Brookhaven High Flux Beam Reactor Decommissioning Project

High Flux Beam Reactor Feasibility Study

September 2007

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 hazardous and radioactive materials contamination at the Brookhaven National Laboratory (BNL) High Flux Beam Reactor (HFBR). 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 be protective of human health and the environment.

BNL is a DOE site 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 HFBR are radiologically contaminated as a result of normal operation and leaks over the history of the facility. Some of these structures and components were constructed using building materials that are hazardous (e.g. asbestos, lead, etc.).

During the last several years, many actions have been taken to remove hazardous materials and radioactively contaminated equipment and components from the HFBR. These actions have been taken in connection with the permanent removal of the reactor from service, and its preparation for continued surveillance and maintenance (S&M). Key actions performed under the National Environmental Policy Act (NEPA) categorical exclusion, include: the removal and shipment of the nuclear fuel to another DOE site; removal of the primary coolant from various HFBR systems and its transportation to another DOE site; demolition and removal of the cooling tower; demolition and removal of the Stack Monitoring Facility (Building 715), Cooling Tower Basin and Pump/Switchgear House (Building 707/707A), Water Treatment House (Building 707B), and guard house (Building 753); removal of some lead shielding, chemicals and scientific equipment for use elsewhere at BNL and other off-site institutions; transfer of the Cold Neutron Facility (Building 751) to another organization for reuse; and modification of the confinement building and spent fuel canal in order to meet Suffolk County Article 12 requirements. Other DOE actions include the radiological and non-radiological characterization of the HFBR reactor complex.

Most of the HFBR's radiological inventory of 65,000 Curies (Ci) (more than 99 percent) is contained in the activated components that are in the heart of the HFBR confinement building. These components include the control rod blades (CRBs) and reactor internals, reactor vessel, thermal shield, inner region of the biological shield and beam plugs. These components are volumetrically activated. That is, the radiological inventory is within and intrinsic to the materials of construction of these components. The calculated radiation dose rates associated with these activated components are high. Short-lived radionuclides (those with half lives less than 10 years) dominate the distribution of this radioactivity. Hence, there is a rapid reduction in the inventory and radiation dose rate because of natural radioactive decay.

The balance of the radiological contamination (which is less than 1 percent of the total) is distributed predominantly within the confinement building structures, systems, and components. There are small amounts of contamination in some ancillary structures and underground duct and piping systems. The soil under the confinement building is contaminated with tritium and there are a number of isolated small areas of soil contamination elsewhere in the HFBR complex. There are also some non-radiological hazardous materials associated with certain building materials that were used to construct the HFBR complex, such as lead and asbestos.

The HFBR complex has been placed and is being maintained in a safe and stable condition. In its current state, there are no credible pathways for human exposure to the radiological and non-radiological hazards that remain. Likewise, there are, in its current state, no credible pathways for release of residual contamination to the environment. Notwithstanding these present day conditions, the considerable radiological and non-radiological contamination inventories need to be carefully managed to ensure that they do not impact human health and the environment over the long-term.

Following an extensive evaluation of completed actions and a careful review of the nature and extent of the remaining contamination, four remedial action alternatives were developed for the HFBR complex and are included in this FS. Remediation of the Waste Loading Area (WLA) is also included in the scope of all four remedial alternatives. The Waste Loading Area is an area of radiologically contaminated soil along the eastern boundary of the Former Hazardous Waste Management Facility (FHWMF). It was left in place (with contaminated soil) so that it can be used as a waste staging and railcar loading area for the BGRR and HFBR projects. Cleanup of the WLA will be performed when it is no longer needed as a waste staging and loading area using the dose-based cleanup goal of 15 mrem/year and methodology specified for the FHWMF in the Operable Unit I (OU I) ROD. The four alternatives are summarized below:

Alternative A, No Additional Action, would include those actions already completed. Alternative A would also include the continuation of S&M and the use of land use and institutional controls (LUICs) for an indefinite period of time to ensure the protection of human health and the environment.

Alternative B, Phased Decontamination and Dismantlement, would include the near-term removal, by Fiscal Year (FY) 2020, of the HFBR ancillary structures as described in Section 1.2, contaminated underground duct and piping systems, and small areas of contaminated soil outside the confinement building footprint. The activated components would remain in place inside the confinement building for a decay period not to exceed

65 years, following the finalization of the HFBR Record of Decision (ROD), to allow for the natural decay of these high dose rate radioactive components. At the conclusion of this radioactive decay period, the balance of the HFBR complex would be dismantled and removed. This alternative provides for the complete removal of the HFBR complex with the possible exception of the subsurface concrete structures of the confinement building base mat and stack foundation. However, the final decision to leave either of these sub-structures in place will be determined on the basis of radiological sampling and dose assessment.

Alternative B would also include the continuation of S&M and the use of LUICs throughout the period of radioactive decay to ensure the protection of human health and the environment. The cleanup, after dismantlement of the confinement building, would satisfy the dose-based cleanup goal of 15 mrem/year and methodology specified in the Operable Unit I (OU I) ROD. There will be no need for any additional period of LUICs.

Alternative C, Phased Decontamination and Dismantlement With Near-Term Control Rod Blade Removal, consists of the same actions as those included in Alternative B. Alternative C results in the same end state as that of Alternative B, the complete removal of the HFBR complex. The difference is limited to the timing of the decontamination and dismantlement activities. Alternative C would include the near-term removal of the HFBR ancillary structures, contaminated underground duct and piping systems, and small areas of contaminated soil. Alternative C also includes the near-term removal, transportation, and disposal of the CRBs and beam plugs by FY 2020.

The balance of the activated components would remain within the confinement building for a decay period of up to 65 years following finalization of the ROD to allow for their natural radioactive decay. At the conclusion of radioactive decay period, the balance of the HFBR complex would be dismantled and removed, including the removal of residual soil contamination underneath the confinement building. Alternative C would also include the continuation of S&M and the use of LUICs throughout the period of radioactive decay to ensure the protection of human health and the environment. The cleanup, after dismantlement of the confinement building, would satisfy the dose-based cleanup goal and methodology specified in the Operable Unit I (OU I) ROD. There will be no need for any additional period of LUICs.

Alternative D, Near-Term Decontamination and Dismantlement, includes the complete near-term removal of the HFBR complex by FY 2026.

Alternative D results in the same end state as that of Alternative B and Alternative C, the complete removal of the HFBR complex by the end of 2026. S&M would be required throughout the near-term period of removal and LUICs may be required for an additional 50 years following the last phase of HFBR dismantlement because of the small amounts of residual soil contamination allowable under the dose-based cleanup goal of 15 mrem per year (for residential use) and methodology specified in the OU I ROD. The need and actual period of LUICs will be determined on the basis of radiological sampling and dose assessment performed after the dismantlement of the confinement building.

EVALUATION OF ALTERNATIVES

The evaluation process includes incorporating important NEPA values such as public participation, have been incorporated in the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA) process used in the development, screening, and evaluation of the remedial alternatives and removal actions for the HFBR.

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 through treatment; 5) short-term effectiveness; 6) implementability; and 7) cost. The comparative analysis of the four alternatives under these criteria is provided as follows:

Criterion 1: Overall Protection of Human Health and the Environment

Most, more than 99 percent, of the HFBR radioactive material is in the form of activated concrete and steel components. In their existing locations and configuration, there are several physical barriers that are inherently effective in preventing human exposure and the potential spread of these radioactive materials to the environment:

- The majority of radioactive materials are actually a part of the activated concrete and steel components. In this form, the radioactive materials are immobile because they are bound up within these components as an intrinsic part of their materials of construction and are inherently non-dispersible.
- The reactor internals and CRBs, the most radioactive of the HFBR components, are encased in the 2-in. thick HFBR reactor vessel.
- The 8-foot thick heavily steel reinforced concrete biological shield surrounds the reactor vessel and thermal shield.
- All of these components are physically located above grade within the steel and concrete HFBR confinement building.

In their current non-dispersible and stable state and with these multiple barriers in place, these components do not pose a threat to human health or the environment. Continued S&M and LUICs are required to ensure the continued effectiveness of these barriers.

Alternative A would leave the HFBR complex in its present physical state. Because of the stability of the radioactive materials and the protective barriers, this remedy is currently protective of human health and the environment. However, the remaining activated components constitute a radiation hazard that would have to be managed for what is essentially an indefinite period of time. In the absence of a plan to eventually remove these components, S&M and LUICs would need to be maintained for this same indefinite period of time in order to ensure that this remedy remains protective. Although S&M can be provided and LUICs maintained for a finite duration, uncertainties arise as to whether these same protective measures can be effectively maintained for an indefinite period of time. Such uncertainties relate to the durability of institutions to implement the S&M program and enforce the LUICs. Alternative A is unique among the four alternatives in this respect, and because of this weakness, Alternative A is rated as MEDIUM under this criterion.

Alternatives B, C and D all provide for the complete removal of all of the HFBR radioactive structures, systems and components. In all cases, S&M and LUICs will be required for finite but different durations:

- Alternative B involves the safe storage of the confinement building and the activated components to allow for their radioactive decay. Following safe storage, these remaining structures and components would be removed during the final phase of physical dismantlement over a three-year period. HFBR S&M would be required for a total duration of 68 years. This includes the 65 year period of radioactive decay and the three years of HFBR dismantlement following this decay period. The cleanup, following the last phase of HFBR dismantlement, would satisfy the dose-based cleanup goal of 15 mrem/year and methodology specified in the Operable Unit I (OU I) ROD. There will be no need for any additional period of LUICs.
- Alternative C includes the near-term removal, by 2020, of the CRBs and beam plugs. However, this would not have any effect on the safe storage duration required for the other activated components. Therefore, S&M and LUICs are also required for the same duration as Alternative B.
- Alternative D results in the dismantlement and removal, over an eight year period, of the HFBR complex. S&M would be required throughout this period, and LUICs may be required for an additional 50 years because of the small amounts of residual soil contamination allowable under the dose-based cleanup goal of 15 mrem/year (for residential use) and methodology specified in the OU I ROD.

As described above, a finite period of S&M and LUICs is required for all three alternatives. The differences in these periods (69 years for Alternative D, and 68 years for Alternatives B and C) are inconsequential to the overall protectiveness of these three remedies because of the inherent physical stability of the activated components. The continuation of the HFBR S&M program and LUICs that are already in place for other remedies at BNL would ensure the protectiveness of these remedies during this interim period of time.

All three of these remedies include the complete removal of the HFBR complex. Therefore, from a long-term perspective, all three remedies are protective of human health and the environment. Based on the foregoing, Alternatives B, C and D were all rated as HIGH under this criterion.

Criterion 2: Compliance with Applicable or Relevant and Appropriate Requirements
Implementation of Alternative A involves the indefinite storage of radioactive materials and would be in conflict with New York State regulations regarding the siting of LLRW disposal facilities. Aside from this, all four alternatives comply with applicable or relevant and appropriate requirements. Therefore, Alternative A is rated as LOW and Alternatives B, C, and D are rated HIGH under this criterion.

Criterion 3: Long-Term Effectiveness
Alternative A would leave the HFBR complex in its present physical state. Because of the stability of the radioactive materials and the protective barriers, this remedy is currently protective of human health and the environment. However, the remaining activated components constitute a radiation hazard that would have to be managed for what is essentially an indefinite period of time. In the absence of a plan to eventually remove these components, S&M and LUICs would likewise need to be maintained for this same indefinite period of time to ensure that this remedy remains protective. Although S&M can be provided and LUICs maintained for a finite duration, uncertainties arise as to whether these same protective measures can be effectively maintained indefinitely. Such uncertainties relate to the durability of institutions to implement the S&M program and enforce the LUICs. Alternative A is unique among the four alternatives in this respect, and, because of this weakness, it is rated as MEDIUM under this criterion.

Alternatives B, C, and D all provide for the complete removal of all of the HFBR radioactive structures, systems and components. Based on the foregoing, Alternatives B, C, and D are all rated as HIGH under this criterion.

Criterion 4: Reduction of Toxicity, Mobility, or Volume through Treatment
None of the alternatives considered include treatment to reduce the toxicity, mobility, or volume of contaminants. Therefore, this criterion is not applicable to the analysis of the alternatives.

Criterion 5: Short-Term Effectiveness
Alternative A, involving no further action other than control and monitoring, poses few uncertainties and implementation risks and is rated HIGH under this criterion. This remedy is limited to the continued use of S&M and LUICs. As described under Criterion 1 above, more than 99 percent of the remaining radiological inventory is in a physically safe and stable form. With no physical dismantlement activity, this remedial alternative would not involve disturbing the radioactive activated components. Because Alternative A does not involve significant implementation risks, it is rated HIGH in terms of short term effectiveness.

Under Alternative B, all of the activated components with high dose rates would be removed only after they were allowed to decay to levels that would reduce the present day radiological risks and hazards during remediation. These components would be maintained in their inherently stable form as the radiation levels are reduced through their radioactive decay. As in the case of Alternative A, this alternative would not involve implementation risks and hazards associated with segmenting, handling, packaging, and transporting the activated components with high dose rates because the calculated dose rates will have decayed to manageable levels by the end of the not to exceed safe storage period of 65 years. The remaining project risks and hazards would be limited to those of a non-radiological nature that are germane to any large construction (i.e. demolition) project. Because Alternative B does not involve significant implementation risks, it was also rated as HIGH in terms of short-term effectiveness.

Under Alternative C, all of the dismantlement activities to remove and dispose of the activated structures, components, and the confinement building would involve standard and field proven nuclear reactor decommissioning and demolition techniques. The near-term CRB and beam plugs removal by FY 2020 would involve underwater handling and packaging and would utilize available tools, equipment and work processes. Since Alternative C does not involve significant radiological and transportation risks and hazards, it was also rated as HIGH in terms of short-term effectiveness.

In contrast to Alternatives A, B, and C, Alternative D involves the near-term segmentation, handling, packaging, transportation, and disposal, by FY 2026, of the large activated components with high dose rates. From a worker and transportation risk standpoint, this represents a significant difference from Alternatives A, B, and C. Alternative D would require more than 36 individual type A or B cask shipments resulting from activated component removal. The segmentation of these components would generate significant quantities of dispersible cutting fines with high dose rate. In a dispersible form, these secondary wastes pose additional personnel radiation exposure risks, and the potential risk of cross-contaminating the confinement building that is essentially free of contamination at this time. In summary, Alternative D involves considerable radiological and transportation risks and hazards in comparison to the other alternatives. Because of these radiological and transportation risks and hazards, the short-term effectiveness of Alternative D is rated as LOW.

Criterion 6: Implementability

Remaining Alternative A activities include the continuation of S&M and LUICs. These protective measures involve field-proven work practices, engineered safeguards and administrative controls. There are no implementability issues or concerns, and Alternative A is rated as HIGH under this criterion.

Under Alternative B, the HFBR confinement building and activated components would be removed only after the high radiation dose rates have decayed during the safe storage period. The radiological risks under Alternative B would be reduced, and simple, field proven construction (i.e., demolition) methods would be employed to complete the physical dismantlement of the HFBR complex. Alternative B is also rated as HIGH under implementability.

Alternative C is comparable to Alternative B. Under Alternative C, the CRBs and beam plugs would be removed near-term, by FY 2020, and the HFBR and remaining large activated components would be removed only after the high radiation dose rates have decayed. As with Alternative B, simple field proven construction methods would be all that are required to complete the physical dismantlement of the remaining structures, systems and components. Because implementation of this alternative is comparable to that for Alternatives A and B, Alternative C is rated as HIGH under this criterion.

Alternative D includes the near-term decontamination, dismantlement, and disposal of the entire HFBR complex by FY 2026 including all structures, systems, and components. Unlike alternatives A, B and C, near-term dismantlement and disposal of the large activated components with high dose rate would involve significant implementation issues and challenges as summarized below:

- Workers cutting apart the large activated components of the reactor vessel, thermal shield, and biological shield would not be able to come near them. In fact, at these calculated dose rates, the work would need to be performed remotely and underwater. The water would serve both as a radiation shield and as a way to minimize the dispersion of radioactive material. Water containment structures would have to be designed and built around the existing contaminated structures and components. Special tools, processes, and equipment would need to be designed, fabricated, and tested. Workers would have to be trained and qualified to perform these activities. Controls would have to be established to monitor and limit the amount of contamination in the water so it would continue to function as a radiation shield. A system to control water clarity would also be needed. Although there is industry experience with this kind of work, each project is highly dependent on the specific site conditions.
- The underwater segmentation of activated components would generate significant quantities of high dose rate dispersible fine particles and contaminated water requiring processing, transportation, and disposal. It is estimated that these segmentation activities could produce up to 100,000 gallons of contaminated water requiring processing and disposal as low level radioactive waste (LLRW).
- The high dose rates would require the use of type B shipping casks for waste transportation to a disposal site. The capacity of these casks is limited, thus the large activated components would need to be cut into small pieces. This would require the use of remotely operated tools and equipment and increase the amount of underwater material handling, further complicating the underwater work. More than 36 individual type A or B cask shipments would be required.

Alternative D implementation challenges and issues represent a significant increase of those described under Alternatives A, B and C. Therefore, the implementability of Alternative D is rated as LOW.

Criterion 7: Cost
The total estimated costs for the HFBR alternatives, including capital, S&M, and LUICs across the project life cycle are:

Alternative A	Indeterminate
Alternative B	$142 million
Alternative C	$144 million
Alternative D	$205million

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

Alternative A
Alternative A will not alter the physical condition of the HFBR reactor complex. Any reduction in the radiological inventory will be that solely attributable to radioactive decay. Under Alternative A, the entire HFBR reactor complex would remain in place for an indefinite period of time. Alternative A would rely on S&M and LUICs for an indefinite period of time to protect human health and the environment from the hazards that remain in the HFBR complex.

The effectiveness of these protective measures has been demonstrated in the recent past. However, the hazards that are present in the HFBR complex would require the effectiveness of S&M and LUICs for an indefinite period of time. Uncertainties remain as to the integrity and effectiveness of S&M and LUICs for an indefinite period of time.

Alternative B
Alternative B provides for the complete removal of the HFBR reactor complex with the possible exception of the subsurface structures limited to the confinement building base mat and stack foundation. However, the final decision to leave either of the structures in place will be determined on the basis of radiological sampling and dose assessment performed in accordance with the methodology specified in the OU I ROD. The highly radioactive components inside the confinement building would be allowed to decay. They would be subsequently removed when the radiological risks and hazards associated with their removal are substantially reduced. Because short-lived isotopes dominate the HFBR radiological inventory, the period of radioactive decay is of a finite duration. S&M and LUICs under Alternative B would be required for a finite duration and within the timeframe of other approved BNL remedies.

Alternative C

Alternative C provides for the complete removal of the HFBR reactor complex. Under this alternative, the high dose rate activated components would be removed only after they have been allowed to decay to levels that would reduce their present day radiological risks and hazards during remediation. This alternative also provides for the removal of the CRBs and beam plugs by FY 2020 and hence the near-term removal of a significant portion of the overall HFBR radiological inventory. The CRBs and beam plugs contain 38 percent of the radioactive material inventory contained at the HFBR and about 31 percent of the long-lived isotopes. Near-term CRB removal will not result in any changes to duration required for the radioactive decay of the other activated components. The duration required to reach the final end-state (i.e. complete removal of the HFBR complex) is the same as that for Alternative B. There are no extraordinary risks and hazards associated with the near-term removal, packaging and transportation of the CRBs and there is no adverse impact on the short-term effectiveness and implementability of Alternative C.

S&M and LUICs under Alternative C would be required for a finite duration and within the timeframe of other approved BNL remedies.

Alternative D

Alternative D provides for the complete near-term removal of the HFBR complex by FY 2026. This is a highly complex project because of the high radiation dose rates associated with the large activated components. The segmentation of the large activated components may generate significant quantities of high dose rate, loose, and dispersible secondary wastes that would have to be carefully managed. This alternative would require numerous shipments of highly radioactive components over a period of a few years. These risks have an unfavorable impact on the short-term effectiveness and implementability of Alternative D.

Evaluation of Remedial Alternatives

Consideration	Alternative A	Alternative B	Alternative C	Alternative D
Total radiological inventory 2007	65,000 curies	65,000 curies	65,000 curies	65,000 curies
Total radiological inventory reduction*	57,000	65,000 curies	65,000 curies	65,000 curies
Overall protection of human health and the environment	Medium	High	High	High
Compliance with applicable or relevant and appropriate requirements**	Low **	High	High	High
Long-term effectiveness and permanence	Medium	High	High	High
Reduction of toxicity, mobility, or volume through treatment	NA	NA	NA	NA
Short-term effectiveness	High	High	High	Low
Implementability	High	High	High	Low
Total estimated cost	Indeterminate	$142 M	$144 M	$205 M
Occupational Dose	Indeterminate	3 Person-rem	4 Person-rem	20 Person-rem

* Including reductions from natural radioactive decay over a period of 68 years

** Implementation of this alternative involves the indefinite storage of radioactive materials and would be in conflict with New York State regulations regarding the siting of LLRW disposal facilities.

This page intentionally blank.

TABLE OF CONTENTS

LIST OF FIGURES AND TABLES

TABLES

This page intentionally blank.

ACRONYMS, ABBREVIATIONS, AND UNITS OF MEASURE

ACM	asbestos-containing material
ALARA	as low as reasonably achievable
Am-241	americium-241
ARARs	applicable or relevant and appropriate requirements
BGRR	Brookhaven Graphite Research Reactor
BNL	Brookhaven National Laboratory
BSA	Brookhaven Science Associates
C-14	carbon-14
CAC	Community Advisory Council
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CFR	Code of Federal Regulations
Ci	curies
CNF	Cold Neutron Facility
Co-60	cobalt-60
COPC	contaminants of potential concern
CRB	control rod blade
Cs-137	cesium-137
D&D	decontamination and decommissioning
DOE	U.S. Department of Energy
DOT	U.S. Department of Transportation
dpm	disintegrations per minute
EM	Environmental Management
EP	Plant Engineering Division, BNL
EPA	U.S. Environmental Protection Agency
Eu-154	europium-154
Eu-155	europium-155
Fe-55	iron-55
FHWMF	Former Hazardous Waste Management Facility
FS	feasibility study
ft	feet
FY	Fiscal Year
H-3	hydrogen (tritium)
HFBR	High Flux Beam Reactor
HVAC	heating, ventilation and air conditioning
in	inch
km	kilometers
lb	pounds
LLRW	low level radioactive waste
LUIC	land use and institutional controls
MCL	maximum contaminant level
MDA	minimum detectable activity
MIT	Massachusetts Institute of Technology
m^3	cubic meters
mrem/yr	millirem per year

MW	megawatts
na	not applicable
NEPA	National Environmental Policy Act of 1969
NESHAP	National Emissions Standards for Hazardous Air Pollutants
Ni-59	nickel-59
Ni-63	nickel-63
NRC	U.S. Nuclear Regulatory Commission
NYCRR	New York Codes, Rules, and Regulations
NYSDEC	New York State Department of Environmental Conservation
NYSDOH	New York State Department of Health
OU I	Operable Unit I
OU III	Operable Unit III
ORNL	Oak Ridge National Laboratory
PAH	polycyclic aromatic hydrocarbons
PCB	polychlorinated biphenals
pCi/gm	picoCuries per gram
RAO	remedial action objectives
RCRA	Resource Conservation and Recovery Act
rem	Roentgen equivalent man
ROD	Record of Decision
S&M	surveillance and maintenance
SCDHS	Suffolk County Department of Health Services
SHPO	State Historic Preservation Officer
Sr-90	strontium-90
SRS	U.S. Department of Energy, Savannah River Site
U.S.C.	United States Code
VOC	Volatile Organic Compound
WLA	Waste Loading Area
WCF	Waste Concentration Facility
yd^3	cubic yards

1.0 INTRODUCTION

1.1 PURPOSE AND ORGANIZATION OF THE REPORT

1.1.1 Purpose

The purpose of this feasibility study (FS) report is to document the development, screening, and evaluation of remedial alternatives and removal actions that will address contamination at the Brookhaven National Laboratory (BNL) High Flux Beam Reactor (HFBR) complex.

1.1.2 Organization

This report is divided into five sections. Section 1 provides an introduction to the HFBR complex and explains the nature and extent of the contamination and radioactive materials remaining at the reactor complex. It describes the basis for action and the remedial action objectives. This section also provides the conceptual site models (CSMs) that explain potential pathways of human exposure to the current state of the remaining radiological hazards and potential pathways for the residual contamination to enter the environment. Section 2 discusses the technologies relevant to HFBR decontamination, dismantlement, and waste disposal and presents a list of federal and state applicable or relevant and appropriate requirements (ARARs). Section 3 provides a description of each of the four remedial action alternatives. Section 4 provides an individual and comparative evaluation of these alternatives against criteria required under the Comprehensive Environmental Remediation, Compensation and Liability Act (CERCLA). Section 5 lists the references cited within this report.

1.2 SITE BACKGROUND AND DESCRIPTION

BNL is owned by the U.S. Department of Energy (DOE) and managed by Brookhaven Science Associates (BSA), a limited-liability company founded by the Research Foundation of the State of New York and Battelle, a nonprofit, applied science and technology organization. One of the 10 DOE national laboratories, BNL conducts research in the physical, biomedical, and environmental sciences, as well as in energy technologies and national security. The Laboratory also builds and operates major scientific facilities available to university, industry, and government researchers.

BNL is located in Suffolk County on Long Island, about 60 miles east of New York City (Figure 1.1). Approximately 1.4 million (M) people reside in Suffolk County and approximately 450,000 reside in Brookhaven Township within which BNL is situated. The BNL site covers almost 5,300 acres, much of which is wooded. BNL has operated since 1947 as a research facility for national science and technology programs, and is expected to continue this mission for the foreseeable future.

Most BNL facilities are located near the center of the site in a developed portion that covers about 1,700 acres. The HFBR complex is within this central portion (Figure 1.2) of the BNL property. The complex covers about 13 acres which is less than one-hundredth of the overall BNL site.

The HFBR operated from 1965 to 1996, and was used solely for scientific research providing neutrons for materials science, chemistry, biology, and physics experiments. During a routine maintenance shutdown in 1996, tritium from the spent fuel canal was found in groundwater south of the reactor. Investigations revealed that the source of the tritium was a small leak in the ceramic tile lined concrete pool where spent nuclear fuel was stored. Operations at the HFBR were suspended and the DOE considered what to do. All of the spent fuel was removed and sent to DOE's Savannah River Site in 1998. The pool was drained and a freestanding, double-walled, stainless steel liner with an instrumented low point sump was installed to eliminate the potential for leakage to the environment. In November 1999, DOE announced it was permanently closing the reactor. The complex consists of multiple structures and systems that were necessary to operate and maintain the reactor (Figure 1.3). Portions of the confinement building structures, systems, and components, some of which are underground, are contaminated with radionuclides and chemicals as a result of previous HFBR and Brookhaven Graphite Research Reactor (BGRR) operations.

The most recognizable feature of the HFBR is the hemispherical dome which is the superstructure of the confinement building (Building 750). This structure is formed of welded steel plates supported on an integral I-beam framework resting on a cylindrical base. The steel plates in the hemispherical section are 0.250 in. thick, and those in the cylindrical base are 0.375 in. thick. The hemispherical portion of the dome is insulated on the outside, and the insulation is covered with aluminum sheets. The inside diameter of the hemisphere at its base is 176 ft 8 in. The cylindrical base is 22 ft 4 in. high and rests on a bedplate that is bolted to the reinforced concrete foundation ring. The foundation of the confinement building is a 5-ft thick reinforced concrete mat bearing on the soil beneath the building.

Access to the confinement building is provided by four airlocks: a personnel airlock (3 ft 3 in. by 7 ft by 9 ft) located between the equipment and experimental levels on the south side of the building; a forklift airlock (6 ft by 8 ft 9 in. by 18 ft) located on the north side of the experimental level; and two tractor trailer airlocks (12 ft by 14 ft by 65 ft) one entering on the north side of the experimental level and the other on the east side of the equipment level. The interior of the confinement building (Figure 1.4) contains the reactor and biological shield and is further divided into equipment, experimental, balcony, and operations levels.

Reactor and Biological Shield - The HFBR core consisted of 28 individual fuel assemblies arranged in a close-packed array (Figure 1.5). The fuel material was highly enriched (93 percent) uranium alloyed in aluminum and clad with aluminum in curved plates. Heavy water (D_2O) served as the moderator/reflector and primary coolant. The reactor vessel was fabricated from a 6061-T6 aluminum alloy and contained the active core, reflector, and control rods. The enclosed volume provided space and access for 16 experimental facilities which utilized the high neutron flux in the core region. The vessel consists of an 82 in. (inside diameter) spherical section welded via a transition piece to a 46 in. (inside diameter) cylinder. The overall height of the vessel assembly is 24.75 ft. The nine horizontal beam reentry tubes are integral parts of the vessel's spherical section.

A 9 in. thick thermal shield surrounds the reactor vessel. The thermal shield consists of a carbon steel shell lined with lead. Surrounding both the reactor vessel and the thermal shield is an 8 ft thick biological shield (Figure 1.6). It consists of an inner and outer steel shell filled with high-density concrete which also serves as an essential component of the structural integrity of the confinement building. The biological shield supports the center of the operations level above.

There are sixteen control rod blades (CRBs) within the reactor vessel, separated into main and auxiliary groups, each containing eight CRBs. The CRBs operated in the reflector region just outside the core. The CRBs are angle-shaped in cross-section, and are made of stainless steel, encapsulating europium oxide (Eu_2O_3) and dysprosium oxide (Dy_2O_3), both neutron absorbers.

Equipment Level - The equipment level is located at an elevation of 93 ft above sea level. It houses most of the reactor and building support equipment such as pumps, heat exchangers, filters, wastewater storage tanks, and piping networks. Shielded cells for the primary cooling water system pumps and heat exchangers are located in the center of the level. The spent fuel cooling and storage canal (also referred to as the spent fuel canal) is located to the east of the shielded cells. The canal is 8 ft wide, 43 ft long, and 20 ft deep for most of its length. A small bay, 8 ft by 10 ft, is located on the north side of the canal and was used primarily for cutting operations to remove the aluminum transition pieces from the spent fuel elements. At the west end of the canal, a 30 ft deep section is located immediately below the fuel discharge chute. The primary coolant purification system and one of its two D_2O storage tanks are installed in pits below the floor in the northeast quadrant. Along the south wall are three cells partitioned from the rest of the level by a confinement wall. These are the transformer room, blower room, and generator room. Each of these rooms has access from outside the building.

***Experimental Level* -** The experimental level, located at an elevation of 113 ft 6 in., was for scientific users. The reactor biological shield which surrounds the reactor occupies the central portion of this level. The large open space surrounding the biological shield housed the substantial amounts of equipment used in the conduct of external neutron beam experiments. Laboratories and offices are located along the perimeter wall of this level. A 20-ton capacity radial traveling beam crane services this level.

Balcony - The balcony, located at an elevation of 128 ft 6 in., is approximately 21 ft wide, with its outer circumference at the confinement shell. Offices, locker rooms, toilets, and HVAC equipment are contained on this level. Two 30 in. diameter duct penetrations that provide fresh air intake are also located on the balcony.

Operations Level- The operations level is located at an elevation of 141 ft 6 in. The reactor biological shielding structure which begins on the experimental level rises to 7.5 ft above the operations level at the center of the building. The southwest quadrant of this level contains a steel building that houses pumps, a heat exchanger, and piping associated with the cooling water system for the experimental facilities. The second of the two D_2O storage tanks is also located in this area. Offices and workrooms are located on the east side of this level, with the reactor control room occupying the second story above the offices. A two-story cinderblock structure containing the instrument shop and offices is located on the west side of this level.

Ancillary buildings and services – The HFBR complex includes several ancillary structures and underground duct and piping systems as shown in Figures 1.3 and 1.9. These facilities include:

- Building 704 – Fan House: This facility was initially constructed to provide primary and secondary cooling air for the BGRR. It encloses the BGRR discharge plenum. The building houses the electrical switchgear and the normal and emergency power batteries for the HFBR. This switchgear also provides normal power to Building 703 and in turn to Building 701. It also provides the pathway for the HFBR Building 750 exhaust through underground ductwork and filter banks.

