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NUREG/CR-7029

Lessons Learned in Detecting, Monitoring, Modeling and Remediating Radioactive Ground-Water Contamination

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ABSTRACT

Brookhaven National Laboratory (BNL) is a multi-discipline Department of Energy (DOE) research institute that has been in operation since 1947. Historical operations included running accelerators, nuclear research reactors, and other large complex equipment. Some of these operations caused groundwater contamination. This report discusses the tritium plume from the High Flux Beam Reactor and several strontium plumes from past operations at the Brookhaven Graphite Research Reactor, their discovery through monitoring, and their treatment. The tritium plume discovery led to public outrage; characterization, design, and implementation of a treatment system within 60 days; and eventual dismissal of Associated Universities Incorporated from the management of BNL despite the small health risk to employees or the public. Management of the strontium plume included a major alteration to the original regulatory cleanup agreement when field data showed the preferred alternative to be economically impractical. The report documents activities used to manage these contamination issues through source control, monitoring, modeling, plume and risk management, and communications. The lessons learned from these cleanup projects have altered the stewardship culture and methods of performing research, communicating with the public, and conducting work at BNL. These valuable lessons are highlighted in this report.

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EXECUTIVE SUMMARY

Brookhaven National Laboratory (BNL) is a multi-discipline Department of Energy research institute that has been in operation since 1947. Historical operations included running accelerators, nuclear reactors, and other large complex equipment. Some of these operations caused groundwater contamination. This report discusses the tritium plume from the High Flux Beam Reactor (HFBR) and several strontium plumes from past operations at the Brookhaven Graphite Research Reactor (BGRR), their discovery through monitoring, and their treatment.

The HFBR operated from 1965 to 1996, and was used solely for scientific research providing neutrons for materials science, chemistry, biology, and physics experiments. During a routine maintenance shutdown in 1996, tritium from the spent fuel canal was found in groundwater south of the reactor. Investigations revealed that the source of the tritium was leakage through the ceramic tile lined concrete walls of the pool where spent nuclear fuel was stored. The tritium plume that resulted from this leakage was located entirely within the Laboratory property. The portion of the plume that exceeded the drinking water standard for tritium (20,000 pCi/l) extended approximately 4,500 feet north of BNL's southern boundary at depths from 40 to 150 feet below land surface. The 20,000 pCi/l plume was approximately 2,600 feet long and 250 feet wide. The highest tritium activity detected was 5,100,000 pCi/l in a monitoring well adjacent to the HFBR. The tritium plume discovery led to public outrage; characterization, design, and implementation of a treatment system within 60 days; and eventual dismissal of Associated Universities Incorporated from the management of BNL.

The BGRR operated from 1950 to 1968. In March of 1997 an underground tank built to collect drainage from piping associated with the BGRR was found to contain about 750 gallons of water that showed elevated levels of strontium-90. Initial characterization analysis of temporary monitoring wells revealed concentrations of Sr-90 in the groundwater as high as 566 pCi/L, approximately 70 times the drinking water standard of 8 pCi/L.

The timing of the discovery of this contamination coincided with the characterization of the tritium plume from the HFBR. The already heightened community and media sensitivity to groundwater contamination created additional outrage at the discovery of this new radiological groundwater contamination. So even though the Sr-90 contamination was very local to its source, it received significant media and community attention. Characterization of this and another Sr-90 plume near a former waste disposal site was conducted in 1997 and 1998 to define the extent of contamination. At that time, site-specific soil K_d measurements were made and modeling was performed for each of these plumes and it was projected that Sr-90 would not leave the BNL site in concentrations exceeding the 8 pCi/l Drinking Water Standard. This combined with institutional controls to prevent on-site access of the contaminated water made this a small risk to the public and BNL employees.

Even though predicted health risks from these plumes were small, the institutional risk due to public outrage and political pressures necessitated a comprehensive effort by BNL to remedy the situation. BNL expended substantial resources to characterize, monitor, model, and manage these plumes. Simultaneously, BNL improved communications with the public and regulators

through regular meetings and updates on the state of all environmental contamination issues at the facility.

The lessons learned from these cleanup projects have altered the stewardship culture and methods of performing work at BNL. These valuable lessons have been divided into five categories: 1) source control, 2) monitoring, 3) modeling, 4) plume/risk management, and 5) communications. The lessons are highlighted in this report and are summarized below.

Source Control

Source control involves the identification and characterization of all potential sources that can lead to releases to the environment. For groundwater contamination, source control also includes containment of the high concentration areas of the plume to prevent migration downgradient (or off-site). Failure to perform adequate early source control will lead to more difficult and more expensive cleanup efforts. Major lessons learned at BNL include:

1. Understanding the potential environmental vulnerabilities and quickly identifying the source of groundwater contamination is critical for achieving credibility with the regulators and the public. (Section 2.3.2)
2. The release of contaminants from the vadose zone, particularly mobile contaminants such as tritium, during periods of water table rise needs to be considered as a continuing source term. Establish field monitoring to achieve early detection of vadose zone releases. (Section 2.4.3)
3. Early cleanup efforts should focus on eliminating the source. Once the source is eliminated a more accurate estimate of life cycle remediation and associated costs can be realized. (Section 2.4)
4. Source hotspots should be controlled even if monitoring and modeling is incomplete. Inaction at the time of discovery of a hotspot concentration can result in longer and more complicated remedial activities further downstream. (Section 2.4.4)
5. Tritium treatment and separation technologies found in the literature are not appropriate for environmental remediation of the relatively low concentrations and large volume of tritiated water in an aquifer or surface water. (Section 4.1)

Monitoring

Monitoring is the collection and evaluation of data to support all phases of cleanup. It should start with monitoring of facilities for leakage and include data collection to support decisions involving remediation and plume management.

6. Facility ground water monitoring is an important defense in the early detection of unexpected releases to the environment. The realization that tritium was being released from the HFBR to the groundwater at BNL occurred many years after the release began due to inadequate facility monitoring. Expansion of the facility monitoring program at BNL after 1997 uncovered other contaminants that needed to be addressed. (Section 2.1)
7. In an attempt to pinpoint the source location, horizontal wells were installed beneath the spent fuel pool. Use of new techniques (horizontal wells for locating the source, in this

case) should be carefully planned and limitations fully understood before implementation. (Section 2.3.5)

8. Geoprobes™ and temporary wells that provided vertical profiles of the contamination concentrations are effective tools for an "early response" plume characterization. Vertical characterization of the plume was important at BNL due to the well-defined (vertically thin) nature of the tritium plume. (Section 2.5)
9. Monitoring well screens should be as short as possible or low-flow purge sampling methods should be used to ensure the detection of vertically discreet layers of tritium. (Section 5.0)
10. Tritium's lack of any retardation in groundwater can quickly cause a permanent monitoring well network to become ineffective in response to rainfall and external pumping and recharge influences. Therefore temporary monitoring wells should be used over the life cycle of the remediation to a much greater extent than with "conventional" plumes. (Section 5.1)
11. Substantial and iterative monitoring data are needed to (Section 5.0):
    - identify changes that could warrant modifications to the monitoring program
    - validate the groundwater model and other remediation assumptions; and
    - provide feedback to stakeholders on the problem and progress of its mitigation.

Modeling

Modeling is the use of computer tools that predict the movement of groundwater and contaminants, and their release from the facility through the vadose zone into the groundwater.

12. It is essential to have a calibrated site-wide groundwater model in place that can (Section 3.2):
    - help select monitoring locations,
    - support risk analysis on the impact of a particular plume
    - support evaluation of remedial alternatives, and
    - support design (location and pumping rate) of the selected remediation system.
13. It is important that site activities that could impact plume movement are documented and their potential impacts evaluated. This includes on-site supply well pumping, impacts of recharge basins, annual rain fall amounts, water table fluctuations, and major spills/leaks. (Section 3.0)
14. Site-specific soil characterization information for input to the groundwater model provides better results and should be used. In some cases, additional data collection may be required to improve model accuracy. The importance of an accurate groundwater model increases over time when assessing the long term impacts of the plume and its remediation. (Appendix A)
15. For porous media that do not cause substantial mechanical dispersion, modeling using finite-difference methods may under predict downgradient concentrations for tritium unless great care is placed in accounting for numerical dispersion. (Section 3.0)

Plume/Risk Management

Plume/Risk Management is the process by which all decisions are made. It entails use of the monitoring data and modeling to evaluate alternatives and to support decisions.

16. A well developed process that ensures that all elements are included in a risk based remediation decision needs to be in place and implemented. The process includes requirements for contingency plans, regular progress reports, and formal periodic reviews. The process mandated by CERCLA as used at BNL is an example of a robust process. (Section 1.5)
17. The required cleanup work should be specified in a performance based format with set goals rather than specific remedies already determined. A performance based format allows flexibility to perform the remediation cost effectively and efficiently. (Section 4.4)
18. Pilot studies are extremely useful in evaluating the effectiveness of remedial alternatives (strontium-90 treatment), providing supporting documentation to improve a final remedy, and in demonstrating responsiveness to the contamination problem. (Section 6.2.1)
19. There are long term benefits for establishing data quality objectives (DQOs) at the beginning of the process. (Section 5.2) These benefits include:
    a. helping to focus data collection and decisions on the performance goals;
    b. forming a basis to demonstrate that sampling frequency can be reduced or should be increased based on trends in the data;
    c. forming a basis for implementing contingency plans when goals are not being met; and
    d. forming a basis to implement an exit strategy, such as turning off an extraction system, when goals are met.
20. From the perspective of the site owner/operator in discussion of risk assessment, it is important to factor in risk to the Institution as a result of public outrage and media attention. At BNL it was often shown that human health and ecological risks were below typical regulatory levels of concern. However, institutional risks (lack of credibility, loss of funding) and public concerns often dominated the discussions. (Section 4.2)
21. Adaptive management techniques are useful when evaluating the monitoring data. BNL has adapted to changes in tritium plume management (hot spot removal) and strontium-90 plume remediation (poor performance of original treatment system) that resulted in long-term positive outcomes. (Section 6.5)
22. Effort should be expended to manage a plume within the facility boundaries. Once off-site migration occurs both real and perceived risk greatly increase. (Section 2.6)

Communication

Communication is needed in all phases of the remediation process and includes describing the contamination problem, what caused the problem, potential risks to the public from the contamination, and what is being done to address the problem. Effective communication requires the willingness to listen to and address, to the extent possible, stakeholder concerns. It also requires frequent discussions to update stakeholders on the progress of the characterization and cleanup.

23. Public perception may not always agree with technical facts. Lack of trust between the community and BNL caused many people to believe they were negatively impacted by BNL operations when in fact they were not. The lack of trust even caused some community members to interpret pro-active public water extensions to address perceived concerns about solvent plumes as a tacit admission of guilt by BNL even though the data indicated that there were no drinking water wells impacted by the contamination from BNL. (Section 7.3)

24. Establishing a public involvement process before there is a problem is important (Good Neighbor Policy). At BNL, it was extremely difficult to establish a Community Advisory Council (CAC) in a crisis situation. Initially there was a complete lack of trust. (Section 7.1)

25. Communications requires continual effort and providing a venue for regular updates to environmental regulators, public officials, and the community is essential (e.g., Brookhaven Executive Roundtable-BER and the Community Advisory Council-CAC). (Section 7.4)

26. The BNL experience revealed some initiatives that did not work. This included providing weekly updates to the media (press releases) of the plume characterization. Some in the community thought the news was a new problem being discovered each week. (Section 7.2)

27. Risk communication is important. It is essential to provide a clear message to the public. BNL had difficulties explaining co-mingled plumes (tritium from HFBR and VOCs from other sources). In some cases, BNL provided too much data including contaminant levels far below the drinking water standards which caused members of the public to believe the extent of contamination was greater than it actually was. (Section 7.2)

28. Workshops and availability sessions were much more effective than large public meetings. Specific items of concern could be addressed more readily in the smaller group settings. (Section 7.2)

ACKNOWLEDGMENTS

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ACRONYMS

ARAR	Applicable or Relevant and Appropriate Requirements
BGRR	Brookhaven Graphite Research Reactor
BNL	Brookhaven National Laboratory
CAC	Community Advisory Committee
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
DOE	U.S. Department of Energy
DWS	Drinking Water Standard
EPA	U.S. Environmental Protection Agency
HFBR	High Flux Beam Reactor
MCL	Maximum Concentration Limit
MSL	Mean Sea Level
NRC	Nuclear Regulatory Commission
NYSDEC	New York State Department of Environmental Conservation
OU	Operable Unit- A project designation under CERCLA
OU III	Operable Unit Three
PFS	Pile Fan Sump associated with the Brookhaven Graphite Research Reactor (BGRR).
PFT	Perfluorocarbon Tracer
ROD	Record of Decision
RI/FS	Remedial Investigation/Feasibility Study
SCDHS	Suffolk County Department of Health Services
SFP	Spent Fuel Pool
TVOC	Total Volatile Organic Compounds
UST	Underground Storage Tank
VOC	Volatile Organic Compounds
WCF	Waste Concentration Facility at BNL

1.0 INTRODUCTION

1.1 Background

Brookhaven National Laboratory (BNL) is located about 60 miles east of New York City, in Upton, Suffolk County, New York, near the geographic center of Long Island (Figure 1-1). Approximately 1.4 million people reside in Suffolk County and approximately 450,000 reside in Brookhaven Township, within which BNL is situated. BNL has operated since 1947 as a research facility for national science and technology programs. BNL is owned by the U.S. Department of Energy (DOE), one of the 17 DOE national laboratories. BNL conducts research in the physical, biomedical, and environmental sciences, as well as in energy technologies and national security. The Laboratory also builds and operates major scientific facilities available to university, industry, and government researchers.

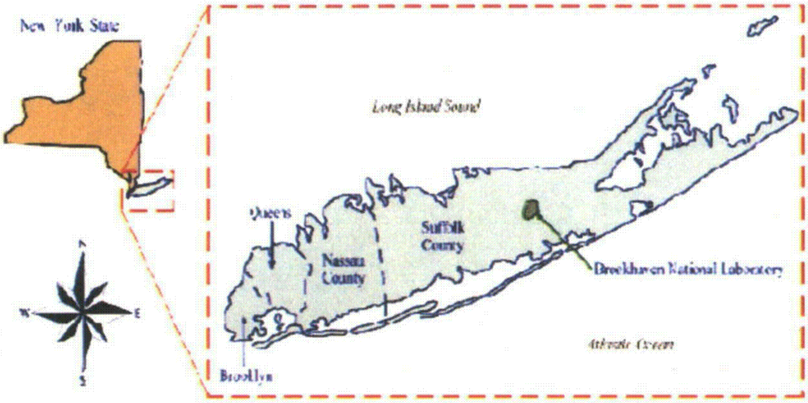


Figure 1-1: Location of BNL (DOE, 2005b)

The BNL property, consisting of over 5,000 acres, is an irregular polygon, and each side is approximately 2.5 miles long. The developed portion of the BNL Site includes the principal facilities, which are located near the center of the BNL Site on relatively high ground (Figure 1-2). The developed portion is approximately 900 acres, 500 acres of which were originally developed for Army use. The remaining nearly 4000 acres is primarily wooded with gently rolling terrain. The land lies on the western rim of the shallow Peconic River watershed, with a tributary of the Peconic River rising in marshy areas in the northern section of the tract.

The sole-source aquifer beneath BNL comprises three water-bearing units: the Moraine and outwash deposits, the Magothy Formation, and the Lloyd Sand Member of the Raritan Formation. These units are hydraulically connected and make up a single zone of saturation with varying physical properties extending from a depth of five to 1,500 feet below the land surface. These three water-bearing units are designated as a "sole source aquifer" by the U.S. Environmental Protection Agency (EPA) and serve as the primary source of drinking water for Nassau and Suffolk Counties.

The U.S. Army occupied the BNL Site, formerly Camp Upton, during World Wars I and II. Between the wars, the Civilian Conservation Corps operated the BNL Site. It was transferred to the Atomic Energy Commission in 1947, to the Energy Research and Development Administration in 1975, and to DOE in 1977. Brookhaven Science Associates (BSA) operates BNL under a contract with DOE. In 1980, the BNL Site was placed on the New York State Department of Environmental Conservation's (NYSDEC) list of Inactive Hazardous Waste Sites. On November 21, 1989, the BNL Site was included on EPA's National Priorities List because of soil and groundwater contamination that resulted from the Laboratory's past operations. Subsequently, the EPA, NYSDEC, and DOE entered into a Federal Facilities Agreement under the Comprehensive Environmental Response Compensation & Liability Act (CERCLA) that became effective in May 1992 to coordinate the cleanup.

Figure 1-2: Aerial View of BNL-2007

The BGRR (Figure 1-3), which was the first reactor in the U.S. built solely to perform experiments, operated from 1950 to 1968. Deactivation of the facility was initiated in September 1969. In March 1972, the last fuel element was removed from the reactor and shipment of the fuel to the DOE Savannah River Site was completed shortly thereafter. Fuel handling operations that occurred during its operating life contributed to the existence of strontium-90 (Sr-90) in the groundwater at BNL. The Sr-90 plume south of the BGRR is approximately 1,000 feet long and 500 feet wide with concentrations as high as 566 pCi/L.

Figure 1-3: Brookhaven Graphite Research Reactor (BGRR); (DOE, 2005b)

Figure 1-4: High Flux Beam Reactor (HFBR); (DOE, 2009)

The HFBR (Figure 1-4) operated from 1965 to 1996, and was used solely for scientific research providing neutrons for materials science, chemistry, biology, and physics experiments. During a routine maintenance shutdown in 1996, tritium from the spent fuel canal was found in groundwater south of the reactor. Investigations revealed that the source of the tritium was leakage through the ceramic tile lined concrete walls of the pool where spent nuclear fuel was stored. Operations at the HFBR were suspended and the DOE considered what to do. All of the spent fuel was removed and sent to DOE's Savannah River Site in 1998. The pool was drained and a freestanding, double-walled, stainless steel liner with an instrumented low point sump was installed to eliminate the potential for leakage to the environment. In November 1999, DOE announced it was permanently closing the reactor.

The tritium plume was always located entirely within the boundaries of the Laboratory. In 1997, the portion of the plume that exceeds the drinking water standard for tritium (20,000 pCi/l) extended approximately 4,500 feet north of BNL's southern boundary at depths from 40 to 150 feet below land surface. The dimensions of the 1,000 pCi/l plume were approximately 3,200 feet long and 625 feet wide. The 20,000 pCi/l plume was approximately 2,600 feet long and 250 feet wide. The highest tritium activity detected was 5,100,000 pCi/l in a monitoring well adjacent to the HFBR.

1.2 BNL Hydrogeology

This section briefly describes the hydrogeologic environment at BNL and the surrounding area. Detailed descriptions of the aquifer system underlying BNL and the surrounding areas are found in the U.S. Geological Survey (USGS) report by Scorca and others (USGS, 1999), *Stratigraphy and Hydrologic Conditions at the Brookhaven National Laboratory and Vicinity, Suffolk County, New York, 1994–97.*

The stratigraphy below BNL consists of approximately 1,300 feet of unconsolidated deposits overlying bedrock (**Figure 1-5**). The groundwater monitoring program at BNL focuses on groundwater quality within the Upper Pleistocene deposits (Upper Glacial aquifer), and the upper portions of the Matawan Group-Magothy Formation (Magothy aquifer). These aquifers provide drinking water to Long Islanders.

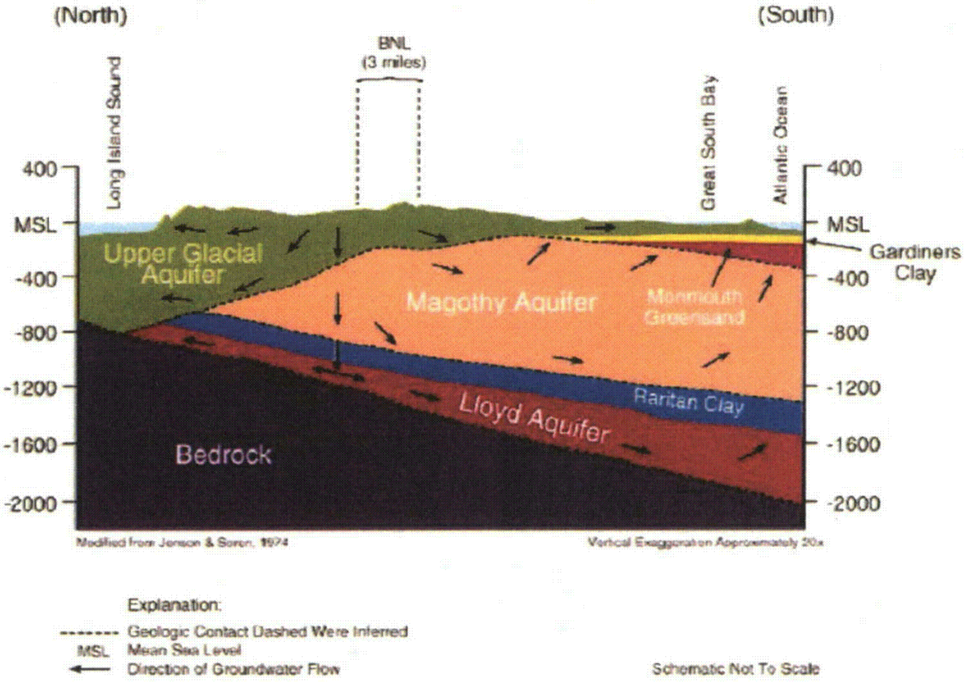


Figure 1-5: Generalized Geologic Cross Section in the Vicinity of BNL (BNL, 1998)

The Pleistocene deposits are about 100–200 feet thick and are divided into two primary hydrogeologic units: undifferentiated sand and gravel outwash and moraine deposits, and the finer-grained, more poorly sorted Upton Unit. The Upton Unit makes up the lower portion of the Upper Glacial aquifer beneath several areas of the BNL site. It generally consists of fine- to medium-grained white to greenish sand with interstitial clay.

In addition to these two major hydrogeologic units, there are several other distinct hydrogeologic units within the Upper Glacial aquifer. They include localized, near-surface clay layers in the vicinity of the Peconic River (including the Sewage Treatment Plant [STP] area), and reworked Magothy deposits that characterize the base of the aquifer in several areas. The Gardiners Clay is a regionally defined geologic unit that is discontinuous beneath BNL and areas to the south. Typically, it is characterized by variable amounts of green silty clay, sandy and gravelly green clay, and clayey silt. Where it exists, the Gardiners Clay acts as a confining or semi-confining unit that impedes the vertical flow and migration of groundwater between the Upper Glacial aquifer and the underlying Magothy aquifer.

The Magothy aquifer is composed of the continental deltaic deposits of the Cretaceous Age that unconformably underlie the Pleistocene deposits. The Magothy aquifer at BNL is approximately 800 feet thick, and because it is composed of fine sand interbedded with silt and clay, it is generally less permeable than the Upper Glacial aquifer. The Magothy aquifer is highly stratified. Of particular importance at BNL is that the upper portion of the Magothy contains extensive, locally continuous layers of grey-brown clay (referred to as the Magothy Brown Clay). Regionally, the Magothy Brown Clay is not interpreted as being continuous; however, beneath BNL and adjacent off-site areas, it acts as a confining unit (where it exists), impeding the vertical flow and movement of groundwater between the Upper Glacial and Magothy aquifers.

Regional patterns of groundwater flow near BNL are influenced by natural and artificial factors. Under natural conditions, recharge to the regional aquifer system is derived solely from precipitation. A regional groundwater divide exists immediately north of BNL. It is oriented roughly east–west, and appears to coincide with the centerline of a regional recharge area. Groundwater north of this divide flows northward, ultimately discharging to the Long Island Sound. Shallow groundwater in the BNL area generally flows to the south and east. During high water-table conditions, that groundwater can discharge into local surface water bodies such as the Peconic River and adjacent ponds. The BNL site is within a regional deep-flow recharge area, where downward flow helps to replenish the deep sections of the Upper Glacial aquifer, the Magothy aquifer, and the Lloyd aquifer. South of BNL, groundwater flow becomes more horizontal and ultimately flows upward as it moves toward regional discharge areas.

1.3 Chronology

This section focuses on the sequence of events beginning in 1997 when tritium contamination was found above the drinking water standard near the HFBR and strontium-90 contamination was found at levels above the drinking water standard in groundwater downgradient of the BGRR.

1.3.1 Tritium from the HFBR

Discovery of tritium in the groundwater near the Brookhaven National Laboratory High Flux Beam Reactor (HFBR) in January 1997 initiated an intense effort to locate its source, determine its extent, and implement remediation methods to mitigate its consequences. The tritium plume that resulted from the slow, long-term leakage of contaminated water from the HFBR spent fuel pool at BNL was the subject of much attention by the media, State and Federal regulators, and the public in 1997. Tremendous amounts of resources were dedicated to characterizing the plume in great detail and in mitigating its consequences (Gunther, 2008).

