Brookhaven Graphite Research Reactor Decommissioning Project

FINAL

Brookhaven Graphite Research Reactor
FEASIBILITY STUDY

16 July 2004

BROOKHAVEN NATIONAL LABORATORY
BROOKHAVEN SCIENCE ASSOCIATES

Under Contract No. DE-AC02-98CH01886 with the
UNITED STATES DEPARTMENT OF ENERGY

EXECUTIVE SUMMARY

The purpose of this Feasibility Study (FS) is to document the development, screening, and evaluation of remedial alternatives and removal actions that will address contamination at the Brookhaven Graphite Research Reactor. The report provides the U.S. Department of Energy (DOE), the U.S. Environmental Protection Agency (EPA), and the New York State Department of Environmental Conservation (NYSDEC), with sufficient data to select a feasible and cost-effective remedial alternative that will protect human health and the environment.

Brookhaven National Laboratory (BNL) is a DOE facility that was placed on the NYSDEC's "Inactive Hazardous Waste Disposal Sites" list in 1980. Subsequently, in 1989, the Laboratory was included on the EPA's National Priorities List for cleanup. The Laboratory ranked high on the EPA rating system and was placed on this list because of the environmental effects of past practices, some of which could pose a threat to Long Island's sole-source aquifer in the vicinity of BNL. The cleanup of BNL is funded by the DOE and overseen by DOE, EPA, and NYSDEC.

Certain structures, components and some soils associated with the Brookhaven Graphite Research Reactor (BGRR) are radiologically contaminated as a result of normal operation, water intrusion, and leaks throughout the history of the facility.

During the last several years, a number of removal actions and other interim actions have been taken to reduce the radiological footprint of the BGRR complex and reduce the potential threat of contamination leakage to the environment. These actions include the removal of 58,000 gallons of contaminated water from the below ground ducts, 39 metric tons of contaminated equipment from within the reactor building, 68 metric tons of contaminated debris from the exhaust fan house, 2,860 cubic yards of contaminated soil and debris associated with the removal of the pile fan sump and fuel canal water treatment house, 325 cubic yards of debris associated with removal of the above ground ducts, and an estimated 1,282 cubic yards of contaminated steel and filter elements from within the below ground exhaust ducts. Removal of the filter elements and contaminated steel within the below ground ducts is ongoing and expected to be completed by the end of fiscal year 2004.

The majority (greater than 99%) of the radiological inventory is contained in the pile and biological shield. Essentially all of the long-lived radioisotopes are also contained in these structures. As expected, contamination has been found in the fuel handling system deep pit and canal, and in the steel and concrete within the below ground ducts. Extensive characterization has determined that the reactor building exterior and interior structures, systems and components, with limited exceptions, are relatively free of contamination. However, because of historic contamination and subsequent decontamination efforts within Building 701 the area remains posted as a radiologically controlled area requiring all work within the facility be controlled for radiological protection purposes. Because of leakage during and after reactor operations, contamination has also been found in soil pockets located under the foundation of certain BGRR structures. Pockets of deep, subsurface contaminated soils have been found in a number of locations around and under the reactor building, below ground ducts and fuel canal. Monitoring downgradient of the BGRR indicates that the reactor facility has been a source of strontium-90 groundwater contamination. These groundwater findings were the driver for many of the removal actions and other interim actions that are described above. Remediation of groundwater contamination resulting from strontium-90 leaching is being addressed pursuant to the Operable Unit III Record of Decision and is not part of this Feasibility Study.

Following an extensive evaluation of completed removal actions and a careful review of the nature and extent of the remaining contamination, four remedial action alternatives were developed for the BGRR facility and are included in this FS. They are summarized below:

Alternative A, Stabilization and Source Management, would include those removal actions already completed and others already in progress. These actions are focused on suspected pathways that resulted in contamination leakage to groundwater in the past. Under Alternative A, the pile and biological shield would remain in place. Alternative A would also include the construction of an impermeable barrier to prevent water intrusion hence reducing the risk of contamination transport to groundwater. After these actions, continued infiltration management and institutional controls would be used to protect human health and the environment.

Alternative B, Pile and Biological Shield Removal, would include pile and biological shield removal in addition to the Alternative A actions. Alternative B would also include the construction of an impermeable barrier to prevent water intrusion and continued infiltration management and institutional controls upon completion of the removal actions.

Alternative C, Removal of Pile, Biological Shield, Fuel Canal Structure and Reasonably Accessible Soils, would include the Alternative B actions. As an ALARA measure, Alternative C would also include the removal of the portion of the fuel canal structure outside the foundation columns of Building 701, and the removal of several deep, subsurface pockets of contaminated soil outside of the reactor building footprint, adjacent to the below ground duct structure, and adjacent to and below the fuel canal structure. Alternative C also includes the construction of an impermeable barrier to limit the mobility of residual contamination, and continued infiltration management and institutional controls upon completion of the removal actions.

Alternative D, Greenfield, includes the removal of the pile, biological shield, reactor building superstructure and foundation, and contaminated soils to the extent required to reach the soil cleanup standards included in the Operable Unit I Record of Decision. Alternative D includes continued monitoring after these removal actions in order to ensure the effectiveness of this remedy.

The FS provides an individual and comparative evaluation of these alternatives against the following CERCLA criteria: (1) overall protection of human health and the environment, (2) compliance with applicable or relevant and appropriate requirements, (3) long-term effectiveness, (4) reduction of toxicity mobility or volume, (5) short-term effectiveness, (6) implementability and (7) cost.

The table included in this executive summary provides an overview of the results of this qualitative evaluation. For each alternative, the table provides the evaluation ratings for the first six criteria listed above, the estimated cost, and the estimate of the radiological inventory that would be removed and that which would remain upon completion. Highlights of the evaluation are discussed below.

Alternative A

The Alternative A removal actions are focused on the 47 Curies that pose the largest potential threat to contamination of the environment. These actions address suspected pathways that have resulted in groundwater contamination in the past. Under Alternative A, the pile and biological shield would remain in place. Alternative A would rely on infiltration management and institutional controls to manage this radiological inventory and protect human health and the environment from this potential hazard.

The effectiveness of these measures has been demonstrated in Brookhaven's recent past. However, the pile and biological shield contain a substantial inventory of long-lived radioisotopes that would require effective infiltration management and institutional controls for an indefinite period of time. There are serious questions and uncertainties as to the persistence and effectiveness of institution controls for an indefinite period of time.

Alternative B

Alternative B would include the removal actions that are the most relevant to the potential radiological hazard remaining at the BGRR complex: The removal of the pile and biological shield. Upon completion, over 99% of the radiological inventory would be removed including essentially the entire inventory of long-lived radioisotopes.

These additional removal actions address the uncertainties of Alternative A. Upon completion, the residual contamination would consist of short-lived isotopes. Institutional controls under Alternative B would be required for a finite duration hence eliminating the questions and uncertainties associated with indefinite institutional controls.

Alternative C

As an ALARA measure, Alternative C removes an additional two Curies of the radiological inventory from the BGRR complex at an incremental cost of $3.5 Million. These actions would shrink the radiological footprint to pockets of inaccessible soils located below the reactor building foundation and below ground duct structures. These actions significantly reduce the pockets of contaminated soils located outside of the protection inherently provided by these massive, reinforced concrete monoliths, hence increasing the long-term effectiveness of infiltration management and institutional controls.

Alternative D

Over $50 Million would be expended removing the last fraction of a Curie of the remaining short-lived radiological inventory. This incrementally strengthens the long-term effectiveness of institutional controls. However, Greenfield decommissioning of the BGRR complex is an enormous construction project. The risks from the additional decommissioning result in an unfavorable impact on short-term effectiveness that offsets the incremental improvement to long-term effectiveness.

Evaluation of Remedial Alternatives

	Alternative A	***Alternative B***	***Alternative C***	***Alternative D***
Total radiological inventory removed	47 Curies	8,091 Curies	8,093 Curies	8,094 Curies
Total radiological inventory remaining	8,047 Curies	3 Curies	1.5 Curie	< 1 Curie
Overall protection of human health and the environment	Medium	High	High	High
Long-term effectiveness	Medium	High	High	High
Compliance with Applicable or Relevant and Appropriate Requirements	QUESTIONABLE*	YES	YES	YES
Reduction of toxicity, mobility or volume through treatment	NA	NA	NA	NA
Short-term effectiveness	High	Medium	Medium	Medium
Implementability	High	High	High	High
Cost	$53.5 Million	$93.3 Million	$96.8 Million	$149.3 Million
Implementation of Institutional Controls and Long Term Response Action (LTRA)	$275k annually $10k per 10-year $700k per 20-year	$275k annually $10k per 10-year $700k per 20-year	$275k annually $10k per 10-year $700k per 20-year	$1k annually

*The indefinite storage or entombment of these radioactive structures may be in conflict with New York State regulations regarding the siting of LLRW disposal facilities. There may be a specific prohibition that would preclude this course of action for the pile and biological shield. This matter would need to be resolved prior to implementation.

TABLE OF CONTENTS

LIST OF FIGURES AND TABLES

FIGURES

TABLES

ACRONYMS, ABBREVIATIONS, AND UNITS OF MEASURE

ALARA	as low as reasonably achievable
Am-241	americium-241
ARARs	Applicable or Relevant and Appropriate Requirement
BGRR	Brookhaven Graphite Research Reactor
BNL	Brookhaven National Laboratory
C-14	carbon-14
Ca-41	calcium-41
CAC	Community Advisory Council
CERCLA	*Comprehensive Environmental Remediation, Compensation, and Liability Act*
CFR	Code of Federal Regulations
Co-60	cobalt-60
COPC	contaminants of potential concern
Cs-137	cesium-137
CRDM	control rod drive mechanism
D&D	decontamination and decommissioning
DOE	U.S. Department of Energy
EM	Environmental Management
EPA	U.S. Environmental Protection Agency
Eu-154	europium-154
Eu-155	europium-155
Fe-55	iron-55
FS	Feasibility Study
H-3	hydrogen (tritium)
km	kilometers
LTRA	Long Term Response Action plan
MCL	maximum contaminant level
MDA	minimum detectable activity
m^3	cubic meters
mrem/yr	millirem per year
NESHAP	National Emissions Standards for Hazardous Air Pollutants
Ni-59	nickel-59
Ni-63	nickel-63
NYCRR	New York Codes, Rules, and Regulations
NYSDEC	New York State Department of Environmental Conservation
NYSDOH	New York State Department of Health
PAH	polycyclic aromatic hydrocarbons
PCB	polychlorinated biphenals
pCi/gm	picoCuries per gram
Pu-329	plutonium-239
RAO	remedial action objectives
RCRA	Resource Conservation and Recovery Act
Sr-90	strontium-90
U-238	uranium-238
U.S.C.	United States Code

1.0 INTRODUCTION

1.1 PURPOSE AND ORGANIZATION OF THE STUDY

1.1.1 Purpose

The purpose of this Feasibility Study report is to document the development, screening and evaluation of remedial alternatives and removal actions that will address contamination at the BGRR complex.

1.1.2 Organization of the Report

This report is divided into five sections. Section 1 provides an introduction to the BGRR complex and explains the nature and extent of the contamination remaining at the reactor facility. This section also provides the conceptual site model that illustrates the potential fate and transport of the contaminants. Section 2 describes the approach in developing the remedial action alternatives and the BGRR remedial action objectives. Section 3 provides a description of each of the four remedial action alternatives while Section 4 provides an individual and comparative evaluation of these alternatives against several criteria required under CERCLA. Section 5 lists the references cited within this report.

1.2 SITE BACKGROUND

1.2.1 Site Description

Owned by DOE and managed by Brookhaven Science Associates, the Laboratory is located in Suffolk County on Long Island, about 60 miles east of New York City (Figure 1.1). Approximately 1.32 million people reside in Suffolk County and a little over 400,000 people reside in Brookhaven Township, within which BNL is situated. The BNL site covers almost 5,300 acres, much of which is wooded. The Laboratory has operated since the late 1940s as a research facility for national science and technology programs, and is expected to continue this mission for the foreseeable future.

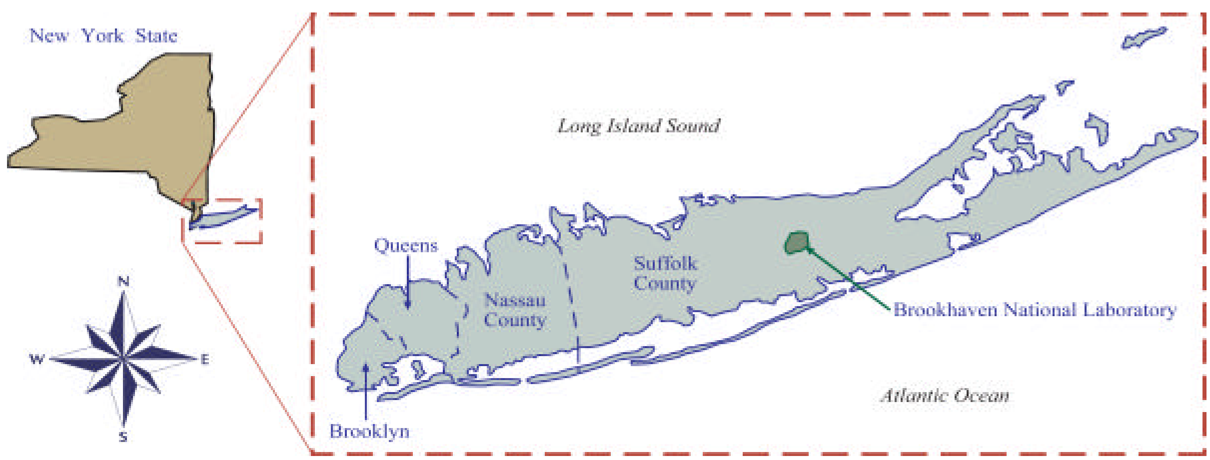


Figure 1.1 – BNL in relation to Long Island, New York

Most Laboratory facilities are located near the center of the site, in a developed portion that covers about 1,700 acres. The BGRR complex is within this central portion (Figure 1.2) of the BNL property. The complex covers about 3.8 acres, which is less than 0.1 percent of the overall BNL site.

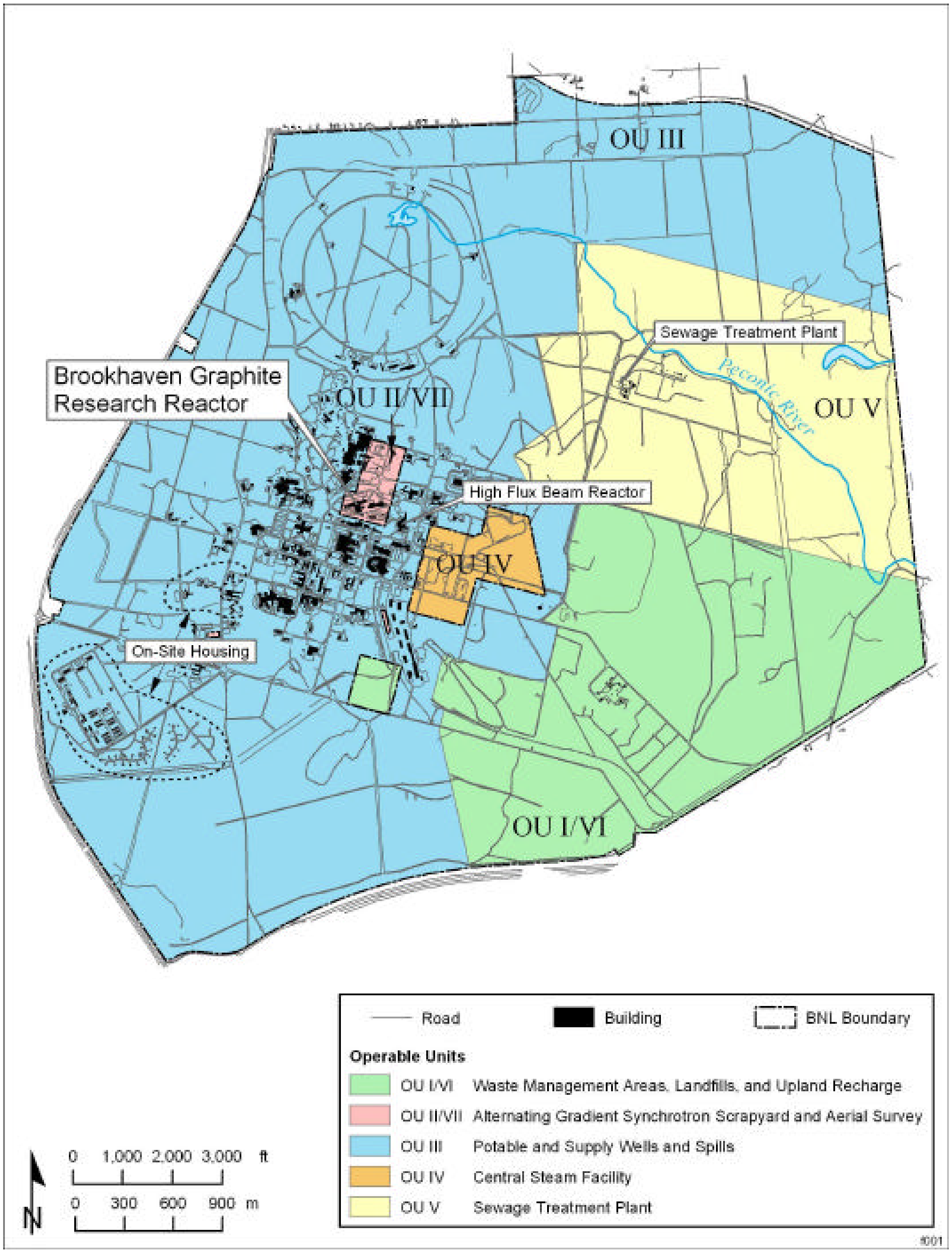


Figure 1.2 – BGRR in relation to BNL Property

The complex consists of multiple structures and systems that were necessary to operate and maintain the reactor. Portions of the reactor building and associated equipment and structures, some of which are underground, are contaminated as a result of previous BGRR operation.