- Building 705 – Stack: The 100 meter tall contaminated stack was initially constructed to provide an elevated exhaust of the BGRR primary and secondary cooling air. Subsequently, additional building exhausts were connected to the stack. They include multiple exhausts streams from Buildings 801, 815, 830, 901 and the HFBR confinement building (Building 750).

- Building 802 – Fan House: This structure houses the fans and equipment that provided the building exhaust flow for Buildings 801, 815 and 830. It also housed the equipment for evaporation of low-level tritiated water.

In addition to the exhaust ductwork connecting the buildings described above, there is a lined liquid waste pipe (D/F waste line) that transported contaminated liquids from the HFBR to Building 801.

1.3 NATURE AND EXTENT OF CONTAMINATION

The HFBR has been continuously maintained under a surveillance and maintenance (S&M) program from its initial operation in 1965. Since it was permanently shutdown in November 1999, a number of actions have been taken to remove contaminated structures, systems, and components from the HFBR complex. These actions are tabulated in the Summary of Interim Stabilization and Removal Actions, Table 1.1. Most of the HFBR reactor systems have been put into a lay-up condition, and only some systems, such as the building heating, ventilation, and cooling (HVAC) systems remain in service.

Between 2000 and 2005, comprehensive sampling and analyses were performed to characterize the HFBR complex. The non-radiological and radiological characterization results were published in several reports included as references to this FS.

Certain chemicals and hazardous materials were used during the construction and operation of the HFBR. They include PCBs, asbestos and lead in materials of construction, organic solvents for degreasing equipment, and elemental mercury in certain instruments used in facility operations. Non-radiological characterization findings include the following:

- Asbestos-containing material (ACM) intrinsic to older floor and ceiling tiles, in gaskets, piping and wiring insulation, switchgear spark arrestors, and roofing materials.
- PCBs intrinsic to original paint, and hydraulic fluids.
- Lead intrinsic to paint, lead blocks and dust, shielding, and batteries.
- Other heavy metals of concern include zinc that was frequently detected and cadmium and beryllium that were found sporadically.
- Sampling for mercury revealed negative results but is intrinsic to capacitors, light ballasts, gearboxes, and in motor-operated valve lubricating oils.
- Solvents, degreasers, lubricants, oils, and petrochemicals intrinsic to equipment such as motors and compressors.
- Sodium hydroxide (NaOH) and sulfuric acid (H_2SO_4) were used for water treatment. Chemical storage tanks were drained and rinsed.
- Lithium arsenite used in the confinement building air conditioning system.
- Suspected trace amounts of cadmium nitrate and gadolinium nitrate on the operations level due to handling spills.

The radiological characterization of the facility included activation analyses of the reactor vessel and its internal components, thermal shield, and biological shield. Radiological characterization also included the reactor building structures, systems, and components and the ancillary buildings comprising the rest of the HFBR complex. Characterization of the outside areas included surface and subsurface soils and various underground duct and piping systems.

The total of the radioactive material remaining at the HFBR complex predominantly consists of activated components within the reactor and the surrounding thermal and biological shields. There are small amounts of contamination contained within the confinement building structures, systems, and components and some of the ancillary structures. There are also isolated small areas of radiologically contaminated soils in the HFBR complex. The entire radiological inventory of the HFBR complex was estimated, as of January 2007, to be 65,000 curies. The nature and extent of this radiological contamination is described in Sections 1.3.1, 1.3.2, and 1.3.3.

1.3.1 Activated Components

Neutron activation of HFBR reactor components and immediately adjacent structures has resulted in a substantial inventory of radioactive material within the reactor and the inner region of the surrounding biological shield. The activated components inventory is calculated to be 65,000 curies as of January 2007, which is more than 99 percent of the total radioactive material remaining at the HFBR complex. Table 1.2 shows the total amount of activity and isotopic distribution contained within the activated components, with radiological decay calculated through 2107. Most of the activated iron (Fe-55) is in the thermal shield, CRBs, and the remaining reactor internals. Most of the cobalt and long-lived nickel (Ni-59 and Ni-63) is in the stainless steel components of the reactor internals and CRBs while all of the europium (Eu-154 and Eu-155) is contained in the

CRBs. Figure 1.7 illustrates the composite radiological decay of all activated components through 2107. Figure 1.8 provides the distribution of activity among the various activated components.

The physical form of these components, activated metal and concrete, makes the hazard primarily a direct exposure risk rather than a risk of environmental contamination through dispersal. The reactor vessel, internals, thermal shield, and the activated portion of the biological shield are well shielded in their current configuration. There are no significant radiological hazards from those materials until they are disturbed during dismantlement and decommissioning.

It is important to note that the calculated dose rates associated with these components are very high. For example, the maximum CRB calculated dose rate is as high as 13,000 rem/hr at one ft. The calculated high dose rates developed in this document are based on standard calculation models that calculate dose rate from total activity and physical size and shape of the components. Dose rates are important to know so that effective controls and methods of handling can be developed. The actual dose rates to which workers would be exposed would be controlled by such means as remote handling, use of robotics, conduct of operations underwater, and the use of shielding. Typically, dose rates would be limited to much less than 100 mrem/hr. Worker radiation exposure, would be controlled to stay within administrative and regulatory limits.

The dominant isotope driving these calculated dose rates is Co-60, with a half-life of 5.3 years. With Co-60 as the dominant dose rate driver, (see Table 1.2) there is a rapid decrease in calculated dose rate as a function of time because of radioactive decay. Typical calculated dose rates for some of these components are shown in Table 1.3. For the CRBs, short-term dose rate is governed by the decay of Co-60 and Eu-154. The decay in activity for each component over the next 100 years, is shown in Table 1.4.

1.3.2 Contaminated Structures, Components and Underground Ducts/Pipelines

The areas within the HFBR confinement building (Building 750) contain almost all of the radioactive contamination remaining in the reactor complex. The confinement building structure itself is contaminated to a small extent. All of the concrete floors and walls within the confinement Building 750 are estimated to contain approximately 0.1 Ci, primarily H-3 and Co-60, of fixed and/or removable contamination. While the Co-60 contamination is mostly found on the equipment level, the H-3 contamination discussed in 1.3.2 is found on all levels of the confinement building. The extent of this contamination is noted “Interior of the confinement shell is contaminated with removable H-3” on the CSMs, Figures 1.11 and 1.12 just under the title “Building 750: Confinement Structure.” The total contamination inventory inside of the reactor systems within the confinement structure is approximately 45 Ci. Estimates of the radiological inventory contained within Building 750, exclusive of the activated components, are detailed in Table 1.5.

Some of the ancillary buildings and underground duct and piping systems outside of the reactor confinement building, shown in Figures 1.3 and 1.9, contain small amounts of radioactive contamination. Contamination of these ancillary buildings and underground duct and piping systems is summarized as follows:

- Building 704 - Fan House: Concrete samples indicate concentrations of Sr-90 up to 92 pCi/g in the fan cells concrete, and activity in the underground duct concrete of up to 6,900 pCi/g Cs-137, 429 pCi/g Sr-90, 503 pCi/g H-3, and 36 pCi/g Am-241. The contamination was generally contained within the first half-inch of the concrete structures. Fixed radioactive contamination levels up to 75,000 dpm/100cm^2 exist in an area near the filter bypass facility. There are also elevated contamination levels near the underground plenum area. It is estimated that the total radioactive material inventory content in the steel, concrete, and soils is about 0.1 Ci, consisting primarily of Cs-137 and Sr-90. It should be noted that the Cs-137, Sr-90 and Am-241 contamination is attributable to previous operation of the BGRR.
- Building 705 - Stack: Smears of the interior lower portion of the stack indicated removable contamination up to 22,000-dpm/100 cm^2. Cs-137 was detected. Core bore samples were analyzed, and the average contamination concentrations over the first half-inch in depth were 141 pCi/g Sr-90, 77 pCi/g H-3, and 344 pCi/g Cs-137. Essentially all the contamination was found in the first 0.5 to 0.75 inches of depth. It is calculated that the total radioactive material inventory content present in the stack concrete is approximately 0.03 Ci. Again, the Cs-137 and Sr-90 contamination is attributable to previous operation of the BGRR.
- Building 751 - Cold Neutron Facility: Radiological surveys of the Cold Neutron Facility indicated background levels. Contaminated equipment that was previously installed inside of Building 751 has been removed and disposed as LLRW. This building has been transferred to another BNL organization for re-use and is no longer part of this project.
- Building 802 - Fan House and Tritium Evaporation Facility: Based on process knowledge, the facility is contaminated with low levels of H-3 and Co-60. It is estimated that the total radioactive material inventory content in the steel, concrete and soils in less than 0.01 Ci.
- Stack underground ventilation ducts and lines: Radiological characterization of the interconnecting ducts indicate that the ducts from Building 750, Building 801 and Building 802 are contaminated. Short sections of the ducts from Building 901 and Building 701 are also contaminated where they are connected to the stack or to other interconnecting ductwork. The activity is a combination of fixed and removable contamination, and it was identified as a combination of H-3, Co-60, Ni-63, and Cs-137. The total activity in these ducts is estimated to be less than 0.1 curie.
- D/F Waste Line: Based on process knowledge, this double-walled underground pipeline that runs between Building 750 and Building 801 is contaminated. It is estimated that less than 0.1 Ci is present in this line, with an isotopic content of H-3, Co-60, Ni-63, and Cs-137.
- Sanitary Sewage Line from the HFBR: – Based on process knowledge the sanitary sewage line is contaminated. It is estimated that less than 0.1 Ci is present in this line, with an isotopic content of H-3, Co-60, Ni-63, and Cs-137.

1.3.3 Contaminated Soils

The soils surrounding and beneath the HFBR and support buildings were surveyed and sampled for radioactive contamination. The majority of the HFBR yard area as shown in Figure 1.3 is free of contamination. There are several, small isolated areas of soil contamination as summarized below:

- Soils under Building 704 - fan house: Sampling indicated soil contamination in the soil floor of the basement containing up to 33 pCi/g Sr-90, and 217 pCi/g Cs-137. It is estimated that the total radioactive material inventory in the soils under building 704 is less than 0.1 Ci. The detection of these radionuclides indicates the source to be the BGRR.
- Soils around Building 705 – stack: Samples indicated Cs-137 concentrations slightly above background levels of about 1 pCi/gram, but less than the values typically used at Brookhaven as cleanup criteria (23 – 67 pCi/g). The highest sample was 6.4 pCi/g. It is estimated the soils around Building 705 contain less than 0.01 Ci of radioactive material.
- Soils under Building 750: Samples indicated soil concentrations up to 47 pCi/g H-3, and up to 7,130 pCi/liter H-3 in the groundwater. It is estimated that the total radionuclide inventory in the soils beneath Building 750 is less than 1.0 Ci. Although the sample locations were chosen to be the most likely for detecting tritium contamination, it is possible that higher levels of tritium are present in soils, especially in isolated pockets.
- Soils around the HFBR complex as shown in Figure 1.10: Twenty-one isolated areas of contamination were initially identified during site characterization. Because of their limited size, many of these areas were actually cleaned up through the process of obtaining the samples required for characterization. The eight soil contamination areas remaining are posted in accordance with DOE procedures. The soil contamination in the vicinity of the HFBR confinement building, sample points 3, 4, 11, 12, and 13, is Co-60 and exhibits dose rates ranging from 5 to11 μrem/hr at one foot. The soil contamination in the vicinity of the fan house, sample points 16, 17, and 18, is Cs-137 and exhibits dose rates from 12 to 20 μrem/hr at one foot. The isolated areas of contamination are shown in Figure 1.10. It is estimated the soils around the HFBR complex contain less than 0.01 Ci of radioactive materials.

1.4 BASIS FOR ACTION

Evaluation of Exposure Pathways - Potential pathways of exposure to HFBR contamination have been assessed, considering current and future land use, institutional controls, and releases via various environmental media. The three means that were used to assess which contaminants from the HFBR 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 vessel 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.

Graphic illustrations depicting existing contaminant sources, actual and potential pathways, and control measures are provided in Figures 1.11 through Figures 1.17 as conceptual site models for the HFBR and associated ancillary facilities. As illustrated by the conceptual site models, the sources of contamination at the HFBR complex are prevented from impacting the postulated receptors. The potential for direct exposure (external radiation, ingestion, and dermal contact) to groundwater contamination has been addressed in the OU III Record of Decision. The remedial actions and LUICs implemented in accordance with the OU III ROD will preclude exposure. This has been noted “SCOPE COVERED IN OU-3” on figures 1.12 through 1.14, 1.16, and 1.17. The monitoring of the sewage treatment plant and recharge basins HO and HS , noted as “Outside scope of HFBR project” in Figures 1.12 and 1.14, is done under the site environmental monitoring program.

Justification for Action - As shown in Section 1.3, the HFBR complex contains a large quantity of radioactive materials including the activated components with high dose rates. There are also non-radiological hazardous materials of construction that were originally used to build the HFBR complex.

There is no immediate threat to human health and the environment associated with these radiological and non-radiological hazards. Several physical barriers and administrative requirements control personnel exposure to these hazards. These barriers also prevent the spread of contamination to the environment. Surveillance and maintenance (S&M) of the HFBR complex ensures the effectiveness of these physical barriers, and land use and institutional controls (LUICs) restrict access to the HFBR and control exposure to the remaining radiological and non-radiological hazards.

Although the quantity of radioactive material and radiation levels will be reduced over time as a result of radioactive decay, the radiological and non-radiological hazards would remain as a potential threat to human health and the environment for what is practically an indefinite period of time. This potential threat warrants remedial action in order to provide long-term and future protection of human health and the environment from:

- Activated components in the confinement building, and radioactive and hazardous materials in other structures, systems, and components in the HFBR complex that could result in unacceptable human or environmental exposure.

- Non-fixed (removable or loose) radiological contamination or hazardous materials in the HFBR complex that could result in unacceptable release of contamination to the environment.
- Contaminated soils around the HFBR complex that could result in unacceptable human or environmental exposure.
- Contamination in soils that could impact groundwater at unacceptable levels.

1.5 REMEDIAL ACTION OBJECTIVES

This FS evaluates potential response actions against the following remedial action objectives (RAOs) to control, minimize or eliminate:

- All routes of future human and/or environmental exposure to radiologically contaminated facilities or materials.
- The potential for future release of non-fixed radiological or chemical contamination to the environment.
- All routes of future human and/or environmental exposure to contaminated soils.
- The future potential for contaminated soils to impact groundwater.

Table 1.6 provides a cross reference between these RAOs and the various components and structures comprising the HFBR complex.