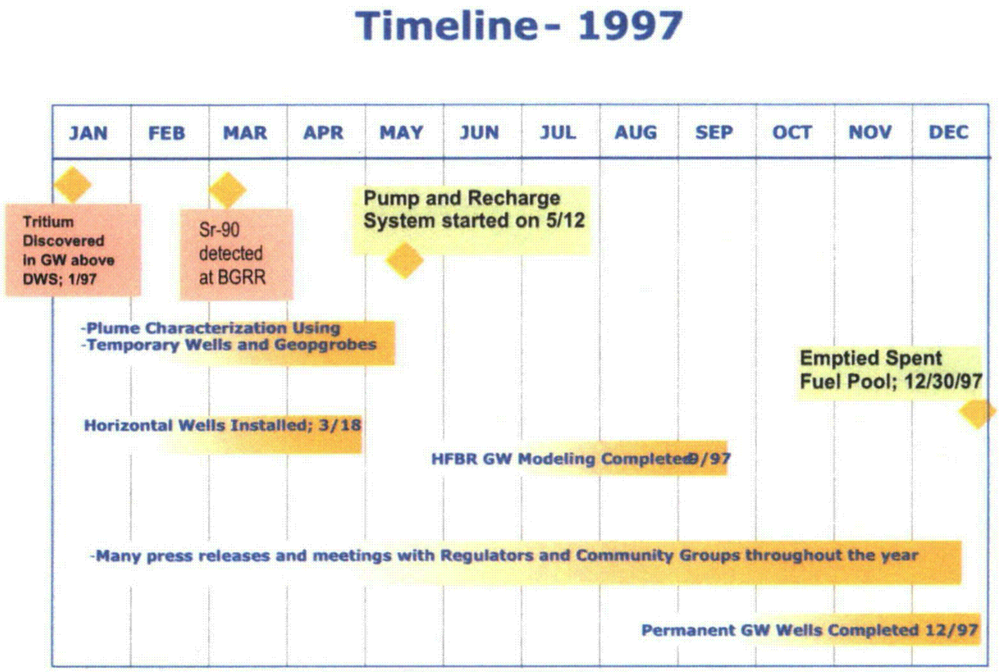


Figure 1-6: Timeline of Major Activities and Accomplishments in 1997

The tritium plume from the HFBR was determined to be approximately 4,200 feet long. The source of the plume was a 12-year-old leak from the reactor's spent fuel pool (SFP). This source of groundwater contamination was removed in December 1997 when the pool was drained. While plans were being developed to remediate the tritium plume, an Interim Remedial Action (IRA) consisting of groundwater pumping and upgradient recharge was implemented at the leading edge of the plume to prevent it from migrating beyond Princeton Avenue, a point approximately 1 mile from the site boundary in the direction of groundwater flow. The IRA system went into operation in May 1997 and was transferred into a standby mode in September 2000 when it was demonstrated that the plume concentrations were lower than specific action levels specified in the Operable Unit III Record of Decision (ROD) (DOE, 2000).

Figure 1-6 illustrates some of the key events that occurred during 1997 related to the discovery of tritium near the HFBR. Besides the construction, installation, and operation of the interim extraction wells in May 1997, other key dates include:

- Installation of two horizontal wells in March 1997
- Installation of over 150 vertical profiles and geoprobes between January and May 1997
- Emptying of the spent fuel pool (source elimination) in December 1997

The ROD had performance based measures that required the restart of the pump and recharge system if tritium concentrations exceeded trigger levels at pre-specified locations. In 2008 a fourth extraction well was added to the pump and recharge system. This additional well has been operated since then as part of the contingency plan agreed to in the ROD.

1.3.2 Strontium-90 Contamination from the BGRR

In March of 1997 an underground concrete collection tank (known as the pile fan sump) built to collect drainage from piping associated with the BGRR was found to contain about 750 gallons of water that showed elevated levels of strontium-90. Analysis of temporary monitoring wells revealed concentrations of Sr-90 in the groundwater as high as 566 pCi/L, approximately 70 times the drinking water standard of 8 pCi/L.

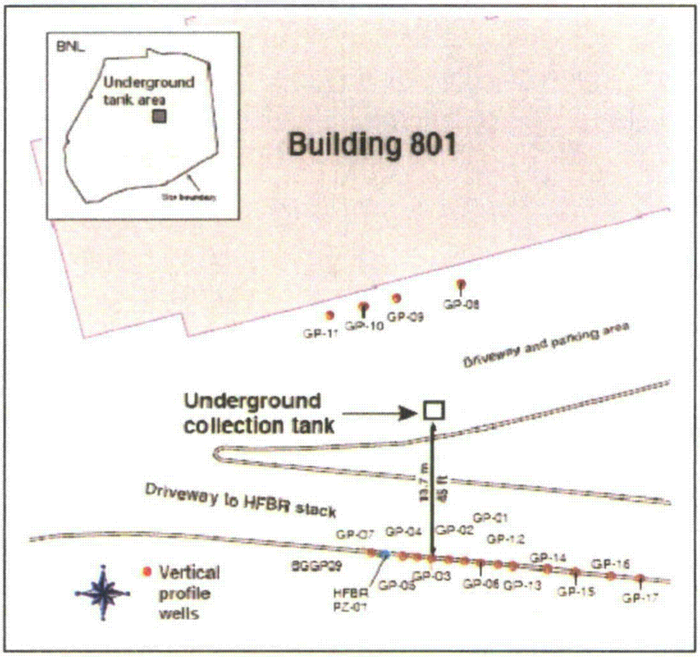


Figure 1-7: Monitoring wells installed to characterize Sr-90 Plume (BNL, 2008b)

The timing of the discovery of this contamination coincided with the characterization of the tritium plume from the HFBR. The all ready heightened community and media sensitivity to groundwater contamination created additional outrage at the discovery of this new radiological groundwater contamination. So even though the Sr-90 contamination was very local to its source, it received significant media and community attention. Characterization of this and another Sr-90 plume near a former waste disposal site was conducted in 1997 and 1998 to define the extent of contamination. At that time, site-specific soil K_d measurements were made (Fuhrmann, 1999). Modeling was performed for each of these plumes and it was projected that Sr-90 would not leave the BNL site in concentrations exceeding the 8 pCi/l Drinking Water Standard. This combined with institutional controls to prevent on-site access of the contaminated water made this a small risk to the public and BNL employees.

1.3.3 Timeline of Major Activities and Accomplishments Since 1997

Table 1-1 presents a brief timeline of important activities/milestones that occurred from the discovery of the tritium plume in 1997 to the present day (2010).

Table 1-1: Timeline of Events from 1997-2010

DATE	MILESTONE
January 1997	Discovery of Tritium in the groundwater just south of the HFBR
March 1997	Detection of Strontium-90 in an underground collection pit and in the groundwater south of the BGRR
1998	Community Advisory Council (CAC) formed
2000	Operable Unit III Record of Decision (ROD) signed
2001	Completed low flow tritium pumping system; removed ~100,000 gallons of tritiated groundwater for off-site disposal
2004	Completed the BGRR Strontium-90 groundwater treatment system
2005	Explanation of Significant Difference Issued; modified the Sr-90 treatment system and goals
2006	Tritium concentrations exceed trigger levels thereby requiring reactivation of the Pump and Recharge system.
2008	Installed additional extraction well to capture the downgradient high concentration tritium slug, as shown by 2008 temporary and permanent well data
2010	Update provided to CAC- need to further modify the Sr-90 treatment system to achieve cleanup goals

1.4 Remedial Action Process

The Remedial Action process, Figure 1-8, used at BNL has a number of well-defined steps that help to insure that cleanup objectives are achieved in an efficient and timely manner.

The initial step involves identifying Applicable or Relevant and Appropriate Requirements (ARARs). Brookhaven National Laboratory is a Department of Energy facility operated by Brookhaven Science Associates. BNL operates under DOE Orders and is also a Superfund site. At BNL, we manage our environmental remediation activities under the CERCLA (Comprehensive Environmental Response, Compensation, and Liability Act) process as overseen by the Environmental Protection Agency (EPA). New York State Department of Environmental Conservation (NYSDEC) is tasked with insuring that State regulations and objectives are met during remediation. The Suffolk County Department of Health (SCDHS) insures that all local regulations are followed. Each of these agencies is actively involved in making decisions within the constraints of being protective of human and ecological health, time, budget, and technical feasibility.

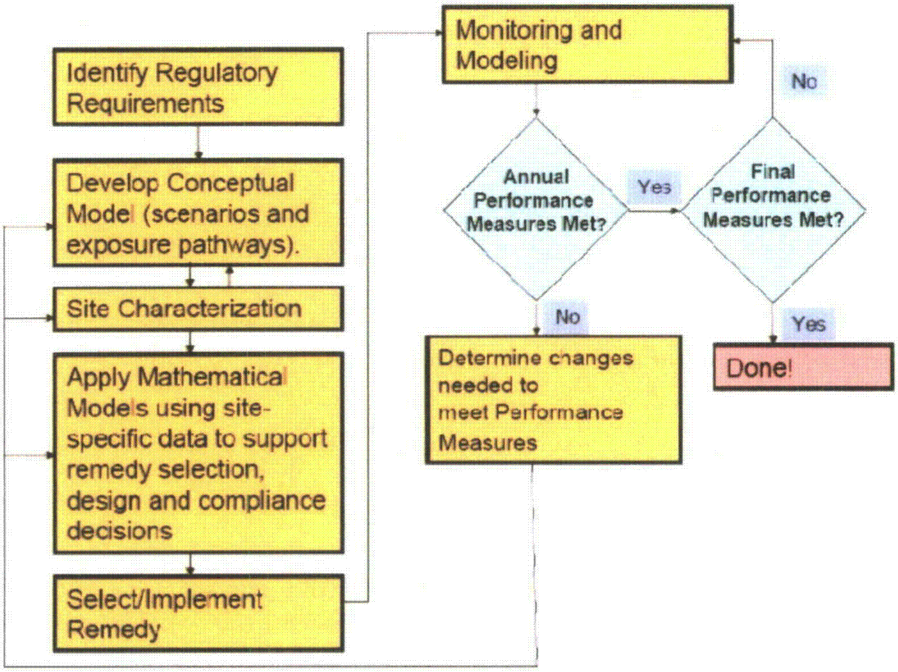


Figure 1-8: Basic steps in the Remedial Action Process

The next step in the process is to develop a conceptual model of the site. This model should identify the scenarios and exposure pathways. Typical scenarios for groundwater contamination include on-site workers that may be exposed due to removal actions and either off site residential exposure, or if institutional control of the site may be lost, a residential scenario located on the current site. Exposure pathways include:

- Ingestion of contaminated water or food grown with contaminated water.
- Inhalation of volatile compounds.
- Absorption through the skin due to washing with contaminated water or exposure to contaminated air.
- Direct exposure to ionizing radiation.

The conceptual model should form the basis for the collection of site characterization data.

Site characterization should be performed to support decisions pertaining to remediation. It will include data to define the regions of contamination as measured by the concentration of the pollutants. Characterization should also include the evaluation of long-term sources from industrial processes or, for groundwater contamination, the effects of the vadose zone acting as a long-term source. Characterization data will also include data to support the models that predict the transport of contaminants to the receptors. For groundwater flow this will include hydraulic head measurements, hydraulic conductivity and porosity of the different soil layers. For contaminants that sorb to the soil, site-specific distribution coefficients should be determined for the different soil layers. Additional characterization data may be needed based on the exposure scenarios and pathways selected for analysis.

Using the conceptual model as the framework, mathematical models (flow and transport, human risk, ecological risk, etc.) are used to predict the movement of the contaminants and human and ecological risks. Modeling is also used to assist in:

- remedy design (for example, capture zone based on flow rate),
- remedy selection through predicting/supplying information to evaluate the costs of the remedy (for example, volume of water that must be treated, volume of ion exchange resin needed, etc.), and
- remedy effectiveness through prediction of the removal rate of contaminants and the time to reach compliance goals.

The modeling results based on site-specific data obtained in the characterization phase are used to support remedy selection. Typically several remedial alternatives will be evaluated with alternatives ranging from monitored natural attenuation through more sophisticated and costly remedies. The selected remedy is proposed by the responsible party (generally the land owner) and must be justified based on meeting clean up goals, costs, time, technical feasibility, and protection of human health and the environment. The proposed remedy must be approved by all regulatory agencies prior to implementation.

1.5 Plume Management

For groundwater contamination problems, the Plume Management Phase begins once the remedy is implemented. An overview of this process is presented in Figure 1-9. Plume management involves monitoring to confirm that cleanup objectives are being met. The monitoring and modeling information should be evaluated annually to determine if the cleanup is going according to plan. If it is proceeding as expected, an evaluation is made to determine if the remediation has been successfully completed. If it is not, monitoring is continued for another year.

Lesson Learned: A well developed process that ensures all elements are included in a risk based remediation decision needs to be in place and implemented. The process mandated by CERCLA at BNL is an example of a robust process.

If the expectations for cleanup (often measured using data quality objectives) are not being met, then additional action is required. At BNL the cleanup agreements include Action Levels (concentrations above a threshold) that invoke contingency plans. This contingency action could require more modeling to assess if the remedy will eventually meet cleanup objectives or if additional treatment measures are needed. If additional measures are needed they could involve any step in the remedial action process as shown in Figure 1-9.

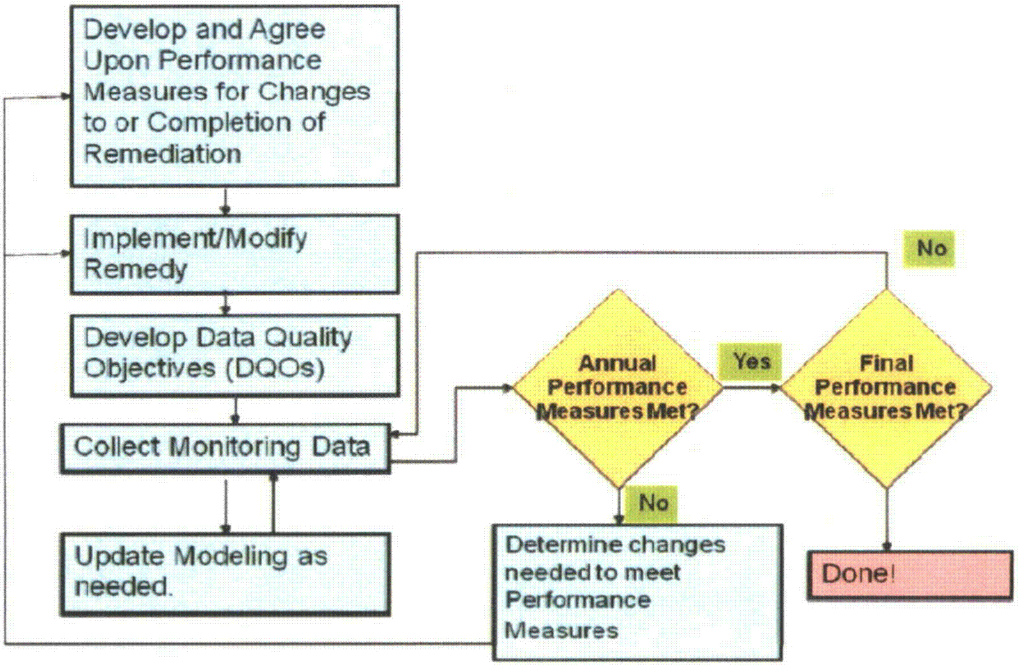


Figure 1-9: Overview of Plume Management

Plume management is often a long-term process. For example, for the Sr-90 plume at BNL, the goal is to meet drinking water standards in the aquifer after 70 years. Due to incomplete characterization and imprecise knowledge of the physical properties that govern flow and transport it is prudent to have an adaptive management scheme that can adjust to unanticipated changes. A critical component of plume management is to develop performance measures that can be used to determine if the cleanup is proceeding as expected and to define when the cleanup is completed. Performance measures can take many forms, for example, lowering concentrations below drinking water standards or achieving a specified mass of contaminants removed. The performance measures often have time or cost constraints. These performance measures can then be used to set Data Quality Objectives (DQOs). The DQOs form the foundation for collecting monitoring data that is useful in the determination of the success of the remediation. The monitoring data is collected and evaluated on a routine basis as specified in agreements with the regulatory agencies.

At BNL a self-evaluation is performed annually. The performance measures used for evaluation are typically a series of questions such as:

(1) *Was the BNL Groundwater Contingency Plan triggered?*

(2) *Has the plume been controlled?*

(3) *Is the system operating as planned? Specifically, is the aquifer being restored at the planned rate identified in the Record of Decision?*

(4) *Have the cleanup goals been met? Can the groundwater treatment system be shut down?*

Based on the answers to these questions, a recommended course of action is provided. The recommendations can be as simple as changing the monitoring schedule or locations based on low measured values at certain locations, adding new monitoring locations to better track the plume, up to substantial changes such as altering the treatment process because the Contingency Plan was triggered. Any change to existing operating procedures must obtain regulatory approval. Examples of this process such as the tritium hot spot removal and changing the Sr-90 cleanup period for Sr-90 from 30 years to 70 years because of unexpected poor performance of the ion exchange media (fouling with non-radioactive contaminants caused excessive use of the resins) are discussed in more detail in this report.

1.6 Report Objectives

This report provides detailed lessons learned on detecting, monitoring, modeling, and remediating ground-water contamination and for communicating the information and analyses to the public within a risk-informed, performance-based approach. It is expected that NRC Licensing and Regional Inspectors can use the insights and lessons for reviewing ground-water remediation and monitoring programs, and for communicating the risks to the public and other government stakeholders.

The technical focus is to obtain lessons learned and insights from the highly detailed, 13-year effort at Brookhaven National Laboratory (BNL) for detecting, monitoring, modeling and remediating ground-water contaminants [i.e., H-3, Sr-90, and volatile organic compounds (VOCs)] at the BNL site. Of significant value is the long-term database available from BNL's confirmatory monitoring program to illustrate the role and effectiveness of various remediation remedies for H-3, Sr-90 and VOC's. The DOE Record of Decision (ROD) identifies monitoring triggers as to when the activation of various combinations of remediation methods are needed for mitigation of the problem.

Simultaneously, modeling studies were performed to predict the contaminant plumes migration over time and how various remediation strategies could be employed to mitigate risks to the public and the environment. There has been considerable interaction with government entities [i.e., EPA, DOE, New York State Department of Environmental Conservation (NYSDEC) and Suffolk County], as well as community groups (e.g. the community advisory council) to develop a consensus on the remediation process.

2.0 HFBR TRITIUM PLUME; SOURCE CONTROL AND CHARACTERIZATION

Tritium was first found above the drinking water standard south of the HFBR during routine sampling of two newly installed groundwater monitoring wells in January, 1997. In response to intense political and public pressure after the discovery, an interim accelerated response was initiated to ensure protection of the public, worker health, and the environment. Accelerated actions are allowed under CERCLA to execute rapid environmental response actions. This section describes the accelerated responses taken and highlights the lessons learned associated with these activities.

2.1 Identification of the Problem

Elevated levels of tritium in the groundwater were first discovered down-gradient (south) of HFBR 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 Spent Fuel Pool was considered a storage tank without secondary containment and, as such, required compensatory groundwater monitoring. Two wells were installed in July 1996 and sampled in October. The initial results reported by BNL in December 1996 through the DOE's Occurrence Reporting and Processing System was that tritium was detected at roughly 1/10 the drinking water standard. Additional sampling conducted in January 1997 revealed tritium in the groundwater above EPA's drinking water standard of 20,000 pCi/L.

Lesson Learned: Facility monitoring is an important early line of defense in an environmental monitoring program. The detection of tritium in the groundwater at BNL took many years due to inadequate facility monitoring.

2.2 Commitment to Take Actions within 60 Days

Three milestones of 30, 60, and 90 days were established by BNL and DOE in February 1997 to help define and guide the remediation efforts planned, and provide a platform for communication with stakeholders. The 30 and 90 day commitments dealt with the spent fuel pool. The 60 day milestone established was to initiate operation of a system which would stop any further migration of the tritium plume above the drinking water standard

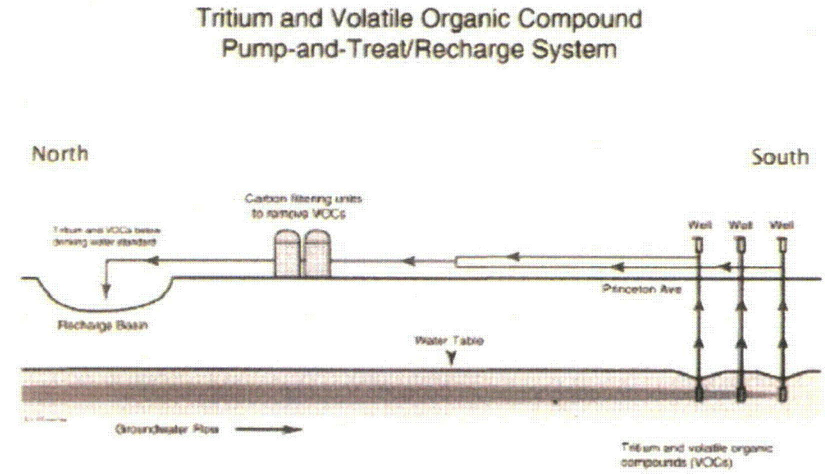


Figure 2- 1: Conceptual Schematic of the Tritium System (BNL, 1998)

towards the southern site boundary. The system, shown in figure 2-1, was ready ahead of schedule but operation was delayed until May 12, 1997 to resolve concerns raised by Suffolk County. Note that because of the existence of chemical contaminants, a filter system was installed prior to recharging the pump effluent.

2.3 Approach to Defining the Extent of Contamination

The initial approach contained two major focuses:

- Identification and control of the source of tritium
- Characterization of the plume

2.3.1 Evaluation of Potential Sources

Investigation of the potential source(s) of the HFBR tritium plume was a major focus of the initial responses to the discovery of tritium in the groundwater beneath and south of the HFBR building. BNL analyzed potential sources where the tritiated water could have leaked without being detected and concluded that the HFBR building must have been the source.

The following findings supported the conclusion that the HFBR must have been the principal source of the tritium in the groundwater:

1) The results of groundwater sampling indicated high tritium concentrations downgradient of the HFBR building,
2) Only low concentrations of tritium were found immediately upgradient of the HFBR Building,
3) Significant contamination was found near the top of the water table in the immediate vicinity of the HFBR Building (suggesting a source near the sample locations based on the known groundwater flow directions),
4) No unusual levels of tritium were detected in the groundwater flow path except from the direction of the HFBR Building,
5) Data on concentrations in the plume were consistent with an assumed long-term continuous source; and,
6) Leak-rate testing confirmed that the leak-rate from the Spent Fuel Pool (SFP) was 6 to 9 gallons per day. *(Note: one gallon of leakage was equivalent to a change in level in the spent fuel pool of .004 inches.)*

2.3.2 Potential Sources within the HFBR Structure

Source identification within the HFBR building consisted of reviewing reactor components that had the potential to release tritium into the environment, and testing components for leaks to determine the integrity of each of the potential sources containing tritium. In some cases leak detection was not possible and engineering evaluations and visual inspections were performed instead.

Lesson Learned: It is important to understand the potential sources of groundwater contamination. This knowledge permits a rapid identification of the source and response for remediation efforts and critical for achieving credibility with the regulators and the public.

As a first step the following systems that manage radioactive fluids were identified and examined:

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

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 isolated to conduct a credible leak test. For those systems, other methods such as detailed engineering evaluations and visual inspections were used to determine the likelihood of a past release.

2.3.3 Results of the Spent Fuel Pool (SFP) Leak Tests

Two separate leak tests confirmed that the SFP was leaking tritiated water at a rate of 6 – 9 gallons per day. These leak tests performed in 1997 were more accurate than the previous leak tests and involved covering the spent fuel pool to eliminate evaporation and measuring water level changes using a laser measurement system. Historical concentrations of tritium in the pool had been nominally 40 million pCi/l, with an increase to about 140 million pCi/L in 1995. These concentrations were determined to be consistent with tritium concentrations observed in groundwater samples from the plume emanating from the HFBR Building (Sullivan and Cheng, 1997).

2.3.4 Sanitary Sewer System

Prior to 1995, the nominal tritium concentration in the sanitary sewer system, as monitored at the outlet of the building, varied from about 10,000 pCi/L to 50,000 pCi/L. 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.

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

2.3.5 Horizontal Wells Installed Beneath the HFBR Containment Structure to Further Isolate the Potential Source of the Tritium Leak

To further characterize the release of tritiated water from the SFP, horizontal wells were installed at two locations under the HFBR Building in March 1997. The need to define the source location this accurately (within a few feet) is not common and horizontal wells are not routinely used for this purpose. The first (downgradient) well was installed 10 feet south, and parallel with the southern wall of the SFP. The second (upstream) well was installed 17 feet north and parallel to the north wall of the SFP (Fig. 2-2). By design, the horizontal wells were to be installed within the uppermost 2 to 3 feet of the saturated zone of the aquifer to allow for the proper monitoring of the tritium plume and to ensure that the wells would not go dry upon minor fluctuations of the water table. During the installation of the wells, variability in soil composition and saturation resulted in minor deviations in the desired borehole position. Although the up-gradient well was installed 1.5 to 2.5 feet below the water table, the down-gradient well was installed slightly lower than designed, at a position 3.5 to 4.5 feet below the water table. This had a major impact on the utility of these wells. The screened section of both wells was 50 feet. Discrete samples were collected at intervals of 10 feet along the screened length (using sample isolating packers) in an effort to pinpoint the source of the leak.

The rationale behind the placement of the two wells was to:

1) determine the extent of leakage along the length of the SFP;
2) determine concentrations of tritium in groundwater directly beneath the SFP; and
3) evaluate whether tritium has been released from other potential up-gradient sources such as buried pits, piping, and trenches in the equipment level floor.

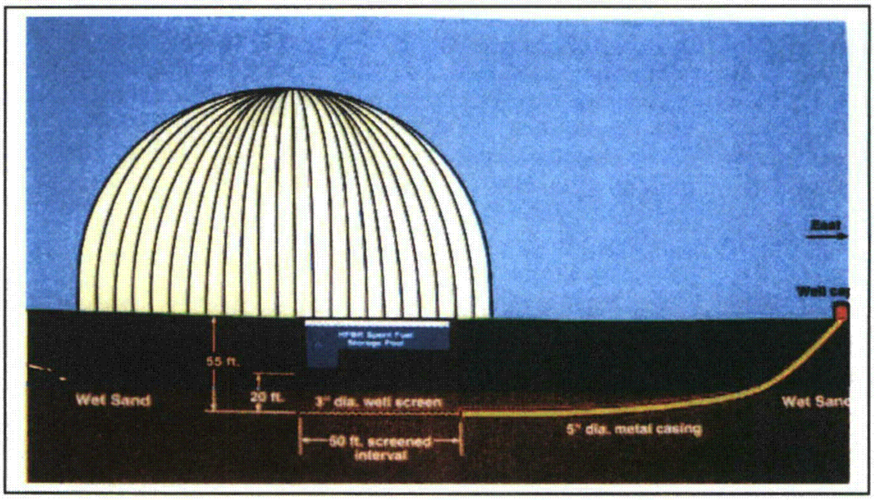


Figure 2-2: Horizontal wells for sampling groundwater below the HFBR (BNL, 1998)

Uncertainties existed in the actual pathway that the tritiated water followed in the vadose zone above the water table, and the tritium from the SFP was detected in the upgradient well due to lateral spreading. Furthermore, based upon groundwater modeling, laminar groundwater flow, and the observed vertical distribution of tritium in wells located immediately downgradient of the HFBR, it was recognized that the tritium directly below the SFP was likely to reside within the uppermost 1 to 2 feet of the aquifer. Thus, the downgradient horizontal well was too far beneath the water table to capture the high concentration section of the plume.