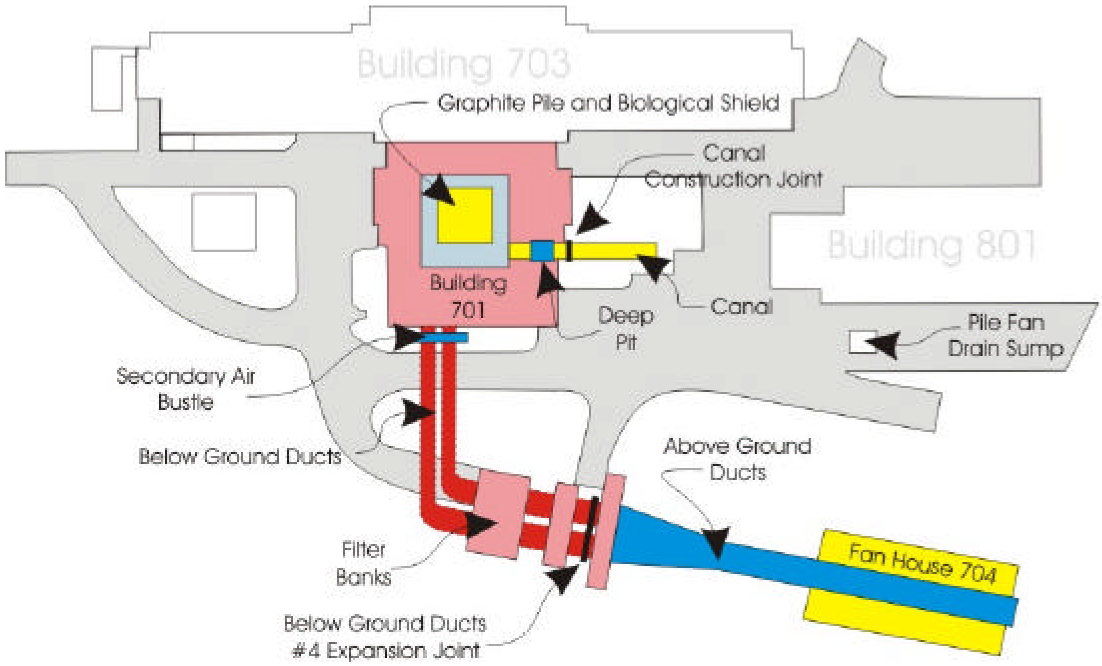


Figure 1.3 – BGRR Complex

1.2.1.1 Exterior Structure

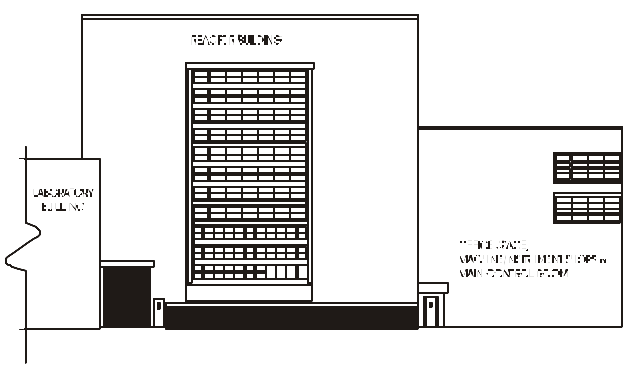


Figure 1.4 – BGRR Reactor Building
(Building 701)

The BGRR reactor building (Figure 1.4) is a riveted steel frame building with brick exterior. It shares a common wall with Building 703 on the north side. Building 703 remains in use for scientific research.

1.2.1.2 Reactor Pile and Biological Shield

The BGRR was an air-cooled, graphite-moderated reactor. It consisted of a graphite cube, built in two halves separated by a vertical gap running east and west, nearly 25 feet on each side and weighing about 700 metric tons. The cube is comprised of 75 horizontal layers of graphite blocks four inches wide and tall and of different lengths extending to more than 45 inches; an illustration of the graphite pile supported on its concrete foundation is shown in Figure 1.5. Reactor operations were controlled by the position of 16 control rods that penetrated the reactor horizontally parallel to the diagonals of the base. These control rods were completely inserted into the reactor core, and the control rod drives were cut when the reactor was shut down.

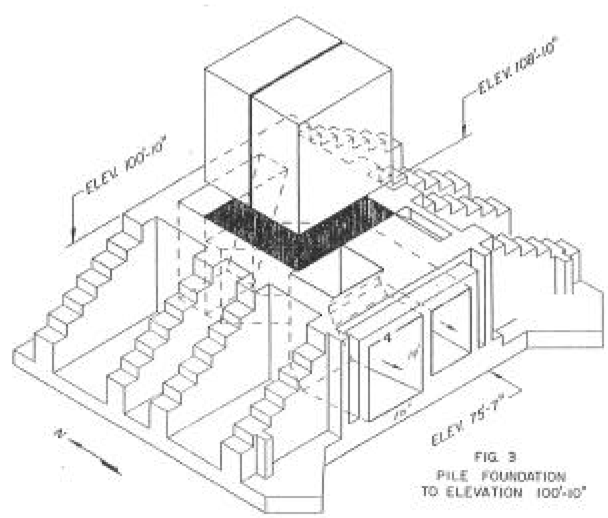


Figure 1.5 Graphite Pile and Foundation

The graphite pile is completely surrounded by a five-foot thick biological shield. This shield was designed to reduce the doses to operating personnel from neutrons and gamma rays resulting from the reactor operation. The shield was built of high-density concrete containing scrap iron, steel, and limonite (a mineral with a high hydration water content, which helped attenuate the neutrons). The graphite pile and biological shield are housed within Building 701, and the pile itself is designated as Building 702.

1.2.1.2 Air Cooling System

During operation, large cooling fans drew outside air into the reactor inlet duct system through two filter banks at the east and west outer walls of Building 701. Of the five primary fans, three were generally used to cool the graphite pile, and a secondary fan was used to cool the outer walls of the underground air-cooling ductwork. The primary and secondary fans together with an emergency fan were located in a separate fan house building (Building 704) southeast of the reactor building.

Cooling air was drawn into the narrow gap in the graphite pile, through the fuel channels, finally exiting the reactor at plenums located at the north and south ends of the pile. The air then was drawn downward and out of the reactor building through two reinforced concrete below ground ducts. These below ground ducts directed hot air from the pile through air- filters and coolers, then rose above ground between the instrument house and fan house. The instrument house contained equipment to monitor operation of the reactor cooling and ventilation system. Figure 1.6 shows features of the reactor and below ground portion of the ventilation system.

The two above ground ducts combined into a single concrete duct, which was located at the west wall line of the fan house and ran the length of and was supported by the roof. The walls of this above ground duct were nine inches thick, and eight penetrations at the bottom corresponded to the five primary cooling fan inlets, two emergency fan lines, and one 30-inch secondary air bypass line. This above ground duct extended a total of 225 feet. The cooling fans drew suction through four-foot diameter ducts that penetrated the fan house roof and connected to the base of the main duct. The above ground ducts and fans downstream of the instrument house were removed during 2001. The filtered, cooled reactor effluent was ultimately discharged through a 330-foot exhaust stack nearby. This stack is also part of the ventilation systems for other buildings that remain in use.

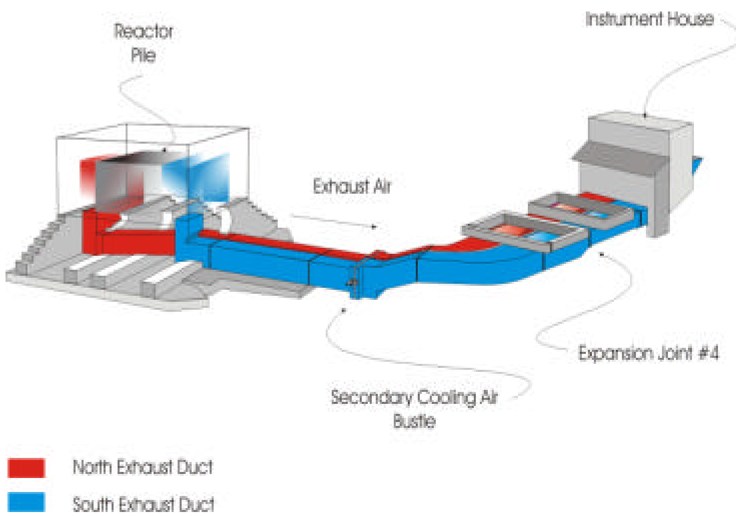


Figure 1.6 Below Ground Exhaust Ducts

1.2.1.3 Fuel Handling System

Spent fuel elements were removed from the south face of the reactor and discharged into an inclined fuel chute, which connects the reactor south plenum chamber to the deep pit in the fuel canal area. Freshly discharged fuel elements were temporarily stored under 20-1/2 feet of water within the deep pit until they decayed sufficiently to permit transfer to the shallow fuel canal area. Once in the shallow canal area, the spent fuel assemblies were segmented and packaged for shipment and disposal.

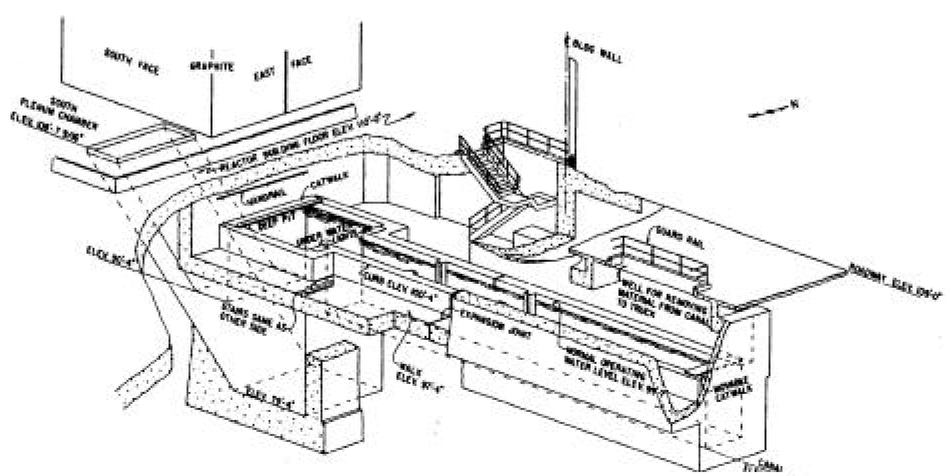


Figure 1.7 Deep Pit and Fuel Canal

1.3 NATURE AND EXTENT OF CONTAMINATION

During the last several years, a number of actions have been taken to remove contaminated structures, systems and components from the BGRR complex. A summary of these actions is provided in Table 1.1 Summary of Interim Actions

Year	Material Addressed	Action Taken	Waste Generated *(m^3 except as indicated)*	Disposition	Facility
1997-1999	Water in underground ducts	Pumped out water, repaired ducts	Contaminated water (220)	Incineration	GTS Duratek
1999	Museum displays, walls, rooms, barriers	Removed from reactor building	Uncontaminated debris (84) Contaminated debris (0.1)	Land disposal Land disposal	Local landfill Envirocare
2000	Equipment, pipes, other material at the graphite pile	Removed from reactor building, sealed pile openings	Uncontaminated debris (nr) Contaminated debris (3) Contaminated shielding (39 MT)	Land disposal Land disposal Land disposal	Local landfill Envirocare Envirocare
1999-2000	Fan house fans, motors, valves, instruments	Removed from fan house	Uncontaminated debris (nr) Contaminated debris (68 MT)	Land disposal Size reduction Land disposal	Local landfill GTS Duratek Envirocare
1999-2000	Concrete pile fan sump, pipes, soil	Removed old sump, diverted drain lines	Contaminated debris/soil (240)	Land disposal	Envirocare
2000-2002	Above-ground concrete ducts; pipes, equipment in instrument house	Removed ducts and sealed openings; removed material from instrument house	Contaminated debris (250)	Land disposal	Envirocare
2001-2002	Equipment, pipes, structural material, asphalt, concrete, soil	Removed material from canal and water treatment houses	Contaminated debris/soil (2,200)	Land disposal	Envirocare
2002-2004	Underground duct cooling coils, exhaust filters, primary liner system	Remove from the two ducts and compact on-site	Contaminated metal debris (8.2) Primary liner system debris (880) Exhaust filters (24)	Land disposal Land disposal Land disposal	Envirocare Envirocare US Ecology

Table 1.1 Summary of Interim Actions

During 2002 and 2003, comprehensive sampling and analyses were performed to characterize the BGRR complex. The non-radiological and radiological characterization results were published in two reports included as references to this FS.

Certain chemicals and materials were used during the construction and operation of the BGRR. For example, PCBs, organic solvents for degreasing equipment, mineral acids for extracting radionuclides, asbestos and lead in materials of construction, and elemental mercury in certain instruments were used at one time or another during the operating life of the facility. Many of these chemicals and materials have since been removed from the BGRR complex as part of several interim removal actions that have already been completed. Non-radiological characterization findings are limited to the following:

- Asbestos intrinsic to insulation, floor tiles, mastic and plaster.
- PCBs and lead intrinsic to original wall paint and floor coatings.
- Isolated areas of PCB surface contamination in freight elevator, personnel elevator and control rod drive mechanism area where motor oil contacted vinyl floor tiles.
- Elevated levels of metals within the reactor building pipe trench

Radiological contamination within the BGRR complex consists of activation and fission products within the reactor graphite pile and surrounding biological shield, contaminated concrete within the fuel handling system deep pit and fuel canal and contaminated steel and concrete within the below ground ducts. Additionally there are isolated pockets of radiologically contaminated soils associated with the below ground duct secondary cooling air bustle and expansion joints, fuel canal outer walls and construction joint, the reactor building pipe trench and Building 701 drains. The nature and extent of this contamination is described in Sections 1.3.1 and 1.3.2.

1.3.1 Contaminated Structures

Several contaminated structures exist at various locations within the BGRR complex (see Figure 1.8 and 1.9).

- **Graphite pile** – The graphite pile is housed within the biological shield and was the neutron moderator for the reactor. The graphite reactor pile is a 25-foot cube made up of 68,000 graphite blocks of various sizes and shapes. A small amount of structural steel was used to support the graphite blocks in place while the reactor operated. The materials of construction (i.e.: graphite blocks and structural steel) have been volumetrically activated as a result of reactor operation. There is also debris located within air passages and at the base of the pile. This debris is contaminated with activation products and also contains fission products as a result of fuel failures during operation. The graphite pile contains approximately 3,239 Curies consisting of H-3 (2,460 Ci), C-14 (767 Ci), Ni-63 (7 Ci), Cs-137 (3 Ci), (Eu-152, 154 & 155 (1 Ci), and Co-60 (<1 Ci). The remaining radioactivity is in the form of trace surface contamination consisting of uranium, plutonium and americium (~0.1 Ci). The estimated volume of radioactive material is approximately 580 cubic yards.

- **Biological shield** – The biological shield is housed within the BGRR reactor building and surrounds the graphite pile. The biological shield has been volumetrically activated as a result of reactor operation. The total radionuclide inventory of 4,805 Curies consists of Ni-63 (1,945 Ci), H-3 (1,648 Ci), Co-60 (871 Ci), Fe-55 (189 Ci), Ca-41 (108 Ci), C-14 (31 Ci), and Ni-59 (13 Ci). The estimated volume of radioactive material is approximately 100 cubic yards.

- **Deep pit and fuel canal under the footprint of Building 701** – Contamination is contained in the top few inches of the concrete floors in deep pit and fuel canal that have been soaked and penetrated by contaminated water containing high levels of fission products from the handling of fuel. Radioactivity associated with the deep pit and fuel canal consists primarily of fission products. The contaminated concrete contains approximately 0.167 Ci consisting of Sr-90 (0.028 Ci) and Cs-137 (0.139 Ci). The remaining radioactivity is in the form of trace surface contamination consisting of uranium, plutonium and americium (~0.0015 Ci). The estimated volume of radioactive material is approximately 65 cubic yards.

- **Fuel canal outside the footprint of Building 701 –** The fuel canal outside the footprint of Building 701 consists of the contaminated concrete on the inner surface of the fuel canal, and walkway drain lines embedded in concrete that were not removed during prior decontamination efforts. This contaminated material contains approximately 0.022 Ci of radioactivity consisting of Sr-90 (0.003 Ci) and Cs-137 (0.019 Ci). There are also trace amounts of residue surface contamination consisting of uranium, plutonium and americium (~0.0002 Ci). The estimated volume of radioactive material is approximately 178 cubic yards.

- **Below ground duct concrete and steel outside Building 701** – This contaminated structure includes the concrete and steel remaining within the portion of the duct located outside of the foundation of Building 701. This contaminated structure will remain following completion of the primary liner removal. The contaminated concrete and steel contains approximately 0.825 Ci consisting primarily of Cs-137 (0.784 Ci), Sr-90 (0.038 Ci) and Co-60 (.001 Ci). The remaining radioactivity consists of uranium, plutonium and americium (~0.002 Ci) in the form of fixed surface contamination. The estimated volume of radioactive material is 2,284 cubic yards of concrete and 700 square meters of steel plate.

- **Below ground duct concrete and steel under Building 701** – This is the section of the below ground duct that extends below Building 701 that will also remain after primary liner removal. The contaminated concrete and steel contains approximately 0.422 Ci of radioactive materials consisting of Cs-137 (0.399 Ci), Sr-90 (0.022 Ci) and Co-60 (.001 Ci). The remaining radioactivity consists of uranium, plutonium and americium (~0.001 Ci) in the form of fixed surface contamination. The estimated volume of radioactive material is 377 cubic yards of concrete and 700 square meters of steel plate.

