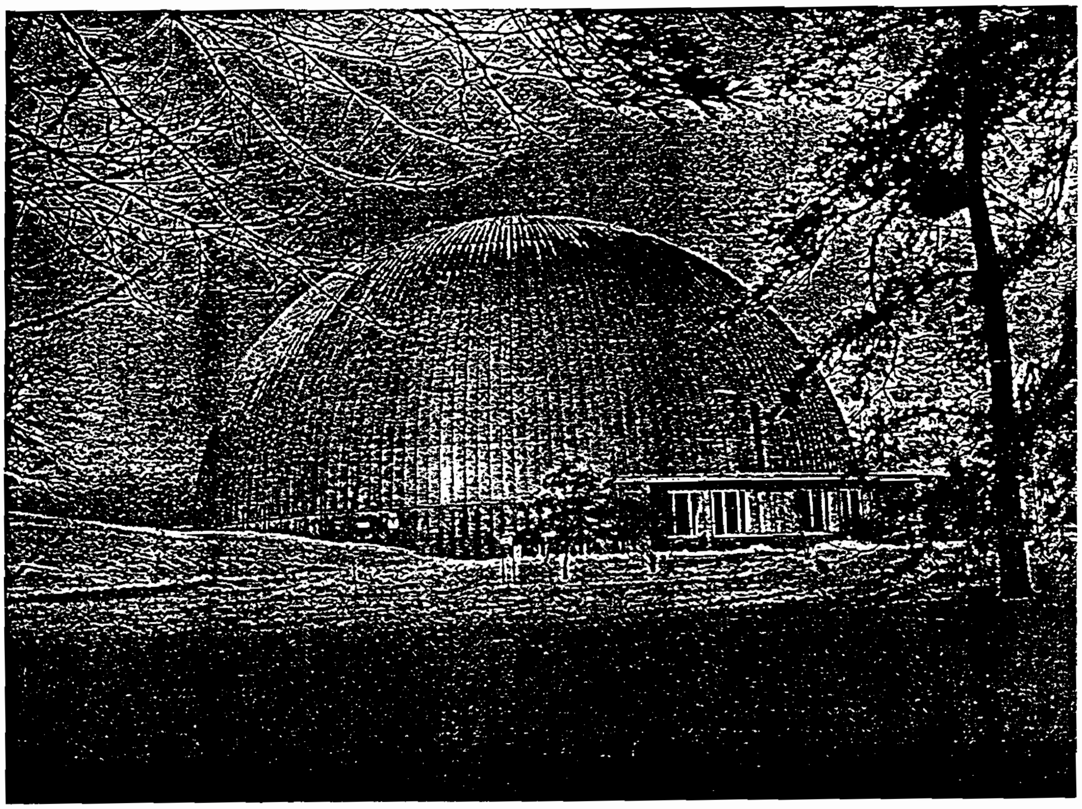
High Flux Beam Reactor Tritium Remediation Project

Summary Report

February 1998



Prepared by

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ACKNOWLEDGMENTS

BNL gratefully acknowledges the support of the DOE organization, particularly BHG/DOE, the local Brookhaven DOE Area office, during the course of the Tritium Remediation Project. The open communication and cooperation between BNL and DOE was a big factor in successfully completing this project. BNL appreciates the cooperation and responsiveness of the local, state, and federal regulatory agencies in providing direction and oversight to the project. The initial support provided by the Idaho National Environmental Engineering Laboratory (INEEL) also is gratefully acknowledged.

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• *INTRODUCTION*

An interim response ensured the protection of human health and the environment.

Tritium, a radioactive isotope of hydrogen, was detected in groundwater adjacent to the High Flux Beam Reactor (HFBR) Building in late 1996. Tritium was first found south of the HFBR Building during routine drilling and sampling of two (2) newly installed groundwater monitoring wells. In response to the discovery, the Department of Energy (DOE) and Brookhaven National Laboratory (BNL) together established the Tritium Remediation Project (TRP) at BNL to manage an interim accelerated response to ensure protection of public health and the environment. Accelerated actions are allowed under the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA) to execute rapid environmental response actions, without first going through the protracted Remedial Investigation/Feasibility Study (RI/FS) process.

Once the presence of tritium in the aquifer was confirmed to be above drinking water standards in early 1997, notification was made to the regulatory agencies, BNL employees, and the general public. Meetings were scheduled on a regular basis to maintain a constant flow of information among laboratory professionals, regulatory agencies, and other stakeholders. Meetings with the general public and BNL personnel took the form of poster sessions and workshops at local community-gathering places to distribute information, answer questions, and listen to concerns.

Communication with local authorities occurred regularly during the planning stages, with formal meetings and briefings scheduled weekly. Through this open communication, DOE and BNL obtained a timely response from the regulatory agencies so that the remedial action could be initiated as quickly as possible. Since the start of the remedial action the need and frequency for meetings has continuously lessened.

DOE and BNL conducted an aggressive campaign of well drilling, tritium sampling, engineering evaluations, and groundwater modeling through the TRP. The resulting information was used to determine the source and extent of the tritium groundwater plume, and to design and construct a groundwater interception system to ensure that the tritium, above the drinking-water standard, does not migrate off the BNL site. The end result of the immediate response activities has been to mitigate the impact of the tritium release.

Project results will be incorporated into the RI/FS CERCLA process.

For the purpose of monitoring the status of contamination remediation activities at BNL, the site has been broken into areas designated as Operable Units (OU). The activities in each OU are then further broken into Areas of Concern (AOC). The TRP is included in the activities within OU III. Data and characterization information gathered during the interim response action have been incorporated into the on-going Remedial Investigation/Feasibility Study (RI/FS) report for OU III. This report characterizes the nature and extent of the contamination, and evaluates the methods and technologies available to remedy the contamination. The HFBR Building's spent fuel pool (SFP) and the associated tritium plume have been designated as Area of Concern 29 (AOC-29) in OU III, and a final remedial action will be determined as part of the OU III Record of Decision (ROD). The ROD documents the regulators' final decision on the selected remedial action.

This report documents the various activities performed as part of the interim response by the project team assembled by BNL and DOE after the HFBR Building tritium plume was discovered. In addition, as appropriate, this report identifies new information or activities needed for further evaluation in the OU III RI/FS.

This report serves as the closeout, or final report, on the activities of the TRP.

A glossary has been included at the end of this report that lists definitions for the terms and acronyms used.

Detection of Tritium South of the HFBR Building

Elevated levels of tritium in groundwater were first discovered down-gradient (south) of the HFBR Building in monitoring wells installed, as compensatory measures, to satisfy Article 12 of the Suffolk County Sanitary Code, which covers the regulation of storage facilities for hazardous materials. The HFBR Building SFP is considered a storage tank without secondary containment by the Suffolk County Department of Health Services (SCDHS) and, as such, requires compensatory groundwater monitoring. Down-gradient monitoring wells were installed in July 1996, and sampling was started in October 1996. The initial results were reported by BNL in December 1996, through the DOE's Occurrence Reporting and Processing System, that groundwater monitoring south of the HFBR Building indicated the presence of tritium at roughly 1/10 the drinking-water standard (Environment, Safety and Health [ES&H] 1997). A subsequent sample in January 1997 revealed tritium in the groundwater above the Environmental Protection Agency's (EPA) drinking water standard (20,000 picocuries per liter [pCi/l]) near the HFBR Building. Following an extensive groundwater investigation to determine the extent of the tritium, the highest tritium concentration detected in groundwater by a Geoprobe™ early in the project was 660,400 pCi/l from a sample collected just south of the HFBR Building (Figure 1). Subsequent measurements during the first round of pre-ROD permanent monitoring well sampling, conducted in the fall of 1997, indicated a tritium level of 1,590,000 pCi/l.

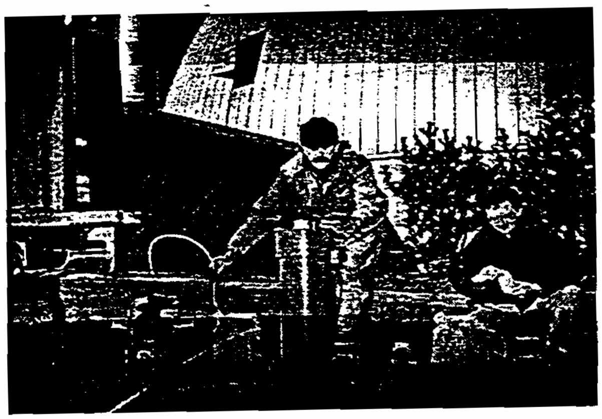


Figure 1 - Geoprobe™ Sampling Near the HFBR Building

Brookhaven National Laboratory's Tritium Remediation Project Management

The TRP was established quickly by BNL and DOE in response to finding tritium above drinking water standards in groundwater just south of the HFBR Building. Initially, the project included source management, plume characterization and remediation, project management, community outreach, vulnerability studies, and reactor restart and upgrades (now incorporated into the Transition Project.) Soon after the project's start, it became evident that the TRP needed to focus on plume remediation and control of the tritium source. As a result, the Transition Project and BNL's site-wide Vulnerability Assessment were made into separate projects. TRP personnel then were able to concentrate on managing the source, remediating the plume, and on the project support activities shown in Figure 2.

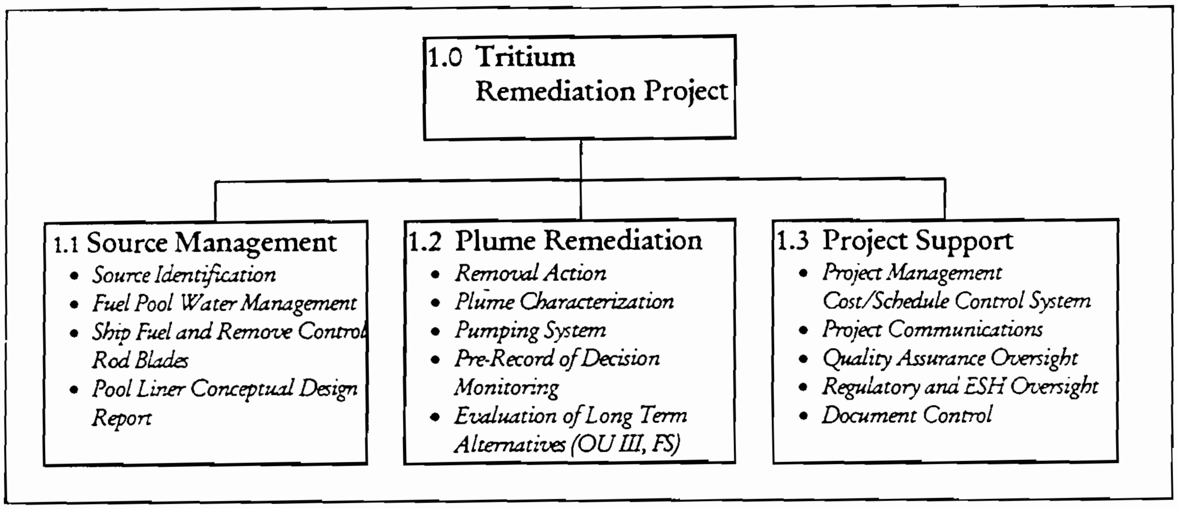


Figure 2 - Work Breakdown Structure for the Tritium Remediation Project

Of necessity, the TRP was started without a detailed resource-loaded baseline. Following clarification of the project's work scope, a Project Management Plan (PMP) was developed that provided the management approach and overall plan for the project. The PMP defined the project's objectives and established the project organization and responsibilities. The PMP was the basis for developing and controlling the project's baseline and described how its performance would be measured and reported. The PMP also outlined and established the approach to implementing environmental, safety, and health controls, as well as to quality assurance and document control. Formal quality assurance and ES&H plans also were issued for use in the project.

A detailed project Baseline Management Document, including a Work Breakdown Structure (WBS) was prepared consistent with the PMP. Work elements were broken down into individual work activities connected in a logical work sequence. Cost and schedule estimates were prepared for each individual activity and summarized for the total project cost and schedule. The project baseline, as developed, established the detailed scope of work, schedule, and budget for managing the project, performance, and reporting. As part of the baseline control process, a procedure was developed to control future baseline changes. The Change Control Procedure defined when baseline changes are appropriate and the process for preparing and authorizing baseline changes. Monthly reporting was implemented to replace the daily and weekly reporting that were previously required prior to establishment of the baseline. BNL continued with weekly reporting to ensure that the regulators and other stakeholders were kept current on the status of the TRP.

Table 1 is a time line that summarizes the major activities and accomplishments for the BNL TRP. Three (3) primary milestones; set at thirty (30), sixty (60), and ninety (90) days, were established at the onset which helped define and guide the remediation efforts planned, and provided a platform for communication with stakeholders. The first milestone was to lower the water level in the SFP by five (5) feet within thirty (30) days. However, the decision was made not to lower the level in the SFP following a recommendation from BNL to DOE based on the fact that the water level would have to then be subsequently raised to provide adequate shielding for workers during removal of the spent fuel from the pool. The next milestone was to initiate operation of a system which would stop any further migration of the tritium plume above the drinking water standard (20,000 pCi/l) towards the southern site boundary. The system was ready ahead of the sixty (60) day schedule; however, actual startup was delayed several days to resolve additional specific concerns from SCDHS. The third milestone was for submission of a conceptual design for a new spent fuel pool liner. This milestone was met within ninety (90) days, thereby fulfilling all project commitments to the agencies, public, and other stakeholders.

Table 1 - Timeline of Tritium Remediation Project

1996 DECEMBER	1997 JANUARY		FEBRUARY			
• Dec. 5, 1996 Analyses show 2,520 pCi/l tritium concentration for Well 75-12 and 454 pCi/l tritium concentration for Well 75-11.	• Jan. 8, 1997 Tritium above drinking water standard of 20,000 pCi/l reported. Analytical results show 44,700 pCi/l tritium for Wells 75-12 & 2, 110 pCi/l tritium for Well 75-11. • Jan. 18, 1997 BNL announces tritium contamination near HFBR Building. • Jan. 23, 1997 Initiated Phase I of Geoprobe™ well sampling at HFBR facility: EPA duplicate samples taken.	• Jan. 27, 1997 Initiated Phase II of Geoprobe™ well sampling approximately 400 feet south of HFBR Building. • Jan. 29, 1997 Revised HFBR tritium plume Recovery Plan. • Jan. 31, 1997 Press release of sampling results. • Jan. 31, 1997 BNL meeting with EPA.	• Feb. 5, 1997 Brookhaven Group (BHG) direction letter to BNL. • Feb. 5, 1997 Formal TRP Project Organization began. • Feb. 5, 1997 BNL meeting with EPA, state, and county regulators. • Feb. 5, 1997 Resampling of on-site and off-site permanent wells for tritium. • Feb. 5, 1997 Raytheon Corp. To assist BNL in evaluating the SFP for liner.	• Feb. 6, 1997 Initiated planning for installation of liner in SFP. • Feb. 6, 1997 Updated press release: Tritium 32 times drinking water standard found in Phase II Geoprobe™ well. • Feb. 6, 1997 First EPA tritium results show good agreement with BNL results. • Feb. 7, 1997 Results of tritium sampling in on-site and off-site wells.	• Feb. 7, 1997 Initiated planning for mitigation of plume. • Feb. 7, 1997 Initiated Phase III of Geoprobe™ well sampling at 1,000 feet south of HFBR facility. • Feb. 13, 1997 Press release update. • Feb. 14, 1997 Completion of DOE Environmental Health (EH) Oversight Review. • Feb. 19, 1997 Commitment made to initiate remediation. • Feb. 20, 1997 Press release update	• Feb. 22, 1997 On-site drilling for vertical profiles begins. • Feb. 27, 1997 SFP leak test completed. • Feb. 27, 1997 Daily and weekly briefings to the regulatory agencies initiated.