The horizontal wells were first sampled in late March and early April. Following the initial sampling, spring rains resulted in a steady rise in water table elevation, and the wells were not in a proper position to accurately monitor the uppermost portion of the aquifer until August 1997.

Lesson Learned: Use of new techniques (horizontal wells for locating the source, in this case) should be carefully planned and limitations fully understood before implementation.

From August 1997 through January 1998 five rounds of samples were collected from the horizontal wells, with collection periods corresponding to each 0.5 foot drop in water table elevation. The results from these samples did not conclusively demonstrate that the SFP was the only source of tritium emanating from the HFBR facility. The highest tritium concentrations were detected in the upgradient well at a maximum concentration of approximately 383,000 pCi/L, whereas tritium concentrations in the downgradient well were much lower, with a maximum observed concentration of approximately 1,700 pCi/l. The observed higher tritium concentrations in the upgradient horizontal well could have been caused by the well's higher elevation than the downgradient well and, therefore, sampling closer to the top of the water table where higher tritium concentrations were expected to occur.

This effort demonstrated that in hydrogeologic conditions where the contamination is within a few feet of the water table, it is too difficult to install horizontal wells at the desired depth. Near the point where the contaminated tritium enters the groundwater there is an extremely thin (< a few feet) vertical distribution of tritium. It is not possible to install the wells perfectly horizontal to the water table. At BNL the downgradient well was a few feet deeper than the upgradient horizontal well. Additionally, near the water table, extraction rates have to be low to prevent drawing the water down to the well depth. All of these factors make accurate definition of the contaminant distribution by a 2 to 4 inch horizontal well very unlikely.

2.4 Source Control

2.4.1 HFBR Building Source Control

All spent fuel elements were removed from the SFP and shipped to the Savannah River Site for storage and final disposition. The last shipment left BNL in early September 1997. 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.

Lesson Learned: Initial efforts should focus on eliminating the source. Once the source is eliminated a more accurate estimate of life cycle remediation needs and associated costs can be determined.

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.

To eliminate the SFP as a potential future source of tritium contamination in the groundwater, a double walled stainless-steel liner with leak detection and collection capability was installed. A freestanding double-walled stainless steel liner with an instrumented low point sump was selected. This renovated SFP is shown in figure 2-3.

Figure 2-3: Double-lined Spent Fuel Pool

Source control is a required component when implementing EPA's Monitored Natural Attenuation Guidance. At BNL, source control was achieved by draining the SFP allowing the plume to be managed in situ on the BNL property.

Further discussion on source control is found in Appendix C, Lessons Learned Applicable to NRC's Buried Piping Initiative. A potential method for detecting leaks from buried piping using perfluorocarbon gas tracers is discussed in Appendix D.

2.4.2 Modification of the Existing HFBR Building

BNL and DOE worked with SCDHS to ensure all buried piping, pits, and trenches conform to SCDHS Article 12. SCDHS Article 12 requires that all systems that contain hazardous waste have secondary containment. Methods of achieving secondary containment included either rerouting or retrofitting underground and embedded piping, pits, and trenches in the HFBR Building. When completed, all potential sources of tritiated water had secondary containment, except for spills to the equipment level floor. BNL also developed 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.

2.4.3 Vadose Zone Source Contribution

A conceptual drawing was generated using available geologic information from below the HFBR building and an understanding of groundwater flow to illustrate the area where tritium might be entering the water table. Log readings from foundation borings drilled during the analysis of the reactor foundation indicated the vadose zone consists of heterogeneous layers of sand mixed with varying amounts of silt, clay, and gravel. Direct investigation beneath the HFBR building was not possible at the time due to containment breach issues.

Tritium from the SFP likely moved preferentially along horizontal layers that contain more coarse grained materials as illustrated in Figure 2-4.

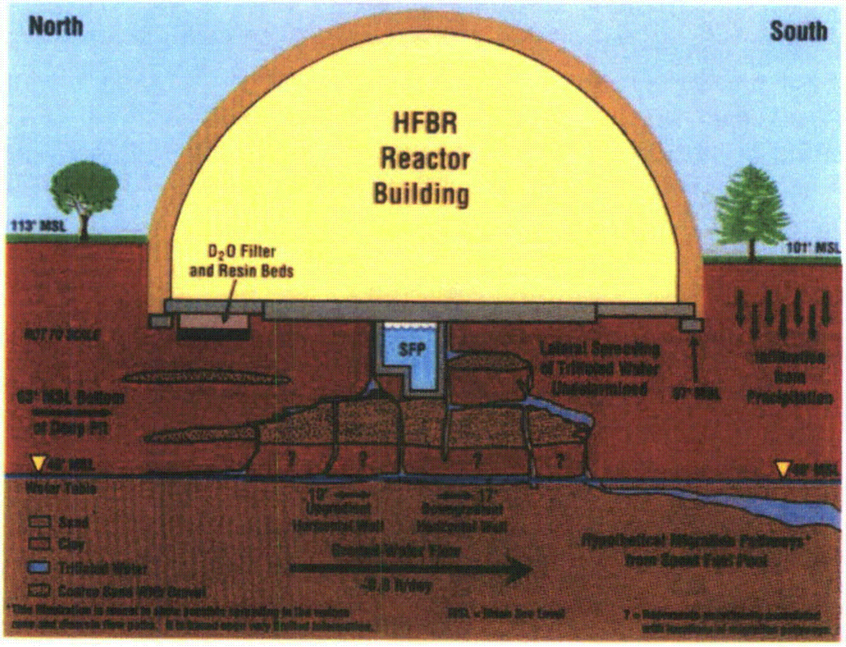


Figure 2-4: Conceptual Drawing of Vadose Zone Transport Beneath the HFBR (BNL, 1998)
(Note that drawing is misleading regarding the width of the clay unit- it is permeable silty clay)

Once the tritium reached the saturated zone of the aquifer, it moved in a thin layer along the top of the water table under the reactor where there was no downward gradient due to rainwater. The observed higher concentrations in the upgradient well were explained as being due to two factors: the upgradient horizontal well was at a higher elevation (closer to the water table with higher tritium concentrations) than the downgradient well: and the tritium likely has moved northward during transport through the vadose zone, to the saturated zone.

This effort at source characterization illustrates the difficulty in defining every flow path close to a potential tritium leak source. However, at greater distances, the extensive network of temporary and permanent monitoring wells was effective in delineating the plume.

Lesson Learned: The release of contaminants from the aquifer's vadose zone, particularly mobile contaminants such as tritium needs to be considered as a continuing source term.

Tritium released into the vadose zone often migrates into and out of dead-end pores. This causes a long-slow release of tritium. This effect has been observed at the HFBR and other tritium leaks at BNL. In addition, water table elevation changes happen on a faster time scale than diffusion. Therefore, when the water table is rising, tritium just above the previous water table elevation in the capillary fringe enters the aquifer. This leads to episodic pulses of tritium being released for transport in the groundwater.

2.4.4 Immediate Hot Spot Removal

Lesson Learned: Hot spot removal in the groundwater for mobile contaminants should be done as soon as possible. Delays can lead to a longer and more complicated cleanup.

Early in the tritium plume investigation the highest concentration of tritiated groundwater ranged up to 5.1 million pCi/L immediately south (downgradient) of the HFBR containment building. Even before modeling and monitoring were completed it was determined that removal of these highest concentrations immediately downgradient of the HFBR building would be considered a form of source control and should be performed as soon as possible. Based on analytical calculations and engineering judgment the lower concentration that would trigger immediate pumping from a monitoring well close to the HFBR was determined to be 2 million pCi/L. Source hotspots should be controlled even if monitoring and modeling is not complete. Inaction at the time of discovery of a hotspot concentration can result in longer and more complicated remedial activities further downstream.

2.5 Detailed characterization of the plume

In January 1997, tritium was detected in groundwater at a concentration of 44,700 pCi/l in a monitoring well approximately 100 feet downgradient of the High Flux Beam Reactor (HFBR). This is in excess of the Federal and State drinking water standard for tritium (20,000 pCi/l). After discovering the tritium contamination, a swift and extensive characterization program was initiated to determine the source and extent of the contamination.

Three types of wells were used for characterization. Characterization included forty-five temporary geoprobe wells drilled to depths of up to 100 feet. These wells were sampled at five foot intervals and used near the HFBR to determine the plume location and concentrations. Geoprobe wells were installed upstream and downstream from the HFBR. These wells confirmed that the HFBR was the source of the tritium.

Twenty-seven permanent monitoring wells were installed downgradient of the HFBR. These wells provide water table measurements needed for accurate modeling of plume movement and provide fixed sampling locations. Several permanent wells were installed close to the HFBR and provide access for withdrawal of high concentration sections of the plume. These wells typically had 10 foot screens.

Sixty-three temporary vertical profile wells were installed at depths to fully characterize the plume (< 200 feet below land surface). These wells had 5 foot screens and were sampled at ten foot intervals from the water table down with approximately 20 sample locations per well. At some sampling locations, VOCs from other sources were found in the groundwater. Therefore, wells were sampled for tritium, VOCs, and other radionuclides. In all over 1500 samples were analyzed for tritium and VOCs within a three month period.

Figure 2-5 shows the well locations used for sampling. Key location references and their approximate distance downgradient from the HFBR in the figure include Cornell Avenue (~100 feet), Temple Place (~ 300 feet), Brookhaven Avenue (~750 feet), Rowland Street (~ 1500 feet), Weaver Drive (~ 2500 feet) and Princeton Avenue (~3000 feet). These streets on the BNL property will be referenced in the following discussions of the plume. Figure 2-6 shows the concentration profile along the centerline of the plume in April of 1997, for approximately 3000 feet from the HFBR and the location where the pump and recharge system was installed, near Princeton Avenue. The peak tritium concentration measured at this time was 651,000 pCi/L and the location was just in front of the HFBR (Figure 2-7).

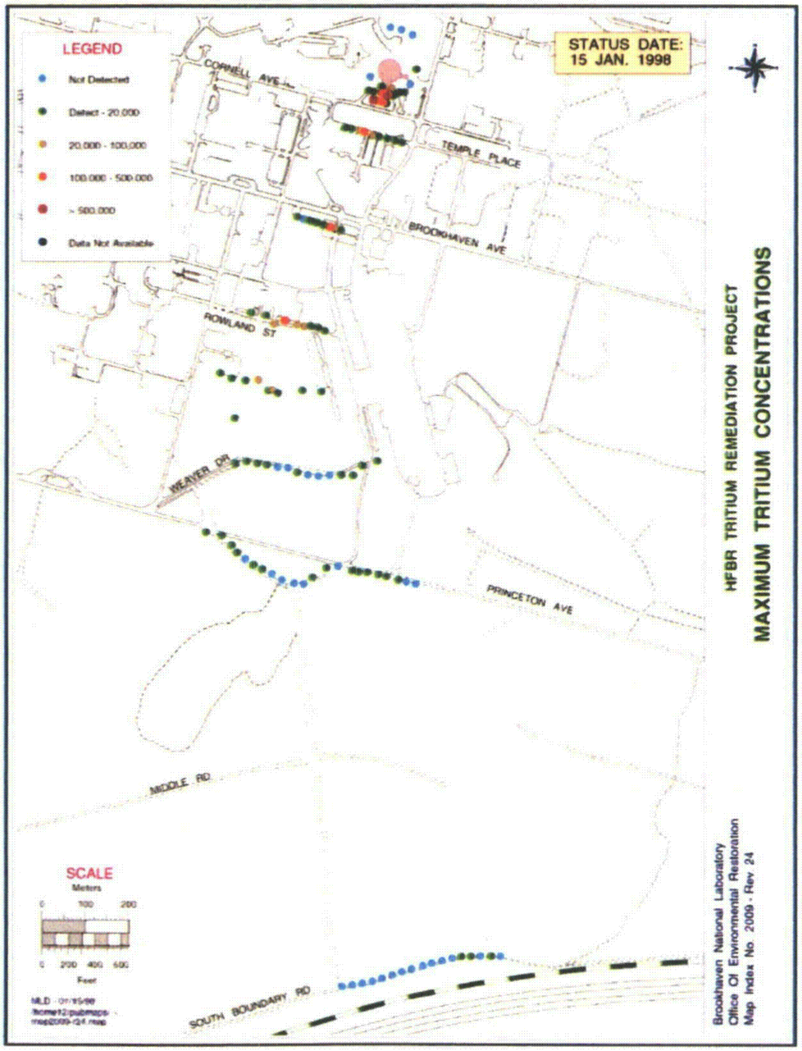


Figure 2-5: Map showing location of sampling wells used to define the tritium plume

The characterization efforts showed that the plume of tritium was vertically thin (30 feet after 2000 feet of movement downgradient). Wells installed for tritiated water sampling must be much more in the center of the plume than is the requirement for contaminants with non-zero retardation coefficients or density differences with water (e.g. VOCs). This required a large number of wells for sampling.

Lesson Learned: Geoprobes™ and temporary wells (vertical profiles) are effective tools for an "early response" plume characterization

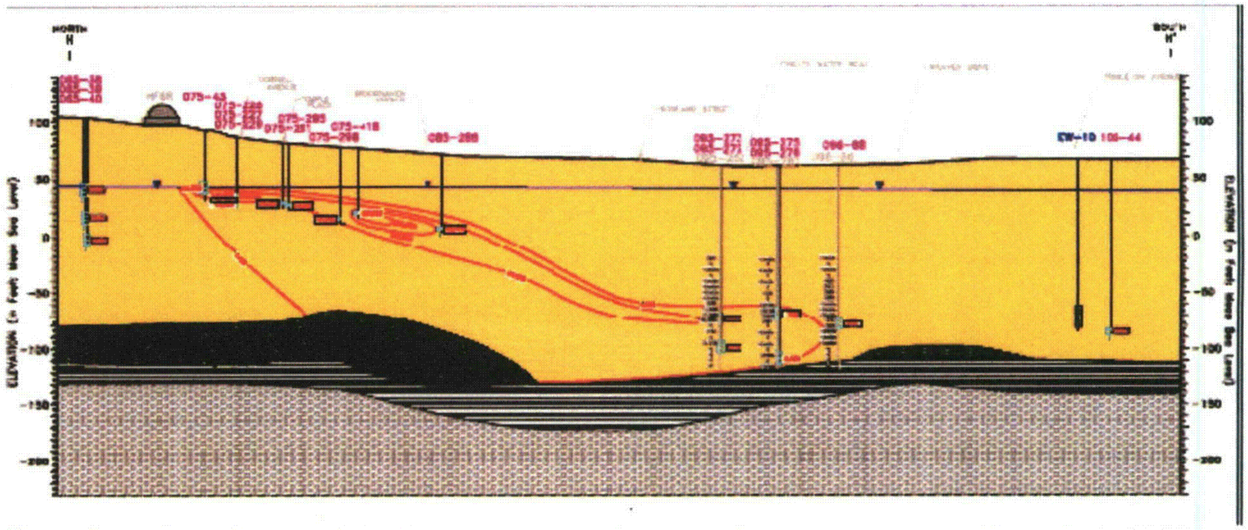


Figure 2-6: Cross Section of the Tritium Plume as function of distance from the HFBR (BNL, 2002)

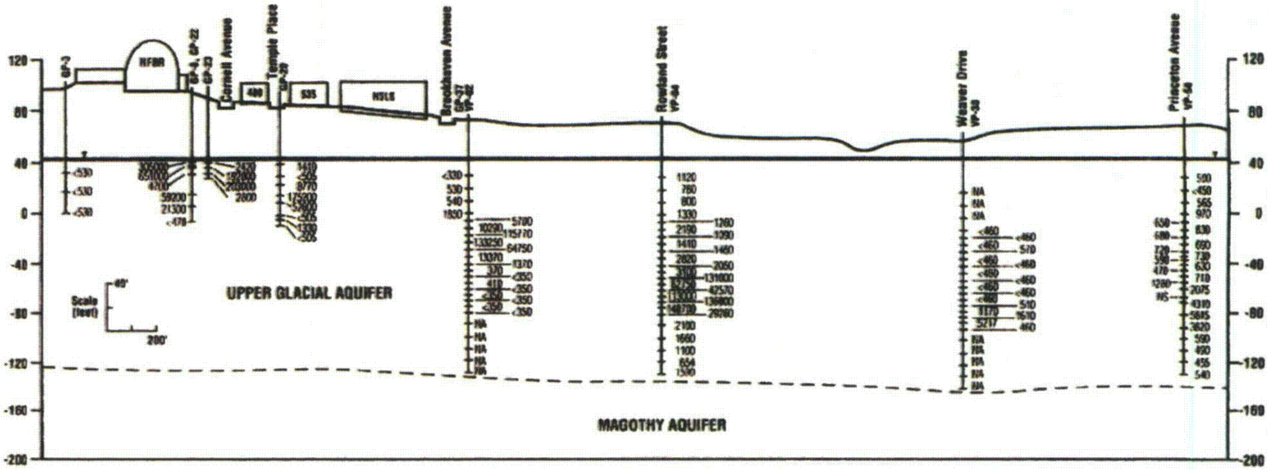


Figure 2-7: Sampling data results associated with the plume characterization (BNL 2002)

Operations at the HFBR were suspended while the source of the tritium was investigated. Wells just upgradient from the HFBR indicated no tritium contamination and therefore confirmed that the leak originated in the HFBR.

All of these efforts led to a detailed definition of the extent of the tritium contamination. Groundwater containing tritium at levels above the drinking water standard was found to extend approximately 2,200 feet south of the reactor; still well within the BNL site. In May 1997, a pump-and-recharge system was installed at the southern edge of the contamination to prevent it from spreading further and confine it to Laboratory property, Figure 2-8. This was a temporary interim action until a formal Record of Decision (ROD) could be obtained for Operable Unit III (OU III) which contained other sources of contamination.

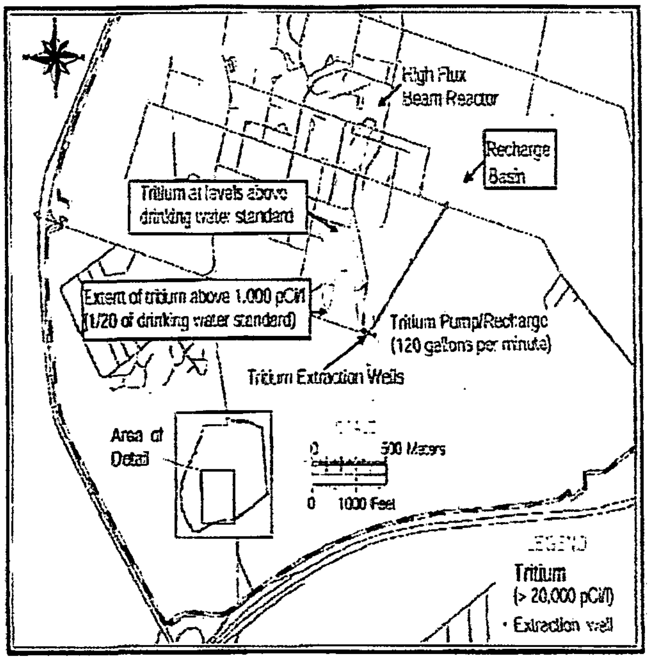


Figure 2-8: Location of High Flux Beam Reactor, tritium plume, extraction wells, and recharge basin (BNL, 2001)

2.6 Regulatory Actions

The remediation of the tritium plume had several regulatory steps. The first, the Interim Removal Action, was reviewed by EPA and NYSDEC under the terms of the Interagency Agreement (IAG) and is documented in the Final Action Memorandum, Operable Unit (OU) III Tritium Removal Action (DOE, 2000). This allowed action to begin on source control and preventing off-site migration of the plume. The proposed method for the long-term remediation of the plume was determined in the OU III RI/FS (Remedial Investigation/Feasibility Study). This was approved as the final remedial action and approved in the OU III ROD. The basic requirement of these actions was to prevent plume growth and off-site migration of the plume.

Lesson Learned: Effort should be expended to manage a plume within the facility boundaries. Once off-site migration occurs both real and perceived risk greatly increase.

3.0 MODELING THE HFBR TRITIUM PLUME

Prior to the discovery of the tritium contamination, BNL had developed a detailed groundwater flow model to address other groundwater contamination issues. The computer code MODFLOW88 was used to simulate groundwater flow around BNL. In 1996 water-level data from 225 wells, stream flow measurements from 12 gage stations on 4 rivers, and historical data of groundwater stressors including operational uses (pumping and surface discharge) and recharge were used in MODFLOW88 to calibrate the groundwater flow model throughout the entire site. This simulation covered an area of approximately 600 square miles and included all of Long Island from the Long Island Sound to the Atlantic Ocean with a width of approximately 30 miles. Eight separate layers were used to simulate the vertical hydrogeologic features on Long Island.

Having a detailed groundwater site model in place was critical for the rapid response needed to address concerns with the tritium contamination. The site model was used as the basis for predicting the migration of the tritium plume over time. However, the spatial resolution of the site model was inadequate to evaluate the movement of the tritium plume. For this reason, a telescopic mesh refinement was used that inscribed a subarea that covered the HFBR vicinity in much greater spatial detail than the site model. The mesh size was reduced to 10' X 10' X 10' in the refined model. This HFBR region sub-model incorporates the hydrogeologic and hydrological data from the larger model and uses the larger model to provide boundary conditions for subsequent calculations. The HFBR sub-model covered an area approximately one mile wide and three miles long. It extended slightly more than a mile south of the southern boundary of the BNL facility.

Lesson Learned: It is essential to have a calibrated site-wide groundwater model in place that can be used to select monitoring locations, and then be employed to obtain more detailed analysis of the impact of a particular plume.

The computer code MT3D was used to simulate the movement of tritium throughout the aquifer. MT3D is based on a modular structure to permit simulation of transport components independently or jointly. MT3D interfaces directly with the groundwater flow model, MODFLOW, for the head solution, and supports all the hydrologic and discretization features of MODFLOW. The MT3D code has a comprehensive set of solution options, including the method of characteristics (MOC), the modified method of characteristics (MMOC), a hybrid of these two methods (HMOC), and the standard finite-difference method (FDM). Use of the MOC method minimizes numerical dispersion and was used in the simulations of tritium movement at BNL.

Lesson Learned: For porous media that do not cause substantial mechanical dispersion, modeling using finite-difference methods may under predict downgradient concentrations for tritium unless great care is placed on accounting for numerical dispersion.

Initial modeling efforts used finite-difference solution techniques that had a difficult time reproducing the concentrations measured in the field. The models under estimated the far-field concentrations. This was a result of the tritium plume being so narrow in the directions perpendicular to groundwater flow. One process that causes spreading of the plume is mechanical dispersion which is caused by the porous media. Even though the refined model used a ten foot grid spacing there was too much spreading of the contamination due to the approximations used to solve the governing equations (numerical dispersion). Ultimately this was circumvented by entering a value of zero for parameters that simulate mechanical dispersion.

The particle tracking code MODPATH was used to assist in tracking flow paths. MODPATH takes output from the MODFLOW88 groundwater flow model to calculate a velocity distribution, which is then used to trace out the flowpaths of particles allowing easy visualization of the flow-field. This was extremely useful in identifying additional locations for monitoring the plume movement.

A summary of the models employed, their focus, and their strengths is captured in table 3-1.

Table 3-1: Summary of Modeling Information

Model Employed	**Focus**	**Strengths**
MODFLOW	Groundwater flow	Determination of water flow rate and direction as a function of withdrawals and recharge (precipitation and basins).
MT3D	Contaminant Transport	Determination of concentrations for comparison to drinking water standards.
MODPATH	Track Flow Path – particle tracking	Determination of capture zone for treatment options

Operational Variables: BNL is an operating research facility that has water requirements of approximately one million gallons per day. There are two major well fields that supply this water. One field, the Western Well Field containing wells 4, 6, and 7, is approximately 3000 feet southwest of the HFBR and has a minor effect on flow near the HFBR. The second supply well field, the Eastern Well Field contains wells 10, 11, and 12 and is approximately 1000 feet north of the HFBR. When the Eastern Well Field is in use, this reduces the hydraulic gradient near the HFBR and can reduce the groundwater flow rate by 30 – 50%. It will also change the flow paths followed by tritium. Much of this water is used for cooling of large machinery and equipment. The cooling water is discharged into recharge basins. The most dominant influences to the tritium plume migration near the HFBR from recharge of cooling water is discharges to Basin HO, which is approximately 500 feet east of the HFBR. Another recharge basin, RA V, which is a few hundred feet south of the HO basin also impacts flow around the HFBR. The facility uses of water complicate the flow of tritium away from the HFBR and must be accounted for to track the plume and define additional monitoring locations. A more detailed description of the models and their evolution is contained in Appendix A.

Lesson Learned: It is important to document and evaluate site activities that could impact plume movement- this includes on-site supply well pumping, impacts of recharge basins, major spills/leaks. Natural activities (annual rain fall amounts and water table fluctuations) that impact release and transport should also be documented.

3.1 Initial Modeling Objectives (1997)

The HFBR sub-model was initially constructed to achieve the following objectives:

- Assist in plume characterization efforts (length, concentration, volume of contaminated water, location, total curie content).
- Design the location and pumping rates of the HFBR Pump and Recharge System at Princeton Avenue,
- Perform comparative analysis of various remediation options to support the OU III Feasibility Study.

