Brookhaven National Laboratory

High Flux Beam Reactor (HFBR)

Characterization Summary Report

Revision No. 1
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Prepared for:

BROOKHAVEN NATIONAL LABORATORY

Prepared by:

DAQ Inc.
Health and Safety Consultants
Hopewell Junction, New York

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0. HFBR Characterization Summary

0.1 Objective:

The Brookhaven National Laboratory (BNL) High Flux Beam Reactor (HFBR) has been shut down since December 1996, and there have been several characterizations of the facility, including the reactor itself, systems and components, ancillary support structures, and the surrounding soil. These characterizations have involved direct radiation surveys, samples for radioactivity, and calculations of activated materials over a period of several years.

The purpose of this HFBR Summary Report is to organize the results of the previous characterizations into a document that provides a "big picture" summary of relevant information in an understandable format. References are provided for access to the detailed data from the previous characterizations.

0.2 Background Information:

The concept for the HFBR used a new approach in reactor design that was optimized to provide intense external beams of neutrons, primarily for neutron scattering experiments. The mission of the HFBR was to provide a source of neutrons for multidisciplinary scientific studies in chemistry, biology, and physics. Following a construction period of four years and one month, the HFBR achieved criticality on October 31, 1965. The reactor was originally designed for operation at a power level of 40 megawatts (MW). In addition to its external beams of neutrons, the HFBR provided seven sample irradiation thimbles for neutron activation experiments. An equipment upgrade in 1982 allowed operations at 60 MW, providing a peak thermal flux of 1.05E+15 neutrons/cm^2-sec. (BNL 1996) In 1989, the reactor was shut down to reanalyze the safety impact of a hypothetical loss-of-coolant accident. The reactor was restarted in 1991 at 30 MW. The HFBR was shut down again in December 1996 for routine maintenance and refueling, when it was discovered that a leak in the spent fuel pool had released tritium-contaminated water to the ground. The reactor remained shut down for almost three years for safety and environmental reviews. By January 1998, all of the spent fuel was removed and shipped off-site. The shipment of the spent fuel and the disposal of miscellaneous reactor components from the canal were necessary to facilitate the canal draining and insertion of a double-walled stainless steel liner for restart. The Secretary of Energy, however, decided to permanently shut down the HFBR in November 1999.

The majority of the HFBR facility is housed within the reactor confinement building (750). Support buildings and structures within the HFBR complex include the Stack (705), the Stack Monitoring Facility (715), and the Cold Neutron Facility (751). Several of these facilities also supported the Brookhaven Graphite Research Reactor (BGRR).

0.3 HFBR Confinement Building (Building 750)

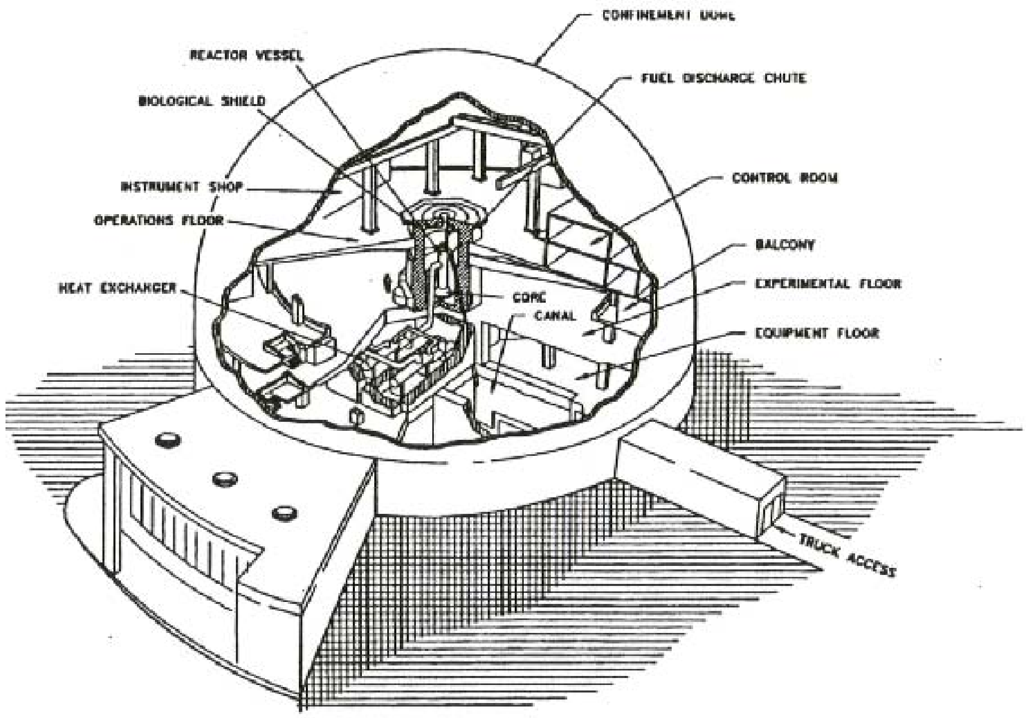

Figure 0-1. Cutaway View of the HFBR, Building 750

The most recognizable feature of the High Flux Beam Reactor is its steel dome structure in the shape of a hemisphere resting on a cylindrical base. This structure is formed of welded steel plates supported upon an integral I-beam framework. The inside diameter of the hemisphere at its base is 176 ft-8 in. The cylindrical base (22 ft-4 in. high) rests upon a bedplate that is bolted to the reinforced concrete foundation ring. The hemispherical portion of the dome is insulated on the outside, and the insulation is covered with aluminum sheets. The steel plates in the hemispherical section are 0.250 in. thick, and those in the cylindrical base are 0.375 in. thick. The foundation of the reactor building is a reinforced concrete mat bearing on the soil beneath the building. The confinement building consists of four levels: the Equipment Level, Experimental Level, Balcony Level, and Operations Level. The descriptions of the systems, structures, and components are taken from the “HFBR Plant Description Manual.” (BNL, 1996)

The HFBR core was formed of 28 fuel elements in a close-packed array. The fuel material was fully enriched (93%) uranium oxide-aluminum, clad with aluminum and shaped into curved plates. Heavy water (D_2O) served as the moderator/reflector and primary water coolant. The reactor vessel is fabricated from a 6061-T6 aluminum alloy and contained the active core, reflector and control rods and 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-inch inside diameter cylinder. Including the closure flange, the over-all height of the vessel assembly is 24.75 ft. The nine horizontal beam reentry tubes are integral (welded) parts of the vessel's spherical section.

There are 16 control rod blades, separated into main and auxiliary rod groups, each containing 8 rods. The control rods operated in the reflector region, just outside the core. The control rod blades are angle-shaped in cross-section, and are made of europium oxide (Eu_2O_3) and dysprosium oxide (Dy_2O_3) in stainless steel, all clad in stainless steel.

In 2000, the reactor vessel was drained of approximately 1,500 gallons of heavy water (D_2O), and replaced with a similar volume of light water (H_2O). The D_2O was shipped off site. In 2003, the light water, in turn, was drained after completion of a CO_2 cavity gas test. Currently, the vessel is filled with helium (He), an inert gas maintained at a slight positive pressure to preserve the vessel from corrosion until future decommissioning.

The Equipment Level, located at an elevation of 93 ft-0 in. above sea level, contains most of the reactor support and building systems equipment, such as pumps, heat exchangers, filters, wastewater storage tanks, HVAC, and piping networks. Shielded cells for the primary cooling water system pumps and heat exchangers are located in the center of the floor. The spent fuel storage canal (also referred to as the spent fuel pool), located to the east of the shielded cells, is 8 ft wide, 43 ft long and 20 ft deep for most of its length. A 30-foot deep section, 8-ft-6 in long resides under the fuel discharge chute at the west end. A small bay, 8 ft wide, 10 ft long and 20 ft deep, located on the north side of the canal, was used primarily for cutting operations to remove the aluminum transition pieces from the spent fuel elements. The heavy water purification system and one of two storage tanks are installed in pits sunken into the floor in the northeast quadrant of the Equipment Level. Three rooms along the south wall are partitioned from the rest of the level by a containment wall. These are the transformer room, the blower room, and the generator room. Each of these rooms has access from outside the building.

The Experimental Level, located at an elevation of 113 ft-6 in., was dedicated to the scientific users. The reactor biological shield occupies the central portion of this level, with open floor space surrounding it for the external beam experiments. Laboratories and offices are located along the perimeter wall of the level. A 20-ton capacity radial traveling beam crane services this level.

The Balcony Level, 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.

The Operations Level is the top floor of the building located at an elevation of 141 ft-6 in. The reactor shielding structure rises 7.5 ft. above the floor at the center of the building.

The southwest quadrant of the level contains an enclosed process area (the Greenhouse), which houses pumps, a heat exchanger and piping associated with the experimental facilities cooling water system. The second of the two heavy water storage tanks is located in this area. A series of offices and workrooms are located on the east side of the Level, with the reactor control room occupying the second story above these offices. A two-story cinderblock structure containing the instrument shop and offices is located on the west side of this Level.

Two air intake ports are located on the Balcony Level. Access into the confinement building is provided by four airlocks: a personnel-size airlock (3 feet - 3 inches by 7 feet by 9 feet) located between the Equipment and Experimental Levels on the south side of the building, a forklift size (6 feet x 8 feet – 9 inches by 18 feet) located on the north side of the Experimental Level and two tractor trailer size (12 feet x 14 feet x 65 feet), one entering on the north side of the Experimental Level and the other on the east side of the Equipment Level.

0.4 HFBR Support Facilities

Figure 0-2 is a site plan showing the location of the HFBR ancillary/support facilities, and Table 0-1 shows the dimensions of these facilities.

The Fan House (Building 704) is a one-story, above-grade structure approximately 168 feet long by 60 feet wide. Concrete block and brick walls and a flat built-up roof cover structural steel supports. This building has been associated with the operation of both the BGRR and HFBR. Most of the equipment associated with the BGRR, such as the exhaust fans, motors and above-grade air ducting, has been removed as part of the BGRR decommissioning project. The fan discharge ducts below the building, which exhausted BGRR air into the base of the stack, remain. The south side of the fan house contains the electrical switchgear currently associated with the HFBR facility.

The Stack (Building 705) was also associated with operation of both the BGRR and HFBR and is included among the HFBR complex buildings. The stack was designed to convey fan discharge radioactive air sufficiently high above the ground (320 feet) to permit adequate mixing and dilution with atmospheric air. (BNL, 1964) Exhaust air, discharged from HFBR building 750 exhaust fans, passes through underground ductwork (750 Plenum Exhaust Line) to a bank of particulate and charcoal filters, before entering the base of the stack. The exhaust air from the BGRR was pulled by fans through an Underground Plenum and into the stack for discharge to the atmosphere.

The Stack Monitoring Facility (Building 715) housed instrumentation used to monitor stack effluents.

The Cold Neutron Facility (CNF -Building 751) has been surveyed and is now released from radiological controls; it is no longer considered part of the HFBR facility.

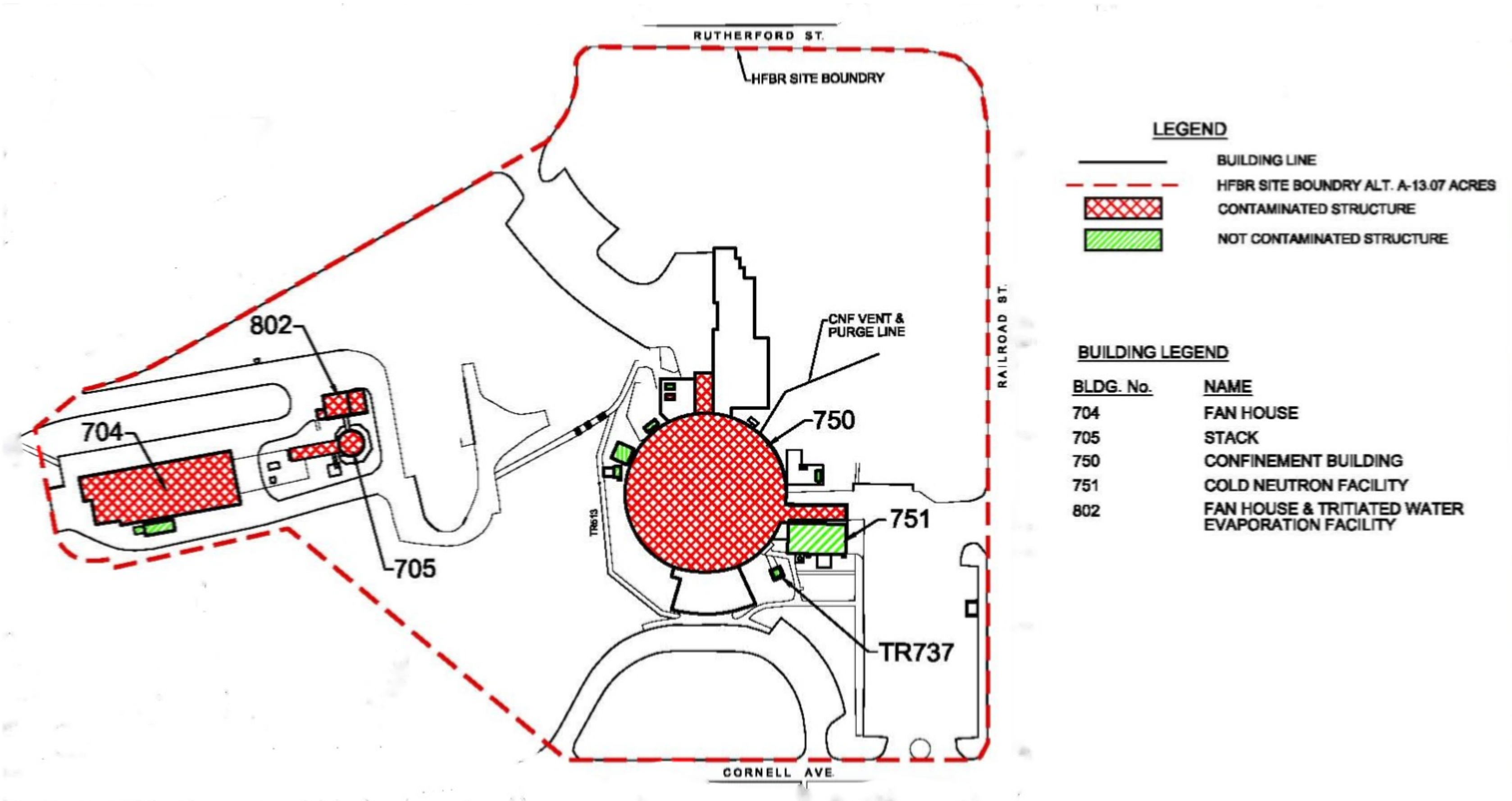

Figure 0-2. HFBR Site Plan

0.5 Previous HFBR Characterizations:

The previous HFBR characterization efforts can be divided into the following groupings:

1. Activated Components (see HFBR Summary Report, Part 1)

   The activated components of the HFBR considered in this part include the reactor vessel, reactor vessel internals, control rod blades, thermal shield, biological shield, and beam plugs, including collimators. The beam plugs and collimators are located in the beam plug storage facility (cheese box) and in transfer shields on the Experimental Level.

2. Reactor Building Structures, Systems, and Components (see HFBR Summary Report, Part 2)

   Characterization of Building 750 consisted of the facility structure itself, including floors, walls, and the dome and it included systems and components within the building. The building was divided into 115 survey areas, and 46 systems. Non-radiological hazards for the building systems, structures, and components are addressed in this section

3. Ancillary/Support Structures and Soil Characterization (see HFBR Summary Report, Part 3)

   Characterization of ancillary structures and buildings that supported the HFBR is addressed in this part, and the characterization includes radiological and non-radiological hazards. The soils surrounding the HFBR and support buildings were evaluated for possible radioactive and non-radioactive hazardous material contamination.