MARCH

- **Mar. 4, 1997** DOE statement released.
- **Mar. 6, 1997** Regulators' Meeting.
- **Mar. 7, 1997** Received approval from DOE for horizontal drilling beneath HFBR Building.
- **Mar. 10, 1997** Press release update.
- **Mar. 13, 1997** Regulators' Meeting.
- **Mar. 14, 1997** Met with SCDHS to review SFP liner plans.
- **Mar. 16, 1997** Additional SFP leak test completed.
- **Mar. 18, 1997** Up-gradient & down-gradient horizontal boring casing and well screens installed beneath the HFBR Building. Well development in progress for both horizontal borings.
- **Mar. 20, 1997** Spent Fuel Shipment Management Plan completed.
- **Mar. 27, 1997** Press release update.
- **Mar. 27, 1997** SCDHS gives conceptual approval for plume remediation.
- **Mar. 28, 1997** Sampling of down-gradient horizontal well completed.

APRIL

- **Apr. 3, 1997** Press release update.
- **Apr. 3, 1997** Sampling of up-gradient horizontal well completed.
- **Apr. 3, 1997** Regulators' Meeting.
- **Apr. 4, 1997** SFP liner draft conceptual design report package submitted for NRC review.
- **Apr. 8, 1997** National Environmental Policy Act of 1969 (NEPA) scoping (DOE) session held to discuss and resolve issues related to fuel shipments, water management, and SFP liner installation.
- **Apr. 9, 1997** Installation of the three extraction wells completed.
- **Apr. 9-10, 1997** Regulator and Technical Peer Review of modeling results and pumping remediation system held at BNL.
- **Apr. 11, 1997** Poster sessions scheduled for 4/15, 4/16, 4/17, 4/21, and 4/23.
- **Apr. 14, 1997** SCDHS requests additional information prior to pump start-up.
- **Apr. 14, 1997** New York State Department of Environmental Conservation (NYSDEC) concurs with the proposed extraction plan.
- **Apr. 15, 1997** Loading of spent fuel for the first spent fuel shipment.
- **Apr. 17, 1997** Regulators' Meeting. Analytical results from horizontal wells presented.
- **Apr. 17, 1997** Project Management Plan approved.
- **Apr. 17, 1997** Tritium Remediation system construction completed.
- **Apr. 17, 1997** Management Decision Proposal for SFP Water Storage and Treatment Options completed.
- **Apr. 18, 1997** EPA region 2 concurs with pumping at leading edge of plume.
- **Apr. 18, 1997** Regulators' Meeting.
- **Apr. 18, 1997** DOE agrees to delay operation to respond to SCDHS concerns.
- **Apr. 20, 1997** Project Baseline begins for performance measurement.
- **Apr. 22, 1997** Meeting with SCDHS to resolve concerns.
- **Apr. 24, 1997** Regulators' Meeting.
- **Apr. 25, 1997** DOE-BHG authorizes pump and aquifer testing.
- **Apr. 25, 1997** Project Baseline approved.
- **Apr. 29, 1997** All five shipping containers are loaded for the first spent fuel shipment.

MAY

- May 3, 1997
Technical review of construction of the horizontal wells and sampling techniques, and review of alternate sampling methods.

- May 6, 1997
Aquifer stress (pumping) test began.

- May 6, 1997
Regulators' Meeting.

- May 6, 1997
SCDHS gives approval to operate remediation system.

- May 7, 1997
Waste storage tanks preliminary design packages sent to SCDHS, EPA, and NYSDEC.

- May 9, 1997
Pumping test of extraction wells completed.

- May 9, 1997
Final Conceptual Design for the SFP Liner completed.

- May 12, 1997
Tritium plume remediation system started.

- May 16, 1997
Final Permanent Monitoring Well Installation Plan submitted to regulators.

- May 20, 1997
Regulators' Meeting.

JUNE

- June 1, 1997
All five shipping containers are loaded for the second fuel shipment.

- June 10, 1997
Waste storage tanks final design package sent to SCDHS, EPA, and NYSDEC.

- June 13, 1997
Recharge basin monitoring wells and piezometers are installed.

- June 17, 1997
Contract awarded for two 20,000 gallon secondarily contained aboveground storage tanks (SCATs).

- June 19, 1997
DOE issued a standown on all radiological work performed at the HFBR.

- June 19, 1997
Tritium Monitoring Plan submitted to Regulators.

JULY

- July 1, 1997
Supplement Analysis approved by DOE (EM-67) for third and fourth spent fuel shipments.

- July 11, 1997
Implementation of air monitoring plan for the Remedial Action V (RA-V) basin approved by DOE.

- July 15, 1997
Nuclear Regulatory Commission (NRC) approved shipping cask amendment for third and fourth spent fuel shipments.

- July 24, 1997
The RA-V Recharge Basin Air Sampling Plan completed.

- July 29, 1997
All five shipping containers loaded for the third spent fuel shipment.

AUGUST

- Aug. 5, 1997
Regulators' Meeting.

- Aug. 15, 1997
All reactor fuel discharged to the SFP.

- Aug. 20, 1997
S/A Plan for HFBR Horizontal Groundwater Monitoring Wells completed.

- Aug. 29, 1997
Recharge basin air sampling monitors installed.

SEPTEMBER	OCTOBER	NOVEMBER	DECEMBER	1998 JANUARY
• Sept. 3, 1997 All five shipping containers loaded for the fourth spent fuel shipment. • Sept. 18, 1997 Final HFBR Source Identification Report, Vols. I & II, distributed to Regulators. • Sept. 26, 1997 Two secondarily contained aboveground storage tanks (SCATs) delivered. • Sept. 26, 1997 Completed dry run of control rod blades transfer cask to new Waste Management Facility (WMF). • Sept. 29, 1997 Removed spent fuel cut ends from spent fuel pool (SFP). • Sept. 30, 1997 The long-term historical transient groundwater modeling run completed.	• Oct. 19, 1997 Equipment removed from SFP for future use. • Oct. 23, 1997 All fourteen control rod blades removed from SFP and stored in two HFBR MH-1A shipping containers. • Oct. 27, 1997 Final Regulators' Meeting • Oct. 31, 1997 Both secondarily contained aboveground storage tanks (SCATs) passed UL-142 pneumatic test.	• Nov. 10, 1997 Equipment removed from SFP for disposal. • Nov. 16, 1997 HFBR sanitary leak test completed. • Nov. 21, 1997 Tritium Compilation Report submitted to DOE. • Nov. 24, 1997 NESHAPs Evaluation of HFBR Canal Dewatering completed.	• Dec. 2, 1997 Primary SFP water transfer piping pressure test completed. • Dec. 3, 1997 SFP confinement tent installed. • Dec. 5, 1997 Secondary piping for SFP water transfer piping pressure tested. • Dec. 12, 1997 Secondarily contained aboveground storage tanks (SCATs) level instrumentation and leak detection operability test completed. • Dec. 16, 1997 SCAT tanks operational readiness review completed. • Dec. 16, 1997 SCDHS approves use of the SCAT tanks and transfer piping. • Dec. 18, 1997 Commence decontamination/ dewatering of SFP. • Dec. 30, 1997 All permanent monitoring wells installed. • Dec. 30, 1997 OU III FS transmitted to Regulators. • Dec. 30, 1997 SFP pumping completed (65,520 gallons).	• Jan. 6, 1998 Fifth horizontal well sample taken. • Jan. 7, 1998 Removed residual wet sediment from SFP pit.

Cost of the Tritium Remediation Project

The discovery of the tritium leak required rapid mobilization of contractors and BNL's staff to determine the source, identify the extent of the plume, and implement the interim remedy for containment of the plume. The immediate nature of the costs associated with these actions required that they be borne by the BNL Reactor Division operating budget until a project baseline could be established and alternate sources of funding identified.

After establishing the TRP Team, preparing the PMP, defining the scope of the TRP, and developing cost estimates and schedules, the TRP Baseline went into effect on April 20, 1997 with a total estimate of $22.6 million, which included $5.5 million in TRP costs incurred before the baseline. These costs, for January 1 through April 20, 1997, were considered "Historical Costs" since they preceded the baseline and were incurred before implementing the techniques of measuring performance required by the PMP.

Identifying available sources of funding became a critical aspect in successfully implementing the TRP. Since the need for project funds was more immediate than the normal congressional budget cycle could provide for, rapid reprogramming of BNL's and other DOE program funds was required to make the necessary funds available. The high level of cooperation and expertise of DOE's financial staff and BNL's Budget Office staff, ensured that the funds were available in time to meet key TRP schedule milestones. Additionally, cost and obligation schedules were carefully managed to prevent exceeding authorizations.

As required by the TRP PMP, baseline changes were submitted during the project to address changes in scope, cost, and schedule. Revision 1 to the Baseline occurred in September 1997. This change reduced the TRP total estimated cost from $22.6 million to $19.8 million due to reductions in scope and managing project costs without the use of contingency. Baseline Revision 2, submitted in January 1998, further reduced costs from $19.8 million to $18.8 million and addressed the completion of the project and transferring the responsibility for managing long-term monitoring and remediation to BNL's Office of Environmental Restoration (OER).

As indicated in Figure 3 - TRP Costs and Obligations, the rapid implementation schedule for the TRP resulted in obligation and costing of nearly $18.0 million over a twelve-month period. TRP cost and schedule performance during this period was generally ahead of schedule and below budget as indicated by monthly performance reports. The remaining TRP cost will be managed by OER for operation of the remediation system and finalization of monitoring prior to approval of the OU III Record-of-Decision (ROD). Approval of the ROD is scheduled for December 1998. Table 2 lists the costs associated with the TRP.

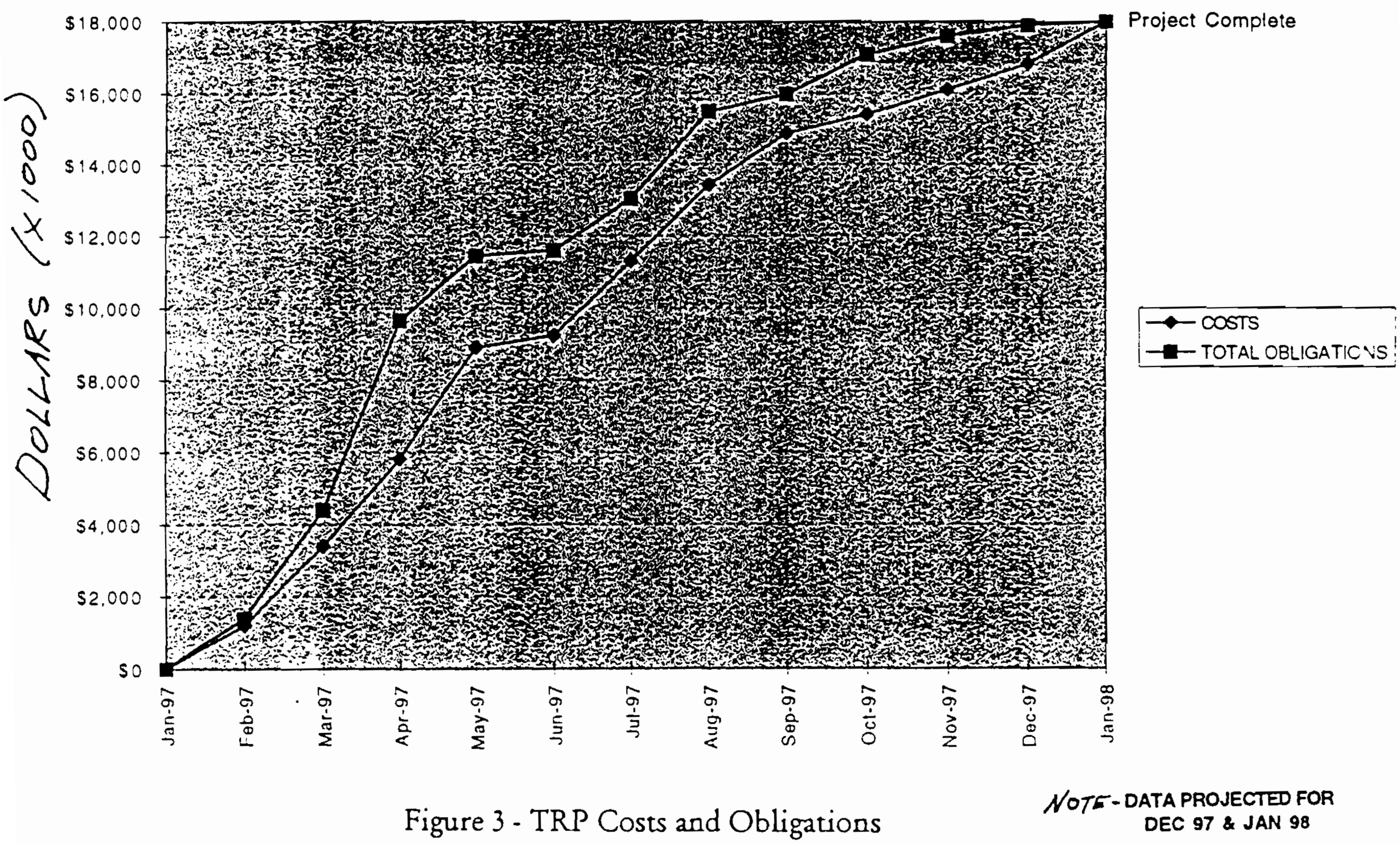


Figure 3 - TRP Costs and Obligations

Table 2 - TRP Costs

WBS No.	Category	Cost ($Millions)
1.1	Source Management	9.5
1.2	Plume Characterization	6.3
1.3	Project Support	2.0
	OER Management and Operation Until ROD	1.0
	TOTAL	18.8

Communications

In response to public concern about the announcement that tritium had been found in the groundwater south of the HFBR Building, DOE and BNL, through the TRP, established various communications activities aimed at informing the public, responding to feedback on the issue of groundwater contamination, and responding to the media to ensure that the distribution of information was timely, accurate, and consistent. These activities are described below.

Community Outreach Activities

To gain an understanding of community concerns and to keep the community informed, Community Relations representatives and subject-matter experts attended meetings of the civic associations of the towns that surround BNL. Approximately fifty presentations and updates on the tritium groundwater investigation were given from January through June 1997.

In addition, presentations were given to numerous elected officials, regulators, environmental committees, Rotary clubs, and Chamber of Commerce groups.

The community-at-large received two mailings that included a briefing page and letter, and a question-and-answer fact sheet about tritium. Five information/poster sessions were held in the surrounding area, including one at BNL for employees. These meetings provided stakeholders the opportunity to interact one-on-one with BNL management and subject-matter experts so that BNL would be aware of the concerns of the community and could answer questions. All information sessions were advertised in local newspapers and in businesses, and announcement posters were sent to all Suffolk County libraries.

Community Relations personnel visited local businesses to respond to their concerns. Two Input Sessions were held to gather feedback from community leaders on the proposed tritium remediation, and briefings were conduced with regulators for input on the final discussion/approval of the tritium remediation pump-and-treat system and public communication and involvement.

