRR Biological Shield Removal Project commenced immediately upon removal of the graphite pile in June 2010 and were completed in January 2011. Preparation activities included the following:

- Removal of balconies;
- Removal of the Chemo-Nuclear loop system;
- Removal of the Air Tight Membrane (ATM);
- Pre-cutting of the experimental and fuel channel ports;
- Removal of the north and south neutron shields, and
- Placement of 3-inch steel plates stabilized by grout over the upper bedplates.

3.1.1 Identification of Additional Tooling

Due to issues with the initial approach for steel cutting, the project re-tooled to use new custom cutting tools which alleviated problems with access and stability of the original tooling. One of the new tools was a magnetically-secured, track-mounted remote-controlled system fitted with oxy-propylene torches. The other tools were custom designed tools for cutting the neutron shield and the fuel channels. The deployment of these new tools allowed successful completion of the steel-cutting phase of the project.

3.1.2 Removal of Pile Sliding Rails

Upon removal of the graphite pile, sliding rails on the upper base plates were removed. Since the upper base plates were not removed, the sliding rails between the upper and lower base plates remain in place.

3.1.3 Removal of Experimental Balconies

Prior to demolishing the seven balconies attached to the outer biological shield walls, the ACM floor tiles on each of the balconies was removed by a New York State licensed asbestos abatement contractor, working under a BNL Facilities and Operations (F&O) Task Order. ACM was handled, packaged and disposed of as further described in Section 3.5.

Photograph 1 – Removing Concrete from the West 127' Balcony with the Brokk Remote Manipulator

Upon completing of the removal of ACM tiles and mastic, the single north and the two west experimental balconies were removed by first breaking the concrete floors with the Brokk Model 330D remote manipulator fitted with a hydraulic breaker hammer. Once the concrete floors were removed, the 3-inch thick balcony floor joists were removed using hand-held oxy-propylene cutting torches. The concrete rubble from the floor demolition was loaded into 20-cubic yard intermodal containers and disposed as Low-Level Radioactive Waste (LLRW). However, the majority of the steel floor joists were placed over the upper bedplates of the biological shield to reduce the dose rate to the workers. During the removal of the west lower balcony, several tons of lead shielding was discovered hidden in the floor, and resulted in a schedule slip of over one week due to the additional controls required to handle the lead. Eventually, the majority of this lead, along with the lead shielding in the Chemo-Nuclear system discussed in 3.1.4, was recycled.

3.1.4 Removal of Chemo-Nuclear System

The Chemo-Nuclear System within the high bay area was removed in its entirety prior to commencement of the demolition of the biological shield. During its removal, over 100,000 pounds of lead shielding was removed and staged for several months until, after extensive surveying to assure lack of radiological contamination or activation, it was sold to a commercial recycler.

Photograph 2 – Removal of the Chemo-Nuclear System

3.1.5 Removal of Air Tight Membrane (ATM)

The east, west and top faces of the graphite pile were covered with the close-fitting ATM, which is depicted in Figure 3-1. The ATM was constructed of ¼-inch thick steel or aluminum and functioned to provide an air-tight seal between the inlet airflow and the seams in the graphite; and directed the cooling air in to the pile through the gap and out of the north/south oriented fuel channels to the exit air plenums.

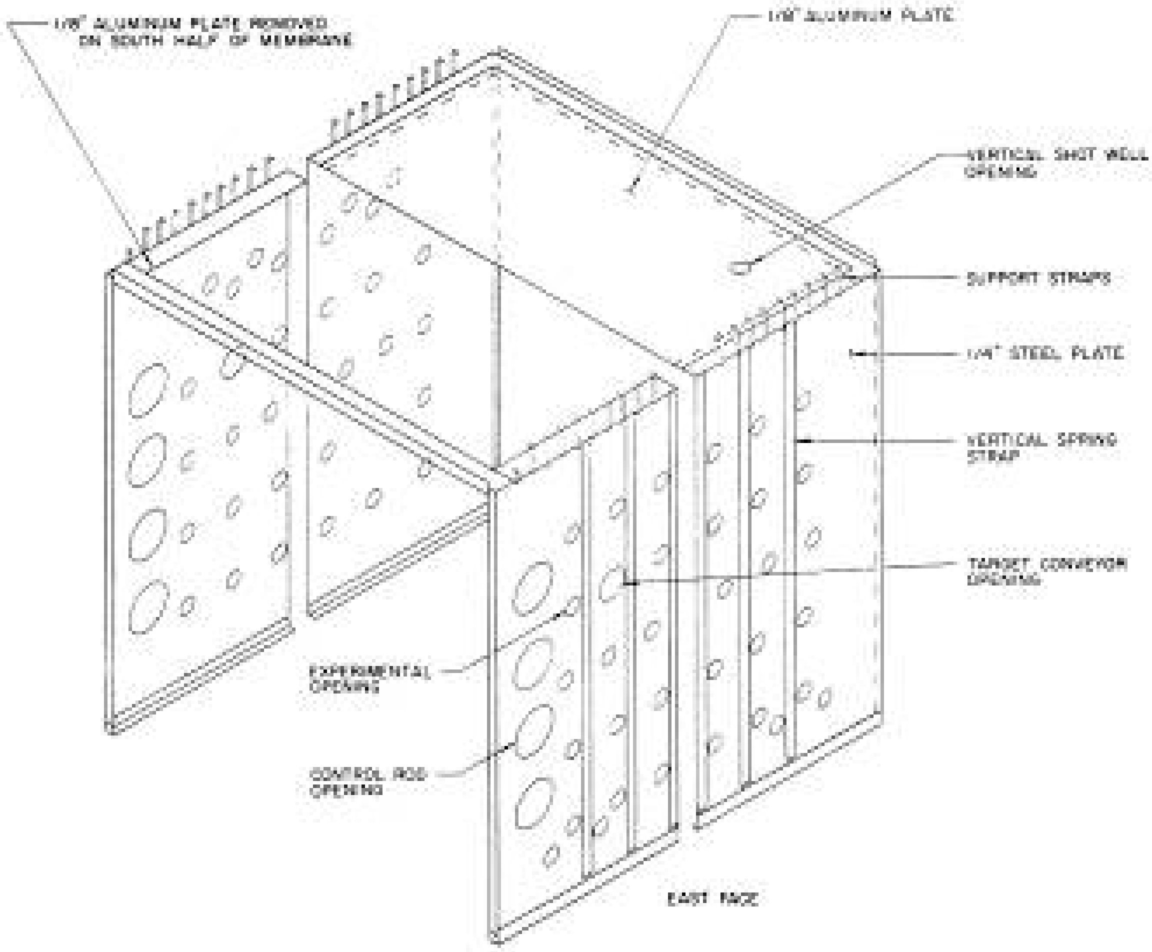


Figure 3-1. Air Tight Membrane Isometric View

The top of the ATM was removed prior to removal of the graphite pile in order to access the graphite blocks. After the graphite pile was removed, the east and west sides of the ATM were held in place by the graphite restraining springs. The project encountered delays associated with unanticipated high dose rates from the ATM, and undocumented design changes which made the removal of the ATM more difficult than planned. The dose rate issue complicated waste transportation, but was resolved through use of shielding in transportation.