Table 0-1 Dimensions of HFBR & Ancillary/Support Facilities

704 Fan House

Main Section (Electrical switch gear, battery room, Fan Rooms) –
Overall dimensions: 130’-0” long x 59’-3” wide x 20’-0” tall structure
6”-12” thick concrete slab floor, 7,702.5 square feet area
2’-1” thick brick walls (1’-1” brick, 4” air gap, 8” brick)
4” thick concrete slab roof

Repair Shop/Secondary Fan Room –
Overall dimensions: 54’-3” long x 27’-5” wide x 13’-0” tall structure
6” thick concrete slab floor, 1,487.35 square feet area
2’-1” thick brick walls (1’-1” brick, 4” air gap, 8” brick)
4” thick concrete slab roof

Emergency Fan Room –
Overall dimensions: 26’-2” long x 9’-6” wide x 13’-0” tall structure
6” thick concrete slab floor, 248.6 square feet area
2’-1” thick brick walls (1’-1” brick, 4” air gap, 8” brick)
4” thick concrete slab roof

Exit Air Filter Facility

1’-6” thick concrete slab floor, 682.6 square feet area
1’-0” thick concrete walls, 125’-10” perimeter length x 11’-1” tall
1’-10” thick concrete slab roof, 682.6 square feet area

705 Underground Plenum (Duct)

Below grade section –
Overall dimensions: 52’-0” long x 12’-0” wide x 13’-0 tall
1’-0” thick concrete walls, roof, and floor

Above grade section -
Overall dimensions: 56’-0” long x 12’-0” wide x 17’-0 tall
1’-0” thick concrete walls, roof, and floor

715 Stack Monitoring Facility

Overall dimensions: 20’-0” long x 10’-0” wide x 10’-0” tall structure
7” thick concrete slab floor, 200 square feet area
8” thick wood walls (studs and siding)
10” thick wood roof (joists, sheets, shingles)

750 HFBR

Confinement Dome –
Overall dimensions: 180 foot diameter half sphere

Dome walls consist of 49,769 square feet of ¼" thick steel plating covered uniformly by 4" thick fibrous insulation and a 1/8" thick aluminum exterior skin

Foundation – Equipment Level Floor Slab –
Perimeter slab: 3'-0" thick heavily reinforced concrete slab, 2,824 square feet area
Interior slab: 5'-0" thick heavily reinforced concrete slab, 16,413 square feet area

750 Plenum (30" Exhaust Line)

390' long x 30" diameter concrete pipe, 3/16" thick

D/F-Waste Line

1,117' double-walled (2" x 4") carbon steel pipe between Buildings 750 and 801.

705 Stack

Overall height: 320'-0"
Interior top diameter: 18.42'
Interior base diameter: 26.58'
Thickness @ top: ~ 7"
Thickness @ bottom: ~ 14"

705 Stack Pedestal

Shape: Octagon
Overall height: 21.5'
Width: 30.5'
Interior diameter: 26.0'

1. Part 1. Characterization Summary - Activated Components

1.1 Summary of Activated Components

The activated components of the HFBR considered here include the reactor vessel, reactor vessel internals, control rod blades, thermal shield and the biological shield (bioshield). The beam plugs are discussed only for information, as the current plans call for the beam plugs to be removed from the HFBR and are stored in a shielded area outside of the bioshield area on the experimental level of the HFBR. The activities of the activated components were determined based on WMG, Inc. calculations (WMG 2007a, WMG 2000b and WMG 2007c), and the beam plugs and collimators activities were determined based on an earlier calculation (Tichler 1995). Figure 1-1 shows the general configuration of the reactor vessel, the thermal shield, and the reactor internals, including the control rod blades.

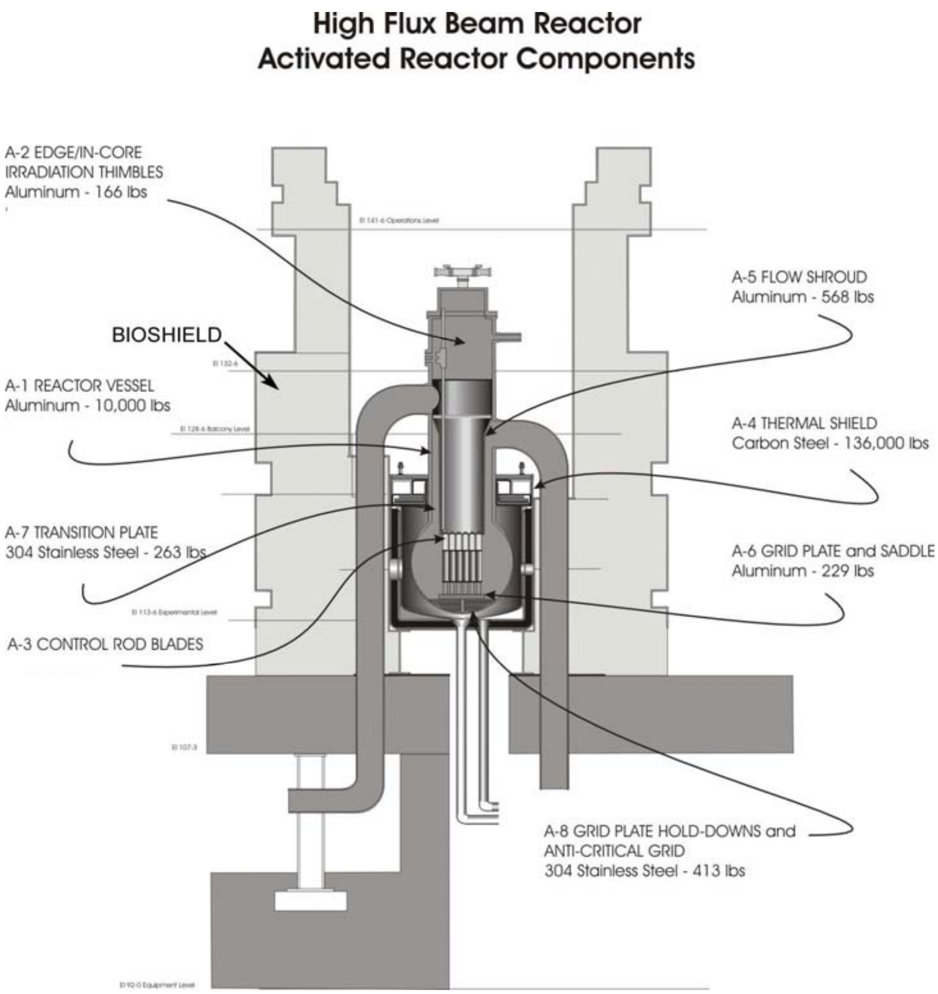

Figure 1-1. High Flux Beam Reactor Activated Components

WMG, Inc. performed a recalculation of the activity of irradiated components in late 2006 and early 2007. The calculation of the activity in the beam plugs was not affected by this recalculation. The summary of the results are shown in WMG Calculation 6117-CRE-072, "Final Characterization of the Brookhaven National Laboratory HFBR" (WMG 2007c), and these calculations were reviewed by Brookhaven scientists (Cheng 2007). The specific list of activated components was taken from the WMG calculation (WMG 2007c); these components are shown in Table 1-1, and a more detailed breakdown is shown in Table 1-2.

Table 1-1 HFBR Activated Components Listing

Index No.	HFBR Component	Material	Weight (lb)	Comments
A-1	Reactor Vessel	Aluminum-6061	10,000 lb	The reactor vessel is a massive aluminum component that stands just over 21 feet high. It consists of a lower hollow sphere approximately 7 feet in diameter, constructed of 1-3/4" thick aluminum and includes the experiment beam port thimbles. The upper portion of the vessel is a cylinder approximately 4 feet in diameter that is welded, via a transition plate, to the bottom sphere.
A-2	Reactor Internals, Edge/In-Core Irradiation Thimbles	Aluminum-6061	166 lb	
A-3	Control Rod Blades	Europium and Dysprosium absorbers	1571 lb	The control rod blades consist of main blades and auxiliary blades. For purposes of the summing of components, the support tube, main rack assembly, and auxiliary rack assembly are included with the control rod blades.
A-4	Thermal Shield	Carbon steel and lead	136,000 lb	The thermal shield is located in the base of the heavy concrete pit. The primary function of the thermal shield was to protect the surrounding concrete biological shield from the extreme heat of the reactor vessel.
A-5	Reactor Internals, Flow Shroud	Aluminum-6061	962 lb	
A-6	Grid Plate and Saddle	Aluminum-6061	229 lb	
A-7	Reactor Internals, Transition plate	304 Stainless Steel	263 lb	The reactor transition plate is a horizontal fixture located immediately above the reactor core that isolates the reactor sphere from the reactor vessel upper cylinder. The plate provided mechanical isolation and alignment of the vertical control rod mechanisms.
A-8	Reactor Internals, Grid Plate Hold-downs and Anti-Critical Grid	304 Stainless Steel	413 lb	The anti-critical grid consists of four quarter sections, each containing 28, 1-in. diameter 304 Stainless Steel bars configured below the grid plate at the bottom of the reactor. The anti-critical grid was designed to prevent a critical mass in the event of a core meltdown.
N/A	Biological Shield	Heavy Concrete	3,420,000 lb	The biological shield is constructed of heavy concrete, with iron punchings (~60% by weight) added to increase the density. Weight is for the entire shield, although the activated portion is on the inner diameter and is closer to 26,000 lb. Note that the biological shield is an integral part of the structure and support of Building 750.

Table 1-2 HFBR Activated Components Definitions (from Ref WMG 2007c)

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High Flux Beam Reactor – Component Definitions[14]							
Item	Component Description	Weight (lbs)	Material	Number of Units	Total Weight (lbs)	References	Notes
1	Anti-Critical Grid	100.0	304 SS	4	400.0	DWG 4653-5012-6	N/A
1a	Anti-Critical Grid Hold-Down Nuts	0.6	304 SS	5	2.9	DWG 4656-5015-5	N/A
2	Lattice-Plate w/ Auxiliary Blade Guides	130.0	Al-6061 T-6	1	130.0	SAR[8] Pg. 4-18, 4-68	Includes 2a and 2b
2a	Auxiliary Blade Guides	See Item 2	Al-6061 T-6	8	See Item 2	See Item 2	N/A
2b	Lattice-Plate	See Item 2	Al-6061 T-6	1	See Item 2	See Item 2	N/A
2c	Grid-Plate Hold-Down Bolts	0.9	304 SS	4	3.5	DWG 4656-5881-2	N/A
3	Auxiliary Blades	9.4	304 SS / Eu	8	75.2	FSA[5] #76 Pg. 3 SAR Pg. 4-10, 4-61	N/A
3a	Auxiliary Rack Assembly	34.0	304 SS	8	272.0	SAR Pg. 9-76	Includes 3c
3b	Auxiliary Spring	4.5	Inconel X	8	36.0	SAR Pg. 9-76	N/A
3c	Auxiliary Blade Coupling	See Item 3a	304 SS	8	See Item 3a	See Item 3a	N/A
3d	Auxiliary Blade Follower Ext. Tubes	3.1	Al-6061 T-6	8	24.7	SAR Pg. 4-61	N/A
4	Main Blades	20.0	304 SS / Eu / Dy	8	160.0	FSA #76 Pg. 3 SAR Pg. 4-10, 4-61	N/A
4a	Main Rack Assembly	42.0	304 SS / Inconel X	8	336.0	SAR Pg. 9-74	Includes 4b
4b	Main Scram Spring	See Item 4a	Inconel X	8	See Item 4a	See Item 4a	N/A

Table 1 2. HFBR Activated Components Definitions (from Ref WMG 2007c)
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High Flux Beam Reactor – Component Definitions[(14)]

Item	Component Description	Weight (lbs)	Material	Number of Units	Total Weight (lbs)	References	Notes
5	Lower Support Tube Assemblies	139.0	304 SS	8	1112.0	SAR Pg. 9-72	Includes 5a and 5b
5a	Auxiliary Blade Lower Support Tubes	See Item 5	304 SS	8	See Item 5	See Item 5	N/A
5b	Main Blade Lower Support Tubes	See Item 5	304 SS	8	See Item 5	See Item 5	N/A
5c	Neutron Shield	27.0	304 SS / Cd	8	216.0	DWG 4656-5510-1	N/A
6	Transition Plate	263.0	304 SS / Al-6061 T6 / Inconel X	1	263.0	SAR Pg. 5-26, 4-69	Includes 6a and 6b
6a	Rod-Penetration Insert	See Item 6	304 SS	8	See Item 6	SAR Pg. 4-69 DWG 4656-5700-1	N/A
6b	Flow Reversal Valves	See Item 6	Al-6061 T6 / 304 SS / Inconel X	4	See Item 6	SAR Pg. 4-23, 4-69 DWG 4656-5311-1	N/A
7	Upper Thermal Shield	29230.0	Carbon Steel	1	29230.0	DWG 4653-7200-5	N/A
7a	Thermal Shield Stud Bolt Assembly	11.9	Carbon Steel	16	189.6	DWG 4653-7205-5	Included in Item 7
7b	Wedge Assembly	80.5	Carbon Steel	16	1288.0	DWG 4653-7205-5	Included in Item 7
7c	Thermal Shield Split Ring	8528.0	Carbon Steel	2	17056.0	DWG 4653-7202-4	Included in Item 7
7d	Thermal Shield Support Ring	10675.0	Carbon Steel	1	10675.0	DWG 4653-7204-5	Included in Item 7

Table 1 2. HFBR Activated Components Definitions (from Ref WMG 2007c)
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High Flux Beam Reactor – Component Definitions[14]							
Item	Component Description	Weight (lbs)	Material	Number of Units	Total Weight (lbs)	References	Notes
8	Anti-Critical Grid Saddle	74.3	Al-6061 T-6	1	74.3	DWG 4656-5015-5	N/A
8a	Anti-Critical Grid Hold-Down Studs (Grid Plate Hold-Down Studs)	0.4	304 SS	5	2.2	DWG 4656-5015-5	N/A
8b	Saddle Hold-Down Cap Screws	1.2	304 SS	4	4.8	DWG 4656-5015-5	N/A
8c	Anti-Critical Grid Locating Pins	0.2	304 SS	2	0.5	DWG 4653-5012-6	N/A
9	Reactor Vessel Closure	5140.0	304 SS	1	5140.0	DWG 4656-5014-6	N/A
9a	Reactor Vessel Cover Plate	770.0	304 SS	1	770.0	DWG 4653-5007-4	N/A
10	Core Flow Shroud	962.0	Al-6061 T6	1	962.0	DWG 4656-5227-2	N/A
11	Lower Thermal Shield	105534	Carbon Steel / Pb	1	105534.0	DWG 4653-7000-12	N/A
11a	Lower Thermal Shield Outer Shell	95308.0	Carbon Steel / Pb	1	95308.0	DWG 4653-7002-11	Included in Item 11
11b	Lower Thermal Shield Inner Shell	10226.0	Carbon Steel	1	10226.0	DWG 4653-7004-8	Included in Item 11

Table 1 2. HFBR Activated Components Definitions (from Ref WMG 2007c)
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High Flux Beam Reactor – Component Definitions(14)							
Item	Component Description	Weight (lbs)	Material	Number of Units	Total Weight (lbs)	References	Notes
12	Reactor Vessel	10000.0	Al-6061 T-6	1	10000.0	DWG 4653-5002-9	N/A
12a	Reactor Vessel Sphere (Bottom 1/3)	1207.3	Al-6061 T-6	1	1207.3	DWG 4653-5003-9	Included in Item 12
12b	Reactor Vessel Sphere (Center 30")	1589.8	Al-6061 T-6	1	1589.8	DWG 4653-5003-9	Included in Item 12, Includes Beam Tubes and Thimbles V-10 to 12
12c	Reactor Vessel Sphere (Top 1/3)	669.6	Al-6061 T-6	1	669.6	DWG 4653-5003-9	Included in Item 12
12d	Reactor Vessel Cylinder (Bottom 3')	1134.5	Al-6061 T-6	1	1134.5	DWG 4653-5003-9	Included in Item 12
12e	Reactor Vessel Cylinder Remaining	5398.8	Al-6061 T-6	1	5398.8	See Item 12	Remaining Weight in Item 12
13a	Core Edge Thimble	58.0	Al-6061 T-6	2	116.0	DWG 4653-8300-3	N/A
13b	Fast Irradiation Thimble	60.0	Al-6061 T-6	2	120.0	DWG 4653-8300-3	N/A

1.2 Current and Future Radioactivity Inventory for Activated Components

The activated components contain the vast majority (>99% in 2007) of the total radioactivity remaining at the HFBR. The physical form of these activated components (activated metal) makes the hazard primarily a direct exposure risk and not a contamination risk. The reactor vessel, internals, and the activated portion of the biological shield are well shielded in the HFBR's current condition, and there are no significant radiological hazards from those materials until they are disturbed during decommissioning. The beam plugs and collimators have been removed from the biological shield area and are in storage in a shielded condition.