During August and November five information/poster sessions were held, and four roundtables were conducted with civic groups, interested individuals, and special interest groups to get feedback from stakeholders. Numerous presentations were given to the Brookhaven Executive Roundtable, elected officials, regulators, civics, Chambers of Commerce, and Rotaries. The HFBR Building was opened during Community Day and Family Day, and for numerous tours for interested groups and individuals. More than nine hundred people visited the facility.

To document the TRP for the CERCLA process, an Action Memorandum was issued which included a public notice, a newspaper advertisement, fact sheets, and a community letter.

Three issues of the Office of Environmental Restoration's Newsletter "*Cleanupdate*" included information on tritium remediation. Two (2)information/poster sessions were held. In addition, a tritium remediation poster and subject-matter expert were included in all subsequent information sessions/poster sessions held on the HFBR (five between August and October 1997), and at the Accelerated Cleanup 2006 Poster Sessions (two in July 1997).

Over a dozen tours of the monitoring well areas and Tritium Remediation Pump and Treat System were given to interested community groups and members. Briefing pages and fact sheets were also written.

Public Affairs/Media Relations

Between January and December 1997, media relations issued approximately forty press releases. Public Affairs and Community Relations personnel informed stakeholders before distributing these releases in order to maintain an open dialogue.

Approximately six press conferences/media availabilities, and approximately one thousand media requests were coordinated and handled. Over two-hundred-fifty calls from concerned citizens, likewise, were answered.

Internal Communications

Between January and December 1997, employees were kept up-to-date on remediation activities and related newsworthy developments through articles in the Brookhaven Bulletin, BNL's internal Weekly Newsletter, board displays, e-mails, and news briefs via the BNL mail system.

The most concentrated effort to communicate with employees took place between March and April 1997. During March, representatives of all on-site groups were contacted to prepare for information meetings that were then held during the month of April. Twenty-three (23) employee information meetings were held for BNL employees. An HFBR Tritium Information Center was designed and set up as a space for all employees to obtain answers to questions and receive the latest updates on the issues.

The High Flux Beam Reactor

The HFBR is a heavy-water-moderated and cooled research reactor used for basic experimental research which requires beams of neutrons. The reactor produces neutrons to support research in scattering experiments in nuclear and condensed matter physics, and structural biology and chemistry. It has facilities for isotope production and material irradiation and is one of only a few such facilities in the world. The reactor began operation in October 1965. The reactor was shutdown for routine maintenance in December 1996 when the tritium plume was discovered.

Typically, the reactor is operated at 30 MW for approximately thirty (30) days, shutdown for refueling for seven (7) days, and then restarted. Because the reactor is heavy-water-moderated and cooled, tritium is produced by neutron absorption in the coolant and, therefore, is a by-product of operation. Tritium concentrations in the primary reactor coolant are maintained in the range of 1.5 to 3.0 Ci/l and tritium concentrations in the spent fuel pool (SFP) have ranged from 40 to 140 million picocuries per liter (pCi/l), [1 Ci = 10^{12} pCi].

The confinement for the HFBR is a steel dome structure with the general shape of a half sphere (Figure 4) and an outside diameter at its base of nearly 180 feet. Within the confinement structure, the reactor is built on a solid concrete central-mat foundation with steel reinforcement, which has a uniform thickness of 5 feet and a diameter of 140 feet. The perimeter bay floor, an annular slab that connects the basemat to the cylindrical perimeter wall, is constructed of reinforced concrete and is 1-foot thick. Cutouts were built into the mat foundation on the east side for the SFP and on the north side of the perimeter bay floor for several pits. These cutouts extend below the bottom of the basemat and perimeter bay floor (Figure 5).

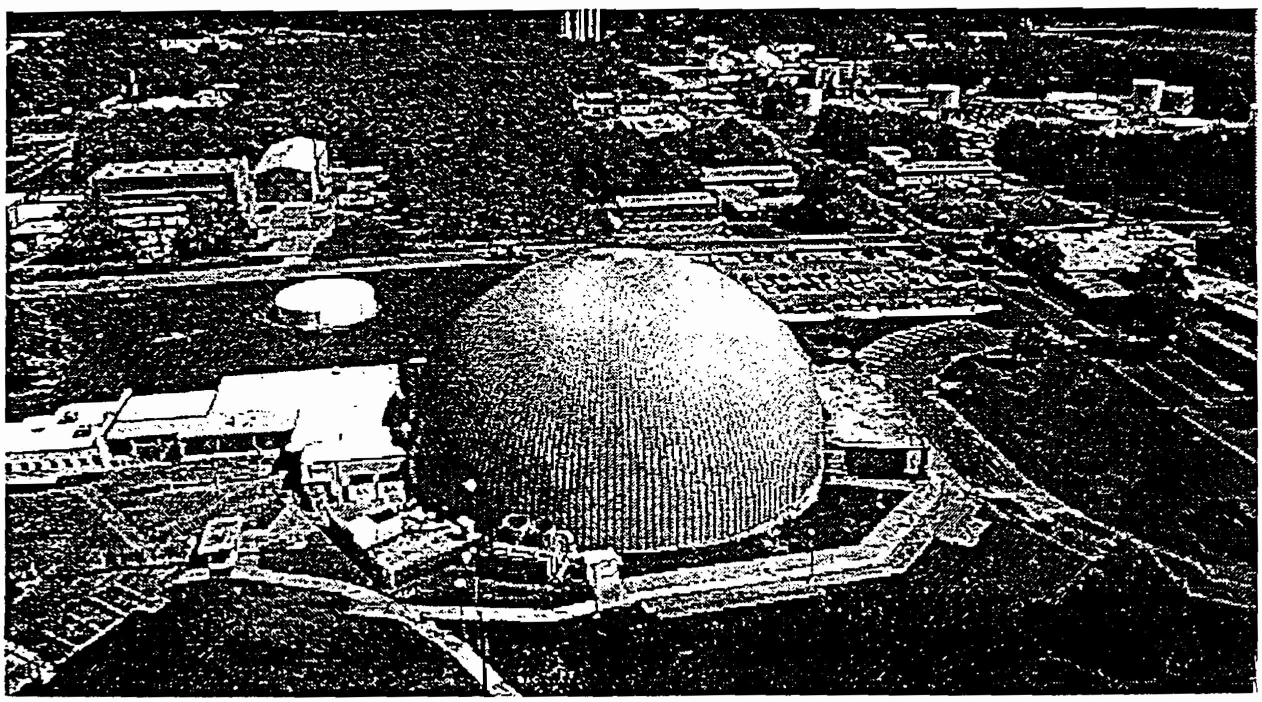
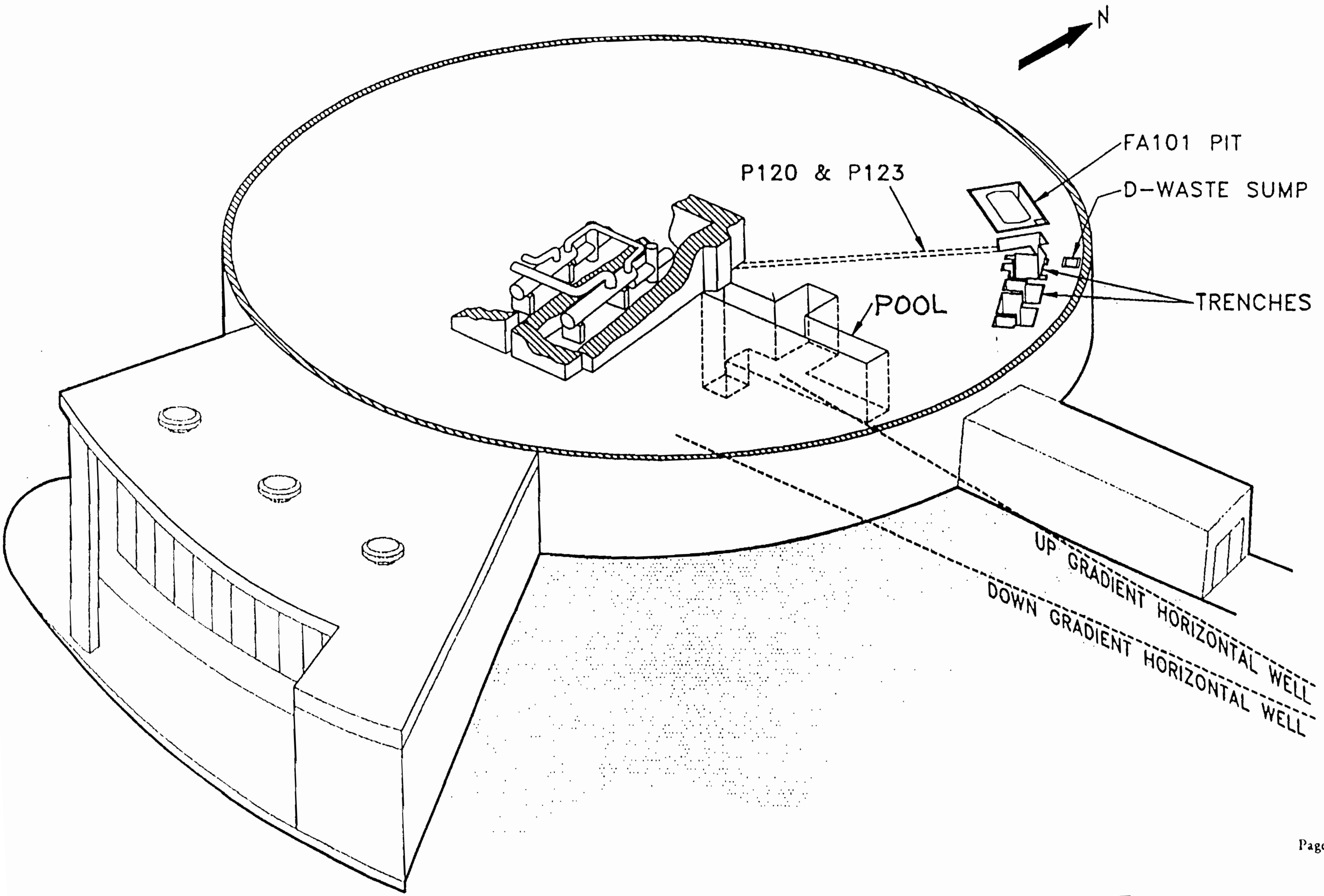


Figure 4 - View of HFBR Building, Looking to the East.

HIGH FLUX BEAM REACTOR



NOT TO SCALE

FIGURE 5 - HFBR CUTAWAY SHOWING PITS, TANKS, PIPING AND POSITIONS OF HORIZONTAL WELLS

The SFP has inside dimensions of 43 by 8 feet, and has an 8 by 10 foot bay on the north side. Most of the pool is 20 feet deep except for a 30 foot deep, 8 by 10 foot well on the west end. The concrete walls and floor of the SFP are 3-feet thick. The interior surfaces of the pool walls are covered with 3/8-inch thick tile. The outside is covered with a waterproof membrane that, in turn, is covered with concrete slabs or fiberglass panels to protect it from sharp objects (Figure 6). The pool nominally holds 68,000 gallons of light water.

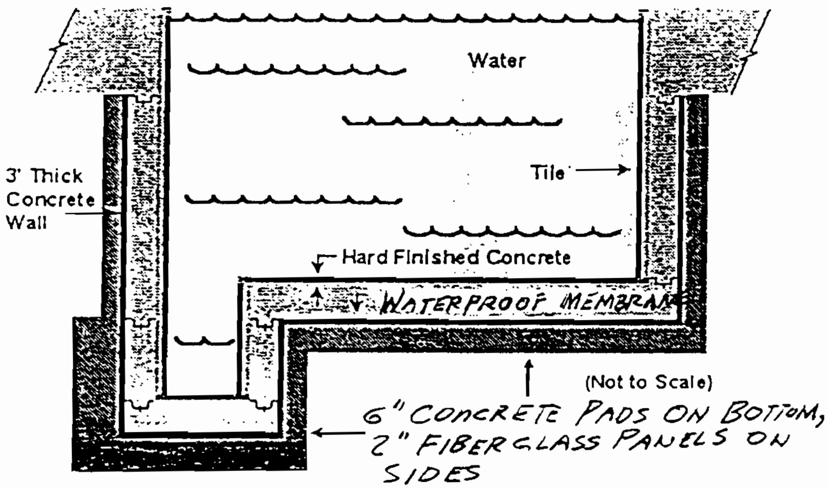


Figure 6 - Schematic Drawing of the Spent Fuel Pool (SFP)

• *SOURCE EVALUATION*

Potential Plume Sources

Investigation into the source(s) of the tritium plume was a major focus of BNL's tritium remediation team. BNL has analyzed the potential locations where tritium could leak into the environment without timely detection. On the basis of several factors, BNL concluded that the source of tritium must be from the HFBR Building. The following facts support the identification of the HFBR Building as the principal source of the tritium plume: 1) The results of groundwater sampling indicate high tritium concentrations down-gradient of the HFBR Building, 2) Only low concentrations of tritium were found immediately up-gradient of the HFBR Building, 3) Significant contamination was found near the top of the aquifer in the immediate vicinity of the HFBR Building (suggesting a nearby source), 4) No unusual levels of tritium were detected outside the flow path from the HFBR Building, 5) Data on concentration in the plume were consistent with a long-term continuous source; and 6) Leak tests confirmed that the leak rate from the SFP is 6 to 9 gallons/day (Ports 1997b).

Potential Sources Within the HFBR Building

The HFBR Spent Fuel Pool (SFP) was identified as the principal source of tritium.

Source identification in the HFBR Building consisted of reviewing reactor components that have the potential to release tritium into the environment, and testing for leaks to determine the integrity of each of the potential sources containing tritium. In some cases, leak testing was not possible. In such cases, visual inspections and engineering evaluations were undertaken where possible.

As a first step, the following systems that manage radioactive fluids or have the potential to come into contact with radioactive or tritiated fluids were identified and examined.

- Embedded piping, pits, and trenches in the equipment level floor
- Equipment level floor seams and other penetrations
- Sanitary and storm-water piping systems
- Secondary cooling water systems

Table 3 summarizes the sources identified within the HFBR Building that have the potential to release tritiated water into the environment. The table is based upon a detailed analysis of all potential tritium sources in the HFBR Building (Derrington 1997a). In general, these systems include pipes, pits, and trenches that are used to manage primary coolant heavy water and light water on or below the equipment level floor (the basement or lowest floor within the HFBR Building). Additionally, all records were reviewed to identify past spills of both primary coolant and light water that may have released tritium to the environment via leaking floor seams and other floor penetrations (e.g., electrical conduits, pipes, and drains).