An additional model was used to confirm that evaporation of tritium from the recharge basin would be at concentrations far below the allowable air quality standard

3.2 Using the Model

The site-wide model was essential for the early evaluation of the potential impact of the tritium plume. But as illustrated in Figure 3-1 using the green highlighted boxes, it, and the plume specific model developed from the site-wide model, continue to be important resources for helping BNL evaluate the effectiveness of the treatment systems and determining if changes to them are needed in order to meet performance objectives. Combined with the reporting of the actual monitoring data, the output from the model provides a mechanism for demonstrating progress to the stakeholders towards the ultimate goal of reaching agreement that the clean up objectives have been met.

Lesson Learned: The site groundwater model was an essential tool used to:

a) evaluate remedial alternatives

b) select design criteria including appropriate downstream pumping well locations, determine pumping rates and capture zones, and locate appropriate well intake screen depths.

c) predict the recirculated groundwater on-site residence time to compare to the design criteria.

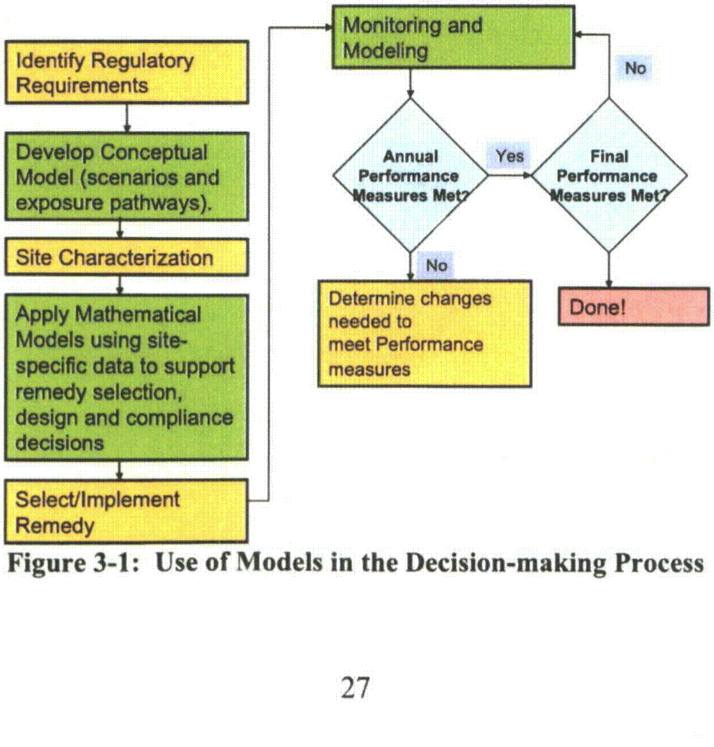


Figure 3-1: Use of Models in the Decision-making Process

4.0 IMPLEMENTATION OF THE SELECTED REMEDY

On April 14, 2000 the OU III ROD was finalized. The OU III ROD covers several VOC contamination plumes, the Sr-90 plume and the Tritium plume from the HFBR. The cleanup objectives in the OU III ROD are to meet drinking water standards in groundwater, to complete the cleanup in a timely manner (for the Upper Glacial aquifer, this goal is 30 years or less), and to prevent or minimize further migration of high concentrations in groundwater.

4.1 Evaluation of Remedial Alternatives

Tritium treatment and separation technologies found in the literature are not appropriate for environmental remediation of the low concentrations and large volume of tritiated water in an aquifer or surface water.

As part of the CERCLA process, potential remedial options ranging from no further action through a series of potential alternatives must be evaluated. Initial HFBR tritium plume design activities began with a tritiated water treatment technology screening effort. Literature searches resulted in a number of potential remediation technologies ranging from groundwater freezing to tritium separation techniques such as electrolysis. Additional techniques that came up in the literature search only applied to tritium gas separation.

Tritiated water treatment technologies can be separated into three categories – immobilization, separation, and, detritiation.

- Immobilization involves freezing the groundwater with pipes containing refrigerant embedded into the volume of aquifer that is to be frozen. This technique is widely used in cold climate construction projects where the permafrost in a construction zone must be prevented from melting during the erection of a structure. Freezing the HFBR tritium plume was considered prohibitively expensive because of energy and installation costs and infeasible due to the volume of water and the high porosity of the aquifer materials.

  Another method of immobilizing groundwater is to install impermeable structures like steel pylons, mixing grout with augers into a vertical barrier zone, or installing a grout curtain. These approaches require an impermeable layer that the bottom of the structure can be keyed into. This type of geologic formation does not exist below the HFBR plume. In other geologic settings one or more of these approaches may be appropriate.

- Separation processes are divided into several types:

  Evaporation and distillation – these processes separate the very slightly heavier tritiated water (HTO) from regular groundwater water (H_2O).

  Mass transfer based equilibrium processes – these techniques attempt to preferentially sorb HTO onto a medium or allow H_2O to preferentially pass. Examples include adsorption, the Girdler Sulfide Process, Liquid Phase Catalytic Exchange, Combined Electrolysis/Catalytic Exchange, and membrane processes.

- Detritiation technologies use electrolysis to separate and capture the hydrogen from HTO and H_2O.

Ultimately it was determined that none of these technologies were appropriate. Immobilization was not possible due to high costs and technical limitations. Separation and detritiation technologies were designed for much higher concentration reactor cooling water applications and/or the production of heavy water and are not applicable for the low environmental concentrations found at BNL. Energy usage and structural needs for stripping towers, piping, catalysts, and chemical reagents make these technologies infeasible for environmental tritium remediation. This evaluation led to the recommendation of pump and recharge as the treatment option.

4.2 Risk Assessment

Lesson Learned: Political and Institutional Risks may dominate technical risks in the decision making process.

A detailed Risk Assessment was conducted to determine ecological and human health risks. The nine CERCLA risk criteria were evaluated and the results presented in the OU III ROD. The analysis showed moderate ecological risks (on-site) and minimal human health risks (Cancer risk less than EPA 10^{-6} criteria). Predicted off-site tritium concentrations were well below the drinking water standard. On-site human health risks to employees are prevented by institutional controls. Risks to on-site personnel that work on the tritium project (sampling) from tritium are also small. Nevertheless, there was public outrage and large political pressure to act quickly. These pressures caused large institutional risks which could have severely impacted the future of BNL had they not been addressed rapidly.

4.3 HFBR Tritium Plume Downgradient Extraction and Recharge System

The pump-and-recharge remediation was an interim action to ensure tritium above the drinking water standard did not migrate beyond the southern BNL boundary. It also gave 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.

BNL designed, constructed, tested, and put into operation an interim system to intercept the leading downgradient edge of the tritium plume (BNL, 2009). The system consisted of a pump-and-recharge recirculation system that operated between May 1997 to April 2000 to prevent the leading edge of the plume from migrating further downgradient thereby ensuring that tritium above the state and federal drinking water standard of 20,000 pCi/l would not leave Brookhaven's southern site boundary.

The groundwater extraction and recharge system provided a layer of protection to ensure that tritium did not migrate towards the BNL site boundary. Subsequently, groundwater modeling predicted the plume would decay and disperse on the BNL property and not leave the site once source control at the HFBR building was achieved. Groundwater modeling was also used to specify the pumping well locations and screen depths and to predict the sufficiency of the expected capture zone.

Three groundwater extraction wells were installed 3,500- feet south of the HFBR Building near Princeton Avenue (5,000 feet north of the BNL property line), where the maximum tritium concentration was 6,440 pCi/1. Groundwater was 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. Each well pumped tritiated groundwater from the aquifer at a rate of about 40 gallons per minute.

Before entering the recharge basin, the water passed through activated carbon filters to remove chemical contamination that was also present in groundwater in the area. 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 were analyzed regularly in accordance with New York State Discharge Permit conditions to determine the tritium concentrations being recharged. Typically, as the water entered the recharge basin, the average tritium concentration was approximately 500 pCi/I, well below the drinking water standard. The decrease in tritium concentrations discharged to the recharge basin was due to the dilution effects achieved by the pumping system.

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 to confirm the calculations. Once the water reentered the ground at the recharge basin, it flowed downgradient (Figure 2-8), taking approximately nineteen (19) years to reach the southern BNL site boundary. By that time, natural decay and dilution were predicted by the groundwater model to have diminished tritium levels to nearly undetectable levels. Monitoring wells located at the BNL boundary provided further assurance that tritium, above the drinking water standard, would not leave the BNL site.

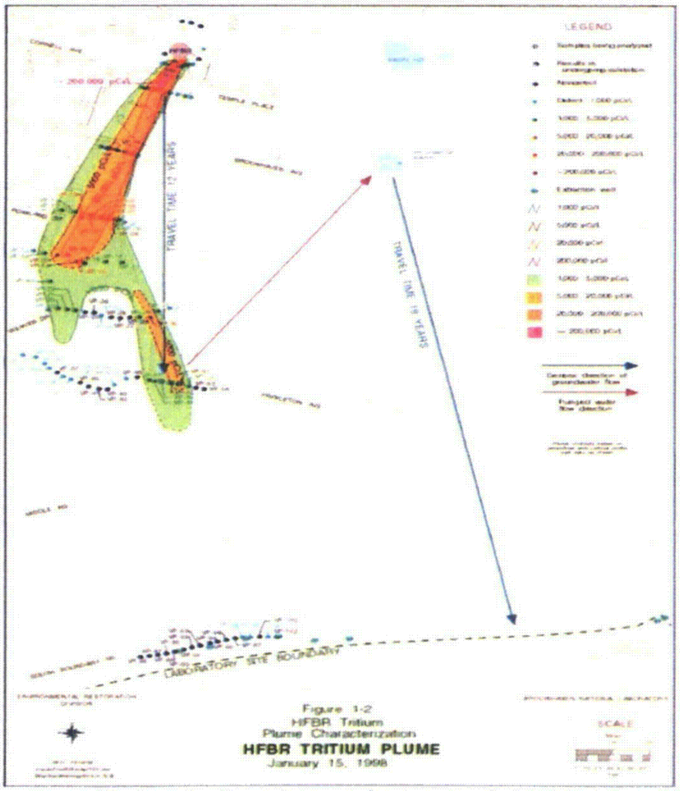


Figure 4-1: Hydraulic Containment System for HFBR Tritium Plume (BNL, 1998)

The tritium plume was co-mingled with a plume containing several VOCs in excess of their drinking water standard. A carbon filter was used to treat the extracted water and lower VOC concentrations to below the drinking water standard before recharge. There was a concern that the spent carbon filter media would be a mixed waste. Tests were performed to verify that tritium trapped in the filter media could be easily removed by rinsing with clean (non-tritiated) water. The rinse water was sampled and recharged since the tritium concentrations were well below drinking water standards.

4.4 Low Flow Pumping Groundwater Extraction

The OU III ROD (DOE, 2000) also contains requirements for implementing various contingency actions to address the HFBR tritium plume if certain concentrations are observed at specified locations that are not consistent with original model projections. These contingencies include:

Lesson Learned: The required cleanup work should be specified in a performance based format with set goals rather than specific remedies already determined. A performance based format allows flexibility to perform the remediation cost effectively and efficiently.

1) Evaluate the need to reactivate the Princeton Avenue Pump and Recharge system if tritium concentrations exceed 25,000 pCi/L at the Chilled Water Plant Road.
2) Reactivate the Princeton Avenue Pump and Recharge system if tritium concentrations exceed 20,000 pCi/L at Weaver Drive.
3) Implement a low-flow groundwater extraction system in the most concentrated area of contamination at Cornell Avenue near the HFBR if concentrations exceed 2M pCi/L.
4) Install and operate an additional low-flow groundwater extraction system near Temple Place. The exact location, operational parameters and treatment and disposal options for the extracted water were to be developed during design. The ROD further states that operation of the Temple Place system is to continue for up to one year. As these extraction wells operate, extensive monitoring is to occur to evaluate the effect of the extraction locally, as well as the entire plume. The monitoring data is to be evaluated and used, in conjunction with modeling, to help determine whether continued operation of this system is needed to achieve the cleanup objectives. The criteria to decide how long to operate the system was developed during the design and based on preventing contingency 1) (above) from occurring.

4.5 Revised Modeling Objectives Activities and Low Flow Pumping

To support the actions required by the ROD, the modeling objectives evolved to support the entire remedial process, including:

a) Assist in characterizing the high concentration areas of the plume,
b) Assist in designing a low flow pumping system at Cornell avenue,
c) Develop a "trigger" level for a low flow pumping system near Temple Place,
d) Assist in evaluating the performance of the low flow pumping system,

e) Assist with the development of a groundwater monitoring plan and interpretation of data,

f) Assist in coordinating site-wide groundwater management decisions that may have an impact in the migration of the plume,

g) Provide early warning forecasts if trigger levels at Roland and Weaver may be exceeded, and

h) Assist in the evaluation of supplemental tritium plume control measures (e.g. high flow pumping, hydraulic control, groundwater recirculation).

Modeling to support objectives b) and c) indicated that drinking water standards (20,000 pCi/L) would be exceeded at Weaver Drive (thereby triggering contingencies 1) and 2) unless action was taken to reduce tritium concentrations from the highest concentrations of the plume. Modeling was used to set a trigger level of 750,000 pCi/L at which groundwater extraction would begin. The model predicted that it would be necessary to remove groundwater that had tritium concentrations greater than 500,000 pCi/L. If this was achieved, modeling showed that no significant plume growth (i.e., no tritiated water above the drinking water standard of 20,000 pC/L would migrate beyond Princeton Avenue and no tritiated water above an action level of 1,000 pCi/L would leave the site boundary) would occur. Additionally the aquifer would be cleaned up to below drinking water standards with 30 years or less (i.e., the plume would disperse and decay within the bounds of its current envelope beneath the BNL property).

Figure 4-2 shows the predicted time to reach drinking water standards using a peak concentration of 750,000 before low flow pumping (year 2000) and after low flow pumping (year 2001). The figure demonstrates that the likelihood of achieving the ROD goals was greater if low flow pumping was performed. Dispersion was turned on and off in the model to help bound the uncertainty of the projections resulting in a range of expected future downgradient concentrations.

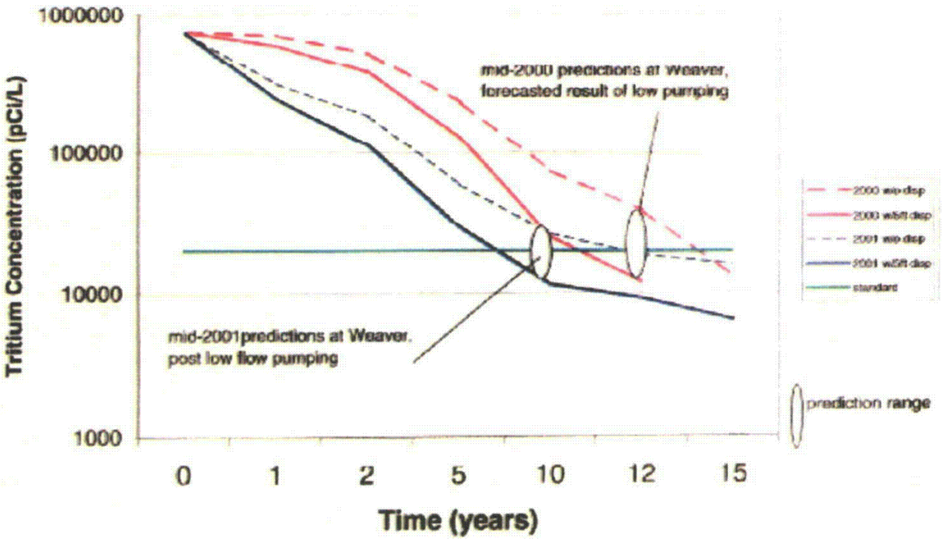


Figure 4-2: Predicted concentrations at Weaver Drive as a function of dispersivity based on initial conditions in 2000 (before hot spot removal) and in 2001 (BNL, 2001)

The modeling was also used to estimate the volume of water that was contaminated above the trigger level, 50,000 gallons, and the total tritium activity in this part of the plume, 0.21 Ci. These predictions (50,000 gallons of water and extraction of 0.2 curies of tritium) were used for design and planning of the removal action. However, it was recognized that there were uncertainties in the model predictions that could lead to the need to remove as much as three times as much groundwater to achieve the goal of not exceeding the drinking water standard for tritium at Princeton Avenue.

4.6 Low Flow Pumping Implementation

Due to the movement of the high concentration section of the plume away from near the HFBR, efforts for hot spot remediation were focused in the Temple Place area approximately 375 – 500 feet downgradient of the HFBR spent fuel pool (ROD contingency 4). Low-flow pumping began in September 2000. Simultaneously, additional geoprobe wells were installed further downgradient to collect samples to define areas that had tritium concentration in excess of the 750,000 pCi/L pumping trigger concentration. A permanent well was installed at each geoprobe location that exceeded this level. This information was used to adaptively determine the frequency of pumping events and determine the need for additional extraction wells and their locations. If the tritium concentration remained above 500,000 pCi/L in a particular well, another extraction cycle was performed at that well. Once the concentration dropped below 500,000 pCi/L another well was chosen for extraction.

Water was extracted at 5 gpm for 16 hours to remove approximately 5000 gallons of water during each event. This water was pumped to a tanker that transported the waste for off-site disposal at a licensed facility. Overall, a total of 95,000 gallons of tritium-contaminated groundwater was removed in 21 pumping events from 10 locations during 2000 and 2001. Sampling of the extracted water indicated that 0.2 Ci of tritium had been removed from the plume while removing 95,000 gallons of water. This was approximately 20% of the entire plume inventory in 2001 and was the amount predicted by the modeling as requiring removal to avoid plume growth. Figure 4.3 also compares the predicted removal efficiency of low flow pumping with the actual results. Approximately twice as much groundwater was extracted than predicted by the model.

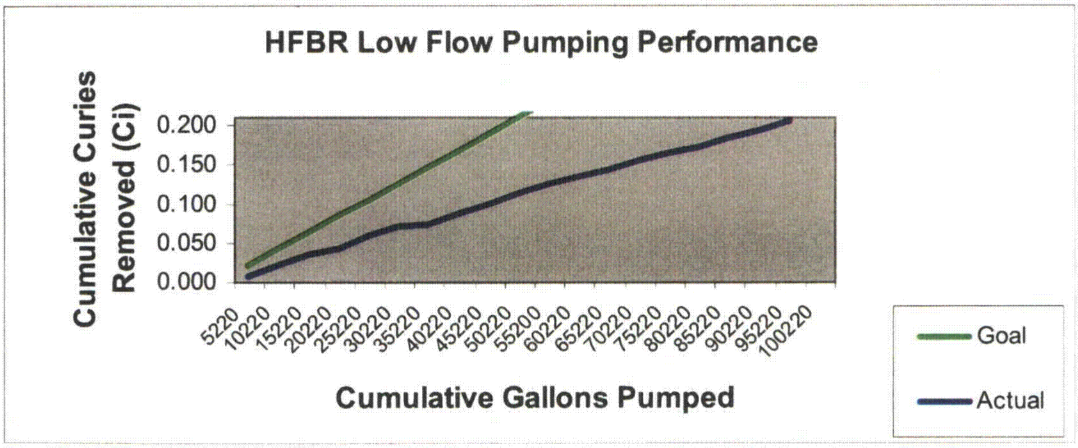


Figure 4-3: Low flow pumping performance-Goal versus Actual

Figure 4-4 shows the location of each low flow extraction well relative to the HFBR and shows the downgradient migration of the highest plume concentration slugs over time.

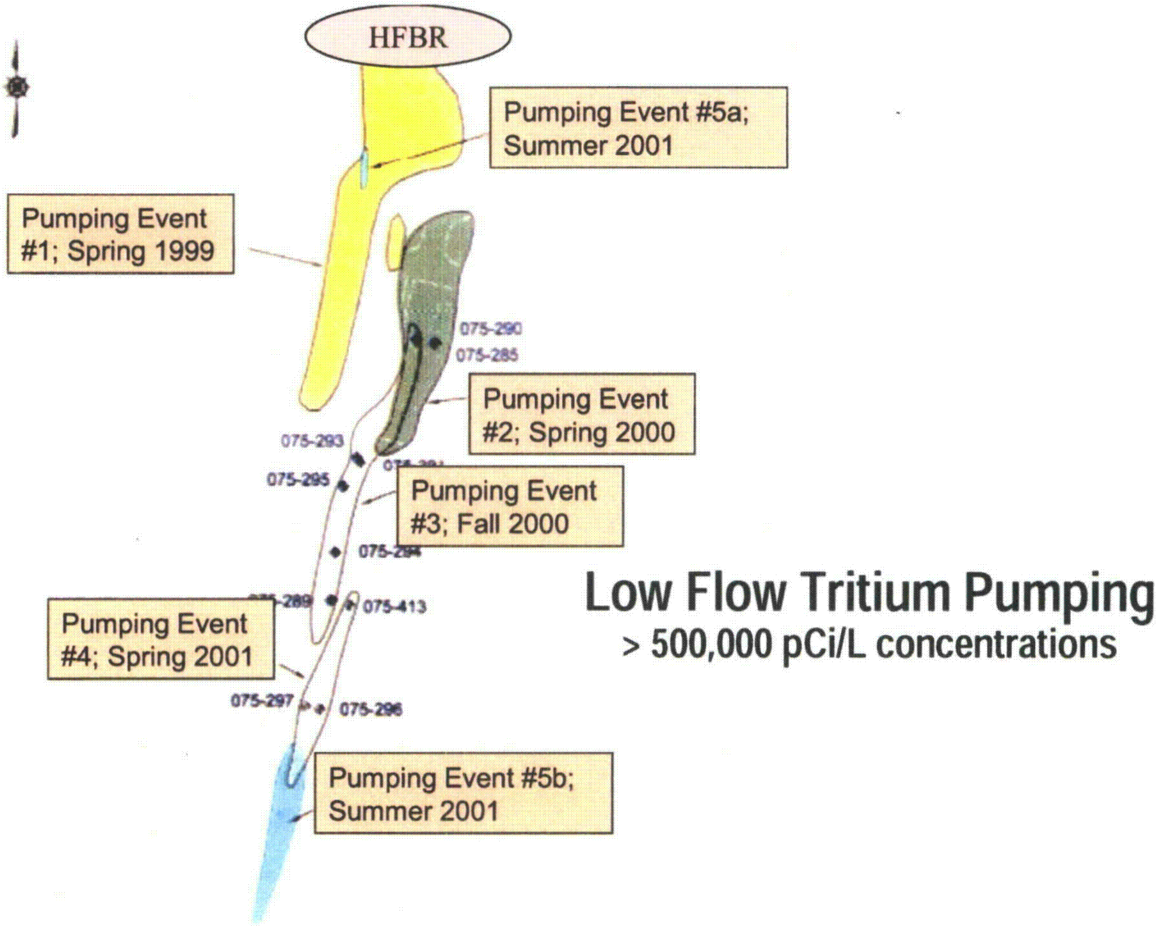


Figure 4-4: Low Flow Pumping Tritium Events (BNL, 2001)

5.0 HFBR PLUME MANAGEMENT

In 2000, tritium concentrations dropped to nondetectable levels at the extraction wells for the HFBR pump and recharge system at Princeton Avenue. With agreement of the regulators, the system was shut down in September 2000. In April, 2001 the low-flow pumping action had successfully reduced all plume concentrations below the 750,000 pCi/L trigger level and low-flow pumping was halted. The dynamic nature of the low-flow extraction process (21 sixteen hour pumping events at ten locations over nine months) and groundwater movement caused fragmentation of the high concentration area of the plume. This uncertainty led to an upgraded monitoring plan to insure that trigger levels in the contingencies would not be exceeded.

A monitoring network with 157 wells (22 new wells in 2001) was designed to provide data to follow the movement of the plume and verify that trigger levels were not exceeded. Tritium has no retardation, which smears the plume, and at BNL there was very little dispersion. To compensate for these characteristics, nested permanent wells with relatively short screens (compared to what would be used for other contaminants in the same location) and/or temporary well sampling should be used for tritium plume characterization.

Lesson Learned: Monitoring well screens should be as short as possible or low-flow purge sampling methods used to ensure the detection of vertically discrete layers of tritium.

BNL's Regional Groundwater Model was used to assist in the placement of the monitoring wells.
This model is periodically updated based on the latest monitoring data for hydraulic head.

Over 300 groundwater samples were collected for tritium analysis in the region of the low flow pumping event over a 1 ½ year period from April 2001, the last pumping event. None of the samples exceeded the trigger level of 750,000 pCi/L that would have required additional pumping to occur. The maximum value recorded was 731,000 pCi/L in July of 2001. This well and another well that had a concentration in excess of 700,000 pCi/L at this time were resampled two and four weeks after this occurrence and the concentration was always below 670,000 pCi/L. Activities in excess of the trigger level have not been detected since completion of the low-flow pumping action in the Summer of 2001. The detailed monitoring provided a technical basis for no further low-flow pumping.

Similarly, enhanced monitoring was performed to confirm that trigger levels near the Chilled Water Plant Road or Princeton Avenue were not exceeded. The fragmentation in the plume and the high concentrations observed in two wells (> 700,000 pCi/L) in July 2001 could lead to tritium levels exceeding trigger levels downgradient. Temporary well groundwater sampling techniques (e.g., Geoprobe) were more effective to monitor tritium plumes than permanent monitor wells. In addition to the dispersion and retardation issues, permanent monitor wells can overly dilute the tritiated water during sampling.

