DECOMMISSIONING MODEL FOR THE BROOKHAVEN GRAPHITE RESEARCH REACTOR

N. H. Lacy, R. G. Nicholas
Burns and Roe Enterprises, Inc.

J. D. Wagner, D. L. Wojtkowiak
Babcock Services, Inc.

A. A. Freitag, J. M. Sullivan
WMG, Inc.

ABSTRACT

As part of its broad commitment to protecting public health and the environment, the U.S. Department of Energy (DOE) is decommissioning the Brookhaven Graphite Research Reactor (BGRR). The BGRR was an air-cooled graphite moderated reactor like many built in the U.S. and U.K. after World War II. The BGRR was the first reactor built for the sole purpose of providing neutrons for scientific research, and operated from 1950 to 1968.

The team of Burns and Roe Enterprises, Inc. (BREI), Babcock Services, Inc. (BSI), and WMG, Inc. (WMG) was commissioned by Brookhaven National Laboratory (BNL) to evaluate and analyze the stability, and progressive decommissioning and removal of BGRR components. This analysis took the form of several detailed decommissioning studies that range from disassembly and removal of the unit's graphite pile to the complete environmental restoration of the reactor site.

The studies provide a decision-making tool for the final end state of the facility. To meet this need, key parameters are fully developed, and include removal methodologies (based on CERCLA criteria), waste streams and volumes, cost and schedule, and total man-rem exposure.

While most of the facility's decommissioning effort is conventional, the graphite pile and its biological shield present the greatest challenge. The studies develop a unique method of removing high-activity waste (primarily from fuel failures) trapped in the graphite joints by over-boring the fuel channels and collecting the debris. Once the high-activity waste is removed, the remainder of the pile lends itself to dismantlement by a compact, electrically powered demolition machine with standard end-effectors.

This methodology for graphite handling and disposal at the relatively small BGRR pile sets the stage for decommissioning of the larger U.K. reactors. With these reactors, special considerations such as Wigner energy and high-activity debris, necessitates a waiting period of up to one hundred years. The BGRR decommissioning model therefore would provide useful and early baseline data that can be applied directly and proactively to the planning and remediation of the U.K. reactors.

INTRODUCTION

When it became operational in 1950, the Brookhaven Graphite Research Reactor (BGRR) at Brookhaven National Laboratory (BNL, Upton, NY) was the first peacetime reactor built in the United States following World War II. Its primary mission was to produce neutrons for scientific research. Experiments at the reactor led directly to development of multigrade motor oils (such as 10W-30) and technetium-99, an important medical diagnostic radioisotope. The facility was placed on standby in June 1968 and then closed permanently.

As part of its broad commitment to protecting public health and the environment, the U.S. Department of Energy (DOE) is decommissioning BGRR. The purpose of the BGRR Decommissioning Project is to plan and implement a safe and cost-effective facility dismantlement to restore the site environmentally. BNL selected the team of Burns and Roe Enterprises, Inc. (Oradell, NJ), Babcock Services, Inc. (Richland, WA), and WMG, Inc. (Peekskill, NY) to perform detailed decommissioning studies that will be used by BNL in the decommissioning decision-making process.

The team has developed two BGRR decommissioning engineering studies. The first analyzes the long-term structural stability of the graphite pile if it is left alone. The second evaluates potential decommissioning alternatives that range from disassembly and removal of the Pile to total remediation of the site to a green field state. This paper summarizes the decommissioning approach of the most critical and challenging components – the graphite pile and the biological shield wall. These represent the two major BGRR source terms.

GRAPHITE PILE DECOMMISSIONING

Graphite Pile Description

The graphite pile, or reactor core, consists of 63,000 interlocking graphite blocks in 2,600 different shapes (see Figure 1). Designed to moderate neutron speed during operation, it forms a 700-ton, 25-foot cube split vertically through the middle by a 3-inch gap. Filtered cooling air was drawn down into this gap to provide cooling. Horizontal rows of round channels extend from the south face of the pile to the north face. These channels housed the fuel rods. Of 1,369 channels, about half were used at any given time. An additional 29 square openings on the east and west faces were used for experiments. Reactions were controlled through 16 borated steel control rods inserted diagonally from two corners of the cube. The Pile rests on two 3-inch-thick steel bedplates that are supported on a set of steel I-beams (known as the *grillage*). Under the grillage is a foundation of four concrete buttresses, which are ultimately supported by a 3.75-ft-thick foundation mat.

Methodology

The disassembly and removal of the BGRR pile is a complex process. The 63,000 interlocking, irregularly shaped graphite blocks are not easily lifted or pulled apart. In addition, some surrounding structures need to be removed to access the graphite block. The most radioactive parts of the pile are fuel channels that experienced fuel failures. The pile itself is contained within a biological shield wall, or Bioshield, which is a double steel walled confinement structure. It allows access to the Pile only through its roof, which complicates disassembly.

Six pile decommissioning concepts were evaluated:

1. Manual disassembly of the Pile.
2. Manual disassembly after boring selected fuel channels.
3. Manual and remote disassembly.
4. Manual and remote disassembly after boring selected fuel channels.
5. Bulk removal of half the Pile, followed by manual and remote removal of remainder.
6. Bulk removal of the Pile in sections.

The preferred concept, manual and remote disassembly after boring selected fuel channels, addresses the complexity of disassembly and removal. By isolating the high-activity waste stream, it vastly simplifies the entire decommissioning and waste removal process. The use of remotely operated equipment significantly limits potential worker exposures.

The first step in the preferred concept calls for boring out the fuel channels and vacuuming and isolating the shavings to separate the high-activity waste from the rest of the Pile. Radiological surveys and physical inspections of the Pile revealed that several fuel channels have very high activity contamination and/or debris within them. These fuel channels with documented high activity and/or high dose rates will be bored (reamed) to remove the contamination/debris, reducing the radiological risk of dismantling the bulk Pile graphite.

An added benefit of boring is that separating high-activity waste from the bulk graphite waste will maximize disposal options and minimize waste transportation and disposal costs. Removing the most contaminated and active areas will significantly reduce airborne releases from the Pile during disassembly.