Table 3 - Summary of Potential Source Evaluations and Testing

Potential Source	Description	Investigations Performed	Leak Tested	Potential for Leak
Primary Coolant Purification System Piping (P-120 & P123 Pipe Legs)	Embedded piping in equipment level floor from reactor to the trenches listed below. Always pressurized during operation.	Engineering evaluation. Leak tested at 425 psig during construction.	During construction	Low
Primary Coolant Purification System Trenches	Trenches containing filters and resin beds located northeast of SFP. Primary leak detection provided by leak tape and building airborne monitoring system.	Visual inspection and air leak test using Leak-Tec. No air shown to be infiltrating at 0.7 inches negative pressure in building.	Yes	Low
DA Drain, D_2O Transfer Piping, and D_2O Storage	Collects, stores, and replaces D_2O from the primary, shutdown, and experimental systems. Drains, vents, storage tanks, and transfer equipment and embedded piping connected to heavy water storage tank.	Visual inspection and air leak test using Leak-Tec. No air shown to be infiltrating FA101 Pit at 0.7 inches negative pressure in building. Sump filled with water and no leakage observed.	Yes	Low
CD Floor Drains	Floor drains in A, B, and shutdown cells for heavy water routed to heavy water storage tank.	Engineering evaluation. Leak tested at 50 psig during construction. Additional leak testing planned to demonstrate compliance with SCDHS Article 12 requirements.	During construction; also planned for Article 12	Low
Spent Fuel Pool Water Purification System Piping	Circulates SFP water for cooling and to auxiliary purification system. Piping is continuously full of SFP water.	The discharge piping to and from purification system was tested at 150 psig. Supply and return lines isolated and leak tested at 50 psig. No loss in system pressure observed.	Yes	Low
D-Waste Floor Drain Piping and Sump	Drainage system collects radioactive light water from various areas and discharges to the D-waste sump.	Engineering evaluation only. Leak tested at 50 psig during construction. D-waste sump and associated drain piping was leak tested during TRP.	Yes	Low

Spent Fuel Pool	A 68,000-gallon pool located on the east side of the reactor core that provides interim storage for spent fuel and a working space for spent fuel cutting operations.	Two (2) leak tests confirm leakage at a rate of 6 to 9 gallons per day. (First test showed 7-14 gpd, but did not account for evaporation and temperature effects.) Visual inspection showed no apparent leakage locations. Horizontal well sampling and analysis inconclusive.	Yes	Confirmed
Equipment Level Floor Seams & Other Penetrations	Penetrations of the floor by pipes, electrical conduit, pipe clean-outs, ground cables, equipment supports, and seams between segments of the foundation.	Leak testing apparatus developed for static water leak tests. Leakage occurred at some locations in A, B, and shutdown cells. CD clean-out drain grouting accepted water at a rate of 1 liter in 9 minutes.	Yes	High
Sanitary and Storm Water Piping Systems	Buried piping runs around the circumference of mat foundation. It is a collection header for the sanitary drains. Until July 1995 this system received condensate from all building air handlers.	Historical tritium concentrations managed in sanitary system have been less than highest concentrations seen in plume with the exception of small streams of higher concentrations of tritium. Waste streams containing higher concentrations of tritium are no longer sent to the sanitary sewer system. The sanitary system was leak tested and found to leak approximately 4-7 gallons per day when filled.	Yes	Medium
Secondary Cooling Water Systems	Secondary coolant system consists of heat exchangers that use secondary water to remove heat from the primary coolant system and a cooling tower system that releases the heat produced to the environment.	Environmental monitoring data shows that the nominal system tritium concentration is normally less than 1000 pCi/l.	Monitored during operation	Low

Each of the potential sources identified in Table 3, was evaluated to determine if it was feasible to conduct a leak test, and, if not, to determine other methods that could be used to evaluate the system's integrity. For those systems that were accessible and for which leak testing was possible, leak tests were conducted. However, in some cases, certain components either could not be taken out of service for testing, or could not be properly isolated to conduct a credible leak test. For those systems, other methods, such as detailed engineering analyses and visual inspections were used to determine the likelihood of a release having occurred in the past.

Results of the SFP Leak Tests

> The SFP leaks at a rate of 6 to 9 gallons per day, and is the principal source of tritium for the plume.

Two (2) separate leak tests confirmed that the SFP is leaking tritiated water. An initial test indicated a leak rate of 7-14 gallons per day, and a second test, conducted over a longer period of time that considered the uncertainties of evaporation and temperature, indicated leakage at a rate of 6 to 9 gallons per day (Ports, 1997a,b). Additionally, historical concentrations of tritium in the pool have been nominally 40 million pCi/l, with a noted increase to about 140 million pCi/l in 1995 following a primary coolant spill when servicing a primary pump. These concentrations are consistent with a calculated source term required to produce the tritium concentrations observed in the plume emanating from the HFBR Building.

The results of leak tests performed on other systems revealed that floor seams and penetrations within all three (3) cells (A, B, and shutdown cells) on the equipment level accepted small amounts of water. Therefore, these seams and penetrations are suspected pathways for primary coolant that spilled in these areas in 1995 to migrate from the HFBR Building. One potential pathway through the equipment level floor is a floor penetration for a contaminated D_2O drain system (CD) pipe drain clean-out, covered by a floor plate, located outside the southwest side of the B cell. A spill of several hundred gallons of primary coolant occurred in this area in 1995 during the servicing of a primary pump and took several hours to clean up. The grout seal around this pipe clean-out is known to accept water (one liter in a 9-minute period during a leak test), and it is likely that some primary coolant drained into the concrete foundation, and possibly, to the underlying soil through this seal. Small volumes of primary coolant may have leaked through the floor seams and also could have been minor contributors to the HFBR Building tritium plume.

Sanitary Sewer System

> The sanitary sewer system is not the principal source of tritium for the plume.

An analysis of the sanitary sewer system near the HFBR Building was conducted using available information and the conclusion was drawn that the sanitary system is not a major source of contamination for the tritium plume (Wood 1997a). To support this conclusion, a test was conducted to assess the overall condition of the sanitary piping under the equipment level floor (Ports 1998). To be a major contributor to the existing plume, a large breach would have to exist in the below-grade portions of the system. The test showed a loss rate of approximately four (4) to seven (7) gallons per day, indicating that the below-grade sanitary piping is in reasonably good condition and confirming that it could not be a major contributor to the existing tritium contamination.

Prior to 1995, the nominal tritium concentration, as monitored at the outlet of the building, varied from about 10,000 pCi/liter to 50,000 pCi/liter. Short duration spikes of up to 300,000 pCi/l were observed several times since 1993. Changes in concentration resulted from operational and maintenance activities and also seasonal changes in atmospheric temperature and relative humidity.

The largest contributor to the tritium concentration in the sanitary system prior to 1995 was the condensate which was collected and drained from equipment level air conditioning units. At that time, the practice was changed and the condensate from the Equipment Level air conditioners was no longer discharged to the sanitary system.

The average tritium concentration of the air conditioning condensate was typically about 150 million pCi/l. The volume discharged from the air conditioners varied due to seasonal variations in relative humidity. This source of tritium was subsequently diluted in the sanitary header by other cleaner water being discharged form the building; in particular, once-through cooling water from the building air compressors and the SFP cooler. The flow through these systems was estimated to be about 35 gpm. There were also smaller diluting flows from other once-through cooling sources and routine sanitary discharges from such items as sinks, showers, and toilets. The total sanitary flow from the building is estimated to be between 50 and 75 gpm.

Since the air conditioning condensate discharges into the sanitary system were historically discrete sources of tritium with relatively high concentrations, the tritium concentration in the sanitary system was not necessarily uniform. The test confirmed that there were no large breaks in the embedded portions of the sanitary system and, therefore, it cannot be a major contributor to the existing plume. However, due to the leak rate and the nominal tritium concentrations, it is reasonable to expect that leakage from the system has contributed to the existing plume.

Accidental discharge to the sanitary drains within the HFBR Building is unlikely because the sanitary drains are elevated off the floor. For a leak or spill to exit through the sanitary system, the spill would have to be approximately 1/2-inch deep. This has never occurred, and is unlikely to occur considering that the SFP, elevator shafts, and D-waste drains are the lowest points in the floor, and spills would flow to these locations first.

• *HYDROGEOLOGY OF BROOKHAVEN NATIONAL LABORATORY*

BNL is located near the north-south center of Long Island above the Nassau/Suffolk aquifer system south of the groundwater divide. The aquifer system is designated as a sole-source aquifer under the Safe Drinking Water Act, and is the principal source of potable water for the surrounding communities, as well as BNL.

Hydrogeologic Framework

The hydrogeologic system is comprised of 1,600 feet of unconsolidated sediments (sand, gravel, and clay) lying upon nearly impermeable crystalline bedrock. Figure 7 is a generalized north-south cross-section of the hydrogeology through Long Island and BNL.

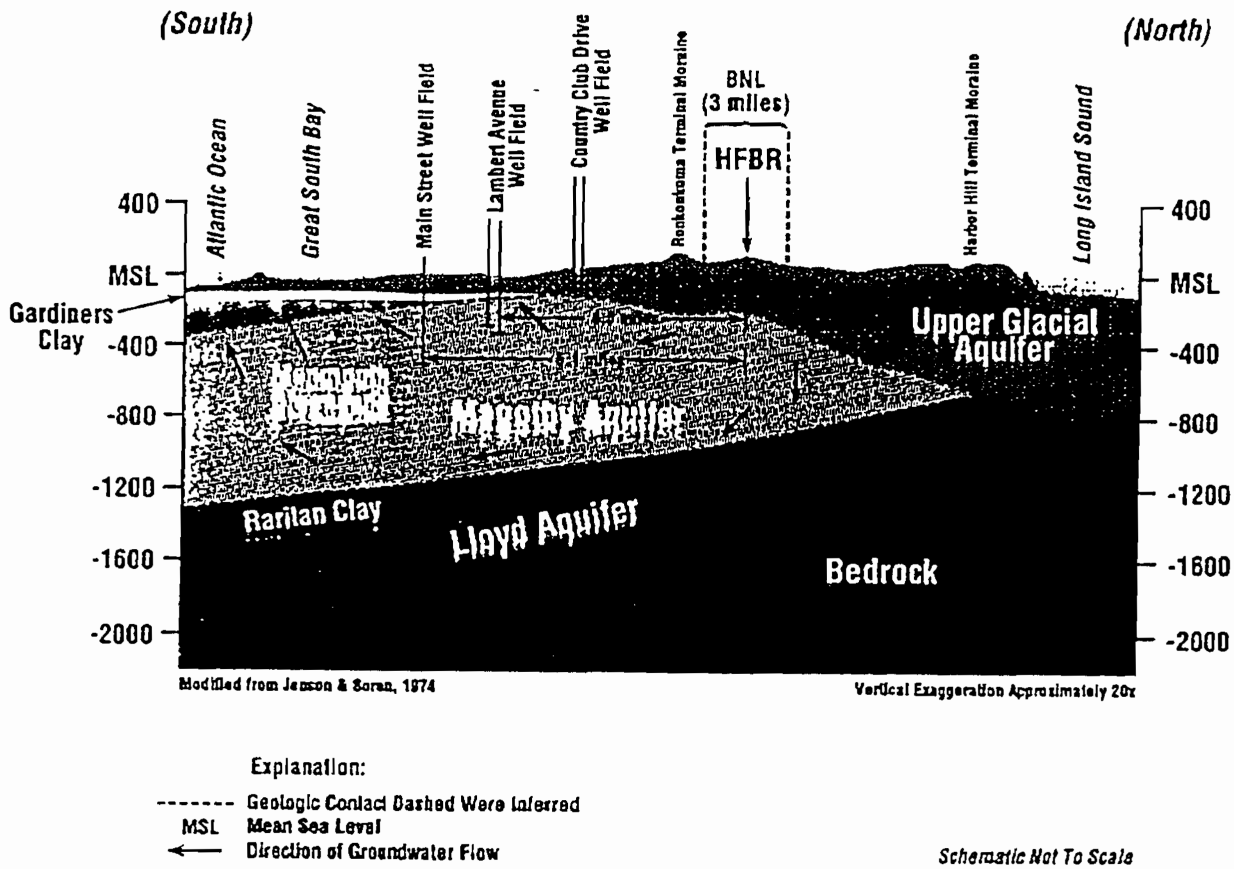


Figure 7 - Generalized North-South Hydrogeologic Cross-Section of Long Island and BNL

Precipitation, in the form of rain or snow, forms the primary source of recharge for the Nassau/Suffolk aquifer system. Average yearly precipitation at BNL is approximately 48 inches, of which approximately 23 inches is lost to evapotranspiration, less than an inch flows directly to surface water, and approximately 25 inches infiltrates to the aquifer (Geraghty and Miller 1996). As a result of the high rate of infiltration, groundwater seepage to streams from the aquifer accounts for more than 95 percent of the total stream flow throughout the area.

Water-table elevation contours and general flow directions within the Upper Glacial aquifer are shown in Figure 8. A groundwater divide runs east-west down the approximate centerline of Long Island and near the northern boundary of BNL. Groundwater flow is northward north of the divide. In general, groundwater flows to the south or southeast beneath BNL carrying any dissolved contaminants in that direction. Production well pumping and water discharge to recharge basins alters the groundwater flow direction locally. The average groundwater flow velocity at BNL is about 0.8 feet/day.

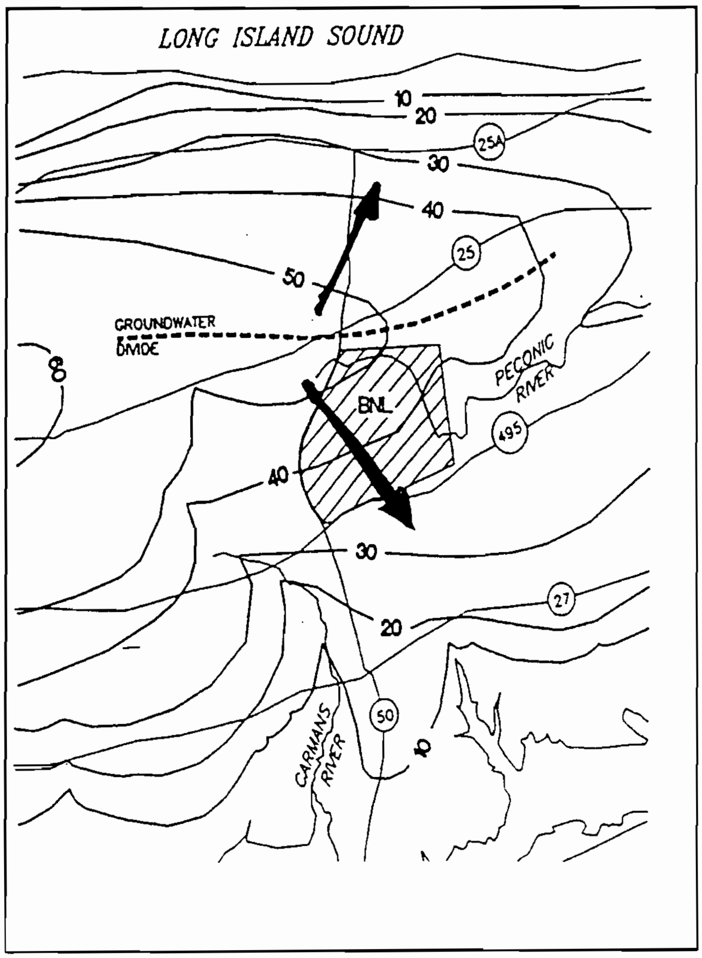


Figure 8 – Water Table Contours/Flow Directions in the Vicinity of BNL

Hydrologic Properties of the Aquifer System

Table 4 lists representative hydraulic properties of the geologic units. Hydraulic conductivity is a measure of how well water travels through the pore spaces of the aquifer. Anistropy is a measure of the ratio of the vertical and horizontal water migration rates. Specific yield is a measure of the water storage capacity of the aquifer materials. The Upper Glacial aquifer has the highest and greatest range of horizontal hydraulic conductivity. Wells operating in this unit can yield in excess of 1,000 gallons per minute. The Suffolk County public water supply is drawn from both the Upper Glacial aquifer and the Magothy aquifer. BNL's water supply is drawn exclusively from the Upper Glacial aquifer.