3.1.6 Placement of 3-inch Steel Plates Over the Upper Bedplates

Prior to initiating removal of the neutron shields, 3-inch thick steel plates from the previously-removed experimental balcony were placed over the upper pile bedplates to provide additional radiological shielding for workers. After the plates were in place, they were secured in place with concrete grout (approximately 10 inches thick) to prevent movement during the upcoming heavy demolition activities.

Photograph 3 – Placement of 3-Inch Steel Plates Over Upper Pile Bedplates

Photograph 4 – Securing 3-Inch Steel Plates In Place Over Upper Pile Bedplates

3.1.7 Removal of North and South Neutron Shields

After placement of shielding plates on the upper bedplates, the removal of the neutron shields commenced on October 29, 2010. The removal of the neutron shields were completed on December 15, 2010.

3.2 Initial Biological Shield Removal

Upon completing the preparation activities described above, the removal of the biological shield commenced in early January 2011. The first activity scheduled in the removal of the biological shield was the removal of the 5’-9” thick concrete and steel roof.

3.2.1 Removal of the Biological Shield Roof

Removal of the 5’-9” thick roof commenced on January 10, 2011 and was completed approximately three months later. The demolition of the roof was complicated by the unanticipatedly high compressive strength of the concrete, estimated to be greater than 9000 pounds per square inch (psi), and the difficulty in getting this unusual concrete to delaminate from the steel reinforcing structure.

Photograph 5 – Workers Cutting Steel I-Beams on Biological Shield Roof (Gradall excavator is in background)

Photograph 6 – Gradall Excavator Breaking Roof Concrete (NE corner shown)

Photograph 7 – Technician Operating Brokk Manipulator to Break Roof Concrete

3.2.2 Removal of Biological Shield Walls

Once the biological shield roof was removed, demolition of the walls commenced. The sequence of the wall demolition was top-down; first cutting and removing a row of inner wall plates, then breaking the concrete between the inner and outer wall plates. Both the magnetically-secured, track-mounted remote-controlled system fitted with oxy-propylene torches and the robotic arm suspended from the gantry crane were used to cut the inner wall plates.

The concrete breaking continued to proceed slowly. The concrete would not separate from the embedded steel angles or experimental and fuel channel ports, and did not break into large pieces. The significant amount of ferrous aggregate included in the wall contributed to the resistance that slowed progress. It was also discovered that the walls contained significantly more rebar than depicted on the design drawings.

Photograph 8 – Cutting West Inside Steel Wall Plates with the Robotic Arm

Photograph 9 – Gradall Excavator Breaking West Wall Concrete

3.3 New Approach and Final Biological Shield Removal

Due to slow progress in removing the biological shield concrete, in June 2011 it was decided to deploy a track mounted excavator with a 10,000 psi hydraulic hammer. The Gradall excavator and Brokk manipulator continued to be used in areas where they were effective. Preparations and modifications to the facility to deploy the track mounted excavator included:

- Creating an opening in the west biological shield wall large enough for the excavator to enter and exit;
- Reinforcement of the exterior High Bay floors to support the weight of the large excavator (estimated at 40-tons). This included grouting void spaces beneath the floor and placement of steel plates over the floor;
- Placement of a one-foot thick reinforced floor inside the biological shield footprint to support the weight of the large excavator;
- Filling the north and south outlet air plenums to support the new one-foot thick reinforced concrete floor mentioned above; and
- Extending the CCE on the west side to enclose the opening in the west biological shield wall and provide a service area for the large excavator.

Photograph 10 – Brokk Manipulator Creating Opening in West Wall for New Holland Access

Photograph 11 –Tool Fitted With Torch Cutting South Plenum Binding Plates

3.3.1 Grouting High Bay Area Void Areas

Due to the weight of the New Holland excavator (40-tons), void areas (West Animal and Instrument Tunnels, and the North Pipe Trench) beneath the Building 701 high bay area outside of the biological shield footprint were filled with grout up to the floor level (elevation 110'). In addition, steel plates were placed atop this floor after the void areas were filled with cementious grout. These steps provided a stable floor for the excavator/hammer unit that was used to dismantle the biological shield.


Photograph 12 – Filling Void Areas beneath the High Bay Area with Grout

3.3.2 Filling the North and South Outlet Air Plenums

To provide support for the excavator, the north and south outlet air plenums were also filled with cementious grout up to the existing floor level (~elevation 109'). Photograph 13 shows the wooden formwork that was constructed in one of the below ground ducts at the bottom of the outlet air plenum. Once the plenums were filled, a 10-inch thick reinforced concrete floor was placed over the entire interior footprint of the biological shield.

Photograph 13 – Concrete Form in One of the Outlet Air Plenums

Photograph 14 – Initial Concrete Placement over Biological Shield Footprint

3.3.3 Extension of the Contamination Control Enclosure (CCE)

The CCE was extended on its west side to enclose to operations associated with the removal of the biological shield. After the CCE extension was completed, the New Holland excavator was brought in to complete the removal of the concrete in the west biological shield wall to create the entrance into the biological shield cavity. Photograph 17 shows the New Holland excavator inside of the biological shield cavity demolishing the east wall concrete.

Photograph 15 – Extension of the CCE

3.3.4 New Holland Excavator

A New Holland EC-350 track-mounted hydraulic excavator with a 10,000 psi class breaker hammer was received at BNL on August 13, 2011. On September 14, 2011 the machine was ready to be placed into service. Concurrent with the preparation work on the New Holland excavator, the project staff completed the facility modifications and completed the opening in the west biological shield wall. On September 16, 2011, the New Holland excavator was driven into the interior of the biological shield and commenced demolition of the remaining walls.

Photograph 16– New Holland Excavator Being Brought into CCE Extension Prior to Initial Use

3.3.5 Final Biological Shield Removal

After completion of the preparations to deploy the New Holland excavator, demolition of the biological shield continued at a faster rate. Work continued on schedule and without any issues until November 29, 2011 when a worker sustained serious injuries when he fell from a scissor-type aerial lift. This event is further discussed in Section 9.0.

After over a month of limited work activities and implementation of corrective actions, BSA resumed unrestricted work and completed the removal of the biological shield without further delays in March 2012. The Gradall bridge, 10-ton gantry crane, and the steel support structure and rails for the Gradall bridge and crane were left in place, and were decontaminated and/or stabilized as noted in Section 3.3.6.

Photograph 17 – New Holland Excavator in Opening in West Wall Demolishing East Wall

Photograph 18 – Stabilization and Radiological Surveys of CCE Prior To Dismantlement

3.3.6 Removal/Stabilization of Loose Radiological Contamination

Visible loose debris was removed and loose radiological contamination in the Building 701 area associated with the removal of the biological shield was removed or stabilized; including the remaining pile support structure within the biological shield footprint.

3.3.7 Placement of Reinforced Concrete

Upon completion of removal of loose contamination on the existing reinforced concrete floor within the biological shield footprint, a preliminary radiological survey was conducted to confirm that the final concrete cap, which would vary in thickness from 1.5-inches to 4-inches, would ensure that the general area radiological dose rate on the floor would be less than 0.1 mrem/hr. On March 28, 2012, the final concrete cap was placed to elevation 110’-0”. Photograph 22 shows the final cap, which has a 28-day compressive strength of 5,200 psi.