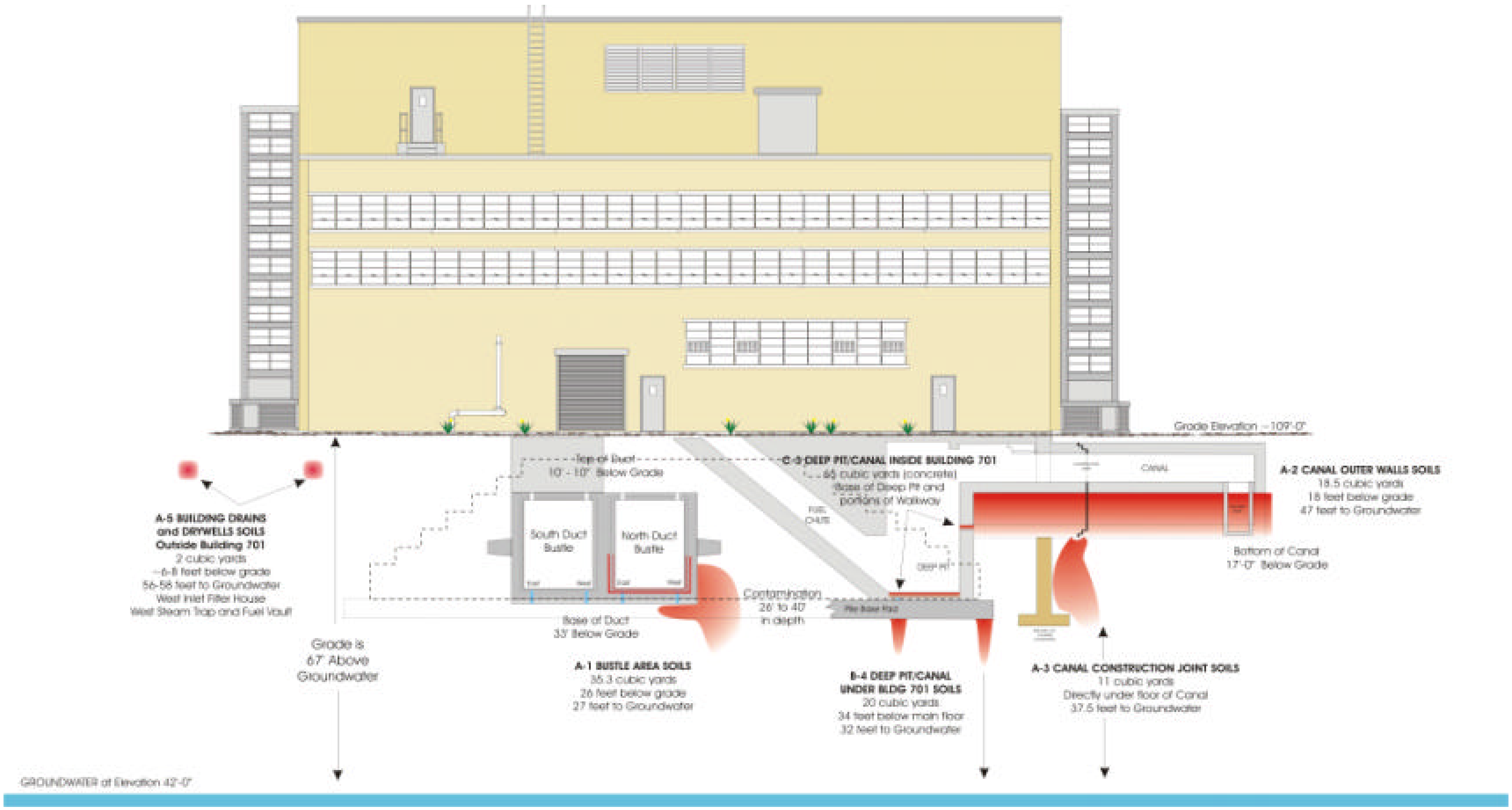


Figure 1.8 BGRR South Elevation (looking north)

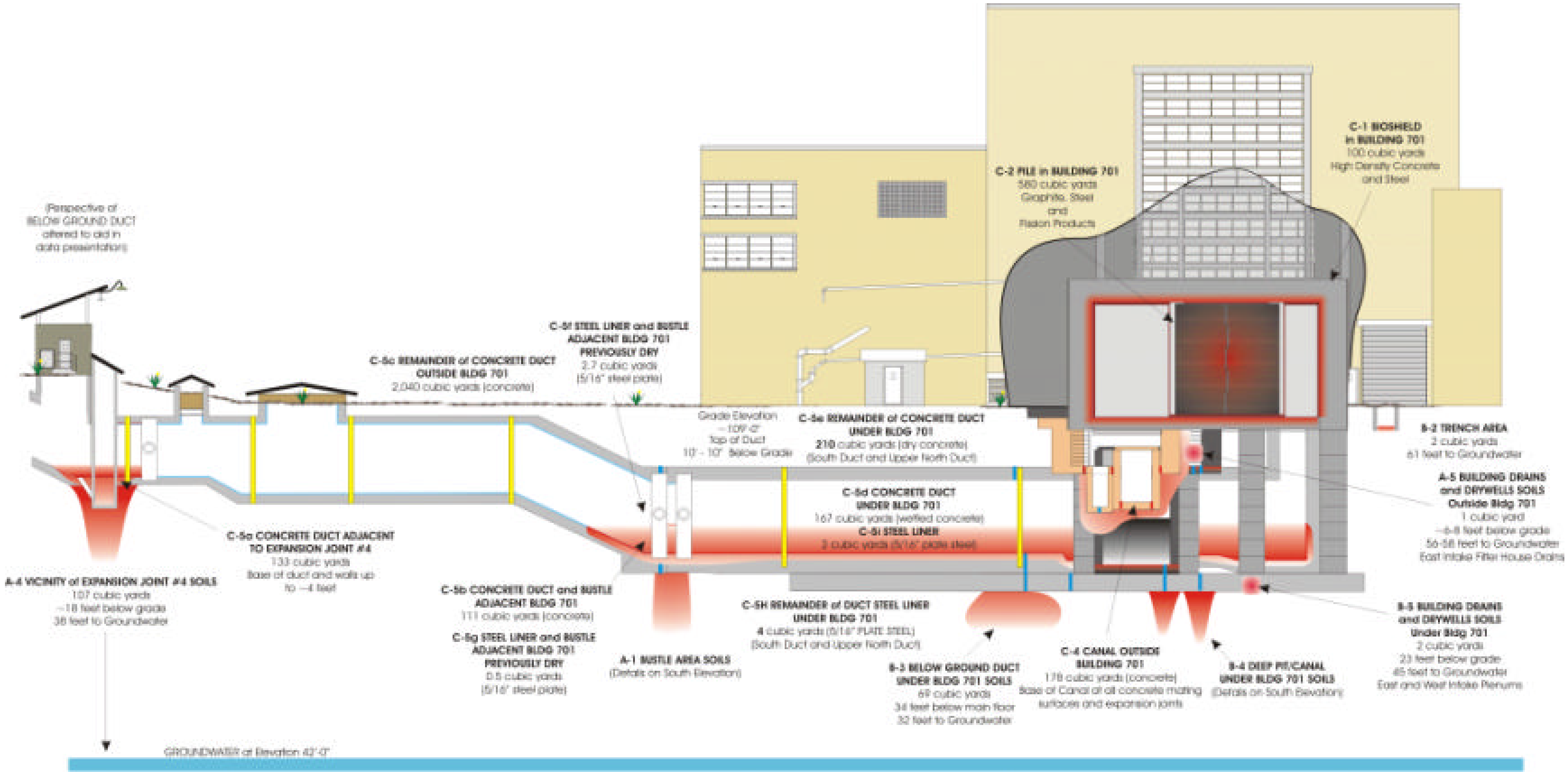


Figure 1.9 BGRR East Elevation (looking west)

1.3.2 Contaminated Soils

Isolated pockets of contaminated soil exist at various locations within the BGRR complex (see Figure 1.10).

- **Bustle area** – The bustle area contamination consists of soils adjacent to the secondary air bustle on the northeast side of the below ground duct where it exits from Building 701. This subsurface soil pocket begins approximately mid-height of the below ground duct (26 feet below grade) and extends to the soil below the duct to a depth of 40 feet below grade corresponding to 27 feet above groundwater. The soil is contaminated with Cs-137 at a peak level of 89,000 pCi/g and Sr-90 at a peak level of 11,200 pCi/g. The estimated volume of contaminated soil is approximately 35 cubic yards.

- **Canal outer walls** – The soil in some areas immediately adjacent to the canal structure is contaminated. This subsurface soil pocket begins approximately mid-height of the outer walls of the canal on the north, east and south walls and extends outward one foot from the surface and below the canal to a depth of 18 feet below grade corresponding to 47 feet above groundwater. The soil is contaminated with Cs-137 at a peak level of 900 pCi/g and Sr-90 at a peak level of 56 pCi/g. The estimated volume of contaminated soil is approximately 18 cubic yards.

- **Lower canal construction joint** – This contamination pocket includes the soil beneath the canal floor in the vicinity of the canal construction joint east of Building 701 foundation column 7 (east wall of Building 701). This subsurface soil pocket begins immediately below the canal structure (12.5 feet below grade) and extends below the canal to a depth of 29.5 feet below grade corresponding to 37.5 feet above groundwater. The soil is contaminated primarily with Cs-137 at a peak level of 1,500 pCi/g and Sr-90 at a peak level of 572 pCi/g. Trace concentrations of U-238 (6.2 pCi/g) and Pu-239 (5.2 pCi/g) were detected at their respective minimum detectable activity (MDA) limits for the sample. The estimated volume of contaminated soil is approximately 11 cubic yards.

- **Expansion joint #4** –Includes soils adjacent to and underneath the north and south ducts main expansion joint #4, near the cooler drain sumps. This subsurface soil pocket begins within soils immediately below the duct and cooler drain sump and extends to a depth of 30 feet below grade corresponding to 38 feet above groundwater. The soil is contaminated primarily with Cs-137 at a peak level of 2,845 pCi/g and Sr-90 at a peak level of 37 pCi/g. The estimated volume of contaminated soil is approximately 110 cubic yards.

- **Drains and drywells outside the footprint of Building 701** – The contamination in the drains and drywells outside the footprint of Building 701 consists of contaminated soil and crushed stone associated with the three building drain drywells located outside of the foundation footprint of Building 701. These include drywells from the east and west inlet air filter house drains, the west steam trap drains, the control rod drive mechanism (CRDM) floor drains, the fuel vault floor drains and east steam trap drains. Each drywell is an independent receptacle constructed of one cubic yard of crushed stone. The drywells are contaminated primarily with Cs-137 and Sr-90 with an average concentration of 93 pCi/g and 56 pCi/g respectively. The estimated volume of the contaminated soil and crushed stone is approximately three cubic yards.

- **Drains and drywells under the footprint of Building 701** – The contamination in the drains and drywells under the footprint of Building 701 consists of contaminated soil and crushed stone associated with the two building drain drywells. These include drywells from the east and west inlet air plenum drains. Each drywell is an independent receptacle, constructed of one cubic yard of crushed stone. The drywells are contaminated primarily with Cs-137 and Sr-90 with an average concentration of 450 pCi/g and 1730 pCi/g respectively. The estimated volume of contaminated soil and crushed stone is approximately two cubic yards.

- **Reactor building trench Area –** The contamination in the reactor building trench area consists of contaminated soils located within the reactor building pipe trench. The trench is constructed with concrete walls extending vertically approximately four feet below the reactor building main floor level with exposed soil at its base. The contamination is isolated to an area of approximately 60 square feet extending to a depth of approximately one foot within the soil. The soil is contaminated primarily with Cs-137 at a peak level of 17,726 pCi/g and Sr-90 at a peak level of 1,020 pCi/g. Trace concentrations of U-238 (0.3 pCi/g), Pu-239 (0.88 pCi/g), and Eu-152 (0.8 pCi/g) were detected at their respective MDA limits for the sample. Elevated levels of metals (cadmium and zinc) were also identified in the contaminated soil. The estimated volume of contaminated soil is approximately two cubic yards.

- **Below ground duct under the footprint of Building 701 –** This pocket consists of contaminated soils located beneath the north duct in the vicinity of the below ground expansion joint immediately south of the reactor. This subsurface soil pocket begins within soils immediately below the duct foundation pad and extends to a depth of two feet, which corresponds to an elevation 32 feet above groundwater. The soil is contaminated primarily with Cs-137 at a peak level of 79,000 pCi/g and Sr-90 at a peak level of 2,200 pCi/g. Trace concentrations of U-238 (0.2 pCi/g), Pu-239 (0.2 pCi/g), and Eu-152 (0.2 pCi/g) were detected at their respective MDA limits for the sample. The estimated volume of contaminated soil is approximately 70 cubic yards.

- **Deep pit and fuel canal under the footprint of Building 701 –** This pocket consists of contaminated soils below the deep pit and portions of the canal that are below the foundation footprint of Building 701. This subsurface soil pocket begins within soils below the pile foundation pad and extends to a depth of two feet below the pad (grade corresponding to 32 feet above groundwater). The soil is contaminated primarily with Cs-137 at a peak level of 405 pCi/g and Sr-90 at a peak level of 103 pCi/g. Trace concentrations of U-238 (0.2 pCi/g) and Pu-239 (0.05 pCi/g) were detected at their respective MDA limits for the sample. The estimated volume of contaminated soil is 20 cubic yards.

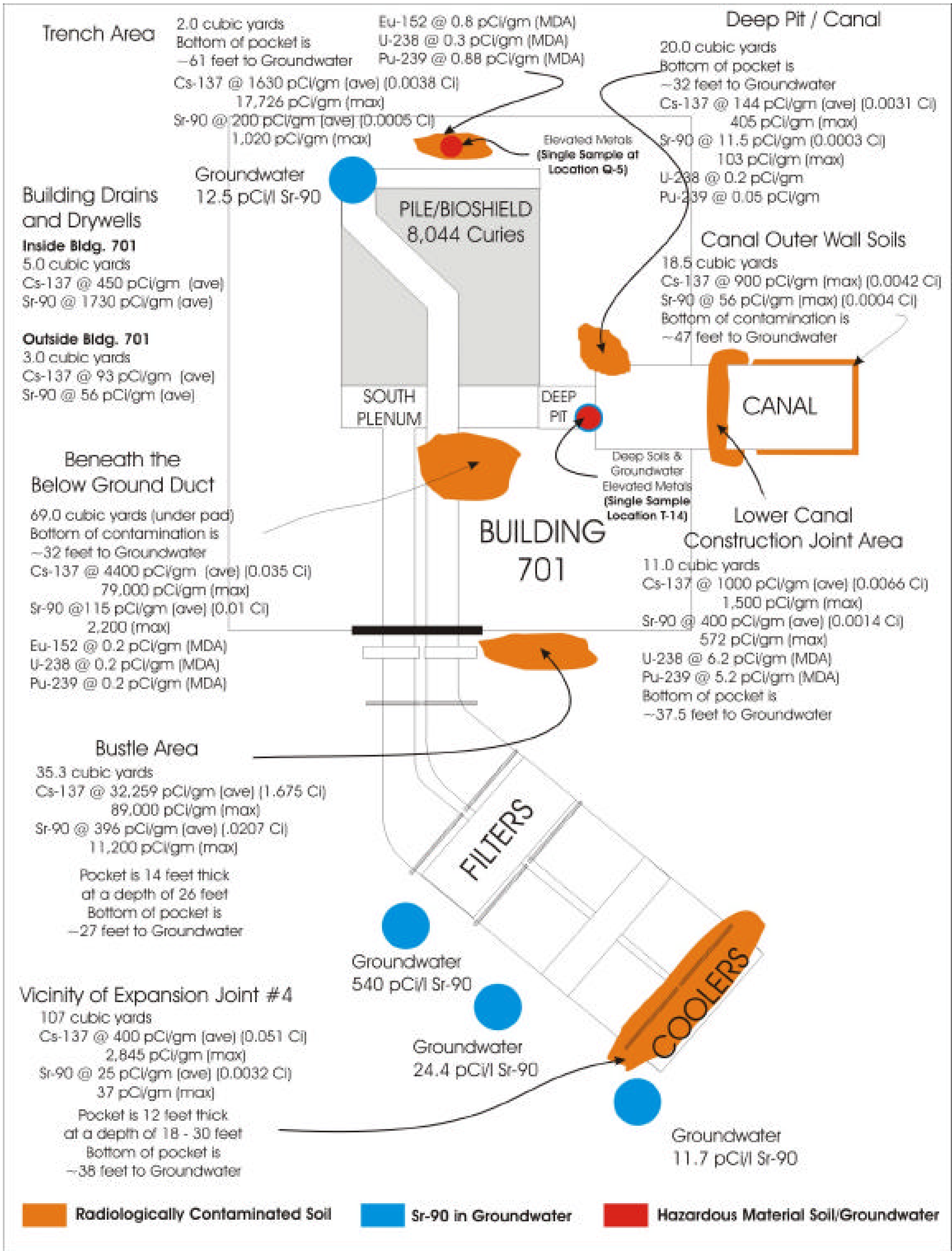


Figure 1.10 – Location of Contaminated Soil

1.4 BASIS FOR ACTION

1.4.1 Evaluation of Contamination Fate and Transport

Remaining contamination within the BGRR complex consists of activation and fission products within the reactor graphite pile and surrounding biological shield, contaminated concrete within the fuel handling system deep pit and fuel canal, and contaminated steel and concrete within the below ground ducts. Additionally there are isolated pockets of radiologically contaminated soils associated with the below ground duct secondary cooling air bustle and expansion joints, fuel canal outer walls and construction joint, the reactor building pipe trench and Building 701 drains. The majority of non-radiological hazardous materials associated with the BGRR have been removed through previous interim removal actions. Isolated pockets of non-radiological hazardous material contamination are present within the reactor building pipe trench and within embedded drain lines. Hazardous materials intrinsic to construction materials such as floor tiles, paint and insulating materials remain within the reactor building.