Table 4 - Representative Hydraulic Parameters for the Aquifer System Beneath BNL

Hydrogeologic Unit	Description	Hydraulic Conductivity	Anistropy (K_h/K_v)	Specific Yield or Specific Storage
Upper Glacial Aquifer	Moderate to highly permeable outwash deposits (sand and gravel)and poorly permeable glacial till.	20 to 300-ft./day	3:1 up to 10:1	Outwash - 0.18 to 3.0 Moraine - 0.10
Gardiners Clay (confining unit)	Poorly permeable, silty clays, few sand lenses.	Low, aquitard	Undetermined	Undetermined
Magothy Aquifer	Poorly to moderately permeable, silty sand and gravel.	30 to 80 ft./day	100:1	6.0×10^{-7}
Raritan Clay (confining unit)	Poorly to very poorly permeable, silty clays, few sand lenses.	Low, aquitard	Undetermined	Undetermined
Lloyd Aquifer	Poorly to moderately permeable, silty sand and gravel.	35 to 75 ft./day	100:1	Undetermined
Bedrock (lower confining unit)	Very low permeability to impermeable crystalline rock	~0	Undetermined	Undetermined

• *CHARACTERIZATION AND MODELING OF THE TRITIUM PLUME*

1,800 groundwater samples were collected.

The tritium plume was delineated by installing and collecting groundwater samples from 45 Geoprobe™ and 77 vertical profile wells. Approximately 1,800 groundwater samples were collected for tritium analysis. Samples were taken from different depth intervals at these locations, thereby providing a vertical profile of tritium concentrations. As the interim response proceeded, the results from groundwater analyses were used to continuously update the known extent of the plume, and to guide the placement of new test holes and the collection of additional groundwater samples. In addition to the Geoprobe™ and vertical profile wells, twenty-seven permanent monitoring wells and piezometers were initially installed to provide long-term plume and water level monitoring, and two horizontal wells were installed beneath the HFBR Building to aid in characterizing the tritium source. Fifty-four additional piezometers and monitoring wells have also been installed to ensure adequate long-term monitoring of the plume.

Plume Delineation Activities

Geoprobe™ Wells

Geoprobe™ samples were collected by hydraulically driving a sturdy well screen to the desired depth(s) below the water table (Figure 9) and pumping the well to retrieve water samples for tritium analysis. Approximately 230 samples were collected and analyzed from the forty-five (45) Geoprobe™ wells; their locations are shown as solid unlabeled dots in Figure 9.

As sampling and plume delineation progressed, the zone of highest tritium concentration was found to increase with depth below the water table in the direction of groundwater flow (Figure 10). Near the HFBR Building, the highest concentrations were found within 10 feet of the water table (50 to 60 feet below land surface). Near Brookhaven Avenue, one thousand (1,000) feet from the HFBR Building, the highest tritium concentrations were found approximately 35 to 55 feet below the water table (80 to 100 feet below land surface). The Geoprobe™ sampling system was not used where the depth of the plume exceeded its operational limit (~ 100 feet).

Vertical Profile Wells

As an alternative to the Geoprobe™ sampling method, BNL used temporary vertical profile wells to collect deeper groundwater samples in the southern portion of the plume. Vertical profile wells were drilled using conventional hollow-stem auger drilling techniques. The typical profile consists of a 2-inch diameter steel casing with a 2 foot long stainless steel screen. Once drilled to the desired depth, the well is sampled, then pulled upward through the aquifer at either 5 or 10 foot intervals. Thus, in a manner similar to the Geoprobe™ system, a vertical profile of contamination distribution is obtained. As many as twenty-five (25) depth-discrete samples were collected from a single vertical profile.

A final total of seventy-seven (77) vertical profile wells was completed in November 1997, from which approximately 1,600 samples were collected and analyzed for tritium. The locations of the vertical profiles are shown on Figure 9.

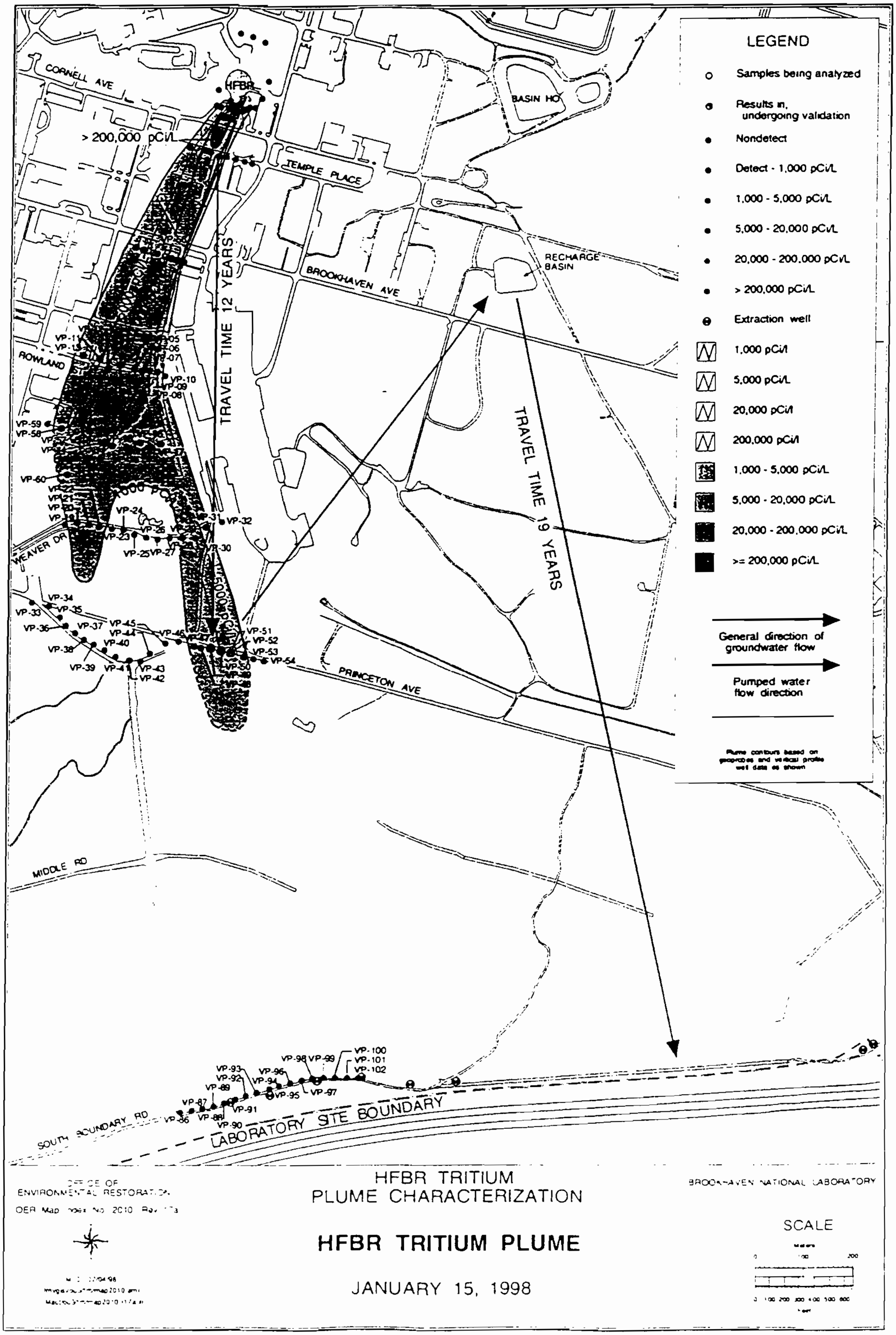


FIGURE 9 - PLUME MAP SHOWING WELL LOCATIONS

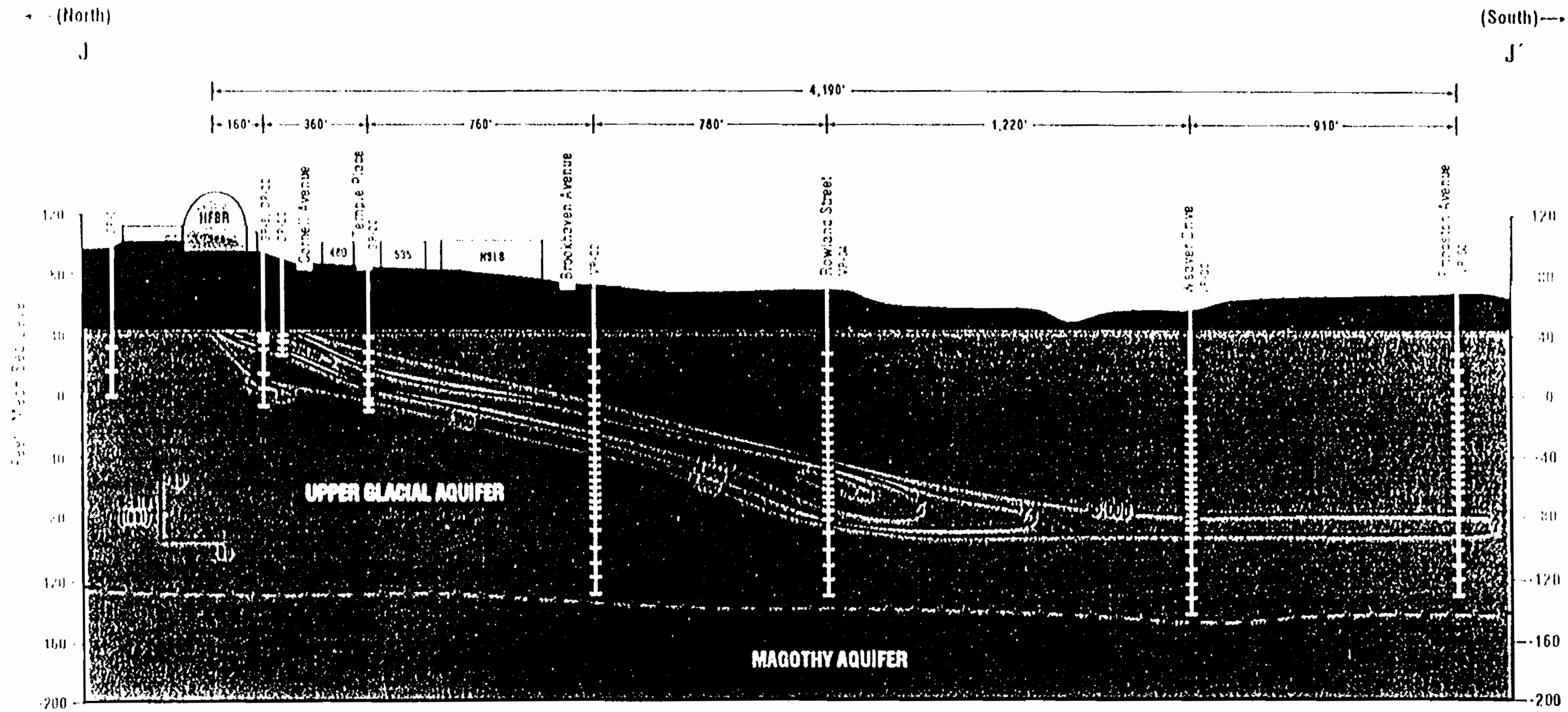
Monitoring Wells and Piezometers

Twenty-seven new piezometers and monitoring wells were installed early in the tritium plume investigation to support groundwater-modeling efforts. Fifty-four additional permanent monitoring wells and piezometers were recently installed. The piezometers and monitoring wells were drilled and installed using hollow stem augers. Piezometers used to monitor water table elevation consist of a 2 inch diameter riser pipe with, typically, a 5-foot well screen placed at a discrete monitoring depth. The monitoring wells used for collecting water samples and water elevations are typically completed with a 4-inch diameter casing and a 5 foot screen at the intended monitoring depth. In addition to the new wells, previously installed wells were also available for characterizing the tritium plume. Both types of wells were used at BNL to measure water levels and collect water samples. The piezometers and monitoring wells also will be used for long-term monitoring of groundwater levels, collection of groundwater samples, and to evaluate the effectiveness of the tritium plume remediation. Eighty-eight (88) monitoring wells will be sampled quarterly for long-term monitoring. Quarterly sampling will occur up to the OU III Record of Decision (ROD).

Results

The HFBR Building plume is located within the boundaries of BNL.

The combined sampling and monitoring results of Geoprobe™ wells, vertical profile wells, and piezometers were used to define the horizontal (Figure 9) and vertical (Figure 10) extent of the tritium plume. The plume is located entirely within the boundaries of BNL. The portion of the plume which exceeds the drinking water standard for tritium (20,000 pCi/l) extends approximately 2,600 feet south of the HFBR Building at depths ranging from 50 to 150 feet below land surface. Tritium concentration in the plume ranges from a highest detected concentration to date in a permanent monitoring well of 1,590,000 pCi/l immediately south of the HFBR Building to approximately 6,440 pCi/l at a point approximately 3,600 feet south of the HFBR Building. As is evident on the vertical profile of the plume (Figure 10), at any particular location, the vertical concentration of tritium increases with depth below the water table until the plume has been penetrated, then concentration decreases. This is due to downward vertical flow within the aquifer resulting from precipitation recharge. The decrease in (horizontal) concentration farther from the HFBR Building is due to natural radioactive decay, which lowers the tritium concentration by half every 12.3 years, and from dilution within the aquifer.



CROSS SECTION J-J´
TRITIUM (pCi/L)

Figure 10 – Hydrogeologic Cross-section along Axis of Tritium Plume.

Currently, the leading edge of the 20,000 pCi/l contour line is approximately 4,800 feet away from the southern BNL boundary. At the average groundwater flow velocity of 0.8 feet/day, it will take groundwater at the leading edge of the 20,000 pCi/l contour line about 6,000 days (16.4 years) to reach this boundary. By that time, natural radioactive decay alone will reduce the tritium concentration to less than half of its current level. Considering combined groundwater flow, radioactive decay and dispersion effects, tritium concentrations above 20,000 pCi/l will never cross the BNL boundary from the HFBR Building tritium plume, even without any remedial action. The long-term historical transient groundwater modeling run supports this projection; however, ongoing monitoring will be used to validate this projection.

Horizontal Wells

To further characterize the release of tritiated water from the SFP, two (2) horizontal wells were installed immediately up-gradient and down-gradient of the SFP (Figure 11). Placement of the horizontal wells was intended to accomplish two objectives: 1) to provide additional evidence that the SFP was the source of tritium by observing high concentrations of tritium in the down-gradient well and none in the up-gradient well, and 2) to rule out any contribution from other up-gradient sources, such as buried pits, piping, and trenches in the equipment level floor. For that reason, the up-gradient well was placed nominally 17-feet north and parallel to the north wall of the SFP. The down-gradient well was placed 10-feet south and parallel to the southern wall of the SFP. The up-gradient well was installed closer to the water table (1.5-feet below the water table) whereas the down-gradient well was deeper, at 4.7 feet below the water table.

Results of the first round of groundwater sampling and analysis from these wells showed detectable tritium concentrations in both wells with the highest concentrations in the up-gradient well. As of January 1998, five (5) rounds of samples have been taken and the results are inconclusive.