As an example of the variability in tritium concentrations in groundwater immediately south of the HFBR building in monitoring well 075-43 increased from 22,600 pCi/L in 2002, to 130,000 pCi/L in 2003. In 1999, tritium concentrations in this well reached 2,500,000 pCi/L. The concentration increase observed in 2003 is likely due to a rise in the water table elevation and resulting flushing of residual tritium from the soil beneath the HFBR. Tritium concentrations in monitoring well 075-43, located on the HFBR lawn, increased to 378,000 pCi/L in February. This is illustrated in figure 4-1 which compares water table elevation with tritium concentrations. Accounting for the travel time between the spent fuel pool and the monitoring wells shows a good correlation between peak water table elevation and tritium concentration. Thus even though the spent fuel was removed from the HFBR in 1997 and there were no further releases from the facility, the vadose zone remained a significant source to the aquifer for several years. After release to the aquifer, this high level slug of tritium continued to migrate downgradient, in October it was detected in well 075-245, located just south of Cornell Avenue, at a concentration of 433,000 pCi/L, a value slightly higher than found near the facility.

Lesson Learned: The release of contaminants from the vadose zone during periods of water table rise needs to be considered as a continuing source term. Establish field monitoring to achieve early detection of vadose zone releases.

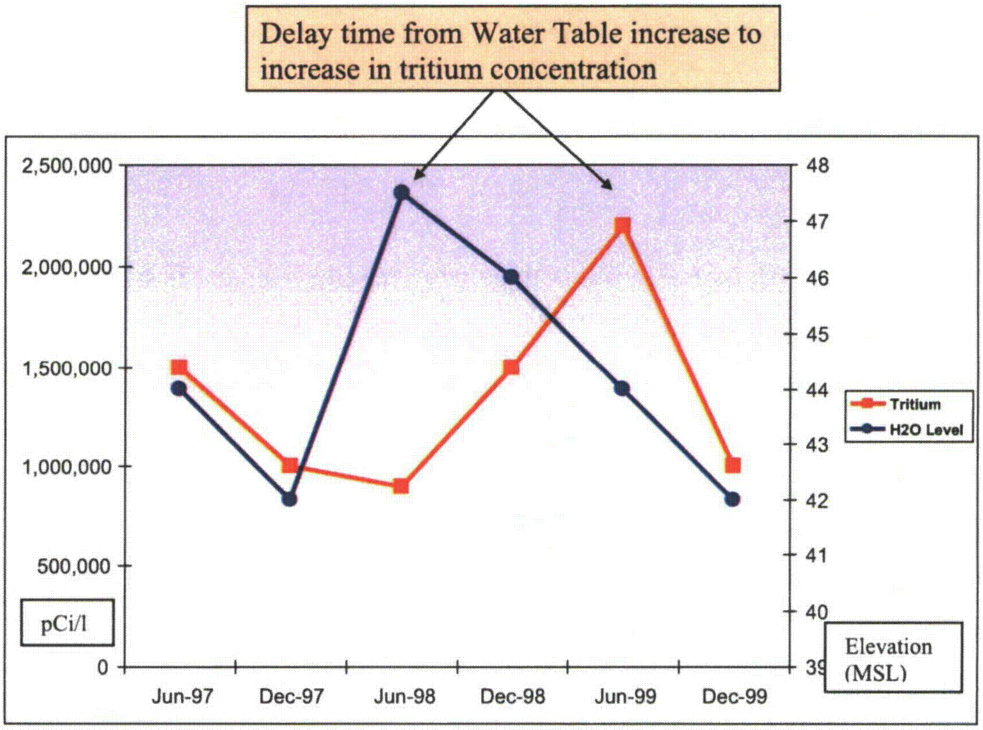


Figure 5-1: Water table changes leading to increases in tritium concentration. Tritium concentrations (red), Water Level Elevations (blue) and travel time from peak in water table to nearest monitoring well.

5.1 Contingency Pumping Triggering Event

The downgradient extent of the higher concentration segment of the HFBR tritium plume was extensively characterized in early 2006. These transects were located to the east of Bell Avenue, east of Chilled Water Facility Road, and east of

Lesson Learned: It is important that site activities that could impact plume movement are documented and their potential impacts evaluated. This includes on-site supply well pumping, impacts of recharge basins, annual rain fall amounts, water table fluctuations, and major spills/leaks.

Weaver Drive. The purpose of these transects was twofold: to characterize the eastward shift of the plume since the monitoring well network was originally installed, and to characterize the location and nature of the high-concentration segment of the plume that had been addressed by low-flow pumping back in 2000–2001.

A tritium concentration of 80,000 pCi/L was observed in a temporary geoprobe monitoring well on the Chilled Water Facility Road. This exceeded the OU III ROD contingency trigger value of 25,000 pCi/L at this location. This exceedance of the trigger value required BNL to evaluate the possibility of reactivating the HFBR tritium pump and recharge wells. Additional groundwater characterization was performed in the vicinity of Weaver Drive where tritium concentrations were observed below the OU III ROD trigger level of 20,000 pCi/L. In the spring of 2006 it was decided to perform semi-annual monitoring of tritium in temporary geoprobe wells located near the Chilled Water Plant Road and Weaver Drive. In addition, the centerline of the plume, south of Brookhaven Avenue, has gradually shifted to the east since 1997 in response to significantly reduced flows to the HO recharge basin, the use of the OU III recharge basin, and the overall reduction in pumping from supply wells 10, 11, and 12 located in the eastern well field. This shift has placed the centerline of the plume to the east of the monitoring well network, as was verified by the groundwater characterization work completed in early 2006. The eastward shift required modeling using the BNL groundwater model and evaluated from the standpoint of whether the Princeton Avenue pump and recharge wells are optimally located to intercept the plume. A recommendation for one additional well to capture the plume was made.

Lesson Learned; Regularly scheduled monitoring data must be used to periodically update modeling projections due to the quick response of a tritium plume to any change in the groundwater flow system, even those caused by natural fluctuations in precipitation.

The OU III Record of Decision (ROD) contingency of 20,000 pCi/L tritium at Weaver Drive was triggered with a detection of 21,000 pCi/L in a temporary well on November 2, 2006. A fourth extraction well (EW-16) was installed to address the plume in the vicinity of Weaver Drive and began operation in December 2007. Extraction well EW-16 was installed approximately 400 feet north of the existing pump and recharge wells located on Princeton Avenue. Extraction wells EW-9, EW-10, and EW-11 are being sampled quarterly and EW-16 is being sampled at a weekly frequency.

Lesson Learned; Tritium's lack of retardation in groundwater can cause a permanent monitoring well network to become ineffective in response to external influences. Temporary monitoring wells should be used.

The pump and recharge well(s) will be operated until the tritium concentrations from Weaver Drive to the new extraction well drop below 20,000 pCi/L. The estimated operational duration of several years is based on the length of the high-concentration area slug and the time it would take to be completely captured by the new extraction well. These wells have been operating continuously to the present (May, 2010) except for planned outages.

The decision to turn the wells back to standby will be based on 1) concentrations of tritium being less than 20,000 pCi/L in the monitoring wells at Weaver Drive as well as the extraction wells, and 2) verification that the new extraction well has captured concentrations of tritium in this area greater than 20,000 pCi/L. This decision will be supported with data from additional permanent and temporary wells as needed.

5.2 Use of Data Quality Objectives

BNL actively manages the tritium plume from the HFBR as described earlier and illustrated in figure 1-9. A key component of this operation is the use of Data Quality Objectives to focus data collection and modeling on decisions regarding plume management.

For each of the HFBR tritium plume BNL prepares an annual report that answers the following questions:

1. *Was the BNL Groundwater Contingency Plan triggered?*
2. *Is the tritium plume growing?*
3. *Are observed conditions consistent with the attenuation model?*
4. *Is the tritium plume migrating toward the zone of influence of water supply wells 10, 11, and 12?*
5. *Has any segment of the plume migrated outside of the existing monitoring network? Have the cleanup goals been met? Can the groundwater treatment system be shut down?*

Based on the answer to these five questions, BNL provides recommendations to improve the HFBR tritium plume management. For example, when the triggering event (question 1) occurred in 2005, BNL recommended the addition of an extraction well located upgradient of existing extraction wells in the high concentration section of the plume.

Lesson Learned: There are long term benefits for establishing data quality objectives (DQOs) for plume management at the beginning of the process.

- Benefits of the DQO process include:
- helping to focus data collection and decisions on the performance goals;
- forming a basis to demonstrate that sampling frequency can be reduced or increased based on trends in the data;
- forming a basis for implementing contingency plans when goals are not being met; and
- forming a basis to implement an exit strategy, such as turning off an extraction system, when goals are met.

6.0 STRONTIUM-90 CONTAMINATION

6.1 Identification of Sr-90 Contamination

Groundwater characterization studies identified two strontium-90 (Sr-90) plumes on the BNL site with concentrations in excess of the Drinking Water Standard of 8 pCi/L. One plume is downgradient of the former "Chemical Holes" disposal site, which is the source of the contamination, and a plume located in the middle of the BNL site. The Chemical Holes area consisted of 55 pits east of the Former Landfill that were used for the disposal of a variety of laboratory chemicals and animal remains. The buried waste was excavated in 1997, repackaged and sent off-site for disposal. The second plume on-site is the result of historical leakage from operations at the Brookhaven Graphite Research Reactor (BGRR), Pile Fan Sump (PFS) near the BGRR and the Waste Concentration Facility (WCF). The WCF processed waste from the BGRR and is located approximately 500 feet north of the BGRR.

These plumes are managed as part of Operable Unit III (OU III) at BNL. Characterization of these plumes was conducted in 1997 and 1998 to define the extent of contamination. At that time, site-specific soil Kd measurements were made (Fuhrmann, 1999). Modeling was performed for each of these three plumes and it was projected that Sr-90 would not leave the BNL site in concentrations exceeding the 8 pCi/l Drinking Water Standard. This combined with institutional controls to prevent on-site access of the contaminated water makes the excess cancer risk to the public and BNL employees much less than the CERCLA goal of less than 10^{-6}.

The 1999 OU III Remedial Investigation and Feasibility Study (RI/FS) considered several remedial alternatives to address this contamination:

- No action
- Natural attenuation with confirmation through monitoring and modeling
- In-situ precipitation with natural attenuation. Continued groundwater monitoring would be a part of this alternative.
- Groundwater Extraction/Ion Exchange/On-Site Discharge. Continued groundwater monitoring also would be a part of this alternative.
- Extraction and Treatment at BGRR/Permeable Reactive Wall at Chemical Holes. Continued groundwater monitoring would also be a part of this alternative.

In the April 2000 Record of Decision (ROD) the groundwater extraction system with ion exchange and on-site discharge of treated water was the selected remedy. The estimated cost to install and operate the system over its 30 year lifetime was $6,500,000.

6.2 Strontium Treatment System Remedial Design

It was recognized that there were several technical uncertainties associated with extracting Sr-90 contamination from groundwater and the subsequent use of ion exchange technology to treat contaminated groundwater. These uncertainties are reflected in the ROD's mandate for a pilot study as a prerequisite to the final remedial design, and the recognition that the final remedy may be modified based on the results of this pilot study.

Specifically, the ROD states: "The selected remedy, alternative S5a, involves installing extraction wells and using ion exchange to remove Sr-90 from the extracted water and on-site discharge of the clean water. Details of the specific number of treatment systems and locations needed to meet the cleanup objectives will be determined during the design process. Before implementation of the remedy, a pilot treatability study will be performed to evaluate the effectiveness of extraction and treatment. The final remedy may potentially be modified based on the results of this study. Residuals that contain Sr-90 will be disposed of off-site". Figure 6-1 provides a depiction of the plumes and the data trends from samples analyzed in 2001.

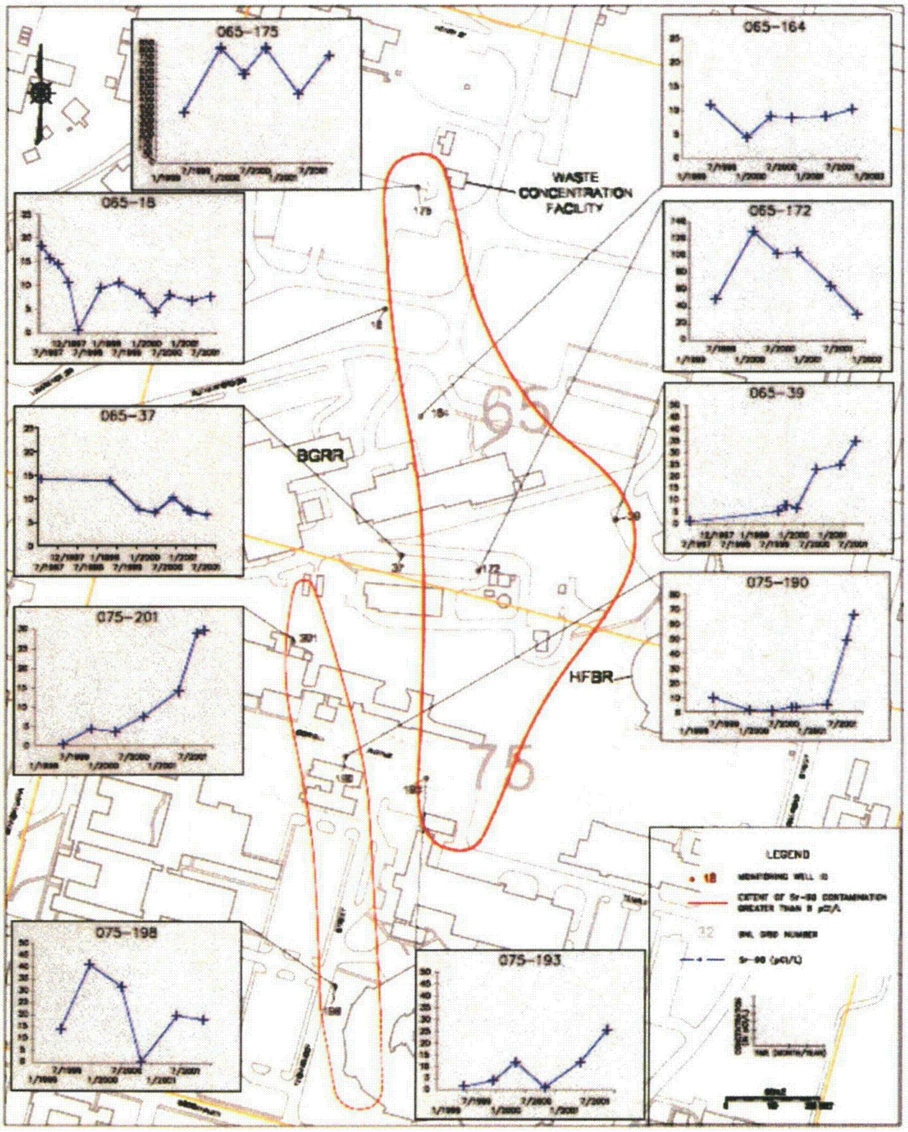


Figure 6-1: Sr-90 Plumes on the BNL Site and Selected Well Concentration Trends (BNL, 2006)

6.2.1 Pilot Study

The DOE directed the design, installation, and operation of the Sr-90 pilot treatment system in 2003 and 2004. The pilot study treatment system was built to treat the smaller contamination plume located downgradient of the former "Chemical Holes" disposal site. This treatment system used one well to extract water at 50 gpm in the area of the highest measured Sr-90 concentration. Two additional well locations were proposed in other areas of the plume; however, they were to be operated sequentially to limit the flow to the treatment system to 50 gpm.

Lesson Learned: Pilot studies are extremely useful in evaluating the effectiveness of remedial alternatives forstrontium-90 treatment, providing supporting documentation to improve a final remedy, and in demonstrating responsiveness to the contamination problem.

The pilot study was highly effective in providing information that was useful and relevant in determining a remediation plan for Sr-90 groundwater contamination on the BNL site. Major pilot study findings are summarized below:

- Sr-90 can be effectively extracted from the aquifer. Even after 14 months of operating at low flow rates, the pilot treatment system continues to extract groundwater from the aquifer with significant concentrations (125 pCi/l) of Sr-90.
- The rate of ion exchange resin usage at the elevated flow rates considered in the RI/FS was significantly higher than anticipated. Although the ion exchange resin is effective in removing Sr-90 from the extracted groundwater, the minerals and other natural impurities in groundwater, contribute to a reduction of the service life of the resin. Hence, there is a disproportionately high rate of resin usage and low-level radioactive waste (LLRW) generation in relation to relatively small quantities of Sr-90 actually removed from the groundwater.
- At the flow rates shown in the RI/FS, this increased rate of resin exchange would result in an increase in the generation, transportation, and disposal of Low Level Radioactive Waste (LLRW) from 540 cubic feet per year to 2,800 cubic feet per year.
- The original estimated life-cycle project costs in the RI/FS and ROD, including treatment system operations and maintenance totaled $6,500,000. In order to meet the same cleanup objective contemplated in the RI/FS and ROD, and driven almost exclusively by increased resin usage, and increased LLRW packaging, transportation and disposal volumes, the life-cycle project costs are now estimated at $55,700,000.

The pilot study has demonstrated that Sr-90 can be extracted from the aquifer. However, a scaled up high flow system to treat Sr-90 groundwater contamination would generate enormous quantities of spent, contaminated resin that would need to be disposed of as LLRW. It would be cost prohibitive to operate the system contemplated in the RI/FS and ROD (BNL, 2006).

6.2.2 Additional Characterization of the Strontium-90 Groundwater Contamination

Prior to the ROD (DOE, 2000), the highest Sr-90 concentrations originally found in these plumes were 769 picoCuries per liter (pCi/l) and 566 pCi/l for the Chemical Holes and BGRR/WCF/PFS plumes, respectively. Sr-90 groundwater contamination has not been detected in areas off of the BNL site.

During the fall of 2003, supplemental characterization was performed to support ongoing remedial design activities. Supplemental sampling and analysis indicate that the Sr-90 contamination plumes are generally of the same size, in the same location, and at the same depth as determined after the original characterization events. However, increased concentrations were found in the Chemical Holes and BGRR/WCF Sr-90 contamination plumes: 2,540 pCi/l and 3,150 pCi/l, respectively. Again, Sr-90 groundwater contamination has not been detected in areas off of the BNL site.

6.2.3 Suggested Alternative Treatment System

The OU III ROD treatment remedy relies on active "pump and treat" and continued monitoring to reach drinking water standards in 30 years. The selected treatment system adopted in the ROD relies on two extraction wells operated at high flow rates. The significantly higher concentrations found in the December 2003 characterization work makes it unlikely that the selected treatment system would meet the goal of having Sr-90 concentrations below the drinking water standard within 30-years. As previously discussed, the treatment of groundwater using ion exchange technology is effective for Sr-90 removal. However, the Pilot study showed that removal of minerals and other natural groundwater impurities contributes to a reduction of the service life of the resin at high flow rates. This in turn results in a significant increase in the rate of resin usage and LLRW generation relative to the relatively small amounts of Sr-90 actively removed from the groundwater.. Increased resin usage and increased LLRW waste disposal costs have resulted in an almost ten-fold increase in the original $6.5 million life cycle cost estimate with little or no improvements in the performance and effectiveness of the remedy. For these reasons, the DOE evaluated other Sr-90 remedial alternatives in light of its pilot study operating experience.

In view of the supplemental characterization data and pilot study findings, seven alternatives were considered for remediating Sr-90 groundwater contamination. They are described in the March 5, 2004 *Sr-90 Plume Alternatives Evaluation.* This report was provided to the EPA, NYSDEC and SCDHS in March 2004 and placed in the Administrative Record in June 2004.

Based on the proposed alternatives, it was decided that the existing pilot study treatment system would continue to be operated for approximately ten years to actively treat the Sr-90 plume downgradient of the former "Chemical Holes" followed by 30 years of natural attenuation and radioactive decay. The total duration to meet drinking water standards for this plume is expected to be 40 years.

At the BGRR/WCF Sr-90 contamination plume located in the center of the BNL site, DOE proposed to install five extraction wells and groundwater treatment system (ion exchange) using lessons learned during the installation, operation and maintenance of the pilot study treatment system. Based on models using the supplemental characterization data, the system would be operated for a period of approximately ten years, followed by 60 years of natural attenuation and radioactive decay. The total duration to meet drinking water standards is 70 years. Hence, the limiting duration to reach drinking water standards is 70 years in contrast to the 30-year objective in the OU III ROD. The total estimated life-cycle cost of the Sr-90 remedial alternative is $14 million.

It should be noted that neither plume is predicted to leave BNL property above drinking water standards and that no drinking-water wells are near this plume. It should be further noted that monitoring wells and a sampling program will continue to monitor the location and extent of the plume.

The DOE proposed an alternative treatment system for the following reasons:

- This alternative provides for active treatment of the Sr-90 groundwater contamination and hence would be effective in controlling plume growth.
- According to groundwater modeling, the Sr-90 contamination in the BGRR/WCF plume would not migrate south of Princeton Avenue or within 6,000 feet of the BNL site boundary above drinking water standards. The Chemical Holes plume likewise would not migrate within 1,000 feet of the BNL site boundary. Because groundwater never exits the BNL site above drinking water standards, there are no receptors and hence no human health risks.
- This alternative provides a 1,800-cubic-foot reduction per year in the packaging, transportation, and disposal of LLRW in comparison with the reference treatment system discussed in the ROD.
- At $14 million, still more costly than the original projected $6.5 million, this alternative results in cost savings of more than $40 million in comparison with the reference treatment system in the OU III ROD.
- There are no credible technical uncertainties and risks associated with the effectiveness of institutional controls relative to the 70-year duration required to reach Sr-90 drinking water standards.

6.3 Institutional Controls for the Groundwater Remediation Program

Institutional controls will also be in place to ensure effectiveness of these and all groundwater remedies. In accordance with the BNL *Land Use Management Plan*, dated August 2003, the following institutional controls will continue to be implemented for the groundwater remediation program:

- Groundwater monitoring, including BNL potable supply systems and SCDHS monitoring of Suffolk County Water Authority well fields closest to BNL
- Five-year reviews as required by CERCLA will be conducted until cleanup goals are met and to determine the effectiveness of the groundwater monitoring program
- Prohibitions to the installation of new supply wells

- Public water service in plume areas south of BNL
- Prohibitions to the installation of new drinking water wells and other pumping wells where public water service exists (Suffolk County Sanitary Code Article 4)
- Property access agreements for treatment systems off of BNL property (deed transfer with property ownership change)

Due to the slow migration of Sr-90 in groundwater, and the slow groundwater flow of the Magothy Aquifer, there is ample time to respond to unexpected conditions or deviations in monitoring data for both plumes. An effective groundwater monitoring well network is vital to assure that the selected remediation approaches are performing as expected and to identify deviations. Monitoring well data trends and plume movement will be evaluated on an annual basis. Several sentinel wells will help monitor plume growth over time to ensure that the Sr-90 plumes remain within BNL property. Increasing trends of Sr-90 contamination in these wells will be evaluated, and if necessary, changes would be made. Changes could include installing additional monitoring wells or adding additional extraction wells.

In addition, during the required five-year reviews, a comprehensive evaluation will be performed to ensure that the plumes are behaving as expected and that the remediation approach continues to be protective of human health. During these reviews, DOE, EPA, and NYSDEC will evaluate if modification of the remedy is needed to ensure this protectiveness.

A certification was included in the BNL Annual Groundwater Status Report that the institutional controls put in place for groundwater are unchanged from the previous certification. It will confirm that nothing has occurred that would impair the ability of the controls to protect human health or the environment or constitute a violation or failure to comply with any operation and maintenance requirements or BNL's Land Use Management Plan.

6.4 Public Involvement

Lengthening the time to reach cleanup goals (drinking water standards) was a major change and required public input. The DOE conducted a public comment period from Wednesday, December 15, 2004 to Friday, January 21, 2005. It was announced by publishing public notices and display advertisements in regional newspapers, conducting mass information mailings including about 2,300 interested community members, posting a notice on the BNL web page, and conducting interactive discussions at Community Advisory Committee (CAC) and Brookhaven Executive Roundtable (BER) meetings. Two public information sessions were held on Tuesday, January 11, one at midday for BNL employees and one that evening for the general public.

The CAC represents a cross section of the community and its meetings are a forum through which public opinion is provided to BNL. The CAC was closely involved in consideration of the changes being proposed. Specifically, during its scheduled meetings, the CAC was given a detailed presentation on May 13, 2004 and again on December 9, 2004. A special question-and-answer session was held for the CAC on January 6, 2005 and the CAC's final discussions occurred during its monthly meeting on January 13, 2005.

A Responsiveness Summary was prepared that provided the DOE's response to comments received during the public comment period. Comments received include a survey of opinions of the CAC members (17 supported the ESD, 4 opposed it and 1 abstained), three letters and three emails.

The DOE believed that the proposed remedies were appropriate because they were protective of human health and the environment and minimized plume growth. The plumes are expected to remain separated and isolated from public drinking water sources on and off of the BNL property. This will be regularly checked by a network of groundwater monitoring wells. Should a plume act differently than anticipated, this monitoring program would detect the change far enough in advance to allow DOE to change the cleanup remedy, when necessary.

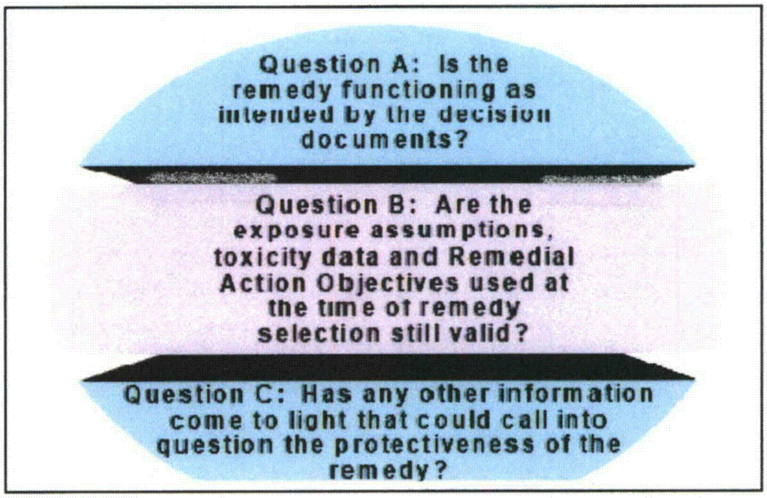
Following this review process, DOE was given permission to modify the OU III ROD to permit a longer cleanup time (DOE 2005a).

