VISCOUS LIQUID BARRIER DEMONSTRATION AT THE BROOKHAVEN NATIONAL LABORATORY LINAC ISOTOPE PRODUCER

John H Heiser[a], Mary North-Abbott[b], Terry Sullivan[a], Hans Ludewig[a], Ken Manchester[b], Marek Zaluski[b], Gail Penny[c], and Jim Brower[d]

ABSTRACT

Groundwater monitoring has detected tritium (^{3}H) and ^{22}Na contamination down gradient from the Brookhaven LINAC Isotope Producer (BLIP), located at Brookhaven National Laboratory (BNL). Site characterization studies indicate that the BLIP is the source of contamination. The highest measured values for ^{3}H were 52,400 pCi/L recorded less than 100 feet south (down gradient) of the BLIP facility. The BLIP produces radioisotopes that are crucial in nuclear medicine for both research and clinical use. The BLIP also supports research on diagnostic and therapeutic radiopharmaceuticals. During operation a proton beam impinges a target (typically salts encapsulated in stainless steel) to produce the required radioisotopes. The proton beam is completely absorbed prior to reaching the soils surrounding the target shaft. However, secondary neutrons are produced that reach the soil causing activation products to form. Among the longer-lived isotopes of concern are tritium and ^{22}Na. Both of these isotopes have the potential to negatively impact the groundwater below the BLIP.

Several corrective actions have been implemented at the BLIP facility in response to tritium detection in the groundwater. The first actions were to improve surface water management (e.g. storm water down spouts) and the installation of a gunite cap around the BLIP facility. These measures are designed to minimize water flow through the activated soils in the vicinity of BLIP. In conjunction with these improvements, BNL is installing a close-proximity subsurface barrier in the activated soils beneath the BLIP facility. The barrier will prevent water migration through the activated soil zone as well as prevent activation product migration out of the zone.

To minimize impacts on the operation of the BLIP requires in-situ barrier installation using low energy techniques that will not disturb the alignment of the BLIP or nearby accelerator beams. BNL chose an innovative barrier technology termed Viscous Liquid Barrier (VLB). This technology was developed at Lawrence Berkeley National Laboratory with funding from the U.S. Department of Energy (EM-50). It uses low-pressure permeation grouting to deliver a colloidal-silica grout to the subsurface. The grout gels in place forming a barrier to liquid movement. MSE Technologies Applications (MSE-TA) has been tasked with designing, installing and verifying the barrier. This paper will discuss the problem faced at BLIP and detail the design and proposed installation of the VLB at the site.

SITE DESCRIPTION

Brookhaven National Laboratory (BNL) is located in Upton, Long Island, New York, near the geographical center of Suffolk County. The terrain is gently rolling with elevations ranging between 13 and 37 meters above sea level. The property lies on the western rim of the shallow Peconic River watershed with a principal tributary of the river flowing through the north and

west sections of BNL. The geological formation at BNL consists of approximately 500 meters of unconsolidated sediments overlaying bedrock. The sediments form a clastic wedge that thickens in a southeastward direction. The regional groundwater system is characterized by a layered sequence of gravel, sand, silt, and clay.

This aquifer system consists of three aquifers and has been designated by the EPA as a Sole Source Aquifer System, pursuant to section 1424(e) of the Safe Water Act. The aquifers are also designated class GA by New York State. The aquifers serve as the primary water source of drinking water for Suffolk County. The Upper Glacial aquifer at BNL, which ranges from about 40 to 45 meters in thickness, is the aquifer of concern.

Groundwater flow in the northwestern portion of the BNL site, where the Brookhaven Linear Accelerator Isotope Producer (BLIP) is located, is generally to the south. The water table is located approximately 17 meters bgl directly below the BLIP building, which is located on a man-made mound.

THE BLIP FACILITY

Operation of BLIP (Figure 1) began in 1972. The facility is a national resource that produces radioisotopes for nuclear medicine for both research and clinical use. BLIP also

Figure 1 The Brookhaven Linear Accelerator Isotope Producer

supports research on diagnostic and therapeutic radiopharmaceuticals. The facility is classified as an accelerator facility and follows DOE Order 5480.5 "Safety of Accelerator Facilities".