After boring, workers will manually create an opening in the center of the Bioshield roof. They will remove the Bioshield roof plugs, top aluminum airtight membrane, and any metal parts that limit access to the Pile. They will then remove the first five layers of graphite blocks and metal tie rods to create the space needed to use a remotely operated compact demolition machine. Dose rates at the top of the Pile and within the first five layers are expected to be relatively low and will permit such work.

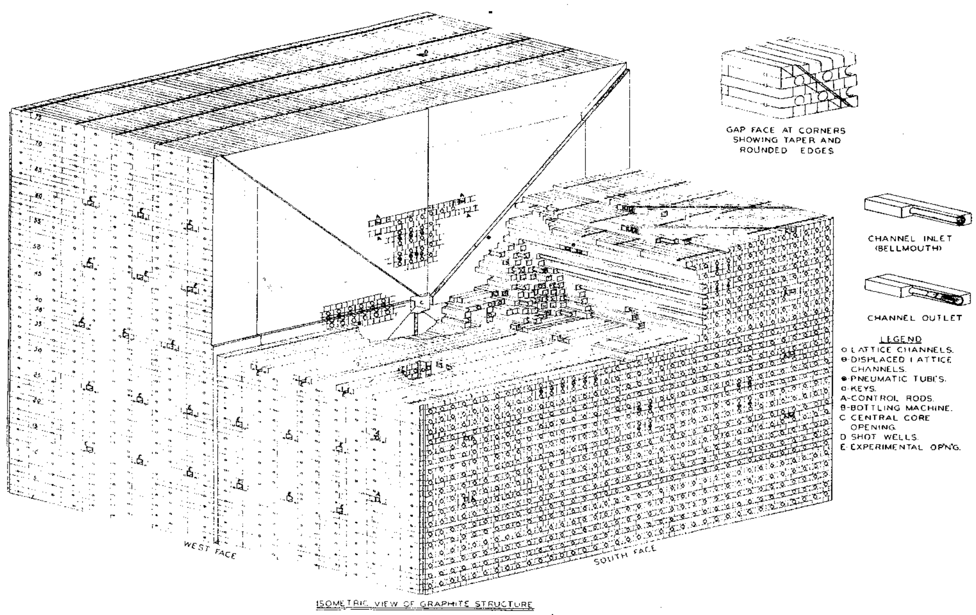


Fig. 1 Isometric view of graphite structure

Workers will then position a Brokk Model 330 or similar remotely operated, compact demolition machine on the north or south side of the Bioshield roof. This will give it access to the exposed Pile. Using an excavating bucket, grapple or other demolition end effectors, the Brokk will continue to pull apart the Pile and place the rubble in containers. It has enough reach to remove more than 50% of the Pile from this position. The unit will be lowered into the Pile pit to remove the rest. Remote operation will eliminate the need for extensive work within the confines of the Bioshield and keep worker exposures as low as reasonably achievable (ALARA). It will also reduce the possibility of heat stress and workplace injuries.

In addition to graphite boring and remote equipment, this decommissioning model also employs other critical technology concepts, such as a contamination confinement enclosure, temporary ventilation units, and contamination fixative. These are further described below.

Pile Boring

Pile boring will employ a boring machine that counter-bores the fuel channel holes to a larger size. All the fuel channels have chamfered edges (0.005 inch at 45 degrees) and seams running along the 12 o'clock and 6 o'clock positions. They have a nominal internal diameter of 2.67 inches in a 4-inch by 4-inch block. Boring a 3-inch hole through the block will ground out the activated graphite in the channel and remove the seam where residual materials have been identified during earlier video surveillance.

Approximately two-third of the fuel failures occurred in the south half of the Pile. If sampling data confirms the failure was confined to the southern half, these channels need not be bored all the way across the Pile. For failures in the northern half, the entire channel will be bored starting from the south face.

The boring machine will sit on the charging elevator located outside of the Bioshield. The Bioshield and temporary shielding will protect the operator from radiation from the Pile. The boring machine's integrated vacuum system will retrieve graphite cuttings from the fuel channels for disposal.

Operators will insert the boring tool through the fuel charging holes in a manner similar to the way the reactor was refueled. This involves using a larger pipe or half-pipe to bridge the air plenum and align the bit with the corresponding hole at the graphite face. The use of overhead periscopes and scanner holes will ensure that the drill bit goes into the proper fuel channel.

Since the fuel channels have a nominal 2.67-inch diameter, the 3-inch tool bit (see Fig. 2) will grind away approximately 0.33 inches of material including the top and bottom seams. This will remove the bulk of the high-activity contamination that remains in the Pile. If radiation remains in the channel, it can be re-drilled with a larger bit of up to 3.5 inches in diameter to remove additional material.

Fig. 2 Boring bit

The bit itself is self-centering and will use guides to remain centered. Its hollow center connects to a vacuum system that will remove cuttings as the bit advances. An inflatable plug can be inserted from the Pile’s north side and advanced to seal the channel at the Pile’s center air gap. This seals both ends of the channel, locking in finely ground graphite particles and creating a better vacuum. When the tool reaches the gap, the inflatable plug will be withdrawn. If necessary, a separate vacuuming tube or nozzle can be inserted into the channels to remove any loose particulates that remain.

The boring tool will be coupled to a compact vacuum system, which has a proven record of use on nuclear decommissioning projects and several important safety features. These include dustless drum change-out, safety interlocks, and a self-cleaning, two-stage positive high-efficiency particulate air (HEPA) filter. It is capable of handling the extremely fine powders graphite boring will create. Because it is compact, after boring it can be reused for lead paint removal and other particulate-generating decommissioning activities.

Graphite Block Removal

The graphite Pile is located within the Bioshield. To remove the Pile, workers will first have to open the top of the Bioshield. Initial preparations include removal of the Bioshield’s concrete roof plugs, airtight aluminum membrane, and associated steel. The vacuum system will be put in place, and temporary ventilation equipment installed to support Pile disassembly. The surrounding floor will be prepared to receive and handle the graphite blocks.

The preparation work will leave the Pile exposed at its top elevation, approximately 30 ft above the floor. Operators will then hoist an electric-powered Brokk Model 330 (Skellefteå, Sweden) into place. It will undergo pre-operational checks and be fitted with an excavating bucket, a grapple, or any other appropriate tool available for demolition work. The use of the remotely operated Brokk is intended to eliminate the need for extensive manual labor within the Bioshield area, minimizing worker exposure, heat stress, and injury potential.