Section 1 Figures and Tables

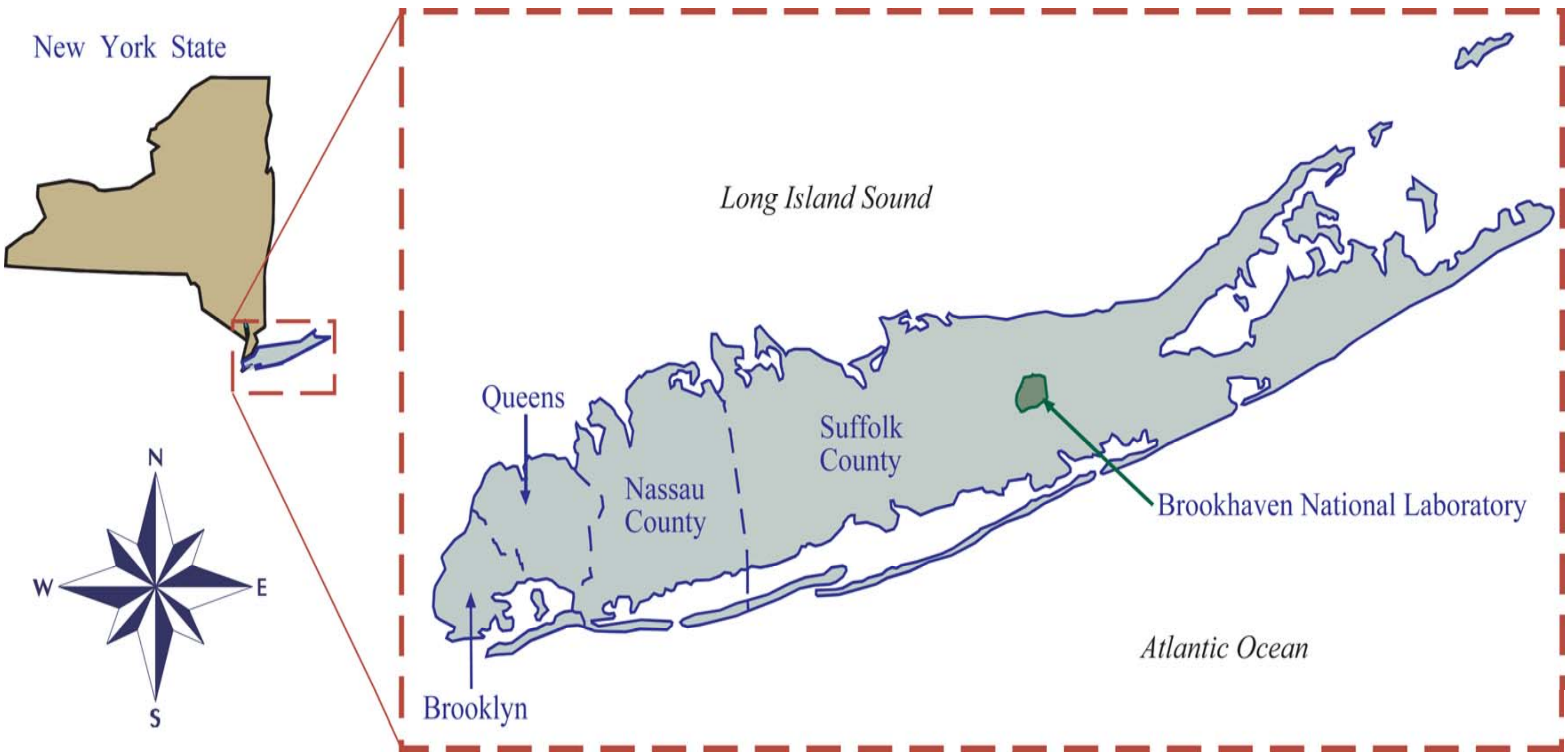


Figure 1.1 BNL in Relation to Long Island, New York

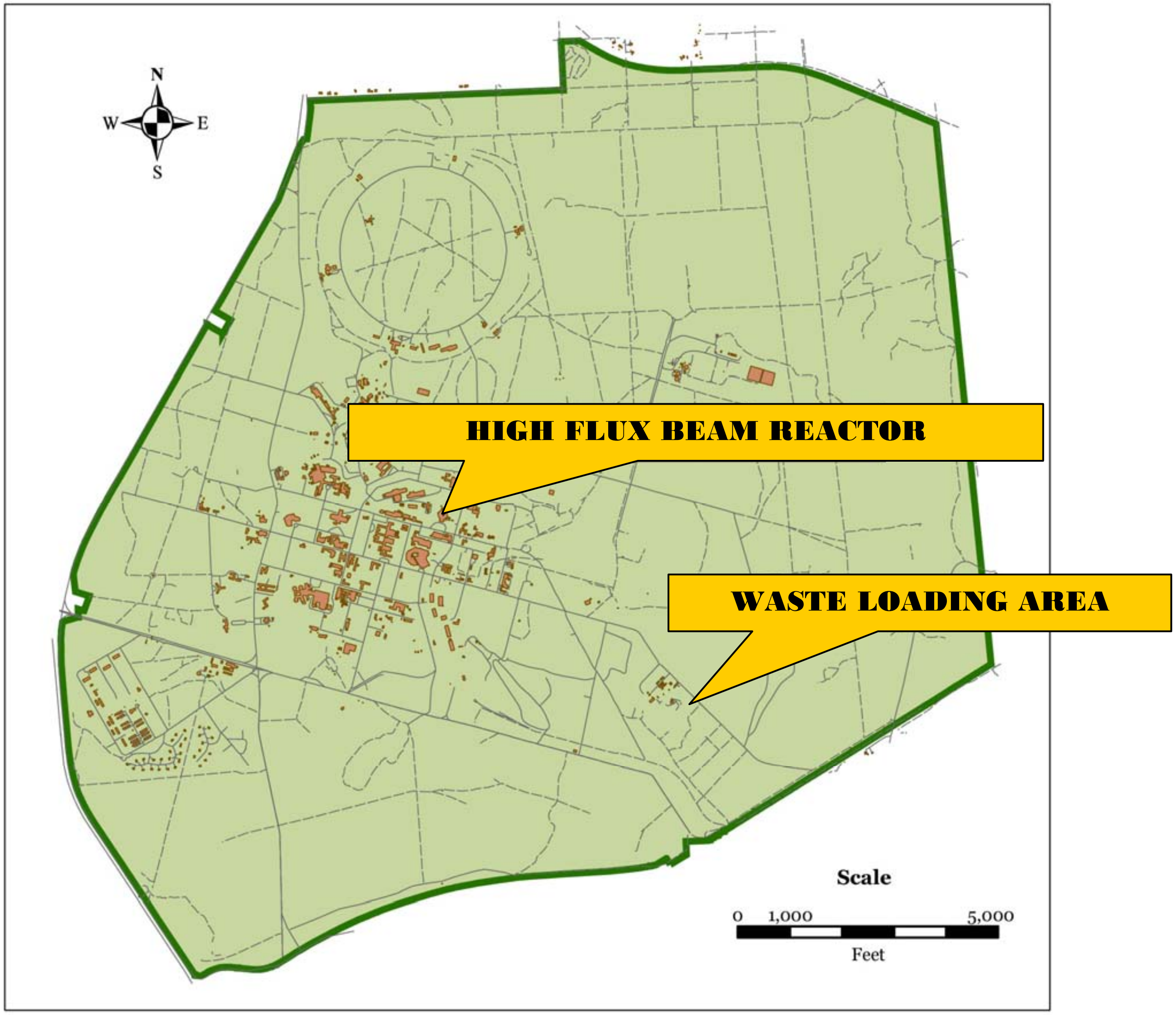


Figure 1.2 HFBR in Relation to BNL Property

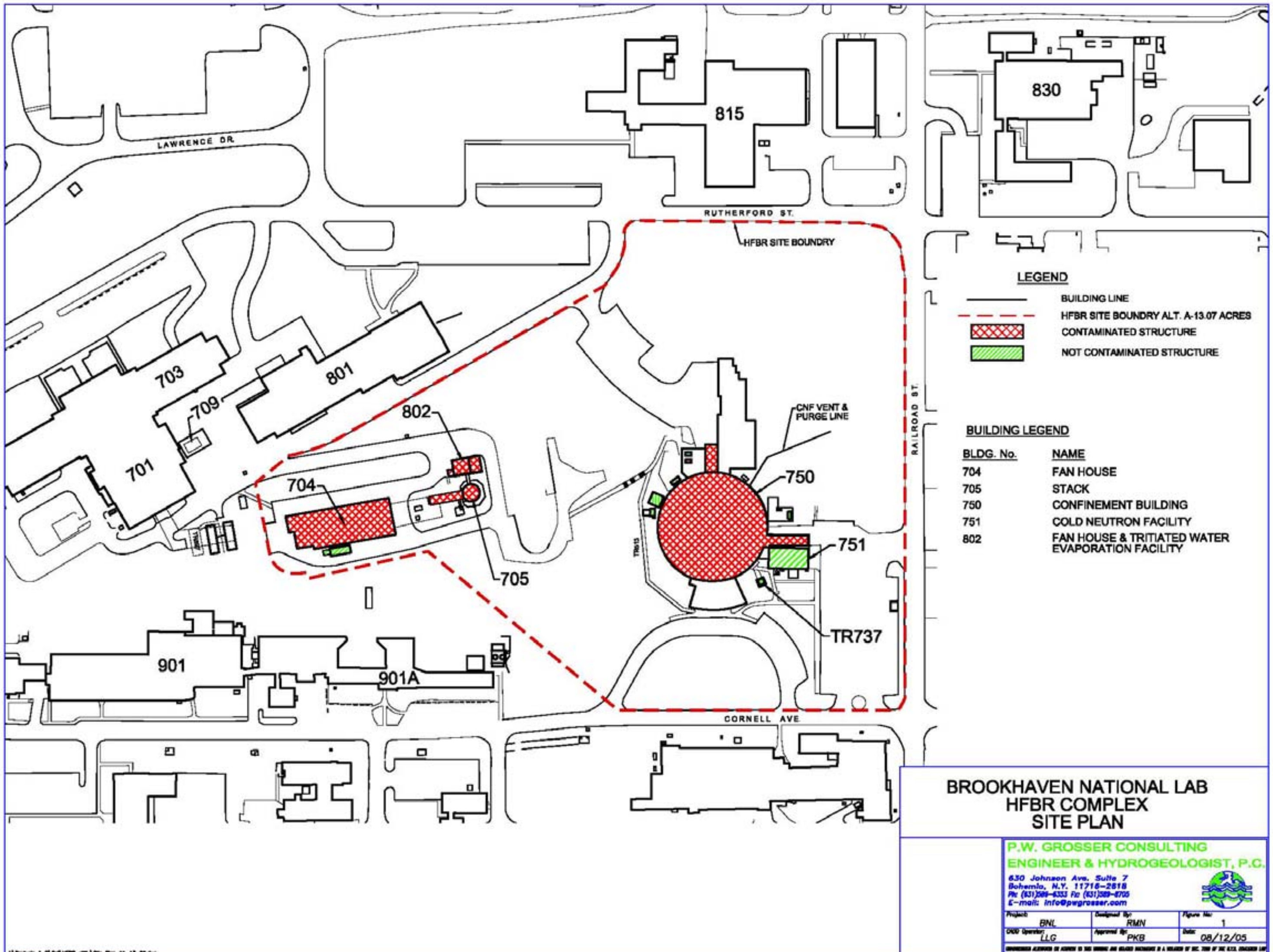


Figure 1.3 HFBR Complex

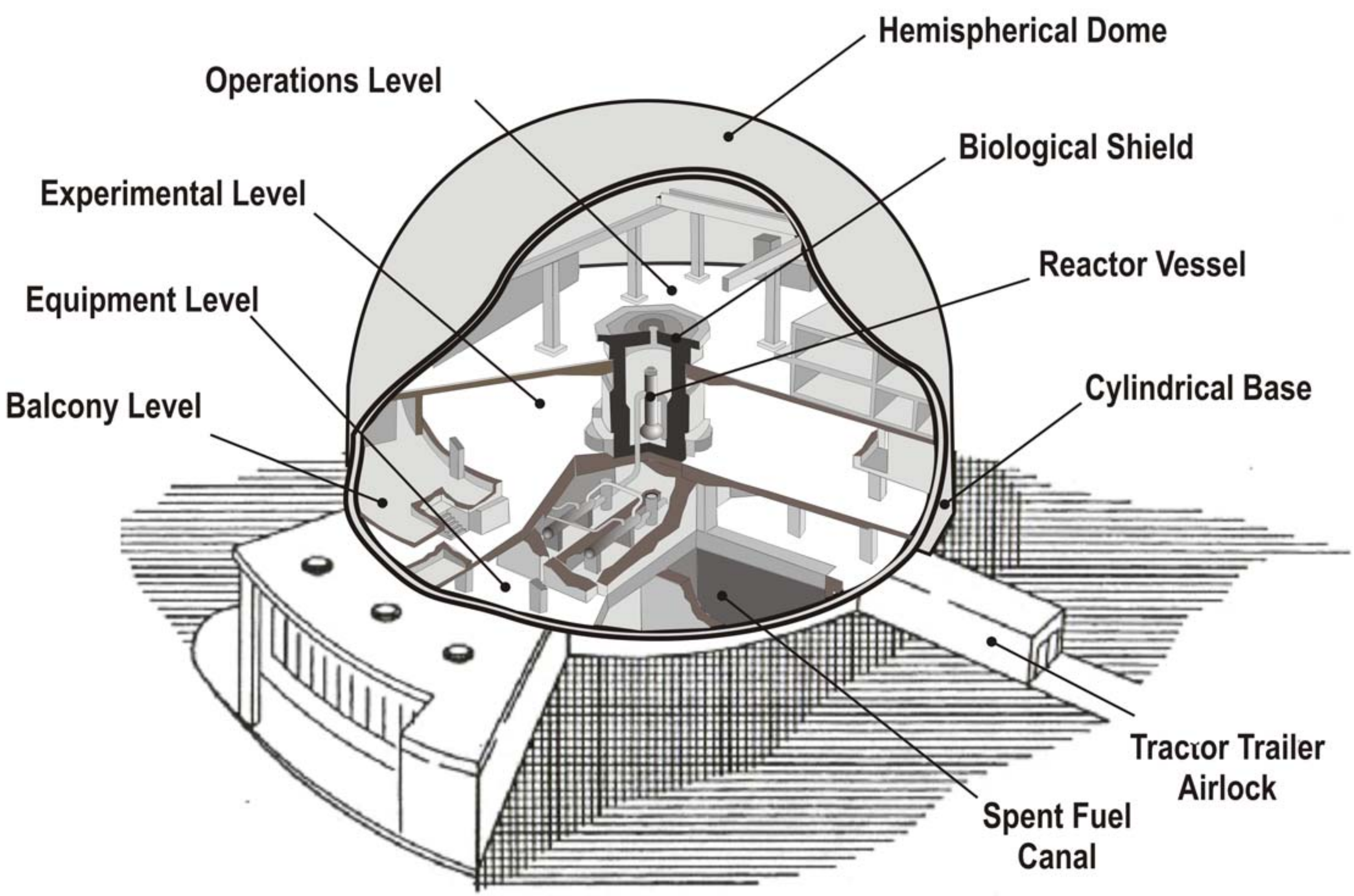


Figure 1.4 Cutaway View of the HFBR, Building 750

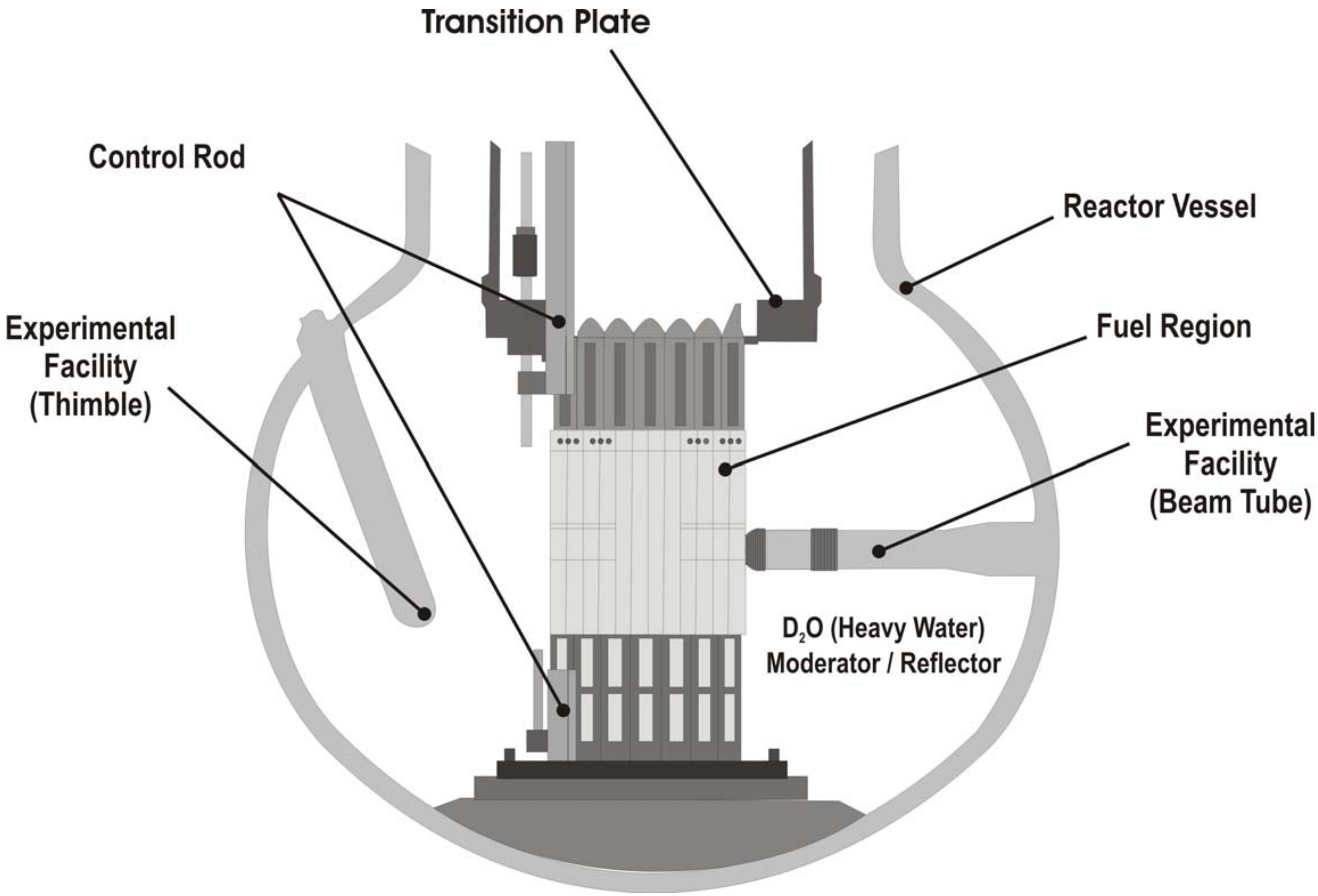


Figure 1.5 HFBR Reactor

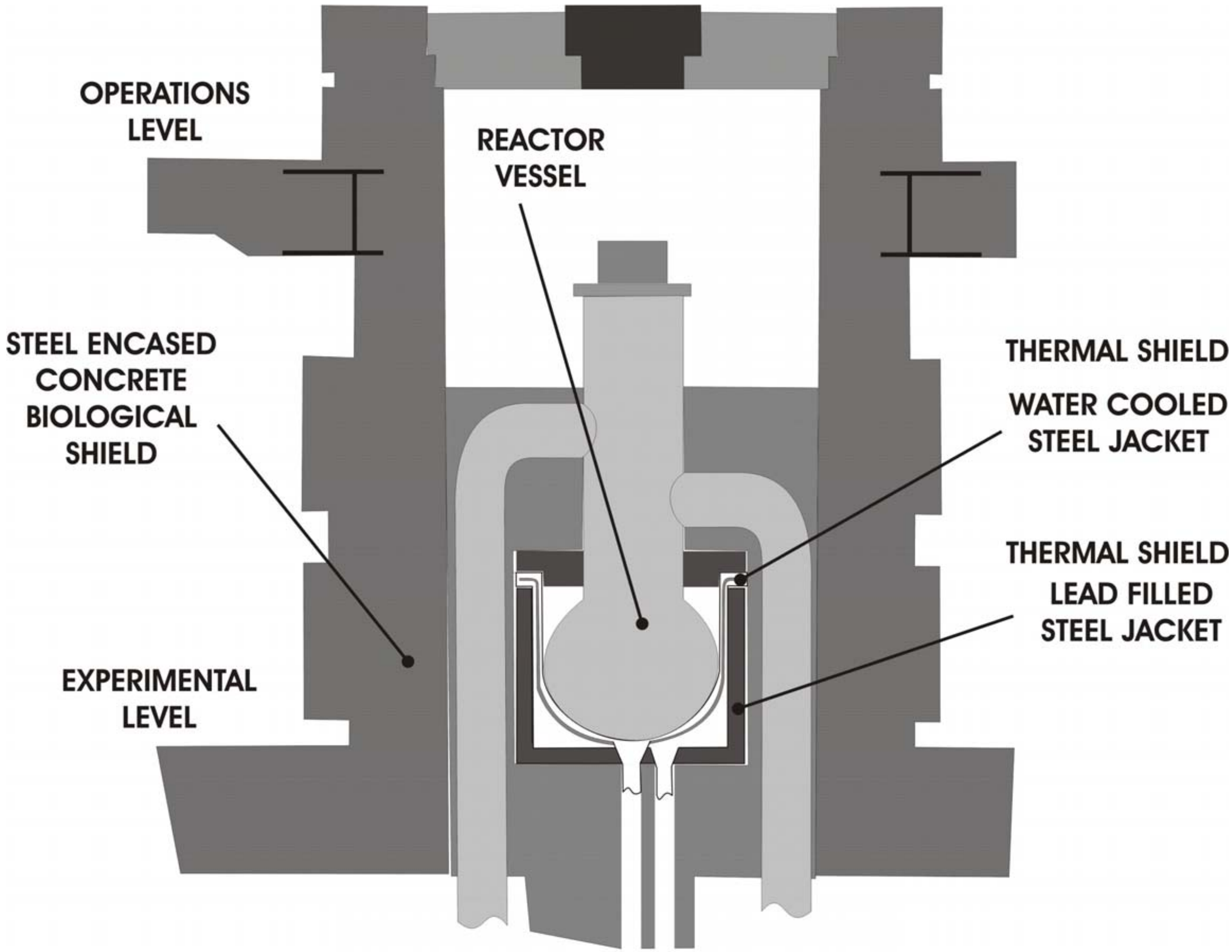


Figure 1.6 Reactor and Biological Shield

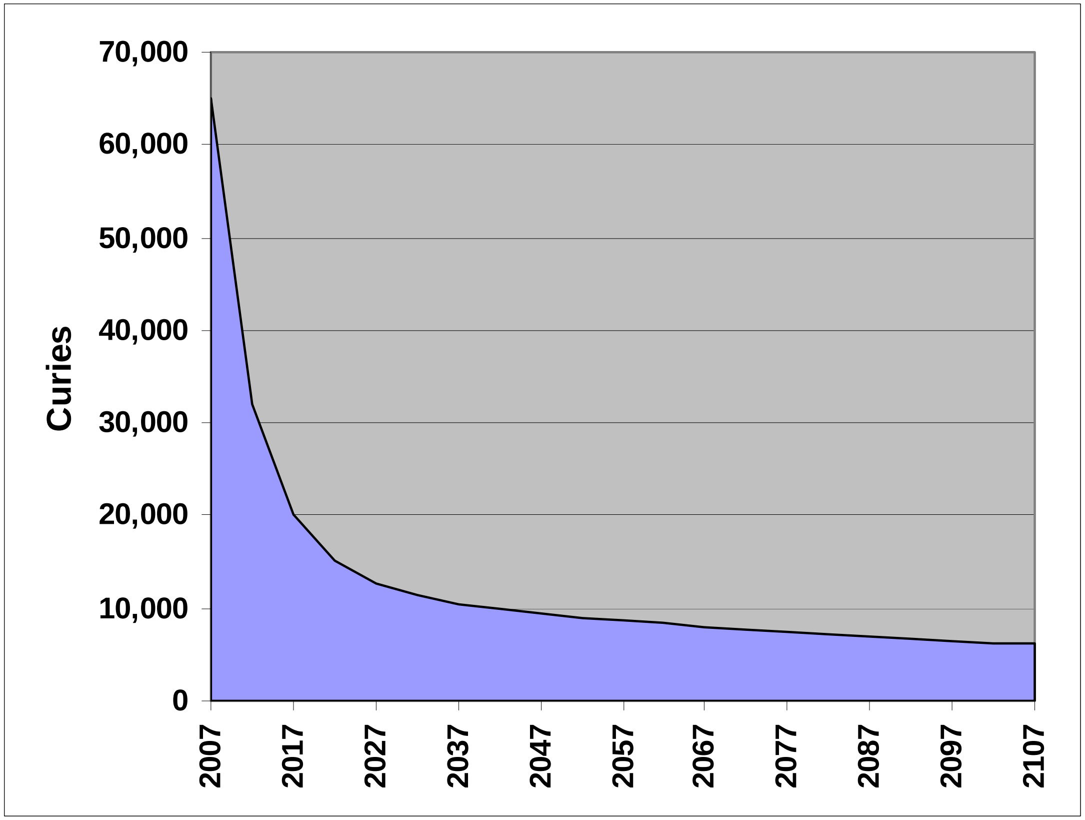


Figure 1.7 HFBR Activated Components – Decay through 2107

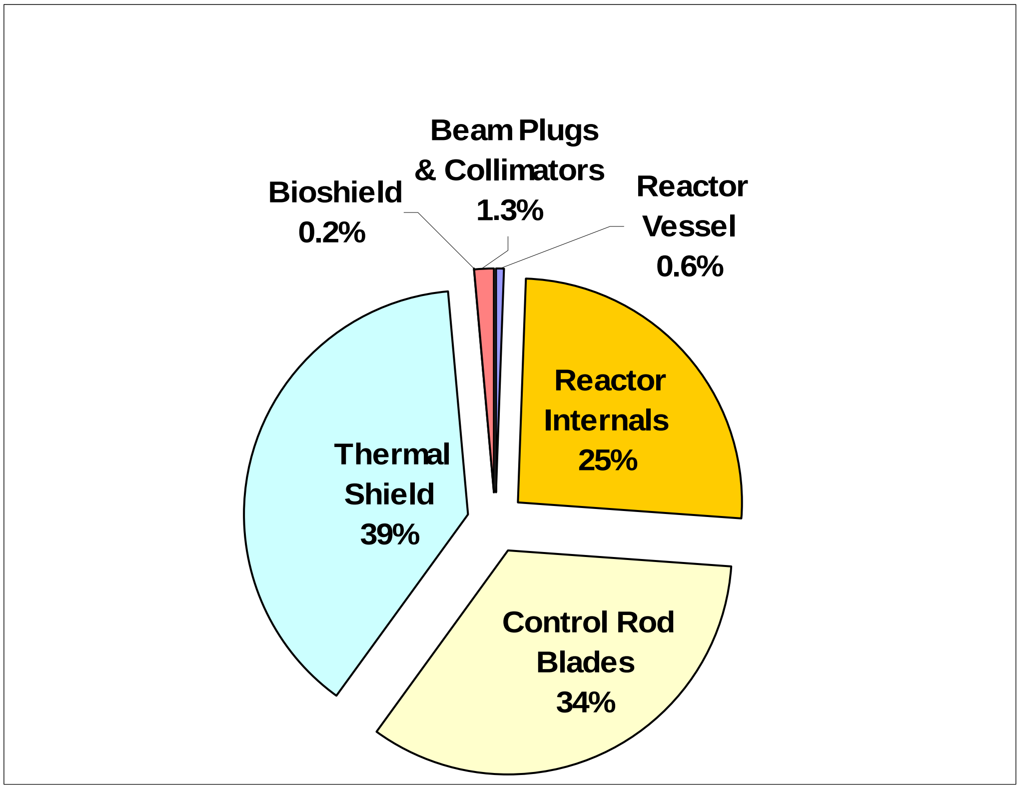


Figure 1.8 Percent of HFBR Activated Component Activity in 2007

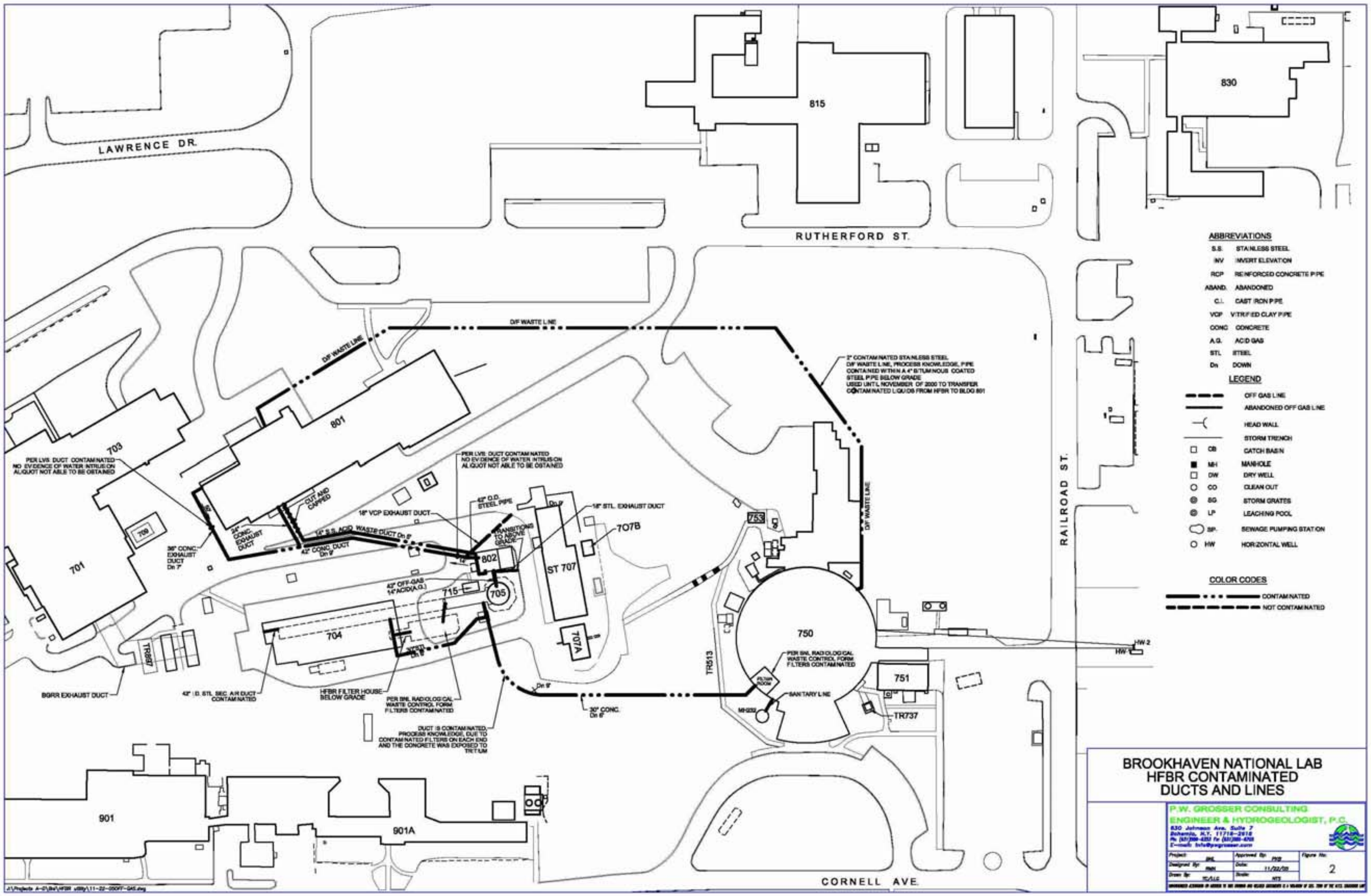


Figure 1.9 HFBR Contaminated Underground Ducts/pipelines

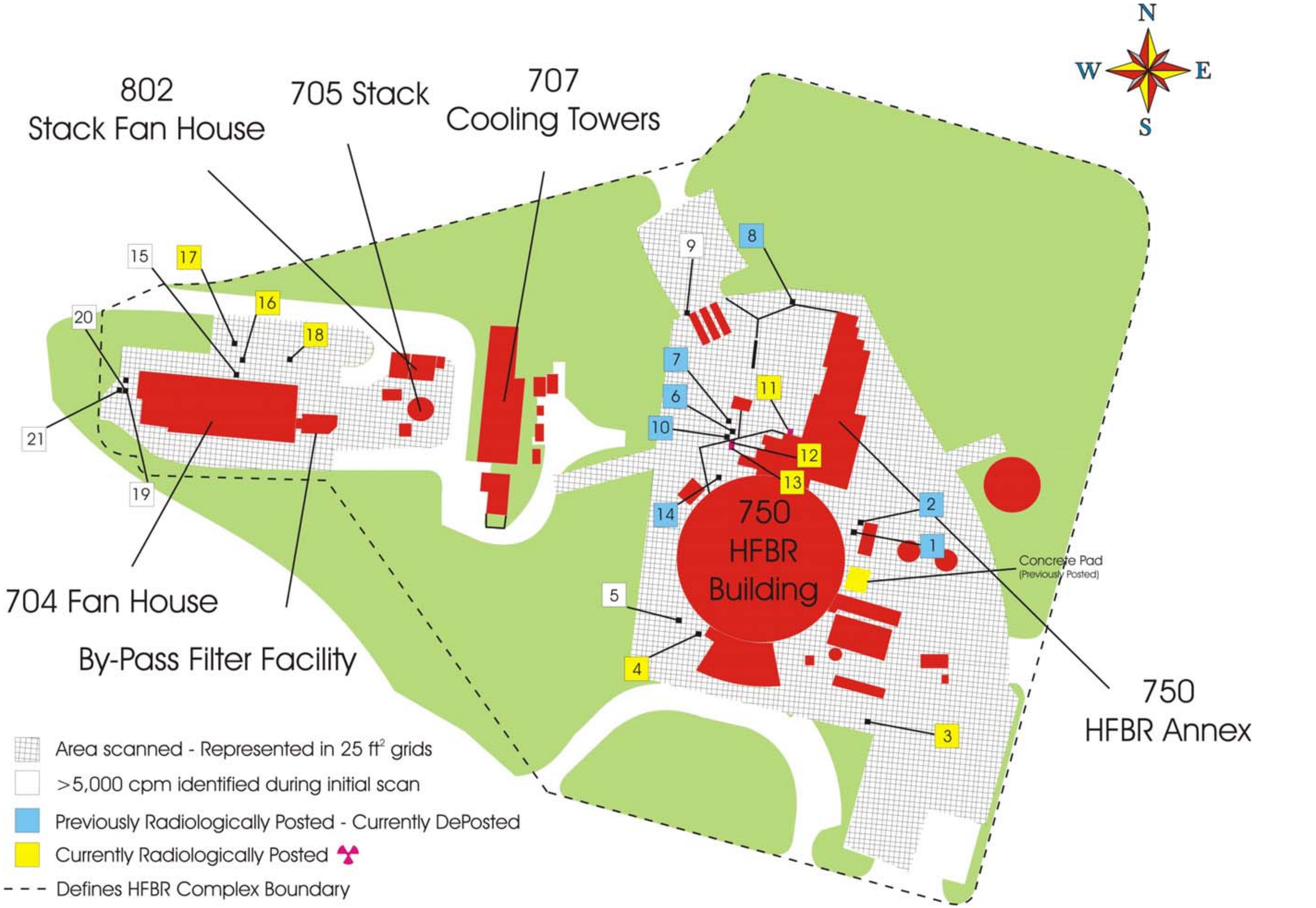


Figure 1.10 HFBR Remaining Soil Contamination Areas

High Flux Beam Reactor Activated Components--Current State

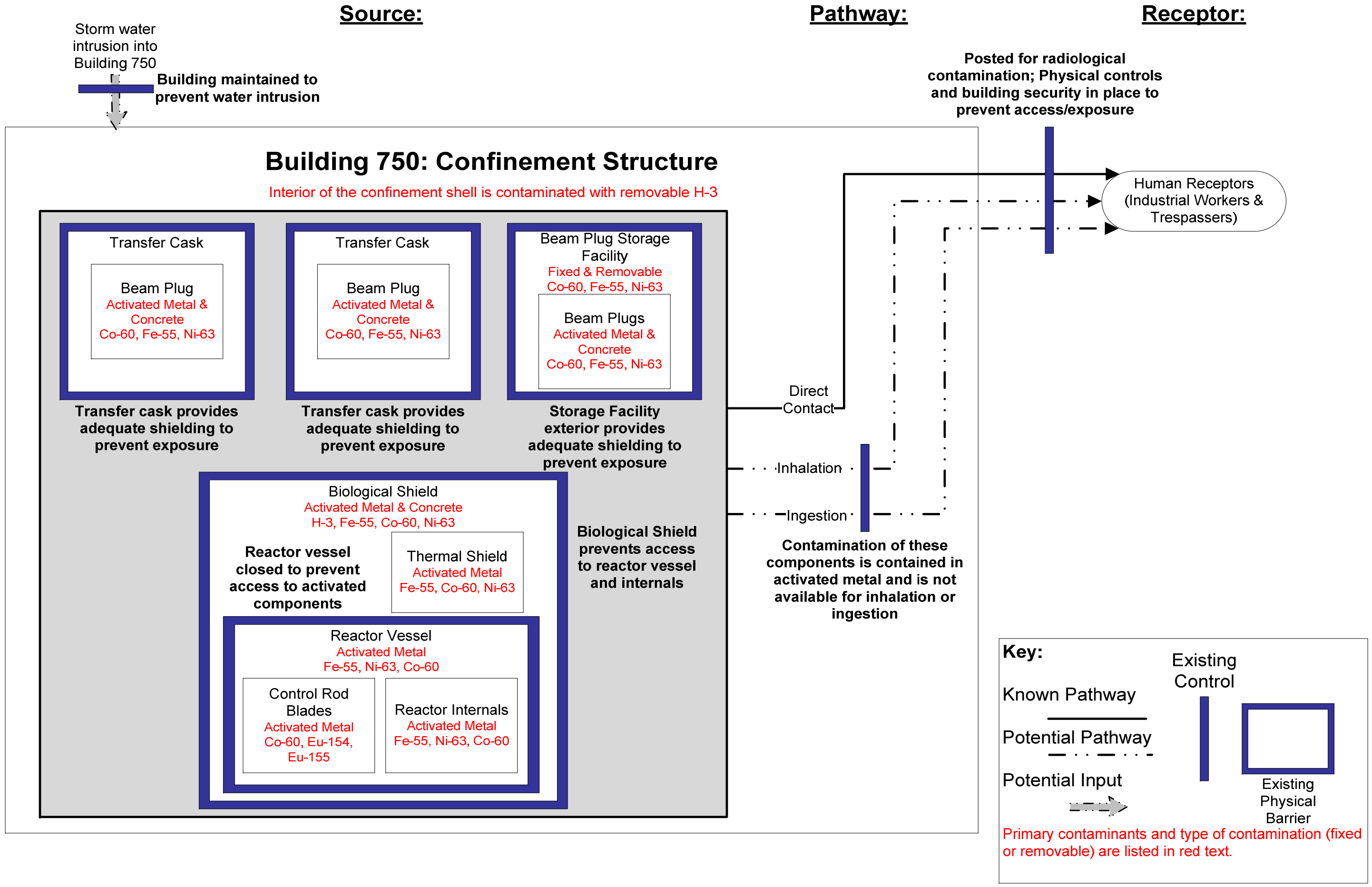


Figure 1.11

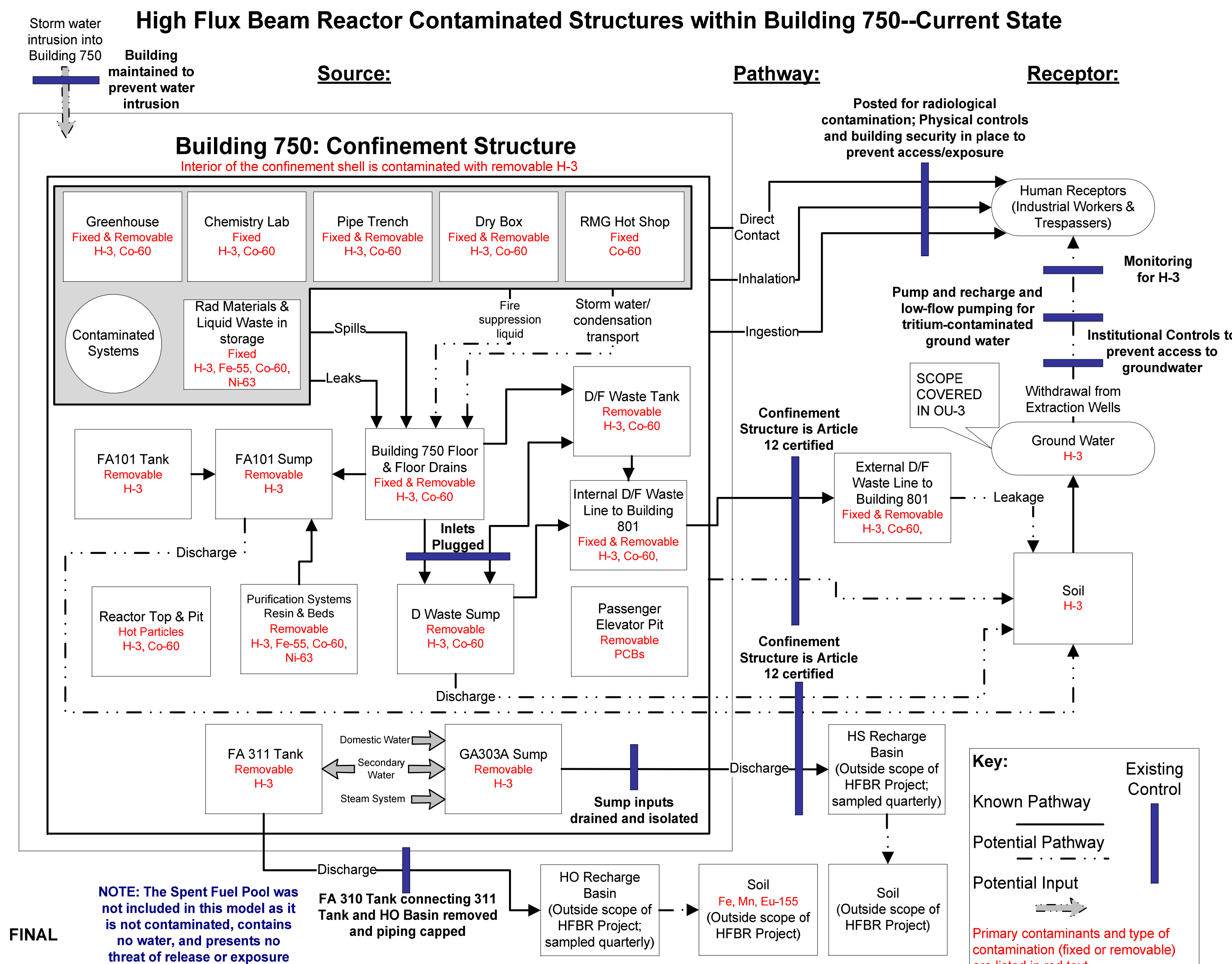
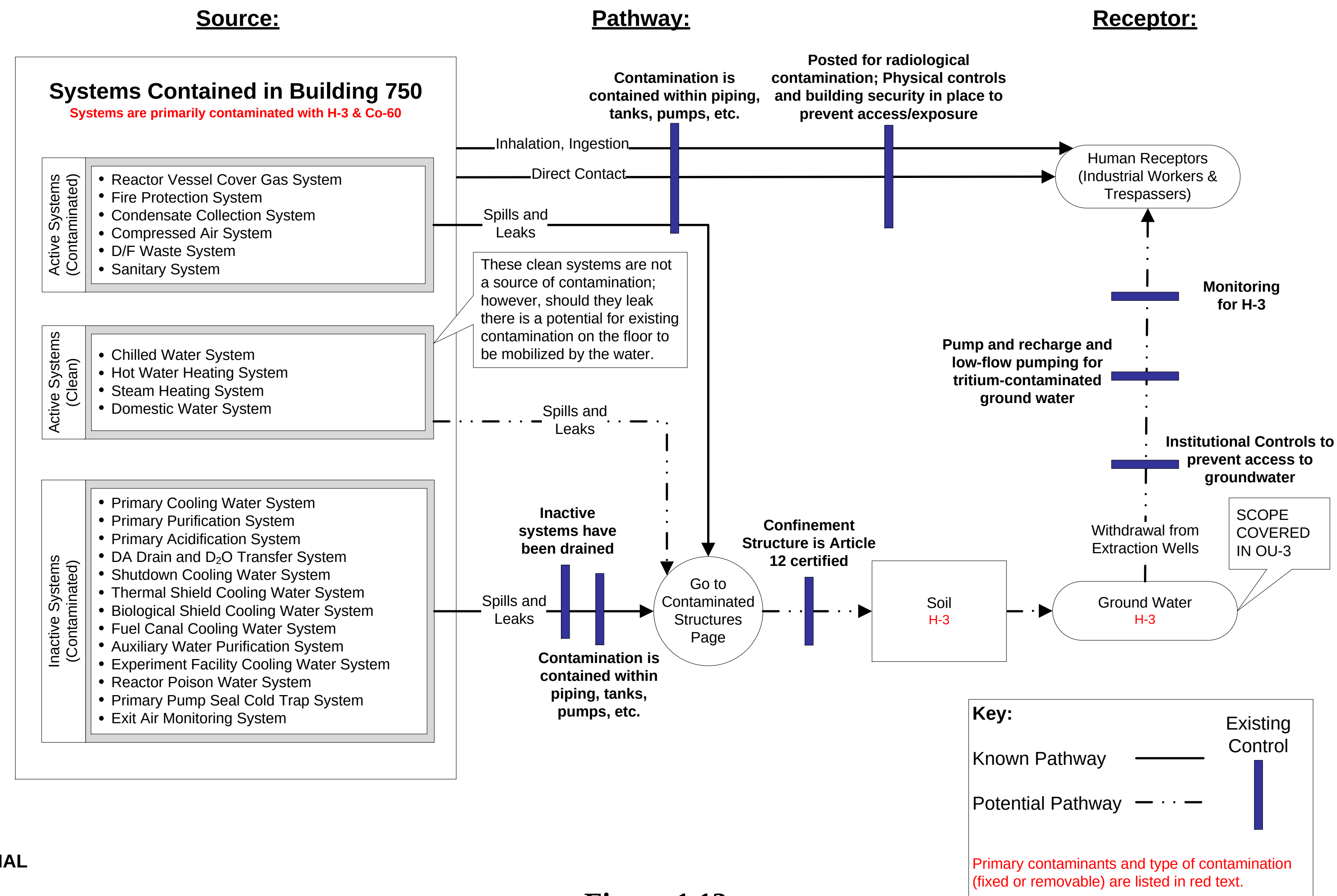

High Flux Beam Reactor Contaminated Structures within Building 750--Current State
Storm water intrusion into Building 750
Building maintained to prevent water intrusion
Source:
Pathway:
Receptor:
Building 750: Confinement Structure
Interior of the confinement shell is contaminated with removable H-3
Greenhouse
Fixed & Removable
H-3, Co-60
Chemistry Lab
Fixed
H-3, Co-60
Pipe Trench
Fixed & Removable
H-3, Co-60
Dry Box
Fixed & Removable
H-3, Co-60
RMG Hot Shop
Fixed
Co-60
Contaminated Systems
Rad Materials & Liquid Waste in storage
Fixed
H-3, Fe-55, Co-60, Ni-63
Spills
Leaks
Fire suppression liquid
Storm water/ condensation transport
D/F Waste Tank
Removable
H-3, Co-60
FA101 Tank
Removable
H-3
FA101 Sump
Removable
H-3
Building 750 Floor & Floor Drains
Fixed & Removable
H-3, Co-60
Internal D/F Waste Line to Building 801
Fixed & Removable
H-3, Co-60,
Inlets Plugged
Discharge
Reactor Top & Pit
Hot Particles
H-3, Co-60
Purification Systems Resin & Beds
Removable
H-3, Fe-55, Co-60, Ni-63
D Waste Sump
Removable
H-3, Co-60
Passenger Elevator Pit
Removable
PCBs
Discharge
FA 311 Tank
Removable
H-3
Domestic Water
Secondary Water
Steam System
GA303A Sump
Removable
H-3
Sump inputs drained and isolated
Discharge
FA 310 Tank connecting 311 Tank and HO Basin removed and piping capped
HO Recharge Basin (Outside scope of HFBR Project; sampled quarterly)
Soil
Fe, Mn, Eu-155
(Outside scope of HFBR Project)
Posted for radiological contamination; Physical controls and building security in place to prevent access/exposure
Direct Contact
Inhalation
Ingestion
Human Receptors (Industrial Workers & Trespassers)
Monitoring for H-3
Pump and recharge and low-flow pumping for tritium-contaminated ground water
Institutional Controls to prevent access to groundwater
SCOPE COVERED IN OU-3
Withdrawal from Extraction Wells
Ground Water
H-3
Confinement Structure is Article 12 certified
External D/F Waste Line to Building 801
Fixed & Removable
H-3, Co-60,
Leakage
Soil
H-3
Confinement Structure is Article 12 certified
Discharge
HS Recharge Basin (Outside scope of HFBR Project; sampled quarterly)
Soil (Outside scope of HFBR Project)
Key:
Existing Control
Known Pathway
Potential Pathway
Potential Input
Primary contaminants and type of contamination (fixed or removable) are listed in red text.
NOTE: The Spent Fuel Pool was not included in this model as it is not contaminated, contains no water, and presents no threat of release or exposure
FINAL