The fate and transport of the existing BGRR contaminants have been assessed, considering current and future land use and institutional controls and environmental conditions to identify what environmental media could be impacted by releases of or direct exposure to the contaminants. The three means that were used to assess which contaminants from this reactor complex could impact potential receptors include:

- *Direct exposure to workers, resident or trespasser.* This includes external gamma radiation emanating from radionuclides remaining in the interior of the reactor building and the graphite pile, residues in the fuel canal and underground ducts, and localized areas of soil.

- *Direct contact to workers, resident or trespasser.* This includes direct exposure to and potential ingestion of radioactive contamination in soil or dispersible radioactive materials on surfaces of structures.

- *Production of airborne or leaching of contaminants from source to the surrounding environment or groundwater*. This includes potential inhalation of radioactive materials created as a result of disturbing contaminants or leaching from subsurface soil and structures.

A graphic illustration depicting existing contaminant sources, actual and potential pathways and control measures are provided in Figure 1.11 as a conceptual site model for the BGRR. Sources of contaminants are shown within heavy bordered boxes. Lines originating from each source and terminating at specific receptors depict actual or potential pathways from each source. A dashed line indicates a pathway that is blocked by an existing barrier or administrative control measure. Solid lines depict active pathways to the respective receptor.

As illustrated by the conceptual site model, with the exception of direct exposure to low-level external radiation dose from the pile and biological shield, the sources of contaminants at the BGRR are blocked (dashed lines) from impacting any of the identified receptors.

1.4.2 Justification for Remedial Actions

With the apparent lack of pathways to hypothetical receptors, the conceptual site model suggests that no action is required. The model accurately depicts the status of the BGRR complex in the present day. The DOE's use of infiltration management and institutional controls provides barriers that are effective in protecting human health and the environment. Recent DOE experience with the BGRR complex, specifically the absence of leaks of releases to the environment, supports this conclusion.

However, there are some key uncertainties not fully illustrated in the conceptual site model that unfavorably impact the certainty of this conclusion. These key issues are discussed below.

<u>Reactor Pile and Biological Shield</u>

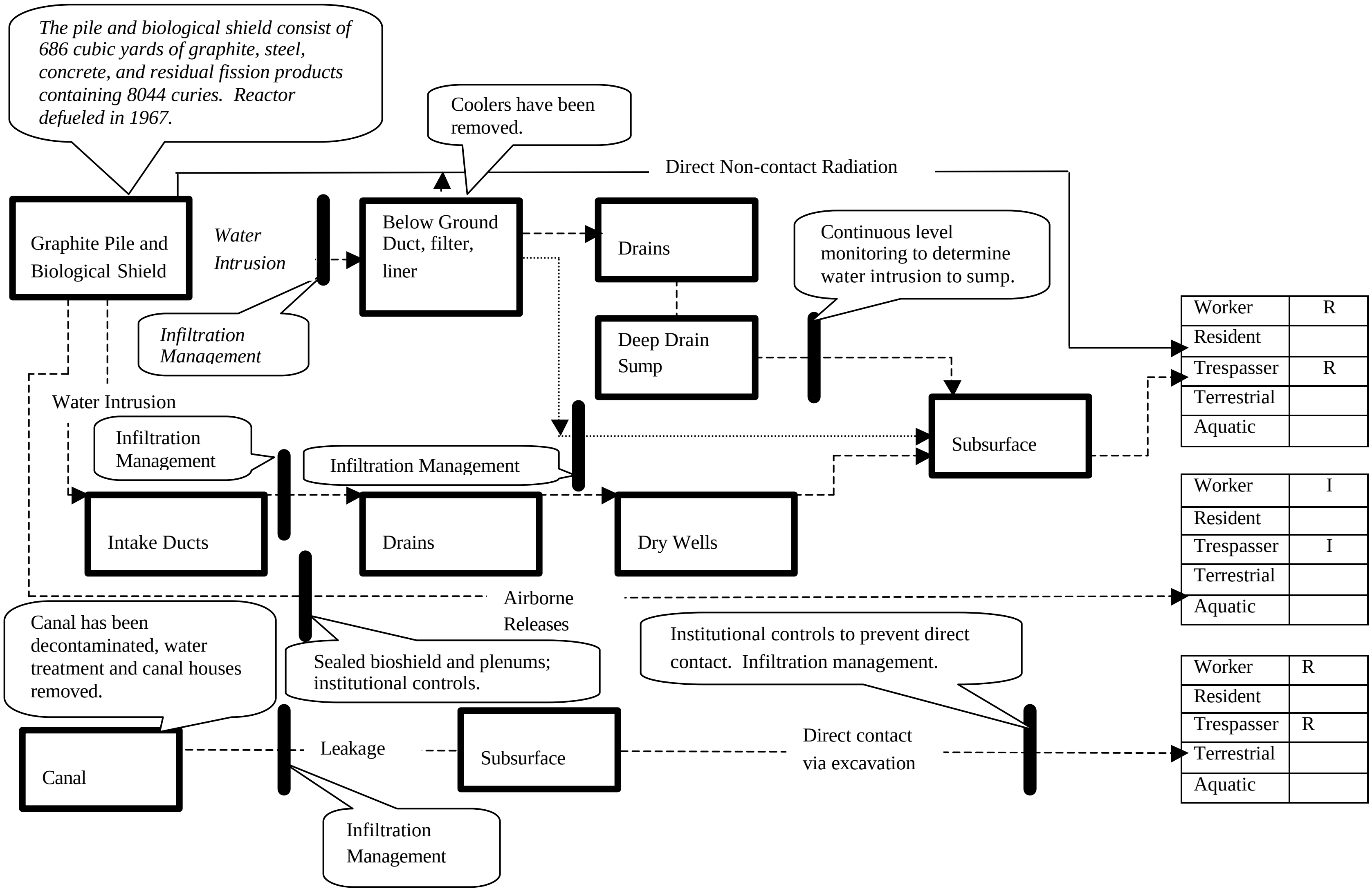
The reactor pile and biological shield contain a radioactive inventory of approximately 8,044 Curies. This substantial inventory warrants appropriate actions, as clearly reflected in the conceptual site model, to protect human health and the environment. Many interim actions have already been taken including various removal actions, infiltration management and institutional controls. However, the substantial radiological inventory contained in the pile and biological shield alone require a careful consideration of final remedial actions to ensure long-term protection of human health and the environment.

<u>Contaminated Structures and Soils</u>

Several leaks of contamination to the environment occurred during and subsequent to the operation of the BGRR. Various contaminated structures and pockets of deep, subsurface contaminated soils contain a radiological inventory of approximately three Curies. The presence of contamination in soil pockets outside of the BGRR reactor building and contamination in groundwater is clear evidence of these historical leaks and contamination transport to the environment.

Numerous interim actions have been taken to specifically address the leakage pathways. The conceptual site model clearly illustrates the importance of barriers to prevent or preclude pathways to hypothetical receptors. On an interim basis, removal actions, infiltration management and institutional controls have been effective in managing this potential threat. However, even after these actions, approximately three Curies remain of concern.

Figure 1.11 Brookhaven Graphite Research Reactor
Conceptual Site Model



2.0 IDENTIFICATION AND SCREENING OF TECHNOLOGIES

2.1 TECHNOLOGY SCREENING

A rigorous characterization program has been completed and the quantities, locations and nature of contamination in the BGRR complex have been well identified. These data and information were in turn used as a basis for conducting comprehensive engineering studies to identify and examine various technical approaches and techniques that are available for deployment at the BGRR. The scope of these studies included all elements of remedial actions from gaining access to the contamination removal, through and including waste handling, packaging transportation and disposal.

No new technologies are required to address the remaining contamination that resides in the BGRR complex. Pile and biological shield removal have been extensively evaluated. These removal actions can be carried out using technologies and techniques that have already been successfully demonstrated at BNL, elsewhere in the DOE complex or in the commercial nuclear power industry. In most cases, the technologies and techniques provide for contamination removal while minimizing the need to place workers in a potentially hazardous environment. For example, advances in robotics technology have been successfully deployed at BNL in connection with the below ground duct filter and liner removal. With a great deal of data in hand, the resulting waste from pile and biological shield removal does not pose any extraordinary technical issues. Existing packaging, transportation capability and disposal capacity are commercially available for managing these wastes, and all required elements for managing those wastes have been well demonstrated. In summary, the requisite technologies and techniques for pile and biological shield removal are commercially available for adaptation and deployment at BNL.

Similarly, standard construction work practices are commercially available for gaining access to and removing much of the contamination on various structures and in deep, subsurface pockets of soil. Shoring, excavation and concrete demolition techniques are standard in the construction industry, and all have already been demonstrated in the radiological cleanup environment at BNL, elsewhere in the DOE complex and in the commercial nuclear power industry. Scaling these practices up to include full Greenfield decommissioning of the BGRR complex does not pose any extraordinary technology issues or gaps. Likewise, all of the required elements to manage the resulting waste have been demonstrated extensively at BNL and throughout the nuclear industry.

Lastly, engineered caps and impermeable barriers have been successfully deployed for managing both radiological and non-radiological hazards. There is an enormous body of experience that can be brought to bear in managing the full range of residual contamination that may remain at the conclusion of interim and/or final removal actions.

In summary, existing and field proven technologies are commercially available for completing a full range of BGRR remedial alternatives. The extensive body of experience with these technologies and techniques better ensures that all remedial alternatives can be implemented while protecting the health and safety of the workers, the laboratory community working at the BNL site, the general public and the environment.

2.2 REMEDIAL ACTION OBJECTIVES

The Remedial Action Objectives (RAOs) used to evaluate the BGRR remedial action alternatives were developed considering land use, Contaminants of Potential Concern (COPCs), Applicable or Relevant and Appropriate Requirements (ARARs), and exposure pathways. The RAOs for the BGRR Decommissioning Project are as follows:

1. Through prudent remedial actions, ensure the protection of human health and the environment from the potential hazards posed by the radiological inventory that resides in the BGRR complex. These remedial actions should ensure protection of human health and the environment without undue uncertainties.

2. Utilize As Low As Reasonably Achievable (ALARA) principle, while implementing the remedial actions, to reduce further the potential hazard to human health and the environment posed by the considerable radiological inventory that resides in the BGRR complex.

3. Following completion of the remedial activities, implement long-term monitoring, maintenance and institutional controls that reflect the controls necessary to eliminate potential hazards to human health and the environment.

3.0 DEVELOPMENT OF ALTERNATIVES

3.1 DEVELOPMENT AND SCREENING OF ALTERNATIVES

Four BGRR remedial action alternatives have been identified, which span the entire range from stabilization and source management through the complete removal of the BGRR reactor facility.

3.2 SUMMARY OF ACTION-SPECIFIC ARARs

The National Contingency Plan Section 300.430 (e)(9)(iii)(B) requires that the selected remedy attains the requirements set by Federal and State ARARs, or that a waiver of an ARAR is obtained. The ARARs listed below apply to all of the alternatives set forth within this report.

Chemical-Specific ARARs

1. 6 New York Code, Rules and Regulations (NYCRR) 212, General Process Emission Sources: This State regulation will be followed to determine the need for air-emission control equipment. All remedial work performed within the alternatives addressed in this feasibility study will be performed in accordance with standards and procedures that will ensure compliance with these regulations. Potential radioactive surface contamination release, airborne radioactivity generation and release or radioactive liquid release will be controlled to eliminate emissions that would affect human health or the environment.

2. 6 New York Code, Rules and Regulations (NYCRR) Part 380, Rules and regulations for Prevention and Control of Environmental Pollution by Radioactive Materials: This regulation is the relevant and appropriate regulation for controlling radioactive emissions and liquid releases to the environment while completing the remedial actions.

3. *Resource Conservation and Recovery Act* (RCRA) (40 Code of Federal Regulations [CFR] 260-268): These Federal regulations define hazardous wastes.

4. *New York State Hazardous Waste Regulations* (6 NYCRR 370 – 373): These regulations define hazardous wastes in New York State. All wastes classified as hazardous will be handled, stored, and disposed of off-site at a permitted facility in accordance with these regulations.

5. *Safe Drinking Water Act* (40 Code of Federal Regulations [CFR] 141.16: Establishes maximum contaminant levels (MCLs) that are used as groundwater standards for sole source aquifers. BNL site wide conformance with the ARAR is addressed in the Operable Unit (OU) III Record of Decision. U.S. Department of Transportation Requirements for the Transportation of Hazardous Materials (49 CFR Parts 100 to 170) will be applicable for any wastes that are transported offsite.

Location-Specific ARARs

1. Memorandum of Agreement Between Brookhaven Area Office and New York State Historic Preservation Office Concerning the BGRR Decommissioning Project: DOE determined that the BGRR is eligible for inclusion in the National Register of Historic Places. DOE also established a number of measures to mitigate the adverse impacts of decommissioning in consultation with the New York State Historic Preservation Officer (SHPO). These measures include the creation of a “Research Guide” to the BGRR (containing documents, drawings, manuals, oral histories, photographs and video or movie footage), the development of a visual record of the operational history of the BGRR and the production of an interactive compact disc intended for release to local, regional, and national museums, schools, and libraries. Final products will be available at the BNL Research Library and filed with the SHPO.

Action-Specific ARARs

1. 10 CFR 835, Occupational Radiation Protection: These rules establish radiation protection standards for all DOE activities. Remedial actions contained within the alternatives addressed within this feasibility study will be performed in accordance with the requirements of BNL’s Radiological Control Manual (RCM) and appropriate procedure established to ensure compliance with this regulation.

2. DOE Order 5400.5, Radiation Protection of the Public and the Environment: This DOE Order establishes the standards and requirements with respect to protection of members of the public and the environment against undue risk from radiation. As with 10 CFR 835, all remedial actions within this feasibility study will be performed in accordance with appropriate procedures established to ensure continued protection of the public and the environment.

3. RCRA (40 CFR 260-268): As described above.

4. New York State Hazardous Waste Regulations (6 NYCRR 370 – 373): As described above.

5. *Clean Air Act* (42 United States Code [U.S.C.] Section 7401, et seq.) and National Emissions Standards for Hazardous Air Pollutants (NESHAP) (40 CFR 61): This Act regulates and limits the emissions of hazardous air pollutants, including radionuclides. All remedial actions contained in the alternatives addressed within this feasibility study that have the potential for creating airborne emissions will require confinement or containment with confirmatory air sampling to verify compliance with these requirements and applicable standards.

To Be Considered Guidance

1. NYSDEC Technical and Administrative Guidance Memorandum ARemediation Guideline for Soils Contaminated with Radioactive Materials@ (#4003), September, 1993. This memorandum contains State guidance for remediating radiologically contaminated soils. The State=s value of 10 mrem/yr above background serves as an additional goal for remediation to be evaluated during remedial design and implementation.

2. NYSDEC's Division of Air Guidelines for Control of Toxic Ambient Air Contaminants, Air Guide 1: This guide will be used to assess the impacts of air emissions for specific remedial action tasks having the potential for creating airborne radioactivity. Contents of this guide will be used to aid in evaluating the need for having air-emissions control equipment.

3. DOE Order 435, Radioactive Waste Management: This order provides guidance and requirements for management and disposal of radioactive waste generated at DOE facilities.

4. ALARA or As Low As Reasonably Achievable is the practical approach to radiation protection used to manage and control exposures (both individual and collective) to the work force and to the general public, to levels as low as is reasonable, taking into account social, technical, economic, practical, and public policy considerations. Technologies and techniques incorporated into remedial actions tasks in each of the alternatives addressed within this feasibility study will be such that radioactive waste is minimized and direct exposure to radiation sources is reduced to as low as reasonably achievable.

5. The Offsite Rule, DOE Office of Environmental Guidance, CERCLA Information Brief EH-231-020/0394: The purpose of the off-site rule was to clarify CERCLA's requirement to prevent wastes generated from remediation activities from contributing to environmental problems at offsite waste management facilities that receive them. In accordance with this rule, BGRR wastes will only be sent to offsite facilities that meet EPA's acceptability criteria.

3.3 DETAILED DESCRIPTION OF ALTERNATIVES

3.3.1 Alternative A – Stabilization and Source Management

3.3.1.1 Scope

Alternative A, Stabilization and Source Management relies on several actions already taken and additional actions now in progress or planned to reduce the radiological footprint of the BGRR complex. This alternative relies heavily on infiltration management, surveillance and monitoring and institutional controls to manage the residual radiological inventory including the reactor pile and biological shield.

Completed activities include:

- Removal of pooled water within the below ground ducts
- Removal of experimental equipment and systems from the reactor building
- Removal of the reactor exhaust fans, motors, valves and instruments
- Removal of pile fan sump, pipes and contaminated soil
- Removal of above ground ducts, pipes and contaminated soil
- Removal of the canal house, water treatment house, equipment, pipes, asphalt, concrete and accessible contaminated soils
- Removal of the reactor exhaust cooling coils

On-going and Scheduled activities include:

- Removal of reactor exhaust filters and below ground duct primary liner
- Removal of below ground duct instrument house
- Design and installation of water infiltration control and monitoring system for structures and contaminated soils under Building 701 foundation and, the remaining portion of the fuel canal, and below ground ducts.
- Refurbishment of Building 701 roof and exterior façade

Implementation of surveillance and monitoring program:

- Groundwater monitoring
- Routine inspection and surveillance of BGRR complex
- Routine maintenance and upkeep

Completion of the remedial actions will rely on established, field-proven practices and standard construction techniques. No new technologies are required and there are no outstanding implementability issues and uncertainties.