The plan calls for removal of approximately the first five layers of blocks. This will be done manually due to low dose rates at this area of the Pile. This will expose the steel tie rods that pass through the graphite blocks. Cutting the tie rods away will create enough clearance under the Bioshield overhang for the Brokk to reach and remove the remaining blocks.

The Brokk will remove the rest of the Pile, working from the inside out from both north and south sides atop the Bioshield. It will reach into the open Pile pit, pick up the graphite blocks using a bucket (or another appropriate tool), and place them into B-25 (or equivalent) metal waste boxes. The Brokk operator will be on top of the Bioshield, and no worker will enter the pit area as part of normal decommissioning operations. This will keep worker exposures ALARA.

After more than half of the layers are removed, operators will use the reactor’s 10-ton bridge crane to lower the Brokk into the pit so that it can complete the job. The crane will also move waste containers in and out of the pit so the Brokk can place the blocks in them. The B-25 boxes themselves will be lined and covered with plastic to contain graphite fines and minimize the possibility of exterior contamination.

The Brokk will pick up graphite by reaching into the 3-inch air gap at the center of the Pile. Working only one layer of blocks at any time, it will use the bucket teeth to pry up the blocks. It will create a small pile in front of itself by pulling them against the 3-inch-thick welded steel plates at the north and south ends of the Pile. Using a specialized loader-clamshell bucket, it will pick up several blocks at a time and place them in a pre-positioned B-25 box. The bridge crane will remove the box and replace it with an empty one. At times, it may be necessary to use a grapple device or shear to pull individual components from the pit.

The Pile consists of 75 layers. This includes nine upper layers outside the fuel region and approximately 22 layers that can be removed before reaching the first layer containing a failed fuel channel. Brokk operators can remove these upper layers to demonstrate the process and fine-tune procedures.

Several steps will be taken to control graphite dust within the workplace. The entire removal operation will take place inside the plastic Contamination Confinement Enclosure (discussed below). A ventilation system will capture and remove airborne and particulate graphite that might drift out of the Pile pit during block removal. Workers will remove loose graphite chips and dust from the Pile pit on a regular basis using long-handled vacuum sweeps. They will also spray a fixative, such as a passive aerosol fogging spray, to "glue" dust into place and control its spread.

Contamination Confinement Enclosure

The work described above will take place within a tent-like Contamination Confinement Enclosure that uses forced ventilation to control and remove radioactive particles and other airborne waste. The tent-like Contamination Confinement Enclosure will serve as a contamination barrier and assist in the control of airborne graphite contamination during Pile (and later Bioshield) removal work. It will consist of heavy-duty, reinforced, flame-retardant, plastic sheeting. At approximately 70 ft by 80 ft by 110 ft, it will cover the entire Pile/Bioshield structure.

Prior to final installation of the Enclosure, workers will complete all preparatory work, such as removal of control rod drives (CRDs). They will also park the bridge crane inside the Enclosure so that it can be used over the Pile area.

Temporary Ventilation Units

The temporary ventilation system is used to control any airborne contamination generated during block removal operations. It also circulates air inside the Contamination Confinement Enclosure. The suction from these units will be connected to the remaining underground concrete ducts that lead to the north and south Pile air plenums. Four 5,000 cfm HEPA ventilation units will be attached to each of the two ventilation ducts, generating 20,000 cfm of air flow from each Pile plenum.

Contamination Fixative Application

To further control the spread of airborne contamination, workers will apply a contamination fixative to glue dust particles in place prior to disassembly. The selected fixative is a passive aerosol fogging spray. It has been used very successfully at DOE's Rocky Flats and Hanford sites, and is fully accepted by the Hanford burial site where some of the graphite waste will be sent.

The spray material is a sugar-free water and glycerin mixture applied as a fog of approximately 1-micron droplets. This fine mist travels like smoke, coating everything it contacts. It is intended to coat the interior surface of the Pile's fuel and air cooling channels. This will be done by introducing spray nozzles through the north and south scanner slot holes and directing the spray into the north-south Pile holes. This will coat the interior faces of the blocks that are most likely to have residual particulate contamination or loose graphite particles from the graphite boring operation. During Pile disassembly, workers can reapply the fixative as needed. This would be done by fogging the open Pile area, then covering the top of the Bioshield with plastic, and allowing the fog to settle on the Pile overnight. Periodic vacuuming, however, may make secondary applications unnecessary.

Waste Management

Decommissioning the Pile will produce approximately 2.1 million lb (1,000 tons) and 17,000 ft^3 of waste. Shipping it will require approximately 471 B-25 boxes for graphite blocks, control rod blades (CRBs), and dry active waste (DAW); one 8-120 cask for high-activity waste; two 40-ft sea vans for control rod drives (CRDs); and either 18 20-ft sea vans or 20 40-ft sea vans and one 8-120 cask for the steel plates and high-density concrete blocks. The total activity calculated for all Pile material is approximately 3,500 Curies (Ci). All waste forms under consideration are contaminated and meet the burial requirements for the appropriate disposal sites. No mixed waste or waste that is solely hazardous has been identified in the BGRR.

Waste forms consist of low-level bulk graphite, segmented steel and aluminum plates surrounding the Pile, high-density concrete blocks, high-activity waste, CRDs, CRBs, and secondary waste. A detailed explanation of each waste form follows below.

Graphite Blocks

The Pile consists of 63,000 individual high-purity graphite blocks that form a cube approximately 25 ft on each side. The blocks are made of four different grades (AGOT, AGHT, CS and AA) based on graphite purity and quality. The higher the quality, the purer the graphite and the better it resists activation. The highest quality graphite was used in the central zone of the Pile's five concentric zones, where the neutron flux was highest. The lowest quality material went into the outer zone, where the flux was lowest. As a result, the activation of the graphite is essentially consistent throughout the Pile and is considered one waste stream.

Table I shows the preliminary characterization results for the bulk graphite pile. Results are based upon analysis of samples taken throughout the reactor. BNL had samples taken and analyzed in October 2000. A geometric average was applied to the raw sample data to determine specific activity (pCi/g). This specific activity was homogeneously distributed throughout the mass of the graphite in the reactor to determine activity (Ci) for each nuclide. This methodology predicts that the Graphite Pile contains approximately 3,240 total Curies, with tritium and ^{14}C as the dominant nuclides.