3.3.8 Cleanout and Stabilization of Canal Deep Pit

Upon initial investigation on March 2, 2012, approximately 4,000 gallons of water was discovered in the Deep Pit. This water is suspected to have come from the water used for dust suppression during the demolition of the biological shield, entering the Deep Pit via the south reactor outlet air plenum. The water was pumped out, and solidified by the BNL EPD, Waste Management Group. Photographs 19 and 20 show the Deep Pit before and after removal of the water.


Photograph 19 – Deep Pit Prior to Removal of Water


Photograph 20 – Deep Pit After Removal of Water

Photograph 21 – Placement of Final Concrete Cap on Elevation 110'-0"

Photograph 22 – Completed Installation of Concrete Cap on Elevation 110'-0"

3.4 Remaining BGRR Outside Areas As-Left Survey

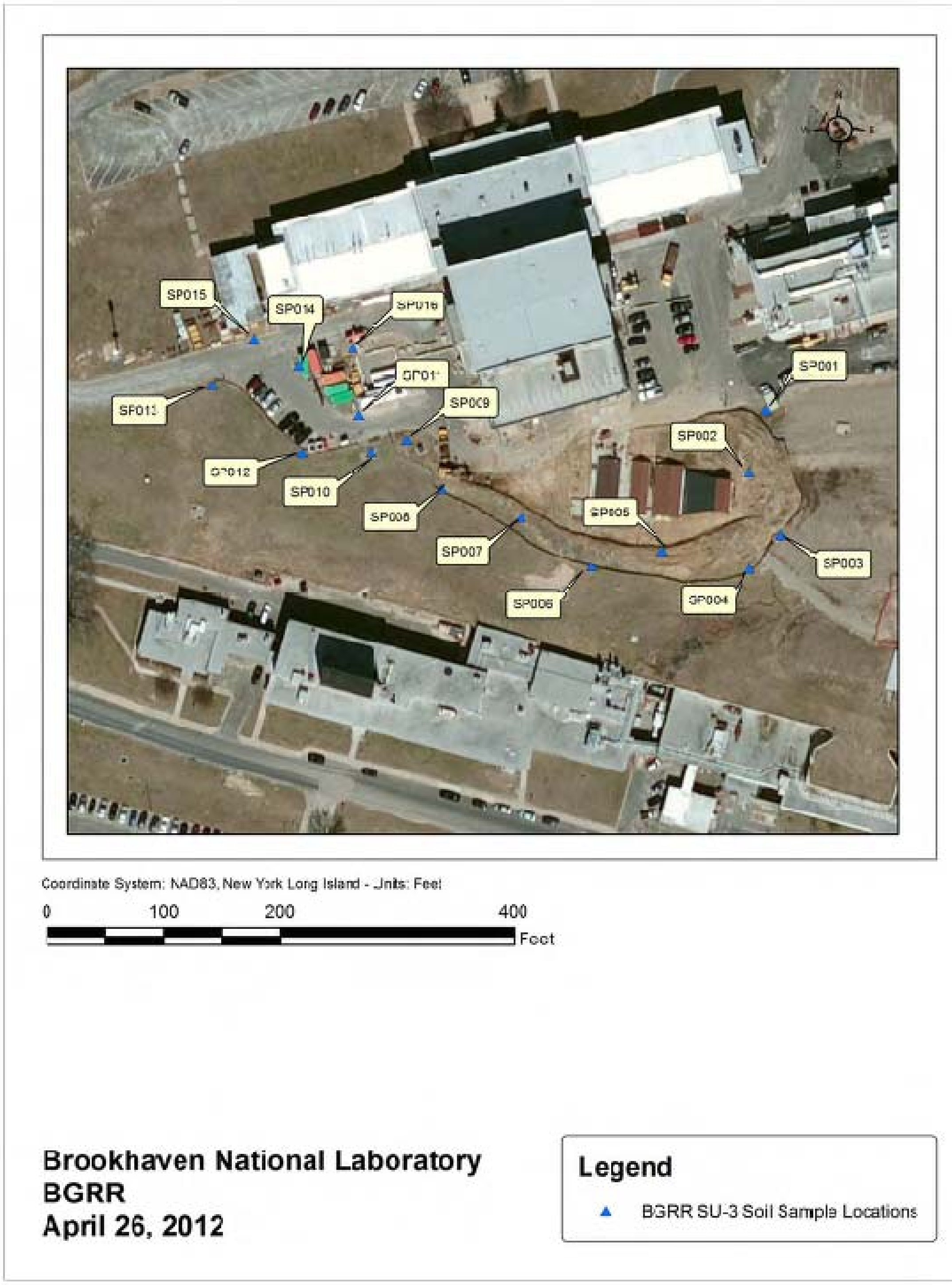
Once the biological shield was removed and the associated equipment was demobilized from the BGRR yard, an as-left radiological survey of the remaining BGRR Outside Areas was performed in accordance with WP-314-35, *As-Left Survey Procedure for the BGRR, Rev.2* (BNL, 2012a). The remaining BGRR Outside Areas are the outside areas within the BGRR complex that were not addressed as part of the BGRR Engineered Cap Project. As discussed in Section 2.1, the primary radionuclides of concern, based on exposure potential, were Cs-137, Ra-226 and Sr-90. Although less likely to be present, certain other radionuclides were monitored and include tritium, gamma emitters (e.g., Co-60, Eu-152 and Eu-154), and alpha emitters such as isotopes of uranium, americium and plutonium.

3.4.1 As-Left Survey Design

A two-step approach to confirming the as-left conditions was followed using the EPA Multi-Agency Radiation Survey and Site Investigation Manual (MARSSIM) approach for the remaining BGRR Outside Areas. The first step consisted of a global positioning system (GPS)-based gamma scintillation walkover survey using a 2-inch by 2-inch Sodium Iodide (NaI) detector in conjunction with a Ludlum Model 2221 scaler/ratemeters and with the PRO XR Satellite Receiver Trimble model TSCe Data Logger (Trimble Unit). The second step involved the collection of soil samples, in accordance with BNL Environmental Management standard operating procedures (SOP) for offsite analysis to quantify residual radiological contamination levels.

The remaining BGRR Outside Areas were covered by a single survey unit (SU), SU-3. SU-1 and SU-2 were addressed during the BGRR Engineered Cap Project and are documented in the *Final Closeout Report for the Brookhaven Graphite Research Reactor Engineered Cap and Monitoring System Installation, Area of Concern 9* (BNL, 2011d). Sixteen surface soil samples were collected within SU-3, which encompasses the southern and western portions of the outside areas of the BGRR complex. Each soil sample was analyzed by onsite gamma spectroscopy. In addition, two composite soil samples were obtained for offsite analysis of the following radiological contaminants: Pu-238, Pu-239/240, U-235/236, U-238, gamma emitters, Sr-90, tritium, Carbon (C)-14, and Ni-63. For chemical contaminants, the two composite samples were analyzed for mercury, beryllium, copper, nickel, zinc, and lead. The approximate soil sample locations are shown on Figure 3-2.

Figure 3-2
Outside Areas (SU-3) Sample Locations



3.4.2 As-Left Survey and Sampling Results

The results of the as-left radiological walkover survey exhibit count rates below 20,400 counts per minute (cpm) for all areas within SU-3, with the exception of the eastern-most extent of the survey unit, as shown in Figure 3-3. As indicated by previous radiological surveys, the count rates above 20,400 cpm are due to high background activity coming from Building 801. The 20,400 cpm count rate was previously determined to approximate a Cs-137 concentration of 23 pCi/g in soil when using the unshielded NaI gamma scintillation detector, as specified in WP-314-35, *As-Left Survey Procedure for the BGRR*, *Rev.2* (BNL, 2012a). Radiological walkover surveys indicated that greater than 90% of the area was less than 15,000 cpm. Appendix A provides the survey form for the walkover survey.