3.3.1.2 End State

Upon completion, this alternative will remove a total of 47 Curies from the BGRR radiological inventory. Approximately 8,047 Curies will remain. The majority (8,044 Curies) of the remaining inventory is contained within the graphite pile and biological shield and will be isolated from the environment by the biological shield itself and the Building 701 superstructure and its massive concrete foundation. Approximately three Curies would be contained within underground structures and deep, subsurface pockets of contaminated soils and will be monitored and controlled through the installation of an impermeable barrier. In the event that future activities cause the contaminated deep soils to become readily accessible, the contaminated soil will be remediated.

Upon completion of the decommissioning activities, an engineered cap will be installed around the outdoor footprint of the BGRR. The engineered cap is envisioned to include the following:

- Grading the existing property to create a slope away from the BGRR Below Ground Duct and Building 701.

- Placing an acceptable polymer liner, such as high-density polyethylene, over the BGRR footprint.
- Placing a low-permeability, properly pre-planned, barrier soil over the polymer liner.
- Placing several inches of blacktop over the barrier soil.

In addition to the engineered cap, stormwater runoff will be collected and conveyed to the BNL stormwater collection system, when practicable. If the BNL stormwater system is not convenient, then stormwater runoff shall be collected and discharged to an area outside of the BGRR footprint.

The long-term response actions associated with this alternative include annual reports, routine inspection and surveillance of the BGRR complex, scheduled upkeep and maintenance of Building 701, infiltration management and groundwater monitoring. A graphic representation of the location, characteristics and volume of contaminants remaining at the BGRR complex following completion of this alternative is provided in Figure 3.A.1 and Figure 3.A.2.

3.3.1.3 Cost/Schedule

As of the end of fiscal year 2003, BGRR removal actions have cost approximately $39.3 million. The remaining ongoing and scheduled activities is estimated to take 18 months at a cost of $14.2 million, resulting in a total project cost of $53.5 million to complete this alternative.

3.3.1.4 Institutional Controls

The residual long-lived radioisotopes in the pile and biological shield would require institutional controls for an indefinite period of time.

The institutional controls for this alternative would specify land use restrictions and reporting requirements. At a minimum, the institutional controls for this alternative would:

- Establish measures for future excavation of residual subsurface contamination including characterization and limitations on use/reuse in accordance with NYSDEC regulations.

- Provide land use restrictions and an acceptable method for evaluating potential impact that the remaining contaminants have on future development.

- Establish a restriction that future use and development of the property is limited to commercial or industrial uses only.

- Specify requirements for annual certification to the NYSDEC, which would certify that the institutional controls and engineering controls put in place, are unchanged from the previous certification and nothing has occurred that would impair the ability of the control to protect public health or the environment or constitute a violation or failure to comply with the site management plan. This annual certification would be prepared and submitted by a professional engineer or environmental professional acceptable to NYSDEC.

- Specify that land use restriction and reporting requirements be passed on to any/all future landowners through an environmental easement on the deed to the property. In light of the fact that a deed does not exist for property owned by a Federal entity, DOE will be responsible for implementing these controls as long as the property is owned by DOE and upon transfer of the property to a non-Federal entity, a deed will be established and an environmental easement will be added to the deed at that time.

Using conservative assumptions, it was calculated that it would take the long-lived radioactive isotopes within the pile approximately 87,000 years to decay to unrestricted levels. This calculation was performed to allow for a comparative analysis of the various BGRR remedial action alternatives, considered herein. It was not intended to establish definitive institutional control durations.

However, institutional controls, including land use restrictions would help ensure that the remaining radioactive materials can be managed to prevent inadvertent direct exposure and future migration to the soil regardless of these calculated durations.

The costs associated with institutional controls will be approximately $275,000 annually for routine surveillance and groundwater monitoring. It will also require approximately $10,000 every ten years for infiltration barrier upkeep and $700,000 every 20 years to refurbish Building 701 exterior façade and roof system. Additionally, groundwater monitoring in the vicinity of the BGRR complex will continue in accordance with the Operable Unit III Record of Decision. Results of the OU-III monitoring will be used to ensure the effectiveness of the remedy.

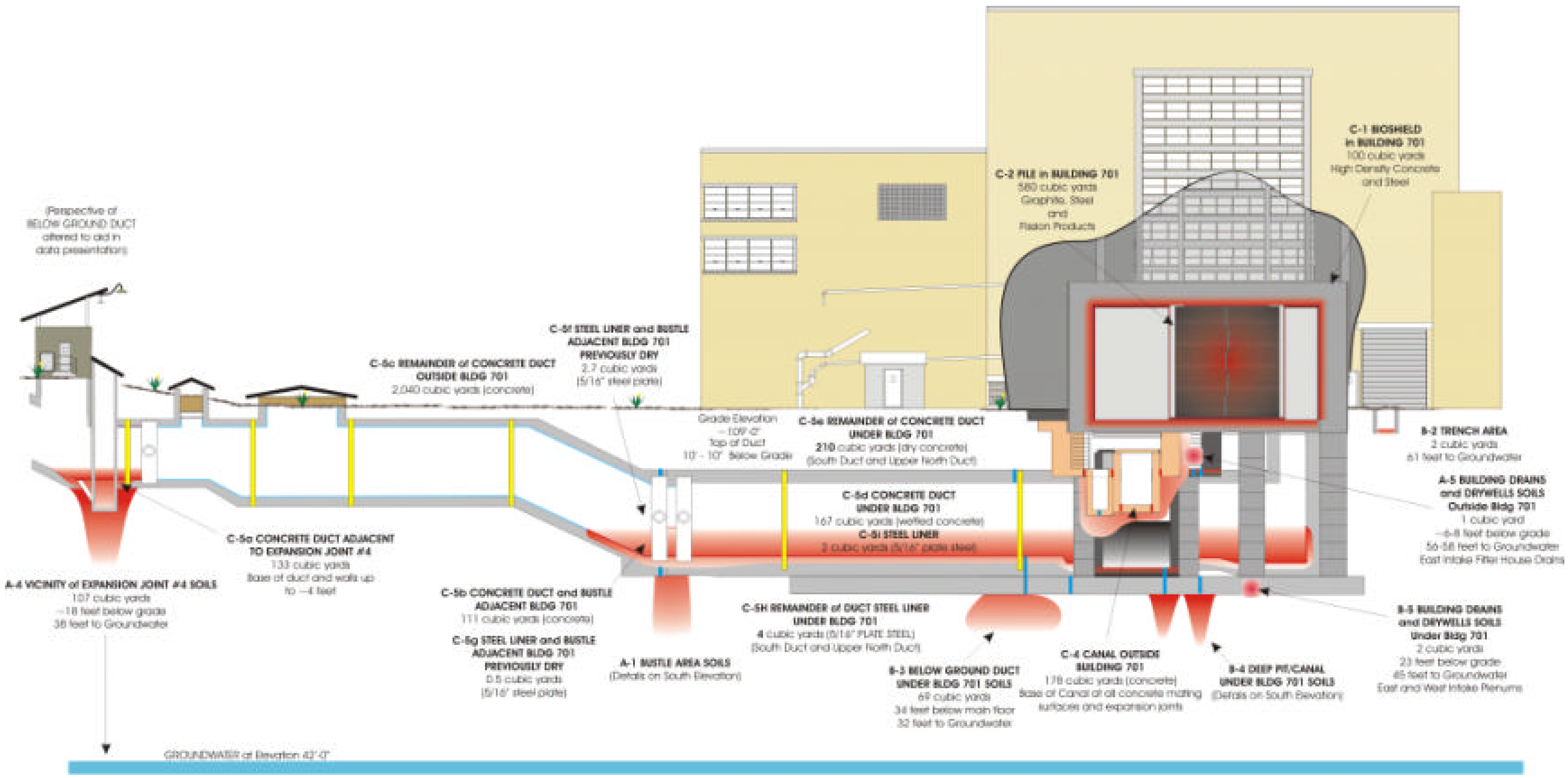


FIGURE 3.A.1 – ALTERNATIVE A Contaminant Location, Characteristics and Volume

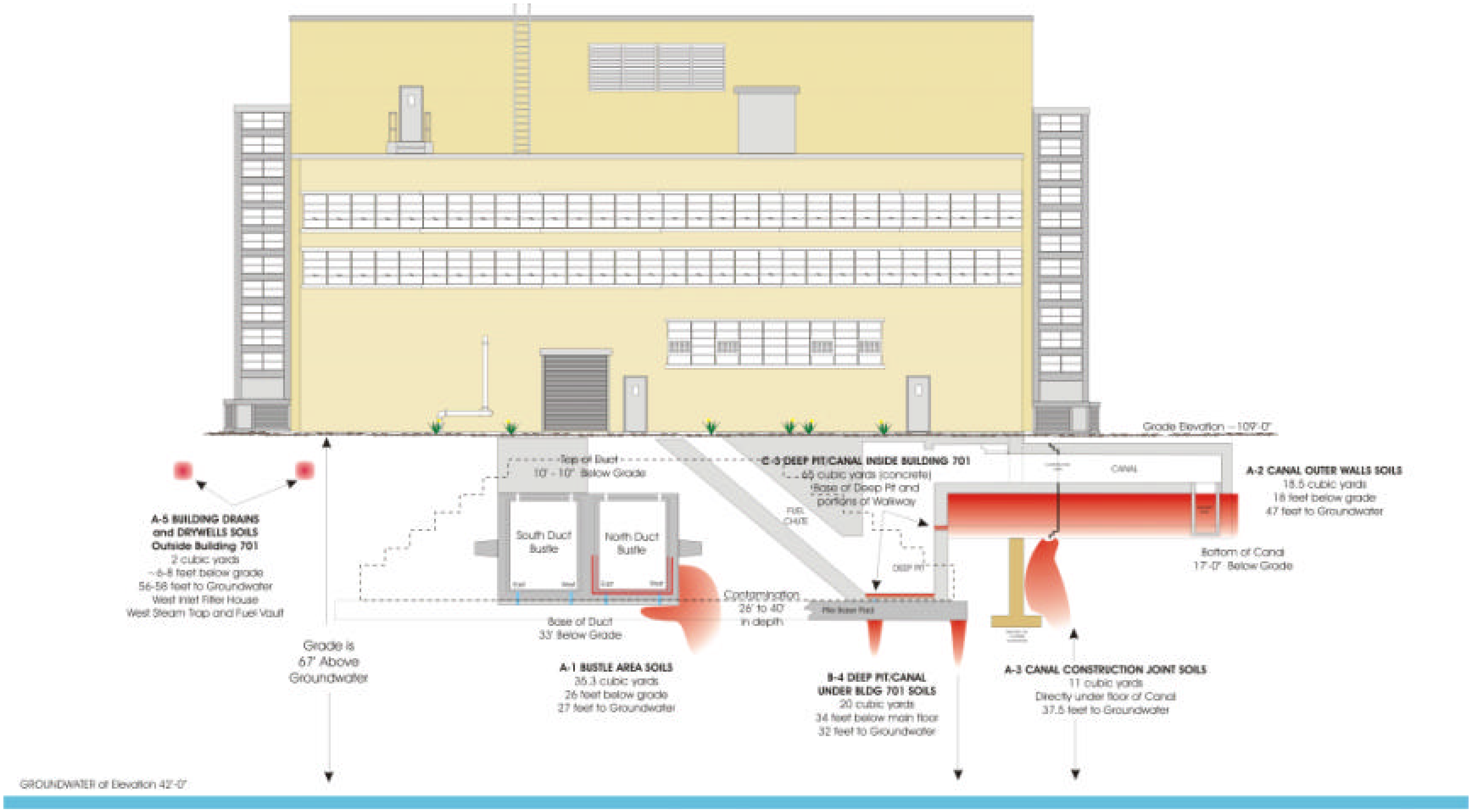


FIGURE 3.A.2 – ALTERNATIVE A Contaminant Location, Characteristics and Volume

3.3.2 Alternative B – Pile and Biological Shield Removal

3.3.2.1 Scope:

This alternative also includes the completion of interim actions that are currently underway or planned and establishing a long-term response action plan implementing the infiltration management, surveillance, and maintenance, and institutional controls at the BGRR complex. Alternative B includes the Alternative A scope and the removal of the pile and biological shield.

Completion of the Alternative B will rely on established, field-proven technologies and techniques. No new technologies are required.

Removal of the pile and biological shield will result in approximately 144,000 ft^3 of LLRW require approximately 500 B-25 boxes for graphite blocks, control rod blades, and dry active waste (DAW); one 8-120 cask for highly radioactive waste removed from fuel channels; two 40-ft sea vans for control rod drives; and approximately 400 20-ft sea vans for steel and high-density concrete.

3.3.2.2 End State

Upon completion, this alternative will remove a total of 8,091 Curies from the BGRR complex. Essentially all of the long-lived radioisotopes will be removed with the graphite pile and biological shield with the exception of trace concentrations within isolated soil pockets near the canal outer walls and the deep pit. Characterization data indicate that the concentrations within these soils are less than the cleanup goals for those radionuclides within soil. Approximately three Curies (predominantly Cs-137 and Sr-90) will remain in contaminated structures below the Building 701 footprint, canal, concrete and steel in the below ground ducts and contaminated sub-surface soils. The remaining radioactivity will be monitored and controlled through the installation of an impermeable barrier and infiltration management system.

Building 701 will remain intact with steel plate installed over the open floor created by removing the pile and biological shield. A fixative will be applied to the exposed surfaces of the reactor pile foundation, support structure, and deep pit to stabilize residual surface radioactivity before covering the opening from the main floor level of Building 701. In the event that future activities cause the contaminated deep soils to become readily accessible, efforts will be made to remediated the soils.

Upon completion of the decommissioning activities, an engineered cap will be installed around the outdoor footprint of the BGRR. The engineered cap is envisioned to include the following:

- Grading the existing property to create a slope away from the BGRR Below Ground Duct and Building 701.
- Placing an acceptable polymer liner, such as high-density polyethylene, over the BGRR footprint.
- Placing a low-permeability, properly pre-planned, barrier soil over the polymer liner.

- Placing several inches of blacktop over the barrier soil.

In addition to the engineered cap, stormwater runoff will be collected and conveyed to the BNL stormwater collection system, when practicable. If the BNL stormwater system is not convenient, then stormwater runoff shall be collected and discharged to an area outside of the BGRR footprint.

Long-Term response actions will include routine inspection and surveillance of the BGRR facility, scheduled upkeep and maintenance of Building 701, and infiltration management and groundwater monitoring. A graphic representation of the location, characteristics, and volume of contaminants remaining at the BGRR complex following completion of this alternative is provided in Figure 3.B.1 and Figure 3.B.2.

3.3.2.3 Cost/Schedule

As of the end of fiscal year 2003, BGRR removal actions have cost approximately $39.3 million. It is estimated that completing the remaining ongoing and scheduled activities including the removal of the graphite pile and biological shield will cost an additional $54 million, resulting in a total project cost of $93.3 million. Depending on the availability of funds, it is estimated that the activities within this alternative will take 30 months to complete.

3.3.2.4 Institutional Controls

The institutional controls for this alternative would specify land use restrictions and reporting requirements. At a minimum, the institutional controls for this alternative would:

- Establish measures for future excavation of residual subsurface contamination including characterization and limitations on use/reuse in accordance with NYSDEC regulations.

- Provide land use restrictions and an acceptable method for evaluating potential impact that the remaining contaminants have on future development.

- Establish a restriction that future use and development of the property is limited to commercial or industrial uses only.

- Specify requirements for annual certification to the NYSDEC, which would certify that the institutional controls and engineering controls put in place, are unchanged from the previous certification and nothing has occurred that would impair the ability of the control to protect public health or the environment or constitute a violation or failure to comply with the site management plan. This annual certification would be prepared and submitted by a professional engineer or environmental professional acceptable to NYSDEC.

- Specify that land use restriction and reporting requirements be passed on to any/all future landowners through an environmental easement on the deed to the property. In light of the fact that a deed does not exist for property owned by a Federal entity, DOE will be responsible for implementing these controls as long as the property is owned by DOE and upon transfer of the property to a non-Federal entity, a deed will be established and an environmental easement will be added to the deed at that time.

With the long-lived radioisotopes within the pile and biological shield removed, the remaining radioactivity consists primarily of residual Cs-137 and Sr-90 contamination in the deep, inaccessible pockets of soil. Using conservative assumptions, it was calculated that it would require approximately 266 years to decay to the Operable Unit I soil cleanup standards for industrial land use of 67 pCi/gm of Cs-137 and 15 pCi/gm of Sr-90. An additional 100 years would be necessary to decay the radioactivity to the acceptable levels for unrestricted land use. This calculation was performed to allow for a comparative analysis of the various BGRR remedial action alternatives, considered herein. It was not intended to establish definitive institutional control durations.

However, institutional controls, including land use restrictions would help ensure that the remaining contaminated structures and soils can be managed to prevent inadvertent direct exposure and future migration to the soil regardless of these calculated durations. The hypothetical excavation of these soils at some time in the future would be evaluated based on the actual distribution, depth and concentrations of the residual radioactive material encountered. Given the depth of these soils and the clean overburden, the concentrations of Cs-137 and Sr-90 would be significantly reduced when mixed with the clean overburden. Institutional controls are highly effective in managing this residual contamination for this finite period of time.

The estimated costs associated with institutional controls will be $275,000 annually for routine surveillance and groundwater monitoring. It will also require approximately $10,000 every ten years for infiltration barrier upkeep and $700,000 every 20 years to refurbish the Building 701 exterior façade and roof system. Additionally, groundwater monitoring in the vicinity of the BGRR complex will continue in accordance with the Operable Unit III Record of Decision. Results of the OU-III monitoring will be used to ensure the effectiveness of the remedy.