Table I Preliminary characterization results for BGRR Graphite (as of 10/1/2002)

Nuclide	Total Activity (Ci)	Contribution (%)
^{3}H	2.46E+03	75.94%
^{14}C	7.67E+02	23.67%
^{60}Co	7.30E-01	0.02%
^{63}Ni	7.36E+00	0.23%
^{90}Sr	3.07E-01	0.01%
^{137}Cs	2.77E+00	0.09%
^{152}Eu	1.87E-01	0.01%
^{154}Eu	5.11E-01	0.02%
^{155}Eu	3.23E-01	0.01%
^{234}U	1.37E-02	0.00%
^{235}U	2.08E-03	0.00%
^{238}U	3.47E-03	0.00%
^{238}Pu	2.92E-02	0.00%
^{239}Pu	4.71E-02	0.00%
^{241}Am	5.28E-02	0.00%
Total	3.24E+03	100%

High-Activity Waste

High-activity waste includes highly contaminated filters produced during the decommissioning activities, graphite shavings from fuel channel borings, and any high-activity debris removed from the Pile, air gap, and/or the north and south plenums. The known high-activity waste would fill a maximum of four Spec 7A drums. The air filtration system's HEPA filters will become contaminated during operation. Contamination will vary with the waste stream. Some filters will contain high-activity waste while others will hold secondary waste (see following section). The Pile's 31 high-activity channels, characterized by dose rates greater than 1 rem/hr (10 mSv/hr), will be bored out to reduce the radiological risk of dismantling the Pile. The boring operation will produce high-activity graphite shavings that will be vacuumed and filtered from these channels and homogeneously deposited into Spec 7A drums. High-activity debris may also exist on the floors of the north and south plenum, underneath the Pile, and in the Pile's air gap. The debris will be removed by vacuuming and distributed into Spec 7A drums. Some debris may require the use of extra shielding inside the Spec 7A drum.

It is known that certain debris within the Pile has significantly greater concentrations (Ci/g) of activity when compared to the balance of the graphite pile. Since this high-activity debris is not available for characterization, its nuclide content and concentration has been derived from samples of high-activity graphite. Table II shows the preliminary characterization results of this high-activity graphite, which adds surface contamination from known high-activity channels to the bulk graphite data above.

The worst-case surface contamination ($\mu Ci/cm^3$) from high-activity channels is based upon a combination of sample and In-Situ Object Counting System (ISOCS) data from high-activity channels. The total activity given in Table I was distributed throughout the Pile to determine the average specific activity for the graphite. Both surface contamination and activation are then distributed throughout the 18.62 ft^3 of waste the boring operation will generate. Due to its low total volume, the total activity for the high-activity waste generated from the boring operation is approximately 5.94 Ci.

Table II Preliminary Characterization Results for High Activity Waste (Graphite) (as of 10/1/2002)

Nuclide	Surface Contamination Specific Activity (μCi/cm^3)	Surface Contamination Activity (Ci)	Activation Specific Activity (μCi/cm^3)	Activation Activity (Ci)
^{3}H	1.57E-03	8.27E-04	6.21E+00	3.27E+00
^{14}C	7.75E-02	4.09E-02	1.93E+00	1.02E+00
^{55}Fe	4.97E-02	2.62E-02	---	---
^{60}Co	8.97E-02	4.73E-02	1.84E-03	9.72E-04
^{63}Ni	1.20E+00	6.34E-01	1.86E-02	9.79E-03
^{90}Sr	2.95E-01	1.55E-01	7.74E-04	4.08E-04
^{99}Tc	1.21E-04	6.40E-05	---	---
^{108}Ag(m)	4.74E-03	2.50E-03	---	---
^{133}Ba	9.64E-03	5.08E-03	---	---
^{137}Cs	1.18E+00	6.21E-01	6.98E-03	3.68E-03
^{152}Eu	4.24E-02	2.24E-02	4.72E-04	2.49E-04
^{154}Eu	3.45E-02	1.82E-02	1.29E-03	6.80E-04
^{155}Eu	1.71E-02	9.04E-03	8.15E-04	4.30E-04
^{234}U	---	---	3.44E-05	1.82E-05
^{235}U	---	---	5.24E-06	2.76E-06
^{238}U	---	---	8.76E-06	4.62E-06
^{238}Pu	2.93E-04	1.54E-04	7.36E-05	3.88E-05
^{239}Pu	5.72E-03	3.02E-03	1.19E-04	6.27E-05
^{241}Pu	8.60E-03	4.54E-03	---	
^{241}Am	7.93E-02	4.18E-02	1.33E-04	7.02E-05
Total		1.63E+00		4.31E+00

Metal Plates / High-Density Concrete Blocks

Accessing the Pile calls for the disassembly of the Bioshield's removable roof. It consists of high-density concrete blocks, steel casing for the blocks, and steel plates. The steel is approximately 84,000 lb (42 tons) and 300 ft^3. The high-density concrete is roughly 530,000 lb (265 tons) and 1,900 ft^3.

Table III shows the preliminary characterization results for worst-case metal plates adjacent to the Graphite Pile. Characterization was based upon activation of steel for the operating history of the BGRR and ISOCS data from the worst-case Bioshield steel. The preliminary assessment derived from ISOCS data shows activity of approximately 84 Ci. Three nuclides, ^{63}Ni, ^{60}Co, and ^{55}Fe, contribute more than 95% of the activity. Furthermore, the steel is approximately 40% the 10 CFR Part 61, Table 2 fraction. These results are subject to change based upon a more rigorous evaluation, but suggest that some steel may exceed NRC Class A waste standards.