Figure 1.12

High Flux Beam Reactor Systems--Current State



FINAL

Figure 1.13

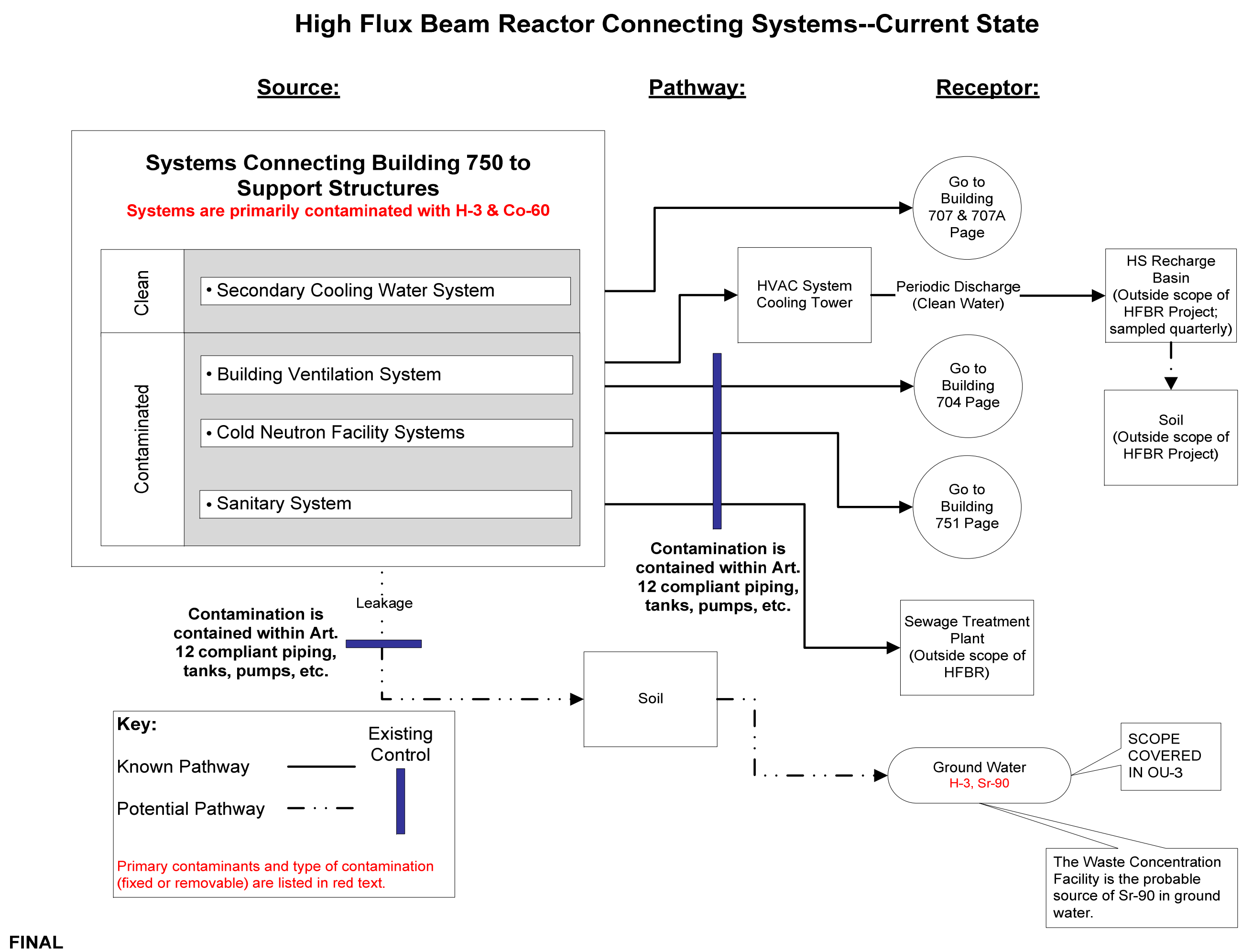

High Flux Beam Reactor Connecting Systems--Current State
Source:
Pathway:
Receptor:
Systems Connecting Building 750 to Support Structures
Systems are primarily contaminated with H-3 & Co-60
Clean
Contaminated
• Secondary Cooling Water System
• Building Ventilation System
• Cold Neutron Facility Systems
• Sanitary System
Go to Building 707 & 707A Page
HVAC System Cooling Tower
Periodic Discharge (Clean Water)
HS Recharge Basin (Outside scope of HFBR Project; sampled quarterly)
Soil (Outside scope of HFBR Project)
Go to Building 704 Page
Go to Building 751 Page
Contamination is contained within Art. 12 compliant piping, tanks, pumps, etc.
Sewage Treatment Plant (Outside scope of HFBR)
Leakage
Contamination is contained within Art. 12 compliant piping, tanks, pumps, etc.
Soil
Ground Water
H-3, Sr-90
SCOPE COVERED IN OU-3
The Waste Concentration Facility is the probable source of Sr-90 in ground water.
Key:
Existing Control
Known Pathway
Potential Pathway
Primary contaminants and type of contamination (fixed or removable) are listed in red text.
FINAL

Figure 1.14

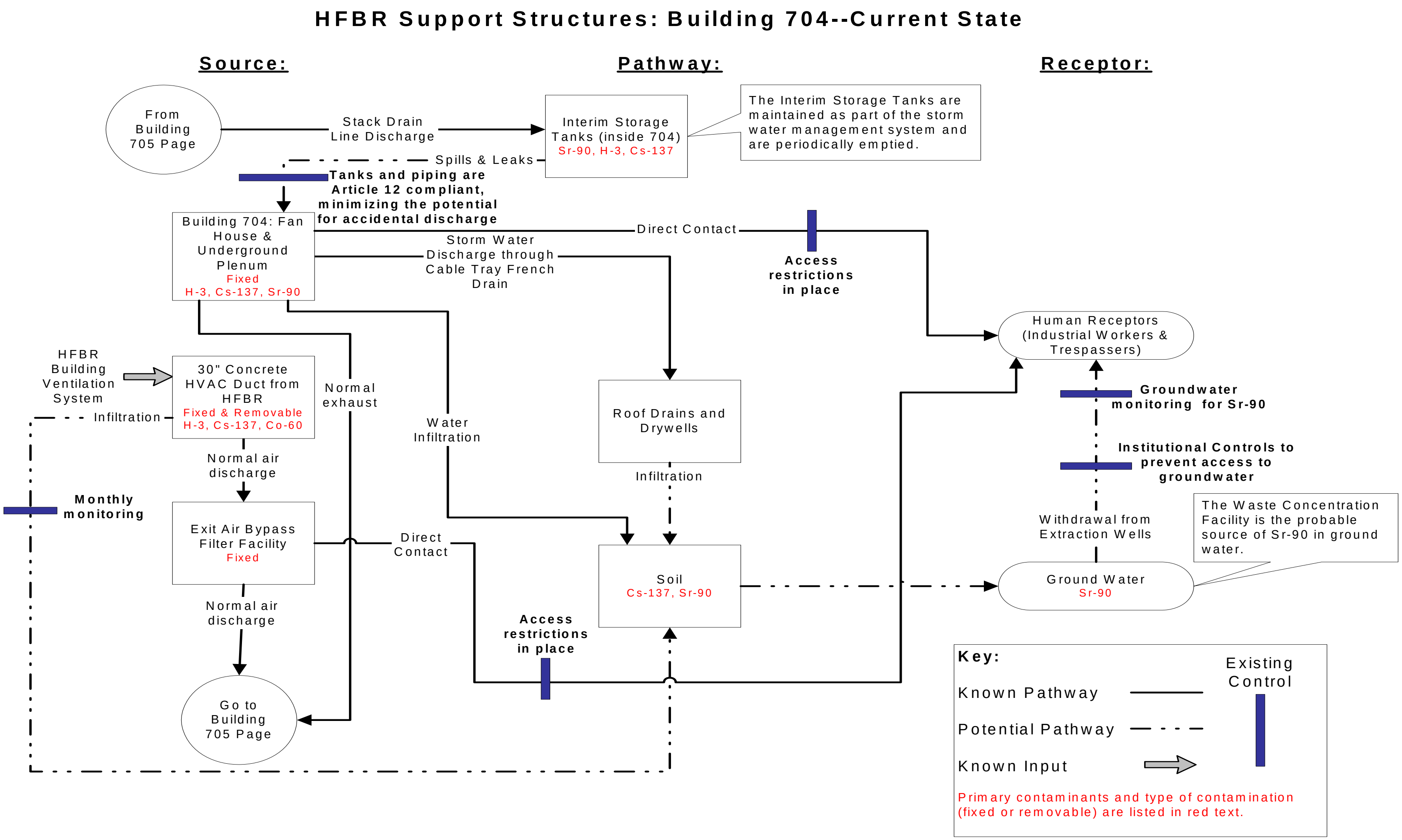

HFBR Support Structures: Building 704--Current State
Source:
Pathway:
Receptor:
From Building 705 Page
Stack Drain Line Discharge
Interim Storage Tanks (inside 704)
Sr-90, H-3, Cs-137
The Interim Storage Tanks are maintained as part of the storm water management system and are periodically emptied.
Spills & Leaks
Tanks and piping are Article 12 compliant, minimizing the potential for accidental discharge
Building 704: Fan House & Underground Plenum
Fixed
H-3, Cs-137, Sr-90
Direct Contact
Access restrictions in place
Storm Water Discharge through Cable Tray French Drain
Human Receptors (Industrial Workers & Trespassers)
HFBR Building Ventilation System
30" Concrete HVAC Duct from HFBR
Fixed & Removable
H-3, Cs-137, Co-60
Normal exhaust
Water Infiltration
Roof Drains and Drywells
Groundwater monitoring for Sr-90
Infiltration
Normal air discharge
Institutional Controls to prevent access to groundwater
Monthly monitoring
Exit Air Bypass Filter Facility
Fixed
Direct Contact
Infiltration
Withdrawal from Extraction Wells
The Waste Concentration Facility is the probable source of Sr-90 in ground water.
Soil
Cs-137, Sr-90
Ground Water
Sr-90
Normal air discharge
Access restrictions in place
Go to Building 705 Page
Key:
Existing Control
Known Pathway
Potential Pathway
Known Input
Primary contaminants and type of contamination (fixed or removable) are listed in red text.

Figure 1.15

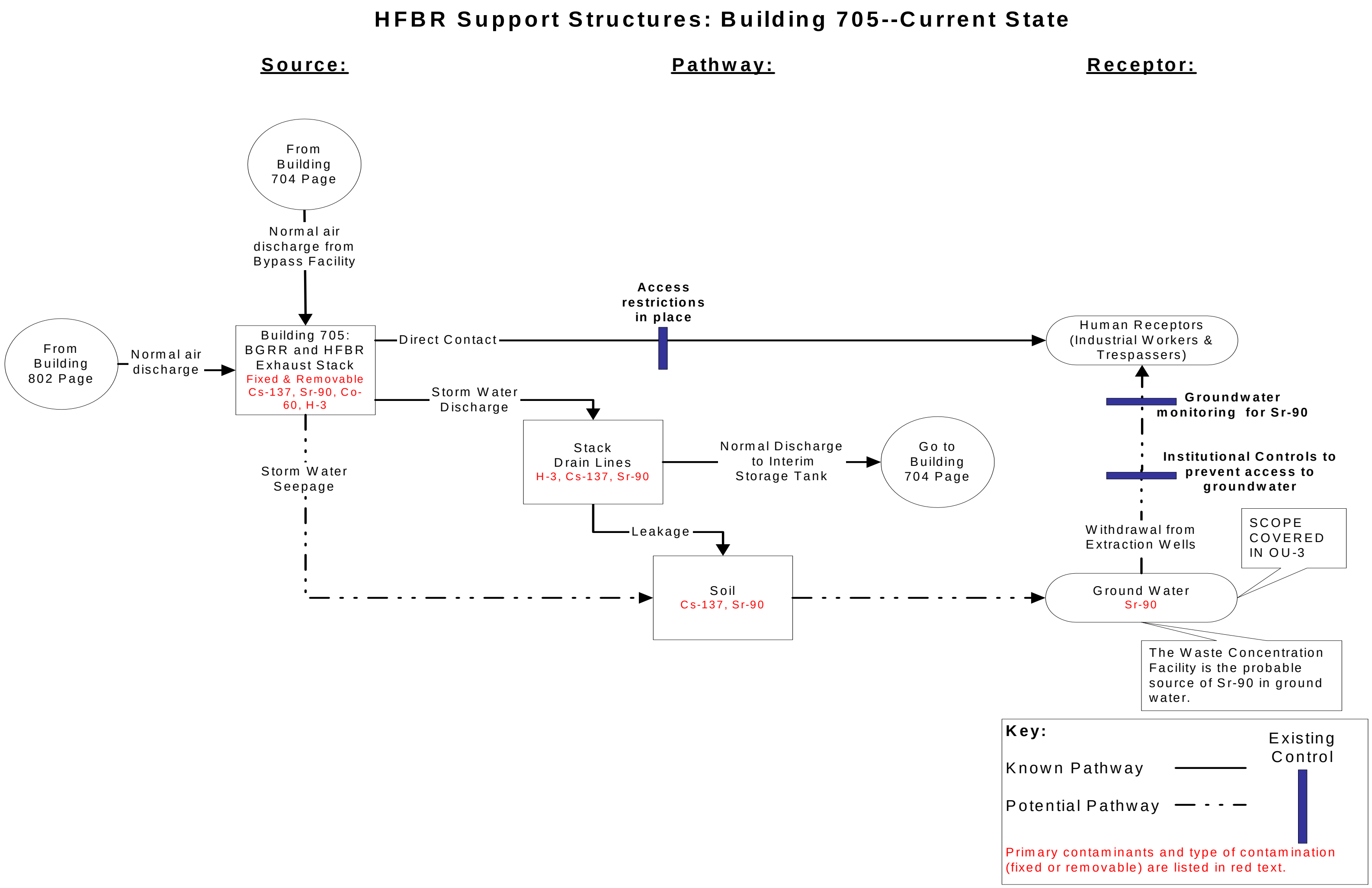

HFBR Support Structures: Building 705--Current State
Source:
Pathway:
Receptor:
From Building 704 Page
Normal air discharge from Bypass Facility
From Building 802 Page
Normal air discharge
Building 705: BGRR and HFBR Exhaust Stack
Fixed & Removable Cs-137, Sr-90, Co-60, H-3
Direct Contact
Access restrictions in place
Human Receptors (Industrial Workers & Trespassers)
Storm Water Discharge
Storm Water Seepage
Stack Drain Lines
H-3, Cs-137, Sr-90
Normal Discharge to Interim Storage Tank
Go to Building 704 Page
Leakage
Soil
Cs-137, Sr-90
Groundwater monitoring for Sr-90
Institutional Controls to prevent access to groundwater
Withdrawal from Extraction Wells
SCOPE COVERED IN OU-3
Ground Water
Sr-90
The Waste Concentration Facility is the probable source of Sr-90 in ground water.
Key:
Existing Control
Known Pathway
Potential Pathway
Primary contaminants and type of contamination (fixed or removable) are listed in red text.

Figure 1.16

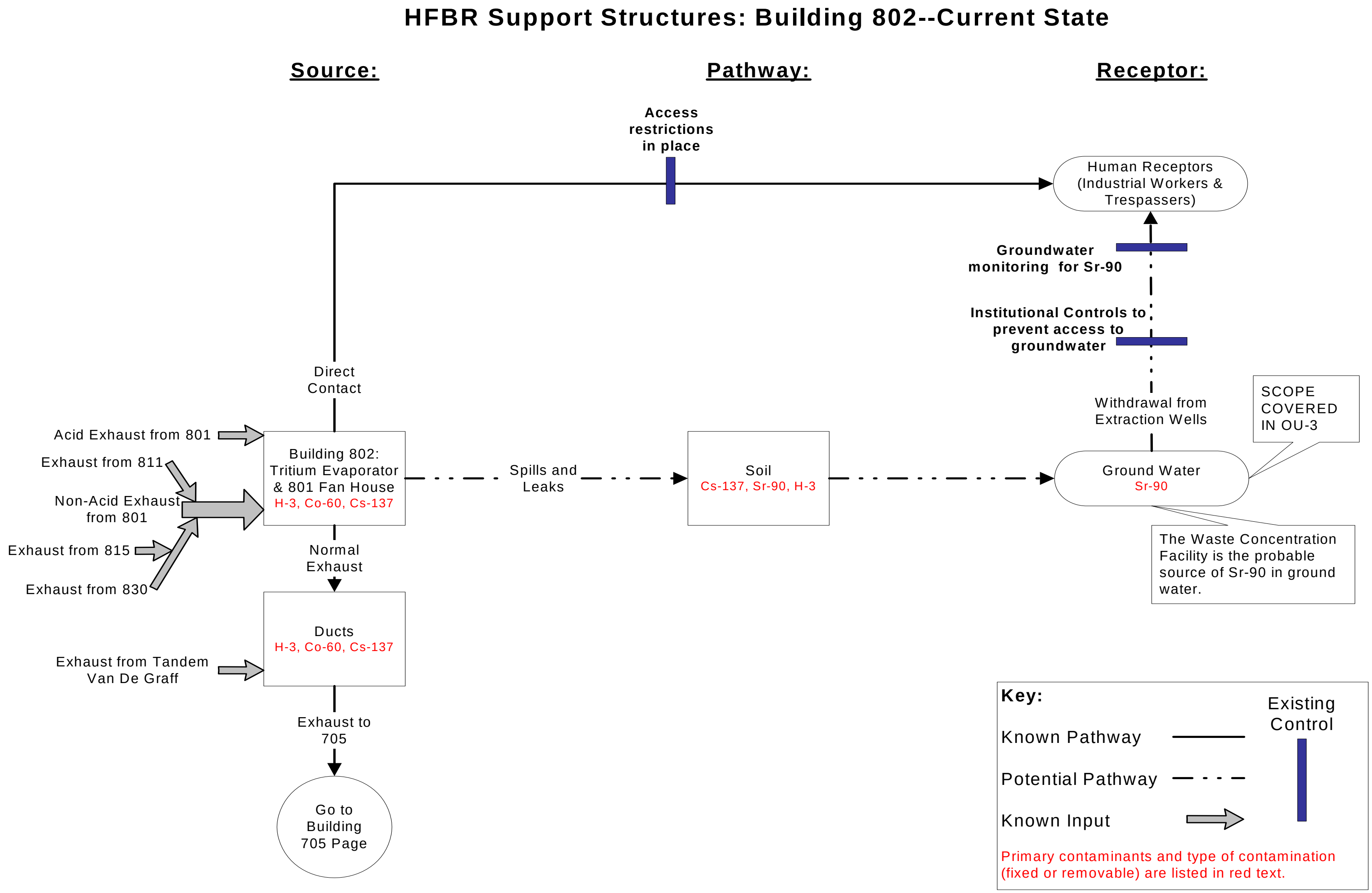

HFBR Support Structures: Building 802--Current State
Source:
Pathway:
Receptor:
Access restrictions in place
Human Receptors (Industrial Workers & Trespassers)
Groundwater monitoring for Sr-90
Institutional Controls to prevent access to groundwater
Direct Contact
Withdrawal from Extraction Wells
SCOPE COVERED IN OU-3
Acid Exhaust from 801
Exhaust from 811
Non-Acid Exhaust from 801
Exhaust from 815
Exhaust from 830
Building 802: Tritium Evaporator & 801 Fan House
H-3, Co-60, Cs-137
Spills and Leaks
Soil
Cs-137, Sr-90, H-3
Ground Water
Sr-90
The Waste Concentration Facility is the probable source of Sr-90 in ground water.
Normal Exhaust
Ducts
H-3, Co-60, Cs-137
Exhaust from Tandem Van De Graff
Exhaust to 705
Go to Building 705 Page
Key:
Existing Control
Known Pathway
Potential Pathway
Known Input
Primary contaminants and type of contamination (fixed or removable) are listed in red text.

Figure 1.17

Table 1.1 Summary of Interim Stabilization and Removal Actions

Year	Material Addressed / Removed	Quantity	Disposition
1998	All spent nuclear fuel	1,050 elements	to SRS
1999	Cooling tower super structure	na	waste
2000	275,000 gal. cooling water holdup tank	74 tons	waste
2000	Shield blocks	500,000lb	C-AD
2000	Shield blocks	168,000lb	PE
2000	Contaminated lead brick	40,000lb	MIT
2000	Chemicals (used in operations and experiments)	1,300 cont.	BNL
2000	Lead	250,000 lbs	waste
2001	Cadmium nitrate/gadolinium nitrate	350 gal	waste
2001	Primary coolant (tritiated heavy water)	10,000 gal	To SRS
2001	Acid	1,500 gal	reuse
2002	Assorted low-level rad waste	11-B12's	waste
2002	Mixed waste	1 B12	waste
2002	H-6 Beam plug	na	waste
2003	Co-60 sources	21μCi	waste
2003	15 gal of used scintillation cocktail liquid (tritiated)	5,000 μCi	waste
2003	Assorted low-level radioactive waste (two B52 boxes)	22 yd^3	waste
2003	Sr-90 source	4 Ci	waste
2003	Cl-36 sources	0.14 μCi	waste
2003	2 CNF liquid nitrogen storage tanks	na	to C-AD
2003	Lead-lined sample hutch (8'x5'x3')	na	to MIT
2004	Suffolk County Sanitary Code – Article 12[1] certification	na	na
2004	Beryllium filters and goniometers	na	to ORNL
2004	20,000 gal double walled long-term cooling water tank	na	Saved for possible re-use
2004	Miscellaneous radioactive sources	1.5 Ci	waste
2004	Assorted low-level radioactive waste (connex boxes)	160 yd^3	waste
2004	Assorted industrial waste (CNF shed, MH-1A spacers)	35 yd^3	waste
2004	Tritiated oil	55 gal	waste
2004	Lead-lined drums and assorted mixed waste	4200 μCi	waste
2004	Assorted mixed waste	55 gal drum	waste
2004	Lead shielding	53,572 lb	waste

2005	Shield blocks	30	waste
2005	RaBe source removed from Sigma Pile	1Ci	waste
2006	Stack Monitoring Facility (Bldg. 715)	100 yd^3 debris 620 yd^3 concrete recycled 30 tons metal recycled	
2006	Cooling Tower Basin and Pump/Switchgear House (Bldg 707/707A)		
2006	Water Treatment House (Bldg. 707B)		
2006	Guard shack (Bldg. 753)		
2006	Cold Neutron Facility (Building 751) contaminated systems (the building was transferred to another organization for re-use.)	2142 ft^2 high bay bldg. w/ bridge crane	reuse

1. Compliance with the codes pertaining to Toxic and Hazardous Material Storage and Handling Controls for the purpose of safeguarding the water resources of the County of Suffolk from toxic or hazardous materials pollution by controlling or abating pollution from such sources.

Table 1.2 HFBR Total Activated Components Activity Decay by Radionuclide (Curies)

	Half-Life (yr)	**2007**	**2012**	**2017**	**2020**	**2026**	**2037**	**2047**	**2057**	**2067**	**2075**	**2087**	**2097**	**2107**
Nuclide	**Half-Life (yr)**	**Total Activity (Ci)**	**Total Activity (Ci)**	**Total Activity (Ci)**	**Total Activity (Ci)**	**Total Activity (Ci)**	**Total Activity (Ci)**	**Total Activity (Ci)**	**Total Activity (Ci)**	**Total Activity (Ci)**	**Total Activity (Ci)**	**Total Activity (Ci)**	**Total Activity (Ci)**	**Total Activity (Ci)**
H-3	12.32	7	5	4	3	2	1	1	0	0	0	0	0	0
C-14	5,715	26	26	26	26	26	26	26	26	26	26	26	26	25
Fe-55	2.73	31,155	8,750	2,456	1,147	250	15	1	0	0	0	0	0	0
Co-60	5.271	16,387	8,489	4,396	2,963	1,345	316	85	23	6	2	0	0	0
Ni-59	76,000	62	62	62	62	62	62	62	62	62	62	62	62	62
Ni-63	101	11,932	11,529	11,140	10,913	10,473	9,711	9,066	8,465	7,903	7,481	6,889	6,432	6,005
Eu-154	8.593	3,610	2,412	1,611	1,264	779	321	143	64	28	15	6	3	1
Eu-155	4.75	1,336	644	310	200	83	17	4	1	0	0	0	0	0
Total	**N/A**	**64,500**	**31,900**	**20,000**	**16,600**	**13,000**	**10,400**	**9,400**	**8,600**	**8,000**	**7,600**	**7,000**	**6,500**	**6,100**

Table 1.3 Calculated Dose Rates at 1 Foot from Components

Component	rem/hr
Reactor Internals*	35,000
Single (maximum) control rod blade	13,000
Reactor vessel	15
Thermal shield	471
Biological shield (inner region)	3

Note: Calculated dose rates at 1 ft from components as of January 2007.

* Represents the calculated dose rate from all of the reactor internals excluding the control rod blades. However, this value is the calculated dose rate at one foot from the transition plate which because of its radionuclide inventory and physical location would mask the dose rate contribution from the other components in this category.

Table 1.4 – HFBR Activated Component Decay

	2007	2012	2017	2020	2026	2032	2042	2052	2057	2067	2075	2082	2107
Nuclide	**Ci**	**Ci**	**Ci**	**Ci**	**Ci**	**Ci**	**Ci**	**Ci**	**Ci**	**Ci**	**Ci**	**Ci**	**Ci**
Reactor Vessel	380	251	207	194	179	170	157	147	142	132	123	119	101
Reactor Internals	16,387	10,249	7,707	6,894	5,961	5,452	4,940	4,575	4,415	4,119	3,900	3,719	3,138
Control Blades	21,900	12,047	7,783	6,380	4,767	3,933	3,231	2,860	2,727	2,509	2,363	2,246	1,890
Thermal Shield	24,876	8,971	4,127	2,993	2,059	1,737	1,521	1,400	1,349	1,259	1,192	1,137	961
Bioshield	125	47	23	17	11	9	8	7	6	6	5	5	4
Beam Plugs & Collimators	847	352	158	100	42	19	5	1	1	0	0	0	0
TOTAL	**64,500**	**31,900**	**20,000**	**16,600**	**13,000**	**11,300**	**9,900**	**9,000**	**8,600**	**8,000**	**7,600**	**7,200**	**6,100**

Table 1.5 HFBR System Radioactivity Calculation Summary

System	System Description	H-3 (Ci)	Co-60 (Ci)	Fe-55 (Ci)	Ni-63 (Ci)	Cs-137 (Ci)	Total Ci in 2007	Total Ci in 2057	Total Ci in 2107
SYS-01	Primary Coolant Water System	34.8	0.04	0.06	0.02	0.07	**35.0**	**2.1**	**0.1**
SYS-02	Primary System Purification	H-3 Note	0.06	0.13	0.02	0.00	**0.2**	**0.0**	**0.0**
SYS-04	Primary Sampling System	Note 1	0.00	0.00	0.00	0.00	**0.0**	**0.0**	**0.0**
SYS-05	Primary Pump Seal Cold Trap System	Note 1	0.00	0.00	0.00	0.00	**0.0**	**0.0**	**0.0**
SYS-06	DA Drain & D20 Transfer System	Note 1	0.00	0.01	0.00	0.01	**0.0**	**0.0**	**0.0**
SYS-08	Reactor Vessel Cover Gas System	Note 1	0.00	0.00	0.00	0.00	**0.0**	**0.0**	**0.0**
SYS-11	Shutdown Cooling System	Note 1	0.03	0.04	0.02	0.00	**0.1**	**0.0**	**0.0**
SYS-12	Thermal Shield Cooling System	Note 1	0.04	0.06	0.02	0.01	**0.1**	**0.0**	**0.0**
SYS-15	Auxiliary Water Purification System	Note 1	0.00	0.00	0.00	0.00	**0.0**	**0.0**	**0.0**
SYS-31	Experimental Facilities Cooling System	Note 1	0.20	0.31	0.11	0.04	**0.7**	**0.1**	**0.1**
SYS-34	Liquid D/F Waste Systems	0.53	0.78	1.20	0.43	0.14	**3.1**	**0.4**	**0.2**
Misc	Miscellaneous Hot Spots	0.00	0.57	0.90	0.32	0.00	**1.8**	**0.2**	**0.2**
Misc	Miscellaneous Low Activity Systems (Note 2)	3.54	0.17	0.27	0.09	0.02	**4.1**	**0.3**	**0.1**
Misc	Low level contamination on floors and structures	0.08	0.01	0.01	0.00	0.00	**0.1**	**0.0**	**0.0**
	Total for All Systems	**39.0**	**1.9**	**3.0**	**1.0**	**0.3**	**45.2**	**3.2**	**0.7**

H-3 Note: the Primary System Purification H-3 (10.5 Ci in 2007, 0.6 Ci in 2057, < 0.1 Ci in 2107) is part of the total estimated H-3 in SYS-01, and is not additive.

Note 1: D20 was drained from systems, but 10 gallons is assumed to be present as residual in various systems. This H-3 activity is included in the Primary Cooling Water System.

Note 2: Several low activity systems were assumed to add up to a combined 10% of the total systems activity.

Note that resin media and filters in various systems will be removed from the facility.

Beam plugs have been removed and are in storage in Bldg 750. They are not part of this systems activity calculation.

The Vertical Irradiation Tubes are part of the in-vessel activity determination

Table 1.6 Application of Remedial Action Objectives

	Control, minimize or eliminate all routes of future human and/or environmental exposure to radiologically contaminated facilities or materials.	Control, minimize, or eliminate the potential for future release of non-fixed radiological or chemical contamination to the environment.	Control, minimize, or eliminate all routes of future human and/or environmental exposure to contaminated soils.	Control, minimize, or eliminate the future potential for contaminated soils to impact groundwater.
Activated Components	X			
Contaminated Structures within Building 750	X	X		X
Contaminated HFBR Systems	X	X		X
Contaminated HFBR Connecting Systems	X	X	X	X
Building 704	X	X	X	X
Building 705	X	X	X	X
Building 802	X	X	X	X

2.0 IDENTIFICATION AND SCREENING OF TECHNOLOGIES

2.1 TECHNOLOGY SCREENING

A comprehensive characterization program has been completed and the quantities, locations, and nature of the contamination in the HFBR complex have been identified. These data and information were considered in engineering studies that evaluated various decontamination and dismantlement technical approaches and techniques available for use at the HFBR. The scope of these studies included the complete range of remedial actions, ranging from HFBR decontamination, dismantlement, and waste management, through radioactive decay-in-storage, and institutional control.

No new technologies are required to develop and implement a remedial action strategy for safely and effectively managing contamination at the HFBR complex. There are two distinct categories of HFBR dismantlement activities: very simple demolition and waste management practices for uncontaminated and lightly contaminated structures, systems and components; and very sophisticated practices involving special tools, engineered equipment, and remote robotic processes for highly radioactive components which include the reactor internals, CRBs, reactor vessel, thermal shield, and inner portions of the biological shield.

2.1.1 Uncontaminated and Lightly Contaminated Structures, Systems, and Components

For dismantling the uncontaminated and lightly contaminated structures, systems, and components that comprise most of the HFBR complex, standard construction work practices are available. For example, shoring, excavation, and structural demolition techniques have been extensively used and field-proven throughout the nuclear industry. Existing waste packaging and transportation equipment are commercially available and have been thoroughly demonstrated at BNL and throughout the DOE complex. Using these technologies and work practices for much of the dismantlement of the uncontaminated and lightly contaminated structures, systems and components does not pose any extraordinary technical issues.

2.1.2 Activated Components

As described in Section 1.3, the vast majority of the HFBR radionuclide inventory resides in the reactor vessel, CRBs, reactor internals, thermal shield, inner portions of the biological shield, and beam plugs. These components have high calculated dose rates in the range of several thousands of rem/hr. For example, the calculated radiation dose rate at one foot distance from the reactor internals is more than 35,000 rem/hr, and the calculated dose rate at one foot distance associated with the maximum CRB is as high as 13,000 rem/hr. The dose rates were calculated by approximating the location of the radioactivity in the component. The calculations did not assume point source geometry. The control blades were assumed to be line sources, and the reactor internals were assumed to be a disc source, as the most radioactive component (transition plate) is a geometry that approximates a disc. These are realistic assumptions, and are used to determine the dose rate without extensive controls and dose reduction techniques.