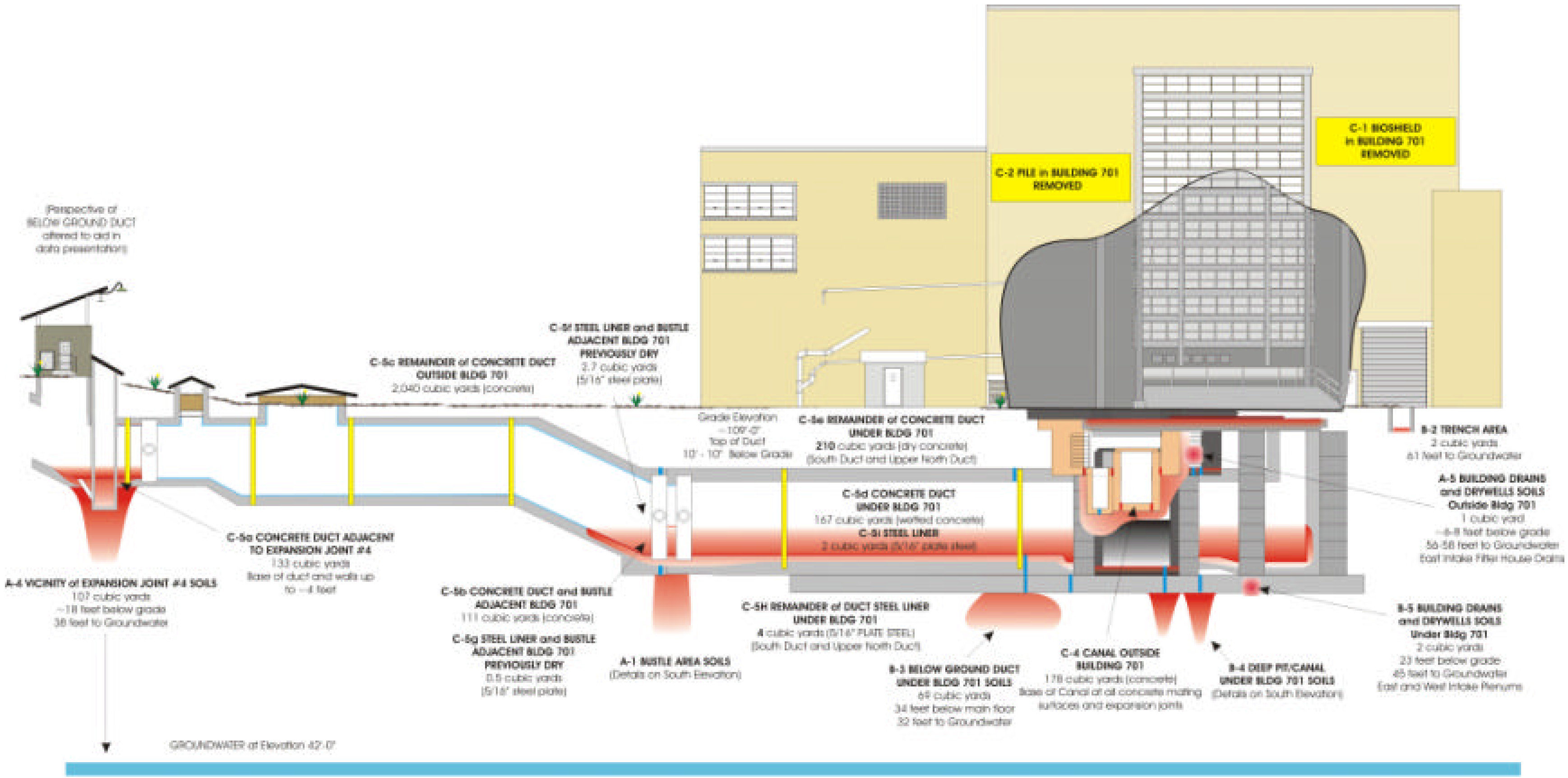


FIGURE 3.B.1 – ALTERNATIVE B Contaminant Location, Characteristics and Volume

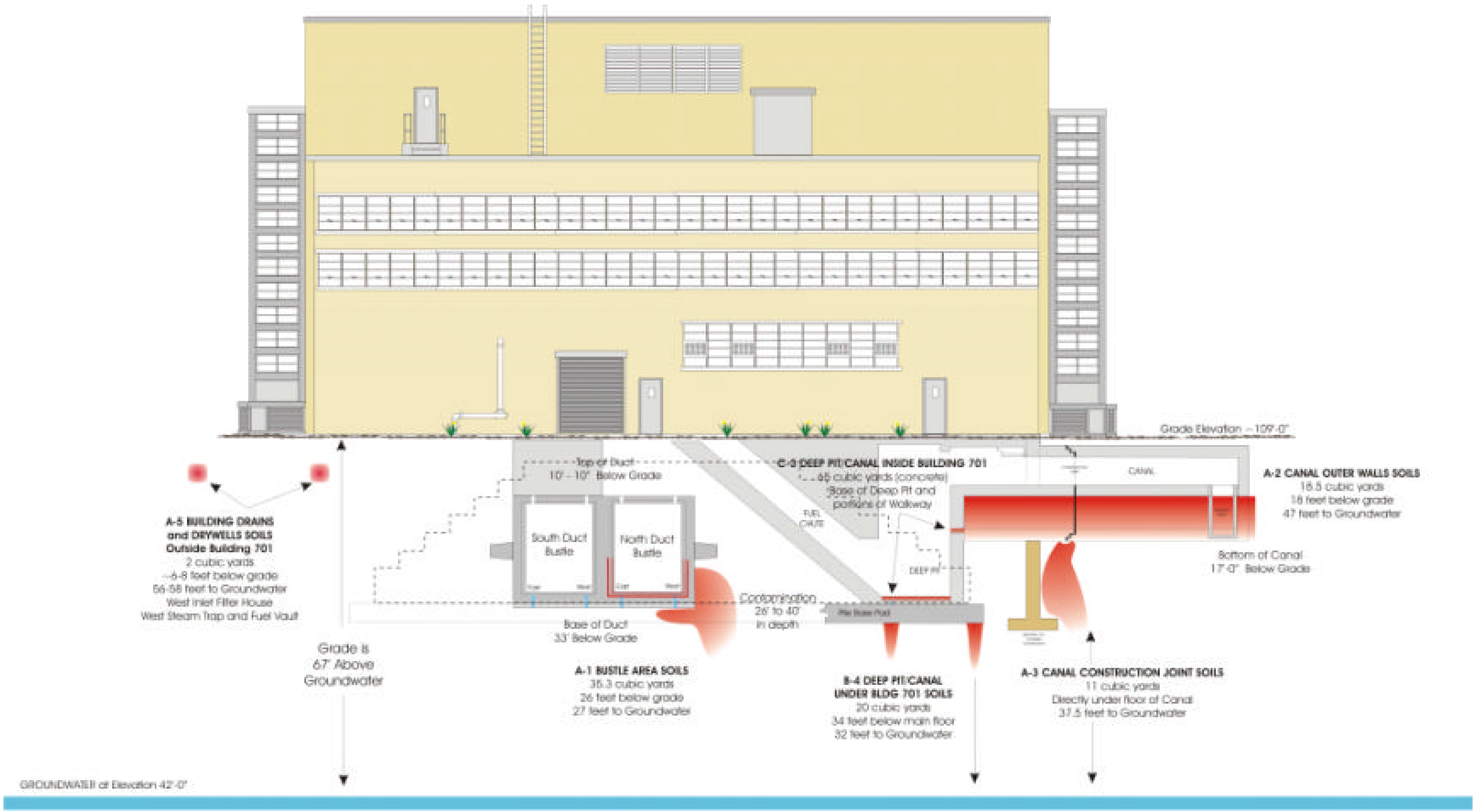


FIGURE 3.B.2 – ALTERNATIVE B Contaminant Location, Characteristics and Volume

3.3.3 Alternative C – Removal of Pile, Biological Shield, Fuel Canal Structure and Reasonably Accessible Soils

3.3.3.1 Scope

Alternative C, includes the Alternative B scope. As an ALARA measure, this alternative also removes accessible pockets of contaminated soil from the BGRR complex and portions of the fuel canal structure external to building 701. This alternative includes removal of contaminated soil pockets adjacent to the below ground duct expansion joint at the duct coolers (expansion joint #4), and soils located outside Building 701 foundation adjacent to and below the fuel canal and near the below ground duct secondary cooling-air bustle. Because of the complexity of the Building 701 foundation and the potential for disrupting the structural integrity of the building, soils located within or below the Building 701 foundation will not be removed. Accessibility of soils will be defined through engineering evaluations determining the impact that removing soils will have on the integrity of the structure and will be included as part of the remedial work plan.

The following structures and subsurface soil pockets would be removed as part of this remedial action alternative:

- Soils adjacent to below ground duct expansion joint #4

  Removal of this soil involves excavation and packaging of approximately 107 cubic yards of contaminated soils. Soils will be loaded and transported by railcar to LLRW disposal facility.

- Fuel canal concrete structure up to the main construction joint and contaminated soils

  Removal of the fuel canal involves excavation and removal of approximately 60 cubic yards of contaminated soils and 140 cubic yards of contaminated concrete. Contaminated soils will be loaded and transported by railcar to a LLRW disposal facility. Contaminated concrete will be packaged in approximately 60 B-25 boxes and similarly transported by truck to LLRW disposal facility.

- Soils adjacent to the below ground duct secondary cooling-air bustle

  This activity involves the excavation and removal of approximately 40 cubic yards of contaminated soils. Soils will be loaded and transported by railcar to LLRW disposal facility.

Alternative C likewise relies on field proven and commercially available technologies and cleanup techniques. No new technologies are required.

3.3.3.2 End State

Upon completion, this alternative will remove a total of 8,093 Curies from the BGRR complex. Essentially all of the long-lived radioisotopes will be removed with the graphite pile and biological shield with the exception of trace concentrations within isolated soil pockets near the canal outer walls and the deep pit. Characterization data indicate that the concentrations within these soils are less than the cleanup goals for those radionuclides within soil. Approximately one Curie (predominantly Cs-137 and Sr-90) will remain embedded in contaminated concrete and steel structures below the Building 701 footprint and within inaccessible soils. These remaining contaminants will be monitored and controlled through the installation of an impermeable barrier and infiltration management system.

As in Alternative B, Building 701 will remain intact with a covering over the open floor space and residual radioactivity within the reactor pile foundation, support structure, and deep pit stabilized in place and sealed from Building 701. Residual radioactivity will remain within inaccessible soils located in deep pockets below the Building 701 foundation and below ground duct concrete structure. These contaminants are bound within concrete, embedded within steel or located within areas that are currently inaccessible and are not considered a groundwater contamination source term. In the event that future activities cause the contaminated deep soils to become readily accessible, efforts will be made to remediated the soils.

Upon completion of the decommissioning activities, an engineered cap will be installed around the outdoor footprint of the BGRR. The engineered cap is envisioned to include the following:

- Grading the existing property to create a slope away from the BGRR Below Ground Duct and Building 701.
- Placing an acceptable polymer liner, such as high-density polyethylene, over the BGRR footprint.
- Placing a low-permeability, properly pre-planned, barrier soil over the polymer liner.
- Placing several inches of blacktop over the barrier soil.

In addition to the engineered cap, stormwater runoff will be collected and conveyed to the BNL stormwater collection system, when practicable. If the BNL stormwater system is not convenient, then stormwater runoff shall be collected and discharged to an area outside of the BGRR footprint.

Long-term response actions will include routine inspection and surveillance of the BGRR facility, scheduled upkeep and maintenance of Building 701, infiltration management, and groundwater monitoring. A graphic representation of the location, characteristics and volume of contaminants remaining at the BGRR complex following completion of this alternative is provided in Figure 3.C.1 and Figure 3.C.2.

3.3.3.3 Cost/Schedule

As of the end of fiscal year 2003, BGRR removal actions have cost approximately $39.3 million. Completing the remaining ongoing and scheduled activities of Alternative A and removal of the graphite pile and biological shield of Alternative B is estimated to cost $54 million. Removal of the readily accessible sources identified within this alternative is estimated to cost an additional $3.5 million. Depending on the availability of funding, completion of this alternative is expected to take approximately 30 months at a total cost of $96.8 million.

3.3.3.4 Institutional Controls

The institutional controls for this alternative would specify land use restrictions and reporting requirements. At a minimum, the institutional controls for this alternative would:

- Establish measures for future excavation of residual subsurface contamination including characterization and limitations on use/reuse in accordance with NYSDEC regulations.

- Provide land use restrictions and an acceptable method for evaluating potential impact that the remaining contaminants have on future development.

- Establish a restriction that future use and development of the property is limited to commercial or industrial uses only.

- Specify requirements for annual certification to the NYSDEC, which would certify that the institutional controls and engineering controls put in place, are unchanged from the previous certification and nothing has occurred that would impair the ability of the control to protect public health or the environment or constitute a violation or failure to comply with the site management plan. This annual certification would be prepared and submitted by a professional engineer or environmental professional acceptable to NYSDEC.

- Specify that land use restriction and reporting requirements be passed on to any/all future landowners through an environmental easement on the deed to the property. In light of the fact that a deed does not exist for property owned by a Federal entity, DOE will be responsible for implementing these controls as long as the property is owned by DOE and upon transfer of the property to a non-Federal entity, a deed will be established and an environmental easement will be added to the deed at that time.

With the risk associated with long-lived radioisotopes removed, and the accessible portions of the contaminated soil pockets located outside of the building foundation footprint remediated, the remaining radioactivity consists of residual Cesium-137 and Strontium-90 contamination in the inaccessible soil pockets below the building foundation. Using conservative assumptions, it was calculated that it would require approximately 180 years to decay to the Operable Unit I soil cleanup standards for industrial land use of 67 pCi/gm of Cs-137 and 15 pCi/gm of Sr-90 and an additional 100 years to decay to the acceptable levels for unrestricted residential land use. This calculation was performed to allow for a comparative analysis of the various BGRR remedial action alternatives, considered herein. It was not intended to establish definitive institutional control durations.

However, institutional controls, including land use restrictions would help ensure that the remaining contaminated structures and soils can be managed to prevent inadvertent direct exposure and future migration to the soil regardless of these calculated durations. The hypothetical excavation of the remaining soils at some time in the future would be evaluated based on the actual distribution, depth and concentrations of the residual radioactive material encountered. Given the depth of these soils and the clean overburden, the concentrations of Cs-137 and Sr-90 that an individual could be exposed to during excavation would be significantly reduced when mixed with the clean overburden. Institutional controls are highly effective in managing this residual contamination for this finite period of time.

The estimated costs associated with institutional controls will be $275,000 annually for routine surveillance and groundwater monitoring. It will also require approximately $10,000 every ten years for infiltration barrier upkeep and $700,000 every 20 years to refurbish the Building 701 exterior façade and roof system. Additionally, groundwater monitoring in the vicinity of the BGRR complex will continue in accordance with the Operable Unit III Record of Decision. Results of the OU-III monitoring will be used to ensure the effectiveness of the remedy.