All soil sample results were below the OU I cleanup goals for Cs-137, Sr-90 and Ra-226, which are 23 pCi/g, 15 pCi/g, and 5 pCi/g, respectively. A summary of the soil sample results for the primary radionuclides of concern is provided in Table 3-2. Additional radionuclides were analyzed, including tritium, C-14, Ni-63 and isotopes of uranium and plutonium; however neither composite soil sample indicated detectable values for these radionuclides, with the exception of U-238. One of the composite samples indicated a U-238 concentration of 0.43 pCi/g. This U-238 result had a "J" qualifier, indicating that the results were above the minimum detectable concentration, but were below the required detection limit. These results are provided in Appendix A.

Figure 3-3
Outside Areas (SU-3) As-Left Radiological Walkover Survey Results

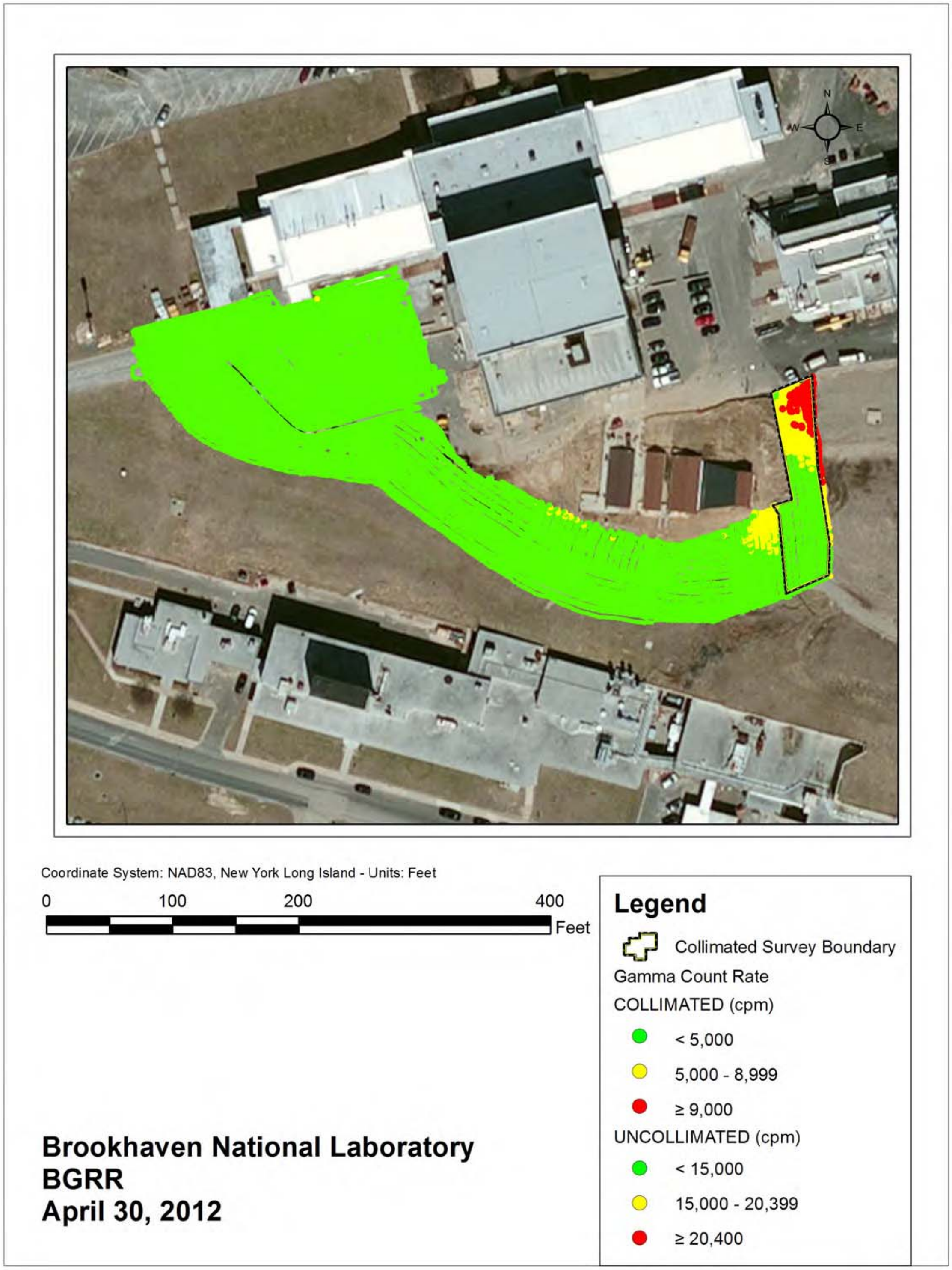


Table 3-2
Summary of BGRR SU-3 Soil Sample Results for Primary Radionuclides of Concern

Radionuclide	Cleanup Goal (pCi/g)	SU-3Onsite Gamma Average (pCi/g)*	SU-3 Onsite Gamma Maximum (pCi/g)*	SU-3 Vendor Lab Composite Average (pCi/g)	SU-3 Vendor Lab Composite Maximum (pCi/g)
Cs-137	23	0.13	0.25	0.21	0.25
Sr-90	15	N/A	N/A	0 (U)	0 (U)
Ra-226	5	N/A	N/A	0.39	0.40

Notes:
* For Cs-137 and Ra-226, results are based on the average of all results, including those that were less than Minimum Detectable Activity (MDA) [U] or estimated [J].
** Sr-90 results are based on the maximum reading from SU-1 and SU-2, as described above.
U – Indicates that the isotope was analyzed for, but was not detected (results less than the MDA).
J – Indicates an estimated value (results above MDA but below the required detection level).

Uncertainty Values:
Cs-137 Onsite gamma average: 0.13 ± 0.06 pCi/g (1 standard deviation)
Cs-137 Onsite gamma maximum: 0.25 ± 0.059 pCi/g
Cs-137 Offsite Lab Composite maximum: 0.254 ± 0.0464 pCi/g
Ra-226 Offsite Lab Composite maximum: 0.397 ± 0.0753 pCi/g

Chemical results for soil samples analyzed for mercury, beryllium, copper, lead, nickel, and zinc also indicated that residual soil concentrations for these contaminants are within their respective cleanup goals. Composite soil sample results for chemical contaminants are provided in Table 3-3.

Table 3-3
Summary of BGRR SU-3 Soil Sample Results for Chemical Contaminants of Concern

Chemical Contaminant	Cleanup Goal (mg/kg)	SU-3 Comp (1-8) (mg/kg)	SU-3 Comp (9-16) (mg/kg)
Mercury	0.7	.0365	.0266
Beryllium	0.43	.201	.144
Copper	270	14.5	18.6
Lead	400	12.7	35.2
Nickel	130	5.52	4.64
Zinc	2,200	30.5	36.9

3.4.3 As-Left Survey Conclusions

As indicated above, results of the as-left survey of surface soils demonstrate conformance to the cleanup goals.