The following tables and figures are presented to show the radioactivity contents for the reactor vessel and other components, and they present the results of radioactive decay over the next 100 years. Half-lives of radionuclides were taken from "Nuclides and Isotopes, Chart of the Nuclides (KAPL 2002). The term "Co-60 Equivalent" represents the number of curies of Co-60 that would provide approximately the same gamma radiation hazard as the total curies of the mix of radionuclides.

Table 1-3 HFBR Reactor Vessel Activity

		Jan-2007	Jan-2012	Jan-2017	Jan-2027	Jan-2037	Jan-2047	Jan-2057	Jan-2082	Jan-2107
Nuclide	**Half-Life (yr)**	**Ci**	**Ci**	**Ci**	**Ci**	**Ci**	**Ci**	**Ci**	**Ci**	**Ci**
Fe-55	2.7	147	41	12	1	0	0	0	0	0
Co-60	5.27	33	17	9	2	1	0	0	0	0
Ni-59	76,000	1	1	1	1	1	1	1	1	1
Ni-63	100	199	192	186	173	161	151	141	118	99
Total Ci	**N/A**	**380**	**251**	**207**	**177**	**163**	**151**	**141**	**119**	**100**
Years Decay		0	5	10	20	30	40	50	75	100
Equivalent Co-60 Curies		33	17	9	2	1	0	0	0	0

Table 1-4 HFBR Reactor Internals Activity

		Jan-2007	Jan-2012	Jan-2017	Jan-2027	Jan-2037	Jan-2047	Jan-2057	Jan-2082	Jan-2107
Nuclide	**Half-Life (yr)**	**Ci**	**Ci**	**Ci**	**Ci**	**Ci**	**Ci**	**Ci**	**Ci**	**Ci**
C-14	5,715	12	12	12	12	12	12	12	12	12
Fe-55	2.7	4,290	1,205	338	27	2	0	0	0	0
Co-60	5.27	5,900	3,056	1,582	425	114	31	8	0	0
Ni-59	76,000	30	29	29	29	29	29	29	29	29
Ni-63	100	6,150	5,940	5,738	5,354	4,995	4,660	4,348	3,656	3,074
Total Ci	**N/A**	**16,381**	**10,242**	**7,700**	**5,846**	**5,152**	**4,732**	**4,397**	**3,697**	**3,115**
Years Decay		0	5	10	20	30	40	50	75	100
Equivalent Co-60 Curies		5,910	3,059	1,583	425	114	31	8	0	0

Table 1-5 HFBR Control Rod Blades Activity

		Jan-2007	Jan-2012	Jan-2017	Jan-2027	Jan-2037	Jan-2047	Jan-2057	Jan-2082	Jan-2107
Nuclide	**Half-Life (yr)**	**Ci**	**Ci**	**Ci**	**Ci**	**Ci**	**Ci**	**Ci**	**Ci**	**Ci**
C-14	5.72E+03	7	7	7	7	7	7	7	7	7
Fe-55	2.73E+00	6,170	1,733	486	38	3	0	0	0	0
Co-60	5.27E+00	7,060	3,657	1,893	508	136	37	10	0	0
Ni-59	7.60E+04	17	17	17	17	17	17	17	17	17
Ni-63	1.00E+02	3,700	3,574	3,452	3,221	3,005	2,804	2,616	2,199	1,849
Eu-154	8.59E+00	3,610	2,411	1,610	718	320	143	64	8	1
Eu-155	4.75E+00	1,340	646	311	72	17	4	1	0	0
Total Ci	**N/A**	**21,904**	**12,044**	**7,777**	**4,582**	**3,505**	**3,011**	**2,714**	**2,232**	**1,874**
Years Decay		0	5	10	20	30	40	50	75	100
Equivalent Co-60 Curies		9,131	3,661	1,895	508	136	37	10	0	0

Table 1-6 HFBR Thermal Shield Activity

		Jan-2007	Jan-2012	Jan-2017	Jan-2027	Jan-2037	Jan-2047	Jan-2057	Jan-2082	Jan-2107
Nuclide	**Half-Life (yr)**	**Ci**	**Ci**	**Ci**	**Ci**	**Ci**	**Ci**	**Ci**	**Ci**	**Ci**
C-14	5,715	7	7	7	7	7	7	7	7	7
Fe-55	2.7	20,100	5,645	1,584	125	10	1	0	0	0
Co-60	5.27	2,910	1,507	780	209	56	15	4	0	0
Ni-59	76,000	14	14	14	14	14	14	14	14	14
Ni-63	100	1,870	1,806	1,745	1,628	1,519	1,417	1,322	1,112	935
Total Ci	**N/A**	**24,902**	**8,980**	**4,131**	**1,984**	**1,606**	**1,454**	**1,348**	**1,133**	**956**
Years Decay		0	5	10	20	30	40	50	75	100
Equivalent Co-60 Curies		2,957	1,520	784	210	56	15	4	0	0

Table 1-7 HFBR Biological Shield Activity

		Jan-2007	Jan-2012	Jan-2017	Jan-2027	Jan-2037	Jan-2047	Jan-2057	Jan-2082	Jan-2107
Nuclide	**Half-Life (yr)**	**Ci**	**Ci**	**Ci**	**Ci**	**Ci**	**Ci**	**Ci**	**Ci**	**Ci**
H-3	12.3	7	5	4	2	1	1	0	0	0
Fe-55	2.7	98	27	8	1	0	0	0	0	0
Co-60	5.27	12	6	3	1	0	0	0	0	0
Ni-63	100	8	8	7	7	7	6	6	5	4
Total Ci	**N/A**	**125**	**47**	**23**	**11**	**8**	**7**	**6**	**5**	**4**
Years Decay		0	5	10	20	30	40	50	75	100
Equivalent Co-60 Curies		12	6	3	1	0	0	0	0	0

Table 1-8 HFBR Beam Plugs and Collimators Activity

		Jan-2007	Jan-2012	Jan-2017	Jan-2027	Jan-2037	Jan-2047	Jan-2057	Jan-2082	Jan-2107
Nuclide	Half-Life (yr)	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci	Ci
Fe-55	2.7	362	102	29	2	0	0	0	0	0
Co-60	5.27	482	250	129	35	9	2	1	0	0
Total Ci	**N/A**	**843**	**351**	**158**	**37**	**9**	**3**	**1**	**0**	**0**
Years Decay		0	5	10	20	30	40	50	75	100
Equivalent Co-60 Curies		483	250	129	35	9	2	1	0	0

Table 1-9 HFBR Total Irradiated Components Activity

		2007	2012	2017	2027	2037	2047	2057	2082	2107
Nuclide	**Half-Life (yr)**	**Ci**	**Ci**	**Ci**	**Ci**	**Ci**	**Ci**	**Ci**	**Ci**	**Ci**
H-3	12.3	7	5	4	2	1	1	0	0	0
C-14	5,715	26	26	26	26	26	26	26	26	25
Fe-55	2.7	31,150	8,749	2,455	194	15	1	0	0	0
Co-60	5.3	16,389	8,489	4,395	1,179	316	85	23	1	0
Ni-59	76,000	62	62	62	62	62	62	62	62	62
Ni-63	100	11,932	11,525	11,132	10,387	9,691	9,042	8,436	7,093	5,964
Eu-154	8.6	3,610	2,411	1,610	718	320	143	64	8	1
Eu-155	4.8	1,336	644	310	72	17	4	1	0	0
Total Ci	**N/A**	**64,511**	**31,911**	**19,995**	**12,639**	**10,448**	**9,362**	**8,611**	**7,190**	**6,052**
Years Decay		0	5	10	20	30	40	50	75	100
Equivalent Co-60 Curies		18,518	9,870	5,304	1,579	494	164	58	6	1