Table III Preliminary characterization results for metal plates (as of 10/1/2002)

Nuclide	Activity (Ci)	Contribution (%)	Activity ($\mu Ci/cm^3$)	10 CFR Part 61, Table 1, Class A Fraction	10 CFR Part 61, Table 2, Class A Fraction
^{3}H	6.29E-01	0.75	1.30E-01	0	0.003
^{14}C	3.34E-01	0.40	6.90E-02	0.009	0
^{55}Fe	4.34E+00	5.19	8.96E-01	0	0.001
^{59}Ni	4.51E-01	0.54	9.31E-02	0.004	0
^{63}Ni	6.63E+01	79.38	1.37E+01	0	0.391
^{60}Co	1.15E+01	13.73	2.37E+00	0	0.003
^{90}Sr	1.00E-09	0.00	2.07E-10	0	0
^{94}Nb	1.88E-03	0.00	3.88E-04	0.019	0
^{99}Tc	1.73E-08	0.00	3.58E-09	0	0
^{129}I	3.97E-19	0.00	8.20E-20	0	0
^{137}Cs	2.75E-08	0.00	5.67E-09	0	0
Total	8.36E+01	100.0	1.72E+01	0.032	0.399

Table IV shows the preliminary characterization results for worst-case high-density concrete blocks. Characterization was based upon activation of high-density concrete for the operating history of the BGRR and ISOCS data from the worst-case concrete within the Bioshield. The preliminary assessment derived from ISOCS data shows total activity of approximately 160 Ci. Three nuclides, ^{3}H, ^{60}Co, and ^{41}Ca, contribute more than 95% of the activity. Furthermore, the steel is approximately 5% the 10 CFR Part 61, Table 2 fraction. This suggests the high-density concrete blocks are not likely to exceed NRC Class A waste standards.

Table IV Preliminary characterization results for high-density concrete blocks (as of 10/1/2002)

Nuclide	Activity (Ci)	Contribution (%)	Activity (μCi/cm^3)	10 CFR Part 61, Table 1, Class A Fraction	10 CFR Part 61, Table 2, Class A Fraction
^{3}H	1.10E+02	68.78	2.05E+00	0	0.051
^{14}C	1.43E+00	0.89	2.67E-02	0.003	0
^{41}Ca	7.24E+00	4.54	1.35E-01	0	0
^{55}Fe	4.14E+00	2.60	7.75E-02	0	0
^{60}Co	3.59E+01	22.55	6.73E-01	0	0
^{59}Ni	6.75E-03	0.00	1.26E-04	0	0
^{63}Ni	9.91E-01	0.62	1.86E-02	0	0.001
^{90}Sr	7.06E-06	0.00	1.32E-07	0	0
^{94}Nb	1.12E-03	0.00	2.09E-05	0.001	0
^{99}Tc	8.30E-07	0.00	1.55E-08	0	0
^{129}I	3.81E-19	0.00	7.14E-21	0	0
^{137}Cs	4.62E-07	0.00	8.65E-09	0	0
Total	1.59E+02	100.0	2.98E+00	0.004	0.053

CRDs and CRBs

Insufficient data was available for proper waste classification of the CRDs and CRBs. Based on the worst-case dose rate of approximately 95 mrem/hr (0.95 mSv), the CRBs will most likely be Class A waste. Activation of the CRDs is predicted to be minimal and they will most likely be disposed as DAW. Material types and more extensive dose survey information are required to determine waste classification of these components.

Secondary Waste

Secondary waste consists of dry active waste (DAW) associated with site work as well as radiation protection. Examples include slightly contaminated filters, protective clothing (PCs), contaminated equipment, the Griffolyn Contamination Confinement Enclosure, and such consumables as rags, mops, and buckets.

Waste will be disposed of in a variety of disposal containers to accommodate the specific physical form and radionuclide activity of each waste form. The final mode of transportation will also determine disposal containers. Truck transportation, however, is the leading candidate. While not limited by number of packages, truck transportation has limits on weight per shipment. Trucks could possibly transport waste to a transfer station where it could be loaded on railcars.

The packaging options considered are B-25 boxes, 20-ft and 40-ft sea vans, Spec 7A drums, and casks. The B-25 boxes will contain low-activity graphite blocks, CRBs, and all secondary waste. Sea vans hold large structures, such as metal plates, high-density concrete blocks, CRBs, and CRDs. Spec 7A drums, which hold high-activity waste, locked into drum carousels inside a CNS 8-120 cask. The high-activity waste may require additional shielding to meet transportation dose limits. The possibility exists that some of the highest activity metal plates may need to be shipped in casks.

Shipping weight limits the maximum amount of material that can be shipped in a sea van. The U.S. Department of Transportation (DOT) imposes a maximum weight limit of 80,000 lb (40 tons) on standard highway shipments. Above that limit, shippers must receive a special permit from each state they cross. A standard flatbed truck weighs 35,000 lb, so its maximum payload cannot exceed 45,000 lb.

Since a 20-ft sea van weighs about 5,000 lb, a standard truck would have room for a payload of 40,000 lb of waste. This is just over the maximum allowable container weight of 39,950 lb, the limit of what a 20-ft sea van could carry.

A 40-ft sea van weighs about 9,000 lb, which leaves 36,000 lb for waste weight. Thus, when shipping by truck, the maximum waste weight allowed in a 20-ft sea van is 39,950 lb and the maximum allowable waste weight allowed in a 40-ft sea van is 36,000 lb.

Environmental Safety and Health

Decommissioning of the BGRR Pile is a potentially hazardous activity that can only be managed through detailed attention to radiological as well as personnel safety and industrial hygiene concerns. It will require multiple strategies to meet the radiological challenges of decommissioning, including task-specific controls and a variety of safety checks to mitigate potential release scenarios.

Radiological Controls

Radiological controls are required for both specific work tasks and to reduce the risk of worst-case release scenarios that might affect occupational radiation workers or release material into the environment. Multiple strategies are required to meet these challenges. These range from the use of confinement enclosures, protective clothing, and controlled ventilation to ongoing radiation monitoring and periodic decontamination. Controls also include final radiological survey components, as well as tracking man-rem exposures for all activities and transportation of waste.

Graphite fuel channel boring, block removal, and routine work area decontamination are the tasks that have the potential to generate high levels of smearable and airborne contamination. Multiple strategies have been employed to reduce these risks. These include the use of a the Contamination Confinement Enclosure over the general work area, a variety of secondary enclosures to protect equipment operators, aggressive use of ventilation systems to remove airborne particulates, and protective clothing for all personnel. Administrative controls and good work practices also provide a level of contamination control.

Man-rem Estimate

The total man-rem for the Graphite Pile removal activities is estimated to be 44.561 rem (445.61 mSv) for occupational radiation workers. The man-rem for transportation of waste to disposal facilities is estimated to be 1.5044 rem (15.044 mSv) for occupationally exposed persons and 9.8604 rem (98.604 mSv) to non-occupationally exposed persons. No individual should receive a dose measurable by thermoluminescent dosimeter (TLD).