3.4.4 Post Remediation Dose Assessment

A dose assessment was conducted to evaluate radiological dose impacts from residual radioactive materials remaining following the completion of the as-left radiological survey for the remaining BGRR Outside Areas. The dose assessment was conducted using RESRAD, Version 6.5. The maximum Cs-137 and Ra-226 concentrations in SU-3 from the onsite analyzed samples and from the two composites sent offsite were used as input to the model in order to determine the projected dose. The average and maximum concentrations (see Table 3-4) are as follows:

- Cs-137: 0.25 pCi/g
- Ra-226: 0.40 pCi/g
- Sr-90: not detected

In addition, U-238 was detected in one composite sample at a concentration near background, but detectable. As a conservative measure, the U-238 was added to the RESRAD calculation at the detected value of 0.46 pCi/g. Note that Ra-226 background on the BNL property had previously been established at approximately 0.56 pCi/g (CDM Federal Programs Corporation, 1996). Therefore, the average Ra-226 value of 0.40 pCi/g from the affected survey units is below established background. For determination of acceptable levels of cleanup, the value of 0.40 pCi/g was used as a conservative measure, with no subtraction of background Ra-226 in the soil. However, when performing the post-remediation dose assessment using RESRAD, background is subtracted to obtain a more accurate result of the dose above background.

Two potential radiological dose scenarios were evaluated following remediation. The first assessment considered the radiation dose to a hypothetical future resident (non-farmer) assuming 50 years of institutional control. The second assessment considered the radiation dose to a current industrial worker (no decay). The parameters and pathways used in this dose assessment for SU-3 are shown in the RESRAD summary reports, provided in Appendix D.

The results of the dose assessment are shown in Table 3-4 below. The maximum projected dose to a resident after 50 years of institutional controls (0.7 mrem/yr) would be below the dose objective (non-farmer) of 15 mrem/yr above background. For a resident with no decay time (Year 0), the maximum projected annual dose (0.6 mrem/yr) is also less than 15 mrem/yr above background. In addition, the maximum projected dose to an industrial worker at Year 0 (0.2 mrem/yr) is less than 15 mrem/yr above background. The results also indicate that the NYSDEC Technical and Administrative Guidance Manual 4003 guideline of 10 mrem/yr would be met under each of the three scenarios described above. If background was not subtracted for Ra-226 (use 0.40 pCi/g without background subtracted), then the residential dose would be 7.3 mrem/yr at year 50, and the industrial dose would be 1.0 mrem/yr at Year 0.

Table 3-4 Summary of Post-Remediation Dose Assessment Results

	Resident at 50 years	Resident at 0 years	Industrial Worker at 0 years
Dose (mrem/yr)	0.7	0.6	0.2

Note: Dose rates shown are dose rates above background

The calculated resident dose at 0 years is almost the same but slightly less than the dose at 50 years due to the radionuclides detected and the RESRAD calculation method. U-238 was detected in one composite sample, and it was conservatively used to represent the survey unit. In year 0, U-238 represents about 12% of the total dose, with Cs-137 comprising the remaining 88%. In year 50, the RESRAD program calculates that the daughter products of the U-238 decay chain are adding dose; therefore, the dose due to U-238 and daughters increases over time. This increasing dose is somewhat balanced by the decrease in Cs-137 dose due to radioactive decay. In year 50, U-238 is about 75% of the dose and Cs-137 makes up about 25% of the dose.

3.4.5 Independent Verification

ORISE performed a Type A independent verification of the as-left survey. The Type A independent verification included a review of project plans and procedures, as well as review of as-left radiological walkover survey and soil sampling results. The ORISE independent verification for the BGRR Biological Shield Removal Project was performed between May 2012 and June 2012. ORISE determined that the appropriate level of effort and records were provided to document the as-left conditions; and that the OU I cleanup goals used as guidance were met. The independent verification is documented by *Project-Specific Type A Verification Letter Report for the Brookhaven Graphite Research Reactor, Brookhaven National Laboratory, Upton New York, DCN: 5098-LT-01-0,* (ORISE, 2012) (Appendix C).

3.5 BGRR As-Left Interior Building As-Left Survey

The as-left radiological survey of the Building 701 interior was conducted following the completion of all the work, the removal of equipment and the stabilizing of dispersible radioactive materials. The as-left radiological survey found only previously identified dispersible radioactive materials within Building 701 with the exception of contamination on the structures erected for dismantling of the biological shield. These dispersible radioactive materials were removed to the extent practical and fixative was applied. Fixed contamination, radiation areas, and radioactive material storage areas are managed through radiological postings verified by periodic surveys. The as-left survey concludes the following:

- Office spaces within Building 701 are free of removable contamination and are at background radiation levels.

- Areas within the reactor high bay indicate areas of fixed contamination, including the steel plates on the 110' elevation. Currently the external whole body radiation levels within the reactor high bay are at background levels with the exception of the biological shield concrete cap, which is 0.01 to 0.08 mrem/hr at 3 feet.
- Building 701 is predominantly free of loose radiological contamination with the exception of the inaccessible areas (above six feet).
- Radiological surveys of the Fuel Chute, Canal Deep Pit and remaining portions of the Fuel Canal indicate the remaining contamination exists primarily within the Canal Deep Pit. Existing contamination levels are approximately 1,000 to 5,000 dpm/100cm^2 beta and <100 dpm/100cm^2 alpha. General area external whole body radiation dose rates while standing at the base of the pit range from 8 to 15 mrem/hr with a one-foot radiation level of 80 mrem/hr at the drain strainer located in the northeast corner of the pit.
- The external surfaces of the top of the biological shield cap contained no removable contamination above normal operational release limits.
- Isolated areas of removable contamination were identified on the interior surface of the reactor building roof, "I" beams, and catwalks. Discrete locations exhibited fixed beta contamination levels up to 1,000 dpm/100 cm^2.

The building will be controlled as a radiological buffer area with discrete identified contamination areas in accordance with 10CFR831 and BSA's Radiological Control Program.

Based on the characterization studies discussed in Section 1.4, previous remedial action completion reports discussed in Section 1.5 and the as-left radiological surveys, the expected and actual post decommissioning general area dose rates and contamination levels are presented in Table 3-5. Survey data are presented in Appendix B.

ORISE performed a Type A independent verification of the BGRR as-left interior survey. ORISE determined that the appropriate level of effort and records were provided to document the as-left conditions. The independent verification is documented by *Project-Specific Type A Verification Letter Report for the Brookhaven Graphite Research Reactor, Brookhaven National Laboratory, Upton New York, DCN: 5098-LT-01-0*, (ORISE, 2012) (Appendix C). The report noted that information had not been provided for them to verify that the south below ground duct and the fuel canal and deep pit were posted and controlled as contamination areas. These areas are appropriately posted and controlled as contamination and radiation areas as required by BSA's Radiological Control Program. Photographs of the postings are presented in Photograph 23 below:

Deep Pit Posting North BGD Posting South BGD Posting

Photograph 23 - Posting of Deep Pit and Below Ground Ducts

Table 3-5
Building 701 Post-Decommissioning Radiological Conditions

Location	Anticipated General Area Dose Rate (mrem/hr)	As-left General Area Dose Rate (mrem/hr)	As-left Maximum General Area Dose Rate (mrem/hr)
Deep pit	10-30	8 - 15	80
High bay	<0.1	<0.01	<0.02
High bay on top of biological shield cap	<0.1	0.01 – 0.07	0.08
Office areas	background	background	background
Yard areas	background	background	background
BGD general area	5	1 - 10	20
South BGD beyond radiation trap	30	1 - 4	5
North BGD below exhaust air plenum	100 - 150	2 - 20	50
Location	**Anticipated General Area Contamination Level (loose beta/gamma) (dpm/100cm^2)**	**As-left General Area Contamination Level (loose beta/gamma) (dpm/100cm^2)**	**As-left Maximum Contamination Level (loose beta/gamma) (dpm/100cm^2)**
Deep pit	1,000 – 2,500	1,000 – 5,000	20,000
High bay – accessible areas (up to 6’)	<1,000	<1,000	<1,000
High bay – remote/inaccessible areas (Gantry crane, excavator, support structure, bldg crane and roof supports)	<3,000	West catwalk - <3,000 Gradall - <1,000 Truss #2 - <3,000 NW Column - <3,000 Gantry - <3,000 East catwalk - <3,000	1,000 500 8,600 1,000 7,700 12,000
High bay – lower pile support plate (before concrete shielding cap)	<10,000	<1,000	<1,000
Office areas	background	background	background
Yard areas	background	background	background
BGD inboard of bustle	7,000	3,000	76,000
North BGD below exhaust air plenum	16,000	8,000	16,800

3.6 Waste Management

3.6.1 Waste Characterization, Handling and Disposal

The waste management strategy, waste characterization, packaging, handling, and staging were performed in accordance with the *Waste Management Plan for Brookhaven BGRR Bioshield Removal* (BNL, 2011c) and BNL Standards Based Management System waste management procedures. Waste generated during the BGRR Biological Shield Removal Project is summarized below and in Table 3-6.

Approximately 4,460 cubic yards of debris resulting from the demolition of the biological shield was characterized as low-level radioactive waste (LLRW) and packaged into Industrial Package Type 1 (IP-1) containers for disposal at either Energy Solutions of Utah or the Nevada National Security Site (NNSS). The majority of the packaged waste was shipped via rail with the balance shipped via truck.

Approximately 41 cubic yards of uncontaminated and unactivated debris resulting from the demolition of the biological shield was placed into construction debris dumpsters and transported via truck and disposed of as construction and demolition waste at the Brookhaven Town Landfill in Brookhaven, New York.

Approximately 440 gallons of oil from the various equipment used in support of the BGRR Biological Shield Removal Project was drained into 55-gallon drums and shipped via truck to Energy Solutions of Utah for treatment and disposal.

Approximately 25 cubic yards of mixed waste was generated from the removal of the experimental ports and various shielded conduits located adjacent to the biological shield. The mixed waste also includes cadmium coated steel shot that was vacuumed from the shot wells. A portion of the lead that was removed was re-used within steel boxes to provide shielding for highly activated components that were removed as waste.

Approximately 4,500 gallons of water was removed during the Building 701 Deep Pit clean-out. This water was solidified into 250-gallon Intermediate Bulk Containers (IBCs) at the BNL Waste Management Facility and was shipped for disposal at the NNSS. In addition, 8.9 cubic yards of sludge was removed from the Deep Pit. This material was stabilized and placed into five B-12 boxes, which was also shipped to the NNSS for disposal.

Waste shipped to the NNSS includes 12.4 cubic yards of contaminated graphite dust that was vacuumed from the pile floor. This material was solidified and placed into two B-25 boxes and one 144 cubic foot IP-1 box.

Table 3-6
Project Waste Summary

Waste Type	Manifested Volume	Containers	Disposal Facility	Shipping Method
Radiologically Contaminated Demolition Debris	4464 yd^3 (LLRW)	197 20- and 25- cubic yard intermodals 9 20-foot Sealand containers	Energy Solutions, Clive, Utah	Rail
Radiologically Contaminated Demolition Debris	127 yd3 (LLRW)	7- 144 cubic foot steel IP-1 boxes and 1 tank as a self package	Energy Solutions, Clive, Utah	Truck
moratorium metal	41 yd3	2-20yd roll-off	Brookhaven Town Landfill	Truck
Radiologically Contaminated Lead/Cadmium	24.8 yd^3 (Mixed LLRW)	Various steel boxes- 5-B-12 boxes 1- 144cuft IP-1 box 1- B-25 box 8- B-6 boxes	Energy Solutions, Clive, Utah	Truck
Radiologically Contaminated Construction Debris	68.3 yd^3 (LLRW)	Various steel boxes- 2 B-25 boxes 1 144cuft IP-1 boxes 5 B-12 boxes 20 250-gal IBCs	NNSS	Truck
Clean Debris and Equipment	N/A	4-20' roll-off containers	Crestwood	Trucks
Radiologically Contaminated oil	440 gallons (Liquid LLRW)	8-55 gallon drums	Energy Solutions, Clive, Utah	Truck

Photograph 24 – Packaging project waste.

3.6.2 Pollution Prevention and Waste Minimization Opportunities

Waste minimization and pollution prevention methods employed during the BGRR Biological Shield Removal Project included transferring left-over non-contaminated personal protective equipment, tools and equipment to other BNL divisions. In addition, approximately 100,000 pounds of lead and 80 cubic yards of clean scrap metal were characterized and released for recycling. Lastly, with assistance from DOE, BSA was able to transfer the majority of the contaminated equipment used in the project to other DOE sites for re-use. Had this equipment not been transferred for re-use, it would have been disposed as radiological waste at a cost exceeding $300,000.00. In addition to the major equipment listed in Table 3-7, the transferred equipment included items such as spare parts, 2-way radios, and video equipment. One of the Brokk manipulators and its end-effectors, whose title has been transferred to DOE's Paducah Gaseous Diffusion Plant (Paducah), will first be shipped to DOE's Separations Process Research Unit (SPRU) Disposition Project where it will be put into service for a short period before it is shipped to its final destination. The following is a summary of the value of the equipment transferred to other facilities for future use:

- Paducah: $991,270.00
- West Valley: $855,745.00
- SPRU: $55,729.

Table 3-7
Summary of Transferred Equipment

Equipment	Transferred To
New Holland Excavator	Paducah
Caterpillar 5-ton Forklift	Paducah
Brokk Remote Manipulators (2)	Paducah
20-cubic yard Intermodal Containers (12)	Paducah
60-foot JLG Aerial Lift	SPRU
Bobcat Skid-steer Payloader	SPRU
High Efficiency Particulate Air Filter Units & Blowers	West Valley
Brokk Hydraulic Saw and Breaker Hammer	West Valley
20-cubic yard Intermodal Containers (50)	West Valley

3.7 Site Restoration

Site restoration was limited to the demobilization of project equipment that was staged both inside Building 701 and within the BGRR Outside Areas. Since containerized waste and equipment (e.g., forklifts, aerial lifts, vehicles) used during the BGRR Biological Shield Removal Project was staged on the BGRR Engineered Cap, an additional radiological walkover survey was conducted of that area to confirm the as-left conditions following the completion of the BGRR work activities. The radiological walkover survey was conducted using a 2-inch by 2-inch NaI detector in conjunction with a Ludlum Model 2221 scaler/ratemeters. The results of the radiological walkover survey exhibit count rates below the 20,400 cpm screening level, with the exception of the eastern-most extent of the cap. As indicated by previous radiological surveys, these areas of the cap exhibit count rates above 20,400 cpm due to high background activity coming from Building 801. The cap radiological walkover survey results are presented in Appendix A. ORISE performed a Type A independent verification of the gamma walkover survey. The independent verification, which confirmed that an appropriate level of effort and records were provided to document the as-left conditions of the cap, is documented by *Project-Specific Type A Verification Letter Report for the Brookhaven Graphite Research Reactor*, *Brookhaven National Laboratory*, *Upton New York*, *DCN: 5098-LT-01-0*, (ORISE, 2012) (Appendix C).