By comparison, when area radiation dose rates are greater than 5 mrem/hr, 100 mrem/hr and 500 RAD/hr, they are designated as radiation, high radiation and very high radiation areas respectively. The increases would be characterized by more restrictive access and increasingly stringent work control practices. To protect workers and the public from these high radiation fields, safely dismantling these components and handling the resulting wastes requires the use of very sophisticated tools, engineered equipment, and special procedures. Radiation dose and exposure reduction measures that would be factored into the dismantlement and disposal of these components with high dose rates that include the following:

- The use of water as a radiation shield. In the case of the reactor vessel and thermal shield, a "floodable" containment would need to be engineered and constructed around these components for their underwater segmentation, removal, and packaging.
- The engineering, design, and qualification of specialized tools and equipment and procedures for the underwater component removal and segmentation.
- Filtration systems and equipment to control water clarity and the high levels of contamination resulting from dismantlement and waste packaging activities.
- Equipment and procedures for managing the secondary wastes such as filtration media, etc.
- Equipment and procedures for packaging and transporting the waste.
- Contingency procedures for off-normal conditions and events.

The packaging, transportation and disposal of the activated components would require the use of special shipping casks because of their high dose rates. Licensed shipping containers capable of transporting this radiological inventory, with its corresponding high dose rates, are commercially available.

2.1.3 Decay-In-Storage

There is a considerable body of experience with using the radioactive decay-in-storage strategy in nuclear reactor decommissioning. Under this strategy, high dose rate structures, systems, and components are placed in a safe and stable condition. Through radioactive decay, the high dose rates and related hazards are reduced during the period of decay-in-storage. During this period, the structures at some facilities have been used for ancillary purposes such as storage or shops though no such use is contemplated for the HFBR. Dismantlement and disposal activities are completed after the radiation fields and related hazards are reduced. Short-lived radionuclides (with half-lives below 10 years) dominate the radiological inventory at the HFBR complex. The significant and relatively rapid reduction in the radiological inventory as a result of radioactive decay has been shown in Figure 1.7. There is also a corresponding reduction in the high present day radiation dose rates associated with the activated components. Figure 2.1 shows the calculated dose rate at one foot for all activated components combined for the period of time being considered for the decommissioning alternatives. Figure 2.2 has been included to show greater detail of the calculated dose rate decay for the period 2047 through 2107.

For activated components with predominantly short-lived radioisotopes, decay-in-storage results in the substantial reduction in dismantlement and waste management risks, hazards, project complexity, and cost. To minimize the risks, hazards, project complexities, and costs associated with dismantlement, safe-storage was defined to be that period of time by which the calculated dose rate at one foot from the large activated components (reactor vessel, thermal shield, and biological shield) would fall below the DOE 100 mrem/hr High Radiation Area threshold. This would allow the use of conventional demolition techniques that necessitate workers to come within close proximity to the components. Using the characterization results, each of these components was evaluated to determine when its calculated dose rate at one foot fell below 100 mrem/hr. That limiting component turned out to be the thermal shield for which the calculated dose rate falls below the threshold in approximately 65 years. The dose rate reduction of this limiting component demonstrating when it falls below the threshold is shown in Figure 2.3. Based on the reduction in risks, hazards, complexities, and costs that could be expected, the safe storage was established at a period not to exceed 65 years.

Eleven reactors at the DOE's Hanford and Savannah River sites rely on decay-in-storage as a key element of the overall decommissioning strategy. These decay-in-storage periods are as long as 75 years. Four test reactors at Savannah River Site (SRS) have relied on decay-in-storage for 35 to 40 years and are now decommissioned. Six other reactors at SRS are currently in storage, one of which has been shutdown for 43 years to date and has recently had its entrances sealed for up to another 60 years of decay-in storage. The effectiveness of this decommissioning strategy has been demonstrated through extensive monitoring.

There is a similar body of experience in the commercial power industry. Nuclear power reactors at the Peach Bottom, Indian Point, and Dresden sites have been safely and effectively managed in a decay-in-storage status for as long as 31 years. With Co-60 as the dominant isotope driving radiation dose rates, the corresponding reduction in dose rates at these sites is as high as 98 percent. As shown, decay-in-storage is a field proven strategy that may offer a significant benefit in reducing the risks and hazards associated with dismantling and disposing of HFBR high dose rate activated components.

2.1.4 Other Possible Approaches

Other possible approaches for managing the risks associated with contamination at the HFBR are summarized below:

- Engineered caps and impermeable barriers have been successfully used for managing both radiological and non-radiological hazards. An enormous body of experience can be brought to bear in managing the full range of residual contamination that may remain at the HFBR during the course of, or at the conclusion of, active decontamination and dismantlement.

- LUICs can be effective in managing the hazards associated with residual contamination at the HFBR. The use of LUICs has been a key element of the overall remedial action strategy used at BNL and elsewhere in the DOE complex.

2.2 APPLICABLE OR RELEVANT AND APPROPRIATE REQUIREMENTS

The National Contingency Plan, Section 40CFR300.430 (f)(1)(ii)(B), requires that the alternatives be assessed to determine whether they comply with federal and state "applicable or relevant and appropriate requirements" (ARARs), unless a waiver is invoked. The ARARs listed below apply to all of the alternatives set forth in this study.

2.2.1 Chemical-Specific ARARs

1. **6 New York Code, Rules and Regulations (NYCRR) part 212, General Process Emission Sources:** These state regulations will be followed to determine the need for air-emission control equipment. All remedial work will be performed in accordance with standards and procedures that will ensure compliance with these regulations.

2. **6 NYCRR Part 380, Rules and Regulations for Prevention and Control of Environmental Pollution by Radioactive Materials:** These regulations are the relevant and appropriate regulations for controlling radioactive emissions and liquid releases to the environment while completing the remedial action. 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.

3. **Resource Conservation and Recovery Act (RCRA) (40CFR260-281):** These federal regulations define hazardous wastes.

4. **New York State Hazardous Waste Management System Regulations (6 NYCRR 370 – 376):** 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 (40CFR141.16):** Establishes maximum contaminant levels (MCLs) that are used as drinking water standards for sole source aquifers. BNL site-wide conformance with the ARAR is addressed in the Operable Unit III (OU III) ROD.

6. **U.S. Department of Transportation Requirements for the Transportation of Hazardous Materials (49CFR Parts 100 to 170):** These regulations will apply to any wastes that are transported off site.

2.2.2 Location-Specific ARARs

1. **National Historic Preservation Act (36CFR800):** This Act requires federal agencies to take into account the effects of their actions on historic properties.

2. **New York State Low Level Radwaste Disposal Facilities (6 NYCRR Part 382-383)**: The regulations in these Parts establish requirements for land disposal of low-level radioactive waste including the siting, design, construction, operation, closure, post-closure monitoring and maintenance, and institutional control of land disposal facilities used for permanent disposal of low-level radioactive waste.

2.2.3 Action-Specific ARARs

1. **10CFR835, Occupational Radiation Protection:** These rules establish radiation protection standards for all DOE activities. Remedial actions and safe storage will be performed in accordance with the requirements of a DOE-approved radiation protection program and dosimetry program, and appropriate procedures will be established to ensure compliance with this regulation.

2. **10CFR830, Nuclear Safety Management:** These rules establish the minimum acceptable quality assurance and nuclear safety controls for all applicable DOE activities. All remedial action will be performed in accordance with the requirements of a DOE-approved quality assurance and nuclear safety control program and appropriate procedures will be established to ensure compliance with this regulation.

3. **RCRA (40CFR260-268):** As described in Section 2.2.1 above.

4. **New York State Hazardous Waste Regulations (6 NYCRR Parts 370 – 376):** As described in Section 2.2.1 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) (40CFR 61):** This Act regulates and limits the emissions of hazardous air pollutants, including radionuclides. All activities with the potential to create airborne emissions will require confinement or containment with confirmatory air sampling to verify compliance with these requirements and applicable standards.

6. **49CFR Sections 173.4 through 173.471, Packaging and Transportation of Radioactive Material.** These rules apply to the proper packaging and transportation of hazardous material, specifically Class 7, radioactive material. Packaging and transportation of all DOE generated waste will be performed in accordance with this regulation.

2.2.4 "To Be Considered" Guidance

1. **DOE Order 451.1B, National Environmental Policy Act Compliance Program:** This order requires that CERCLA actions address NEPA values.

2. **NYSDEC Technical and Administrative Guidance Memorandum Remediation 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 millirem per year (mrem/yr) above background serves as an additional goal for remediation that will be evaluated during remedial action planning and implementation.

3. **NYSDEC's Division of Air Guidelines for Control of Toxic Ambient Air Contaminants, Air Guide 1:** This guide will be used to assess activities with the potential to create airborne radioactivity. Contents of this guide will aid in evaluating the need for air-emissions control equipment.

4. **DOE Order 5400.5, Radiation Protection of the Public and the Environment:** This order establishes the standards and requirements for protecting members of the public and the environment against undue risk from radiation. As with 10CFR835, remedial action will be performed in accordance with appropriate procedures that will be established to ensure continued protection of the public and the environment.

5. **DOE Order 435.1, Radioactive Waste Management:** This order provides guidance and requirements for managing and disposing of radioactive waste generated at DOE facilities.

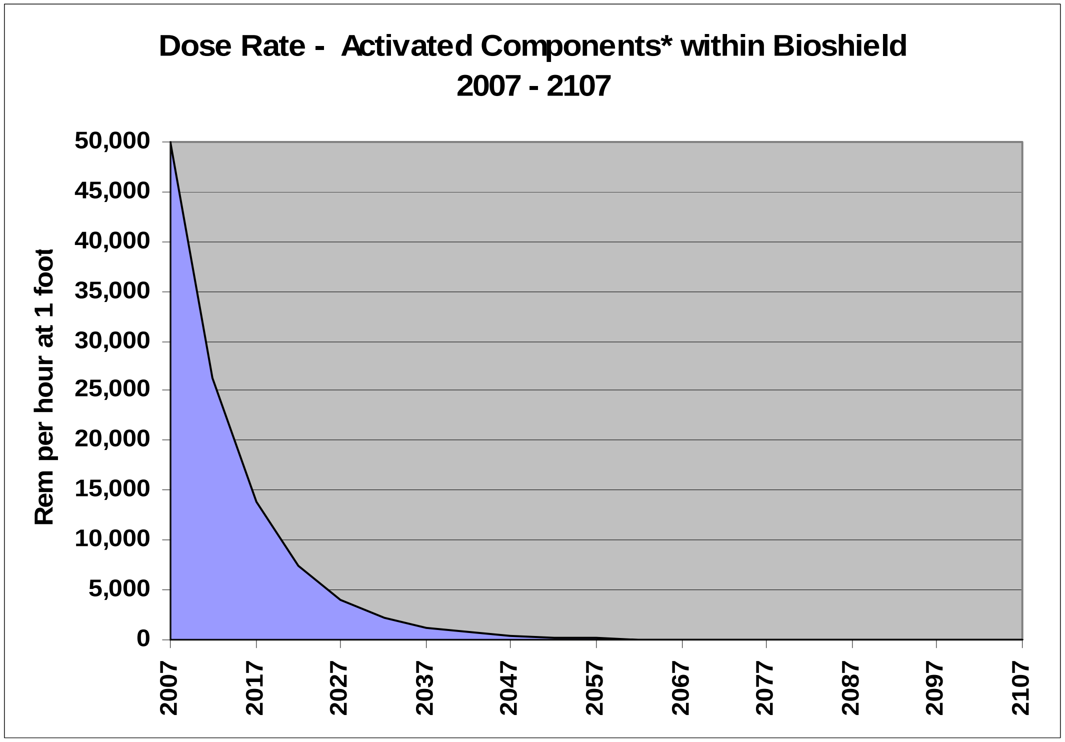
6. **As Low As Reasonably Achievable (ALARA):** This is the practical approach to radiation protection used to manage and control exposures (both individual and collective) of the work force and the general public, to levels as low as is reasonable, taking into account social, technical, economic, practical, and public policy considerations. Technologies and techniques will be incorporated into this remedy so that radioactive waste is minimized and direct exposure to radiation sources is reduced to as low as is reasonably achievable.

7. **40CFR300.440, Off-Site Rule (52FR49200):** The purpose of this rule is to avoid having wastes generated from response actions that are authorized or funded under CERCLA contribute to present or future environmental problems. This is accomplished by directing the waste to management units that have been determined to be environmentally sound. The rule establishes compliance and release criteria, and establishes a process for determining whether facilities are acceptable based on those criteria. The rule also establishes procedures for notifying waste management units of their unacceptability, for reconsidering unacceptability determinations, and for re-evaluating unacceptability determinations. In accordance with this rule, HFBR wastes will only be sent to off-site facilities that meet EPA acceptability criteria.

8. **National Historic Preservation Act (NHPA) Compliance:** DOE determined that the HFBR is eligible for inclusion in the National Register of Historic Places in accordance with the National Historic Preservation Act of 1966. DOE also established a number of measures to mitigate the adverse impacts of decommissioning. These mitigating measures, are identified in the BNL Cultural Resources Management Plan (e.g. video taping the interior and exterior of the HFBR Confinement Building, photographing support structures and preservation of scale models and mock fuel elements) and will be carried out in consultation with the New York State Historic Preservation Officer (SHPO).

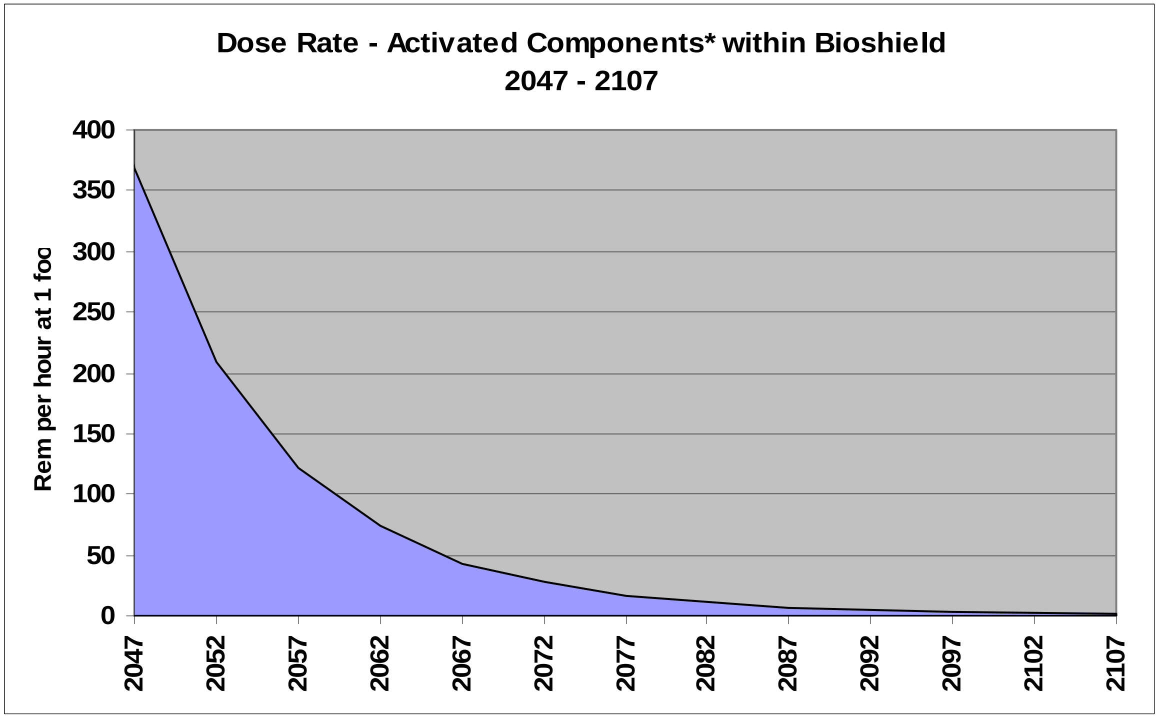
9. **Suffolk County Sanitary Code – Article 12 Toxic and Hazardous Materials Storage and Handling Controls:** This code requires the use of all available practical methods of preventing and controlling water pollution from toxic and hazardous materials. For the Article 12 registered components remaining, detailed surveillance and maintenance actions will be included in the S&M program

Section 2 Figures



***Excluding beam plugs and collimators**

Figure 2.1 HFBR Dose Rate Reduction 2007 - 2107



***Excluding beam plugs and collimators**

Figure 2.2 HFBR Dose Rate Reduction 2047 – 2107

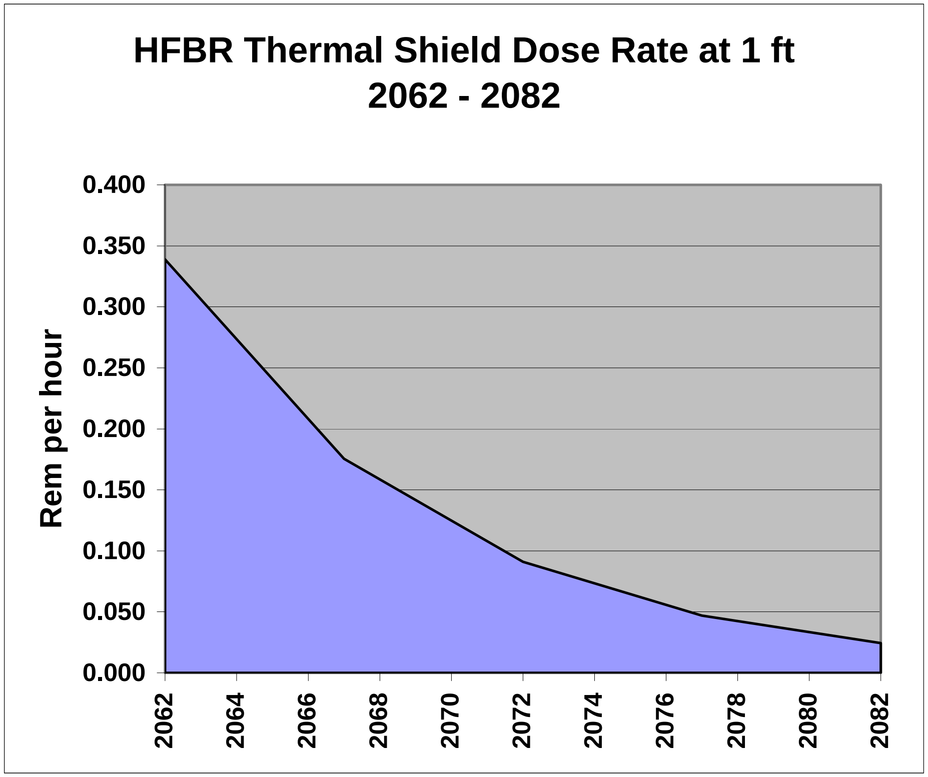


Figure 2.3 HFBR Limiting Large Activated Component Dose Rate Reduction 2062 - 2082

3.0 IDENTIFICATION OF ALTERNATIVES

Four HFBR remedial action alternatives have been identified and are considered in this FS. The four remedial action alternatives were developed with the involvement of representatives from DOE, EPA, NYSDEC, NYSDOH, and SCDHS. These alternatives are as follows:

Alternative A: No Additional Action

Alternative B: Phased Decontamination and Dismantlement

Alternative C: Phased Decontamination and Dismantlement with Near-Term Control Rod Blade Removal

Alternative D: Near-Term Decontamination and Dismantlement

These alternatives are described in Sections 3.1 through 3.4.

It should be noted that the remediation of the Waste Loading Area (WLA) is included in the scope of all four remedial alternatives.

As shown in Figure 3.1 the WLA is an area of radiologically contaminated soil along the eastern boundary of the Former Hazardous Waste Management Facility (FHWMF). There is no non-radiological hazardous material contamination at the WLA. Of the radiological contamination the predominant radionuclides and their average concentrations are Cs-137 at 125 pCi/gm and Sr-90 at 30 pCi/gm. It was left in place (with contaminated soil) so that it can be used as a waste staging and railcar loading area for the BGRR and HFBR projects. The remediation of this area (approximately two acres) is included in the HFBR scope of work. The transfer of the WLA from the FHWMF to the HFBR project was documented in a modification to the FHWMF Remedial Design Implementation Plan. Cleanup of the WLA will be performed when it is no longer needed as a waste staging and loading area. Cleanup of this area will be performed using the same cleanup goal and methodology specified for the FHWMF in the Operable Unit I (OU I) Record of Decision (ROD).

Since there are many similarities among the alternatives, Table 3.1 has been added to show the end-states and timeframes of the major dismantlement and removal activities.

3.1 ALTERNATIVE A -- NO ADDITIONAL ACTION

3.1.1 End State

Alternative A, no additional action, is used as a baseline alternative and is required to be considered under CERCLA. The Alternative A end state is defined as the as-is condition of the HFBR complex. This end state includes the intact structures, systems, and components described in Section 1.2. The end state radiological conditions are those determined during HFBR characterization and described in Section 1.3. The radiological inventory of 65,000 Ci would remain in place, and future reductions in this inventory would be solely the result of radioactive decay (For example, 65 years from the finalization of the HFBR ROD, the level of activity would be reduced by approximately 88 percent to 7,700 curies.) The radiological inventory remaining over time for this alternative is graphically demonstrated in Figure 3.2.

3.1.2 Scope of Alternative A

3.1.2.1 Active Decontamination and Dismantlement

Alternative A includes those actions described in Section 1.3 and listed in Table 1.1 that have already been completed. These actions are summarized as follows:

- The HFBR fuel was removed and sent to an off-site facility.
- The primary coolant was drained and sent to an off-site facility.
- Scientific equipment was removed and is being reused.
- Shielding and chemicals were removed and are being reused at BNL and other facilities.
- The cooling tower superstructure was dismantled and disposed.
- The confinement structure and spent fuel canal were modified to meet Suffolk County Article 12 requirements.
- Stack Monitoring Facility (Building 715) was dismantled and disposed.
- Cooling Tower Basin and Pump/Switchgear House (Building 707/707A) were dismantled and disposed.
- Water Treatment House (Building 707B) was dismantled and disposed.
- Cold Neutron Facility (Building 751) contaminated systems were removed and the clean building has been transferred to another organization for re-use.
- Guard house (Building 753) was dismantled and disposed.

3.1.2.2 Surveillance and Maintenance

To manage the residual radiological inventory in the HFBR complex, Alternative A relies on S&M for an indefinite period of time. HFBR S&M would be implemented to ensure that the radiological inventory is maintained in a safe condition, to prevent water infiltration, and to preclude human exposure pathways or migration outside of the confinement structure and into the environment. S&M activities would include:

- Groundwater monitoring and response actions continue in accordance with OU III ROD
- Continuation of air effluent monitoring
- Periodic physical examination of the confinement building and interior structures, including inspection for water infiltration
- Routine maintenance of the confinement building and repair of deficiencies found during confinement building inspections in order to preserve the physical barriers that contain the radioactive materials in the HFBR complex
- Periodic reporting to EPA and NYSDEC

The HFBR S&M plan would be developed by DOE in consultation with EPA and the NYSDEC.

3.1.2.3 Land Use and Institutional Controls
LUICs for Alternative A would be deployed for an indefinite period of time. At a minimum, these LUICs would include:

- Measures for controlling future excavation and other actions that could otherwise disturb residual subsurface contamination, including characterization and limitations on use/reuse in accordance with NYSDEC regulations.
- Land use restrictions and an acceptable method for evaluating potential impact that the remaining contaminants have on future development.
- Land use restriction and reporting requirements that are passed on to any and 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 remains under its ownership. In the event of property transfer to a non-federal entity, DOE will ensure that a deed is established and that the required environmental easements are added to the deed at that time.
- Requirements for annual certification to NYSDEC stating that the institutional and engineering controls put in place are unchanged from the previous certification, and that nothing has occurred that would impair the ability of the controls 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.

These LUICs are described in the Land Use Controls Management Plan developed by DOE and reviewed and approved by EPA and NYSDEC.

An assessment of the long-term effectiveness of these S&M activities and LUICs would be included in the CERCLA Five-Year Reviews, that are to be conducted by DOE, and reviewed and approved by EPA and NYSDEC. The purpose of the five-year reviews is to determine whether the remedies implemented at BNL (including the HFBR) continue to be protective of human health and the environment. The five-year reviews will include an evaluation of the effectiveness of S&M activities, engineering controls, and LUICs.

The methods, findings, and recommendations of the reviews will be documented in Five-Year Review Reports.

3.1.3 Implementation of Alternative A
The HFBR and its radiological inventory have been effectively managed since its initial operation in 1965. The S&M actions described herein are the same as those already taken at the HFBR. Likewise, comprehensive LUICs have been put in place for other CERCLA remedies at BNL. No new technologies or administrative controls would be required and there are no outstanding implementability issues and uncertainties.

3.1.4 Schedule and Cost of Alternative A

By definition, the active (i.e., construction) phase of Alternative A is now complete except for the remediation of the WLA. The cleanup of the WLA will be performed using the same dose-based cleanup goal of 15 mrem/year and methodology specified in the OU I ROD. The soil contamination at the WLA is estimated to cover an area of 57,500 ft^2 to a depth of 18 in. It will be removed and shipped for off-site disposal. Following the completion of contaminated soil removal, BSA will perform a Final Status Survey (FSS) to demonstrate that the cleanup goal for the WLA has been satisfied and will include a verification survey performed by an independent DOE contractor, Oak Ridge Institute for Science and Education. As shown in Figure 3.3, S&M and LUICs would continue for an indefinite period of time.

Previous expenditures to perform the work completed to date total approximately $25M. Based on a bottoms-up estimate, using production rates from RS Means and historical experience at BNL in the removal, transportation, and disposal of contaminated soil, the additional capital cost to complete the WLA cleanup is approximately $1M resulting in a total capital cost estimate to complete Alternative A of $26M.

Based on operating experience, annual costs for S&M and LUICs total $400,000 per year. Because there is no limit on the required duration, the total cost of S&M and LUIC's cannot be estimated.

3.2 ALTERNATIVE B – PHASED DECONTAMINATION AND DISMANTLEMENT

3.2.1 End-State`

Alternative B provides for the near-term dismantlement and removal of the ancillary buildings, contaminated underground and piping systems, and the cleanup of contaminated HFBR yard area soils by FY 2020. The near-term soil cleanup of the HFBR yard area would be performed in accordance with the dose-based cleanup objectives for radiological soil contamination (for residential use) and methodology specified in the OU I ROD. The boundaries of the HFBR yard area soils are defined in the HFBR complex site plan (Figure 1.3).

This alternative includes a period of radioactive decay not to exceed 65 years to allow for the natural reduction of the high radiation dose rates associated with the activated components. The radiological inventory remaining over time, for this alternative, is graphically demonstrated in Figure 3.4. The radioactive material would remain bound within the metal and concrete of the activated components (reactor internals, CRBs, reactor vessel, thermal shield and biological shield). At the conclusion of this period, all remaining HFBR structures, systems, and components would be dismantled and disposed with the possible exception of the subsurface concrete structures, of the confinement building base mat and the stack foundation. However, the final decision to leave either of the structures in place will be determined on the basis of radiological sampling and dose assessment performed in accordance with the methodology specified in the OU I ROD. The entire remaining radiological inventory would be removed at the conclusion of the period of radioactive decay. The cleanup, after dismantlement of the confinement building, would satisfy the dose-based cleanup objectives for radiological contamination (for residential use) and methodology specified in the OU I ROD. The impact of this removal on the remaining radiological inventory, over time, is seen more clearly in Figure 3.5. There will be no need for any additional period of LUICs.

3.2.2 Scope of Alternative B

3.2.2.1 Active Decontamination and Dismantlement

Alternative B includes those actions described in Section 1.3 and listed in Table 1.1 that have already been completed. These actions are summarized as follows:

- The HFBR fuel was removed and sent to an off-site facility.
- The primary coolant was drained and sent to an off-site facility.
- Scientific equipment was removed and is being reused.
- Shielding and chemicals were removed and are being reused at BNL and other facilities.
- The cooling tower superstructure was dismantled and disposed.
- The confinement structure and spent fuel canal were modified to meet Suffolk County Article 12 requirements.
- Stack Monitoring Facility (Building 715) was dismantled and disposed.
- Cooling Tower Basin and Pump/Switchgear House (Building 707/707A) was dismantled and disposed.
- Water Treatment House (Building 707B) was dismantled and disposed.
- Cold Neutron Facility (Building 751) contaminated systems were removed and the clean building has been transferred to another organization for re-use.
- Guard house (Building 753) was dismantled and disposed.

Alternative B would also include the near-term dismantlement and disposal of the remaining HFBR ancillary buildings, contaminated underground duct and piping systems, and the removal and disposal of contaminated yard area soils by FY 2020 as further described below.

All of the remaining HFBR ancillary buildings, including the structures, systems and components (Figure 1.3) would be dismantled and disposed in the near-term, by FY 2020, to at least two ft below grade. Sampling and analysis would then be performed to verify that the underlying soils cleanup would be performed in accordance with the dose-based cleanup objectives for radiological soil contamination (for residential use) and methodology specified in the OU I ROD. To the extent required, contaminated soils would be removed to meet this cleanup goal. The remaining ancillary buildings include the following:

- Stack (Building 705)
- Fan house including underground plenum (Building 704)
- Fan house (for Building 801) and tritium evaporator (Building 802)

Contaminated underground duct and piping systems would be removed in the near-term, by FY 2020, including the confirmation and/or cleanup of soils, to the extent required, to be in accordance with the dose-based cleanup objectives for radiological soil contamination (for residential use) and methodology specified in the OU I ROD. The extent of underground service and piping system removal is shown on Figure 1.9, and Table 3.2 provides a description of this work. These services and piping systems include:

- Building exhaust ducts from Buildings 750, 801, and 802
- Sections of exhaust ducts from 815, 830, and the Tandem Van de Graaff generator
- Sanitary discharge line
- D/F waste line

Cleanup of the WLA will be performed when it is no longer needed as a waste staging and loading area.

Confirmatory sampling and analysis would be conducted in order to confirm that cleanup of the HFBR yard area soils is in accordance with the dose-based cleanup objectives for radiological soil contamination (for residential use) and methodology specified in the OU I ROD. Contaminated soil would be removed in the near term to the extent required to meet this goal. The boundaries of the HFBR yard area soils are defined in the HFBR complex site plan (Figure 1.3).

Subsequent to the completion of these decommissioning activities the HFBR confinement building would be prepared for long-term safe storage to allow for the radioactive decay. The safe storage physical preparations include:

- Modification of building ventilation exhaust system to ensure the atmosphere in the confinement is safe for personnel access for S&M activities
- Modification of security system and alarms on all entryways to confinement
- Installation of water infiltration detection system with remote alarms
- Modification of confinement building fire detection system with local and remote alarms
- Modification of confinement building lighting and electric power distribution to support surveillance activities

Implementation of miscellaneous physical preparatory activities that will also be required include:

- Correction of confinement building minor deficiencies
- Drain-down of mechanical systems including the removal of residual heavy water from the primary system piping and components
- Removal of miscellaneous waste and excess combustible materials
- Improvement to storm water drainage by adjustment of grades so it drains away from the HFBR in four areas outside the transformer room, north of the east truck lock, by the air conditioning cooling tower, and the entrance to the blower room.

When the physical preparations are complete, an S&M program for the long-term safe storage of the confinement building will be deployed, as described in the Surveillance and Maintenance subsection below.