To assess the area where tritium might be entering the water table, a conceptual drawing was generated using available geologic information from below the HFBR Building and an understanding of groundwater flow (Wood 1997b). Log readings from foundation borings drilled during the analysis of the reactor foundation indicate the vadose zone consists of heterogeneous layers of sand mixed with varying amounts of silt, clay, and gravel (Feld 1961). Because of the layering, tritium from the SFP likely moves laterally along layers that contain more fine-grained clay and/or silt immediately above gravel layers, which act as capillary barriers, as illustrated in Figure 12 (Wood, 1997b). The tritium also is likely to spread laterally as the moisture in the drier soil under the building equilibrates with the more moist soil outside the building. These processes may cause the plume to spread in the vadose zone toward the up-gradient horizontal well.

Once the tritium reaches the aquifer, it moves in a thin layer along the top of the water table under the reactor where there is no infiltration of rainwater. Thus, there is no force pushing the tritium deeper into the groundwater. Because the up-gradient horizontal well is at a higher elevation (closer to the water table with higher tritium concentrations) than the down-gradient well, and because the tritium may move northward in the vadose zone, the observed higher concentrations in the up-gradient well are explainable.

This conceptualization of flow suggests that at 17 feet north of the SFP, the northern horizontal well may not be completely up-gradient of the tritium footprint at the water table. Additionally, because the two horizontal wells are installed at different depths, the effects of the strong vertical concentration gradient near the HFBR Building are more significant than the horizontal concentration gradient. This effort at characterization also illustrates the difficulty in defining every flow path adjacent to the SFP. However, at greater distances, the extensive network of temporary and permanent monitoring wells made the task of delineating the plume less problematic.

A team was established to evaluate various options for resolving the inconclusive data from the horizontal wells. Two groundwater experts assisted the team. Dr. Brian Looney of the Savannah River Site Technology Center, and Dr. Gary Robbins, Professor of Hydrogeology from the University of Connecticut, reviewed the horizontal well data and helped develop a monitoring strategy (Derrington 1997b) for the horizontal wells to: 1) develop a monitoring procedure for resampling the wells using a micro-purge technique, 2) sample during low water levels when the water level is near the well screen, and 3) collect a sequential set of samples to determine the relationship between the water table elevation and tritium concentration. A horizontal well sampling plan was developed and implemented based on these recommendations.

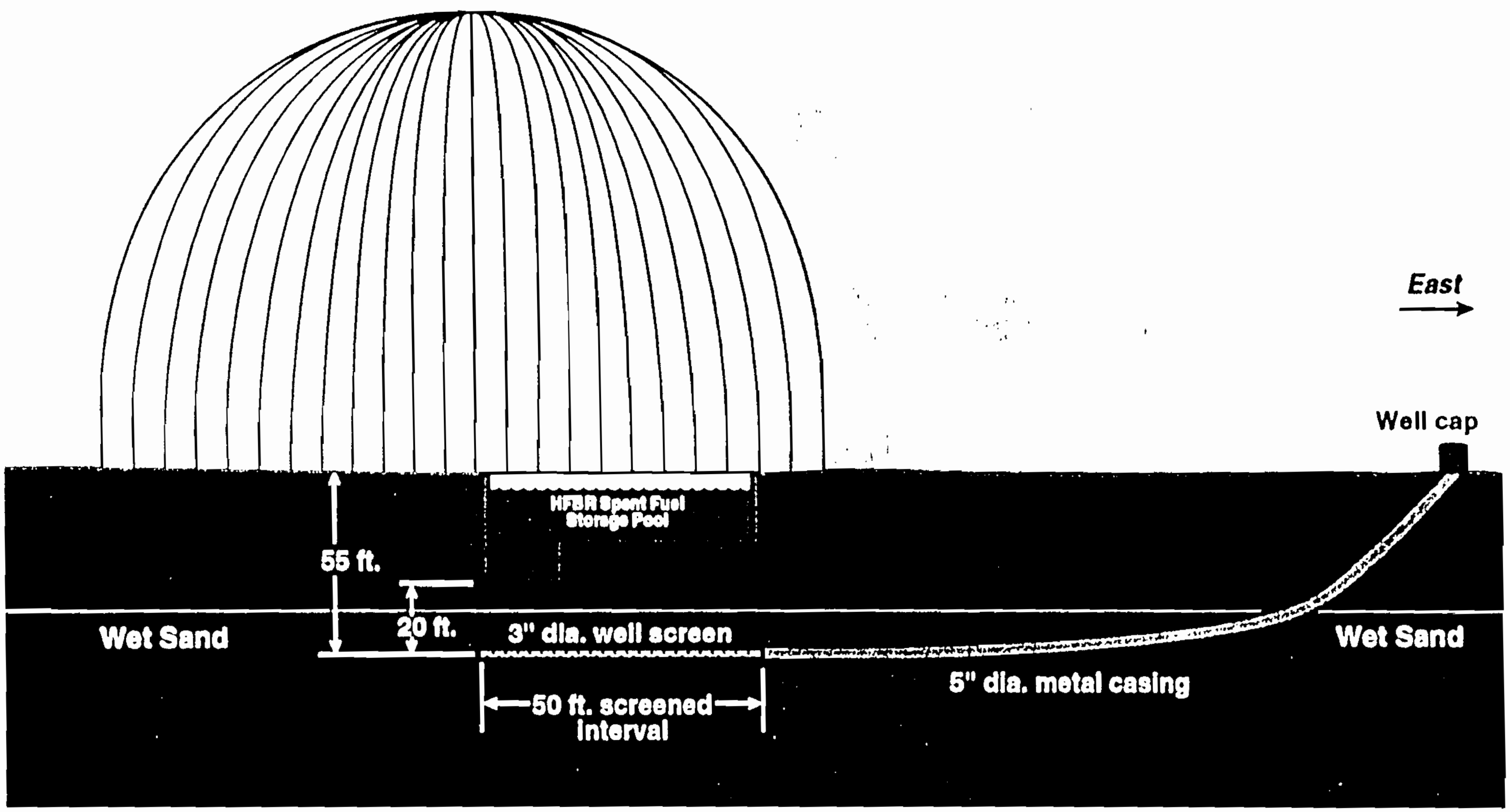


Figure 11 – Horizontal Well For Sampling Ground Water

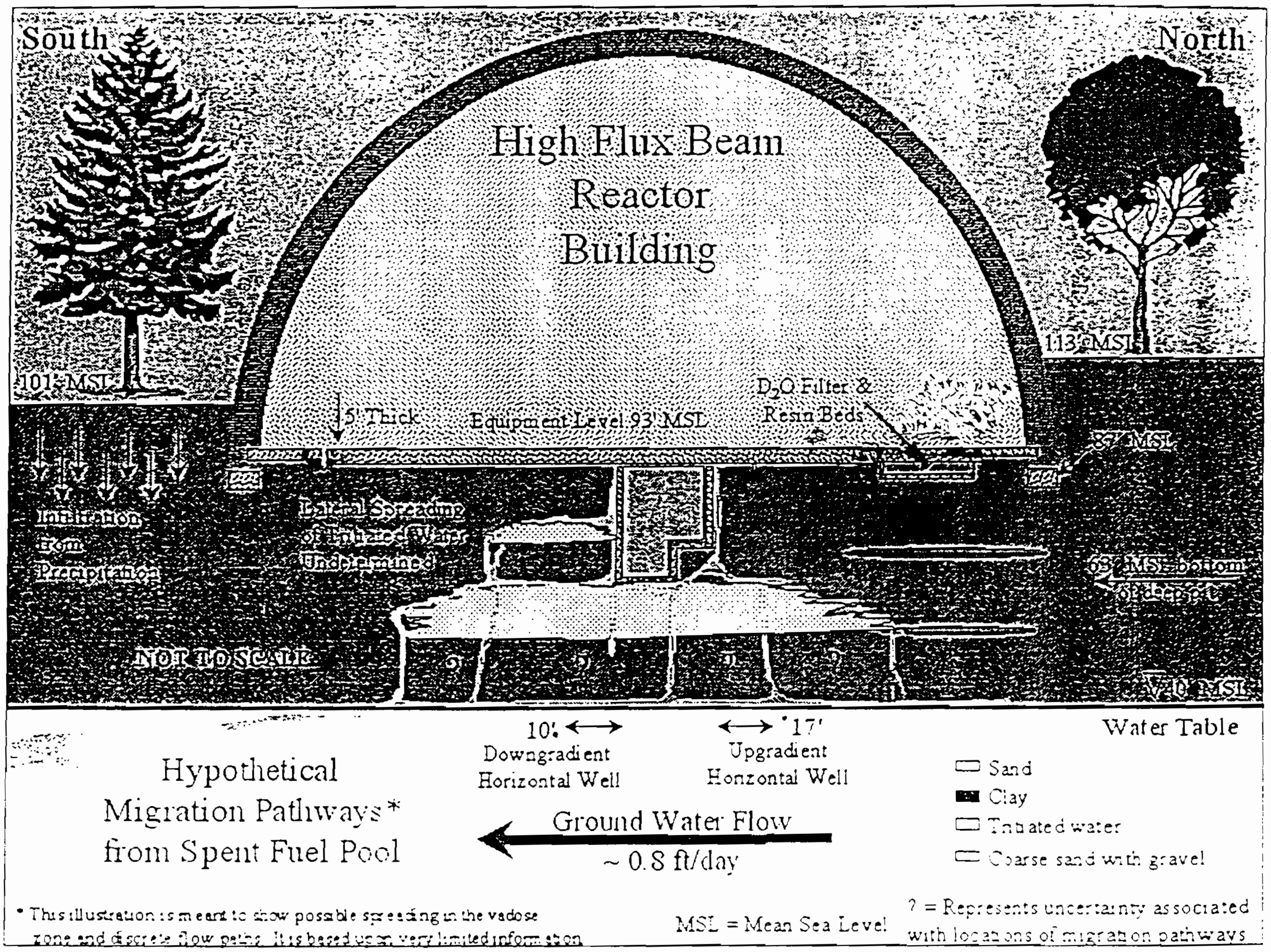


Figure 12 – Conceptual Drawing of Vadose Zone Transport Beneath HFBR

Vadose Zone Transport

> Soil layering and other factors cause tritium to spread as it migrates to the water table.

Figure 12 is a conceptualization of the migration of tritiated water from the SFP to the water table, and was discussed in the preceding section. The vertical travel path is 20 to 50 feet, depending on where the leak originates from the SFP. In the model, tritiated water from a small constant source infiltrates vertically in the unsaturated zone, until the boundary with a coarser grained material is intercepted, at which time the flow spreads laterally. This interpretation is based upon four (4) geotechnical borings (and associated soil descriptions) that were installed for foundation studies before the HFBR Building was constructed (Feld 1961). There is no other direct information on the unsaturated soil beneath the HFBR foundation.

Unsaturated flow can be divided into two general types: 1) gravity driven, and 2) capillary-tension driven. Gravity flow occurs during draining of wet soil, and intuitively, it is dominated by vertical flow to the water table. Gravity flow will occur in areas of relatively high precipitation and infiltration. Water flow in relatively dry soil, as might exist beneath the foundation of the HFBR Building, which prevents the infiltration of rainwater, is driven mostly by capillary tension and flow proceeds in the direction of increasing pore water tension (or suction), which can be in any direction. Also, because fine-grained, poorly sorted soil typically has smaller pore space than clean, well-sorted soil, capillary tension in fine-grained soil is typically higher, given equal moisture contents.

Thus, under relatively dry conditions, unsaturated flow may preferably occur in the finer textured soil, and cleaner, coarser grained materials may preferentially act as flow barriers (Kramer and Cullen 1995). For these reasons, the conceptual drawing presented in Figure 12 depicts potentially significant lateral spreading of the infiltrating water directly beneath the HFBR Building. However, the area with the highest potential for significant lateral spreading of contaminants in the unsaturated zone is limited to the area directly beneath the HFBR Building and any attached paved area. Beyond this area, given the relatively high average infiltration from precipitation on Long Island, it is predicted that the primary mode of vadose zone flow would be gravity driven, as pulses of precipitation infiltrate to the water table.

Regions of higher than expected tritium concentrations, detected within the plume, may indicate the effects of a rising and falling water table on the transport of tritium to the groundwater (Cahn and Baker 1997). Tritium movement to the aquifer during periods of high water may be greater because the water table picks up contamination as it rises, and there is less tritium moving to the aquifer when the water table is low or falling. Assuming the groundwater velocity averages 0.8 feet per day, the travel time between the HFBR Building and Rowland Street (the area of higher-than-expected tritium) is seven years. In 1990, water levels were higher than at present and it is possible that more tritium was released to the aquifer due to this soil-rinsing effect. Other possible causes would be additional HFBR Building sources and changes in contaminant release-rates.

The vadose zone underneath the HFBR Building has not been characterized due to the difficulties associated with sampling under the HFBR Building. Any future releases from the vadose zone to the water table will be addressed through continued down-gradient monitoring of the HFBR Building tritium plume.

Groundwater Modeling

Transport models indicate tritium will never exceed drinking water standards at the site boundary, even if no remediation is performed.

The geometry, source, and rate of migration of the tritium plume have been investigated using techniques that range from simple mass-balance calculations to analytical models and more complex numerical models. Despite the varying assumptions inherent in the different approaches, all of these techniques have given similar results. In combination with other work such as direct characterization, investigation of potential sources, and the SFP leak tests, these analyses confirm that the HFBR SFP is the principal source of the tritium plume. The major differences and similarities between the approaches used to evaluate the tritium plume are summarized in Table 5 (Cahn and Baker 1997). Although some analyses suggest a larger source than assumed from the SFP alone, or an additional past source, the differences do not alter the main conclusions: 1) the HFBR SFP is the principal source of the tritium plume; 2) the plume is in, or close to, equilibrium (i.e., the plume is not migrating significantly); 3) drinking-water standards for tritium will never be exceeded at the site boundary from the HFBR Building plume; and 4) pumping from three extraction wells at Princeton Avenue, each at 40 gpm, will not adversely affect the highly contaminated portions of the plume near the HFBR Building. In addition, some modeling results suggest that tritium concentrations may increase by up to a factor of four over the next few years, compared to the 660,400 pCi/l found during early plume characterization near the HFBR Building, even after the source is removed because of delayed transport through the unsaturated zone of the more recently released SFP water. This water has had a tritium concentration of 140 million pCi/l since 1995. Observed tritium concentrations near the HFBR Building in the future may also be sensitive to fluctuations in the water table.

Table 5 - HFBR SFP Comparison of Tritium Calculations and Models

Model	Author	Assumptions/Methodology	Results/Conclusions
Mass Balance Calculation	Fiegler	Constant source, porosity = 0.33, results compared to data for one cross section.	A 0.0012 Ci/day (0.44 Ci/yr.) Source, leak from SFP would need to be 6.6 gal/day at 40 μCi/L concentrations (pre 1995) or 2.2 gal/day at 130 μCi/L concentration (recent data). SFP is likely source.
Mass Balance Calculation	Baker	Variable source, porosity = 0.24, results compared to data at five cross sections.	Increase in observed mass at Rowland Ave. Suggests other release in the past. SFP is likely predominant source.
Analytical Advection/ Dispersion Model w/Sources	Sullivan and Cheng	Uniform flow field, constant source, 2-D advection, 3-D dispersion, sensitivity analysis, analysis of other possible sources, comparison to data.	0.365 Ci/yr. Source, source geometry (point, line, area) unimportant at greater than 150-feet down-gradient. Continuous source, not one time leak. SFP is likely principal source, not primary coolant or sanitary sewer. Determined transport parameters (velocity and dispersion) that best fit the data. Tritium plume will reach equilibrium, and drinking water standards will never be exceeded at the site boundary. Concentrations may increase after the source is removed due to travel time through the unsaturated zone and tritium concentration increases in the SFP in recent years.
Regional Finite Difference (Numerical) Flow Model	Geraghty and Miller	Calibrated, steady state, flow only-no transport, 3-D. Used MODFLOW.	Model calibrated to June 1996 hydraulic head data. Outstanding match to model targets, tritium plume not modeled. Established flow boundary conditions for use in local scale transport model.
Local Finite Difference (Numerical) Model	Geraghty and Miller	Steady state, constant source, 3-D, assumes 40 μCi/L source at 14 gal/day. Used MODFLOW and MT3D.	Layered model accounts for major stratigraphic units. Best match to plume geometry, dispersivity values only approximate. Shows plume is in equilibrium or close to it. Predicts no off-site migration above drinking water standards. Negligible effect on plume of continuous source for 1 more year. Used to design remediation well locations and pumping rates. Results presented at external peer review meeting 4/97.