4.0 CHRONOLOGY OF EVENTS

The following table lists a chronology of the main events for the BGRR Biological Shield Removal Project.

Table 4-1
Chronology of Events

Date	Event
March 17, 2005	BGRR ROD Approved
March 28, 2008	Draft Final Remedial Design/Remedial Action Work Plan for the removal of the BGRR Biological Shield
June 2010 – January 2011	Initial Preparations (balcony, Chemo-Nuclear loop, ATM and neutron shield removal)
January 2011 – May 2011	Removal of the biological shield roof
May 2011 – September 2011	Removal of the biological shield walls (initial approach)
June 2011	Change in technical approach and preparations
September 2011 – March 2012	Continue biological shield wall removal with new technical approach (New Holland excavator)
March 29, 2012	Placement of final concrete cap over biological shield footprint
May 4, 2012	Completion of fieldwork
April 30, 2012	Completion of Building 701 as-left radiological survey
June 4, 2012	Completion of the remaining BGRR Outside Areas as-left radiological survey, including IV by ORISE
June 21, 2012	Final approval of BGRR Explanation of Significant Differences
June 30, 2012	Completion of project waste shipment
August 17, 2012	Completion of project waste disposal

5.0 PERFORMANCE STANDARDS & QUALITY CONTROL

The performance standard was the removal of the BGRR biological shield in accordance with project specifications. As described in Section 3.5, an as-left radiological survey of Building 701 was performed after the completion of remedial activities and stabilization of loose radiological contamination to confirm the anticipated end states were achieved. The results of the Building 701 as-left radiological survey indicate that the anticipated general area dose rates and contamination levels specified in the *BGRR Decommissioning End Points* (BNL, 2010a) were met.

In addition, an as-left radiological survey was performed in the remaining BGRR Outside Areas, as described in Sections 3.4 and 3.6, to verify the as-left conditions following the completion of BGRR work activities. As-left concentrations for Cs-137, Sr-90 and Ra-226 in surface soils were below the cleanup goals of 23 pCi/g, 15 pCi/g, and 5 pCi/g, respectively. In addition, concentrations of mercury, beryllium, lead, nickel, copper and zinc in soil were below the cleanup goals of 0.7 mg/kg, 0.43 mg/kg, 400 mg/kg, 130 mg/kg, 270 mg/kg and 2,200 mg/kg, respectively. These results are provided in Appendix A.

Quality assurance/quality control (QA/QC) soil samples were collected in accordance with Work Procedure 314-35, *As-Left Survey Procedure for the BGRR, Rev. 2* (BNL, 2012). Field duplicates were collected at a minimum frequency of one per twenty soil samples and analyzed for the radiological contaminants of concern. QA/QC results are summarized with asphalt and overburden soil survey and soil sample results provided in Appendix A.

An additional radiological walkover survey of the engineered cap area, where project equipment was staged, was performed to verify the as-left conditions following the completion of the BGRR work activities. The survey results are provided in Appendix A.

6.0 Final Inspection and Certifications

In accordance with the BGRR ROD, as-left surveys were performed for Building 701 and the remaining BGRR Outside Areas. These results were previously discussed in Sections 3.4, 3.5 and 3.7.

During all facets of the BGRR Biological Shield Removal Project there was strict adherence to industrial safety and radiological safety requirements. All work was performed under the authorization of written and approved procedures. JSAs were prepared and approved as a part of each work package. General oversight was provided by ERP Managers.

6.1 Industrial Hygiene Oversight & Monitoring

Industrial hygiene oversight and monitoring was conducted by the ERP Safety and Health Manager in accordance with ERP procedures. A JSA was prepared for each work package, identifying hazards associated with each of the tasks and specifying required controls for each hazard. The ERP Safety and Health Manager ensured that monitoring occurred as specified in the JSA. Industrial hygiene monitoring included noise monitoring and silica/dust monitoring.

6.2 Radiological Oversight & Monitoring

Radiological controls during the BGRR Biological Shield Removal Project were specified in *ERP-OPM-6.16, Radiological Monitoring during BGRR Biological Shield Removal Activities, Rev 1* (BNL, 2010c). Both area and personnel radiation monitoring was performed by qualified Radiological Control Technicians. Area radiation monitoring consisted of routine dose rate and contamination surveys (e.g., daily, weekly, monthly, etc.) as well as air monitoring. Alpha and beta sensitive Continuous Air Monitors (CAMs) were established outside the CCE. These CAMs monitored air in the CCE and also in the Building 701 High Bay. Additionally, passive area monitoring was conducted in non-radiological areas of Buildings 701 and 703 to assure that non-occupational workers were not exposed above limits.

Job specific radiological work permits were utilized during the BGRR Biological Shield Removal Project to specify protective clothing and radiological monitoring requirements for all aspects of the work activities.

Because the CCE was posted and controlled as a Contamination Area and Radiation Area, personal protective equipment for entry consisted of a single set of anti-contamination clothing and alarming electronic personnel dosimeters. Personnel who processed waste boxes were also required to wear to loose-fitting Powered Air Purifying Respirators, which allowed for better communications and provided the necessary protection. Upon exiting, the CCE workers were required to monitor themselves using automated personnel contamination monitors (PCMs) such as the PCM-2.

All equipment, including waste boxes, that were released from the CCE were surveyed in accordance with FS-SOP-1005, *Radiological Surveys Required For Release of Materials from Areas Controlled For Radiological Purposes* (BNL, 2007).

Cameras located inside the CCE were used for remote observation of equipment operation but also for oversight of workers when they entered the CCE. The ability to remotely view workers performing IP-1 container processing operations led to work planning enhancements and reduced personnel exposure. Additionally, ERP used a commercially available software program that enabled remote read out of CAMs and electronic personnel dosimeters. This remote instrument read out capability allowed oversight personnel to ensure workers did not exceed radiological work permit dose limits and directly contributed to ERP's ALARA Program. These tools enabled ERP to keep its collective dose for the project to approximately 8.9 person-rem which was well below the estimate of 12 person-rem.

7.0 OPERATION AND MAINTENANCE ACTIVITIES

The *Long-Term Surveillance and Maintenance Manual for the Brookhaven Graphite Research Reactor* (BNL, 2012c) was prepared to includes monitoring, maintenance, and inspection activities and frequencies for the BGRR complex, including Building 701, the BGRR Engineered Cap and Water Intrusion Monitoring System and the remaining BGRR Outside Areas. The monitoring and inspection frequencies vary depending on the activity being performed, and include quarterly, semi-annual, annual, every five years, or as conditions require after major natural events. These activities will include:

- Inspections and maintenance of Building 701 exterior, including the roof, perimeter walls and doors, and associated transformers and circuit breakers;
- Inspection and maintenance of the Building 701 interior (i.e., high bay, canal, deep pit, office spaces and sample room).
- Testing, maintenance and monitoring of the BGRR Water Infiltration Detection System within the Below Ground Ducts and the Deep Pit;
- Inspections and maintenance and of the engineered cap asphalt, concrete pads and coatings;
- Annual certification to the regulators that the Institutional and Engineering Controls are in place and functioning; and
- Institutional controls (land use controls, notifications and restrictions such as no parking or vehicular traffic within 10 feet of the cap geomembrane anchor points, work planning controls such as digging permits, and government ownership).