At the conclusion of the radioactive decay period, Alternative B would include the segmentation, removal and disposal of activated structures and components:

- Reactor vessel and internals
- Control rod blades
- Thermal shield
- Biological shield
- Beam plugs

Subsequent to activated component removal, this alternative would include the dismantlement and removal of the reactor confinement building (Building 750), including:

- All Building 750 structures, systems and components
- Cleanup of underlying soils to the extent require to meet the cleanup goal and methodology specified in OU I ROD

At the conclusion of Alternative B, the entire HFBR complex and contaminated soils would be removed allowing for residential land use. All structures will be removed to at least two ft below grade, with the possible exception of the subsurface concrete structures of the confinement building base mat and stack foundation,

3.2.2.2 Surveillance and Maintenance

An S&M program would be deployed to manage the inventory of radioisotopes that would remain throughout the period of radioactive decay and the active phase of this alternative. HFBR S&M would be implemented to ensure that the inventory of stored radioisotopes and all residual contamination is maintained in a safe condition, and to preclude future human exposure pathways or migration from their locations within the reactor confinement building and HFBR yard area. The S&M program would cover the 65 year period of radioactive decay and the three years of HFBR dismantlement. The cleanup following the last phase of HFBR dismantlement would meet residual soil contamination levels that would allow for residential land use pursuant to the OU I cleanup goal, specified in the ROD. S&M activities would include:

- Groundwater monitoring and response actions would continue in accordance with OU III ROD requirements
- Continuation of air effluent monitoring
- Routine inspection of the reactor complex, including the maintenance and periodic refurbishment of structures, systems, and components that are important to the storage of the inventory of HFBR radioisotopes throughout the period of radioactive decay

- Routine inspection of the yard area, including routine maintenance and periodic refurbishment of ground cover to prevent soil erosion
- Periodic reporting to EPA and NYSDEC

The HFBR S&M plan would be developed by DOE in consultation with EPA and the NYSDEC.

3.2.2.3 Land Use and Institutional Controls

LUICs for Alternative B would be deployed for a 65 year period of radioactive decay and the three years of HFBR dismantlement, as described above. At a minimum, these LUICs would include:

- Measures for controlling future excavation and other actions that could otherwise disturb residual subsurface contamination, including characterization and limitations on use or reuse in accordance with NYSDEC regulations.
- Land use restrictions and an acceptable method for evaluating potential impact that the remaining contaminants have on future development.
- Land use restriction and reporting requirements that are passed on to any and 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 would be responsible for implementing these controls as long as the property remains under its ownership. In the event of property transfer to a non-federal entity, DOE would ensure that a deed be established and that the required environmental easements are added to the deed at that time.
- Requirements for annual certification to NYSDEC stating that the institutional and engineering controls put in place are unchanged from the previous certification, and that nothing has occurred that would impair the ability of the controls 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.

These LUICs are described in the Land Use Controls Management Plan developed by DOE and reviewed and approved by EPA and NYSDEC.

An assessment of the long-term effectiveness of these S&M activities and LUICs would be included in the CERCLA 5-Year Reviews that are to be conducted by DOE and reviewed and approved by EPA and NYSDEC. The purpose of the five-year reviews is to determine whether the remedies implemented at BNL (including the HFBR) continue to be protective of human health and the environment. The five-year reviews will include an evaluation of the effectiveness of S&M activities, engineering controls, and LUICs and an assessment of new technologies that could be implemented to reduce the overall time for remedy completion.

The methods, findings, and recommendations of the reviews will be documented in Five-Year Review Reports.

3.2.3 Implementation of Alternative B

The dismantlement and removal of the HFBR complex would be carried out using standard demolition and waste management work practices routinely used throughout the nuclear industry. The removal of the ancillary buildings, underground services and duct and piping systems, and contaminated soils, including the WLA, would not pose extraordinary technical issues and challenges. The dismantlement of the confinement building would also be carried out using simple and field-proven work practices.

The radioactive decay period would result in substantial reductions in the radiation dose rates attributable to the activated components and structures of the HFBR. Hence, their dismantlement would likewise be performed using field-proven demolition and waste management work practices used throughout the nuclear industry. The removal of these activated components would not pose any extraordinary technical challenges, issues, and complexities.

The estimated occupational radiation exposure required to perform the work included in Alternative B is 3 person-Rem.

3.2.4 Schedule and Cost of Alternative B

Earlier dismantlement of the remaining HFBR structures, systems, and components will be considered as part of the CERCLA Five-Year Reviews, and in any event would be removed after no more than 65 years. For the purpose of schedule and cost estimate development and comparison purposes, the 65 year bounding duration was used. After this period the balance of the HFBR structures, systems and components would be removed over a 3-year schedule. An S&M program and LUICs would be maintained throughout this entire duration. Following the active phase, there will be no need for any additional period of LUICs. The implementation schedule for Alternative B is illustrated in Figure 3.3.

Previous expenditures to perform the work completed to date total approximately $25 M. The additional capital cost to complete the active phase of Alternative B, including the WLA, is $110M, and the total capital cost estimate is $135M.

Based on operating experience, the annual costs of S&M is $400,000. With modifications to the HFBR complex, S&M costs would be reduced to $100,000 per year. Throughout 65 years of radioactive decay, major equipment refurbishment would be conducted at 20-year intervals. The estimated costs are $100,000 per interval. Following radioactive decay and upon completion of final HFBR dismantlement, the cost for implementing HFBR S&M and LUICs would be eliminated. Based on the foregoing, the consolidated cost estimate for the S&M and LUIC for Alternative B is $7 M.

The total estimated cost of Alternative B is $142 M, including capital, S&M, and LUIC costs across the entire project lifecycle.

3.3 ALTERNATIVE C- PHASED DECONTAMINATION AND DISMANTLEMENT WITH NEAR-TERM CONTROL ROD BLADE REMOVAL

3.3.1 End State

The Alternative C end state is the same as that for Alternative B. As discussed herein, the only difference is in the timing of the dismantlement and removal activities.

Alternative C provides for the near-term dismantlement and removal of the ancillary buildings, contaminated underground services and duct and piping systems, and the remediation of contaminated HFBR yard area soils by FY 2020. The near-term soil cleanup of the HFBR yard area would be performed in accordance with the dose-based cleanup objective and methodology for radiological soil contamination (for residential use) specified in the OU I ROD. The boundaries of the HFBR yard area soils are defined in the HFBR complex site plan (Figure 1.3). In addition, Alternative C provides for the near-term removal, by FY 2020, of the CRBs and beam plugs. The radiological inventory remaining over time for this alternative is graphically demonstrated in Figure 3.6.

This alternative includes a period of radioactive decay not to exceed 65-years to allow for the natural reduction of the high radiation dose rates associated with the remaining activated components. During this period the radioactive material would remain bound within the metal and concrete of the activated components (reactor internals, reactor vessel, thermal shield and biological shield). At the conclusion of this period, all remaining HFBR structures, systems, and components would be dismantled and removed with the possible exception of the subsurface concrete structures of the confinement building base mat and the stack foundation. However, the final decision to leave either of the structures in place will be determined on the basis of radiological sampling and dose assessment performed in accordance with the methodology specified in the OU I ROD. The entire remaining radiological inventory would be removed at the conclusion of the period of radioactive decay. The cleanup, after dismantlement of the confinement building, would satisfy the cleanup goal (for residential use) and methodology specified in the OU I ROD. The impact of this removal on the remaining radiological inventory over time is seen more clearly in Figure 3.7. There will be no need for any additional period of LUICs.

3.3.2 Scope of Alternative C

3.3.2.1 Active Decontamination and Dismantlement

Alternative C is almost identical to that of Alternative B. The only difference is in the timing of the removal of the CRBs and beam plugs.

Alternative C includes those actions described in Section 1.3 and listed in Table 1.1 that have already been completed. These actions are summarized as follows:

- The HFBR fuel was removed and sent to an off-site facility.
- The primary coolant was drained and sent to an off-site facility.

- Scientific equipment was removed and is being reused.
- Shielding and chemicals were removed and are being reused at BNL and other facilities.
- The cooling tower superstructure was dismantled and disposed.
- The confinement structure and spent fuel canal were modified to meet Suffolk County Article 12 requirements.
- Stack Monitoring Facility (Building 715) was dismantled and disposed.
- Cooling Tower Basin and Pump/Switchgear House (Building 707/707A) was dismantled and disposed.
- Water Treatment House (Building 707B) was dismantled and disposed.
- Cold Neutron Facility (Building 751) contaminated systems were removed and the clean building has been transferred to another organization for re-use.
- Guard house (Building 753) was dismantled and disposed.

Alternative C would also include the near-term dismantlement and removal of the HFBR ancillary buildings, contaminated underground services and duct and piping systems, the removal of contaminated yard area soils, and the removal of the 16 CRBs and beam plugs by FY 2020, as further described below.

All of the HFBR ancillary buildings, including the structures, systems and components, (Figure 1.3) would be dismantled and removed in the near-term, by FY 2020, to at least two ft below grade. Sampling and analysis would be performed in accordance with the dose-based cleanup goal and methodology to verify that the underlying soils meet the cleanup goal specified in the OU I ROD for residential land use. To the extent required, contaminated soils would be removed to meet this cleanup goal. Ancillary buildings include the following:

- Stack (Building 705)
- Fan house including underground plenum (Building 704)
- Fan house (for Building 801) and tritium evaporator (Building 802)

Contaminated underground services and piping systems would be removed in the near-term, by FY 2020, including the confirmation and/or cleanup of soils to the extent required to meet the cleanup goal specified in the OU I ROD for residential land use. The extent of underground service and duct and piping system removal is shown in Figure 1.9 and Table 3.1 provides a description of this work. These services and duct and piping systems include:

- Building exhaust ducts from Buildings 750, 801, and 802
- Sections of exhaust ducts from 815, 830 and the Tandem Van de Graaff generator
- Sanitary discharge line
- D/F waste line

Cleanup of the WLA will be performed when it is no longer needed as a waste staging and loading area.

Confirmatory sampling and analysis would be conducted in accordance with the dose-based cleanup objective for radiological soil contamination in order to confirm that HFBR yard area soils meet the cleanup goal specified in the OU I ROD for residential land use. Contaminated soil would be removed in the near-term, by FY 2020, to the extent required to meet this goal. The boundaries of the HFBR yard area soils are defined in the HFBR complex site plan (Figure 1.3).

The 16 CRBs in the reactor and the 9 beam plugs located on the experimental level would also be removed in the near-term, by FY 2020. Removal of the CRBs would require flooding of the reactor vessel, interconnecting piping, and spent fuel canal. The spent fuel canal, originally a ceramic tile lined concrete pool, was modified to include a freestanding, double-walled, stainless steel liner with an instrumented low point sump to eliminate the potential for leakage to the environment. The CRBs would be removed from the reactor; transferred to the spent fuel canal; and packaged in shielded transportation casks for shipment and disposal. Following CRB removal, the up to 75,000 gallons of water used to flood the reactor and spent fuel canal would be processed and disposed. The reactor would be reassembled, and the spent fuel canal would be decontaminated. The beam plugs would be transferred from the beam plug storage facility and loaded into shielded transportation casks for shipment and disposal.

Subsequent to the completion of these decommissioning activities, the HFBR confinement building would be prepared for long-term safe storage to allow for the radioactive decay. The safe storage physical preparations include:

- Modification of building ventilation exhaust system that ensure the atmosphere in the confinement is safe for personnel access for S&M activities
- Modification of security system and alarms on all entryways to confinement
- Installation of water infiltration detection system with remote alarms
- Modification of confinement building fire detection system with local and remote alarms
- Modification of confinement building lighting and electric power distribution to support surveillance activities

Implementation of miscellaneous physical preparatory activities that will also be required include:

- Correction of confinement building minor deficiencies
- Drain-down of mechanical systems including the removal of residual heavy water from the primary system piping and components
- Removal of miscellaneous waste and excess combustible materials
- Improvement to storm water drainage by adjustment of grades so it drains away from the HFBR in four areas outside the transformer room, north of the east truck lock, by the air conditioning cooling tower, and the entrance to the blower room.

Upon completion of the physical preparations an S&M program for the long-term safe storage of the confinement building, as described in the Surveillance and Maintenance subsection below, will be deployed.

After the remainder of the 65 year decay period, Alternative C would include the segmentation, removal and disposal of activated structures and components:

- Reactor vessel and internals
- Thermal shield
- Biological shield

Subsequent to activated structures and components removal, this alternative would include the dismantlement and disposal of the reactor confinement building (Building 750), including:

- All Building 750 structures, systems and components
- Cleanup of underlying soils to the extent required to meet the cleanup goal and methodology specified in the OU I ROD

At the conclusion of Alternative C, the entire HFBR complex and contaminated soils would be removed allowing for residential land use. All structures will be removed to at least two ft below grade, with the possible exception of the subsurface concrete structures of the confinement building base mat and stack foundation.

3.3.2.2 Surveillance and Maintenance

An S&M program would be deployed to manage the inventory of radioisotopes that would remain throughout the period of radioactive decay and the active phase of this alternative. HFBR S&M would be implemented to ensure that the inventory of stored radioisotopes and all residual contamination is maintained in a safe condition, and to preclude future human exposure pathways or migration from their locations within the reactor confinement building and HFBR yard area. The S&M program and LUICs would cover the 65 year period of radioactive decay and the three years of HFBR dismantlement. The cleanup following the last phase of HFBR dismantlement would meet residual soil contamination levels that would allow for residential land use pursuant to the cleanup goal and methodology specified in the OU I ROD. S&M activities would include:

- Groundwater monitoring and response actions would continue in accordance with OU III ROD requirements
- Continuation of air effluent monitoring
- Routine inspection of the reactor complex, including the maintenance and periodic refurbishment of structures, systems, and components that are important to the storage of the inventory of HFBR radioisotopes throughout the period of radioactive decay
- Routine inspection of the yard area, including routine maintenance and periodic refurbishment of ground cover to prevent soil erosion
- Periodic reporting to EPA and NYSDEC

The HFBR S&M plan would be developed by DOE in consultation with EPA and the NYSDEC

3.3.2.3 Land Use and Institutional Controls

LUICs for Alternative C would be deployed for a 65 year period of radioactive decay and the three years of HFBR dismantlement, as described above. At a minimum, these LUICs would include:

- Measures for controlling future excavation and other actions that could otherwise disturb residual subsurface contamination, including characterization and limitations on use or reuse in accordance with NYSDEC regulations.
- Land use restrictions and an acceptable method for evaluating potential impact that the remaining contaminants have on future development.
- Land use restriction and reporting requirements that are passed on to any and 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 would be responsible for implementing these controls as long as the property remains under its ownership. In the event of property transfer to a non-federal entity, DOE would ensure that a deed be established and that the required environmental easements are added to the deed at that time.
- Requirements for annual certification to NYSDEC stating that the institutional and engineering controls put in place are unchanged from the previous certification, and that 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.

These LUICs are described in the Land Use Controls Management Plan developed by DOE and reviewed and approved by EPA and NYSDEC.

An assessment of the long-term effectiveness of these S&M activities and LUICs would be included in the CERCLA 5-Year Reviews that are to be conducted by DOE and reviewed and approved by EPA and NYSDEC. The purpose of the five-year reviews is to determine whether the remedies implemented at BNL (including the HFBR) continue to be protective of human health and the environment. The five-year reviews will include an evaluation of the effectiveness of S&M activities, engineering controls, and LUICs and an assessment of new technologies that could be implemented to reduce the overall time for remedy completion.

The methods, findings, and recommendations of the reviews will be documented in Five-Year Review Reports.

3.3.3 Implementation of Alternative C

The dismantlement and removal of the HFBR complex would be carried out using standard demolition and waste management work practices routinely used throughout the nuclear industry. The removal of the ancillary buildings, underground services and duct and piping systems, contaminated soils including the WLA, and CRBs would not pose extraordinary technical issues and challenges. The dismantlement of the confinement building would also be carried out using simple and field-proven work practices.

Because of the high calculated radiation dose rates, removal would need to be carried out underwater. The CRBs would be disconnected, removed from the reactor vessel, and packaged in a transportation cask remotely. CRB removal, including transfer to the spent fuel canal and loading into shipping casks has been performed at the HFBR in the past. These operations would utilize existing or readily available tools and equipment. These evolutions are routinely conducted throughout the industry and their implementation would not pose undue radiological risks or hazards. Because CRB removal has not been performed since 1987, DOE will include task specific worker training and qualification in the plans to perform this work.

Removal of the CRBs will require flooding of the reactor vessel and may require flooding of the interconnecting piping and spent fuel canal. Other near-term CRB removal activities could include:

- Mock-up training and qualification of tools and personnel.
- Flood-up of the reactor, interconnecting piping and spent fuel canal.
- Disconnection of the CRBs, and their transfer to the spent fuel canal and shipping cask.
- Transportation and disposal at an approved disposal facility.

Following CRB removal, interconnecting piping systems would be drained, and the spent fuel canal would be drained and decontaminated.

Similarly the beam plug removal involves the transfer, packaging, and transport of activated components with high radiation dose rates. The beam plugs would be removed from the beam plug storage facility utilizing existing or readily available tools, equipment, and methods. Beam plug removal, including transfer from the beam plug storage facility and loading into shipping casks has been performed at the HFBR in the past. Evolutions similar to this are routinely conducted throughout the industry and their implementation would not pose undue radiological risks or hazards.

Transfer of the beam plugs from the beam plug storage facility will include the interim use of a shielded transfer cask, individual transfer of the beam plugs to a shielded liner, and loading of the liner into a transportation cask. Some of these operations will have to be done remotely. Because beam plug removal has not been performed for a long time, mock-up training and qualification of tools and personnel, as with the CRB removal, will also be employed.

Subsequent to completing the near term decommissioning activities described in Section 3.3.2.1, the HFBR confinement building would be prepared for long-term safe storage as described above. Because the large components will require extensive segmentation and handling their dismantlement and disposal would be performed only after the not to exceed 65 year decay period. This would result in substantial reductions in the radiation dose rates attributable to the remaining HFBR activated components and structures. Hence, they would likewise be performed using field-proven demolition and waste management work practices used throughout the nuclear industry. These activated components would not pose any extraordinary technical challenges, issues, and complexities.

The estimated occupational radiation exposure required to perform the work included in Alternative C is 4 Person-rem.

3.3.4 Schedule and Cost of Alternative C

Alternative C provides for the near-term removal and disposal, by FY 2020, of the CRBs and beam plugs. These activities will be accomplished prior to preparation of the confinement building for long-term safe storage.

Earlier dismantlement of the remaining HFBR structures, systems, and components will be considered as part of the CERCLA Five-Year Reviews, and, in any event, would be removed after no more than 65 years. For the purpose of schedule and cost estimate development and comparison purposes, the 65 year bounding duration was used.

The cost estimate considers all of the CRB removal activities. After the decay period, the balance of the HFBR structures, systems, and components would be removed over a three-year schedule. An S&M program and LUICs would be maintained throughout this entire duration. Following the active phase, there will be no need for any additional period of LUICs. The implementation schedule for Alternative C is illustrated in Figure 3.3.

Previous expenditures to perform the work completed to date total approximately $25 M. The additional capital cost to complete the active phase of Alternative C, including the WLA is $112M, and the total capital cost estimate is $137M.

Based on operating experience, the annual costs of S&M is $400,000. With modifications to the HFBR complex, S&M costs would be reduced to $100,000 per year. Throughout the period of radioactive decay, major equipment refurbishment would be conducted at 20-year intervals. These estimated costs are $100,000 per interval, respectively. Following radioactive decay and upon completion of final HFBR dismantlement, the estimated cost for implementing HFBR S&M and LUICs is $35,000 per year. Based on the foregoing, the consolidated Alternative C S&M and LUIC cost estimate is $7 M.

The total estimated cost of Alternative C would be $144 M, including capital, S&M, and LUIC costs across the entire project lifecycle.

3.4 ALTERNATIVE D - NEAR-TERM DECONTAMINATION AND DISMANTLEMENT

3.4.1 End State

Alternative D provides for the complete near-term removal, by FY 2026, of the reactor complex. It includes the near-term dismantlement and disposal of all HFBR structures, systems, and components, with the possible exception of the subsurface concrete structures, confinement building base mat and the stack foundation. However, the final decision to leave either of the structures in place will be determined on the basis of radiological sampling and dose assessment performed in accordance with the methodology specified in the OU I ROD. The entire radiological inventory of 65,000 Ci described in Section 1.3 would be removed in the near-term, by FY 2026, with the limited exception of a small amount of residual contamination that would be allowable under the OU I cleanup goal. The radiological inventory remaining over time for this alternative is graphically demonstrated in Figure 3.8. Alternative D results in the dismantlement and removal of the HFBR complex by the end of 2026. S&M would be required through this period, and LUICs would be required for an additional 50 years because of the small amounts of residual soil contamination allowable under the OU I soil cleanup goal for residential use.

3.4.2 Scope of Alternative D

3.4.2.1 Active Decontamination and Dismantlement

Alternative D includes those actions described in Section 1.3 and listed in Table 1.1 that have already been completed. These actions are summarized as follows:

- The HFBR fuel was removed and sent to an off-site facility.
- The primary coolant was drained and sent to an off-site facility.
- Scientific equipment was removed and is being reused.
- Shielding and chemicals were removed and are being reused at BNL and other facilities.
- The cooling tower superstructure were dismantled and disposed.
- The confinement structure and spent fuel canal were modified to meet Suffolk County Article 12 requirements.

- Stack Monitoring Facility (Building 715) was dismantled and disposed.
- Cooling Tower Basin and Pump/Switchgear House (Building 707/707A) was dismantled and disposed.
- Water Treatment House (Building 707B) was dismantled and disposed.
- Cold Neutron Facility (Building 751) contaminated systems were removed and the clean building has been transferred to another organization for re-use.
- Guard house (Building 753) was dismantled and disposed.

Alternative D includes the near-term dismantlement and removal, by FY 2026, of all HFBR structures, systems, and components as described below.

All of the HFBR ancillary buildings, including the structures, systems and components, (Figure 1.3) would be dismantled to at least two ft below grade. Sampling and analysis would be performed to verify that the remediation of the underlying soils was performed in accordance with the dose based cleanup objectives for radiological contamination and methodology specified in the OU I ROD for residential land use. To the extent required, contaminated soils would be removed to meet this cleanup goal. All ancillary buildings listed below would be removed:

- Stack (Building 705)
- Fan house including underground plenum (Building 704)
- Fan house (for Building 801) and tritium evaporator (Building 802)

Contaminated underground duct and piping systems would be removed, including the confirmation and/or cleanup of soils to the extent required to meet the OU I cleanup goal specified in the ROD for residential land use. These services and piping systems include:

- Building exhaust ducts from Buildings 750, 801, and 802
- Sections of exhaust ducts from 815, 830 and the Tandem Van de Graaff generator
- Sanitary discharge line
- D/F waste line

Cleanup of the WLA will be performed when it is no longer needed as a waste staging and loading area.

Alternative D would include the near-term segmentation, removal, and disposal, by FY 2026, of activated structures and components:

- Reactor vessel and internals
- Control rod blades
- Thermal shield
- Biological shield
- Beam plugs

This alternative would also include confinement building dismantlement and disposal, including:

- All Building 750 structures, systems, and components
- Cleanup of underlying soils to the extent required to meet the OU I ROD cleanup goal for residential land use

Confirmatory sampling and analysis would then be conducted in order to confirm that HFBR yard area soils meet the OU I ROD cleanup goal for residential land use. Contaminated soil would be removed to the extent required to meet this goal. The boundaries of the HFBR yard area soils are defined in the HFBR complex site plan (Figure 1.3).

At the conclusion of Alternative D, the entire HFBR complex would be removed and residual soil contamination would meet the OU I ROD cleanup goal for residential land use. All structures will be removed to at least two ft below grade, with the possible exception of the subsurface concrete structures of the confinement building base mat and stack foundation.

3.4.2.2 Surveillance and Maintenance

An S&M program will be deployed to manage the small amount of contamination remaining in the HFBR complex. HFBR S&M would be implemented to ensure that this residual contamination is maintained in a safe condition, and to preclude future human exposure pathways or migration from its location within the HFBR yard area. The S&M program would be implemented for a period of 50 years following the completion of the active phase of decontamination and dismantlement. As described in OU I ROD, this 50-year period is the time required to reach radiological conditions that would allow for residential land use. S&M activities would include:

- Groundwater monitoring and response actions would continue in accordance with OU III ROD
- Routine inspection of the yard area
- Routine maintenance and periodic refurbishment of ground cover to prevent soil erosion
- Periodic reporting to EPA and NYSDEC

The HFBR S&M plan would be developed by DOE in consultation with EPA and the NYSDEC.

3.4.2.3 Land Use and Institutional Controls

LUICs for Alternative D would be deployed for a period of 50 years as described above, following the completion of active decontamination and dismantlement. At a minimum, these LUICs would include:

- Measures for controlling future excavation and other actions that could otherwise disturb residual subsurface contamination, including characterization and limitations on use or reuse in accordance with NYSDEC regulations.
- Land use restrictions and an acceptable method for evaluating potential impact that the remaining contaminants have on future development.
- Land use restriction and reporting requirements that are passed on to any and 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 remains under its ownership. In the event of property transfer to a non-federal entity, DOE will ensure that a deed is established and that the required environmental easements are added to the deed at that time.
- Requirements for annual certification to NYSDEC stating that the institutional and engineering controls put in place are unchanged from the previous certification, and that nothing has occurred that would impair the ability of the controls 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.

These LUICs are described in the Land Use Controls Management Plan developed by DOE, and reviewed and approved by EPA and NYSDEC.

An assessment of the long-term effectiveness of these S&M activities and LUICs would be included in the CERCLA 5-Year Reviews that are to be conducted by DOE and reviewed and approved by EPA and NYSDEC. The purpose of the five-year reviews is to determine whether the remedies implemented at BNL (including the HFBR) continue to be protective of human health and the environment. The five-year reviews will include an evaluation of the effectiveness of S&M activities, engineering controls and LUICs. The methods, findings, and recommendations of the reviews will be documented in Five-Year Review Reports.

3.4.3 Implementation of Alternative D

The near-term, by FY 2026, decontamination and dismantlement of much of the HFBR would be carried out using standard demolition and waste management work practices routinely used throughout the nuclear industry. The removal of the ancillary buildings, underground services and duct and piping systems, and contaminated soils, including the WLA, would not pose extraordinary technical issues and challenges. The dismantlement of much of the confinement structure would likewise be carried out using simple and field proven work practices.

However, the near-term dismantlement and disposal of the activated HFBR components would involve extraordinary technical risks and challenges. These components include the reactor vessel and internals, thermal shield, and biological shield. The radiation calculated dose rates attributable to these components are as high as 35,000 rem/hr. At these dose rates, the dismantlement and disposal of these activated components would require engineered methods and means to protect workers during dismantlement and waste packaging. In developing the HFBR alternatives, DOE studied and evaluated two methods: removing the reactor vessel, reactor internals, CRBs, and thermal shield as one piece; and removal in smaller, segmented sections. Both of these methods are relevant to the near-term removal of the activated components under Alternative D. One- piece removal involves the removal, loading and transportation as a single package to an approved off-site disposal facility. The segmentation option consists of the in-place dismantlement of these same components for loading into smaller reusable shielded shipping containers, requiring multiple shipments.

One-piece removal would require the design, qualification and licensing of a Type B shipping cask. Following U.S. Nuclear Regulatory Commission review and approval of the design, the cask would be fabricated and transported to BNL for loading. One-piece removal would require the dismantlement of physical interferences and structural modifications of the HFBR confinement building. After loading this shipping package (cask and components) would then be transported to the DOE's Nevada Test Site for final disposal.

The transportation of this 200-ton shipping package would require extensive engineering and logistical planning. The weight and physical dimensions of the package would likely preclude transportation using the Long Island Railroad system. The only other viable alternative is to transport it over the roadways and waterways accomplished by:

- Loading the shipping package onto a heavy-load transporter for transport to a barge slip on Long Island
- Transporting it along public roadways where special considerations would be made for weight as well as height limitations of bridges and overpasses
- Transferring the package onto an ocean-going barge
- Towing the barge along the eastern seaboard along approved shipping lanes to a pre-selected port in the Gulf Coast
- Off-loading the package onto another heavy-load transporter or specially-designed railcar
- Transporting it along public roadways where special considerations would be made for weight as well as height limitations of bridges and overpasses
- Off-loading it at the Nevada Test Site for final disposal

Numerous project risks and hazards would require careful management throughout all phases of this task. There are technical uncertainties regarding neutron embrittlement of the thermal shield and the ability to safely rig and handle the assembly as one piece. Loading conditions during rigging and handling could result in brittle fracture of the thermal shield welds or base material. One-piece removal involves regulatory approvals of a one-of-a-kind Type B transportation package, and regulatory and stakeholder approvals at various points along the heavy haul route. These external approvals pose uncertainties and project risks.

As summarized below, the segmentation and removal of the HFBR reactor in pieces involves the same level of project risks, hazards and complexities:

- The segmentation of these activated components would need to be accomplished remotely, and at these dose rates, would need to be performed underwater. It could include flooding of the spent fuel canal, originally a ceramic tile lined concrete pool, which was modified to include a freestanding, double-walled, stainless steel liner with an instrumented low point sump to eliminate the potential for leakage to the environment. Specialized tools, processes, and equipment would need to be designed, qualified, and deployed to undertake component dismantlement.
- Establishment of a floodable cavity to enable underwater segmentation of the reactor vessel, thermal shield and a portion of the biological shield.
- The dose rates and inventory of radioisotopes would require the use of Type B casks for waste transportation to a DOE disposal site. After considering the limitations of spent fuel canal size and crane capacity and the need for the cask to be certified for the transport of activated metals, there are only a few Type B casks currently available. The size and payload of these casks is very small. Hence, near-term dismantlement would involve a great deal of underwater segmentation and material handling. This would in turn increase the number, types, and complexity of tools that would be required to complete HFBR dismantlement.
- These radioactive components are volumetrically activated and the radioisotopes are physically stable. The radioactive contamination is contained with the actual matrix of these steel, aluminum, and concrete structures and components. Their segmentation would result in the generation of a large quantity of dispersible and highly radioactive cutting fines. It is estimated that these segmentation activities would generate up to 100,000 gallons of contaminated water requiring processing and disposal as LLRW. These secondary wastes would require the design, installation, operation, and maintenance of treatment systems to control water clarity and limit the amount of contamination in the volume of water used as a radiation shield. The generation of a significant quantity of dispersible and highly radioactive cutting fines would open up a wide spectrum of potential off-normal conditions and events, any one of which could result in the cross contamination of the HFBR confinement structure, which is essentially free of radioactive contamination at the present time.
- The transportation of these highly radioactive components and waste articles would require the use of special shipping casks and the implementation of existing DOE and DOT transportation procedures and controls. As many as 30 individual type A or B cask shipments would be required.

Both options for the removal of the reactor and internals involve similar levels of project hazards, risks and complexities. After further review, DOE concluded that the segmentation method would be preferable in the event that near-term reactor removal is required.

Based on these evaluations, DOE concluded the best option for removing the reactor and activated components would be *segmentation*. Therefore, the segmentation option is used as the basis for comparison with the other HFBR alternatives (i.e., Alternatives A, B, and C).

The estimated occupational radiation exposure required to perform the segmentation option is included in Alternative D is 20 Person-rem.

3.4.4 Schedule and Cost of Alternative D

The active phase of Alternative D decontamination and dismantlement would be completed over an 8-year schedule. At the conclusion of this active phase, S&M and LUICs would continue for a period of 50 years. The Alternative D implementation schedule is shown in Figure 3.3.

Previous expenditures to perform the work completed to date total approximately $25 M. The additional capital cost to complete the active phase of Alternative D, including the WLA, is $176 M, and resulting total capital cost estimate is $201 M.

Upon completion of the active phase, the estimated cost to implement HFBR S&M and LUICs is $35,000 per year. Based on the foregoing, the S&M and LUIC costs associated with Alternative D would total $4 M for the required 50-year period.

The total estimated cost of Alternative D would be $205 M, including capital, S&M, and LUIC costs across the project lifecycle.