Radioisotopes are formed when a high-energy proton beam impinges a target. The target is located approximately 9meters below the floor of BLIP and is contained in a 41 cm diameter

stainless-steel tube filled with 1100 liters of cooling water. The target tube is contained within a 2.5 meter diameter tank. The target typically contains eight different materials. A proton beam, generated by the LINAC (linear accelerator) penetrates the target. The proton beam does not impinge the soil as it is attenuated by the target and water. However, secondary neutrons that are generated are capable of reaching the soil and have produced activation products within the soils surrounding the target area.

NATURE AND EXTENT OF THE BLIP CONTAMINATION

Since 1993, monitoring wells south of BLIP and LINAC have indicated low levels of tritium (up to 1450 pCi/l) and ^{22}Na (up to 27 pCi/l) in the groundwater. Quarterly samples collected in February 1998 indicated high levels of tritium (14,000 pCi/L) and ^{22}Na (43.6 pCi/L) downgradient of the BLIP facility. A field investigation revealed that the BLIP facility had experienced leakage from the cooling water systems prior to 1998. This investigation continued with a Phase 1 groundwater characterization effort (five monitoring wells installed) initiated in March 1998 to delineate the extent of the tritium and ^{22}Na contamination. Phase II characterization conducted in June 1998 included the installation of eight monitoring wells to determine the source of the contamination. Results of Phase I and II characterization indicate that elevated levels of both tritium and ^{22}Na occur in the groundwater downgradient of the BLIP and that the BLIP is the likely source of contamination. Nine of the 57-groundwater samples collected had tritium concentrations that ranged between 2,360 and 52,400 pCi/L, (MCL of 20,000 pCi/L) with the highest tritium concentration recorded less than 30 meters south of the BLIP facility.

To gain a better understanding of the volume and magnitude of contamination resulting from activation of soil surrounding the BLIP target, BNL conducted state-of-the-art numerical modeling of soil activation using Monte Carlo radiation transport codes including LAHET-283, MCNP and ORIGEN-2B. Modeling efforts identified the isotopes in Table I as the major contributors to the total inventory of isotopes formed in the soils surrounding the BLIP target and beam dump. Model results are based on a 200 MeV beam operating continuously for 1 year. The major contributors to the activity are ^{3}H, ^{7}Be, ^{22}Na, ^{54}Mn, and ^{55}Fe. These radionuclides account for more than 80% of the inventory.

Table I Isotopes of Concern (Calculated) For BLIP Beam Dump After 1 Year Operation

Isotope	Total curies after 7 days cooling	Total curies after 30 days cooling
^{3}H	0.5	0.5
^{7}Be	6.4	4.7
^{14}C	0.0	0.0
^{22}Na	3.4	3.4
^{32}P	0.5	0.2
^{37}Ar	1.9	1.2
^{49}V	0.0	0.0
^{51}Cr	0.6	0.3
^{52}Mn	0.2	0.0
^{54}Mn	1.3	1.2
^{55}Fe	2.3	2.2
^{86}Rb	0.2	0.1
^{88}Y	0.3	0.2
^{88}Zr	0.1	0.1
^{89}Zr	0.0	0.0
^{131}Cs	0.1	0.0
^{181}Hf	0.3	0.2
Total	18.1	14.3

The modeling efforts divided the beam dump/target area into a grid containing three layers, three rings and eight azimuthal sections of 45 degrees each. The layers are 30 cm thick and the beam line bisects the middle layer. For ease or discussion the top most layer is labeled layer 1, the middle layer is Layer 2 and the bottom is Layer 3. The rings are similarly numbered one to three, with Ring 1 being the inner most ring that contacts the steel tank, and Ring 3 the outer most soil volume. Rings 1 and 2 are 40 cm thick and Ring 3 is 50 cm thick. Each ring is further subdivided into eight azimuths, with each encompassing 45 degrees of the ring.