6.5 Sr-90 Plume Management

BNL actively manages the three Sr-90 plumes that are on-site using the process illustrated in Figure 1-9. A detailed discussion of the BGRR and WCF plumes can be found in Appendix B. As part of the regulatory agreement, DOE used Data Quality Objectives to focus data collection and modeling on decisions regarding plume management. For each of the three Sr-90 plumes BNL prepares an annual report that answers the following questions: (Note that these questions relate to EPA's Approach for reviewing the performance of cleanup alternatives in their 5 year review process- Figure 6-2)

1. *Was the BNL Groundwater Contingency Plan triggered?*
2. *Has the plume been controlled?*
3. *Is the system operating as planned? Specifically, is the aquifer being restored at the planned rate identified in the Explanation of Significant Differences to the OU III Record of Decision?*
4. *Have the cleanup goals been met? Can the groundwater treatment system be shut down?*

Based on the answer to these four questions, BNL provides recommendations to improve plume management. For example, for the Chemical Holes plume the original system design was for one extraction well operating for approximately 10 years to actively treat the Sr-90 plume, followed by 30 years of natural attenuation and radioactive decay. Based on increased Sr-90 concentrations identified in monitoring wells further downgradient, two additional extraction wells were installed in 2007 to ensure the cleanup goals would be met. The additional two extraction wells are also expected to operate approximately 10 years. Recommendations also included suggestions on removing wells that were no longer effectively treating the plume and changing the frequency of monitoring.



Question A: Is the remedy functioning as intended by the decision documents?

Question B: Are the exposure assumptions, toxicity data and Remedial Action Objectives used at the time of remedy selection still valid?

Question C: Has any other information come to light that could call into question the protectiveness of the remedy?

Figure 6-2: EPA 5 Year Remedy Evaluation Process (EPA, 2001)

7.0 COMMUNICATIONS

7.1 History of Community Involvement

Lesson Learned: Establishing a public involvement process before there is a problem is important (Good Neighbor Policy). At BNL, it was difficult to establish a Community Advisory Council (CAC) in a crisis situation in an atmosphere of distrust.

Historically, public involvement in BNL's environmental restoration activities was low, but after a Community Relations program was established in 1991, public interest and contact with BNL increased. Two major "events" spiked public interest in the Laboratory restoration activities. First, the free public-water hookups offered to residents directly south of BNL in January, 1996 prompted over 700 people to attend a public meeting at BNL. A year later, the second event was the identification of a leak in the spent-fuel pool of the High Flux Beam Reactor that brought significant media attention and stakeholder concern. Interaction with the community has been a major focus of BNL's administration and employees since the tritium leak was found. Surveys of employees and the community have provided a baseline of information on the status of community relations and revealed avenues for improving them. These avenues were actively pursued.

Laboratory-wide, several new venues for community involvement were established. BNL employees now can join an "Envoy" program and represent BNL in community groups to which they already belong. The BNL Speaker's Bureau was re-instituted and employees are going out into the community and speaking on a wide variety of topics. But by far the most important is an independent Community Advisory Council (CAC), composed of representatives of established stakeholders' groups on Long Island, BNL employees, and several other individuals. The CAC meets monthly to learn about and discuss Laboratory issues and to offer recommendations to BNL's Director. A new "Community Involvement Plan" was jointly developed by community members, BNL's staff and the Department of Energy in April, 1999. The plan provides a framework for involving the community in decision-making at the Laboratory.

Established venues for exchanging information continue. The Brookhaven Executive Roundtable (BER), established in August 1997, is composed of elected officials (or their representatives), regulators, and the Suffolk County Water Authority. Community members routinely attend the meetings and there is an opportunity for public comment available at each meeting. The BER was created to facilitate and expedite the flow of information from BNL to some of its key stakeholders on significant environmental, operational, regulatory, and oversight issues. It has been very successful by providing up-to-date information (background, status, steps forward) and doing so early in the process.

The goals of the community relations program have been, and are, the following:

- To inform stakeholders (on-site employees and the public) about the issues being addressed by the Environmental Restoration Division.
- To solicit input from stakeholders about these issues.

- To provide stakeholder input to DOE/BNL senior management and regulators to be used as one of the decision-making criteria for evaluating cleanup alternatives.
- To develop good relationships with on-site employees, community members and leaders, and community environmental activists.
- To increase regular communication with stakeholders by expanding the ERD stakeholder mailing list.

7.2 Summary of Community Participation Activities

There were five major areas of community-relations activities for OU III:

- The Removal Action V / Operable Unit I Groundwater Removal Action and Operable Units I and III Public-Water Hookups
- The HFBR Tritium Remediation Project
- The OU III Off-site Removal Action
- Early Community Input on OU III Cleanup Alternatives
- OU III Remedial Investigation/Risk Assessment Report, Feasibility Study, and Proposed Plan

The focus of this report is on Community Relations for the HFBR tritium project.

HFBR Tritium Remediation Project

On January 18, 1997, the U.S. Department of Energy (DOE) and Brookhaven National Laboratory (BNL) announced that routine monitoring had identified tritium concentrations exceeding the drinking water standard in groundwater at the center of the Laboratory site, just south of BNL's High Flux Beam Reactor. This announcement, in combination with previously discovered groundwater contamination by volatile organic chemicals, led to a lack of public confidence in the Laboratory's commitment to public health and safety and the protection of the environment.

Lesson Learned: Having good community relations is critical in times when site operations negatively impact the community. The lack of good relations led to an extensive multi-year effort to regain the trust of our neighbors.

In response to this public concern, DOE and BNL actively sought and received feedback from stakeholders, and responded to the media to ensure that accurate information was disseminated in a timely and consistent manner.

January - June 1997: To understand the community's concerns and to keep people informed, Community Relations representatives and subject-matter experts attended meetings of civic associations that surround BNL. Approximately 50 presentations and updates on tritium were given from January through June. 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 a letter, and a question and answer fact sheet about tritium and letter. Five information / poster sessions were held in the surrounding area, including one at BNL for employees. These 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 tritium remediation proposal, and briefings were conducted with regulators for input on the final discussion and approval of pump-and-recharge and public communication and involvement.

Superfund Activities: When the tritium remediation project was phased into BNL's Superfund activities, an Action Memorandum describing the pump-and-recharge system was issued. This Action Memorandum 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 information / poster sessions (mentioned above) were conducted. In addition, a tritium-remediation poster was included and subject-matter expert attended all subsequent information sessions / poster sessions held on the HFBR, and at the Accelerated Cleanup 2006 poster session in July 1997. Well over a dozen tours of the monitoring-well areas and remediation system were given to community groups.

Lesson Learned; Workshops and availability sessions were much more effective communication tools than large public meetings. Specific items of concern could be addressed more readily.

Media Relations: Between January and December, 1997, media relations issued approximately 40 press releases on the tritium remediation project. Personnel from Public Affairs and Community Relations informed stakeholders before distributing these releases in order to maintain an open dialogue.

Lesson Learned; The BNL experience revealed some public relations initiatives that did not work. Providing weekly updates of the plume characterization to the media via press releases is one example. Some in the community thought that the newspaper article was a new problem being discovered each week.

Approximately six press conferences/media availabilities and approximately 1000 media requests were coordinated and handled. Briefing pages and fact sheets were written. Over 250 calls from concerned citizens were answered.

7.3 Public Water Hook-ups

A 1995 residential well sampling program in the area south (downgradient) of BNL showed no radiological or chemical contamination from BNL above drinking water standards (groundwater solvent contamination thought to originate from a local business south of BNL was found in some wells).

The Agency for Toxic Substances and Disease Registry (ATSDR), a division of the U.S. Department of Health and Human Services, released its Health Consultation Report and an equally important Addendum to the report. The Agency began the consultation at the request of the U.S. Department of Energy (DOE) as part of the ongoing Superfund cleanup at BNL. The purpose of the Health Consultation was to examine the groundwater quality and determine the potential impact, if any, to public health if area residents were to use water from their private wells for drinking or bathing. The Agency stated that "there is no indication that anyone is being exposed to all the contaminants or all the plumes." Based on the sampling results of private residential wells, the Agency has concluded that the contamination, which includes volatile organic compounds (VOCs) and low-level radionuclides, is "not sufficient to produce adverse health effects."

However, as a precautionary measure, the U.S. Department of Energy (DOE) extended water mains and offered home and business owners free hookups to the public water supply. The DOE offer was initiated in January 1996. As of January 1998, 1,500 property owners in North Shirley, East Yaphank, and Manorville had been connected to public water.

Providing public water to these homes downgradient from BNL guarantees the drinking water supply will not be impacted by BNL operations. However, many people in the community took this act as tacit proof that contamination may negatively impact their health. This reflects the lack of trust between BNL and the community at that time.

Lesson Learned; Public perception may not always agree with technical facts. Lack of trust between the community and BNL caused many people to believe they were negatively impacted by BNL operations.

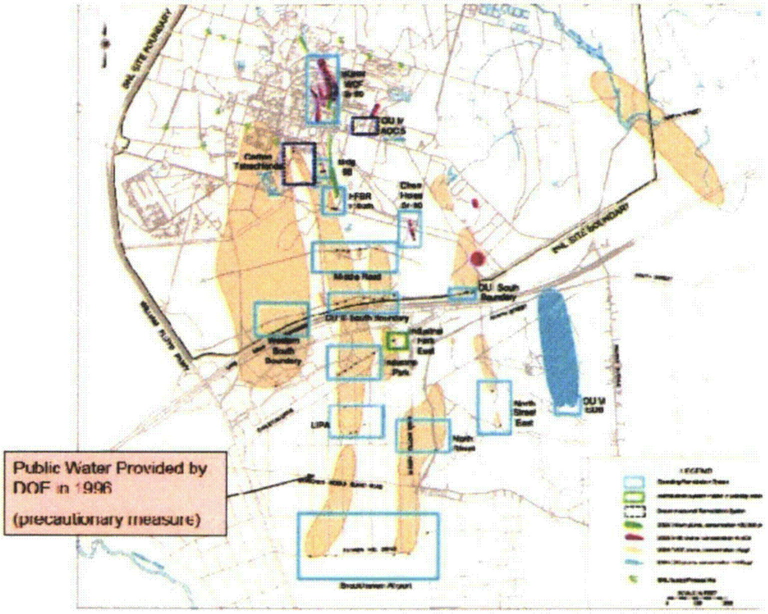


Figure 7-1: Location of plumes and treatment systems (boxed areas) VOC contamination off-site (BNL, 2008a)

7.4 Continuing Community Involvement

The Community Advisory Council (CAC) continues to be an active element in providing a communication link between the community and the Laboratory on a wide range of issues. Figure 7-1 shows plume treatment systems operating in 2008. Among other issues, all plumes are actively followed by the CAC. They meet monthly and provide recommendations to the Laboratory Director as requested. As noted on their web page http://www.bnl.gov/community/cac/default.asp the CAC was formed in 1998 to advise the Laboratory Director on selected issues, particularly on the environment, safety, and health. It is the intent of the Laboratory that the Community Advisory Council (CAC) represents a diverse range of interests and values of individuals and groups who are interested in or affected by the actions of the Laboratory. The CAC consists of representatives from 25 local business, civic, education, activist, environment, employee, emergency, and health organizations.

In September 2008, the CAC celebrated their 10th anniversary. They were presented with a Certificate of Appreciation from the U.S. Department of Energy acknowledging their role in regaining the community's confidence and trust in the Laboratory and for their dedication, curiosity, and guidance. Many New York State and local officials also recognized the CAC for their contributions and exemplary service to the community.

The CAC sets its own agenda, brings forth issues important to the community, and works to provide consensus recommendations to Laboratory management. Meetings are held on the second Thursday of each month.

8.0 SUMMARY

Discovery of tritium in the groundwater near the Brookhaven National Laboratory (BNL) High Flux Beam Reactor (HFBR) in January 1997 initiated an intense effort to locate its source, determine its extent, and implement remediation methods to mitigate its consequences. The tritium plume that resulted from the slow, long-term leakage of contaminated water from the HFBR spent fuel pool at BNL was the subject of much attention by the media, State and Federal regulators, and the public in 1997. Tremendous amounts of resources were dedicated to characterizing the plume in great detail and in mitigating its consequences. The subsequent discovery of strontium-90 in March 1997 at levels exceeding the drinking water standard exacerbated the situation.

The BNL experience in managing radioactive groundwater contamination has led to several potentially useful lessons that are presented in this report. The lessons have been divided into five categories: 1) Source control, 2) Monitoring, 3) Modeling, 4) Plume/Risk Management, and 5) Communications as described in Figure 8.1. The specific lessons that may be of value to the NRC are summarized in this section.

Source Control

Source control involves the characterization of all potential sources and the identification of the source(s) that can lead to releases to the environment. For groundwater contamination, source control also includes containment of the high concentration areas of the plume to prevent migration downstream (or off-site).

Monitoring

Monitoring is the collection and evaluation of data to support all phases of cleanup. It should start with monitoring of facilities for leakage to the environment and include data collection to support cleanup decisions such as the effectiveness of the remedy and the ability to stop collecting data when the plume migrates away from the well or the remedy has successfully met its objectives.

Communication

Communication is needed in all phases of the remediation process and includes describing the contamination problem, what caused the problem, potential risks to the public from the contamination, and what is being done to address the problem. Effective communication requires the willingness to listen to and address, to the extent possible, stakeholder concerns. It also requires frequent discussions to update stakeholders on the progress of the cleanup

Modeling

Modeling is the use of computer tools that predict the movement of groundwater and contaminants, and their release from the facility through the vadose zone into the groundwater.

Plume/Risk Mgt.

Plume/Risk Management is the process by which all decisions are made. It entails use of the monitoring data and modeling to support decisions

Figure 8.1: Lessons Learned Summary by Topic

8.1 Source Control

1. ***Understanding the potential environmental vulnerabilities and identifying the source of groundwater contamination is critical for achieving credibility with the regulators and the public.***

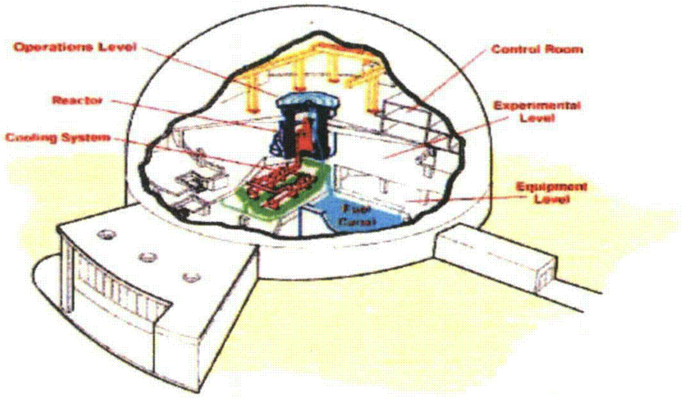


Figure 8-2: Potential Vulnerabilities at the HFBR for Impacting the Environment

At BNL, a loss of credibility occurred when initial groundwater monitoring results could not be explained. It took several months to evaluate all of the potential sources and determine that previous testing of leakage from the spent fuel pool had been inadequate. Ultimately, groundwater monitoring data and modeling simulations led to the identification of the spent fuel pool as the only source that could provide the concentrations of tritium being measured in the groundwater. Contributions from other potential sources involved a multi-disciplinary approach – including system engineers and hydrogeologists. Completion of a vulnerability analysis can provide immeasurable benefit

2. ***The release of contaminants from the vadose zone, particularly mobile contaminants such as tritium, during periods of water table rise needs to be considered as a continuing source term. Establish field monitoring to achieve early detection of vadose zone releases.***

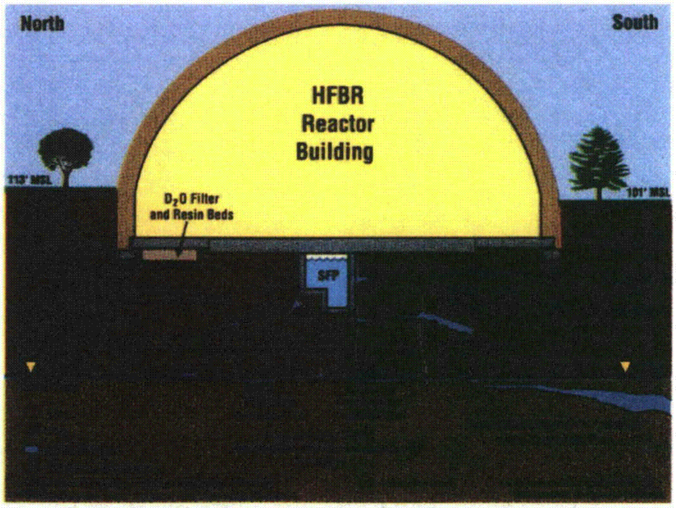


Figure 8-3: Continuing contribution from the vadose zone

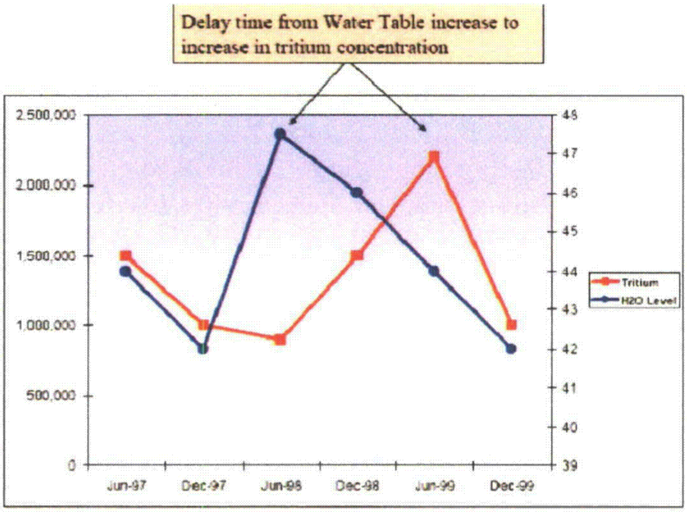


Figure 8-4: Continuing Source Term with Increase in the Water Table Level

3. ***Source hotspots should be controlled even if monitoring and modeling is not complete. Inaction at the time of discovery of a hotspot concentration can result in longer and more complicated remedial activities further downgradient.***

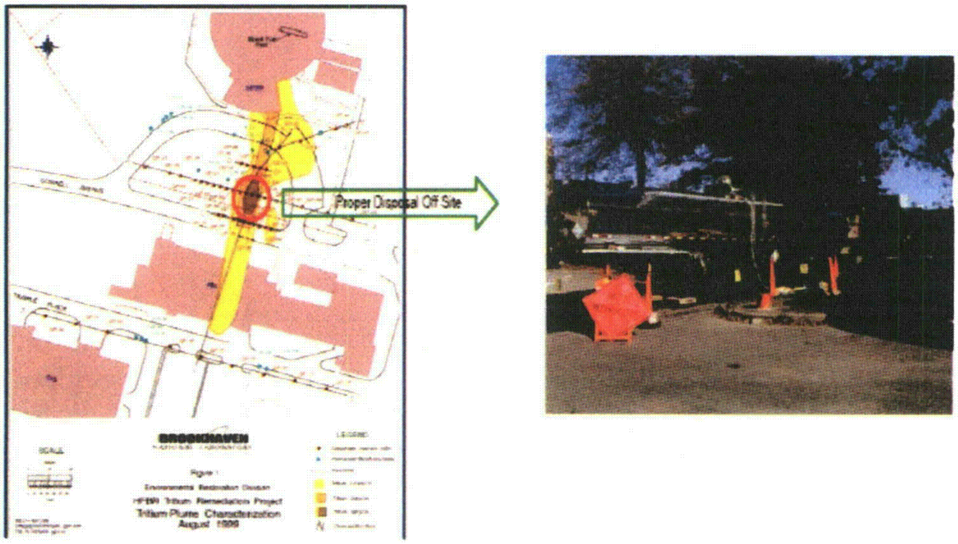


Figure 8-5: Low Flow pumping of high concentrations of tritium (BNL, 2001)

At BNL, a total of about 100,000 gallons of tritiated water with concentrations greater than 500,000 pCi/L were extracted using low flow pumping (5 gallons per minute) over a two year period to reduce the source term. Reducing the source term at BNL had a measureable impact on reducing the downgradient concentrations of tritium.

8.2 Monitoring

BNL did not adequately monitor leakage from HFBR systems, particularly the small losses from the spent fuel pool. The detection of strontium-90 in the groundwater near the BGRR also indicated the need to expand facility monitoring to include auxiliary drain lines and subsystems where contaminated water could accumulate. The key lessons learned for the monitoring area are:

4. ***Facility monitoring is an important defense in the early detection of unexpected releases to the environment. The realization that tritium was being released from the HFBR to the groundwater at BNL occurred many years after the release began due to inadequate facility monitoring. Expansion of the facility monitoring program at BNL after 1997 uncovered other contaminants that needed to be addressed.***

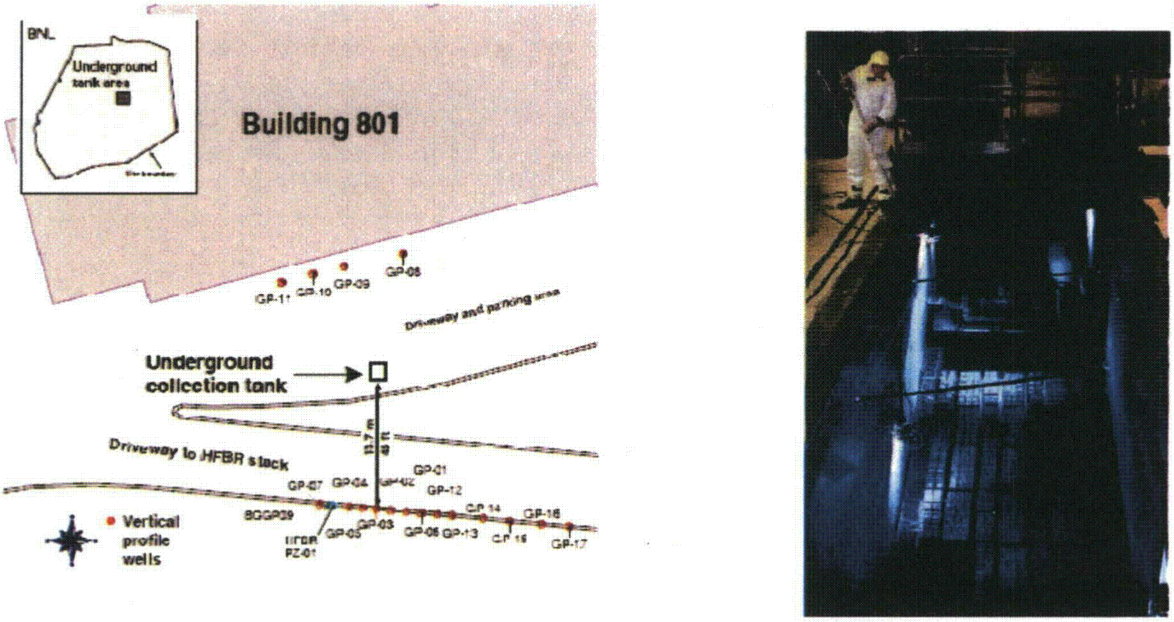


Figure 8-6: Leakage from underground collection tank (Sr-90) and the HFBR spent fuel pool (tritium)

5. ***Geoprobes™ and temporary wells that provided vertical profiles of the contamination concentrations are effective tools for an "early response" plume characterization. Vertical characterization of the plume was important at BNL due to the well-defined (vertically thin) nature of the tritium plume.***

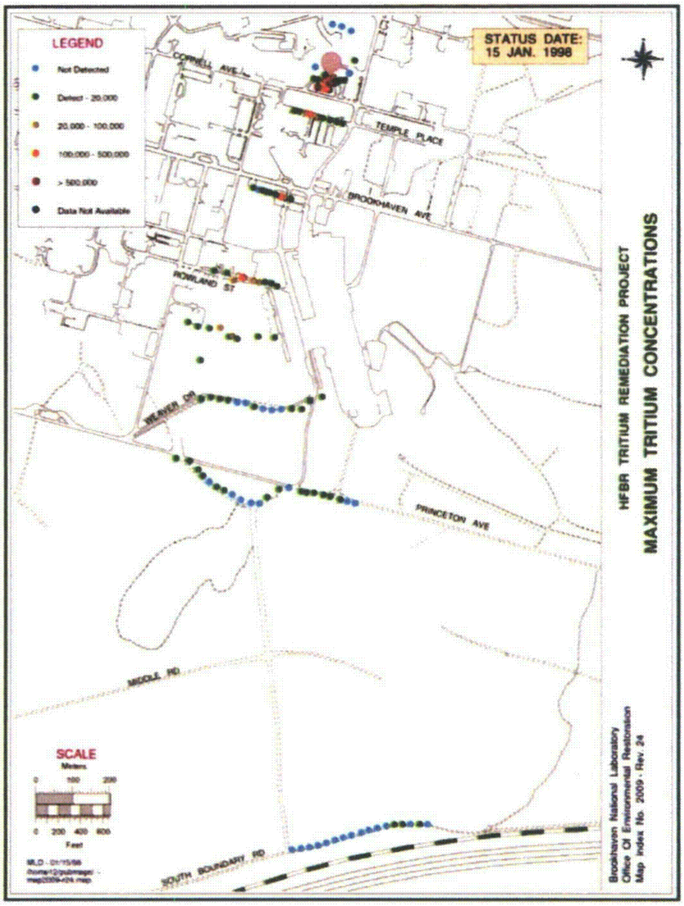


Figure 8-7: Temporary and Permanent Monitoring Wells Used to Characterize the HFBR Tritium Plume

8.3 Modeling

Modeling is the use of computer tools that predict the movement of groundwater and contaminants, their release from the facility through the vadose zone into the groundwater. The availability of a site-wide model prior to the discovery of tritium and strontium-90 in the groundwater greatly enhanced the ability to evaluate the potential impacts of the contamination on public health and safety and the environment.