Section 3 Tables and Figures

Table 3.1 End-states and Timeframes

	ALTERNATIVES			
	A	**B**	**C**	**D**
End State	Everything remains as is	Everything removed	Everything removed	Everything removed
Ancillary Buildings and Associated Soils	Everything remains as is	By end of FY 2020	By end of FY 2020	By end of FY 2026
Ducts, Underground Piping, and Associated Soils	Everything remains as is	By end of FY 2020	By end of FY 2020	By end of FY 2026
Control Rod Blades and Beam Plugs	Everything remains as is	After a decay period, not to exceed 65 years	By end of FY 2020	By end of FY 2026
Other Activated Components	Everything remains as is	After a decay period, not to exceed 65 years	After a decay period, not to exceed 65 years	By end of FY 2026
Confinement Building	Everything remains as is	After a decay period, not to exceed 65 years	After a decay period, not to exceed 65 years	By end of FY 2026
HFBR Complex Contaminated Soils	Everything remains as is	After a decay period, not to exceed 65 years	After a decay period, not to exceed 65 years	By end of FY 2026

Table 3.2 Contaminated Ducts/Pipelines Requiring Removal

Size/Material	Duct/Line	Length (feet)	Contamination Status	Basis	Notes
36"/concrete	Duct Bldg. 801 to 42" duct	205	Contaminated	Characterization.	Duct runs from west wall of Bldg. 801 to a point approximately 60' south of Bldg. 801where it transitions from 36" to 42" diameter.
24"/concrete	Duct Bldg. 801 to 42" duct	60	Contaminated	Characterization.	Duct runs from south wall of Bldg. 801 to the 42" diameter duct just downstream of point where it transitions from 36" to 42".
42"/concrete	From connection with 36" duct from Bldg. 801 to Bldg. 802	220	Contaminated	Characterization.	Duct runs from transition point with the 36" duct to Bldg. 802.
42"/steel and 36"/steel	Duct from 42" concrete duct to Bldg. 802 and then to Bldg. 705	60	Contaminated	Characterization.	At 10' west of Bldg. 802 line transitions from concrete to steel. Includes all steel piping under Bldg. 802 and connection from south side of Bldg. 802 to Bldg. 705
14"/stainless steel	Acid Waste Line Bldg. 801 to stack	300	Contaminated	Characterization.	An approximately 40' section of this line running south from Bldg. 801 was previously removed. Includes continuation of line to the south wall of Bldg. 802 and outside Bldg. 802 to Bldg. 705.
30"/steel	Duct Bldg. 704 to Bldg. 705	165	Contaminated	Process Knowledge	Steel duct runs from valve pit to Bldg. 705 and back to HFBR Filter House inlet, below grade, to the BGRR plenum and from the filter house outlet to the plenum just upstream of Bldg. 705. Process knowledge shows filters up and downstream of duct are contaminated.
30"/concrete	Duct Bldg. 750 to Bldg. 705	415	Contaminated	Process Knowledge	Concrete duct runs from Bldg. 750 to valve pit adjacent to the Bldg. 705 where it transitions to steel. Process knowledge shows filters up and downstream are contaminated

Table 3.2 Contaminated Ducts/Pipelines Requiring Removal

18”/vitrified clay pipe	Duct Bldg. 815/830 to 42” duct	80	Contaminated	Characterization.	Characterization determined duct from Bldg. 815/830 clean to point 80’ upstream of connection with 42” duct (closest point excavation could be made). Line cut and capped. Remaining 80’ will be removed when 42” duct is removed.
18”/steel	Duct Bldg. 901A to Bldg. 705	22	Contaminated	Characterization.	Duct clean from Bldg. 901A to point just upstream of connection with 42” from Bldg. 802 to Bldg. 705. Removal of 22’ section will encompass contaminated section and clean pipe upstream to a point where duct is 2 ft below grade.
42”/steel	Duct Bldg. 701 to Bldg. 704	60	Contaminated	Characterization.	Encompasses all steel duct work, including source of cross contamination, below floor of Bldg. 704 upstream to transition from steel to concrete duct coming from Bldg. 701.
8”/vitrified clay pipe	Line Bldg. 750 to Manhole MH232	26	Contaminated	Process Knowledge	Line from Bldg. 750 to manhole MH232. Routine discharge of tritiated water from Bldg. 750 to sanitary system.
2”/steel within 4”/bituminous coated steel	D/F Line from Bldg. 750 to Bldg. 801	1,083	Contaminated	Process Knowledge	Buried line runs from Bldg. 750 around the Bldg. 750 Annex to Bldg. 802. Process knowledge is that there was routine transfer of contaminated liquids until Nov 2000

Figure 3.1 Waste Loading Area

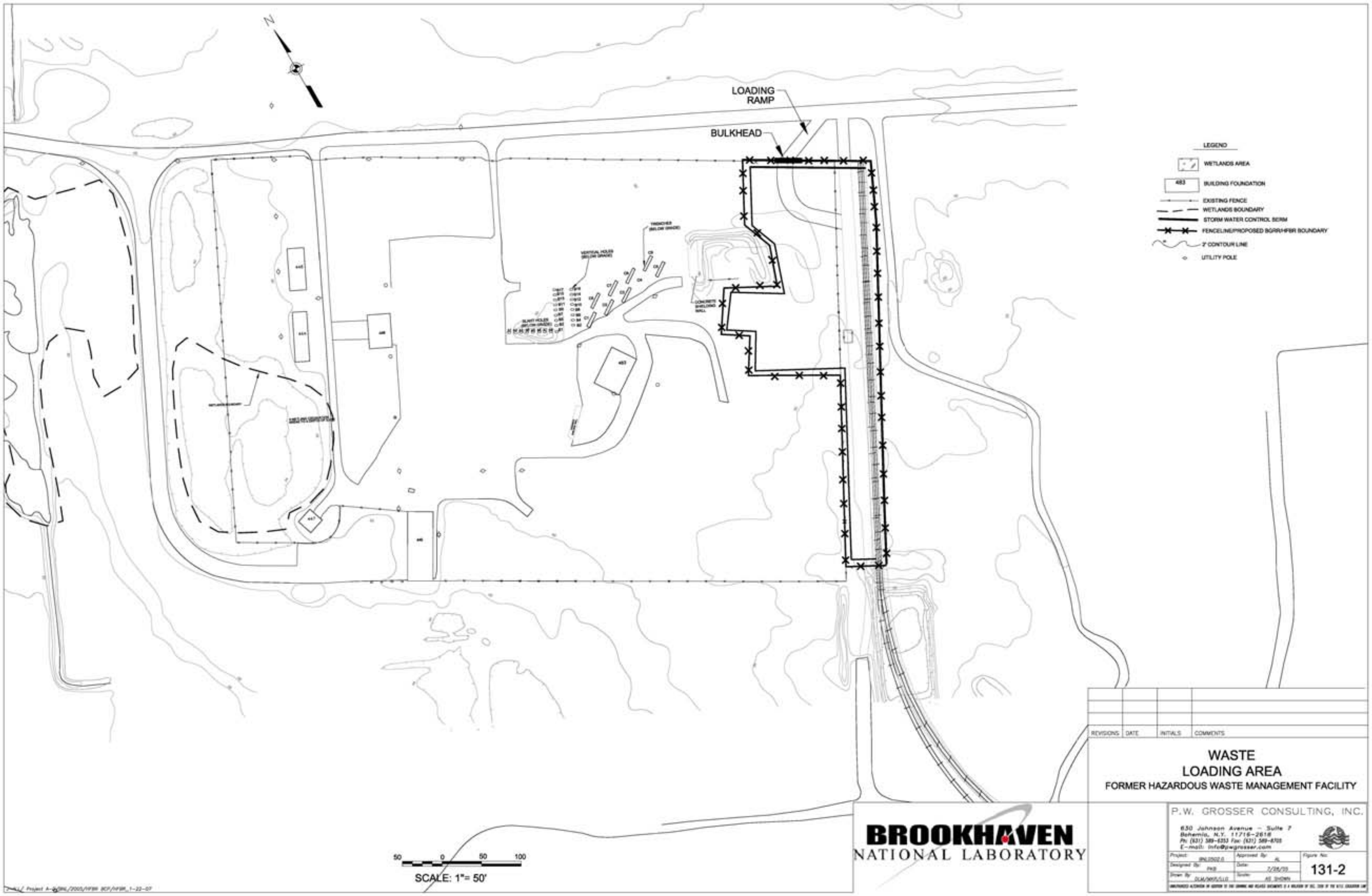
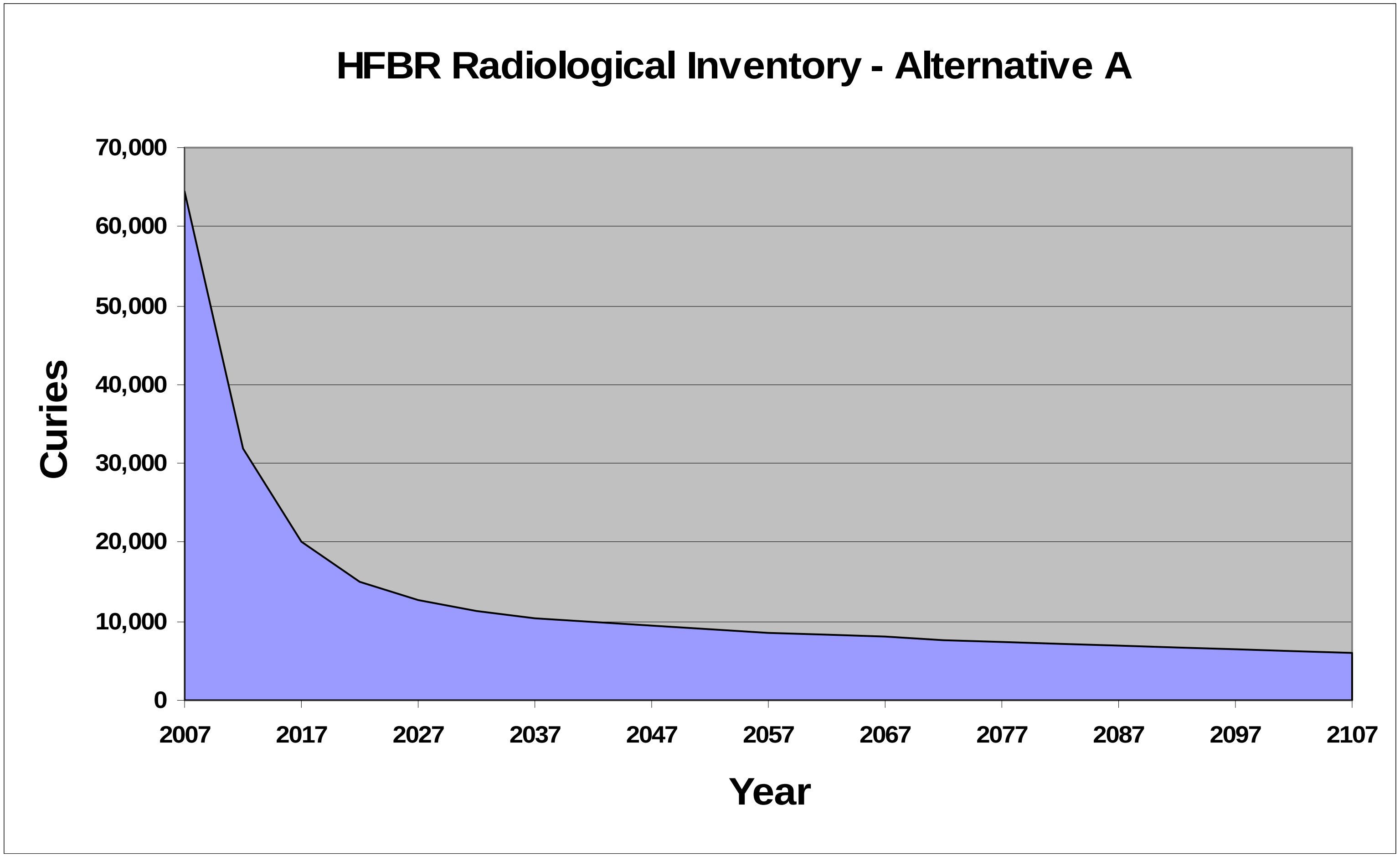


Figure 3.2 Radiological Inventory Remaining - Alternative A 2007-2107



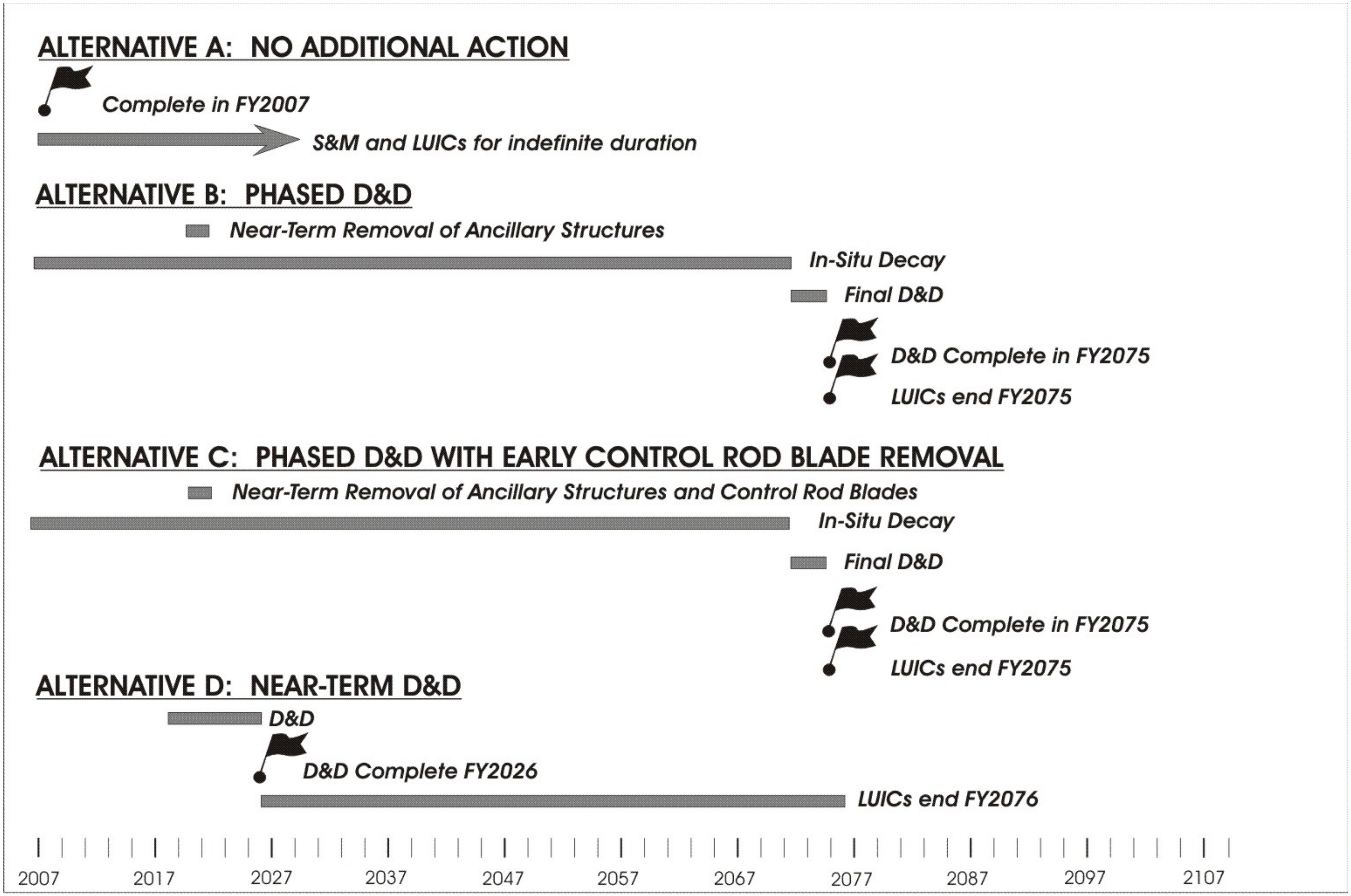


Figure 3.3 - Comparison of Alternative Schedules

Figure 3.4 Radiological Inventory Remaining – Alternative B 2007-2107

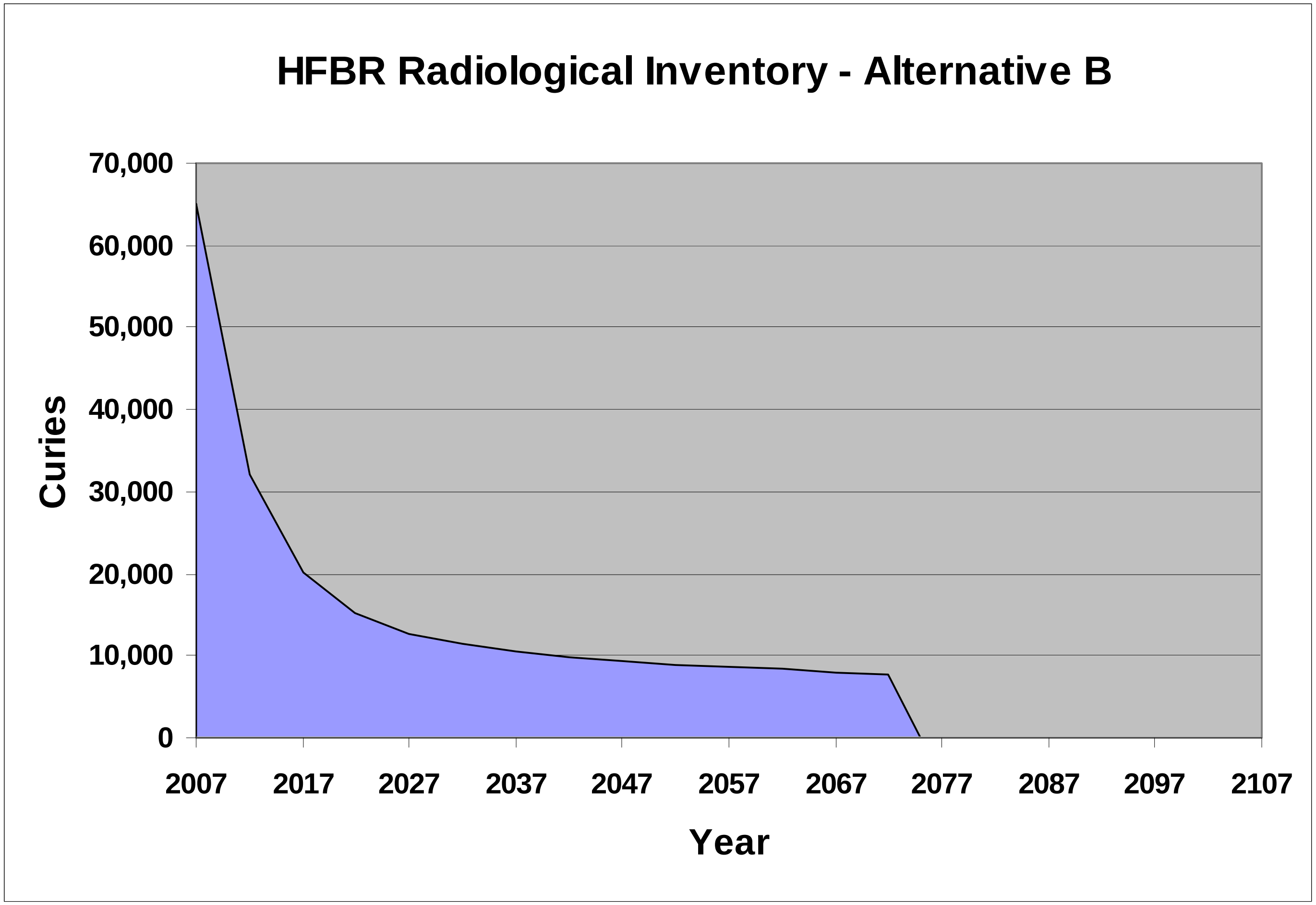


Figure 3.5 Radiological Inventory Remaining – Alternative B 2042 - 2107

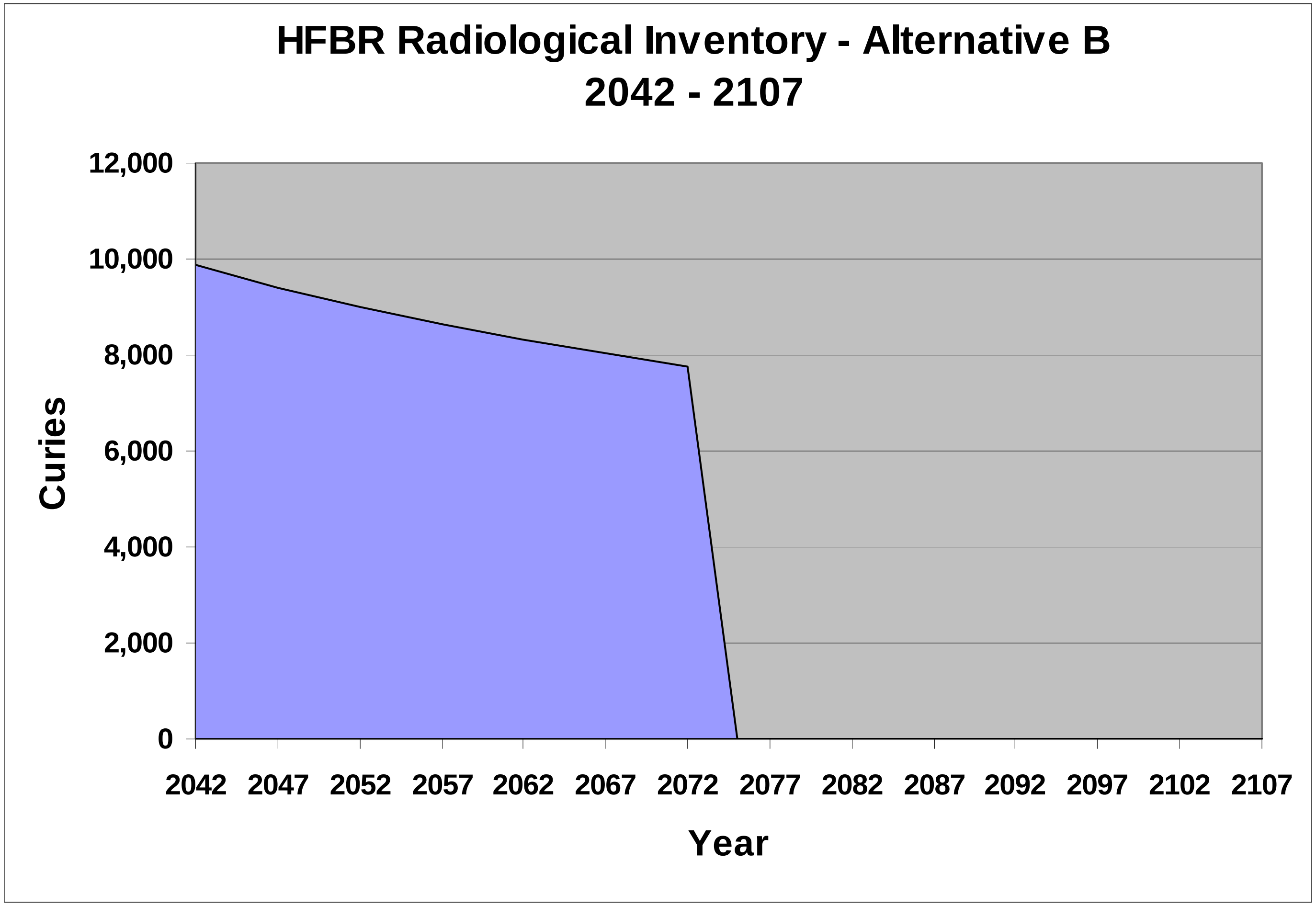


Figure 3.6 Radiological Inventory Remaining – Alternative C 2007-2107

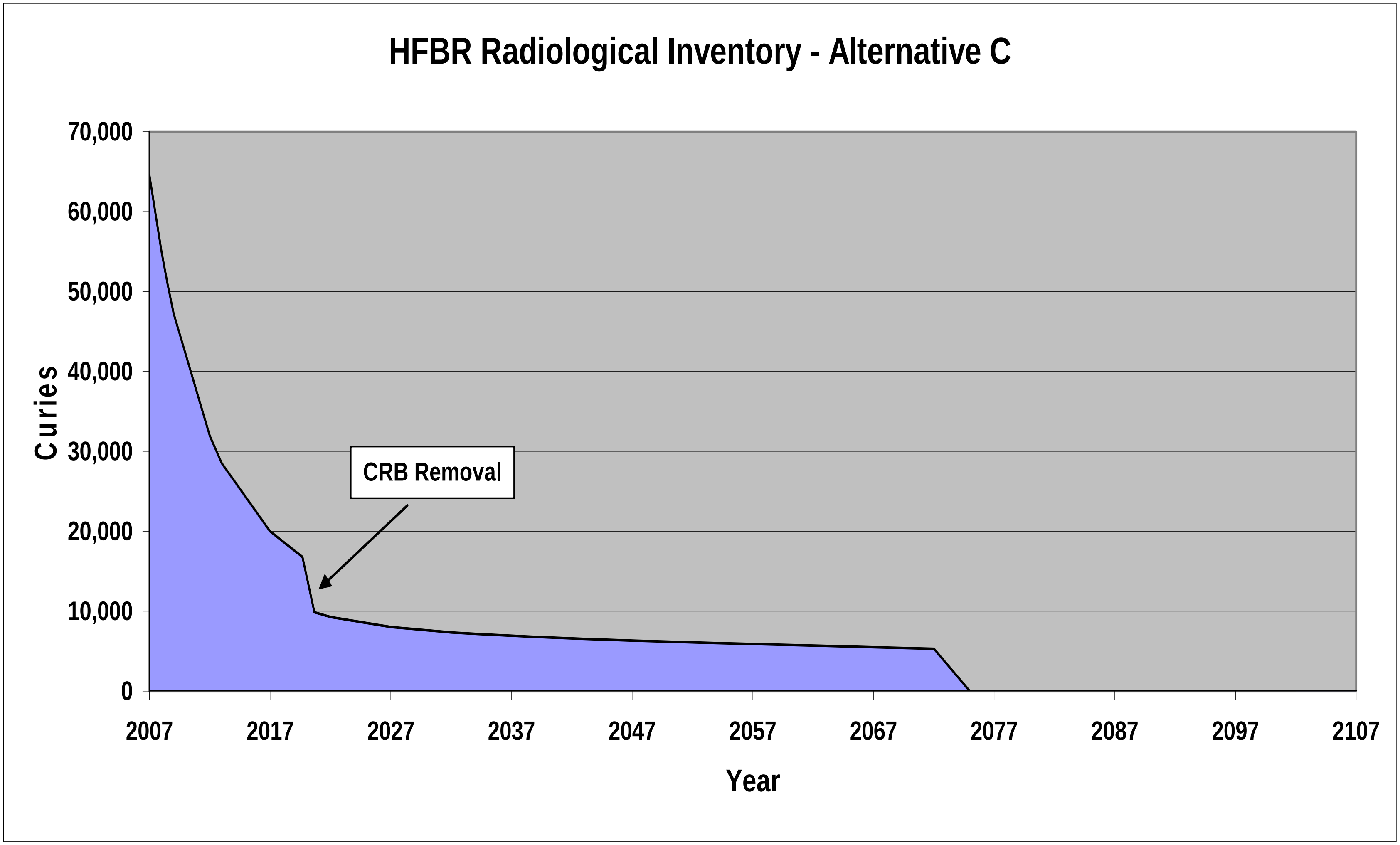


Figure 3.7 Radiological Inventory Remaining – Alternative C 2007 - 2023

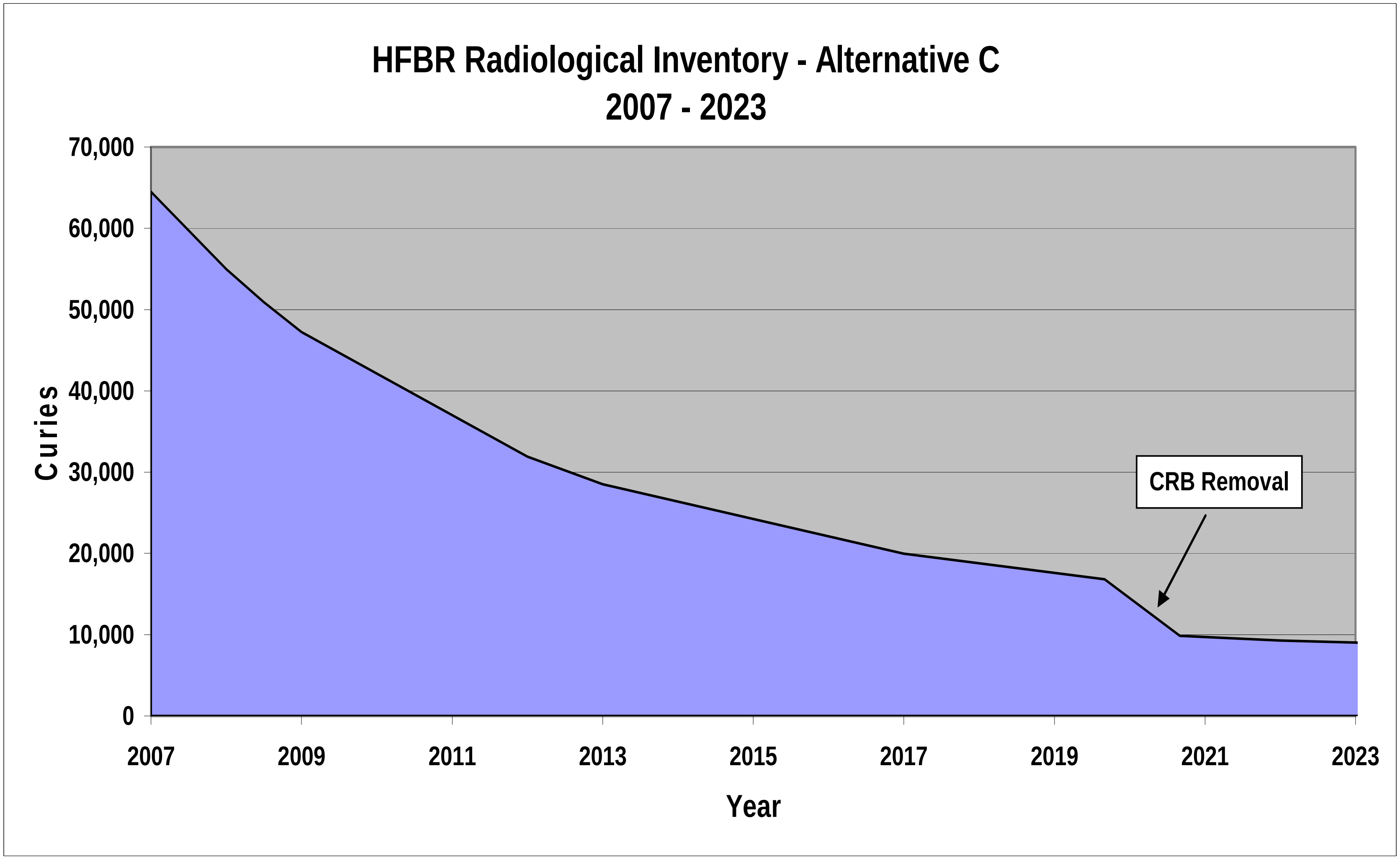
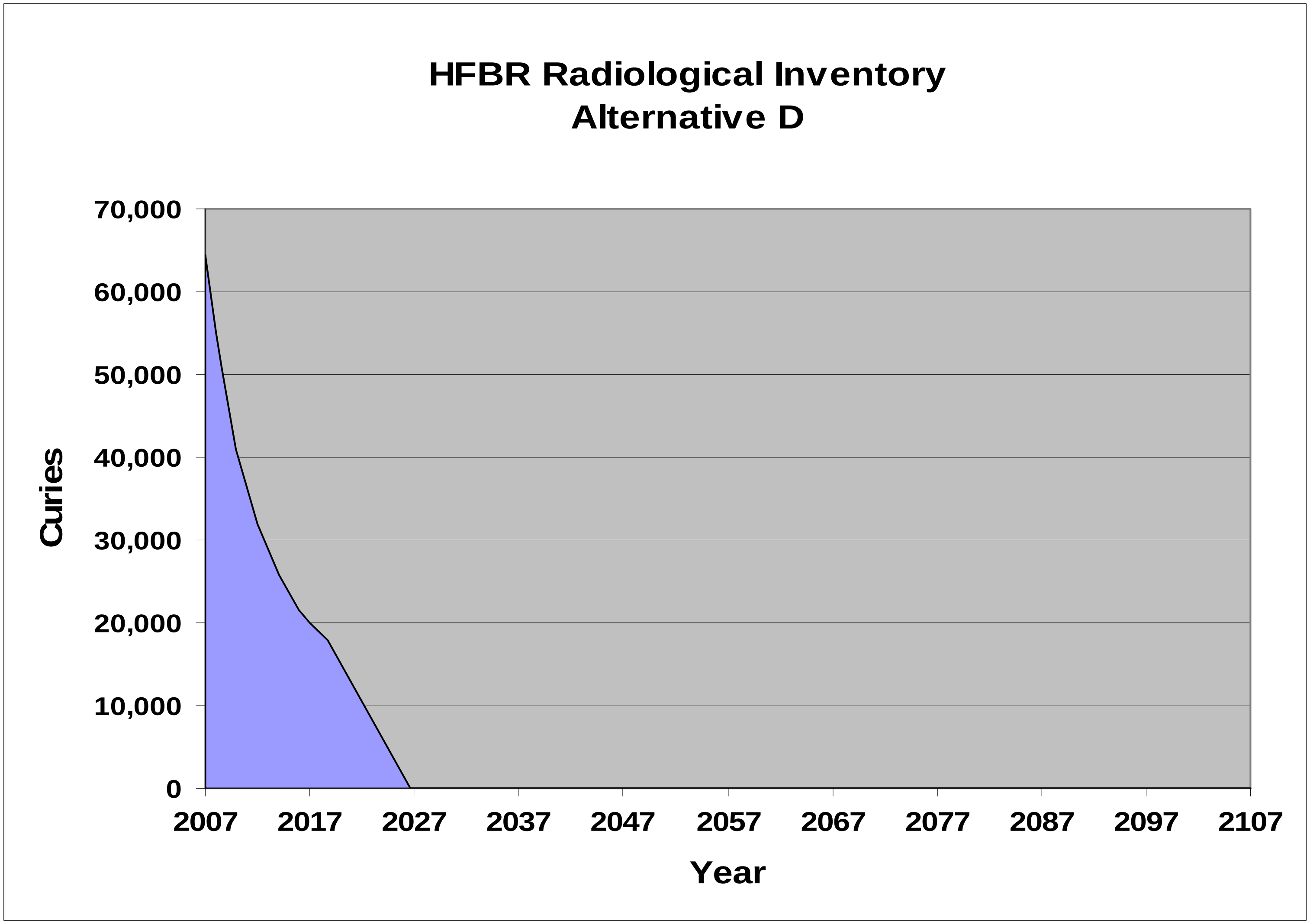


Figure 3.8 Radiological Inventory Remaining – Alternative D 2007 - 2107



4.0 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:

Criterion 1
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.