BIOLOGICAL SHIELD DECOMMISSIONING

Biological Shield Description

The biological shield wall, or Bioshield, encloses the pile, and shielded work areas from radiation (see Figs. 3 and 4). It is 55-ft long by 37.5-ft wide by 33.6-ft tall, weighs 5,000 tons, and consists of concrete sandwiched between an inner and outer steel wall. The outermost wall is a 3-in-thick steel plate. On the inside of the plate is a 4.25-foot-thick high-density concrete barrier that contains scrap iron and limonite (an iron-bearing ore). Inside the concrete is another wall made of two 3-in-thick steel plates. The innermost plate of these plates and some iron scrap inside the concrete barrier are activated.

The Bioshield wall lines up with the 1,369 fuel channels and 29 experimental openings in the Pile. The experimental holes were closed and/or plugged during preliminary decommissioning in the early 1970s. All holes have since been plugged and sealed with steel plates. The same buttressed foundation that holds the pile also supports the Bioshield.

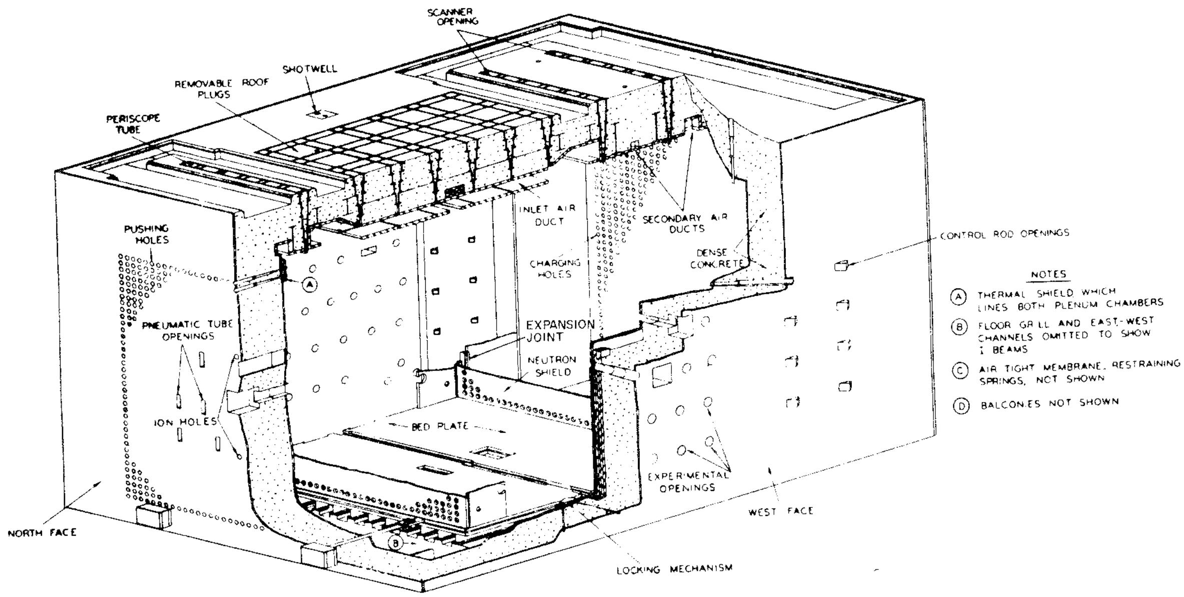
Methodology

Once the Pile is removed, decommissioning efforts are focused on the Bioshield. Four concepts were evaluated for this structure:

1. Diamond wire cutting.
2. Abrasive water-jet cutting.
3. Oxygen burning.
4. Peeling using conventional torch cutting and rubblizing.

The most feasible concept employs the use of manual torch cutting and remote rubblizing to systematically remove layers of Bioshield wall from the top down, a few feet at a time. This approach is the fastest, least expensive, and safest of the four concepts considered. The Bioshield interior is activated and has high enough dose rates to preclude the possibility of disassembly by having personnel working inside of it for any length of time. To keep exposures ALARA, the Bioshield must be disassembled from the outside in.

Workers will work from the top down and the outside in, taking down a few feet of the shield's perimeter at a time. By moving from the outside of the structure inwards, the outer steel wall and concrete filler will shield workers from the inner steel walls, which have the highest degree of activation. This preserves the structural integrity of the wall and reduces the possibility of a breach that might put workers at risk. It will also keep exposures as low as reasonably achievable (ALARA).



CUTAWAY ISOMETRIC VIEW OF SHIELD

FIGURE G04.02-3

Fig. 3 Isometric view of Bioshield structure.

Initial disassembly of the Bioshield will start at the its flat top. At this level, the concrete roof will be rubblized with the Brokk machine and removed, gradually exposing the Bioshield interior. Once this is done, workers will cut apart and remove any remaining Pile components, such as the end plates and steel springs, using the Brokk and long or remote handled torches and metal shears.

At this point, workers will begin peeling off the Bioshield vertical walls. They will use conventional flame cutters to remove the 3-inch-thick outer steel skin. The pieces will be small enough for the cutting crew and the facility overhead crane to handle them and readily fit them into disposal containers. No or very minimal contamination or activation is expected on the outmost skin.

Next, the exposed concrete will be rubblized and packaged using the Brokk machine. Multiple crews will work on the wall at the same time. Once the steel cutting crew finishes a section, it will move on to the next section and a second crew will begin rubblizing and packaging the exposed concrete. The crews will continue stripping layers off the Bioshield until the outer structures are down and only the inner steel plates remain in a section.