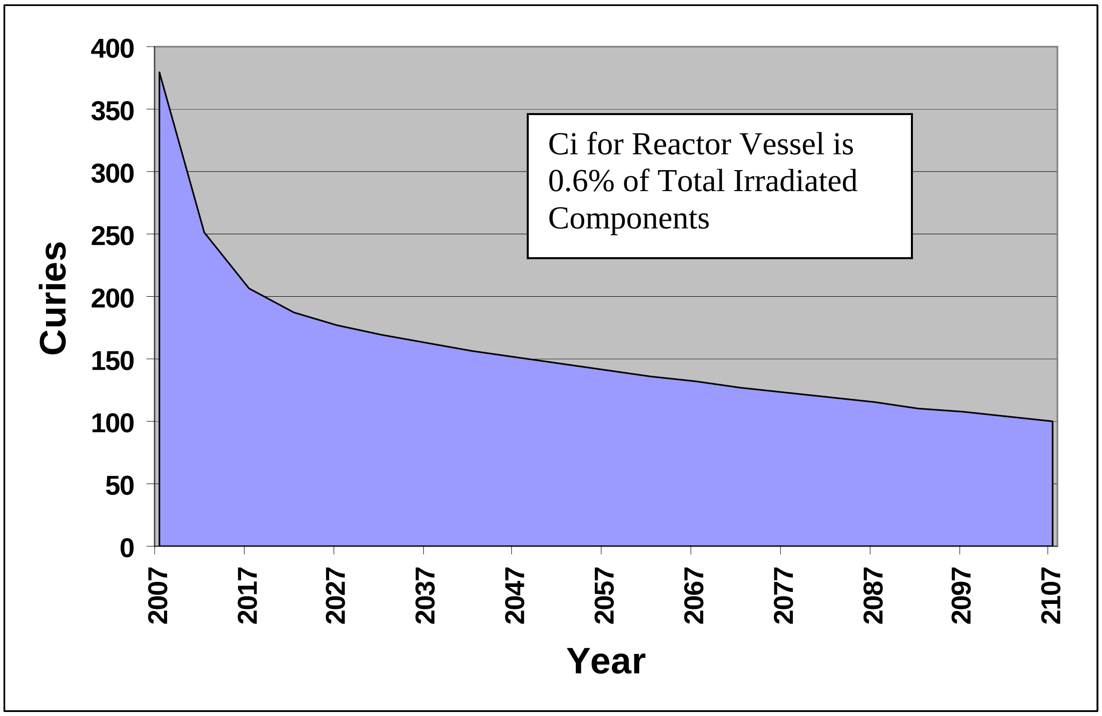

Figure 1-2. Reactor Vessel Total Curies 2007-2107

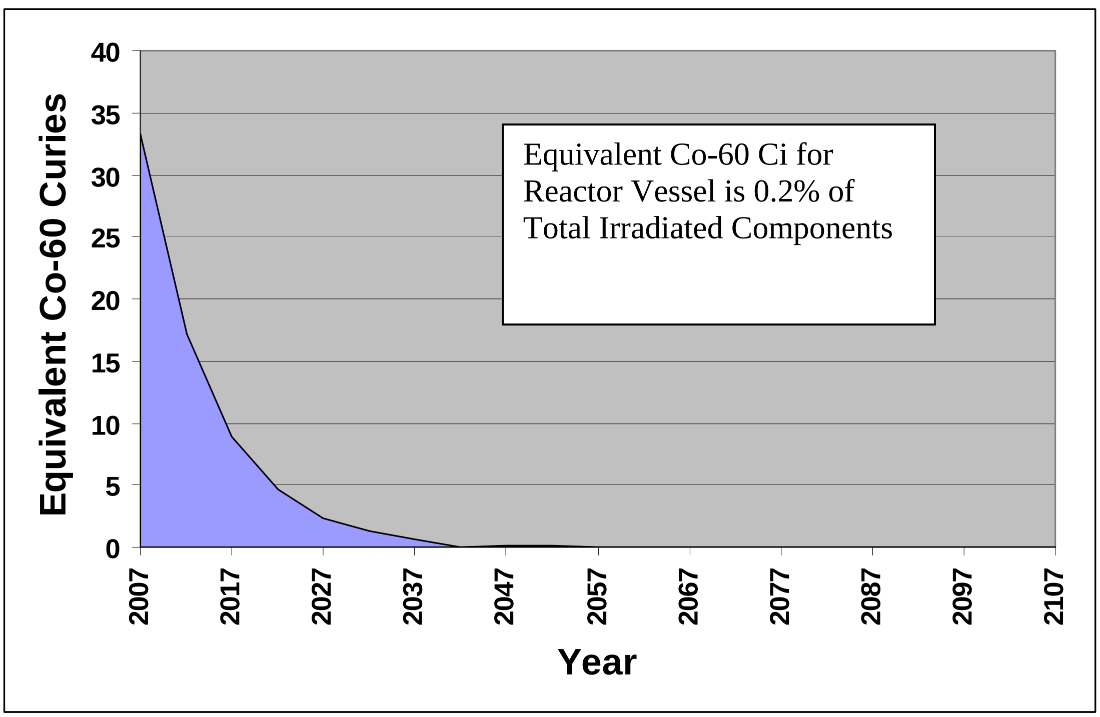

Figure 1-3. Reactor Vessel Equivalent Cobalt-60 Curies

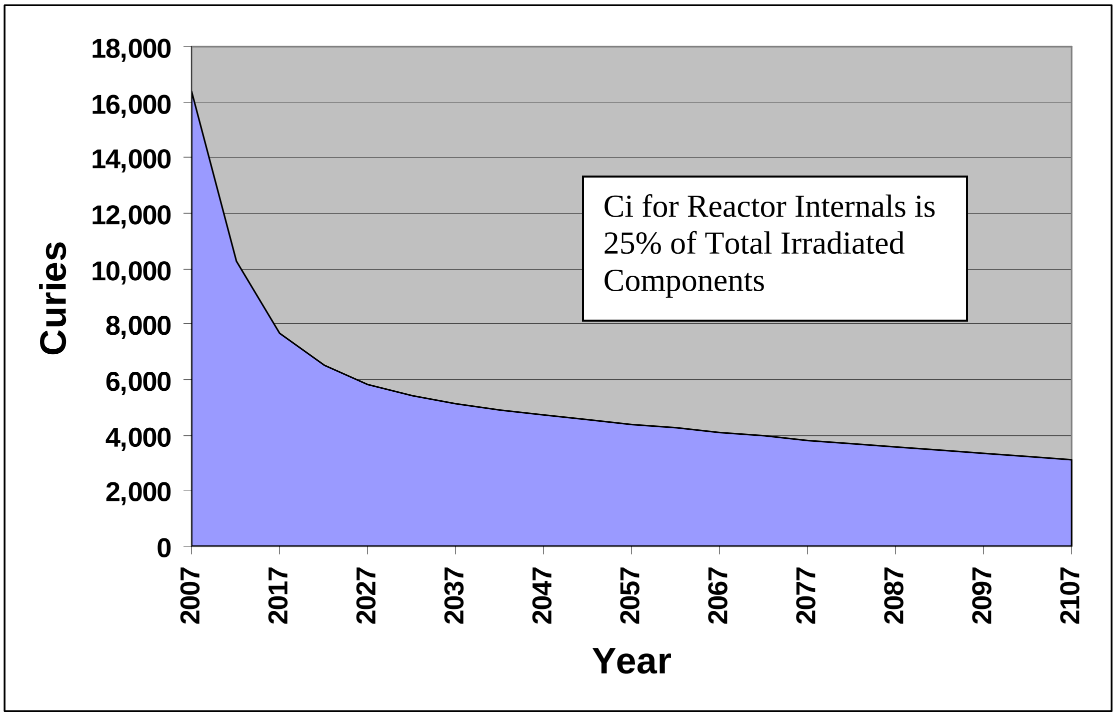

Figure 1-4. Reactor Internals Total Curies 2007-2107

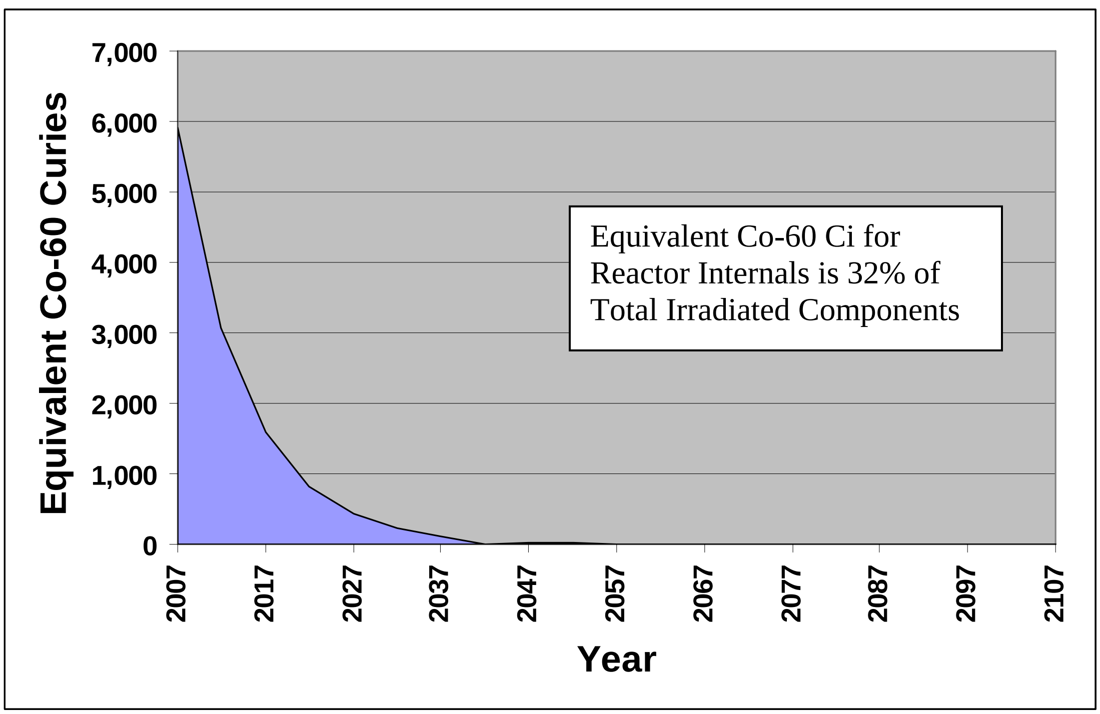

Figure 1-5. Reactor Internals Equivalent Cobalt-60 Curies

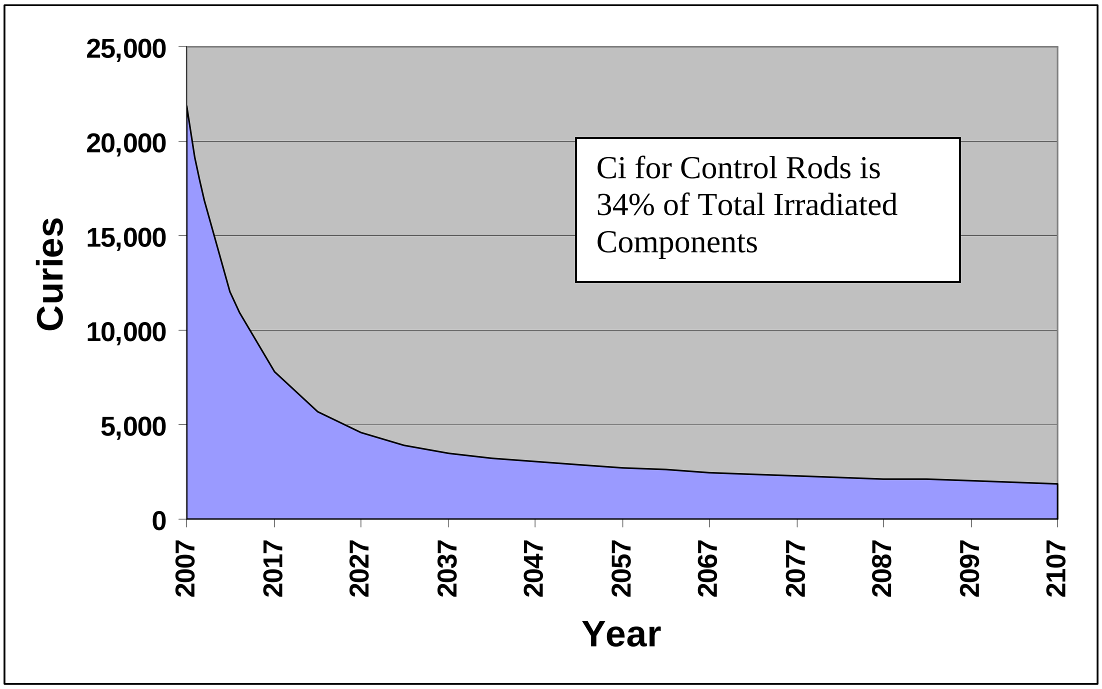

Figure 1-6. Control Rods Total Curies 2007-2107

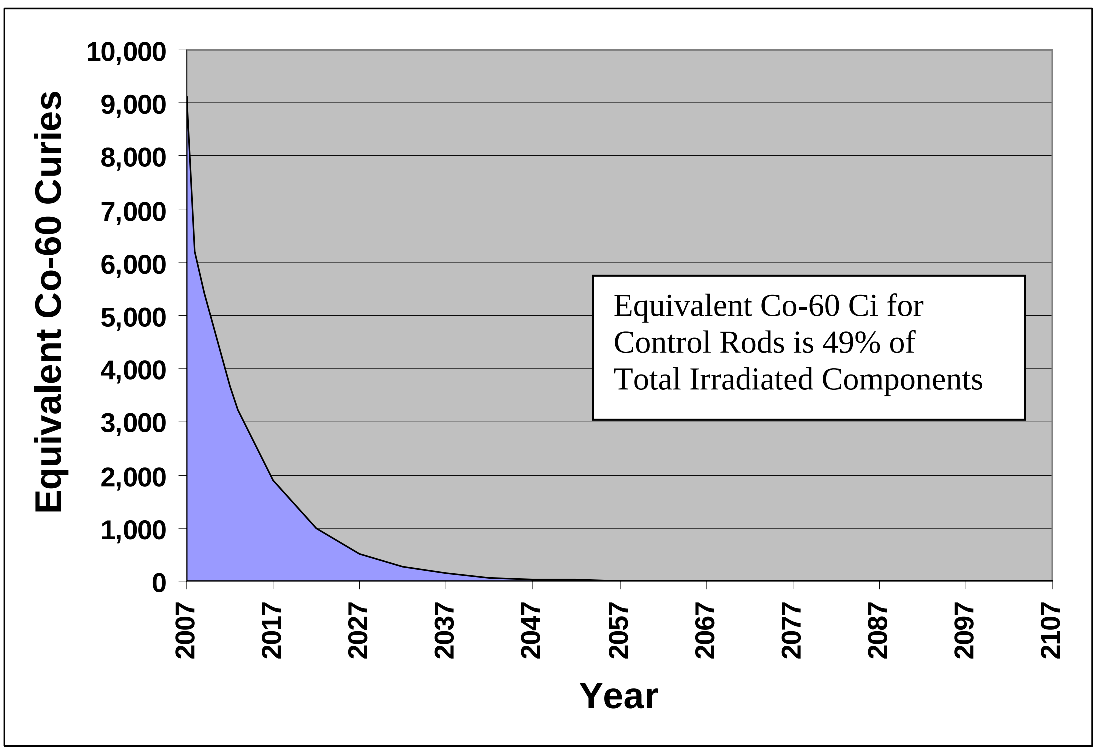

Figure 1-7. Control Rods Equivalent Co-60 Curies

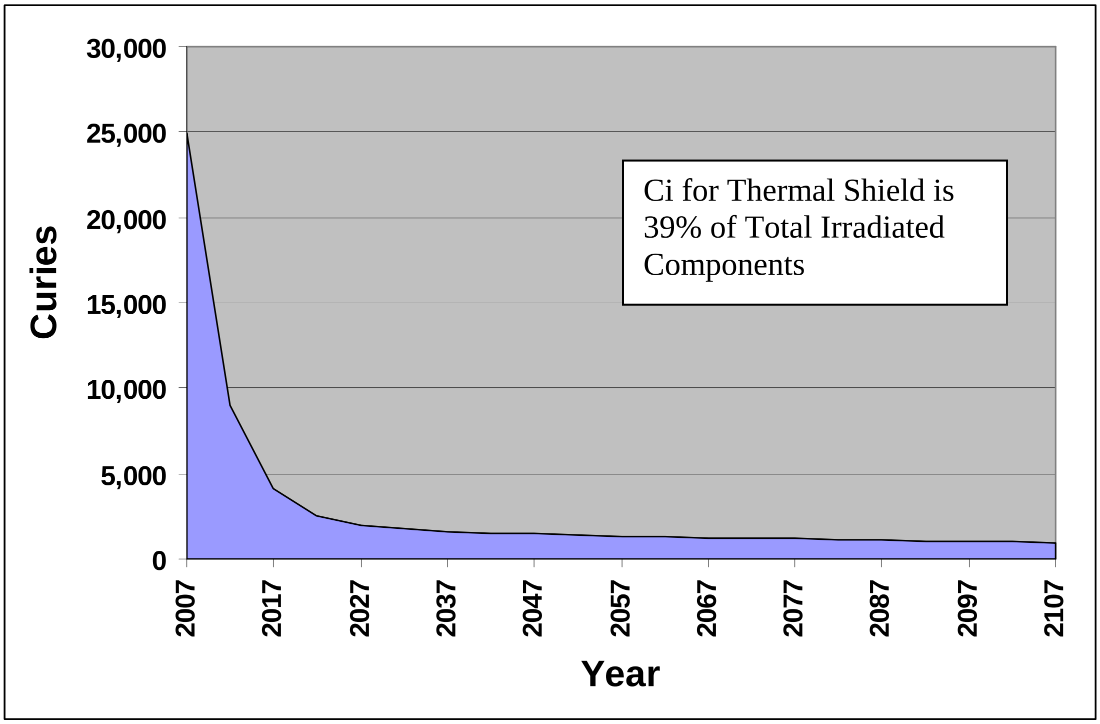

Figure 1-8. Thermal Shield Total Curies 2007-2107

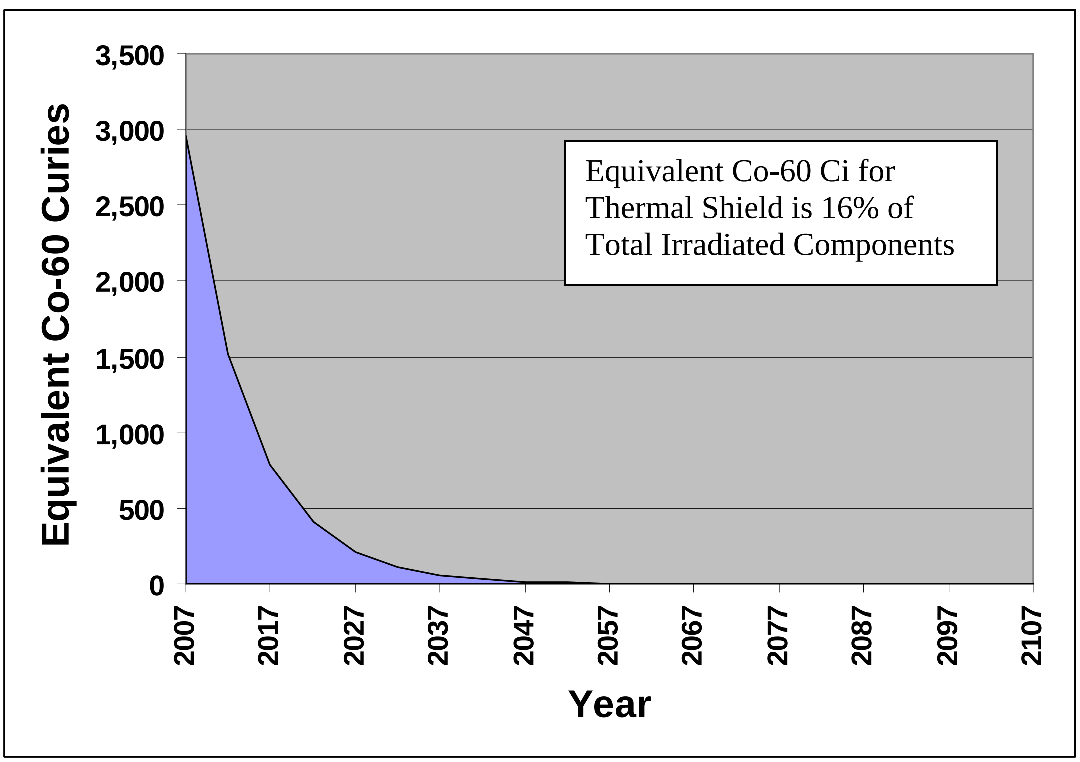

Figure 1-9. Thermal Shield Equivalent Cobalt-60 Curies

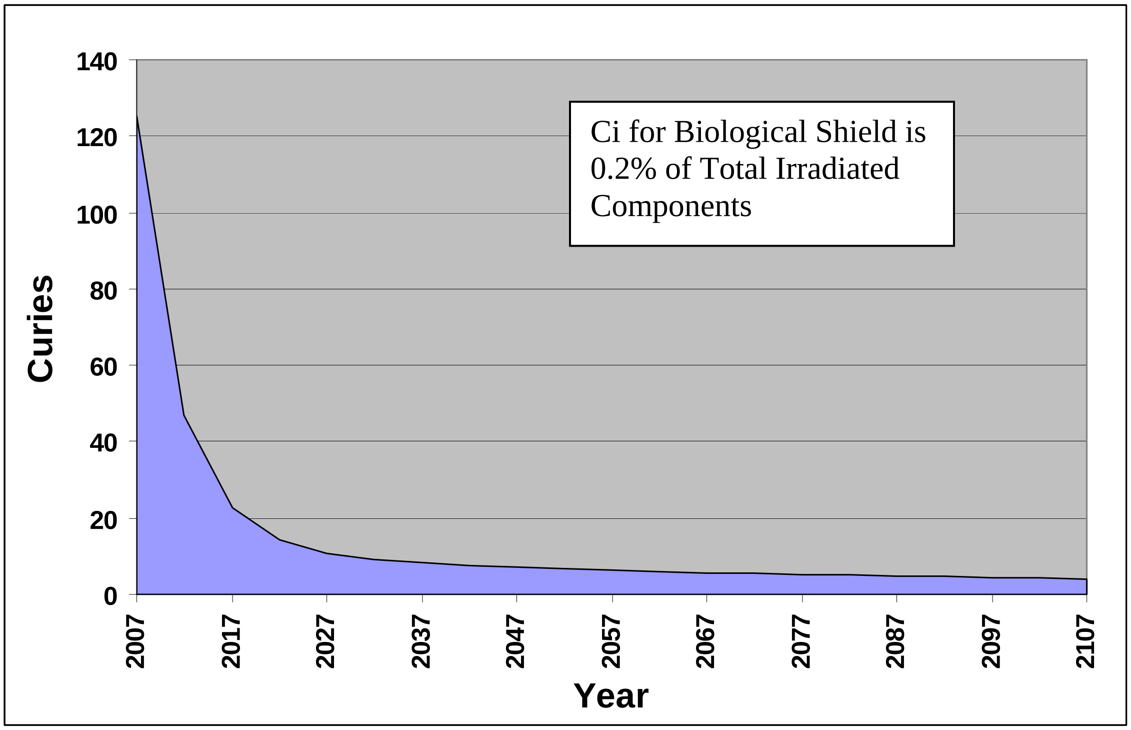

Figure 1-10. Biological Shield Total Curies 2007 - 2107

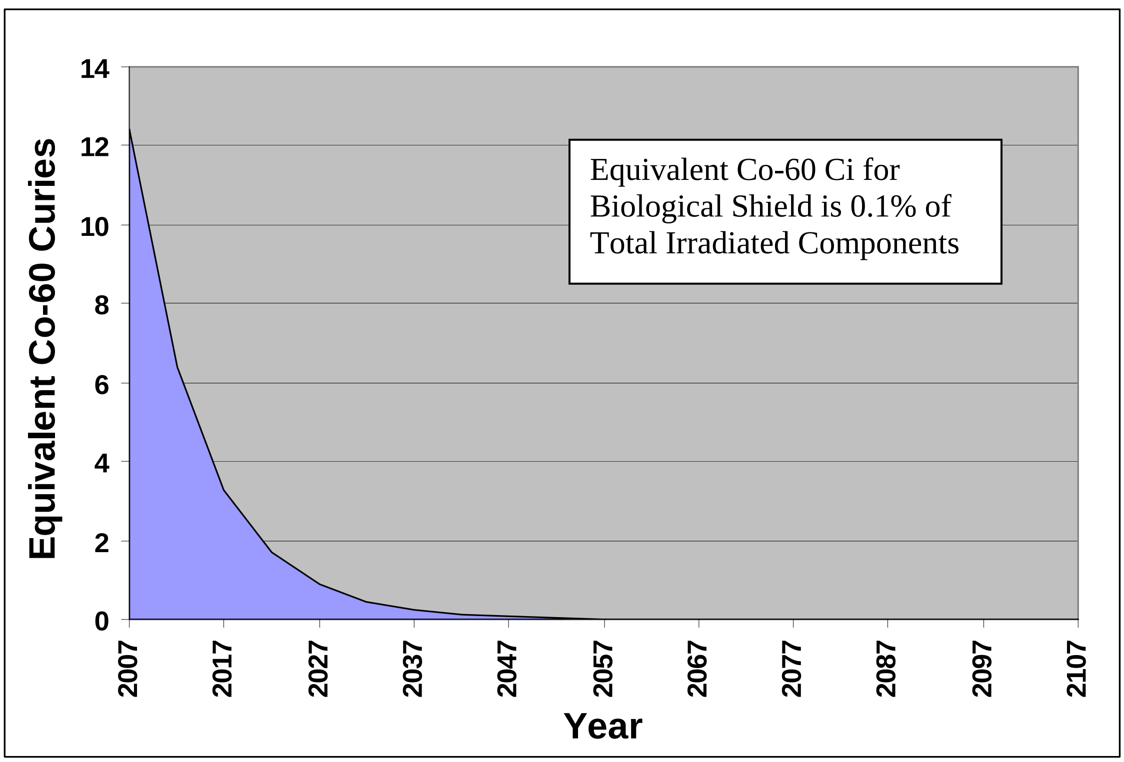

Figure 1-11. Biological Shield Equivalent Cobalt-60 Curies

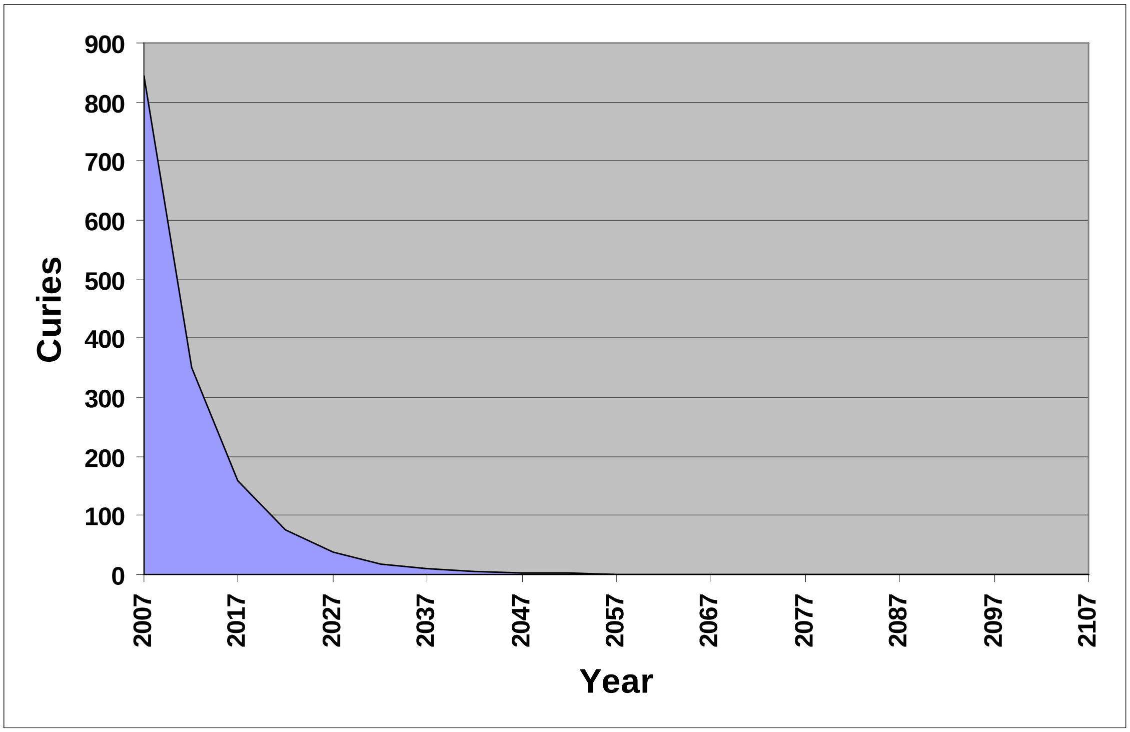

Figure 1-12. Beam Plugs and Collimator Total Curies

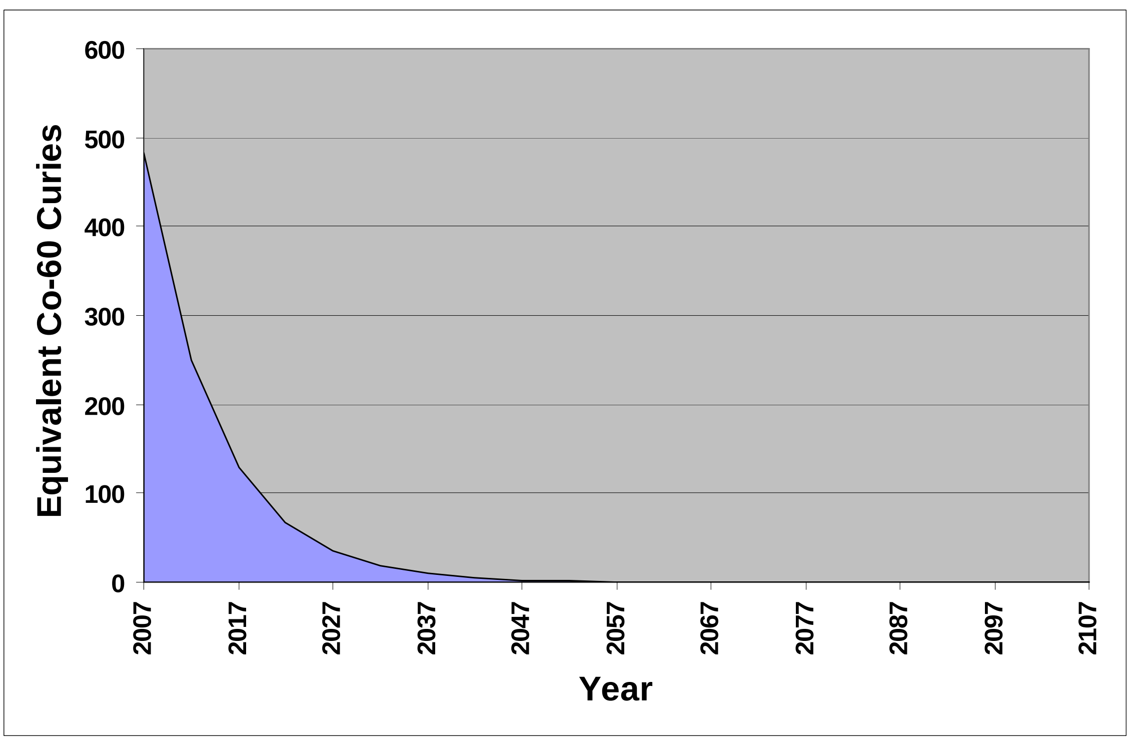

Figure 1-13. Beam Plugs and Collimators Equivalent Cobalt-60 Curies

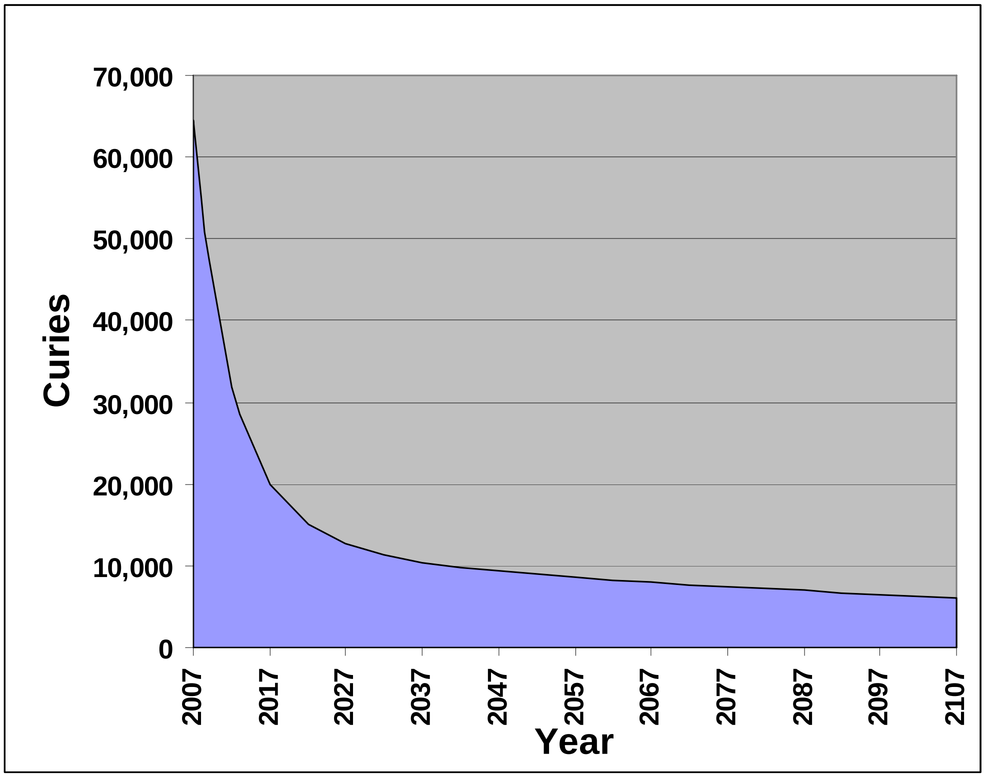

Figure 1-14. HFBR Total Irradiated Components- Curies 2007-2107

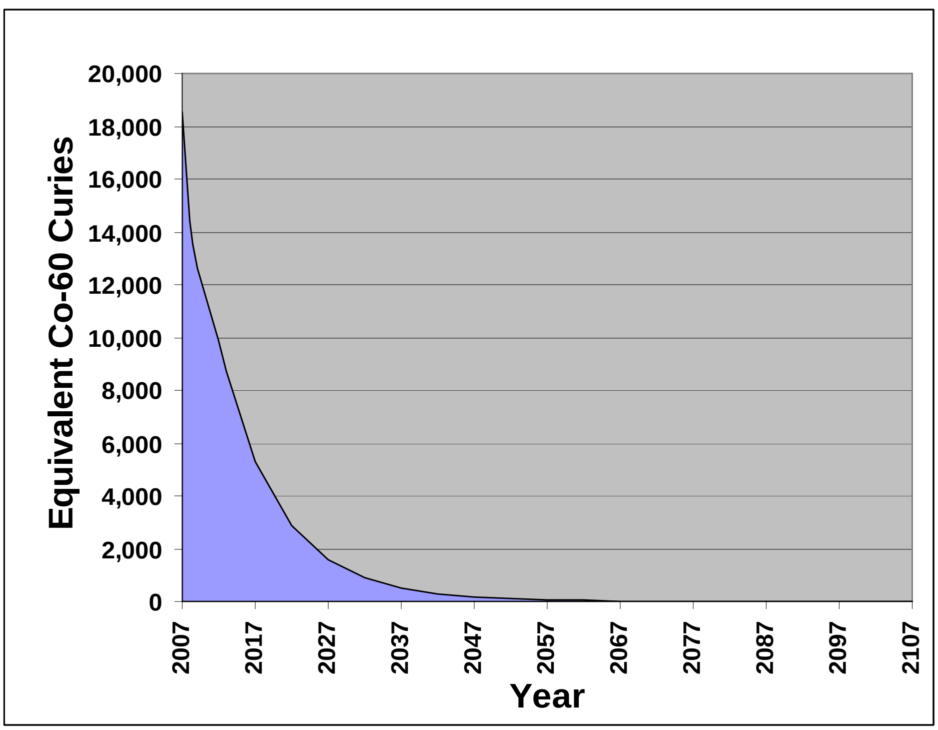

Figure 1-15. HFBR Total Irradiated Components – Equivalent Co-60 Curies

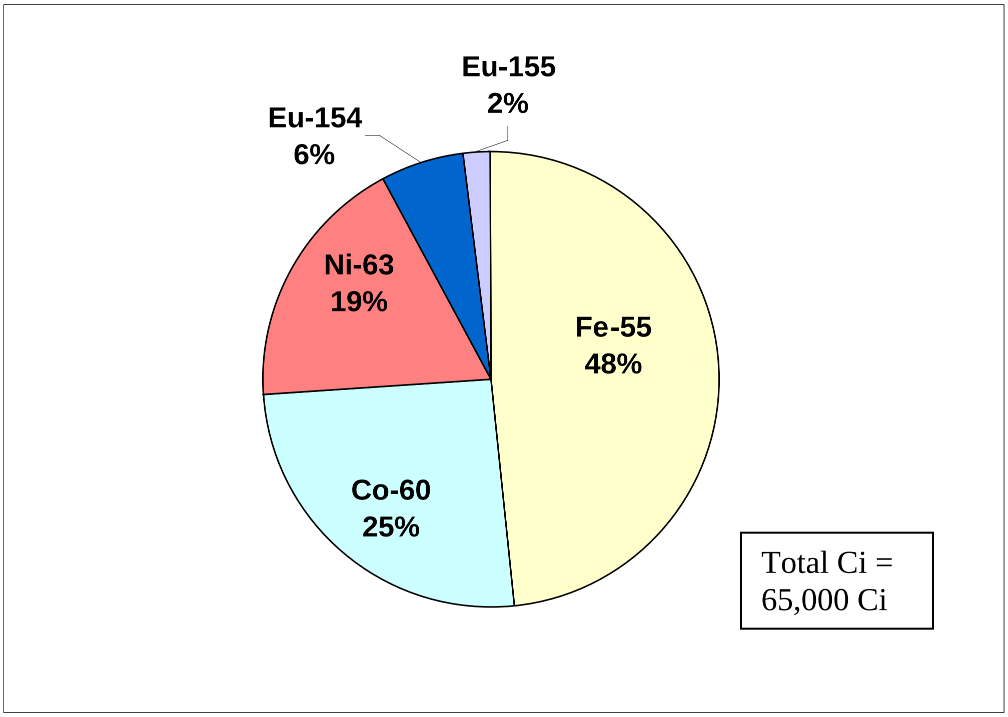

Figure 1-16. HFBR Total Irradiated Components – Radionuclide Percent- 2007

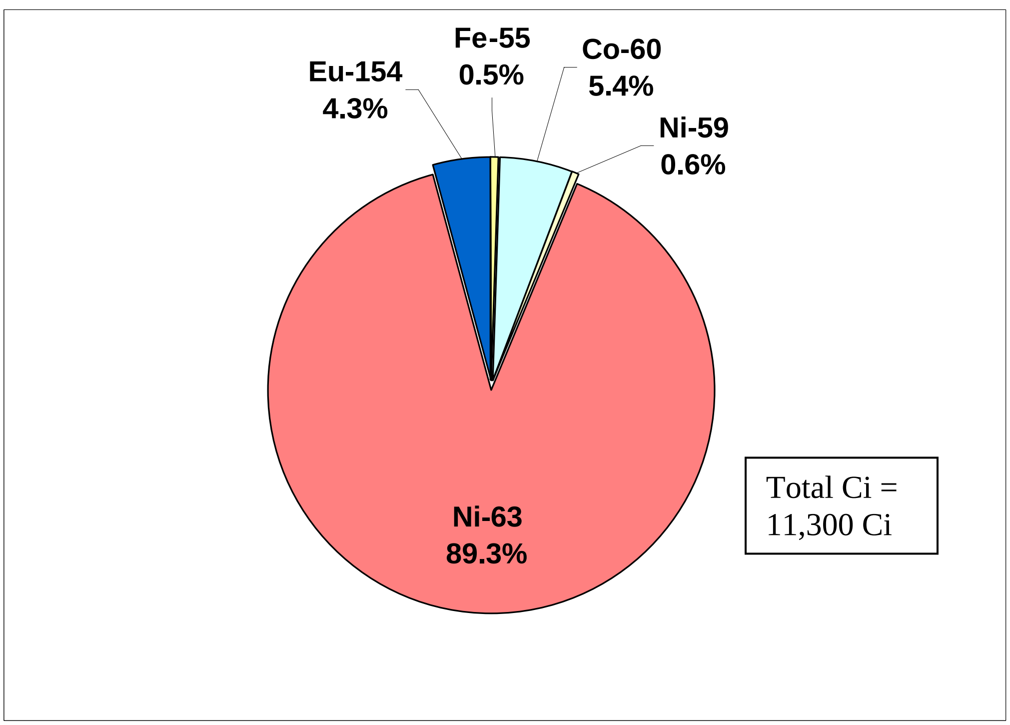

Figure 1-17. HFBR Total Irradiated Components – Radionuclide Percent- 2032

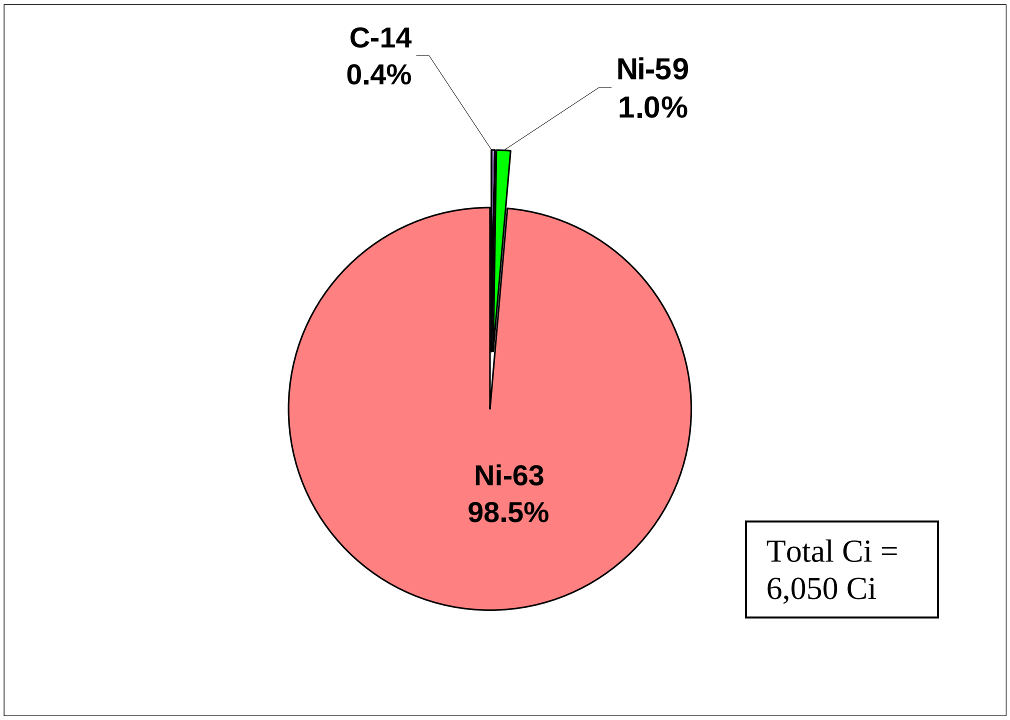

Figure 1-18. HFBR Total Irradiated Components – Radionuclide Percent- 2107

2. Part 2. Characterization Summary – Reactor Building Systems, Structures, and Components

2.1 Summary Description of Reactor Building Systems, Structures, and Components

Characterization of Building 750 consisted of the facility structure itself, including floors, walls, and the dome, and it included systems and components within the building. A more detailed description of the facility is contained in the HFBR Plant Description Manual (BNL, 1996) and in the introductory portion of this document, a synopsis of the reactor building and structures is provided below.

The steel dome structure acts as the confinement of the HFBR, and it is in the shape of a hemisphere resting on a cylindrical base. The hemispherical portion of the dome is insulated on the outside, and the insulation is covered with aluminum sheets. The confinement building consists of four levels: the Equipment Level, Experimental Level, Balcony Level, and Operations Level.

The Equipment Level contains most of the reactor support and building systems equipment, such as pumps, heat exchangers, filters, wastewater storage tanks, Heating Ventilation and Air Conditioning (HVAC), and piping networks. Shielded cells for the primary cooling water system pumps and heat exchangers are located in the center of the floor. The spent fuel storage canal resides under the fuel discharge chute at the west end. The heavy water purification system and one of two storage tanks are installed in pits sunken into the floor of the Equipment Level.

The Experimental Level was dedicated to the scientific users. The reactor biological shield occupies the central portion of this level, with open floor space surrounding it for the external beam experiments. Laboratories and offices are located along the perimeter wall of the level.

The Balcony Level is approximately 21 feet wide, with its outer circumference at the confinement shell. Offices, locker rooms, toilets, and HVAC equipment are contained on this level.

The Operations Level is the top floor of the building. The reactor shielding structure rises above the floor at the center of the building. The level contains an enclosed process area (the Greenhouse), which houses pumps, a heat exchanger and piping associated with the experimental facilities cooling water system. A series of offices and workrooms are located on the east side of the Level, with the reactor control room occupying the second story above these offices

The list of systems considered in this section is shown in Table 2-2, "HFBR Systems and Components."

2.2 Characterization of Reactor Building Systems, Structures, & Components

A number of characterization efforts have been undertaken in order to better understand the remaining hazards inside the HFBR (Building 750). These characterizations were intended to support a variety of purposes, including current work activities, long-term storage and maintenance, and decommissioning.