Criterion 2
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.

Criterion 3
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.

Criterion 4
Reduction of Toxicity, Mobility, or Volume through Treatment 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.

Criterion 5
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.

Criterion 6
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.

Criterion 7
Cost refers to an evaluation of the capital, operations and maintenance, and monitoring costs for each alternative.

Criterion 8
State Acceptance indicates whether New York State concurs with, the analyses and preferred alternative, as described in the FS and Proposed Remedial Action Plan.

Criterion 9
Community Acceptance assesses the general public response to the analyses and preferred alternative as described in the Proposed Remedial Action Plan received during the public comment period and open community meetings are an important indicator of community acceptance.

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.

4.1 INDIVIDUAL EVALUATION OF ALTERNATIVES

4.1.1 Alternative A – No Additional Action

4.1.1.1 Overall Protection of Human Health and Environment
Under Alternative A, the removal of contaminated structures, systems, and components would be limited to those activities already completed. The radiological inventory described in Section 1.3 would remain at the HFBR complex.

The vast majority of this radiological inventory resides in volumetrically activated structures and components. Embedded within and as an intrinsic part of these steel and concrete structures and components, these radioactive materials are in a stable and non-dispersible form. There are multiple barriers that are inherently effective in preventing human exposure and/or spread of these radioactive materials. to the environment. The reactor internals and CRBs are contained within the 2 in thick reactor vessel. An eight-foot thick biological shield surrounds the reactor vessel and thermal shield, and all of these structures and components are housed within the HFBR confinement building. In summary, there are multiple barriers to prevent human exposure and also serve as redundant barriers to preclude migration to the environment.

Recent HFBR experience demonstrates that these physical barriers have been effective in preventing direct human exposure to these radiological hazards. Likewise, these physical barriers in combination with S&M have been effective in preventing water infiltration into the confinement building. In the absence of water infiltration or any other drivers, there is no evidence of contaminated effluents or leakage of radioactive material from the HFBR confinement structure. However, the effectiveness of these barriers on a long-term basis is dependent on S&M and LUICs.

Alternative A does not have any impact on the substantial radiological inventory remaining in the HFBR complex. With no plan to undertake its removal, S&M and LUICs would need to be maintained for an indefinite period of time. Although S&M can be provided and LUICs can be effectively maintained for a finite duration, uncertainties arise as to whether these same protective measures can be effectively maintained over an indefinitely long period. Such uncertainties relate to the durability of political institutions to implement the S&M program and enforce the LUICs. Alternative A is unique among the four alternatives in this respect, and, because of these weaknesses, the overall protectiveness of Alternative A is rated as MEDIUM.

4.1.1.2 Compliance with Applicable or Relevant and Appropriate Requirements
Alternative A would leave the radiological inventory in place at the HFBR complex for an indefinitely long period of time. Implementation of Alternative A involves the indefinite storage of radioactive materials and would be in conflict with New York State regulations regarding the siting of LLRW disposal facilities. Because of this conflict, Alternative A is rated as LOW. There are no ARARs that otherwise appear to be in conflict with Alternative A.

4.1.1.3 Long-Term Effectiveness
The radiological inventory in the HFBR complex represents a radiological hazard that would be present for an indefinite period of time. Hence, this alternative requires effective implementation of an S&M program and LUICs for this indefinite period. Although S&M can be provided and LUICs maintained for a finite period of time with little or no uncertainties, serious questions arise as to whether these same protective measures can be effectively maintained over an indefinite period. Because of the uncertainties related to maintaining S&M and LUICs for an indefinite period of time, the long-term effectiveness of Alternative A is rated as MEDIUM.

4.1.1.4 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.

4.1.1.5 Short-term Effectiveness
As explained in Sections 3.1.2.2 and 3.1.3, Alternative A involves standard S&M activities in a non-operating and deactivated nuclear reactor facility. All of these activities rely on standard industrial work practices. With no removal activity, apart from WLA, this remedial alternative would not involve implementation risks and hazards associated with segmenting, handling, packaging and transporting the highly radioactive activated components. Cleanup of the WLA will be performed using the same cleanup goal and methodology specified for the FHWMF in the Operable Unit I (OU I) Record of Decision (ROD). Therefore the implementation of Alternative A does not pose extraordinary risks and hazards to the workers, public and the environment, and those risks and hazards that do exist can be effectively mitigated and managed using existing safety and work control procedures. Based on the foregoing, short-term effectiveness of Alternative A is rated as HIGH.

4.1.1.6 Implementability
Alternative A involves the continued use of established, field-proven work practices engineered safeguards, and administrative controls. Programs for S&M and LUICs are

already in place at BNL. There is also considerable experience with similar programs at numerous government and commercial nuclear reactor sites. For these reasons, there is a high level of assurance that the HFBR S&M and LUICs can be implemented with no extraordinary uncertainties. Implementability of Alternative A is rated as HIGH.

4.1.1.7 Cost
Previous expenditures to perform the work completed to date total approximately $25 M. The additional capital cost estimate to complete the WLA cleanup is approximately $1 M and the resulting total estimated capital cost of Alternative A is $26 M. Based on operating experience, annual costs for S&M and LUICs total $400,000 per year. Because there is no limit on the required duration, the total cost of S&M and LUIC's and the total lifecycle cost could not be determined.

4.1.2 Alternative B – Phased Decontamination and Dismantlement

4.1.2.1 Overall Protection of Human Health and Environment
Alternative B involves the safe storage of the confinement building and the activated components for a period not to exceed 65 years. Following safe storage, the entire radiological inventory that is present in the HFBR complex would be removed over a three year period in accordance with the dose-based cleanup objectives for radiological soil contamination specified in the OU I ROD for residential land use. Under this cleanup goal, LUICs will not be required following the last phase of HFBR dismantlement.

This alternative provides for the complete removal of the radiological hazard. Hence, the overall protectiveness of Alternative B is rated as HIGH.

4.1.2.2 Compliance with Applicable or Relevant and Appropriate Requirements
There are no ARARs that are in conflict with Alternative B. Hence, Alternative B is rated as HIGH.

4.1.2.3 Long-Term Effectiveness
This alternative provides for the complete removal of the radiological hazard. Hence, the long-term effectiveness of Alternative B is rated as HIGH.

4.1.2.4 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.

4.1.2.5 Short-Term Effectiveness
As explained in Sections 3.2.2.2 and 3.2.3, all of the dismantlement activities would involve construction and demolition techniques that are field proven and standard to the business of reactor decommissioning and dismantlement. Under Alternative B, all of the highly radioactive activated components would be removed only after they were allowed to decay to levels that would essentially eliminate their present day radiological risks and

hazards. HFBR dismantlement would still require the safe handling, packaging, shipment, and disposal of a substantial quantity of radioactive waste using waste practices that are standard to the nuclear industry. Alternative B does not pose extraordinary risks and hazards to the workers, public and the environment, and those risks and hazards that do exist can be effectively mitigated and managed using existing safety and work control procedures. Based on the foregoing, short-term effectiveness of Alternative B is rated as HIGH.

4.1.2.6 Implementability

HFBR decontamination and dismantlement has been extensively evaluated. Radioactive decay under Alternative B results in the substantial reduction in the extreme radiological conditions that exist in the present day. This poses no extraordinary technical challenges and issues related to the HFBR dismantlement. The removal of HFBR structures, systems, and components 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 BNL in connection with the other cleanup projects. 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, the implementability of Alternative B is rated as HIGH.

4.1.2.7 Cost

Previous expenditures to perform the work completed to date total approximately $25 M. The additional capital cost estimate to complete the active phase of Alternative B, including the WLA, is $110 M, and the total estimated cost is $135 M. The S&M and LUIC cost estimate associated with Alternative B is $7M for the full project life cycle. The total estimated cost of Alternative B is $142M including capital, S&M and LUIC costs across the entire project lifecycle.

4.1.3 Alternative C - Phased Decontamination and Dismantlement with Near-Term Control Rod Blade Removal

4.1.3.1 Overall Protection of Human Health and Environment

Alternative C provides for the safe storage of the confinement building and most of the activated components for a period not to exceed 65 years. The CRBs and beam plugs constituting one third of the radiological inventory would be removed in the near-term by FY 2020. Following safe storage, the entire radiological inventory remaining in the HFBR complex would be removed over a three year period in accordance with the dose-based cleanup objectives for radiological soil contamination specified in the OU I ROD for residential land use. Under this cleanup goal, LUICs will not be required following the last phase of HFBR dismantlement.

This alternative provides for the complete removal of the radiological hazard. Hence, the overall protectiveness of Alternative C is rated as HIGH.

4.1.3.2 Compliance with Applicable or Relevant and Appropriate Requirements

There are no ARARs that are in conflict with Alternative C. Hence, Alternative C is rated as HIGH.

4.1.3.3 Long-Term Effectiveness
This alternative provides for the complete removal of the radiological hazard. Hence, the long-term effectiveness of Alternative C is rated as HIGH.

4.1.3.4 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.

4.1.3.5 Short-Term Effectiveness
As explained in Sections 3.3.2.2 and 3.3.3, all of the dismantlement activities to remove and dispose of the activated structures, components and the confinement building would involve construction and demolition techniques that are field proven and standard to the business of reactor decommissioning and dismantlement. HFBR dismantlement would require the safe handling, packaging, shipment and disposal of a substantial quantity of radioactive waste using waste management practices that are standard to the nuclear industry. Segmentation of the CRBs will not be required and all of the CRBs can be transported and disposed in one or two cask shipments. Since Alternative C does not involve significant radiological and transportation risks and hazards, it was also rated as HIGH in terms of short-term effectiveness.

4.1.3.6 Implementability
HFBR decontamination and dismantlement has been extensively evaluated. For the most part, radioactive decay results in the substantial reduction in the radiological conditions that exist in the present day. This eliminates most of the extraordinary technical challenges and issues related to the HFBR work. Hence, the removal of HFBR structures, systems, and components would largely 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 BNL in connection with the other cleanup projects. Waste streams resulting from these activities can be safely managed using commercially available packages and transportation services. No new or untested technologies are required.

Alternative C is comparable to Alternative B. Under Alternative C, the HFBR and activated components would be removed after the calculated high radiation dose rates have decayed to manageable levels. Alternative C would not require CRB segmentation, and CRB disposal would be completed in one or two cask shipments. As with Alternative B simple field proven construction methods would be all that is required to complete the physical dismantlement of the remaining activated structures, systems, and components and the confinement building. Because implementation of this alternative is comparable to that for Alternatives B, Alternative C is rated as HIGH under this criterion.

4.1.3.7 Cost
Previous expenditures to perform the work completed to date total approximately $25 M. The additional capital cost estimate to complete the active phase of Alternative C, including the WLA, is $112 M, and the total estimated cost is $137 M. The S&M and

LUIC cost estimate associated with Alternative C is $7M for the full project life cycle. The total estimated cost of Alternative C is $144 M including capital, S&M and LUIC costs across the entire project lifecycle.

4.1.4 Alternative D – Near Term Decontamination and Dismantlement

4.1.4.1 Overall Protection of Human Health and Environment

Alternative D includes the near term removal of the entire radiological inventory that is present in the HFBR complex with the limited exception of small quantities of residual soil contamination that would be allowable in accordance with the dose-based cleanup objectives for radiological soil contamination specified in the OU I ROD for residential land use. Under this cleanup goal, the HFBR site would be acceptable for residential land use within 50 years following the complete removal of the radiological hazard. S&M and LUICs would be required for this finite period of time.

This alternative provides for the complete removal of the radiological hazard. There are no credible uncertainties regarding S&M and LUIC effectiveness for a finite, 50-year period of time. Hence, the overall protectiveness of Alternative D is rated as HIGH.

4.1.4.2 Compliance with Applicable or Relevant and Appropriate Requirements

There are no ARARs that are in conflict with Alternative D. Hence, Alternative D is rated as HIGH.

4.1.4.3 Long-Term Effectiveness

This alternative provides for the complete removal of the radiological hazard. There are no credible uncertainties regarding S&M and LUIC effectiveness associated with managing the small amount of residual radioactive contamination for a finite, 50 year period of time. Hence, the long-term effectiveness of Alternative D is rated as HIGH.

4.1.4.4 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.

4.1.4.5 Short-Term Effectiveness

Under Alternative D, all of the highly radioactive activated components that are presently in an inherently safe and stable form would be physically disturbed. As explained in Sections 3.4.2.2 and 3.4.3, this alternative involves the near term segmentation, handling, transportation and disposal of highly radioactive structures and components. These activities pose serious risks and hazards that need to be carefully managed in order to protect the decommissioning workers and the public as described in Section 2.1.2. Disturbing physically stable structures and components and creating highly radioactive and dispersible secondary wastes poses a serious threat of cross contaminating the HFBR complex and greatly expanding the scope and complexity of the overall project. Because of these risks and complexities, the short-term effectiveness of Alternative D is rated as LOW.

4.1.4.6 Implementability
The near term dismantlement of the HFBR complex has been extensively evaluated. As discussed in Section 3.4.3, the highly radioactive activated structures and components involve significant technical challenges, risks, and complexities. These risks and complexities extend from the component segmentation in the reactor confinement building out into the public domain during the course of waste transportation. In summary, Alternative D is a complex project involving the highest level of risks and hazards. Because of the significant issues and risks associated with near term dismantlement, the implementability of Alternative D is rated as LOW.

4.1.4.7 Cost
Previous expenditures to perform the work completed to date total approximately $25 M. The additional capital cost estimate to complete the active phase of Alternative D, including the WLA, is $176 M, and resulting total estimated cost is $201 M. The S&M and LUIC cost estimate associated with Alternative D is $4 M for the full project lifecycle and the total estimated cost of Alternative D is $205 M.

4.2 COMPARATIVE ANALYSIS OF ALTERNATIVES

A summary of the comparative analysis is provided in Table 4-1.

4.2.1 Overall Protection of Human Health and the Environment
The majority, more than 99 percent, of the HFBR radioactive material is in the form of activated concrete and steel components. In their existing locations and configuration, there are several physical barriers that are inherently effective in preventing human exposure to the radiation associated with these components or the potential spread of radioactive material to the environment:

- The radioactive material is actually a part of the activated concrete and steel components. In this form, the radioactive material is immobile because it is bound up within these components as an intrinsic part of their materials of construction. In this form, the radioactive material is inherently non-dispersible.
- The reactor internals and CRBs, the HFBR components with the highest dose rates, are encased in the 2-in thick HFBR reactor vessel.
- The 8-ft thick heavily steel reinforced concrete biological shield surrounds the reactor vessel and thermal shield.
- All of these components are physically located above grade within the steel and concrete HFBR confinement building.

In their non-dispersible and stable state, and with these multiple barriers in place, these components do not pose a threat to human health or the environment. Continued S&M and LUICs are required to ensure the continued effectiveness of these barriers.

Alternative A would leave the HFBR complex in its present physical state. Because of the stability of the radioactive materials and the protective barriers, this remedy is currently protective of human health and the environment. However, the remaining activated components constitute a radiation hazard that would have to be managed for what is essentially an indefinite period of time. In the absence of a plan to eventually remove these components, S&M and LUICs would likewise need to be maintained for this same indefinite period of time in order to ensure that this remedy remains protective. Although S&M can be provided and LUICs maintained for a finite duration, uncertainties arise as to whether these same protective measures can be effectively maintained indefinitely. Such uncertainties relate to the durability of institutions to implement the S&M program and enforce the LUICs. Alternative A is unique among the four alternatives in this respect, and, because of this weakness, it is rated as MEDIUM under this criterion.

Alternatives B, C, and D all provide for the complete removal of all of the HFBR radioactive structures, systems, and components. In all cases, S&M and LUICs will be required for finite but different durations:

- Alternative B involves the safe storage of the confinement building and the activated components for a period not to exceed 65 years. Following safe storage, these remaining structures and components would be removed over a three-year period. S&M and LUICs would be required through this 68 year period of time. Following the last phase of dismantlement the dose-based cleanup goal of 15 mrem per year and the methodology specified in the OU I ROD would be achieved and there will be no further need for any additional period of LUICs.
- Alternative C includes the near-term removal of the CRBs and beam plugs by the end of 2020. However, this near-term action would not have any effect on the safe storage duration required for the other activated components. Therefore, S&M and LUICs are also required for the same durations as Alternative B.
- Alternative D results in the dismantlement and removal of the HFBR complex by the end of 2026. S&M would be required through this period, and LUICs may be required for an additional 50 years following the last phase of dismantlement because of the small amounts of residual soil contamination allowable under the dose-based soil cleanup goal of 15 mrem per year and the methodology specified in the OU I ROD.

As shown, a finite period of S&M and LUICs is required for all three of these alternatives. The differences in these periods is inconsequential to the overall protectiveness of these three remedies because of the inherent physical stability of the activated components. The continuation of the HFBR S&M program and LUICs that are already in place for other remedies at BNL would ensure the protectiveness of these remedies during this interim period of time.

All three of these remedies include the complete removal of the HFBR complex. Therefore, from a long-term perspective, all three remedies are protective of human health and the environment. Based on the foregoing, Alternatives B, C, and D were all rated as HIGH under this criterion.

4.2.2 Compliance with Applicable or Relevant and Appropriate Requirements

Alternative A involves the indefinite storage of the HFBR radiological inventory. The indefinite storage of these radioactive materials would be in conflict with New York State's siting requirements for LLRW waste disposal facilities. There are statutory issues that would preclude the indefinite storage or entombment of these radioactive materials over Long Island's sole source aquifer. Aside from this, all four alternatives comply with applicable or relevant and appropriate regulations. Therefore, the compliance with ARARs of Alternative A is rated as LOW.

Alternative B, Alternative C, and Alternative D do not pose compliance issues or conflicts with ARARs. Therefore, the compliance with ARARs of Alternatives B, C, and D is rated HIGH.

4.2.3 Long-Term Effectiveness

Alternative A would leave the HFBR complex in its present physical state. Because of the stability of the radioactive materials and the protective barriers, this remedy is currently protective of human health and the environment. However, the remaining activated components constitute a radiation hazard that would have to be managed for what is essentially an indefinite period of time. In the absence of a plan to eventually remove these components, S&M and LUICs would likewise need to be maintained for this same indefinite period of time in order to ensure that this remedy remains protective. Although S&M can be provided and LUICs maintained for a finite duration, uncertainties arise as to whether these same protective measures can be effectively maintained indefinitely. Such uncertainties relate to the durability of institutions to implement the S&M program and enforce the LUICs. Alternative A is unique among the four alternatives in this respect, and because of this weakness, it is rated as MEDIUM under this criterion.

Alternatives B, C, and D all provide for the complete removal of all of the HFBR radioactive structures, systems and components. Based on the foregoing, Alternatives B, C, and D are all rated as HIGH under this criterion.

4.2.4 Reduction of Toxicity, Mobility, or Volume through Treatment

None of the four alternatives considered in this FS include treatment to reduce the toxicity, mobility or volume of contaminants. Therefore, this criterion is not applicable to the analysis of the alternatives.

4.2.5 Short-Term Effectiveness

Alternative A, involving no further action other than control and monitoring, poses few uncertainties and implementation risks and is rated HIGH under this criterion. This remedy is limited to the continued use of S&M and LUICs. As described under Criterion 1, above, the majority, more than 99 percent, of the remaining radiological inventory is in a physically safe and stable form. With no physical dismantlement activity, this remedial alternative would not involve disturbing these activated components. Therefore, Alternative A is rated HIGH in terms of short-term effectiveness.

Under Alternative B, all of the activated components with high dose rates would be removed only after they were allowed to decay to levels that would essentially eliminate their present day radiological risks and hazards. These components would be maintained in their inherently stable form as the radiation levels are reduced through their radioactive decay. As in the case of Alternative A, this alternative would not involve implementation risks and hazards associated with segmenting, handling, packaging and transporting activated components with high dose rates because they will have decayed to safe and manageable levels by the end of safe storage period. The radiological risks and hazards would be essentially eliminated at the time in which the HFBR confinement building and activated components are removed. The remaining project risks and hazards would be limited to those of a non-radiological nature that are germane to any large construction (i.e. demolition) project. Because Alternative B does not involve significant implementation risks, it was also rated as HIGH in terms of short-term effectiveness.

Under Alternative C, all of the dismantlement activities to remove and dispose of the activated structures, components, and the confinement building would involve construction and demolition techniques that are field proven and standard to the business of reactor decommissioning and dismantlement. HFBR dismantlement would require the safe handling, packaging, shipment, and disposal of a substantial quantity of radioactive waste using waste management practices that are standard to the nuclear industry. The near-term CRB removal by FY 2020 would involve underwater handling and packaging and would utilize available tools, equipment and work processes. CRB removal, including transfer to the spent fuel canal and loading into shipping casks has been performed at the HFBR in the past. Since Alternative C does not involve significant radiological and transportation risks and hazards, it was also rated as HIGH in terms of short-term effectiveness.

In contrast to Alternatives A, B, and C, Alternative D involves the near-term segmentation, handling, packaging, transportation and disposal, by FY 2026, of activated components with high dose rates. From a worker and transportation risk standpoint, this represents a significant difference from Alternatives A, B, and C. Alternative D would require more than 30 individual type A or B cask shipments resulting from activated component removal. The segmentation of these components would generate significant quantities of dispersible cutting fines with high dose rates. In a dispersible form, these secondary wastes pose additional personnel radiation exposure risks, and the potential risk of cross-contaminating the confinement building that is essentially free of contamination at this time. In summary, Alternative D involves considerable radiological and transportation risks and hazards in comparison with the other alternatives. Equipment, processes and procedures can be devised to carry out their safe removal. However, because of these radiological and transportation implementation risks and hazards, the short-term effectiveness of Alternative D is rated as LOW.

4.2.6 Implementability

Remaining Alternative A activities include the continuation of S&M and LUICs. These protective measures involve field-proven work practices, engineered safeguards and administrative controls. There are no implementability issues or concerns, and Alternative A is therefore rated as HIGH under this criterion.

Under Alternative B, the HFBR confinement building and additional components would be removed only after the high radiation dose rates have decayed to manageable levels during the safe storage period. The radiological risks and hazards under Alternative B would be essentially eliminated, and simple, field proven construction (i.e., demolition) methods would be all that is required to complete the physical dismantlement of the HFBR complex. Therefore, Alternative B is also rated as HIGH under implementability.

Alternative C is comparable to Alternative B. Under Alternative C, the CRBs and beam plugs would be removed in the near-term, by FY 2020, utilizing available tools, equipment, and work processes. CRB disposal would be completed in one or two shipments and the rest of the HFBR and activated components would be removed after the high radiation dose rates have decayed to manageable levels. As with Alternative B, simple field proven construction methods would be all that is required to complete the physical dismantlement of the remaining activated structures, systems, and components and the confinement building. Because implementation of this alternative is comparable to that for Alternatives B, Alternative C is rated as HIGH under this criterion.

Alternative D includes the near-term decontamination, dismantlement, and disposal of the entire HFBR complex including all structures, systems, and components by FY 2026. Unlike Alternatives A, B, and C, dismantling and disposing of the large activated components with high dose rates would involve significant implementation issues and challenges. The calculated radiation dose rates attributable to these components are as high as 35,000 rem/hr. These high calculated dose rates represent significant radiological risks and hazards as summarized below:

- Workers cutting apart the activated components would not be able to come near them. In fact, at these dose rates, the work would need to be performed remotely and underwater. The water would serve both as a radiation shield and as a way to minimize the dispersion of radioactive material. Water containment structures would have to be designed and built around the existing contaminated structures and components. Special tools, processes, and equipment would need to be designed, fabricated, and tested. Workers would have to be trained and qualified to perform these activities. Controls would have to be established to monitor and limit the amount of contamination in the water so it would continue to function as a radiation shield. A system to control water contamination levels and clarity would also be needed. Although there is industry experience with this kind of work, each project is highly dependent on the specific site conditions.
- The underwater segmentation of activated components would generate significant quantities of highly radioactive, dispersible particles and contaminated water requiring processing, transportation, and disposal. It is estimated that these segmentation activities would produce up to 100,000 gallons of contaminated water requiring processing and disposal as low level radwaste.

- The high calculated dose rate wastes would require the use of special shipping casks for transportation to a disposal site. The capacity of these casks is limited, so the large activated components would need to be cut into small pieces. This would require the use of remotely operated tools and equipment and increase the amount of underwater material handling, further complicating the underwater work. More than 30 individual type A or B cask shipments would be required.

In summary, Alternative D is a complex project involving the highest level of risks and hazards of the four alternatives. The implementation challenges and issues of Alternative D represent a significant increase over those described for Alternatives B and C. Therefore, the implementability of Alternative D is rated as LOW.

4.2.7 Cost

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

Alternatives Costs, in Dollars

	A	B	C	D
Previous Expenditures	25M	25M	25M	25M
Additional Capital Cost Estimate	1M	110M	112M	176M
Total Capital Cost Estimate	26M	135M	137M	201M
S&M and LUIC Cost Estimate	*	7M	7M	4M
Total Estimated Cost	*****	**142M**	**144M**	**205M**

As expected, Alternative A is the least costly of the three HFBR cleanup alternatives in terms of capital costs. However, the total cost of Alternative A is indeterminate because the required duration of S&M and LUICs is not definable.

The total capital cost estimates of Alternatives B, Alternative C and Alternative D are $135M, $137M and $201M, respectively. These substantial increases over Alternative A are attributable to the extensive amount of HFBR dismantlement and waste disposal. The favorable impacts of radioactive decay in reducing dismantlement risks and project complexities are reflected in the large cost differential between Alternative D and the two phased decommissioning alternatives (i.e., Alternatives B and C). Near-term CRB and beam plug removal accounts for the $2M difference in capital cost estimates between Alternative B and Alternative C.

The 65-year period of radioactive decay has a significant impact on consolidated S&M and LUIC costs for Alternatives B and C. However, as shown, the S&M and LUIC cost differential is significantly less than the differences in capital cost estimates in comparison with Alternative D. Alternative B is the lowest cost alternative that removes the HFBR radiological inventory from the BNL site. For a relatively small $2M incremental increase in cost, the near-term removal of the CRBs and beam plugs, by FY

2020, would provide a 38 percent reduction in the overall HFBR radiological inventory after only 5 years.

Section 4 Tables

Table 4.1 Comparative Analysis of the Remedial Alternatives

Consideration	Alternative A	Alternative B	Alternative C	Alternative D
Total radiological inventory–2007	65,000 curies	65,000 curies	65,000curies	65,000 curies
Total radiological inventory reduction	57,000*	65,000 curies	65,000 curies	65,000 curies
Criterion 1: Overall protection of human health and the environment	Medium	High	High	High
Criterion 2: Compliance with applicable or relevant and appropriate requirements	Low**	High	High	High
Criterion 3: Long-term effectiveness and permanence	Medium	High	High	High
Criterion 4: Reduction of toxicity, mobility, or volume through treatment	NA	NA	NA	NA
Criterion 5: Short-term effectiveness	High	High	High	Low
Criterion 6: Implementability	High	High	High	Low
Criterion 7: Total estimated cost	Indeterminate	$**142** M	$144 M	$205 M
Previous expenditures	$25 M	$25 M	$25 M	$25 M
Additional capital cost estimate***	$1 M	$110 M	$112 M	$176 M
S&M and LUIC cost estimate	Indeterminate	$7 M	$7 M	$4 M
Occupational Dose	Indeterminate	3 Person-rem	4 Person-rem	20 Person-rem

* This includes reductions from radioactive decay over a period of 68 years
** Implementation of this alternative involves the indefinite storage of radioactive materials and would be in conflict with New York State regulations regarding the siting of LLRW disposal facilities.
*** Includes Waste Loading Area cleanup cost of $1 M.

5.0 REFERENCES

WMG, 2007, *Final Characterization for Brookhaven National Laboratory High Flux Beam Reactor,* WMG Report 6117-RE-072, prepared by WMG Inc. February 2007.

DAQ, 2007, *Calculation of HFBR Activated Components Activity and Dose Rates,* prepared by DAQ, Inc. February 2007

WMG, 2007, *HFBR CRB and Beam Plug Removal, Handling, Packaging, and Disposal Concepts Study,* WMG Report 7002-RE-073, prepared by WMG, Inc. January 2007

PW Grosser 2005, *High Flux Beam Reactor & Balance of Plant Supplemental Characterization Summary,* prepared by PW Grosser Consulting June 2005

DAQ, 2007, *Brookhaven National Laboratory High Flux Beam Reactor Characterization Summary Report,* Rev. 1, prepared by DAQ, Inc.
February 2007

BNL, 2001, *Brookhaven National Laboratory High Flux Beam Reactor Final Characterization Report,* prepared by Brookhaven Science Associates for U.S. Department of Energy, Brookhaven Area Office, Upton New York, September 2001

P. W. Grosser, 2005 *High Flux Beam Reactor and Balance of Plant Structures Preliminary Assessment/Site Inspection Report,* prepared by PW Grosser Consulting January 2005

P. W. Grosser, 2005, *Brookhaven National Laboratory Building 705 Stack Resolution of End-State,* prepared by PW Grosser Consulting February 2005

DAQ, Inc., 2005, *High Flux Beam Reactor: Building 751. Portable Structure 549, Interconnecting Ducts, Selected Components, & Soils Sampling and Analysis Report*, prepared by DAQ, Inc., December 2005

BNL, 2005, *Land Use Controls Management Plan, Revision 1,* prepared by Brookhaven Science Associates for the U. S. Department of Energy, August 2005

DOE, 2005, *Letter from R. Rimando (DOE) to J. Lister (NYSDEC) and D. Pocze (EPA), Subject: Remedial Design Implementation Plan (RDIP), Operable Unit I, Area of Concern 1, Former Hazardous Waste Management Facility (FHWMF)*,
September 30, 2005

BNL, 2006, *Evaluation of HFBR Surveillance and Maintenance Alternative,* prepared by Brookhaven Science Associates for the U. S. Department of Energy, Brookhaven Site Office, Upton, New York, April 2006