A third crew will cut and remove the inner steel plates. Most of the inner Bioshield wall is 6 inches thick. The 3 inches of the 6-inch wall closest to the pile is orders of magnitude more activated than the outer 3 inches adjacent to the concrete. Workers will use long extensions to cut the steel while working behind temporary shielding. By keeping the highly activated inner portion of the steel facing away from them, the outer layer of steel will help shield

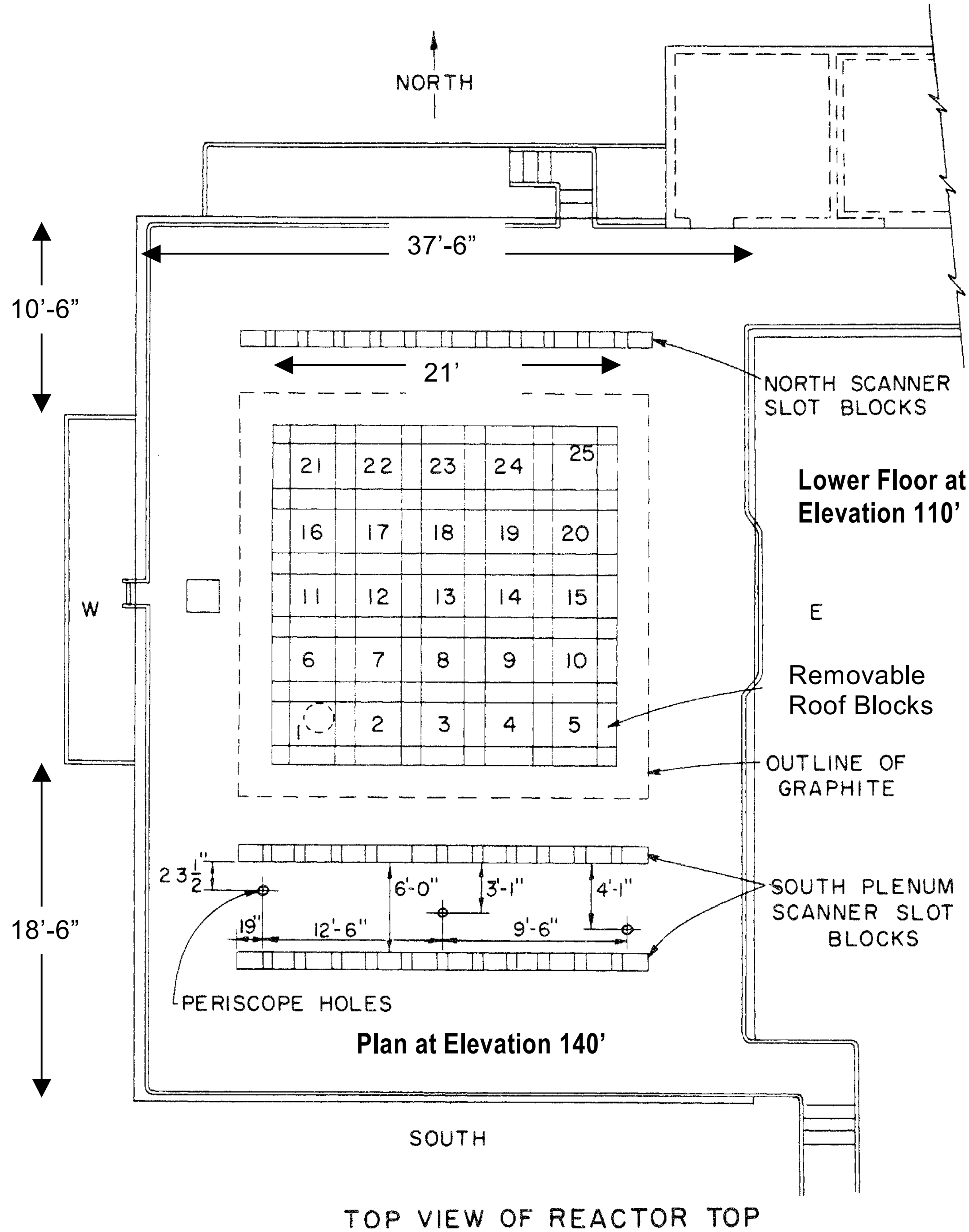


Fig. 4 Top view of reactor

them. They will cut holes in each section they cut and shackle the part to the overhead crane to safely handle and maneuver the plates into a disposal container. This process will continue until the entire shield is down. Shifts will be managed to keep exposures ALARA.

During Bioshield sidewall removal, the Brokk and the work crews will operate from the mezzanines, or balconies, that surround the Bioshield.

As with the Pile, the remediation of the Bioshield will utilize the Contamination Confinement Enclosure, the ventilation units, and the application of the contamination fixative.

Waste Management

Dismantling the Bioshield will yield approximately 10.5 million lb (5,300 tons) and 110,000 ft^3 of waste. This is in addition to the 2.1 million lb (1,000 tons) and 17,000 ft^3 of waste produced by decommissioning the Graphite Pile discussed above. Shipping the waste produced by Bioshield will require 20 B-25 boxes for processed and secondary waste and either 377 20-ft or 419 40-ft sea vans for high-density concrete and metal plates. The total activity calculated for all Bioshield material is 4,800 Ci. All waste forms under consideration meet the burial requirements for the appropriate disposal sites.

Waste forms include high-density concrete, steel and aluminum plate, thermal shields, and secondary waste. A detailed explanation of each waste form follows.

High-Density Concrete

A high-density concrete barrier 4.25 ft thick surrounds the entire Bioshield, which is 55 ft long by 37.5 ft wide by 33.6 ft tall. The concrete consists in part of scrap iron and limonite. It is 279 lb/ft^3, compared to 145 lb/ft^3 for conventional concrete. This yields approximately 7.9 million lb (4,000 tons) and 28,000 ft^3 of high- density concrete, not including the concrete associated with the removable roof section.

Table V shows the preliminary worst-case characterization results for high-density concrete. It is based upon ISOCS data and estimates of concrete activation over BGRR's operating history. Preliminary ISOCS data shows that the concrete at this survey point is approximately 5% of the 10 CFR Part 61, Table 2 fraction. While these results may change with more rigorous evaluation, they show that Bioshield high-density concrete is most likely Class A waste.