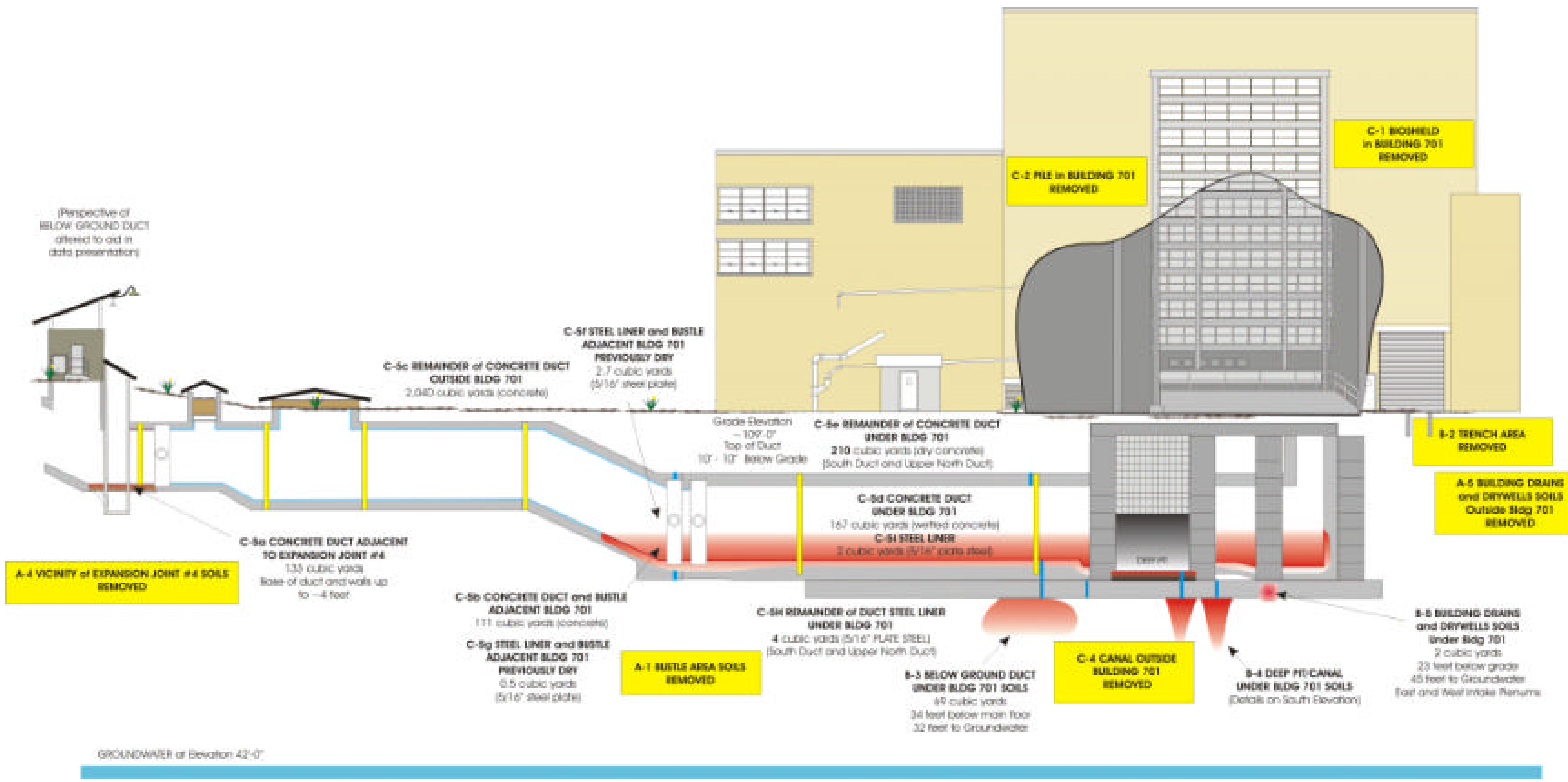


FIGURE 3.C.1 – ALTERNATIVE C Contaminant Location, Characteristics and Volume

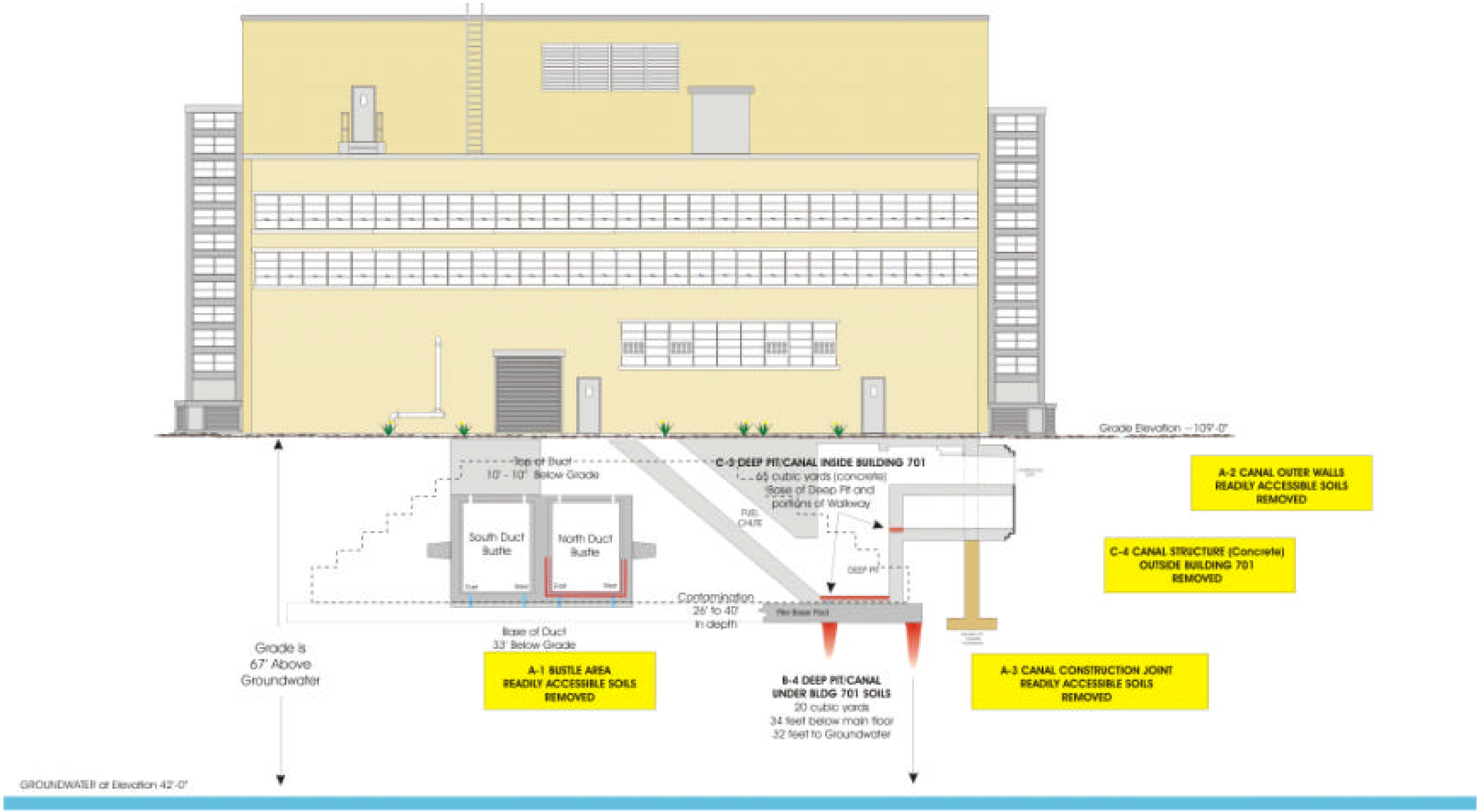


FIGURE 3.C.2 – ALTERNATIVE C Contaminant Location, Characteristics and Volume

3.3.4 Alternative D – Greenfield

3.3.4.1 Scope

Alternative D includes the complete removal of the BGRR complex systems, structures and components, and the removal of underlying soils necessary to reach the soil cleanup levels of 67 pCi/gm Cs-137 and 15 pCi/gm Sr-90 established in the Operable Unit I Record of Decision for industrial land use. Upon achieving these cleanup goals land use at the BGRR complex would be maintained under institutional controls for approximately 100 years before reaching the acceptable levels for unrestricted residential land use.

This alternative includes completion of all the activities identified in Alternative C and full removal of the Building 701 superstructure, underground foundations, deep soil pockets below the foundation footprint, and remaining underground structures including the remainder of the fuel canal, deep pit, and below ground duct concrete and steel.

In addition to those removed in Alternative C, the following structures and subsurface soil pockets would be removed as part of this remedial action alternative:

- Removal of Building 701 superstructure

  This activity involves the demolition and removal of the above ground structure of Building 701. Radiological characterization of Building 701 determined that the reactor building exterior and interior structures, systems and components, are relatively free of contamination. However, because of historic contamination within Building 701 the area remains posted as a radiologically controlled area requiring all work within the facility be controlled for radiological protection purposes. Additionally, due to its operational history, radiological control procedures require performance of formal release surveys for all materials removed from BGRR, making free release of demolition debris impractical from a cost and schedule standpoint. Demolition of Building 701 will create approximately 3,800 cubic yards of low-level radioactive wastes. The lower portion of the north wall of the reactor building (Building 701) will remain in place as an exterior wall of the adjoining BGRR research laboratories (Building 703).

- Removal of Building 701 foundation and remaining underground structures

  This activity involves removing the remainder of the fuel canal from the outer construction joint to the pile foundation buttresses, the reactor pile foundation buttresses and foundation pad, isolated soil pockets under the foundation pad, and remaining below ground duct concrete and steel. Completion of this action will create approximately 8,300 cubic yards of low-level radioactive wastes consisting of steel, concrete and soil.

Completion of these removal actions will rely on established, field-proven practices and standard construction techniques. No new technologies are required.

3.3.4.2 End State

Following removal of Building 701 superstructure and underground foundation, the BGRR complex will be excavated to approximate the original grade using clean fill, topsoil and indigenous plant life.
Upon completion, this alternative will remove all radioactivity with the exception of residual contamination (less than 1 Curie) intermixed within deep soils. If the radiological conditions following soil remediation warrent, an impermeable engineered cap will be installed. The engineered cap is envisioned to include the following:

- Grading the existing property to create a slope away from the previous foundation of the Below Ground Duct and Building 701.
- Placing an acceptable polymer liner, such as high-density polyethylene, over the BGRR footprint.
- Placing a low-permeability, properly pre-planned, barrier soil over the polymer liner.
- Placing several inches of blacktop over the barrier soil.

In addition to the engineered cap, stormwater runoff will be collected and conveyed to the BNL stormwater collection system, when practicable. If the BNL stormwater system is not convenient, then stormwater runoff shall be collected and discharged to an area outside of the BGRR footprint.

To ensure the effectiveness of these actions, the remaining radiological inventory will be monitored for the institutional control period established for industrial land use contained within the Operable Unit I Record of Decision.

3.3.4.3 Cost/Schedule

As of the end of fiscal year 2003, BGRR removal actions have cost approximately $39.3 million. Depending on the availability of funding, completing the activities identified within this alternative is expected to take 56 months at an additional cost of $110 million for a total cost of approximately $150 million.

3.3.4.4 Institutional Controls

This alternative removes structural interferences making the soils beneath the building foundation accessible.

The institutional controls for this alternative would specify land use restrictions and reporting requirements. At a minimum, the institutional controls for this alternative would:

- Establish measures for future excavation of residual subsurface contamination including characterization and limitations on use/reuse in accordance with NYSDEC regulations.

- Provide land use restrictions and an acceptable method for evaluating potential impact that the remaining contaminants have on future development.

- Establish a restriction that future use and development of the property is limited to commercial or industrial uses only.

- Specify requirements for annual certification to the NYSDEC, which would certify that the institutional controls and engineering controls put in place, are unchanged from the previous certification and nothing has occurred that would impair the ability of the control to protect public health or the environment or constitute a violation or failure to comply with the site management plan. This annual certification would be prepared and submitted by a professional engineer or environmental professional acceptable to NYSDEC.

- Specify that land use restriction and reporting requirements be passed on to any/all future landowners through an environmental easement on the deed to the property. In light of the fact that a deed does not exist for property owned by a Federal entity, DOE will be responsible for implementing these controls as long as the property is owned by DOE and upon transfer of the property to a non-Federal entity, a deed will be established and an environmental easement will be added to the deed at that time.

Using conservative assumptions, it was calculated that if the remaining contaminated soils within the BGRR complex were remediated to the Operable Unit I soil cleanup standards of 67 pCi/gm for Cesium – 137 and 15 pCi/gm for Strontium 90 it would take approximately 100 years to allow the contaminants to decay to acceptable levels for unrestricted land use. This calculation was performed to allow for a comparative analysis of the various BGRR remediation alternatives, considered herein. It was not intended to establish definitive institutional control durations.

However, following the excavation of the remaining contaminated soils, the risk to human health and the environment would be evaluated based on the actual distribution, depth and concentrations of the residual radioactive material encountered. The duration and need for institutional controls would be determined based on the results of this evaluation.

If determined necessary, institutional controls will consist primarily of implementing facility and land use restrictions. The estimated cost for these administrative controls is less than $1,000 per year over the duration of the institutional control period. Additionally, groundwater monitoring in the vicinity of the BGRR complex will continue in accordance with the Operable Unit III Record of Decision. Results of the OU-III monitoring will be used to ensure the effectiveness of the remedy.

4.0 DETAILED ANALYSIS OF ALTERNATIVES

4.1 CRITERIA FOR EVALUATION AND EVALUATION SUMMARY

The EPA has established nine evaluation criteria that must be considered in the selection of a remedial action alternative. These evaluation criteria and a brief description of their content are summarized below:

- ***Overall Protection of Human Health and the Environment*** is the primary objective of the remedial action and addresses whether a remedial action provides adequate overall protection of human health and the environment. This criterion must be met for a remedial alternative to be eligible for consideration.

- ***Compliance with Applicable or Relevant and Appropriate Requirements (ARARs)*** addresses whether a remedial alternative will meet all the applicable or relevant and appropriate requirements and other federal and State of New York environmental statutes, or provide grounds for invoking a waiver of the requirements. This criterion must be met for a remedial alternative to be eligible for consideration.

- ***Long-Term Effectiveness and Permanence*** refers to the magnitude of residual risk and the ability of a remedial alternative to maintain long-term reliable protection of human health and the environment after remedial goals have been met.

- ***Reduction of Toxicity, Mobility, or Volume*** refers to an evaluation of the anticipated performance of the treatment technologies that may be employed in the remedy. Reduction of toxicity, mobility and/or volume contributes to overall protectiveness.

- ***Short-Term Effectiveness*** refers to evaluation of the speed with which the remedy achieves protection. It also refers to any potential adverse effects on human health and the environment during implementation of the remedial action.

- ***Implementability*** refers to the technical and administrative feasibility of a remedial action, including the availability of materials and services needed to implement the selected solution.

- ***Cost*** refers to an evaluation of the capital, operations and maintenance, and monitoring costs for each alternative.

- ***New York State Acceptance*** indicates whether New York State concurs with, opposes, or has no comment on the preferred alternative based on review of the feasibility study and the Proposed Plan.

- ***Community Acceptance*** accesses the general public response to the Proposed Plan, following review of the public comments received during the public comment period and open community meetings. The remedial action is selected only after consideration of this criterion.

The last two criteria, New York State Acceptance and Community Acceptance, are not included in this evaluation. Comments received during the public comment period will be used to assist in evaluating the effectiveness of each of the alternatives to these criteria.

4.2 INDIVIDUAL EVALUATION OF ALTERNATIVES

4.2.1 Alternative A - Stabilization and Source Management

4.2.1.1 Overall Protection of Human Health and Environment

Under Alternative A, removal actions would include those already taken and those additional actions that are in progress or planned. The pile, biological shield, subsurface structures and several pockets of deep, subsurface soil contamination would remain in place.

The pile and biological shield are contained within Building 701. The biological shield itself is a heavily reinforced concrete and steel structure that protects the radiological inventory contained in the biological shield and the graphite pile. In short, there are two physical barriers to prevent direct exposure to humans and serve as redundant barriers to the environment. Recent BGRR experience demonstrates that these engineered barriers have been effective in preventing water infiltration into the pile and biological shield structures. Likewise, these physical barriers and access controls have been effective in preventing direct exposure to these hazards. In the absence of water infiltration or any other drivers, there is no evidence of contaminated effluents or contamination leakage from the pile and biological shield structures. The pile and biological shield contain substantial inventories of long-lived isotopes that would remain as a potential threat to humans and the environment for thousands of years. Hence, Alternative A relies on infiltration management, and institutional controls for an indefinite period of pile and biological shield storage.

The management of the remaining pockets of deep, subsurface soils rely on a similar approach: Institutional controls would remain in place to ensure that these pockets are not unearthed resulting in direct human exposure. Building 701 provides an infiltration barrier to protect soil pockets located below the Building701 footprint. Engineered caps would serve as infiltration barriers external to this footprint. However, there is some uncertainty as to the absolute effectiveness of these barriers. As an additional measure, actions to be taken pursuant to the Operable Unit III Record of Decision include Sr-90 remediation of contamination that has entered groundwater. Because the soil pockets contain short-lived isotopes, they do not pose the same indefinite hazard and challenge presented by the pile and biological shield.

Alternative A removes a small fraction of the overall contamination inventory from the BGRR complex. The substantial inventory that remains includes several long-lived isotopes that pose serious uncertainties since institutional controls would need to be maintained for the indefinite future. Because of these uncertainties, the overall effectiveness of Alternative A is rated as medium.

4.2.1.2 Long-term effectiveness

Existing controls, in conjunction with the actions taken pursuant to the Operable Unit III Record of Decision have been effective in protecting human health and the environment from the potential threats posed by the pile, biological shield and contaminated soil pockets. For a finite period of time with DOE control of the site, with these same infiltration management and institutional controls in place, long-term effectiveness would be rated as high.

However, the pile and biological shield represent a radiological hazard for an indefinite period of time. Some of these isotopes have half-lives of thousands of years. Hence, this alternative requires effective infiltration management, and institutional controls for an indefinite period of time. Because of the uncertainties of maintaining these barriers and controls in place for an indefinite period of time, the long-term effectiveness of Alternative A is rated as medium.

4.2.1.3 Compliance with applicable or relevant and appropriate requirements

Alternative A would leave the pile and biological shield in place at the BGRR complex for an indefinite period of time. The indefinite storage or entombment of these radioactive structures may be in conflict with New York State regulations regarding the siting of LLRW disposal facilities. There may be a specific prohibition that would preclude this course of action for the pile and biological shield. This matter would need to be resolved prior to implementation.

There are no ARARs that otherwise appear to be in conflict with Alternative A. The BNL technical and programmatic infrastructure ensures that all removal actions would be in compliance with ARARs.

4.2.1.4 Reduction of toxicity, mobility, or volume through Treatment

None of the alternatives considered in this FS include treatment intended to reduce the toxicity, mobility, or volume of contaminants. The principal contaminants of concern are various radioactive isotopes. There are no known technologies to change the radioactive properties of radioisotopes through the use of treatment systems.

4.2.1.5 Short-term effectiveness

Existing safety and work control programs ensure that all hazards to the workers, the public, and the environment are identified and mitigated as part of the work controls process. Completion of the remaining actions involve minimal exposure to radioactivity and very low likelihood of uncontrolled spread of radioactivity to the environment. All remaining activities can be completed with a high degree of confidence that human health (including workers) and the environment will be protected while achieving the remaining remediation objectives. Short-term effectiveness of Alternative A is rated as high.

4.2.1.6 Implementability

Alternative A involves the use of established, field-proven practices and standard construction practice. For this reason, there is a high level of assurance that the completion of the remaining remedial actions and long-term response actions are fully implementable with no extraordinary or noteworthy uncertainties. Implementability of Alternative A is rated as high.

4.2.1.7 Cost

As of the end of fiscal year 2003, BGRR removal actions have cost approximately $39.3 Million. An additional $14.2 Million will be required to complete the actions of Alternative A. The total estimated capital cost of Alternative A is $53.5 Million. Once complete, it will require approximately $275,000 annually to provide surveillance and monitoring throughout the period of institutional control. Additionally, $10,000 in repairs to the infiltration management system every ten years and $700,000 every twenty years for Building 701 superstructure will be required.

4.2.2 Alternative B - Pile and Biological Shield Removal

4.2.2.1 Overall Protection of Human Health and Environment

Alternative B includes the removal of the pile and biological shield in addition to the removal actions described in Alternative A. As a result of these removal actions, more than 99% of the radiological inventory would be removed from the BGRR complex. More importantly, Alternative B includes the complete removal of the long-lived radioisotopes that are driving the indefinite duration of institutional controls for Alternative A.