Model projections show a forward and backward peak relative to the direction of the beam line. ^{22}Na and ^{7}Be are biased towards the forward peak and ^{3}H and ^{55}Fe are biased backwards. Model projections suggest higher concentrations of ^{3}H and ^{55}Fe than the measured values, which were taken from the front of the beam line. This highlights the value of modeling used in conjunction with the data collection. Figure 2 depicts the radial distribution of ^{3}H and ^{22}Na at the center layer (Layer 2) predicted through modeling.

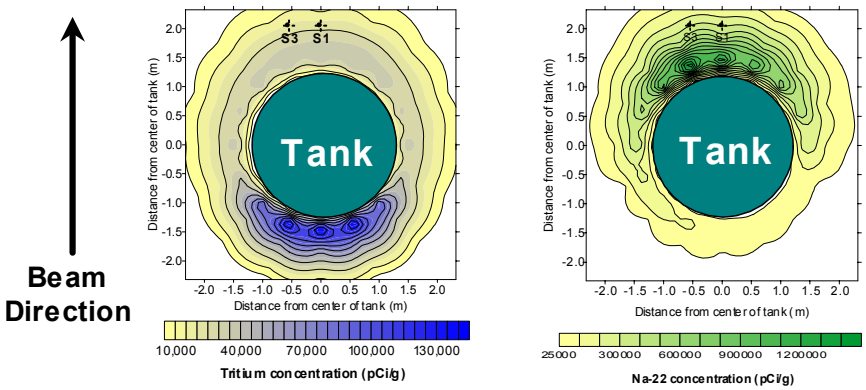

Figure 2. Plan View of Calculated distribution of Tritium and Sodium-22 around the BLIP target area - Middle Layer

Modeling also shows a steep rise in concentrations of isotopes from Ring 3 (farthest from the target and beam) to Ring 1 (adjacent to the tank and closest to the target and beam). This is as expected and shows the source term to be much greater than might be expected from the sampling data taken. As it turned out, the measured values are from near the outer reaches of the isotope production zone. For ^{22}Na the measured value was ~43,000 pCi/g. Using this value and the trend of the calculated values, the resultant contamination "expected" near the tank is ~700,000 pCi/g. The other isotopes follow similar trends, and all increase at least an order of magnitude from Ring 3 to Ring 1.

The volume of soil that will need to be treated is approximately 85 m^3. This assumes a cylinder two meters thick and three meters high surrounding the BLIP tank. The model projections indicate that this volume contains more than 99.9% of the activated soil inventory.

The goal of modeling the isotope production in the beam dump of the BLIP is to assist in estimating the source term in the soil and to determine future contamination concerns. To be useful, the modeling results should be validated experimentally. An attempt to validate the model results was made using the results of analysis of soil contamination at the BLIP. In September 1998 samples were collected in the unsaturated zone from four locations underneath and around the BLIP building. Radiological analyses were performed by BNL. Sample S1 was located directly opposite the beam line, just outside the 2.5 meter diameter BLIP tank. S2 was located approximately 1 meter south of S1 to confirm the radial extent of the contamination. Sample S3 was slightly east of S1 and S4 was located outside the BLIP facility near the southwest corner of the structure where no contamination was expected.

Modeling data indicate that S1 and S3 are located within the estimated activation zone (Figure 2) and S2 is located near the perimeter of the activation zone. Sample S4 is outside the activation zone. Analytical results (see Table II) indicates that subsurface soil concentrations of contaminants 8 to 8.5meters below ground level, within the known activation zone (samples S1 and S3), are generally one to two orders of magnitude greater than concentrations measured three feet south at S2. Subsurface radionuclide contaminants were not detected in soil samples from S4.

Table II gives comparisons of actual measurements of radioactivity in the BLIP soil to the model results (which are based on soil compositional analysis, e.g. 6 ppm of lithium) for the azimuth the sample was taken from (bold) as well as to the nearest neighbors to the sampling location. The results are promising in that the actual values for ^{3}H, ^{7}Be, ^{22}Na, ^{54}Mn and ^{55}Fe are within the same order of magnitude to the calculated values. Calculated values were consistently larger than measured values. This adds conservatism to estimates of groundwater contamination based on the calculated values.