BSA will perform surveillance and maintenance activities. In addition to groundwater monitoring and maintaining institutional controls, BSA will ensure that that routine maintenance/inspections are performed. DOE will ensure enforcement of all institutional controls. The BGRR complex will be included in the next sitewide statutory Five-Year Review in 2016.

8.0 SUMMARY OF PROJECT COSTS

The BGRR Biological Shield Removal Project was completed at a total cost of approximately $26,071K, of which $16,908K was funded by ARRA. The following provides the cost breakout for the project (in $K):

Item	ARRA-funded	Base-funded	Total
Engineering and Planning:	$1,794K	$0.00	$1,794K
Field Oversight:	$6,063K	$2,884K	$8,947K
Fieldwork:	$7,462K	$3,210K	$10,672K
Waste Transport & Disposal:	$1,589K	$3,069K	$4,658K
Total:	**$16,908K**	**$9,163K**	**$26,071K**

9.0 EVENTS AND LESSONS LEARNED

9.1 Events

On November 29, 2011, during a torch cutting operation of the 3-inch thick south wall of the BGRR outer biological shield, a worker fell approximately 16 feet from a scissor lift platform to a concrete floor. The scissor lift guard rail system was determined to have been unlatched. Both workers in the scissor lift were under the impression that the other had performed the required pre-use inspection of the lift, and did not perform it themselves. The worker sustained broken bones from the fall. The accident investigation determined that the responsibility for inspection had not been specifically assigned to an individual in the pre-job briefing. Corrective actions addressed specification of personnel responsible for pre-use equipment inspections, and broadly addressed other equipment inspection and configuration issues.

9.2 Lessons Learned

- <u>Oxy-Propylene Torch Cutting</u>. When performing oxy-propylene cutting of doubled three-inch thick steel beams that had a small air gap between beams, it was not possible to cut through both three-inch thicknesses at the same time. As a result, slag would build up in the gap between the beams when cutting the first beam; and the hot slag would occasionally "pop" and blow out of the gap. The hot slag, travelling upward, presented a hazard to the operator. At one point, a piece of the hot slag landed on the oxy-propylene hoses behind the operator and immediately burned through the propylene hose, starting a fire. Fortunately, the hose orientation was such that the fire was directed away from the operator. When the fire occurred, the Job Supervisor and fire watch personnel immediately pulled the fire alarm, turned off the cutting equipment gases (extinguishing the fire) and lowered the operator's platform. During subsequent cutting, it was determined that after the cut in the first beam had commenced, placing a deflector on the gap above the cut prevented the hot slag from blowing upward or on the operator. Precautions were also taken to arrange the cutting gas hoses away from the operator and to avoid placing them where they could be damaged (hoses were sleeved and routed so they were away from the worker). These techniques should be considered during work planning activities for similar cutting operations.

- <u>Smoke and Fume Management</u>. The biological shield removal subcontractor made the initial assumption that a single 6,000 cubic feet per minute air handler ("smoke eater") would be adequate to control the smoke and fumes generated from the torch-cutting operations. Although a single unit performed adequately in shop testing, actual torch-cutting generated more smoke and fumes than this single unit could manage. This had a negative effect on the air quality in the high bay, which resulted in the smoke particulates being filtered by the CCE ventilation systems pre-filters. This resulted in additional labor costs associated with filter change-out, and a significant cost increase in replacement filters which exceeded $100K. The BSA project engineers determined that in order to manage the smoke from one or two torch-cutting operations, a minimum of four, and more ideally six, smoke eaters should have been utilized.

- Waste Lifting/Handling Hoppers. ERP acquired two different material lifting hoppers from different manufacturers as part of the project planning process. Both hoppers had a capacity of 8 tons but the dumping operation of each hopper was different. The hopper had a positive locking cam for the dumping operation that is controlled with the crane. For example, as the load is off the lifting arm, the arm swings away from the dumping end and locks into angled position for re-lifting. As the hopper is lifted, the material is emptied from the hopper. The second hopper featured a pull-cable that unlocks the swing arm after the load is off. As the hopper is re-lifted, the weight of the material in the hopper causes the tilt and material is emptied. For this operation to occur, however, the load has to be even throughout the hopper or more towards the dumping end. If the load is toward the back end, the hopper does not tilt and additional equipment has to be used to assist the operation. For similar operations, project personnel should ensure that the load is towards the dumping end.

- Intermodal Containers. Early in planning phase for the disposal of the biological shield waste, BSA recognized that utilization of the industry standard 25-cubic yard intermodal containers would result in a significant “under filling” of containers because of the high density of the steel and concrete debris. At best it was estimated that a 25-cubic yard container could only be filled to two-thirds volume capacity or less before its maximum payload weight was reached. Considering that the unit waste disposal cost in BSA’s contract with Energy Solutions of Utah was based on 80-percent of the container volume and not actual waste volume, using partially-filled 25-cubic yard containers would result in a significant cost in waste disposal for empty volume. Also, due to “above-the-rail” height restriction of 15’-6” imposed by the Long Island Railroad, the 25-cubic yard containers could not be double-stacked. This would limit the number of containers on a flatcar to four (4), resulting in additional transportation costs. Based on this, BSA determined that a 20-cubic yard container would be ideal because it could not only be loaded without “under filling”, they could be double-stack on the rail flatcars. BSA prepared technical specifications for these containers with separate chassis and solicited competitive pricing through BNL Procurement and Property Management. A contract was awarded for fifty (50) containers. Use of these special containers is estimated to have saved approximately $570,000.00 in waste transportation and disposal costs. The purchase price of the intermodals was approximately $500,000, however rental costs for intermodals were avoided and at the end of the project the intermodals were available for transfer to other DOE sites for use, therefore saving even more rental costs in the future.

- Water Accumulation in Shipping Containers. Free-standing water was discovered inside of one of the intermodal waste containers when it arrived at the waste disposal facility. It was determined that the container had been damaged during operations and that the damage had not been identified through routine inspections. Upon transport of the container by rail, the damage propagated because of vibration and wind loading, and rainwater intrusion caused substantial accumulation of water. Careful inspection and documentation of the condition of waste containers is important in assuring safe transport.

10.0 PROTECTIVENESS

The removal of the BGRR biological shield is protective of human health and the environment. The action removes a significant radiological source term, and the installation of the concrete floor sealing the remaining radioactive contamination in the floor of the building is protective of that configuration from disturbance. Continued monitoring, inspection and repair of the building's shell by BSA's EPD will assure that rainwater intrusion into the building is prevented and that the concrete floor will remain in good condition, preventing spread of the encapsulated contamination into the environment.

11.0 FIVE YEAR REVIEW

Five-year reviews will be conducted to determine whether the remedy implemented continues to be protective of human health and the environment. These reviews will be performed in accordance with the *Comprehensive Five-Year Review Guidance, OSWER No. 9355.7-03B-P* (EPA, 2001). The BGRR complex will be included in the next sitewide statutory Five-Year Review in 2016.

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