With the removal of the pile and biological shield, the remaining activity is limited to short-lived isotopes in deep subsurface pockets of soil. Their deep, subsurface locations inherently preclude direct human exposure. The effectiveness of infiltration management and institutional controls has already been demonstrated at Brookhaven. Earlier leakages to the environment have been arrested, and there is an extensive groundwater monitoring and surveillance program in place at this time. Because these contamination pockets contain short-lived isotopes, the required longevity of institutional controls is of a finite duration and hence does not introduce global uncertainties over the effectiveness of these controls. Hence, overall protectiveness is rated as high.

4.2.2.2 Compliance with applicable or relevant and appropriate requirements

There are no ARARs that are in conflict with Alternative B. Alternative B includes the removal of the pile and biological shield. Hence, the potential applicability of New York State regulations pertaining to LLRW disposal facility siting is no longer a consideration. The BNL technical, programmatic infrastructure and work management infrastructure ensures that all removal actions would be taken in compliance with ARARs.

4.2.2.3 Long-term effectiveness

Infiltration management and institutional controls, in conjunction with the completed and planned actions pursuant to the Operable Unit III Record of Decision, would be effective in managing the potential threats posed by the remaining deep, subsurface pockets of contaminated soils. For the complete and finite duration in which infiltration management and institutional controls are required, long-term effectiveness is rated as high.

4.2.2.4 Reduction of toxicity, mobility, or volume through Treatment

None of the alternatives considered in this FS include treatment to reduce the toxicity, mobility or volume of contaminants. The principal contaminants of concern are radioactive isotopes and there are no technologies to change the radioactive properties of these isotopes through the use of treatment systems.

4.2.2.5 Short-term effectiveness

Existing safety and work control programs will ensure that all hazards to the workers, the public and the environment are identified and mitigated. As explained in section 4.2.2.6, below, all of the removal actions will involve construction and demolition techniques that are field proven and standard to the business of reactor decommissioning and dismantlement. Nonetheless, pile and biological shield removal involves a substantial scope of work in a harsh radiological environment. These removal actions will require the safe handling, packaging, shipment and disposal of a substantial quantity of radioactive waste. Based on the foregoing, short-term effectiveness of Alternative B is rated as medium.

4.2.2.6 Implementability

Pile and biological shield removal has been extensively evaluated. The removal of these structures will rely on technologies, equipment and practices that have been proven throughout the DOE complex and the commercial nuclear power industry. Many of these techniques have already been demonstrated at Brookhaven in connection with the removal of the filters and liner from the below ground ducts. Waste streams resulting from these activities can be safely managed using commercially available packages and transportation services. No new or untested technologies would be required. Hence, implementability of Alternative B is rated as high.

4.2.2.7 Cost

As of the end of fiscal year 2003, BGRR removal actions have cost approximately $39.3 Million. An additional $54 Million would be required to complete Alternative B. The total estimated capital cost of Alternative B is $93.3 Million. Once complete, it will require approximately $275,000 annually to provide adequate surveillance and monitoring throughout the institutional control period for controlling the remaining deep, subsurface pockets of contaminated soil. Additionally, as in Alternative A, there is an expected expenditure of $10,000 for repairs on the infiltration management system every 10 years and $700,000 every twenty years for Building 701 superstructure.

4.2.3 Alternative C – Removal of Pile, Biological Shield, Fuel Canal Structure and Reasonably Accessible Soil and Canal Structure

4.2.3.1 Overall Protection of Human Health and Environment

Alternative C includes the additional work to remove several pockets of deep, surface contaminated soil that are located outside of the Building 701 footprint. As an ALARA measure, the soil pockets external to the Building 701 footprint and under the canal structure would be removed. These additional actions would result in the removal of approximately two Curies.

This additional work would remove deep, subsurface pockets of contaminated soils hence reducing the risk of direct human exposure. Likewise, these removal actions would further reduce the risk of exposure through groundwater: The remaining radiological inventory located in deep, subsurface pockets would be substantially reduced. The contaminated soil that would remain would be protected by the massive Building 701 foundation and superstructure. These structures form a significant barrier to future excavation and direct exposure, and would serve as an effective barrier to prevent the migration of the remaining contaminants to groundwater. Coupled with infiltration management and institutional controls that would be required for a finite period of time, these removal actions would be effective in protecting humans and the environment.

Alternative C includes the substantial removal (99%) of the radiological inventory in the BGRR complex and essentially the entire long-lived radiological inventory. Infiltration management and institutional controls are viable given the finite duration that they will be required. Hence, Alternative C is rated as high under this evaluation criterion.

4.2.3.2 Compliance with applicable or relevant and appropriate requirements

There are no ARARs that are in conflict with Alternative C. Alternative C includes the removal of the pile and biological shield. Hence, the potential applicability of New York State regulations pertaining to LLRW disposal facility siting is no longer a consideration. The BNL technical and programmatic infrastructure ensures that all removal actions would be taken in compliance with ARARs.

4.2.3.3 Long-term effectiveness

Infiltration management and controls, in conjunction with the completed and planned actions pursuant to the Operable Unit III Record of Decision, would be effective in managing the hazards represented by the remaining deep, subsurface pockets of contaminated soils. Because of the additional removal actions included in Alternative C, there would be a small, incremental reduction in the threat to groundwater posed by the remaining contamination. For the complete finite duration in which the infiltration management and institutional controls are required, long-term effectiveness is rated as high.

4.2.3.4 Reduction of toxicity, mobility, or volume through Treatment

None of the alternatives considered in this Feasibility Study include treatment to reduce the toxicity, mobility or volume of contaminants. The principal contaminants of concern are radioactive isotopes and there are no technologies to change the radioactive properties of these isotopes through the use of treatment systems.

4.2.3.5 Short-term effectiveness

Existing safety and work control programs will ensure that all hazards to the workers, the public and the environment are identified and mitigated. As explained in section 4.2.3.6, below, all of the removal actions will involve construction and demolition techniques that are field proven and standard to the business of reactor decommissioning and dismantlement. Nonetheless, pile and biological shield removal involves a substantial scope of work in a harsh radiological environment. These removal actions will require the safe handling, packaging, shipment and disposal of a substantial quantity of radioactive waste. Based on the foregoing, short-term effectiveness of Alternative C is rated as medium.

4.2.3.6 Implementability

Pile and biological shield removal has been extensively evaluated. The removal of these structures will rely on technologies, equipment and practices that have been proven throughout the DOE complex and the commercial nuclear power industry. Many of these techniques have already been demonstrated at Brookhaven in connection with the removal of the filters and liner from the below ground ducts. Likewise, the removal of the accessible deep, subsurface pockets of contaminated soils will involve standard construction practices that also have been demonstrated at Brookhaven. Waste streams resulting from these activities can be safely managed using commercially available packages and transportation services. No new or untested technologies are required. Hence, implementability of Alternative C is rated as high.

4.2.3.7 Cost

As of the end of fiscal year 2003, BGRR removal actions have cost approximately $39.3 Million. An additional $57.5 Million would be required to complete Alternative C. The total estimated capital cost of Alternative C is $96.8 Million. Once complete, it will require approximately $275,000 annually to provide adequate surveillance and monitoring for managing the remaining pockets of deep soil contamination under the foundation footprint of Building 701. Additionally, as in Alternatives A and B, there is an expected expenditure of $10,000 for repairs on the infiltration management system every 10 years and $700,000 every twenty years for Building 701 superstructure.

4.2.4 Alternative D - Greenfield

4.2.4.1 Overall Protection of Human Health and Environment

Removal of all structures, foundations, and contaminated soil pockets will essentially eliminate the risk of direct exposure to contamination in the BGRR complex. With complete removal, potential pathways to the environment are no longer relevant. Because of the enormous scope of work, Alternative D poses additional risks to workers, the general public and the environment attendant to the demolition of the massive BGRR structures and management of the resulting waste streams. However, these risks can be mitigated through effective use of existing work management tools. Based on the foregoing, Alternative D is rated as high under this evaluation criterion.

4.2.4.2 Compliance with applicable or relevant and appropriate requirements

The BNL technical and programmatic infrastructure ensures that all removal actions would be taken in compliance with ARARs. There are no outstanding ARAR issues or concerns.

4.2.4.3 Long-term effectiveness

Alternative D removes the pile, biological shield, all of the structures and the contaminated pockets of deep, subsurface soils from the BGRR complex. Residual contamination would be bounded by the Operable Unit I Record of Decision cleanup standards. Hence, infiltration management and institutional controls would be highly effective in managing any small quantities of residual contamination. Based on the foregoing, long-term effectiveness of Alternative D is rated as high.

4.2.4.4 Reduction of toxicity, mobility, or volume through Treatment

None of the alternatives considered in this Feasibility Study include treatment to reduce the toxicity, mobility or volume of contaminants. The principal contaminants of concern are radioactive isotopes and there are no technologies to change the radioactive properties of these isotopes through the use of treatment systems.

4.2.4.5 Short-term effectiveness

Existing safety and work control programs will ensure that all hazards to the workers, the public and the environment are identified and mitigated. As explained in section 4.2.4.6, below, all of the removal actions will involve construction and demolition techniques that are field proven and standard to the business of reactor decommissioning and dismantlement. Nonetheless, pile and biological shield removal involves a substantial scope of work in a harsh radiological environment. The demolition of the BGRR complex structures is an enormous undertaking. While these removal actions will involve standard construction and demolition work practices, the magnitude of this project poses a special challenge to work management and work control.

All of these removal actions will require the safe handling, packaging, shipment and disposal of an enormous quantity of radioactive waste. Based on the foregoing, short-term effectiveness of Alternative D is rated as medium.

4.2.4.6 Implementability

All of the activities that will be required to completely remove all structures, foundations and pockets of contaminated soil from the BGRR complex involve the use of established, field-proven practices and standard construction techniques. Implementability of Alternative D is hence rated as high.

4.2.4.7 Cost

As of the end of fiscal year 2003, BGRR removal actions have cost approximately $39.3 Million. This alternative will require an additional $110 Million to completely remove all structures, foundation pockets of contaminated soil from the BGRR complex. The total estimated capital cost is $149.3 Million. Institutional controls, such as facility and land use restrictions commensurate with the potential hazard posed by the residual radiological inventory will be required. The estimated cost for these administrative controls is less than $1,000 per year over the duration of the institutional control period.

4.3 COMPARATIVE ANALYSIS OF ALTERNATIVES

4.3.1 Overall Protection of Human Health and the Environment

All four alternatives provide for varying degrees of contamination removal and include measures such as infiltration management and/or institutional controls to manage any residual contamination. The removal actions in conjunction with these measures are fully capable of preventing direct human exposure and/or the spread of contamination to the environment for some long-term but finite period of time, However, from an overall perspective, the indefinite nature of the required longevity of institutional controls sets Alternative A apart from the other three alternatives.

Alternative A would leave the pile and biological shield in place at the BGRR complex. These structures contain long-lived radioisotopes that would remain as a potential threat for thousands of years. Infiltration management and institutional control would be required for what is essentially an indefinite period of time. Alternatively, a schedule would need to be established for the removal of these structures on some finite time line. Infiltration management and institutional controls can be effectively maintained for a finite duration. However, there are serious questions that arise over the sustainability of these same protective measures over an indefinite time frame. This is the largest single difference among the four BGRR cleanup alternatives. Alternatives B, C and D require institutional controls for a finite period of time. In the case of these alternatives, the long-lived radionuclides would be removed as a result of pile and biological shield removal. From an overall perspective, Alternatives B, C and D provide equivalent protection of human health and the environment.

4.3.2 Compliance With Applicable or Relevant and Appropriate Requirements

Alternative A involves the storage of the long-lived radioactive contaminants in the pile and biological shield. The indefinite storage of these radioactive structures brings to rise questions regarding the applicability of New York State's siting requirements for LLRW waste disposal facilities. There are several statutory issues that may preclude the indefinite storage or entombment of the pile and biological shield over Long Island's sole source aquifer. This is a material question that would need to be resolved before proceeding with Alternative A.

There are no apparent compliance issues or conflicts with ARARs.

4.3.3 Long-Term Effectiveness

Alternative A would leave the pile and biological shield in place at the BGRR reactor facility. Because these structures contain significant quantities of long-lived radioisotopes, the DOE would be required to implement infiltration management and institutional controls for an indefinite duration. The indefinite nature of the longevity of this potential threat poses numerous questions that point to uncertainties over the fidelity of institutional controls over the undefined period of time. Pile and biological shield removal set Alternative A apart from the other three BGRR cleanup alternatives.

Alternatives B, C and D, in contrast all include the removal of the pile and biological shield. For all three, these removal actions result in the removal of essentially all of the long-lived contaminants from the BGRR complex. Residual contamination would require infiltration management and/or institutional controls in the case of all three alternatives. However, the duration of these measures would be for a finite period of time that would not impose the same issues and uncertainties germane to Alternative A. These three alternatives are equivalent from a long-term effectiveness perspective.

4.3.4 Reduction of Toxicity, Mobility, or Volume through Treatment

None of the alternatives considered in this Feasibility Study include treatment to reduce the toxicity, mobility or volume of contaminants.

4.3.5 Short-Term Effectiveness

Alternative A has a relatively small scope of work in a radiologically harsh environment. In view of the diminished risk of contamination dispersion to the environment and transportation incidents, this alternative poses the least uncertainties in the area and thus is rated as high.

The removal of the pile and biological shield set Alternatives B, C and D apart from Alternative A. Over 8,000 Curies of contaminated material would be removed from the BGRR complex. For all three alternatives, this involves a significant amount of work in a radiologically harsh environment. While not extraordinary from a waste form and activity standpoint, the wastes resulting from pile and biological shield removal would have to be carefully managed. Existing work controls and procedures will mitigate the risks of potential threats to humans and the environment. The ALARA principal would be used to manage direct human (worker) exposure throughout all phases of pile and biological shield removal. Nonetheless, these removal actions pose potential threats and uncertainties to short-term effectiveness. While the scope of work varies significantly among Alternatives B, C and D, the relative complexity and challenges are minor in comparison to pile and biological shield removal. Hence, Alternatives B, C and D are equivalent.

4.3.6 Implementability

All four BGRR cleanup alternatives will rely on field proven techniques and practices. Most of these techniques and practices have been previously demonstrated at Brookhaven, or elsewhere in the DOE complex or commercial nuclear power industry. These proven techniques and practices encompass all elements of cleanup, through and including waste handling, packaging, transportation and disposal. All four alternatives are equivalent from an implementability standpoint and are rated as high.

4.3.7 Cost

The capital cost for each of the four alternatives is summarized as follows:

Alternatives Capital Costs, in Dollars

	A	B	C	D
Previous Costs	39.3 Million	39.3 Million	39.3 Million	39.3 Million
Complete Remaining Activities	14.2 Million	14.2 Million	14.2 Million	14.2 Million
Remove Pile and Biological Shield		39.8 Million	39.8 Million	39.8 Million
Remove Accessible Soil Pockets			3.5 Million	3.5 Million
Remove Building and Foundation				52.5 Million
Total Costs	**53.5 Million**	**93.3 Million**	**96.8 Million**	**149.3 Million**

Alternative A is the least costly of the four BGRR cleanup alternatives. There is a large incremental increase of $40.2 Million for Alternative B because of pile and biological shield removal. The removal of the accessible pockets of deep, subsurface contaminated soils (Alternative C) results in a small incremental increase of $3.5 million. Alternative D results in another large incremental cost of $52.5 because of the enormous scope of work and waste transportation and disposal involved with the demolition of the Building 701 superstructure and foundation.

5.0 REFERENCES

BNL, 1995, *Brookhaven National Laboratory Future Land Use Plan*, BNL-62130, prepared by Associated Universities, Inc. for U.S. Department of Energy, Brookhaven Area Office, Upton, New York, August 31.

BNL, 2002a, *Draft Characterization Report for the Below ground Ducts and Associated Soils, Brookhaven Graphite Research Reactor Decommissioning Project*, BGRR-049, Rev. E, prepared by Brookhaven Science Associates for U.S. Department of Energy, Brookhaven Area Office, Upton, New York, January 30.

BNL, 2002b, *Draft Below ground Ducts Engineering Evaluation/Cost Analysis*, Brookhaven Graphite Research Reactor Decommissioning Project, BGRR-050, Rev. D, prepared by Brookhaven Science Associates for U.S. Department of Energy, Brookhaven Area Office, Upton, New York, January 30.

BNL 2002c, *Decommissioning Engineering Studies for the Brookhaven Graphite Research Reactor*, prepared by Burns and Roe Enterprises, Inc. for U. S. Department of Energy, Brookhaven Area Office, Upton New York, February 28

BNL, 2002d, *Draft Canal and Water Treatment Houses, Equipment, and Associated Soils Completion Report, Brookhaven Graphite Research Reactor Decommissioning Project*, BGRR-048, Rev. C, prepared by Brookhaven Science Associates for U.S. Department of Energy, Brookhaven Area Office, Upton, New York, April 15.

BNL, 2002e, *Characterization Report for Building 701 Above Ground Surfaces, Systems, and Structures, Brookhaven Graphite Research Reactor (BGRR) Decommissioning Project*, BGRR-054, Rev. A, Draft, prepared by Brookhaven Science Associates for U.S. Department of Energy, Brookhaven Area Office, Upton, New York, November.

BNL, 2003a, *Characterization Report for the 701 Below ground Structures, 702 Pile, and Remaining Soils, Brookhaven Graphite Research Reactor Decommissioning Project*, BGRR-055, Rev. B, Draft, prepared by Brookhaven Science Associates for U.S. Department of Energy, Brookhaven Area Office, Upton, New York, January.