6. ***It is essential to have a calibrated site-wide groundwater model in place that can be used to:***
    - ***select monitoring locations,***
    - ***support risk analysis on the impact of a particular plume***
    - ***support evaluation of remedial alternatives, and***
    - ***support design (location and pumping rate) of the selected remediation system.***

Having a detailed groundwater site model in place was critical for the rapid response needed to address concerns with the tritium contamination. The site model was used as the basis for predicting the migration of the tritium plume over time. However, the spatial resolution of the site model was inadequate to evaluate the movement of the tritium plume. For this reason, a telescopic mesh refinement was used that inscribed a subarea that covered the HFBR vicinity in much greater spatial detail than the site model. The HFBR sub-model covered an area approximately one mile wide and three miles long. It extended slightly more than a mile south of the southern boundary of the BNL facility.

7. ***It is important that site activities that could impact plume movement are documented and their potential impacts evaluated. This includes on-site supply well pumping, impacts of recharge basins, annual rain fall amounts, water table fluctuations, and major spills/leaks.***

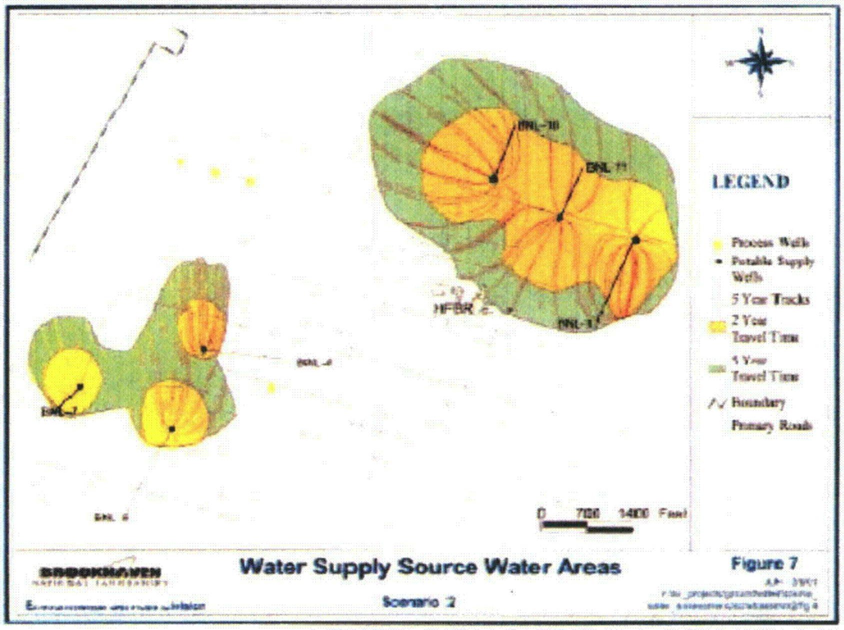


Figure 8-8: Potable and Process Well Influence

8.4 Plume/Risk Management

Plume/Risk Management is the process by which all decisions are made. It entails use of the monitoring data and modeling to support decisions.

8. ***A well developed process that ensures that all elements are included in a risk based remediation decision needs to be in place and implemented. The process includes requirements for contingency plans, regular progress report, and formal periodic reviews. The process mandated by CERCLA as used at BNL is an example of a robust process.***

At BNL a self-evaluation is performed annually. The performance measures used for evaluation are typically a series of questions such as:

(1) *Was the BNL Groundwater Contingency Plan triggered?*

(2) *Has the plume been controlled?*

(3) *Is the system operating as planned? Specifically, is the aquifer being restored at the planned rate identified in the Record of Decision?*

(4) *Have the cleanup goals been met? Can the groundwater treatment system be shut down?*

This kind of approach leads to the next two lessons learned:

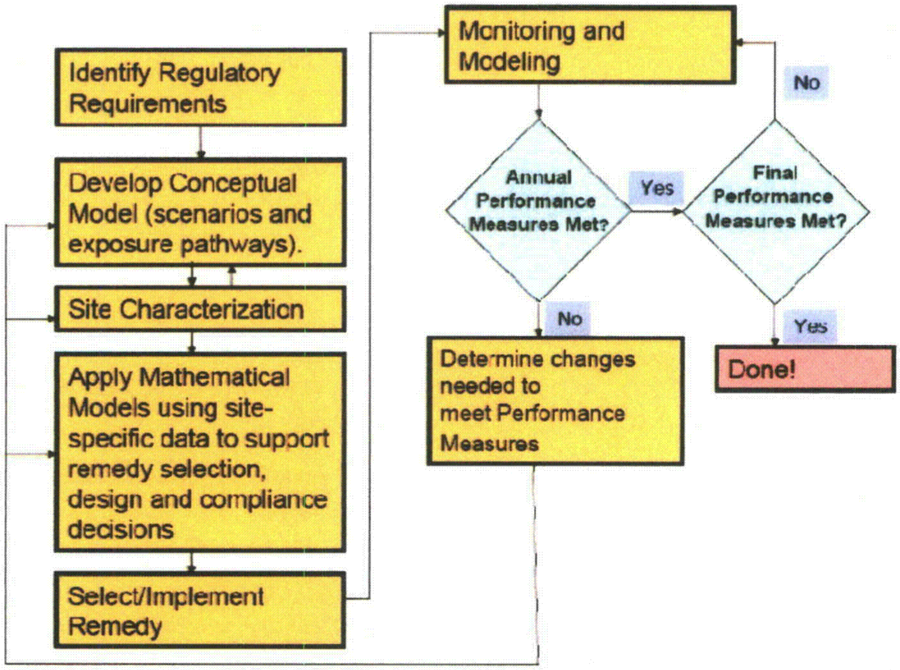


Figure 8-9: Integration of Modeling and Monitoring to Support Performance Measures

9. ***There are long term benefits for establishing data quality objectives (DQOs) at the beginning of the process. These benefits include:***
   - ***helping to focus data collection and decisions on the performance goals;***
   - ***forming a basis to demonstrate that sampling frequency can be reduced/increased based on trends in the data;***
   - ***forming a basis for implementing contingency plans when goals are not being met; and***
   - ***forming a basis to implement an exit strategy, such as turning off an extraction system, when goals are met.***

10. ***In discussion of risk assessment, it is important to factor in risk to the Institution as a result of public outrage and media attention. At BNL it can often be shown that human health and ecological risks are below typical regulatory levels of concern. However, institutional risks (lack of credibility, loss of funding) and public concerns are often not trivial.***

8.5 Communication

Communication is needed in all phases of the remediation process and includes describing the contamination problem, what caused the problem, potential risks to the public from the contamination, and what is being done to address the problem. Effective communication requires the willingness to listen to and address, to the extent possible, stakeholder concerns. It also requires frequent discussions to update stakeholders on the progress of the cleanup. Because the contaminants at BNL are common with those being found at decommissioned and operating commercial plants, the following lessons learned are applicable:

11. ***Public perception may not always agree with technical facts. Lack of trust between the community and BNL caused many people to believe they were negatively impacted by BNL operations. The lack of trust even caused some community members to interpret pro-active public water extensions as a tacit admission of guilt by BNL even though the data indicated that there were no substantive human health risks.***
12. ***Establishing a public involvement process before there is a problem is important (Good Neighbor Policy). At BNL, it was extremely difficult to establish a Community Advisory Council (CAC) in a crisis situation. Initially there was a complete lack of trust.***
13. ***Communications requires continual effort and providing a venue for regular updates to environmental regulators, public officials, and the community (Brookhaven Executive Roundtable-BER and the Community Advisory Council-CAC) is essential.***
14. ***The BNL experience revealed some initiatives that did not work. This included providing weekly updates to the media (press releases) of the plume characterization. Some in the community thought the news was a new problem being discovered each week.***
15. ***Risk communication is important. It is essential to provide a clear message to the public. BNL had difficulties explaining co-mingled plumes (tritium from HFBR and VOCs from other sources). In some cases, BNL provided too much data including contaminant levels far below the drinking water standards which caused members of the public to believe the extent of contamination was greater than it actually was.***
16. ***Workshops and availability sessions were much more effective than large public meetings. Specific items of concern could be addressed more readily.***

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APPENDIX A: HIGH FLUX BEAM REACTOR TRITIUM MODELING STUDIES

Prior to the discovery of the tritium contamination, BNL had developed a detailed groundwater flow model to address other groundwater contamination issues. The computer code MODFLOW88 was used to simulate groundwater flow around BNL. In 1996 water-level data from 225 wells, stream flow measurements from 12 gage stations on 4 rivers, and historical data of groundwater stressors including operational uses (pumping and surface discharge) and recharge were used in MODFLOW88 to calibrate the groundwater flow model throughout the entire site. This simulation covered an area of approximately 600 square miles and included all of Long Island from the Long Island Sound to the Atlantic Ocean with a width of approximately 30 miles. Eight separate layers were used to simulate the vertical hydrogeologic features on Long Island.

Having a detailed groundwater site model in place was critical for the rapid response needed to address concerns with the tritium contamination. The site model was used as the basis for predicting the migration of the tritium plume over time. However, the spatial resolution of the site model was inadequate to evaluate the movement of the tritium plume. For this reason, a telescopic mesh refinement was used that inscribed a subarea that covered the HFBR vicinity in much greater spatial detail than the site model. The mesh size was reduced to 10' X 10' X 10' in the refined model. This HFBR region sub-model incorporates the hydrogeologic and hydrological data from the larger model and uses the larger model to provide boundary conditions for subsequent calculations. The HFBR sub-model covered an area approximately one mile wide and three miles long. It extended slightly more than a mile south of the southern boundary of the BNL facility.

The computer code MT3D was used to simulate the movement of tritium throughout the aquifer. MT3D is based on a modular structure to permit simulation of transport components independently or jointly. MT3D interfaces directly with the groundwater flow model, MODFLOW, for the head solution, and supports all the hydrologic and discretization features of MODFLOW. The MT3D code has a comprehensive set of solution options, including the method of characteristics (MOC), the modified method of characteristics (MMOC), a hybrid of these two methods (HMOC), and the standard finite-difference method (FDM). Use of the MOC method minimizes numerical dispersion and was used in the simulations of tritium movement at BNL.

A set of model predictions of tritium distribution downgradient from the HFBR over time were performed using the refined HFBR subregion mode. Initial tritium concentrations for the model were obtained from the site-specific data collected during characterization. At that time, the peak measured tritium concentration was 651,000 pCi/L. Model predictions included:

- Tritium plume location and concentration over 30 years based on historic groundwater conditions with and without source control. These studies indicated that tritium would not pass the BNL site boundary in excess of the drinking water standard even without source control.

- Optimization of Pump and Recharge system in terms of well locations, screened depths and pumping rate. The treatment system design specified three wells separated approximately 75 feet at Princeton Avenue. The wells are screened at a depth of 130 - 150 feet with each well removing 40 gpm. This water was sent through carbon filters to remove VOC contamination from another source on-site. This filtered water was sent to recharge basin RA V. Tritium concentrations in this water were predicted to be between 1000 – 2000 pCi/L.
- Impacts of recharge on tritium transport pathways. The selected recharge basin, RA V, was close enough to the HFBR plume that the discharge of 120 gpm to the basin alters the hydraulic gradient in the vicinity and slightly changes the flow direction. Model predictions suggested that this could shift the tritium plume to the west by 50 – 300 feet at Princeton Avenue. This shift impacts future monitoring plans and could require additional extraction wells.

Location and concentration of tritium plume emerging from the recharge basin. Although, tritium concentrations in the water extracted from Princeton Avenue were expected to be between 1000 – 2000 pCi/L, a full transport analysis was done for tritium. The travel time to the sight boundary from this recharge basin is 19 years and predicted concentrations crossing the site boundary would be less than 200 pCi/L, which is 1% of the drinking water standard.

Application of the Groundwater Models at BNL

Two types of model simulations were run using the detailed HFBR submodel; a long-term transient historical simulation and a predictive steady-state simulation. The goal of the transient historical analysis was to evaluate the ability of the model to simulate the evolution of the tritium plume. The goal of the predictive simulation was to determine the fate of the tritium plume after 30 years of transport. As noted above, a regional model had been developed in 1996 that was used as the basis for the HFBR submodel that was completed in 1998. However, prior to the development of the transient and predictive submodels, the regional groundwater model was recalibrated by inputting the water level data obtained in the vicinity of the HFBR in January 1997. According to G&M, this minor modification resulted in a subtle change in flow direction that improved the ability of the model to simulate the current observed path of the plume. This minor change came from incorporating in the model additional vertical layers to improve the resolution of the shallow portion of the aquifer. Testing showed that an improvement resulted in the ability of the model to simulate the observed migration path of the tritium plume. This was a good example of how specific permeability data that was obtained during well drilling could improve the predictive accuracy of the model. Fine tuning the model to reflect the current plume characteristics comes with some risk since one may not be aware of other variables that could have contributed to the plume's current configuration that may not be relevant in the future.

For the historical transient analysis, actual pumping data from on-site wells was input into the model. Precipitation records were also reviewed to determine the amount of recharge for each time period (quarterly time periods over 33-years was used to reflect the operation of the HFBR).

Model Assumptions:

- A constant source at the reactor pool was simulated using three injection wells totaling 9 gallons a day at a concentration of 40 million pCi/L. It was assumed that this source of tritium from the pool began in 1964 and that the plume contained 6.32 curies of tritium. This information was not critical to the model since monitoring well data were used as the initial input conditions to the model. However, the calculated amount of tritium was used to perform a mass balance to account for the tritium in the future simulations.
- For simulations including dispersivity, a 10 to 1 ratio was fixed between longitudinal and lateral dispersivity. Vertical dispersivity was assumed to be negligible.
- Little historical data exists for the distribution of water discharged to on-site basins so current data was used for the predictive analysis. The construction of new facilities such as the Center for Functional Nanomaterials (CFN) and NSLS-II could alter the on-site recharge characteristics enough to warrant a modification to the model, because of their proximity to the plume.
- The performance of the low-flow high tritium concentration system was not modeled directly. The groundwater model assumed that the system worked as designed and that the concentration of the source term was reduced to 100,000 pCi/L at that point. This may be a contributor to the fact that the model is under predicting the concentrations of tritium in the upgradient part of the plume (Dorsch 2003).
- The plume was simulated to migrate under existing long-term average regional hydrologic conditions.
- The groundwater recharge rate is assumed to be 23 inches per year. This is based on an average precipitation rate of 48 inches per year (BNL historical records) and an average of 50% recharge and a small % lost to evapotranspiration.
- Horizontal hydraulic conductivity of 160 to 175 feet per day. This is substantiated by on-site pumping tests in the Upper Glacial aquifer.
- An effective porosity of 0.20 to 0.24 was used.
- The model assumes that the source term has been eliminated as a result of the spent fuel pool being emptied. However, the release of tritium from the unsaturated zone during periods of natural water table rise was not considered. (Current monitoring data indicates that this is in fact occurring). This is a very important assumption for simulating the plume near the HFBR. If the source term has not been eliminated, then the simulation that shows the plume disappearing near the HFBR is not accurate. For the purposes of the remediation system, however, it is not relevant since the pumps are in place to capture the plume if concentrations exceed the 750,000 pCi/L threshold.
- Overall, the detailed modeling, supported by the extensive monitoring effort, resulted in accurate predictions that have been effective tools for managing the contamination and have helped to foster community and regulatory trust.

Transport Model Calibration:

Transport in porous media is governed by the processes of advection, dispersion, molecular diffusion, and sorption. Molecular diffusion is not an important transport mechanism at BNL due to the groundwater flow rates being around 0.5 – 1.0 ft/day. Tritium does not exhibit sorption. Thus, advection and dispersion are the dominant transport mechanisms. Advection is dependent on water flow. The site wide groundwater flow went through extensive calibration efforts as described in the initial paragraph of this Appendix. The calibrated groundwater flow model was used to generate groundwater velocity values used in the transport analysis.

Prior to the tritium plume BNL typically used values of 30 feet, 3 feet, and 0.5 feet for longitudinal (along the flow path), transverse (perpendicular to the flow path in the horizontal plane), and vertical dispersivity (perpendicular to the flow path in the vertical plane). The tritium contamination data showed that these values were far too large, particularly in the vertical plane which showed a very narrow band of tritium (low dispersion). Calibration of an analytical model to the initial monitoring data (1997 data) showed the best match between model predictions and the data was achieved with longitudinal dispersivity between 3 and 10 feet, lateral dispersivity of 10% of longitudinal dispersivity, and transverse dispersivity of 0.01 to 0.005 feet.

Numerical modeling using the method of characteristics in the code MT3D led to over prediction of dispersion and the best fit to the monitoring data was obtained by setting all dispersion parameters to zero. Thus, the models inherent numerical dispersion was sufficient to account for the actual physical dispersion caused by non-uniform flow paths.

APPENDIX B: OPERATION OF SR-90 TREATMENT SYSTEMS

BGRR/WCF Strontium-90 Treatment System

The OU III Brookhaven Graphite Research Reactor (BGRR)/Waste Concentration Facility (WCF) Treatment System addresses the Sr-90 plumes in groundwater downgradient of these facilities. Some of the wells included in the OU III BGRR/WCF network are also monitored as part of the OU III HFBR Tritium program. These wells are sampled concurrently for all of these programs to avoid duplication of effort.

The BGRR/WCF remedy consists of:

- Operation of five extraction wells using ion exchange to remove Sr-90, with on-site discharge of the clean water to injection wells
- Operation of the system to minimize plume growth and meet DWS by 2070
- Continued monitoring and evaluation of data to ensure protectiveness
- Institutional controls and five-year reviews

System Description
System operations for this treatment system began in January 2005. There are two extraction wells (SR-1 and SR-2) located south of the WCF and three extraction wells (SR-3, SR-4, and SR-5) located south of the BGRR. The treatment system typically operates at an average rate of 25 gpm total from the five extraction wells. Groundwater from the five extraction wells is transported through pipelines to an ion exchange treatment system. The vessels of ion exchange media are designed to treat groundwater contaminated with Sr-90 to below the 8 pCi/L DWS. In addition, the influent is also treated for low-level concentrations (less than 10 µg/L) of TVOCs using liquid-phase activated carbon. Effluent is recharged to the Upper Glacial aquifer via three drywells approximately 850 feet west of the treatment system. A New York SPDES equivalency permit regulates this discharge.

Groundwater Monitoring

Well Network
A network of 86 monitoring wells is used to monitor the Sr-90 plumes associated with the BGRR, WCF, and Pile Fan Sump (PFS) areas. For the WCF plume in the vicinity of the HFBR, this network is currently being supplemented with temporary wells to monitor the high concentration Sr-90 and tritium slugs from an accelerator operation ("g-2") identified in this area in 2007 and 2008. Temporary wells were installed in this area during the fourth quarter of 2008 and the first quarter of 2009.

Sampling Frequency and Analysis
In 2008, the sampling frequency for the BGRR and PFS plumes was shifted from a start-up to O&M phase (semiannual to annual) for most wells. The WCF plume remained at a semiannual frequency in order to obtain sufficient data to characterize this plume and support pre-design groundwater modeling for system modification. The well samples are analyzed for Sr-90.

Monitoring Well/Temporary Well Data

The Sr-90 plume distribution map is shown on **Figure B-1**. The distribution of Sr-90 throughout the BGRR, WCF, and PFS areas is depicted based on groundwater data obtained from the fourth-quarter 2008 and first-quarter 2009 sampling of the monitoring well network and temporary wells. The following cross-sectional views are also provided:

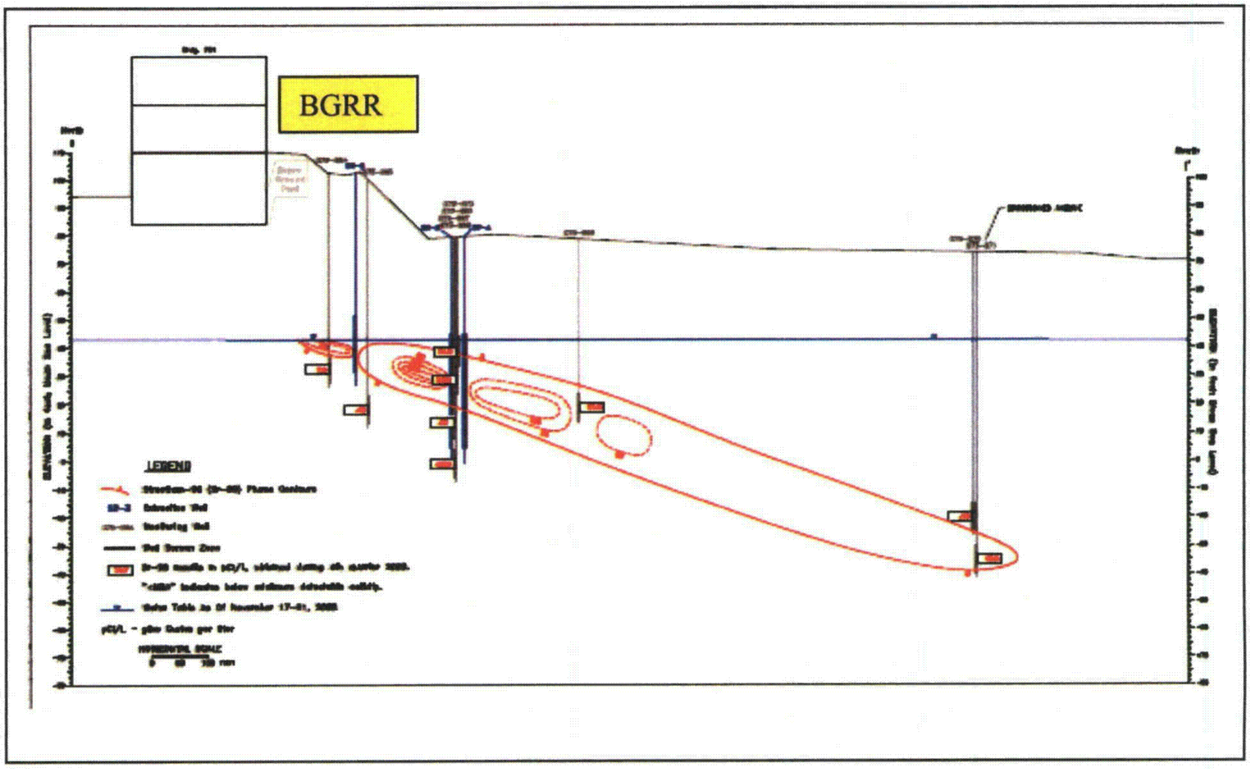

Figure B-1: BGRR Sr-90 Plume Distribution-2007

Historically, the highest overall Sr-90 concentration (3,150 pCi/L) occurred in 2003 in a temporary well installed approximately 200 feet south of the BGRR and slightly upgradient of the current location of extraction well SR-3. The highest historical Sr-90 concentration in the WCF area (1,560 pCi/L) occurred in April 2003 in a temporary well installed immediately downgradient of the six former underground storage tanks (USTs A/B) and approximately 25 feet north of the WCF (Building 811). This area within the WCF is upgradient of the current location of extraction well SR-1. The highest historical Sr-90 concentration in the former PFS area (566 pCi/L) occurred in March 1997 in a temporary well installed downgradient of the PFS. The following is a summary of the 2008 monitoring well data for the three Sr-90 plumes.

System Operations

In accordance with the SPDES equivalency permit, the required frequency for Sr-90 and VOC sampling is monthly and the pH measurement is weekly. However, samples from the influent, effluent, and midpoint locations of the treatment system were collected twice a month throughout 2008 in order to optimize resin usage. All system samples were analyzed for Sr-90 and VOCs.

The influent was also analyzed for tritium, and both the influent and effluent were analyzed weekly for pH.

January – September 2008 Well SR-1 was off from January to May and well SR-3 was off February through April due to electrical and mechanical problems. The entire system was off from August 11 to 26 due to damage from a lightning strike. A resin vessel change-out was performed from July 11 to August 6, during which time the system was down. A second resin change-out was performed in February 2008.

October – December 2008: The treatment system ran normally for the entire period.

Extraction Well Operational Data: During 2008, approximately 8.5 million gallons were pumped and recharged by the OU III BGRR/WCF SR-90 Treatment Systems, with an average flow rate of 16 gpm.

System Operational Data During 2008, influent concentrations of Sr-90 ranged from 26 to 137 pCi/L, with the highest concentration observed in January. The highest influent tritium concentration during 2008 was 324 pCi/L in April. During 2008, Sr-90 was detected once in the effluent samples, at a concentration of 1.7 pCi/L in January. This detection was below the limit of 8.0 pCi/L. There were no VOCs detected above the SPDES Equivalency Permit discharge limits in the 2008 influent or effluent samples. During 2008, approximately 8.8 million gallons of groundwater were processed through the system.

Cumulative Mass Removal Average flow rates for each monitoring period were used, in combination with the Sr-90 influent concentrations, to calculate the number of milliCuries (mCi) removed. During 2008, the flow averaged 17 gpm. Approximately 2.7 mCi of Sr-90 was removed during 2008, for a total of 16.9 mCi removed since system start-up in 2005

Extraction Wells

Maximum Sr-90 concentrations in each of the extraction wells during 2008 were as follows:

- SR-1 113 pCi/L in January
- SR-2 146 pCi/L in October
- SR-3 269 pCi/L in January
- SR-4 23 pCi/L in January
- SR-5 116 pCi/L in January
- During 2008, no VOCs were detected above the drinking water standard in the extraction wells.

System Evaluation: The OU III BGRR/WCF Strontium-90 Pump and Treat System and Monitoring Program was evaluated in the context of four basic decisions established for this program using the groundwater DQO process:

1. *Was the BNL Groundwater Contingency Plan triggered?*

   WCF Plume: No. There were no unusual or unexpected concentrations in the monitoring wells associated with this program during 2008.
   BGRR Plume: No.