Table V Preliminary characterization results of bioshield concrete (as of 10/1/2002)

Nuclide	Activity (Ci)	Contribution (%)	Activity ($\mu Ci/cm^3$)	10 CFR Part 61, Table 1, Class A Fraction	10 CFR Part 61, Table 2, Class A Fraction
^{3}H	1.63E+03	68.78	2.05E+00	0	0.051
^{14}C	2.12E+01	0.89	2.67E-02	0.003	0
^{41}Ca	1.08E+02	4.54	1.35E-01	0	0
^{55}Fe	6.17E+01	2.60	7.75E-02	0	0
^{60}Co	5.36E+02	22.55	6.73E-01	0	0
^{59}Ni	1.01E-01	0.00	1.26E-04	0	0
^{63}Ni	1.48E+01	0.62	1.86E-02	0	0.001
^{90}Sr	1.05E-04	0.00	1.32E-07	0	0
^{94}Nb	1.67E-02	0.00	2.09E-05	0.001	0
^{99}Tc	1.24E-05	0.00	1.55E-08	0	0
^{129}I	5.69E-18	0.00	7.14E-21	0	0
^{137}Cs	6.89E-06	0.00	8.65E-09	0	0
Total	2.37E+03	100.00	2.98E+00	0.004	0.053

Segmented Metal Plates

Steel and aluminum plates surround the Pile, provide a thermal shield, and line the inside and outside of the Bioshield. The east, west, and top faces of the pile are covered with a close fitting membrane of both aluminum and steel plates. The east and west faces are covered with 0.25-inch steel. Half the top face is covered with 0.125-inch aluminum.

Two 3-inch steel plates missing about 25 percent of their volume cover the north and south faces. A 3-inch outer casing surrounds the sides and top of the Bioshield. In general, a 6-inch thick steel layer lines the Bioshield. The 6-inch interior steel plate is supplemented by a band 12 inches thick by 20 inches wide that wraps around the east, west, top and bottom of the Bioshield. The north and south plenums are lined on five sides by the thermal shield that consists of eight 0.125-inch crimped aluminum sheets sandwiched between two 0.25-inch steel plates.

These metal plates weigh approximately 2.5 million lb (1,300 tons) and occupy 84,000 ft^3. This weight and volume does not include the steel plates associated with the removable roof.

Table VI shows the preliminary worst-case characterization results for Bioshield steel. It is based upon In Situ Object Counting System (ISOCS) data and estimates of steel activation over BGRR's operating history. The interior wall adjacent to core experienced the highest flux and is considered the most highly activated component in the BGRR.

The preliminary assessment derived from ISOCS data shows approximately 2,400 total Ci of activity. Three nuclides, ^{63}Ni, ^{60}Co, and ^{55}Fe, contribute approximately 95% of the activity. Furthermore, the steel is approximately 40% of the 10 CFR, Part 61, Table 2 fraction. While these results may change with more rigorous evaluation, they show that some Bioshield steel may exceed Class A waste.

Table VI Preliminary Characterization Results of Bioshield Steel (as of 10/1/2002)

Nuclide	Activity (Ci)	Contribution (%)	Activity (μCi/cm^3)	10 CFR Part 61, Table 1, Class A Fraction	11 CFR Part 61, Table 2, Class A Fraction
^{3}H	1.84E+01	0.75	1.30E-01	0	0.003
^{14}C	9.74E+00	0.40	6.90E-02	0.009	0
^{55}Fe	1.27E+02	5.19	8.96E-01	0	0.001
^{59}Ni	1.31E+01	0.54	9.31E-02	0.004	0
^{63}Ni	1.93E+03	79.38	1.37E+01	0	0.391
^{60}Co	3.35E+02	13.73	2.37E+00	0	0.003
^{90}Sr	2.92E-08	0.00	2.07E-10	0	0
^{94}Nb	5.48E-02	0.00	3.88E-04	0.019	0
^{99}Tc	5.06E-07	0.00	3.58E-09	0	0
^{129}I	1.16E-17	0.00	8.20E-20	0	0
^{137}Cs	8.01E-07	0.00	5.67E-09	0	0
Total	2.44E+03	100.00	1.72E+01	0.032	0.399

Secondary Waste

The secondary wastes identified under the decommissioning of the Pile will be generated here as well.

Bioshield waste will be disposed of in a variety of disposal containers as discussed for the Pile.

Environmental Safety and Health

As with the Pile, the structural demolition of the Bioshield presents potentially hazardous activities. Careful planning is required to address hazards with both mechanical equipment and radiological conditions. Again, multiple strategies are needed to meet the radiological challenges of decommissioning, such as task-specific controls and safety checks to mitigate potential release scenarios.

Radiological Controls

The removal of the Bioshield adds another potential activity that can generate high levels of smearable and airborne contamination. Therefore, the Contamination Confinement Enclosure, aggressive use of ventilation systems to remove airborne particulates, and protective clothing for all personnel will be retained for this work.

Man-Rem Estimate

The total man-rem estimate for the Bioshield removal portion of the work is 31.868 rem (318.68 mSv). The man-rem for transportation of Bioshield waste to disposal facilities is estimated to be 3.8228 rem (38.228 mSv) to occupationally exposed persons, and 14.283 rem (142.83 mSv) to non-occupationally exposed persons. No individual should receive a dose measurable by thermoluminescent dosimeter (TLD).

Safety

Safety issues deserve equal attention because many tasks are hazardous, complex, and take place in confined areas. BNL and all DOE sites require an Integrated Safety Management (IMS) program, which involves the workers. Job Safety Analyses, periodic job safety meetings, a safety incentive program, and additional safety training facilitate their involvement. The safety incentive program is envisioned as cash award program that rewards contractor employees for successful safety performance. This type of program has proved highly successful in preventing injuries on construction projects.

CONCLUSION

The BGRR decommissioning will reduce the potential long-term risk to the public health and the environment. While an end state of the facility has not yet been selected, the detailed decommissioning studies conducted by BREI, BSI, and WMG will provide input and basis for a final decision.

This paper summarizes the decommissioning approach of the facilities major components and source terms; the Pile and Bioshield. The overall results of these studies are summarized in Table VII.

Table VII Pile and Bioshield Removal

	Pile	Bioshield	Totals (Pile + Bioshield)
Schedule Duration	37 months	4 months	41 months
Activity	3,500 Ci	4,800 Ci	8,300 Ci
Total Onsite Occupational Exposure	44.561 rem (445.61 mSv)	31.868 (318.68 mSv)	76.429 (764.29 mSv)
Total Transportation Occupational Exposures	1.5044 rem (15.055 mSv)	3.8228 (38.228 mSv)	5.3272 (53.272 mSv)
Total Non-Occupational Transportation Exposures	9.8604 rem (98.604 mSv)	14.2830 (142.830 mSv)	24.1434 (241.434 mSv)

This BGRR model for graphite handling and disposal provides useful baseline data that can be applied to the planning and remediation of the U.K. reactors, which have significant graphite liabilities.