A portion of the HFBR characterization was conducted in 2001, when deactivation of the facility was ongoing. At that time, many of the plant systems were operational and the experimental level still had significant amounts of equipment in place, and some personnel were stationed in the HFBR as their routine place of work. A "Characterization Project Plan" was developed (BNL, 2001a) in March 2001, and since additional cleanup was being performed, the surveys were planned as a "snapshot" of the conditions at that time. The results of that characterization were reported in September 2001 in the "HFBR Final Characterization Report" (Cabrera 2001b). It was understood that future operational and remediation activities could change the characterization results. The survey area breakdowns utilized for the studies divided up the HFBR into 115 survey areas, as shown in Table 2-3, "HFBR Elevation and Structure Survey Areas."

In late 2004 and early 2005, an update to the 2001 characterization was performed, and the intent was to determine any changes since 2001 and to determine radiological conditions prior to potentially entering an extended period of reactor facility storage and monitoring. The plan for these additional surveys was documented in "HFBR Building 750 Floor Mat and Groundwater Sampling and Analysis Plan (Grosser 2004). In addition, the activity remaining within the plant systems was calculated based on plant conditions and the results of the 2004 surveys.

The results of the most recent characterization are presented in several documents, "BNL High Flux Beam Reactor Systems and Building Characterization and End Point Review" (DAQ 2004), and "HFBR Systems and Components Activity Calculation" (DAQ 2005). Area surveys were performed and the results are on file with the Facilities Support group. The general plant conditions are such that there are very few areas within the HFBR where high levels of radiation or contamination are accessible for routine entry.

The results of the radioactivity estimates for HFBR systems are summarized in Table 2-4, "HFBR System Radioactivity Calculation Summary." The total activity in all systems, exclusive of the reactor vessel and internals, control rod blades, thermal shield, biological shield, and beam plugs/collimators is less than 0.1 percent of the activated materials associated with the reactor. While the activated components contain the vast majority of the total radioactivity remaining at the HFBR, the physical form of these activated components (activated metal) makes the hazard primarily a direct exposure risk, and not a contamination risk. The systems and components are much lower activity, and while it is unlikely to have an event that will release radioactivity, the probability of releases from the systems to the environment is more likely than a release from activated components.

The majority of the radioactivity remaining in the systems is from tritium, due to small amounts of residual D_2O left over from system drain down, Figure 2-1 "HFBR Systems: Radionuclide Percent of Out-of-Core Activity – 2007" shows the relative amounts of the system radionuclides. Figure 2-2 shows the decay of these radionuclides over time. Both Figure 2-1 and 2-2 represent out-of-core activity, since the irradiated materials in and near the reactor core, vessel, and biological shield are much higher in radioactivity content.

Cleanup has been ongoing at the HFBR for the last few years, and there has been removal of radioactive sources, radioactive waste, and hazardous materials. Table 2-5 provides details of specific quantities of materials removed from the facility.

The 2004 portion of the characterization included the coring through the base mat of the HFBR directly into the soil and down to groundwater. The primary purpose of this sampling was to determine if a significant source of tritium remains in the soil and/or the groundwater below the HFBR. Sample locations are shown in the sampling and analysis plan (Grosser 2004), and include two locations near the spent fuel canal, three locations near the heat exchanger cells, and one location near the elevator shaft and Heavy Water Storage Room. Each location resulted in approximately 25 samples of soil and water. The tritium analysis results indicate that none of the soil samples had detectable tritium, and the range of tritium in the groundwater was from non-detectable to 7130 pCi/liter (Grosser 2005c). This maximum level in the groundwater is less than the EPA drinking water standard of 20,000 pCi/liter.

2.3 <u>Hazardous materials and safety concerns</u>

Hazardous material surveys were performed during the 2001 characterization by the collection of samples from building materials, drain and trap sediments and sludge, and direct sampling methods. The samples were submitted to a qualified laboratory for analyses. Analytical detection limits were determined by laboratory analytical techniques and standard methodologies. HFBR characterization samples submitted for laboratory analyses were subject to the detection limits in Table 2-1 "Hazardous Material Analytical Detection Limits" (NYSDEC, 1994).