2. *Has the plume been controlled?*

   WCF Plume: No. Based on the monitoring well data, the area of high Sr-90 contamination near the WCF is controlled and captured by extraction wells SR-1 and SR-2. However, based on the additional temporary well data collected in the vicinity of the HFBR in 2007 through early 2009, there are high Sr-90 concentrations that are not actively controlled. Preliminary groundwater modeling of the recent data indicates that if left untreated, the OU III ESD cleanup objective of meeting the DWS by 2070 would not be met.
   BGRR Plume: Yes. Based on the monitoring well data, the high concentration portion of the plume is being captured by extraction wells SR-3, SR-4, and SR-5.

3. *Is the system operating as planned? Specifically, is the aquifer being restored at the planned rate identified in the Explanation of Significant Differences to the OU III Record of Decision?*

   WCF Plume: The hydraulic capture performance of the system is operating as modeled in the system design. The system has been removing Sr-90 from the aquifer and the resin is effectively treating the Sr-90 to below MCLs. However, based on current model projections on the long-term restoration of the aquifer, the elevated Sr-90 concentrations identified just north of the HFBR indicate that the ESD cleanup objective of meeting DWS by 2070 may not be met. Additional extraction wells will be necessary to reduce the high concentration slug (identified as part of the recent characterization effort) to levels that will attenuate in accordance with the cleanup goal. A complication to addressing the high concentration slug is that it is co-located with tritium from the g-2 plume, well in excess of the DWS. This will not permit pumping of the Sr-90 high concentration slug for the next six months to a year. The g-2 tritium slug has been well defined, and is moving in the aquifer at a rate five to 10 times faster than Sr-90. Once the tritium slug has moved south of this area it will be possible to pump and treat this segment of the plume.

   BGRR Plume: The hydraulic capture performance of the system is operating as modeled in the system design, and the system has been removing Sr-90 from the aquifer. The resin is effectively treating the Sr-90 to below DWS. The ESD objectives are expected to be met.

4. *Have the cleanup goals been met? Can the groundwater treatment system be shut down?*

   WCF Plume: No. The cleanup goal of meeting the DWS in the aquifer has not yet been met. However, the system is minimizing plume growth of the higher concentrations of Sr-90 near the WCF. Based on the temporary well data from 2007 through March 2009, the OU III cleanup goal will not be met if the high concentration areas of the plume near the HFBR are not actively addressed.

BGRR Plume: No. The cleanup goal of achieving the DWS in the aquifer has not been met, but the system is preventing and minimizing plume growth of the higher concentrations of Sr-90.

Recommendations: The following are the 2008 recommendations for the BGRR/WCF Groundwater Treatment System and Monitoring Program:

- Perform groundwater modeling for modifying the system to address the high concentration Sr-90 area in the vicinity of the HFBR. Utilize the fourth-quarter 2008 permanent and temporary well data and the first-quarter 2009 temporary well data for model initialization. Determine the number and placement of extraction wells necessary to remediate this area and reduce Sr-90 concentrations to levels that will allow for achievement of OU III ROD cleanup goals.
- Install additional extraction wells to address the Sr-90 hot spot identified in the WCF plume. The modification to the existing Sr-90 treatment system will consist of several new extraction wells. The location and exact number of wells will depend on the distribution of the hot spot following the departure/attenuation of the g-2 tritium slug from this area. It is currently estimated that the modification will be implemented in 2010.
- For the BGRR Sr-90 plume, install temporary wells to determine the width of the downgradient portion of the plume.
- Install a temporary well adjacent to monitoring well 075-664 to determine if a permanent well screened at a shallower depth is necessary at this location.
- Eliminate sampling at monitoring wells 065-11 and 065-177. These wells are significantly outside of the current plume position and have not detected more than trace levels of Sr-90 over a number of years.

APPENDIX C: LESSONS LEARNED APPLICABLE TO THE NRC'S BURIED PIPING INITIATIVE

"The headlines have not been pretty. As a scientist, I know the relative risk of tritium. In the grand scheme of radiation, it is well down the scale, but in the area of public perception, it takes on greater significance. People are asking legitimate questions— what's leaking, where's it leaking, how much is leaking, and—most importantly—what's being done to deal with the problem? The NRC always inspects licensees who have such leaks and in each case makes certain that licensees are taking the appropriate steps to find the source, and to protect the public and the environment." (NRC Chairman Jaczko's speech of 2/17/10)

Nuclear power plants have extensive piping systems. Some of these pipes are buried and transport water that may contain slightly elevated levels of radioactive isotopes, most commonly tritium. While leakage from some of these pipes has occurred, so far these incidents have not jeopardized public health and safety. Nonetheless, the NRC and the nuclear power industry are reexamining the issue of buried piping to determine whether any changes are required in the current approach to the design, maintenance, and inspection of buried piping.

In 2006, leakage of tritium into the groundwater from different sources at several nuclear power plants led the NRC to establish a Tritium Task Force. Their investigation resulted in nearly two dozen recommendations, several of which are applicable to this report:

1. The NRC should develop guidance to the industry for detecting, evaluating, and monitoring releases from operating facilities via unmonitored pathways.
2. The NRC should evaluate the need to enact regulations and/or provide guidance to address remediation.
3. The staff should provide guidance to the industry which expands the use of historical information and data in their 50.75(g) files to the operational phase of the plant. The data provides good information on current and future potential radiological hazards that are important during routine operation, and can aid in planning survey and monitoring programs.
4. The NRC should require adequate assurance that leaks and spills will be detected before radionuclides migrate offsite via an unmonitored pathway.
5. NRC should evaluate whether the present decommissioning funding requirements adequately address the potential need to remediate soil and groundwater contamination, particularly if the licensee has no monitoring program during plant operation to identify such contamination.

In his speech of 2/27/10, Chairman Jaczko went on to discuss the need to reevaluate these recommendations in light of the recent events at nuclear power plants regarding tritium in the groundwater. He stated:

"Following reports of leaks at a few plants, the NRC created a special task force in 2006 to conduct a lessons-learned review of these incidents. The task force made more than two dozen recommendations—a great many of those have been incorporated in the guidance we provide to plants. While there are NRC requirements for documenting releases into the groundwater and soil and for ensuring that any releases offsite are below the regulatory limits, the NRC also has relied on licensees to adhere to certain measures as best practice. Guidance is one thing. A regulatory requirement is another. Therefore, I intend to ask the staff to relook at the 2006 lessons learned recommendations and determine whether any changes in this area might be advisable." (NRC Chairman Jaczko's speech of 2/17/10)

HFBR Lessons Learned

Investigation of the potential source(s) of the HFBR tritium plume was a major focus of the initial responses to the discovery of tritium in the groundwater beneath and south of the HFBR building. BNL analyzed potential sources where the tritiated water could have leaked without being detected and concluded that the HFBR building must be the source.

The following findings supported the conclusion that the HFBR must have been the principal source of the tritium in the groundwater:

1) The results of groundwater sampling indicated high tritium concentrations downgradient of the HFBR building,
2) Only low concentrations of tritium were found immediately upgradient of the HFBR Building,
3) Significant contamination was found near the top of the water table in the immediate vicinity of the HFBR Building (suggesting a source nearby the sample locations based on the known groundwater flow directions),
4) No unusual levels of tritium were detected in the groundwater flow path except from direction of the HFBR Building, and
5) Data on concentrations in the plume were consistent with an assumed long-term continuous source

Note: Subsequent leak-rate testing confirmed that the leak-rate from the SFP was 6 to 9 gallons per day.

Potential Sources within the HFBR Structure

Source identification within the HFBR building consisted of reviewing reactor components that had the potential to release tritium into the environment, and testing components for leaks to determine the integrity of each of the potential sources containing tritium. In some cases leak detection was not possible and engineering evaluations and visual inspections were performed instead where possible. Figure C-1 provides a general view of the piping and potential sources of tritium from the HFBR as identified below.

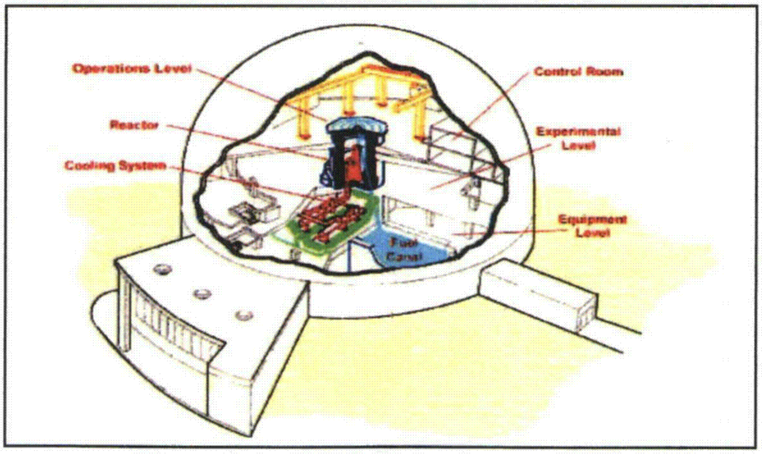

Figure C-1: HFBR Piping Layout (DOE, 2009)

As a first step the following systems that manage radioactive fluids were identified and examined:

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

Table C-1summarizes the sources that have been identified that have the potential to release tritium into the environment. 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 C-1: Summary of Potential Sources of Tritium from the HFBR

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's 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

Each of the potential sources identified in Table C-1 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 isolated to conduct credible leak test. For those systems other methods such as detailed engineering evaluations and visual inspections were used to determine the likelihood of a release in the past.

Results of the Spent Fuel Pool (SFP) Leak Tests

Two separate leak tests confirmed that the SFP was leaking tritiated water. An initial test indicated a leak rate of 7 to 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. 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. These concentrations are consistent with an assumed source that would produce the tritium concentrations observed in samples from the plume emanating from the HFBR Building.

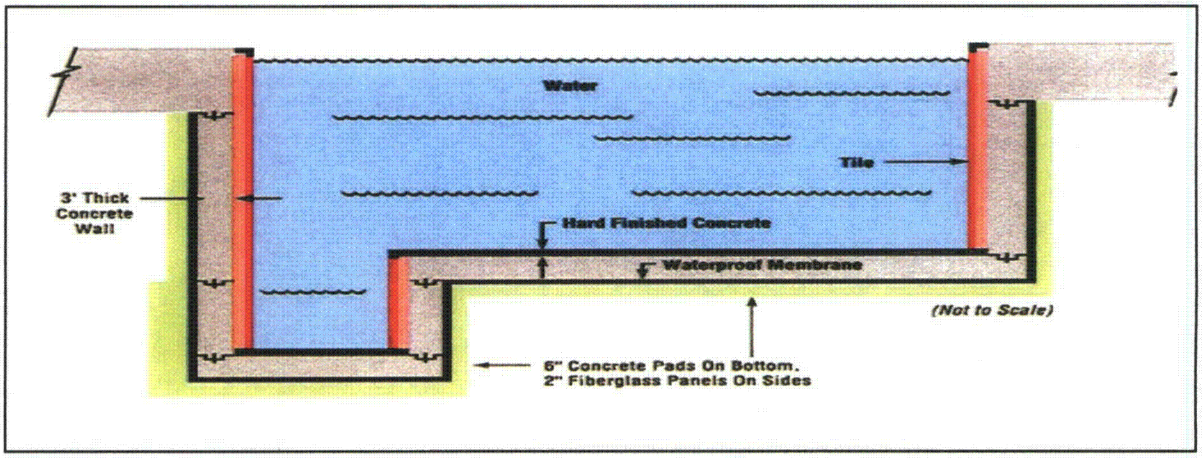

Figure C-2: Cross section of spent fuel pool (BNL, 1998)

The results of leak tests performed on other systems revealed that floor seams and penetrations within all three HFBR cells (A, B, and shutdown cells) on the equipment level accepted small amounts of water. Cells are rooms within the HFBR Building. Therefore, these seams and penetrations were suspected pathways for primary coolant that spilled in these areas in 1995 to migrate from the HFBR Building.

Sanitary Sewer System

An analysis of the sanitary sewer system near the HFBR Building was conducted using available information and it was concluded that the sanitary system was 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 worst-case loss rate of approximately 4 to 7 gallons per day, indicating that the below-grade sanitary piping was 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 in the sanitary sewer system, as monitored at the outlet of the building, varied from about 10,000 pCi/L to 50,000 pCi/L. 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 water being discharged from 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 was 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 could not have been a major contributor to the existing plume.

Accidental discharge to the sanitary drains within the HFBR Building was 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 had never occurred, and was 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.

To further characterize the release of tritiated water from the SFP, horizontal wells were installed at two locations under the HFBR Building in March 1997. The first (downgradient) well was installed 10 feet south, and parallel with the southern wall of the SFP. The second (upgradient) well was installed 17 feet north and parallel to the north wall of the SFP.
The rationale behind the placement of the two wells was to:

1) determine the extent of leakage along the length of the SFP;
2) determine concentrations of tritium in groundwater directly beneath the SFP; and
3) to evaluate whether tritium has been released from other potential up-gradient sources such as buried pits, piping, and trenches in the equipment level floor.

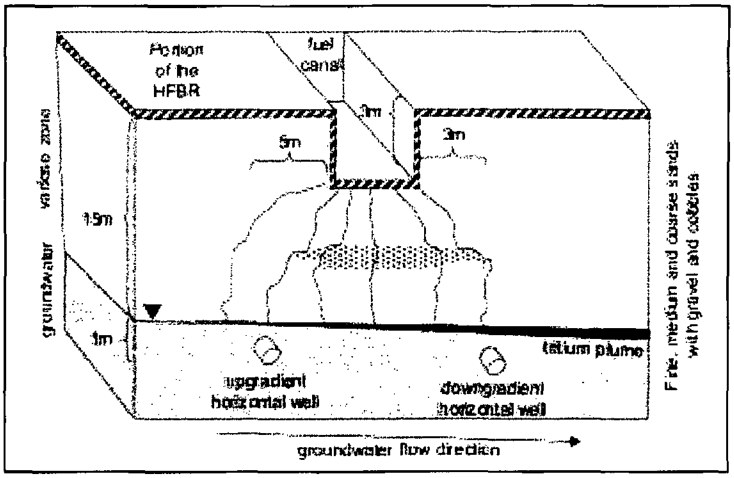

Figure C-3: Use of Horizontal Wells to Detect Source Location

However, uncertainties existed in the actual pathway that the tritiated water followed in the vadose zone above the water table (Fig. C-3) and the tritium from the SFP may be detected in the upgradient well due to lateral spreading. Furthermore, based upon groundwater modeling, laminar groundwater flow, and the observed vertical distribution of tritium in wells located immediately downgradient of the HFBR, it was recognized that the tritium directly below the SFP was likely to reside within the uppermost 1 to 2 feet of the aquifer.

By design, the horizontal wells were to be installed within the uppermost 2 to 3 feet of the saturated zone of the aquifer to allow for the proper monitoring of the tritium plume and to ensure that the wells would not go dry upon minor fluctuations of the water table. During the installation of the wells, variability in soil composition and saturation resulted in minor deviations in the desired borehole position. Although the up-gradient well was installed 1.5 to 2.5 feet below the water table, the down-gradient well was installed slightly lower than designed, at a position 3.5 to 4.5 feet below the water table.

The horizontal wells were first sampled in late March and early April. However, the initial sampling technique resulted in possible dilution of the samples, making it more difficult to obtain meaningful estimates on peak tritium concentrations within the plume. Following the initial sampling, spring rains resulted in a steady rise in water table elevation, and the wells were not again in a proper position to accurately monitor the uppermost portion of the aquifer until August 1997.

From August 1997 through January 1998 five rounds of samples were collected from the horizontal wells, with collection periods corresponding to each 0.5 foot drop in water table elevation. The results from these samples did not conclusively demonstrate that the SFP was the only source of tritium emanating from the HFBR facility. The highest tritium concentrations were detected in the upgradient well at a maximum concentration of approximately 383,000 pCi/L, whereas tritium concentrations in the downgradient well were much lower, with a maximum observed concentration of approximately 1,700 pCi/l. The observed higher tritium concentrations in the upgradient well could have been caused by the well's higher elevation than the downgradient well and, therefore, closer to the top of the water table where higher tritium concentrations are expected to occur. Obtaining discrete groundwater samples from the uppermost foot of the aquifer in the downgradient well was complicated by a steadily rising water table following heavy rains in mid January 1998.

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 (BNL, 1998). Log readings from foundation borings drilled during the analysis of the reactor foundation indicated the vadose zone consists of heterogeneous layers of sand mixed with varying amounts of silt, clay, and gravel. Because of the layering, tritium from the SFP likely moved preferentially along horizontal layers that contain more coarse grained materials.

Another possible explanation for tritium's horizontal and upgradient spread from the SFP was that it resulted from equilibration of the moisture in the drier soil under the building with the more moist soil outside the building footprint.

Once the tritium reached the saturated zone of the aquifer, it moved in a thin layer along the top of the water table under the reactor where there was no downward gradient due to rainwater. Because the upgradient horizontal well was at a higher elevation (closer to the water table with higher tritium concentrations) than the downstream well, and because the tritium may move northward in the vadose zone, the observed higher concentrations in the up-gradient well were explainable.

This effort at source characterization illustrates the difficulty in defining every flow path close to a potential tritium leak source. However, at greater distances, the extensive network of temporary and permanent monitoring wells made the task of delineating the plume more effective.

HFBR Building Source Control

All spent fuel elements were removed from the SFP and shipped to the Savannah River Site for storage and final disposition. The last shipment left BNL in early September 1997. 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.

To eliminate the SFP as a potential future source of tritium contamination in the groundwater, a double walled stainless-steel liner with leak detection and collection capability was installed. A freestanding double-walled stainless steel liner with an instrumented low point sump was selected.

Modification of the Existing HFBR Building

BNL and DOE worked with SCDHS to 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. Methods of achieving secondary containment included either rerouting or retrofitting underground and embedded piping, pits, or trenches in the HFBR Building. When completed, all potential sources of tritiated water had secondary containment, except for spills to the equipment level floor. BNL also developed 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.

Subsequently, the Secretary of Energy made a decision to permanently shut down the HFBR. It is currently in the process of being decommissioned. The double lined spent fuel pool has been used to temporarily store the highly radioactive components being removed from the facility.

APPENDIX D: DETECTING LEAKS FROM UNDERGROUND PIPING SYSTEMS

Background

Perfluorocarbon Tracer (PFT) technology has been widely used to study air movement and leak detection since the early 1980s. BNL has used PFTs to study atmospheric transport and dispersion on local, regional, and national scales. These studies have led to increased understanding of the movement of pollutants and other hazardous substances in the atmosphere and to improvement and validation of atmospheric transport models. These research programs have application to issues of critical national and global importance such as homeland security, air quality, and climate change. BNL has used PFTs for leak detection to study infiltration into Nuclear Power Plant Control rooms (Dietz, 2002) and the integrity of subsurface pipes, ducts and barriers (Sullivan, 1998, Heiser, 2001, Heiser, 2002, Heiser, 2005).

There are seven different PFTs that can be analyzed simultaneously. This allows great flexibility in the design and implementation of tests to localize the source of a leak. In addition, PFTs make good tracers because of their physical characteristics and because they are present in the atmosphere at low levels. Background concentrations are several parts in 10^{15} (parts per quadrillion by volume, ppqv) so the release of small amounts of PFT results in unambiguous signals. The large numbers of fluorine atoms and the structure of these molecules cause them to have high electron affinities, approximately 3 eV. They are detectable at femtogram (10^{-15}) levels using an electron capture detector (ECD) or using negative ionization chemical ionization mass spectrometry (NICI-MS). Their relatively low vapor pressures allow PFTs to be concentrated on adsorbents so the sampling process can be used to increase the PFT signal. PFTs typically used as tracers are given in Table D-1.

Table D-1: PFTs commonly used as tracers, acronyms, names, chemical formulae, molecular weights, and boiling points.

Acronym	Chemical Name	Formula	Molecular Weight (g mol^{-1})	Boiling Point (°C)
PDCB	Perfluorodimethylcyclobutane	C_6F_{12}	300	45.0
PMCP	Perfluoromethylcyclopentane	C_6F_{12}	300	48.1
PMCH	Perfluoromethylcyclohexane	C_7F_{14}	350	76
o-PDCH	Perfluoro-1,2-dimethylcyclohexane	C_8F_{16}	400	102
PECH	Perfluoroethylcyclohexane	C_8F_{16}	400	102
i-PPCH	Perfluoroisopropylcyclohexane	C_9F_{18}	450	130
PTCH	Perfluorotrimethylcyclohexane	C_9F_{18}	450	125

Subsurface Leak Detection from Dielectric Fluid Filled Pipes

Brookhaven's commercially-accepted perfluorocarbon tracer (PFT) technology for underground leak detection of utility industry dielectric fluids can cost-effectively detect fuel pipeline system leaks to about 1 gallon per hour (GPH)—3 orders-of-magnitude better than any on-line system (Ghafurian, 1999).

Figure D-1 provides a schematic diagram of the subsurface pipe leak detection process. To find a subsurface dielectric fluid (OF) leak, a very small amount of a PFT liquid-- which is itself an excellent dielectric fluid, is dissolved uniformly into the existing OF in the cable along its entire length. The PFT liquids are environmentally and biologically benign, and are compatible with cable system. When a leak occurs, the leaking cable OF wets an area of subsurface soil. The dissolved PFT in the dielectric fluid evaporates into the soil air. The PFT is then transported by conventional driving forces (diffusion, barometric pumping, wind-induced pressure gradients, etc.), ultimately venting into the air above the street. This venting generally occurs close to the subsurface leak location. Usually the emissions of PFT vapors into the air reach steady state in less than 24 hours. Based on the tagging levels used, the magnitude of the leak, the prevailing meteorology, and a number of other site conditions (e.g., depth to the feeder and the street/above-ground interface conditions), the typical PFT concentrations in the air above the street at a leak site are in the few to several hundred parts-per-quadrillion (ppq or 10,15) range. This can be easily detected using an almost real time Dual Trap Analyzer housed in a van that can go up to 15 – 20 mph. The dual trap analyzer has one trap sampling the air as the van drives along while the other trap is being analyzed with a two minute analysis time. This continuing process provides an integrated PFT signal along the pipeline route; the magnitude should be at the ambient background unless a leak site has been passed.

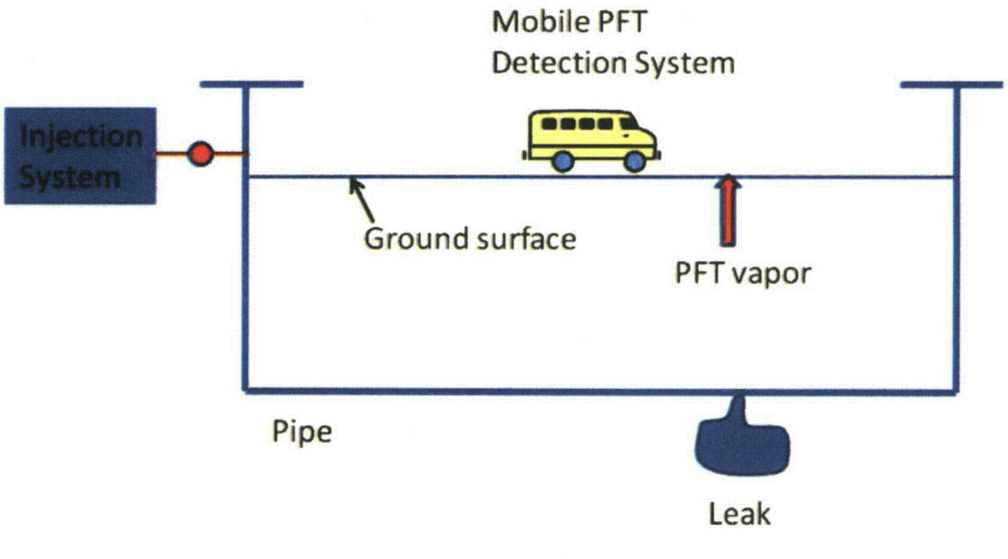

Figure D-1: Schematic of Mobile PFT Leak Detection System

If elevated concentrations are determined while driving, the location of the leak is confirmed by repeated driving through the area of elevated concentrations at slower speeds. Further localization is obtained by driving sample probes into the subsurface and sampling the soil vapor for PFTs. With subsurface sampling, the leak location can be determined within less than 10 feet. The magnitude of detected leaks can be calculated based on meteorological conditions. Mobile surveys (such as those used periodically in the gas pipeline industry) at about 15 – 20 miles per hour would allow such small leaks to be detected by tagging the fluid with 10-ppb of perfluorocarbon tracer under worst-case meteorological dispersion conditions. Smaller leaks could be detected by proportionately larger tagging concentrations. PFTs have been successfully used to pinpoint leaks in power lines contained in fluid-filled pipes under the streets of Boston, Chicago, Detroit, and New York City. Consolidated Edison purchased their own mobile PFT analyzer to conduct leak hunts.

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Jacob Philip, NRC Project Manager and Thomas Nicholson, Technical Monitor

11. ABSTRACT *(200 words or less)*

Brookhaven National Laboratory (BNL) is a multi-discipline Department of Energy (DOE) research institute that has been in operation since 1947. Historical operations included running accelerators, nuclear research reactors, and other large complex equipment. Some of these operations caused groundwater contamination. This report discusses the tritium plume from the High Flux Beam Reactor and several strontium plumes from past operations at the Brookhaven Graphite Research Reactor, their discovery through monitoring, and their treatment. The tritium plume discovery led to public outrage; characterization, design, and implementation of a treatment system within 60 days; and eventual dismissal of Associated Universities Incorporated from the management of BNL. Management of the strontium plume included a major alteration to the original regulatory cleanup agreement when field data showed the preferred alternative to be economically impractical. The report documents activities used to manage these contamination issues through source control, monitoring, modeling, plume and risk management, and communications. The lessons learned from these cleanup projects have altered the stewardship culture and methods of performing research and conducting work at BNL. These valuable lessons are highlighted in this report

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