• *REMEDIATION ACTIVITIES*

Three (3) paths for remediation were chosen: 1) removing the tritiated water from the SFP and the conceptual design of a new double-walled stainless steel liner, 2) eliminating other potential sources of leakage by bringing the HFBR Building into compliance with SCDHS Article 12, and 3) groundwater pumping at the leading edge of the plume.

Spent Fuel Pool Liner

> A double-walled stainless steel liner is being designed to prevent future leakage from the SFP.

All spent fuel elements have been removed from the SFP and shipped to the Savannah River Site for storage and final disposition (i.e., they will not be returned to the Brookhaven site). After disposal of the spent fuel, equipment in the pool (such as control rod blades, fuel storage racks, the strike-plate, and the spent fuel retard chute) was removed for storage or disposal. Water from the pool, totaling 65,520 gallons, was pumped to double-walled storage tanks via double-walled piping installed at Building 811, the Waste Concentration Facility (WCF), in compliance with SCDHS Article 12. The storage tanks were approved for use by SCDHS on December 16, 1997. Pump-out of the SFP water commenced on December 18, 1997 and was completed on December 30, 1997.

The SFP water will be stored at the WCF until the SFP liner is installed. The WCF consists of four (4) secondarily contained storage tanks which are used to store BNL's liquid radioactive waste before processing and disposal. The TRP will also upgrade the transfer area of the WCF to comply with Article 12 should off-site disposal of the SFP water be required via tanker truck.

To eliminate the SFP as a potential future source of tritium contamination in the groundwater, a double-walled stainless steel liner is recommended, with leak detection and collection capability. To assist in developing the conceptual design for the pool liner and leak detection system, BNL hired Raytheon Engineers & Constructors, Inc. (Raytheon 1997). The Conceptual Design for the Impervious Liner for the HFBR Spent Fuel Storage Canal (BNL 1997) defined the applicable requirements, identified potential options for satisfying the requirements, evaluated five of the most promising options, and described the recommended option and its installed cost and schedule, as well as uncertainties and contingencies. A freestanding double-walled stainless steel liner with an instrumented low point sump was selected. The selected liner system for the SFP satisfies DOE, BNL, EPA, NRC, and NYSDEC requirements and guidance, and the applicable portions of SCDHS Article 12.

Upgrade of the Existing HFBR Building

BNL and DOE continue to work with SCDHS to develop a plan that will ensure all buried piping, pits, and trenches conform with SCDHS Article 12. SCDHS Article 12 requires that all systems that contain hazardous waste have secondary containment. BNL is currently examining methods, through the HFBR Transition Project, to either reroute or retrofit underground and embedded piping, pits, and trenches in the HFBR Building. When completed, all potential sources of tritiated water will have secondary containment, except for spills to the equipment level floor. BNL is also developing a plan to repair and maintain floor seams and other penetrations within the equipment level floor to mitigate the potential for future releases from accidental spills of tritiated water.

Groundwater Extraction System

A pump and recharge system ensures that tritium above the drinking-water standard will not leave BNL's site boundary.

BNL designed, constructed, tested, and put into operation an interim system to intercept the tritium plume (Mecham 1997). The system uses a pump-and-recharge system that has been in operation since May 12, 1997 to ensure that tritium above the state and federal drinking water standard of 20,000 pCi/l will not leave Brookhaven's site boundary. The groundwater extraction system provides redundancy in light of the current understanding of the tritium plume and groundwater flow modeling. This understanding and modeling suggest that tritium greater than the drinking water standard, even without the groundwater extraction system, will not leave the BNL site boundary from the HFBR Building tritium plume.

Three (3) groundwater extraction wells were installed 3,500-feet south of the HFBR Building near Princeton Avenue, where the maximum tritium concentration is 6,440 pCi/l. Groundwater is pumped from a depth of about 150 feet below land surface and piped 3,300-feet northward to an existing recharge basin within the BNL site (Figure 9). Each well pumps tritiated groundwater from the aquifer at a rate of about 40 gallons per minute (Figure 13).

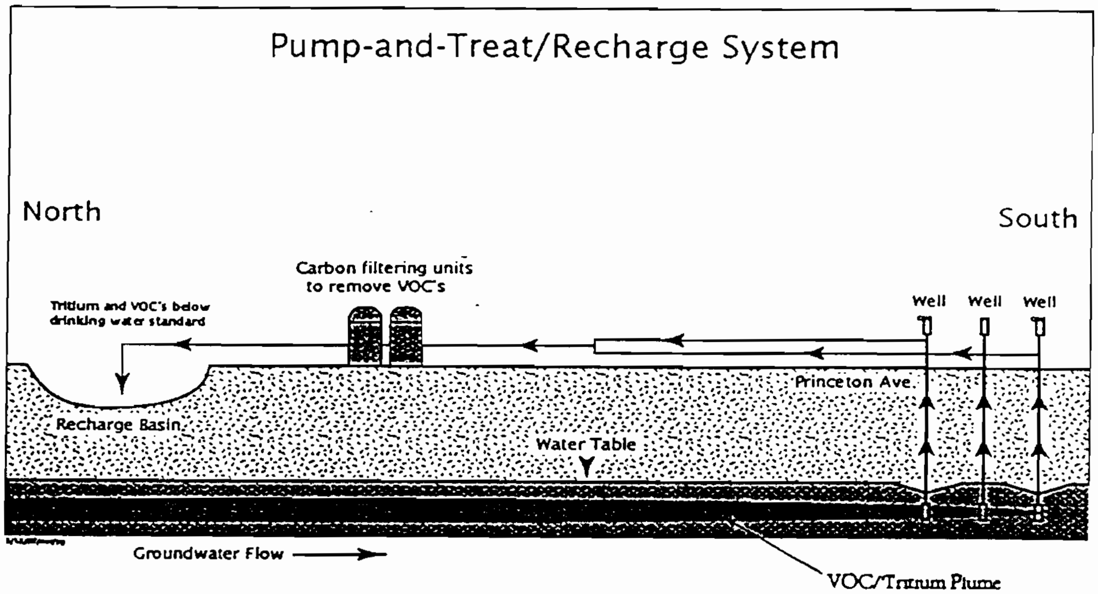


Figure 13 - Generalized Schematic of Pump and Recharge System

Before entering the recharge basin, the water passes through activated carbon filters to remove chemical contamination that is also present in groundwater in the area due to other past BNL activities. The activated carbon filters installed in the pumping system remove all of the Volatile Organic Compounds (VOCs) as an added benefit to the system. Samples of treated water are analyzed regularly in accordance with NYSDEC Discharge Permit Conditions to determine the tritium concentrations being recharged. Currently, as the water enters the recharge basin, the average tritium concentration is approximately 500 pCi/l, well below the drinking-water standard. Evaporation of tritiated water from the recharge basin was calculated and shown not to pose a risk to human health or the environment. Air monitoring stations were established near the recharge basin and samples analyzed regularly to measure the tritium in the air confirm the calculations.

Once the water has reentered the ground, it will flow southward (Figure 9), taking approximately nineteen (19) years to reach the southern BNL site boundary. By that time, natural decay and dilution will have diminished tritium levels to nearly undetectable levels. Monitoring wells located at the BNL boundary will provide further assurance that tritium, above the drinking water standard, will not leave the BNL site.

The pump-and-recharge remediation is an interim action to ensure tritium above the drinking water standard does not migrate across the BNL boundary. It also will give BNL and DOE time to study alternative remediation technologies or monitoring strategies, and to prepare a plan to address the high levels of tritium found immediately south of the HFBR Building.

The long-term remediation of the plume will be determined in the OU III RI/FS as AOC-29.

Additional Activities

The following additional remedial activities have been completed:

1. The construction of a SFP water management facility that included two new secondarily contained aboveground storage tanks (SCAT) in compliance with SCDHS Article 12 requirements.

2. Construction of a SFP water management facility that included two new secondarily contained aboveground storage tanks (SCAT) in compliance with SCDHS Article 12 requirements.

3. Implementation of a comprehensive plan for monitoring the groundwater plume and installation of additional groundwater monitoring wells as needed for long-term monitoring.

4. A detailed analysis of tritium transport from the source under transient conditions of recharge and pumping, including a variable concentration release to the aquifer.

The following additional remedial activities are ongoing:

1. On an ongoing basis, recontouring the tritium plume using the most recent tritium monitoring well data and evaluating implications on the pump-and-recharge system.

2. On the basis of the Operable Unit III Feasibility Study (FS), it will be determined if any additional actions are required, such as additional extraction wells and/or source containment. The OU III F/S has been submitted to regulators for comments.

• *SUMMARY*

Over the past year, an aggressive technical effort was undertaken by BNL and DOE, through the Tritium Remediation Project, to mitigate any potential health risk from the tritium discovered in groundwater south of the HFBR Building. Steps are underway to prevent additional releases of tritium from the HFBR Building. The SFP, which has been determined to be the principal source of tritium, has been drained and eliminated as a future source. Figure 14 shows the SFP; full of tritiated water before it was drained. The square objects that appear to be covering the bottom of the pool in the picture are actually the ends of the spent fuel elements stored in the pool prior to being drained. The ends of the spent fuel elements visible in the picture are actually several feet above the SFP floor and more than 15-feet below the surface of the pool water. The empty SFP is shown in Figure 15. The figure shows the floor of the 20-foot deep section, looking to the west. Also visible is the fuel discharge chute connection and the 30-foot deep section of the pool. The wet areas on the floor are from the final rinsing operation.