Table 2-1. Hazardous Material Analytical Detection Limits

Analyses	Detection Limit
Asbestos	1%
Mercury	<0.2 ppm
Elemental Lead	<5.0 ppm
PCB's	<1.0 ppm
Zinc	<100 ppm
Beryllium	<10 ppm
Cadmium	<5.0 ppm

Asbestos Containing Material (ACM) was found throughout the HFBR in older floor and ceiling tiles. Certain piping and valves have Garlock™ gaskets with ACM. Asbestos insulation is also present around many pipes. While the HFBR is in a storage condition and the equipment and materials containing asbestos are not disturbed, no special precautions are necessary. Asbestos abatement technologies will be required when proceeding to equipment removal during decommissioning.

Lead is present in many products throughout the HFBR. The most obvious is lead shielding used to reduce area radiation levels. Some of the shielding is plastic coated to mitigate lead dust. The results of wipe testing for metals indicated that lead is detected consistently. Lead paint is also apparent on many metal and concrete surfaces. The HFBR dome and crane/rail system is coated with lead based paint. Other areas have also identified lead in the paint.

Samples were analyzed for several heavy metals, with beryllium, cadmium, lead, and zinc being the chemicals of concern. In addition to lead, zinc was frequently detected above the level in Table 2-1. Cadmium and beryllium were sporadically detected.

PCB-paint (chlorinated rubber paint) was a common paint used in the period 1955-1975 for metal constructions and on pipelines. PCBs can be suspect on much of the painting throughout the facility. PCBs were contained within the pit of the passenger elevator of the HFBR. The PCBs were secured in place with paint and the unit continues to remain on the inventory list. Less than 10% of the ballasts in the building are expected to contain PCBs.

Chemical hazards have been largely eliminated; however, the potential remains in the residual quantities of certain materials, such as acids and caustic associated with resin regeneration, lithium bromide, arsenite, and chromates associated with the Air Conditioning Absorbers, and ethylene glycol associated with the Chill Water System.

Other potential hazards for entry and surveillance include the normal construction/utility industrial hazards such as confined space issues (tank entries), electrical hazards, fire hazards, and fall hazards.

Table 2-2 HFBR Systems and Components

Survey Unit Number	Elevation / Area	Survey Area Description	Conditions as of January 2007
SYS-01	Operations Experimental Equipment	Primary Cooling Water System & Instrumentation	System is drained; Reactor Vessel drained with helium blanket.
SYS-02	Equipment	Primary Purification System	System and resin beds are drained, but resin remains in the vessels.
SYS-03	Equipment	Primary Acidification System	System was drained, rinsed, and neutralized with NaOH, but the storage tank now contains semi-neutralized battery acid.
SYS-04	Equipment	Primary Sampling System	System is drained and blown down.
SYS-05	Equipment	Primary Pump Seal Cold Trap System	System has been de-energized.
SYS-06	Equipment Experimental Operations	DA Drain & D_2O Transfer System	System is drained.
SYS-08	Operations	Reactor Vessel Cover Gas System & Instrumentation	System is functioning.
SYS-09	Operations	SPAM System (Supplemental Poison Addition Method)	In 2001, system was partially removed. Flex hoses, piping and drums were removed from the isolation valve to the reactor on the operations level. The 6' of piping closest to the Reactor Vessel is contaminated and will stay as an abandoned system.
SYS-10	Operations Experimental Equipment Outside	Light Water Make Up System	In 2001, the system was partially removed, and the remaining parts were drained.
SYS-11	Operations Experimental Equipment	Shutdown Cooling Water System & Instrumentation	System is drained and pumps are electrically disconnected.
SYS-12	Operations Experimental Equipment	Thermal Shield Cooling Water System. & Instrumentation	System is drained, pumps disconnected, and valves shut.
SYS-13	Operations Experimental Equipment	Biological Shield Cooling Water System & Instrumentation	System is drained, valves shut, and electrical leads for pumps are lifted.
SYS-14	Equipment	Canal Cooling Water System	System is drained.
SYS-15	Equipment	Auxiliary Water Purification System BG201	System is drained; resin is removed, but charcoal remains in the purification system. Small amounts of Sodium Hydroxide and Hydrochloric Acid may be present.
SYS-16	Operations Experimental Equipment Outside	Secondary Cooling Water System & Instrumentation	System is drained; tanks have been flushed and neutralized.