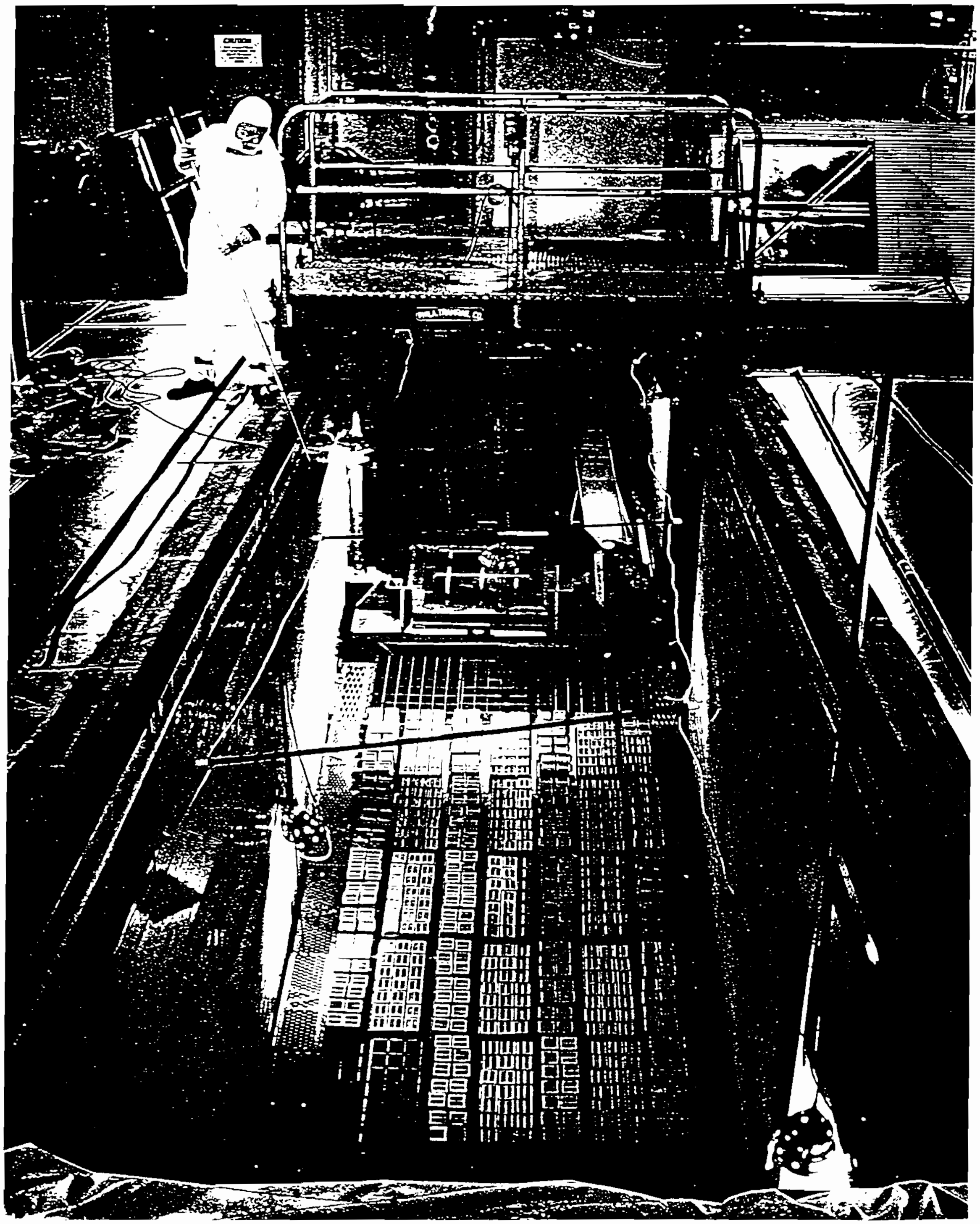


Figure 14 - View of Spent Fuel Pool Before Draining

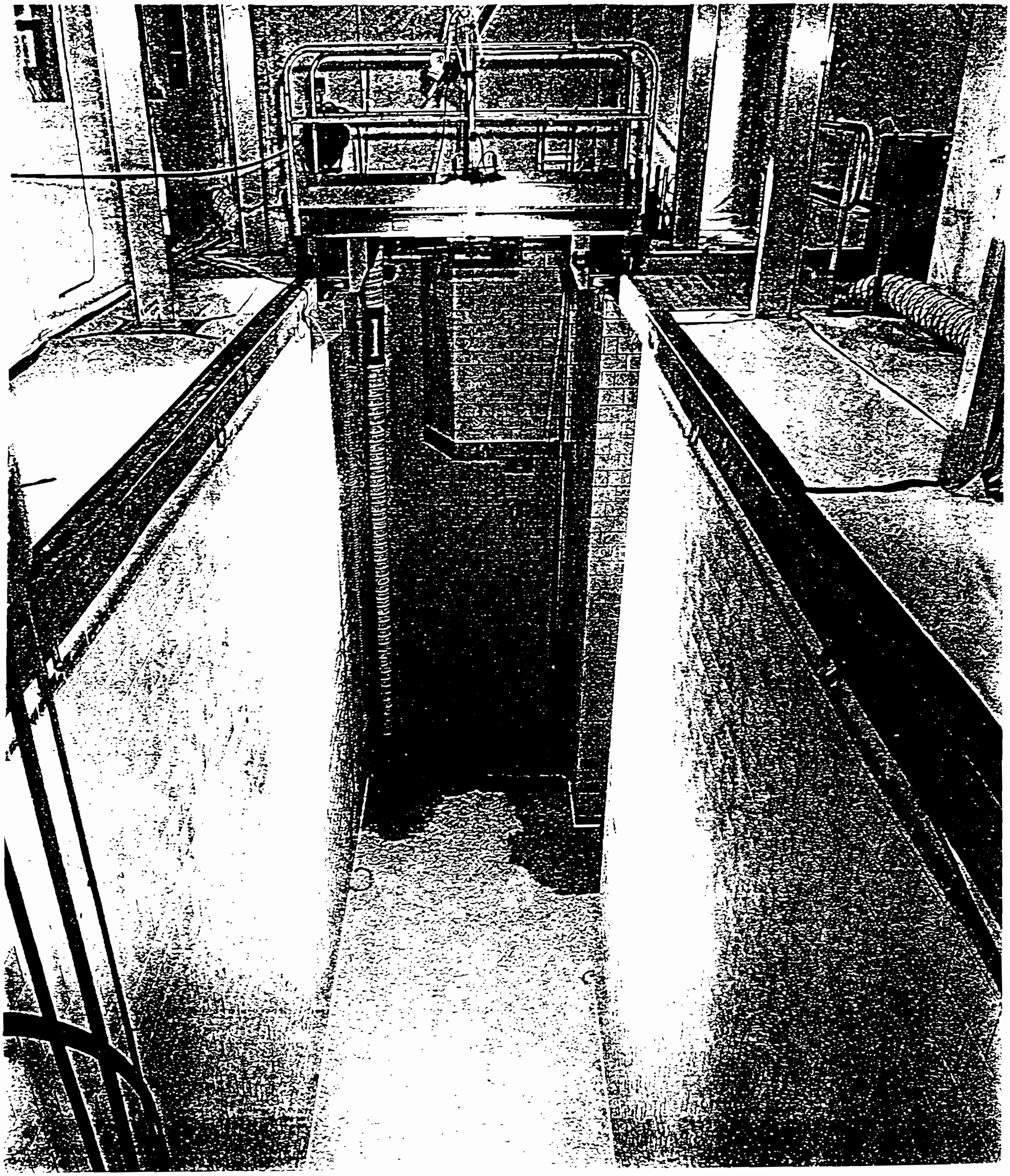


Figure 15 - View of Spent Fuel Pool After Being Drained

A groundwater extraction-and-recharge system has also been put into operation. The system further assures that migration of the tritium contamination will not occur until a permanent remedy for the tritium plume is established through the process of regulatory approval and community involvement.

Numerical modeling of the SFP tritium plume, based upon the detailed hydrogeological and contaminant distribution information collected to date suggests that, even without the extraction-and-recharge system, tritium levels above the drinking-water standard would not cross the BNL boundary. Now that the major short-term objectives of the Tritium Remediation Project have been achieved, groundwater restoration efforts have been transferred to the BNL Environmental Program for completion under the Interagency Agreement with the New York State Department of Environmental Conservation (NYSDEC) and the United States Environmental Protection Agency (EPA).

Project activities have been closed out, or are being transferred to the Office of Environmental Restoration (OER) for further activity under OU III, AOC-29 following the closure guidance provided in the TRP Quality Assurance Plan.

Conclusions

The following conclusions can be drawn from the studies, tests, and analyses that have been conducted to date by the Tritium Remediation Project:

1. The principal source of tritium from the HFBR Building is the SFP which was leaking at a rate of 6 to 9 gallons per day (~0.5 Curies per year). The extent of the tritium plume indicates that the SFP has been leaking for at least twelve years. Other potential minor contributing sources include historical sanitary system releases, and spills which could have leaked small volumes of primary coolant through floor seams and floor penetrations.

2. A freestanding double-wall stainless steel liner with an instrumented low-point sump is the best design option for eliminating future leakage from the SFP.

3. The proposed upgrades to the HFBR Building are designed to prevent leaks to the aquifer.

4. Continued slow migration beneath the HFBR Building through the vadose zone to the aquifer, combined with recent increases in tritium concentration in the SFP, may result in short-term increases in tritium concentrations in monitoring wells immediately down-gradient of the HFBR Building.

5. Groundwater modeling indicates that even without pumping, the tritium concentration in the plume will be less than the drinking-water standard at the BNL site boundary.

• *GLOSSARY*

Acronyms

BHG	Brookhaven Group (DOE)–The on-site DOE Area Office
BNL	Brookhaven National Laboratory
DOE	U.S. Department of Energy
EPA	U.S. Environmental Protection Agency
ESH	Environment, Safety, and Health
*HFBR	High Flux Beam Reactor
INEEL	Idaho National Engineering and Environmental Laboratory
*NEPA	National Environmental Policy Act (NEPA)
NRC	Nuclear Regulatory Commission
NYSAGO	New York State Attorney General's Office
NYSDEC	New York State Department of Environmental Conservation
NYSDOH	New York State Department of Health
*OU III	Operable Unit III
QA	Quality Assurance
SCDHS	Suffolk County Department of Health Services
SEP	Safety and Environmental Protection
*TRP	Tritium Remediation Project
*WBS	Work Breakdown Structure

*Refer to "Definitions" for additional information.

Definitions

AOC-29 - Each operable unit is subdivided into areas of concern (AOC) and Area of Concern 29 is the High Flux Beam Reactor (HFBR) Building Spent Fuel Pool and the associated groundwater tritium plume.

Article 12 - Actually Article 12 of the Suffolk County Sanitary Code which covers the regulation of hazardous material storage facilities.

Aquifer - An underground layer of rock, sand, or gravel capable of storing water within cracks and pore spaces, or between grains. When water contained within an aquifer is of sufficient quantity, it can be tapped and used for drinking or other purposes. The water contained in the aquifer is called groundwater.

Aquitard - A subsurface confining unit which is characterized by low permeability that does not readily permit water to pass through it despite the fact that it stores large quantities of water.

CD Drain - A drain system for contaminated D_2O (Deuterium Oxide or heavy water), the Reactor's primary coolant. Heavy water is processed in various systems throughout the Reactor Building and the CD drain system is part of the water management system for it.

Carbon Adsorption/Carbon Treatment - A treatment system in which contaminants are removed from groundwater, surface water, and air by forcing water or air through tanks containing activated carbon, a specially treated material that attracts and holds or retains contaminants. In the case of the TRP, the water removed from the ground and directed to the recharge basin in the pump and treat system is processed through a carbon treatment system before being recharged.

Characterization - Facility or site sampling, monitoring and analysis activities to determine the extent and nature of contamination. Characterization provides the basis for acquiring the necessary technical information to select an appropriate cleanup alternative.

Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) - Also known as Superfund. Federal statute enacted in 1980, that provides the statutory authority for cleanup of hazardous substances that could endanger public health, welfare, or the environment. Program activities include establishing the National Priorities List, investigation sites for inclusion on the list, determining their priority level on the list, and conducting, and/or supervising the ultimately determined cleanup and other remedial actions.

Contour Line - A line that has the same value along its entire length. The value of a contour line could be a concentration, height, temperature, etc. In the case of the TRP, it is a line of equal concentration (pCi/l) and height of the water table (feet).

D-Waste - Slightly radioactive water.

D-Waste Drains - Handle D-Waste liquid.

Decontamination - The removal or reduction of radioactive or hazardous contamination from facilities, equipment, or soils by washing, heating, chemical or electrochemical action, mechanical cleaning or other techniques to achieve a stated objective or end condition.

Down-gradient - A location of lower groundwater elevation toward which groundwater is moving.

Effluent - Wastewater, treated or untreated, that flows out of a treatment plant, sewer or industrial outfall; generally refers to wastes discharged into surface waters.

Environmental Restoration - Cleanup and restoration of sites contaminated with radioactive and/or hazardous substances during past Department of Energy activities.

Evapotranspiration - Evapotranspiration describes the total water removed from an area by transpiration and by evaporation. Transpiration is the evaporation of water from the leaves of plants.

Feasibility Study (FS) - A process for developing and evaluating remedial actions, using data gathered during the remedial investigation to: define the objectives of the remedial program for the site and broadly develop remedial action alternatives; perform an initial screening of these alternatives; and perform a detailed analysis of a limited number of alternatives which remain after the initial screening stage. An FS has been prepared for the TRP.

Geoprobe™ - The geoprobe unit is a modified hydraulic rotary hammer drill mounted on a fold-away assembly in a vehicle. The assembly transfers the weight of the vehicle onto the probe and couples it with the force of a hydraulic hammer. This combination enables the operator to drive probes to depths as great as 100-feet below land surface to collect groundwater samples.

Groundwater Divide - A ridge in the water table or other potentiometric surface from which groundwater moves away in both directions normal to the ridge line.

HFBR - High Flux Beam Reactor. One of the world's premier research reactors for using neutron beams to perform experiments in nuclear and solid-state physics, materials science, biology, and chemistry.

HFBR Building - The half spherical dome-like structure that houses the High Flux Beam Reactor, numerous supporting mechanical systems and, in the facility's basement, the Spent Fuel Pool (SFP).

Hazardous Waste - Toxic, corrosive, reactive, or ignitable materials that can negatively affect human health or damage the environment. They can be liquid, solid, or sludge, and include heavy metals, organic solvents, reactive compounds, and corrosive materials. They are defined and regulated by the Resource Conservation and Recovery Act.

Hydrogeology - The study of the interrelationship of geologic materials and processes with water.

Heavy Water - A form of water in which the hydrogen atoms ordinarily present in water are replaced by deuterium (symbol D), the heavy stable isotope of hydrogen. Heavy water (Deuterium Oxide, D_2O) is used as both a moderator and coolant in the HFBR.

Influent - Water, wastewater, or other liquid flowing into a reservoir, basin, or treatment plant.

Interagency Agreement - A written agreement between the U.S. Environmental Protection Agency (EPA) and a federal agency that has the lead for site cleanup activities (e.g., U.S. Department of Energy), that sets forth the roles and responsibilities of the agencies for performing and overseeing the activities. States are often parties to interagency agreements, as the New York State Department of Environmental Conservation (NYSDEC) is regarding Brookhaven National Laboratory (BNL).

Light Water - Ordinary water, but identified as "light" in the nuclear industry to distinguish it from heavy water to avoid any ambiguities with regard to process systems using water.

Micro Purge - The process of purging (pumping) a small volume of water from a well at the screen zone of that well. This is in contrast to the typical purging of a well that requires three to five well casing volumes to be pumped out prior to collecting samples.

National Environmental Policy Act (NEPA) - Enacted in 1970, NEPA established a national policy for federal review of environmental impacts before undertaking any action that might significantly affect the quality of the environment.

National Priorities List (NPL) - The Environmental Protection Agency's (EPA) list of the most serious hazardous waste sites identified for possible long-term remedial action under CERCLA (Superfund). The list is based primarily on the score a site receives from the Hazardous Ranking System. EPA is required to update the NPL at least once a year.

Operable Unit (OU) - The cleanup of a site can be divided into a number of operable units, depending on the complexity of the problems associated with a site. Operable units may address geographical portions of a site, specific site problems, or initial phases of an action, or may consist of any set of actions performed over time or any actions that are concurrent but located in different parts of a site.

Operable Unit III (OU III) - The BNL site is divided into a number of operable units and the TRP is located within Operable Unit III (OU III).

Outfall - The place where wastewater is discharged into a recharge basin or receiving waters.

pCi/l **(picocuries per liter)** - A curie is the conventional unit of activity defined as the quantity of a given radioisotope that undergoes nuclear transformation or decay at a rate of 3.7×10^{10} (37 billion) disintegrations each second. Because the curie is a very large amount of activity, subunits of the curie are often used; for example, 1 picocurie (pCi) = 10^{-12}Ci, or 1 picocurie = 0.000 000 000 001 Ci. The tritium plume is characterized with this unit of measure.

Plume - A body of contaminated groundwater flowing from a specific source. The movement of the groundwater is influenced by such factors as local groundwater flow patterns, the character of the aquifer in which the groundwater is contained, and the density of the contaminants.

Project Baseline - Definition of project scope, cost and schedule which forms the basis for measuring performance and controlling changes to the project plan.

Radionuclide - An unstable isotope of any chemical element that decays or disintegrates spontaneously, emitting radiation.

Record of Decision (ROD) - Documents the regulators' decision for the selected remedial action, and includes the responsiveness summary and a bibliography of documents that were used to reach the remedial decision. When the ROD is finalized, remedial design and construction can begin.

Release - Spilling, leaking, pumping, pouring, emitting, emptying, discharging, injecting, escaping, leaching dumping, or disposing of a hazardous substance, pollutant, or contaminant into the environment. The National Contingency Plan also defines the term to include a threat of release.

Remedial Investigation (RI) - Through extensive sampling and laboratory analyses, the RI characterizes the nature and extent of contamination, defines the pathways of migration, and measures the degree of contamination in surface water, groundwater, soils, air, plants, and animals. Information gathered during the RI attempts to fully describe the contamination problem at the site so that the appropriate remedial action can be developed. An RI has been prepared for the TRP.

Removal Actions or Removals - Such actions are undertaken to prevent, minimize, or mitigate damage to the public health or environment which may otherwise result from a release or threatened release of hazardous substances, pollutants, or contaminants pursuant to CERCLA, and which are not inconsistent with the final remedial action.

Stakeholder - An organization or individual that has an interest in issues or activities that affect BNL. Includes neighbors, civic organizations, elected officials, media, regulators, etc.

Superfund - The common name for the federal program established by the Comprehensive Environmental Response, Compensation and Liability Act of 1980, as amended in 1986. The Superfund Law authorizes the U.S. Environmental Protection Agency to investigate and clean up sites nominated to the National Priorities List.

Tritium - Tritium is the only radioactive form of hydrogen, created when a second neutron attaches to a normal hydrogen atom. Tritium has a half-life of 12.3 years; that is, its radioactive strength decreases by half every twelve years. Normally found as a gas or liquid, tritium is produced in nature when cosmic rays interact with gases in the earth's upper atmosphere. At BNL, liquid tritium is produced in the cooling water of the HFBR, which is a reactor used to produce neutrons for experimental research. Tritium is commonly used in: glow-in-the dark wristwatches, luminant highway and room "exit" signs, and bio-medical studies as a "tagging" agent. Tritium produces low-energy beta radiation that can travel less than an inch through air and cannot pass through barriers such as paper or dead skin cells. It does not pose an external radiation exposure threat to humans. Tritium enters the body the same way as water: through the mouth (ingestion), breathed in with the air we breath (inhalation), or through the skin (absorption). When tritium is taken into the body, it dilutes evenly through all body fluids and is eventually excreted. A person eliminates, through excretion or perspiration every ten to fifteen days one half of any tritium in the body.

Tritium (Cont.)
The U.S. Environmental Protection Agency sets standards for safe drinking water. The standard assumes a person drinks two quarts of water per day for a year. At the tritium standard of 20,000 picocuries per liter, a person would receive a radiation dose of 1 millirem a year. In comparison, the average person in the United States receives about 300 millirem a year from natural sources.

Tritium Remediation Project (TRP) - A project jointly established by DOE and BNL at BNL to remediate the tritium contamination found in the groundwater south of the HFBR Building.

Up-gradient - A location of higher groundwater elevation.

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