Survey Unit Number	Elevation / Area	Survey Area Description	Conditions as of January 2007
SYS-17	Outside	Secondary Cooling Water Treatment System	System was partially removed, and was drained, flushed, and partially neutralized. Chemical tanks are still present.
SYS-18	Operations Experimental Equipment Outside	Building Ventilation System	System is in place and in use.
SYS-19	Equipment	A/C Absorbers	System is in place.
SYS-20	Operations Experimental Equipment	Chill Water System	System is in place.
SYS-21	Operations Experimental Equipment	Hot Water Heating System	System is in place and in use.
SYS-22	Equipment	Steam Heating System	System is in place and in use.
SYS-23	Operations Experimental Equipment Outside	Domestic Water System	System is in place and in use.
SYS-24	Operations Experimental Equipment	Sanitary System	System is in place and in use.
SYS-25	Operations Experimental Equipment Outside	Fire Protection System	System is in place and is available for use.
SYS-26	Operations Experimental Equipment Outside	Helium Supply System	System is in place and is operational, providing a cover gas over the vessel
SYS-27	Outside Equipment	Carbon Dioxide Gas System	System is out of service; no CO2 remains in system.
SYS-28	Experimental	Beam Tube Plugs and Cheese Box (storage)	Beam plug H-6 has been removed. Remaining beam plugs are awaiting disposal.
SYS-30	Operations	Vertical Irradiation Thimbles	System is in place, and drained. High dose rates and contamination levels are on the system.
SYS-31	Operations Experimental	Experimental Facilities Cooling Water System & Instrumentation	System is not in service, and it is drained.
SYS-32	Experimental Equipment Outside	Cold Neutron Facility and Systems	Facility is out of service; equipment has been removed.
SYS-33	Operations Experimental Equipment Outside	Building Compressed Air System	System is in place and in service.

Survey Unit Number	Elevation / Area	Survey Area Description	Conditions as of January 2007
SYS-34	Operations Experimental Equipment Outside	Liquid D/F Waste System, including underground piping	System is in service.
SYS-35	Operations Experimental Equipment	Breathing Air System	System not in service; piping is disconnected with compressor in place.
SYS-36	Equipment	Fuel Cladding Failure System	System has been removed
SYS-38	Equipment	Exit Air Monitoring System	System is in place and NOT in service.
SYS-40	Operations Experimental Equipment	Water & Cover Gas Sampling & Monitoring	System is in place and NOT in service.
SYS-41	Outside	Stack Effluent Monitoring System	System has been removed.
SYS-42	Operations Experimental Equipment	Break Tank Water Supply System	System is valved off and drained.
SYS-43	Operations Experimental Equipment	Condensate Collection System	System is in place and in service.
SYS-44	Outside	Emergency Generator & Propane Supply	System is valved off and drained of fluids. Propane storage has been removed.
SYS-45	Operations	Rx Poison Water System (Cadmium-Nitrate)	Tank was emptied, rinsed, and is out of service.
SYS-46	Equipment	Vent Seal Collection System	N/A
750	Equipment	Special Nuclear Material Rack & Vault	All material has been removed from the vault. Radiation levels may have changed since previous survey.
750	Reactor	Installed Control Rod Blades	Control rods are in place within the reactor.

Table 2-3 HFBR Elevation and Structure Survey Areas

Survey Unit Number	Elevation / Area	Survey Area Description
BAL-01	Balcony	Offices B-6 to B-14
BAL-02	Balcony	Mens / Ladies Room
BAL-03	Balcony	Office B-4 & B-5
BAL-04	Balcony	Walkways
BAL-05	Balcony	Walls in open area
BAL-06	Balcony	Pipes in open area
BAL-07	Balcony	Ceiling in open area
BAL-08	Balcony	Crawl Space
LOB-01	Lobby	Lobby, Conference Room, office
OPS-01	Operations	Rx Group Offices (Leader/ass't leader/secretary)
OPS-02	Operations	Day Crew shop area
OPS-03	Operations	OPS Bullpen
OPS-04	Operations	Water Chemistry Laboratory (2 rooms)
OPS-05	Operations	RMG Hot Shop
OPS-06	Operations	Research Coordination Group Area
OPS-07	Operations	Dome
OPS-08	Operations	Crane
OPS-09	Operations	Trenches/Pipe trays
OPS-10	Operations	RMA above WCL
OPS-11	Operations	Iodine Sample Prep/Counting Area
OPS-12	Operations	Walkway behind South Stairwell
OPS-13	Operations	Custodians Area (behind North Stairwell)
OPS-14	Operations	Walkway behind locker room
OPS-15	Operations	Locker Room
OPS-16	Operations	Bridge from Rx top to control room
OPS-17	Operations	Control Room - Mens room
OPS-18	Operations	RIG Areas
OPS-19	Operations	Hutch
OPS-20	Operations	Dry box
OPS-21	Operations	Greenhouse
OPS-22	Operations	Top of Greenhouse
OPS-23	Operations	Security Observation Stations
OPS-24	Operations	General Walkways
OPS-25	Operations	Emergency Hatch Area
OPS-26	Operations	Reactor Top

Survey Unit Number	Elevation / Area	Survey Area Description
OPS-27	Operations	Reactor Pit (Upper and Lower)
OPS-28	Operations	Stairwells (North and South)
OPS-29	Operations	Offices (WCL, Day Crew Supervisors, HP)
OPS-30	Operations	Positron Blockhouse
EXP-01	Experimental	Mens Room
EXP-02	Experimental	L-2
EXP-03	Experimental	L-4
EXP-04	Experimental	L-6 & L-7
EXP-05	Experimental	L-8 & L-9
EXP-06	Experimental	L-9B & L-10
EXP-07	Experimental	L-10B
EXP-08	Experimental	L-11 & L-11A
EXP-09	Experimental	L-12 & L-13
EXP-10	Experimental	L-14 & L-15
EXP-11	Experimental	L-16
EXP-12	Experimental	Cheesebox
EXP-13	Experimental	H-1 trench to H-8 trench (floor) Not completed due to beam plug removal project
EXP-14	Experimental	H-7 trench to H-6 trench (floor) Not completed due to beam plug removal project
EXP-15	Experimental	H-5 trench to H-4 trench (floor) Not completed due to beam plug removal project
EXP-16	Experimental	H-9 trench to H-3 trench (floor) Not completed due to beam plug removal project
EXP-17	Experimental	H-2 trench to trench (floor) Not completed due to beam plug removal project
EXP-18	Experimental	C1 to C2 (floor)
EXP-19	Experimental	C2 to C3 (floor)
EXP-20	Experimental	C3 to C4 (floor)
EXP-21	Experimental	C4 to C5 (floor)
EXP-22	Experimental	C5 to C6 (floor)
EXP-23	Experimental	C6 to C7 (floor)
EXP-24	Experimental	C7 to C8 (floor)
EXP-25	Experimental	C8 to C10 (floor)
EXP-26	Experimental	C10 to C11 (floor)
EXP-27	Experimental	C11 to C12 (floor)
EXP-28	Experimental	C12 to C13 (floor)
EXP-29	Experimental	C13 to C14 (floor)
EXP-30	Experimental	C14 to C15 (floor)

Survey Unit Number	Elevation / Area	Survey Area Description
EXP-31	Experimental	C15 to C16 (floor)
EXP-32	Experimental	C16 to C1 (floor)
EXP-33	Experimental	Trenches
EXP-34	Experimental	Ceiling
EXP-35	Experimental	Crane Rail & Base
EXP-36	Experimental	South & North Quiet Rooms
EXP-37	Experimental	Health Physics Office
EXP-38	Experimental	Receiving Area
EXP-39	Experimental	Machine Shop
EXP-40	Experimental	RMG Storage Area
EXP-41	Experimental	Receiving/Storage Area
EXP-42	Experimental	North Truck Lock
EXP-43	Experimental	Outside Receiving Area
EXP-44	Experimental	Lunch Room
EXP-45	Experimental	Passenger Elevator
EXP-46	Experimental	Freight Elevator
EXP-47	Experimental	Experimental Radiation Survey
EQ-01	Equipment	Transformer Room
EQ-02	Equipment	Generator Room
EQ-03	Equipment	Blower Room
EQ-04	Equipment	Filter Room
EQ-05	Equipment	East Truck Lock
EQ-06	Equipment	D_2O Room
EQ-07	Equipment	SNM Vault
EQ-08	Equipment	Fuel Vault
EQ-09	Equipment	Locker Room
EQ-10	Equipment	Exhaust Plenum Area
EQ-11	Equipment	Resin Processing Area
EQ-12	Equipment	BG201 Area
EQ-13	Equipment	FA101 Pit
EQ-14	Equipment	CNF vacuum pump area
EQ-15	Equipment	A Cell
EQ-16	Equipment	B Cell
EQ-17	Equipment	Shutdown Cell
EQ-18	Equipment	Thermal Shield Area
EQ-19	Equipment	Primary Purification System Beds
EQ-20	Equipment	Canal
EQ-21	Equipment	Fuel Handling Blower

Survey Unit Number	Elevation / Area	Survey Area Description
EQ-22	Equipment	Overhead Piping
EQ-23	Equipment	Shutdown Pump Area
EQ-24	Equipment	RMG Hot Shop
EQ-25	Equipment	Ceiling
EQ-26	Equipment	Equipment Room (outside of building)
EQ-27	Equipment	Decontamination Sink Area
EQ-28	Equipment	Equipment Level Radiation Survey
EQ-29	Equipment	SNM & Fuel Vaults

Table 2-4 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	34.84	0.04	0.06	0.02	0.01	**35.0**	**2.1**	**0.1**
SYS-02	Primary System Purification	10.54*	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	0.00	**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 Systems associated with Note 2	3.54	0.17	0.27	0.09	0.02	**4.1**	**0.3**	**0.1**
	Total for All Systems	**38.9**	**1.9**	**3.0**	**1.0**	**0.2**	**45.1**	**3.1**	**0.7**

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 plant activity, exclusive of the reactor vessel and internals.

Note that Beam Plugs and resin in various systems are not part of this total.

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

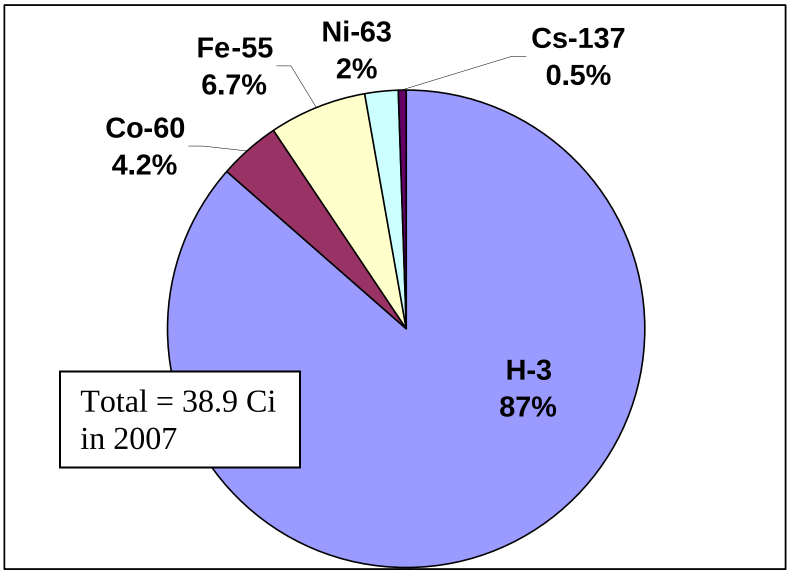

Figure 2-1. HFBR Systems: Radionuclide Percent of Out-of-Core Activity- 2007

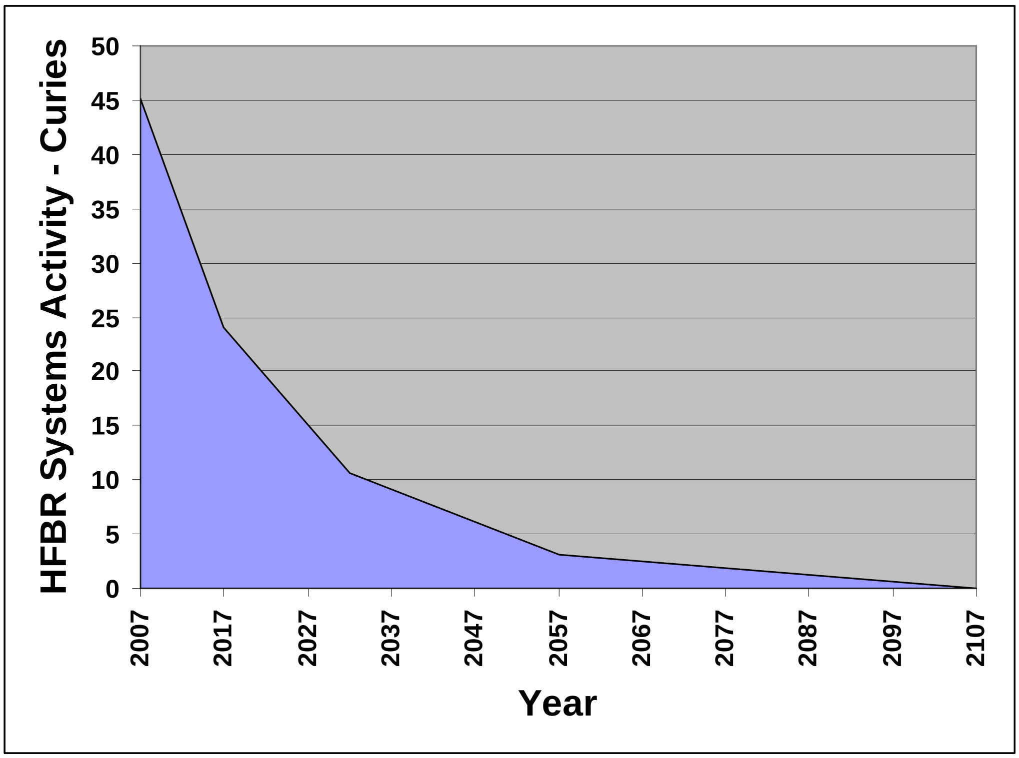

Figure 2-2. HFBR Systems: Total Out-of-Core Activity- 100 year Decay

Table 2-4 HFBR Waste Removed from Building 750

Fiscal Year	Description of Materials Removed
2003	6 Co-60 sources (21 micro curies)
	15 gals of used scintillation cocktail liquid (5000 micro curies of tritium)
	22 cubic yards of assorted Low Level Waste (2 B52 boxes)
	Sr-90 source (4 curies)
	5 Cl-36 sources (.14 micro curies)
	2 Cold Neutron Facility (CNF) Nitrogen Storage Tanks to CAD
	Lead lined Sample Hutch (8'x5'x3') shipped to Massachusetts Institute of Technology.
2004	One B12 box beryllium filters and ganiometers to Oak Ridge National Laboratory
	20,000 gal double walled long-term cooling water tank.
	60 sources (~1.5 curies)
	35 cubic yards of industrial waste (CNF storage shed, MH-1A spacers and metal lugger)
	55 gallons of tritiated oil
	4 lead lined drums (16 cubic feet) of assorted waste (4200 micro curies)
	55 gallon drum of assorted mixed waste.
	53,572 pounds of lead.
	H6 beam plug.
	11 B12 boxes of Low Level Radioactive Waste
	Asbestos pipe lagging from “Greenhouse”
2005	4,352 cubic feet of assorted low level waste; put into Connex ™ boxes in 2004
	30 concrete and steel shield blocks
	RaBe source (1 Ci)

3. Part 3. HFBR Characterization Summary - Ancillary/Support Facilities and Soil Characterization

3.1 Summary of Ancillary/Support Facilities

The HFBR facilities considered here include: Building 704 Fan House and associated Exit Air Facility; Building 705 Stack and associated Pedestal and Underground Plenum; Building 715 Stack Monitoring Facility; and D/F-Waste Line. A brief description of these facilities is provided in the overview section of this report.

3.2 Previous Characterizations for Ancillary/Support Facilities and Soil

A specific list of the ancillary/support facilities associated with the HFBR was derived from the "Brookhaven National Laboratory High Flux Beam Reactor – Final Characterization Report, (Cabrera 2001b) and "High Flux Beam Reactor and Balance of Plant Structures Preliminary Assessment/Site Inspection (Work Plan, Sampling and Analysis Plan, Health and Safety Plan, Waste Management Plan)", (Grosser 2001). Based on a review of these reports, a scope of work was developed for further Site Inspection (SI) activities. The Preliminary Assessment (PA) identified issues that had the potential to impact surface or subsurface soils, and ultimately groundwater, and classified them as Areas of Interest (AOIs). A total of 27 AOIs associated with the HFBR project were identified. The results of the SI actions associated with these AOIs were published in the document "High Flux Beam Reactor and Balance of Plant Structures Preliminary Assessment/Site Inspection Report, Final", which was issued as Final in 2005 (Grosser 2005a).

Of the 27 AOIs investigated throughout the HFBR complex, 23 were eliminated as AOIs and four warranted additional action. No Areas of Concern (AOCs) were identified.

It was established that radiological results for all AOIs, other than the four warranting further investigation; all fell within the Preliminary Remediation Goals (PRGs) -50 Years Criteria.

In May 2004, a gap analysis was performed to determine where fill-in data was required. It was determined that additional characterization was needed for:

- Building 705 Exit Air Facility and Stack
- Building 704 Fan House and Below Ground Duct
- Surrounding soils (surface and deep soils): Buildings 704 and 715

A program of coring/sampling and analysis was performed in and around these buildings from September through December 2004. The results of this characterization effort are documented in data packages on file with Environmental Management. The results of the work performed in and around Building 705 Stack, including work performed in 2001, are documented in the report "Building 705 Stack Resolution of End-State, February 2005" (Grosser 2005b).

3.3 Characterization Results for Ancillary/Support Facilities and Soil

Figure 3-1. Building 704 Fan House

The Fan House was constructed in 1950 and was originally designed to support operations at the Brookhaven Graphite Research Reactor (BGRR). Following shutdown of the BGRR, the Fan House was designated as an HFBR Balance of Plant System since it housed electrical switchgear for AC and DC power to the HFBR, as well as for Buildings 701 and 703. The building housed five primary fans and a secondary fan, which took suction through ducts that penetrated the roof and connected to the above ground duct bottom. These fans discharged into a below grade exhaust duct directly below the fan compartments. Presently, the below grade duct is still intact, running under and along the northern portion of the building in the basement. As a result of past operations, the Fan House is a radiological controlled area.

Building 704 – Fan House: Characterization Notes:

Item 1: Sampling performed in the basement of Building 704 has identified a location on the soil floor containing radionuclides above the cleanup criteria. The sample was collected at a zero to six-inch depth at a location designated as AOI 006-02. Results from this sample location indicated elevated levels of cesium-137 and strontium-90. Contamination at this location was likely the result of water leaking through the floor seams of the fan cell above. Results from the 4.5 to 5.0 foot sample depth met cleanup criteria. It was recommended that limited soil remediation at this location be performed, with endpoint sample collection.

Item 1 Results:
The results are shown in Table 3-1 and indicate that there is Sr-90 contamination in the Secondary Air Fan Cell and in Fan Cell 3 (Grosser 2005c). The gross beta results in those two locations are also indicative of the potential for other radionuclides, likely to be Cs-137 based on the history of what has been detected in the stack.

Table 3-1 Building 704 – Soil Core Samples in Fan Cells – Results

Location	Sr-90 (pCi/g)	H-3 (pCi/g)	Gross Alpha (pCi/g)	Gross Beta (pCi/g)
704-Sec. Air Fan Cell	92	<MDA	3.7	270
Fan Cell 3-AB	17	<MDA	<MDA	415
Fan Cell 3-CD	5.3	<MDA	<MDA	45
Fan Cell 5	2.1	<MDA	<MDA	18
Surface Soil Cleanup Criteria	*15*	*1010*	*N/A*	*N/A*

Item 2: The Below Grade Exhaust Duct carried exhaust from the fan cells to Building 705 (Stack). Two locations in the concrete duct were sampled; floor and wall samples were taken at each location. The locations were chosen to be next to expansion joints.

Item 2 Results:
The results are shown in Table 3-2, “Building 704 – Below Grade Duct Concrete Core Results”, and indicate that there is Sr-90 contamination and other non-specific beta contamination. ISOCS™ results indicated Cs-137 up to 6900 pCi/g and Am-241 up to 36 pCi/g in the duct. Low levels of tritium were also detected. (Grosser 2005c)

Table 3-2 Building 704 – Below Grade Duct Concrete Core Results

Location	Sr-90 (pCi/g)	H-3 (pCi/g)	Cs-137 (pCi/g)	Gross Alpha (pCi/g)	Gross Beta (pCi/g)
704-FC3-wall	246	261	295 - 5280	17 (1)	750
704-FC3-floor	53	503	76 - 2100	13	233
704-FC5-wall	429	194	545 - 6900	25 (2)	4080
704-FC5-floor	174	425	133 - 3030	47	10,300
Surface Soil Cleanup Criteria	*15*	*1010*	*23*	*N/A*	*N/A*

(1) Am-241 detected via ISOCS™ at 36.3 pC/g
(2) Am-241 detected via ISOCS™ at 19.7 pC/g

Fixed radioactive contamination levels above release criteria exist in some areas (east area near filter bypass facility), up to 75,000 dpm/100cm^2. Dose rates are generally at 5-10 uR/hr, near background level, except near the underground plenum area, where levels up to 200 uR/hr are found.

Hazardous materials: Hazardous materials include lead, batteries, applied lead paint, asbestos wiring, insulation, and roof under the tar, oils and petrochemicals, PCBs, and mercury. Direct readings for lead paint show positive results on the door of the battery room. Sampling for mercury revealed negative results, however, mercury is suspected in the ballasts, capacitors, light ballasts, gear boxes, and in limit torque valve control oils.

Figure 3-2. Building 705 – Stack

Building 705 – Stack: Characterization Notes:
Radiological characterization work of the stack has taken place over several years, and is documented in the "Building 705 Stack Resolution of End-State, February 2005" (Grosser 2005b). A summary of the characterization results is shown below:

- 2001: Smears of the interior lower portion of the stack (the base near the plenum inlet). These smears indicated removable contamination up to 22,000 dpm/100 cm^2. Cs-137 was identified in the results.

- 2001: Soil samples collected from excavations around the stack were analyzed using gamma spectroscopy, and Cs-137 was detected slightly above background levels in three out of nine samples. The highest sample result was 6.4 pCi/g, which is below the BNL-specific criteria of 23 pCi/g for Cs-137.

- 1997 – 2004: Characterization data for water samples collected from the stack drain during the period of 1997 though 2004 were analyzed for gross alpha/beta levels and tritium and Cs-137 activities. Strontium-90 analysis was performed for 2003 and 2004. The results reveal that water samples collected from the stack drain system are in excess of NYSDEC ambient water quality standards.

- 1999: A radiological characterization effort was conducted on the buried interconnecting ducts between Buildings 801, 802, 811, 815 and 830, all of which discharge to the 705 Stack. This characterization was qualitative in nature, but determined that the following ducts were contaminated:

- Duct between Building 801 and Building 811 (10” diameter, cast iron)
- Duct between Building 801 and Building 802 (42” diameter, concrete)

2004: During December 2004, a characterization effort was performed that involved collecting core samples at various heights around the stack perimeter. Three concrete cores were collected from four different elevations: one set from the pedestal, one set from 10" above the top of the pedestal (elev. 145.5'), one set at the lowest platform (elev. 225.5'), and one set from the middle platform (elev. 333'). No concrete cores were collected at the upper platform (elev. 433'). The concrete cores were sampled and analyzed for radiological contamination on the interior surfaces and to determine the depth that contamination has penetrated into the concrete. Table 3-3 below provides the sample locations, contamination penetration depths, and average concentrations of radionuclides present. (BNL 2004a, BNL 2004b, and BNL 2004c) The table includes a comparison to the surface soil cleanup criteria used for remediation of soils, based on precedence at BNL for Sr-90 and Cs-137. The concentrations have been decayed to January 2007.

Table 3-3 Stack Concrete Core Analytical Results

Location	Penetration Depth (inch)	Sr-90 (pCi/g)	H-3 (pCi/g)	Cs-137 (pCi/g)
Pedestal	0.25	462	104	1154
Pedestal	0.50	86	86	62
Elev. 145.5'	0.25	58	25	333
Elev. 225.5'	0.25	174	45	425
Elev. 225.5'	0.50	51	25	13
Elev. 225.5'	0.75	36	21	6
Elev. 333'	0.25	187	50	629
Elev. 333'	0.50	16	191	3
Gross Average Concentration	**N/A**	**134**	**68**	**328**
Surface Soil Cleanup Criteria	*N/A*	*15*	*1010*	*23*

The “gross average concentration” is only used as an indicator to compare to the surface soil cleanup criteria, and does not represent the actual concentration over the entire stack. The concentrations of Sr-90 and Cs-137 on the contaminated stack surfaces (the first one half inch) are above the surface soil cleanup criteria; however, if the concentration were averaged over the entire weight of the stack concrete, the values would be less than the cleanup criteria.

It is estimated that the total Curie content present in the Building 705 Stack concrete is about 28 millicuries in January 2007, as shown in Table 3-4.

Table 3-4 Estimated Surface Activity in Building 705 Stack

		2007	2017	2027	2057	2082	2107
Nuclide	**Half-Life (yr)**	**Stack mCi**	**Stack mCi**	**Stack mCi**	**Stack mCi**	**Stack mCi**	**Stack mCi**
Sr-90	28.8	18.6	14.6	11.5	5.6	3.0	1.7
Cs-137	30.1	7.2	5.7	4.5	2.3	1.3	0.7
H-3	12.3	2.7	1.5	0.9	0.2	0.0	0.0
Total	**N/A**	**28**	**22**	**17**	**8**	**4**	**2**
Years Decay	N/A	0	10	20	50	75	100

Figure 3-3. Building 715 – Stack Monitoring Facility

<u>Building 715 – Stack Monitoring Facility Characterization Notes:</u>

Surveys of radiation and radiological contamination within the building indicate background levels. There had been indications of contaminated soil based on previous characterization; therefore, additional soil samples were taken in 2004 to determine if remediation was necessary. Three samples were taken in November and December of 2004 at depths of 0-2 feet and 2-4 feet. Samples were analyzed for gross alpha, gross beta, Sr-90, tritium, and gamma spectroscopy. All samples were consistent with background radioactivity, and no reactor related radionuclides were detected (BNL, 2005a).

Figure 3-4. Building 751 – Cold Neutron Facility

Building 751 – Cold Neutron Facility Characterization Notes:
Surveys of radiation and radiological contamination within the building indicate background levels. The CNF has been surveyed and released from radiological controls; it is no longer considered part of the HFBR facility.

Hazardous materials include solvents, degreasers, lubricants, oils and petrochemicals, and lead shielding. The hazardous materials are associated with equipment, such as motors and compressors with contained fluid. When this equipment is removed, the source of the hazardous materials will be removed (Cabrera, 2001b).

D/F-Waste Line:
The liquid waste system provided a means of storage and disposal of potentially contaminated liquid wastes, including spilled heavy water. "D" wastes were pumped from the D/F Storage tank on the equipment level of the HFBR to the BNL waste treatment area where it was distilled with the distillate being solidified in waste disposal vaults. The portion of the D/F-Waste Line under consideration in this section that outside the HFBR confinement, and the line consists of about 1,117 feet of double-walled (2" within 4") carbon steel pipe that runs between Buildings 750 and 801. Figure 3-5 shows the general location of the pipe as it leaves the HFBR.

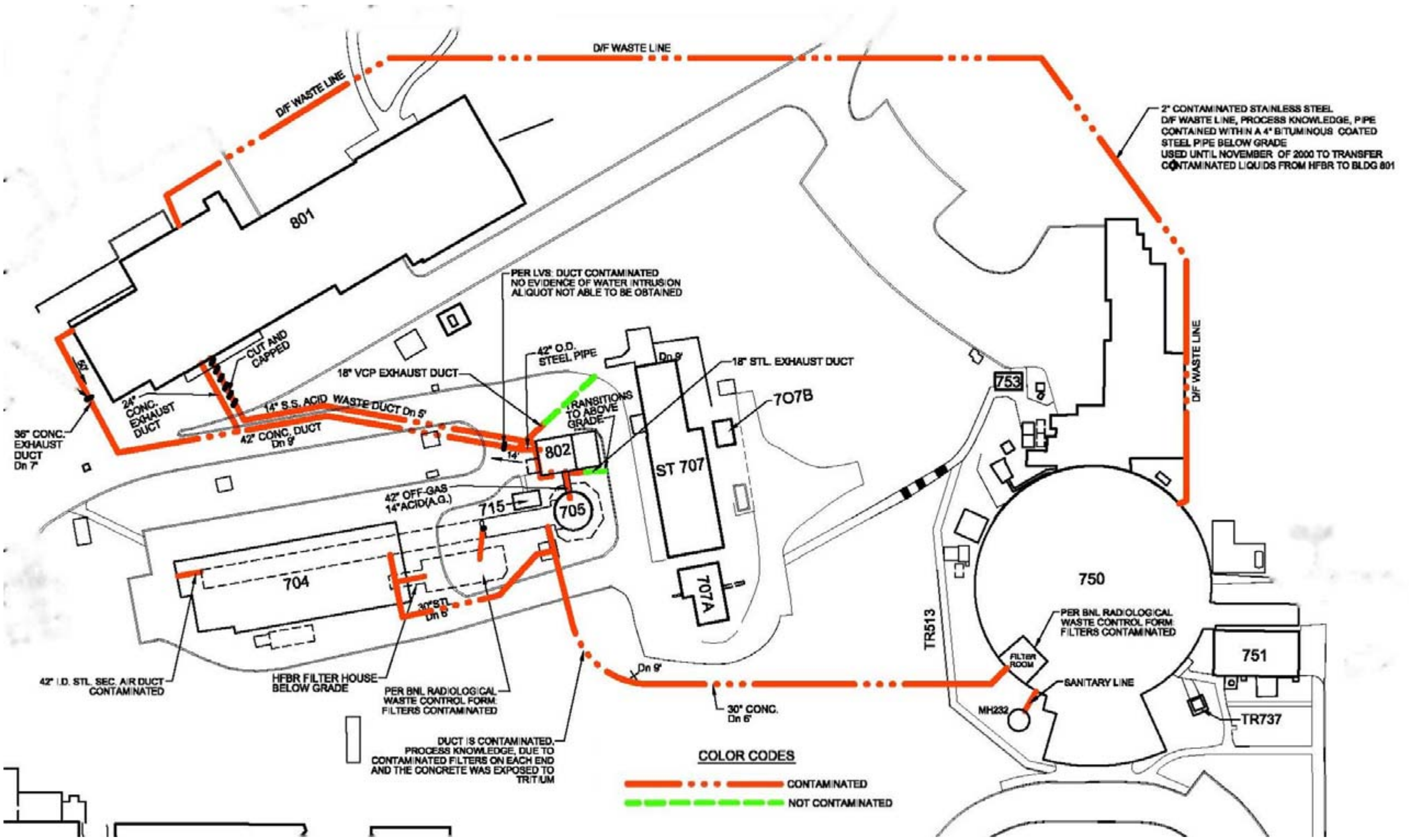

Figure 3-5. HFBR Site Plan, showing location of D/F-Waste Line

4. References

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18. (Tichler 1995) Memorandum from Paul Tichler, *Estimates of Neutron Activation in the HFBR Reactor Vessel, Vessel Internals and the Thermal Shield and Biological Shield*, January 25, 1995.

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