There are also isotopes in the calculated list that do not appear in the actual analysis. Some missing isotopes are due to a short half-life. For instance, ^{37}Ar found in the projected results but not in the samples, is a gas and would not be present in the soil sample by the time it was analyzed. In addition, some of the isotopes are beta emitters and would be lumped under the non-volatile beta in the actual measurements. For example, in S1 the calculated concentration for ^{32}P is ~22,000 pCi/g, ^{86}Rb is ~1,000pCi/g and ^{181}Hf is ~3,000 pCi/g, for a total of ~26,000 pCi/g. The measured nonvolatile beta is ~40,000 pCi/g.

Further site characterization was performed in April 1999. Two additional soil samples were collected underneath the BLIP building from 7 M bgl to 10.5 M bgl at locations S5 and S6 to further determine the extent of the activated zone and validate the BNL model. S5 and S6 are approximately 0.6 and 1.3 meters south of S3 respectively. Radiological analyses for these samples indicate the subsurface activation product concentrations at locations S5 and S6 are significantly lower than concentrations found at sample location S2. This sample analysis supports the BNL model for the activation zone.

To assess the impacts that the contaminated soil could have on the aquifer, model simulations were performed using one and two-dimensional models. The one-dimensional model DUST-MS can be used twice in succession to simulate flow in the unsaturated zone down to an aquifer and then in the second simulation, transport through the aquifer is modeled. The two model runs are coupled using conservation of mass at the interface between the saturated and unsaturated zones. Due to the absence of dispersion and mixing in the transverse directions, the 1-D models tend to predict higher concentrations than multidimensional models. To demonstrate the effects of dispersion several two-dimensional simulations were performed.

Five radionuclides were selected for modeling based on the characterization and modeling data performed for the BLIP. They are ^{3}H, ^{7}Be, ^{14}C, ^{22}Na, and ^{55}Fe. These radionuclides span the range of half-lives and cover the highest measured inventories. Predicted inventories based on the three-dimensional Monte Carlo soil activation calculations formed the basis for the inventory estimates.

Using conservative estimates of the flow rate, inventory, release and transport parameters in modeling, the activated soil around the BLIP indicate substantial quantities (above drinking water standards) could reach the aquifer within a few years of being generated. These predicted values were typically higher than the measured values at the three sampling locations. The maximum measured value of ^{3}H is 54,000 pCi/l at a well located approximately 100 meters from the source area. This is more than an order of magnitude lower than the predicted values. This

is believed to be due to the conservative modeling assumptions pertaining to inventory and transport parameters.

Preliminary estimates showed that if the flow rate through the activated soil can be reduced to values of less than 1 cm/yr, short-lived isotopes including tritium will not reach the aquifer at levels exceeding the drinking water standard.

Table II Isotope Concentrations (pCi/g) For Soil Cores S1 and S3 Versus Model Values

		Layer 1	Layer 1	Layer 2	Layer 2		**Layer 1**	Layer 1	Layer 2	Layer 2
	Core ID	**Ring 3**	Ring 2	Ring 3	Ring 2	Core ID	**Ring 3**	Ring 2	Ring 3	Ring 2
isotope	S1-28-30	**Azimuths 2/3**	Azimuths 2/3	Azimuths 2/3	Azimuths 2/3	S3-28-30	**Azimuth 3**	Azimuth 3	Azimuth 3	Azimuth 3
^{3}H *	4020	**8828**	25000	12968	21500	3830	**4305**	11979	12815	35654
^{7}Be	73200	**255273**	522409	312248	661076	31000	**148902**	417853	223287	626594
^{14}C	5	**86**	677	121	716	6	**0**	827	0	690
^{22}Na	42600	**84826**	332577	121478	450851	19700	**87995**	261390	151776	450851
^{32}P		**21979**	39014	2043	4438		**34484**	51092	2012	2981
^{37}Ar		**40460**	137869	29518	147231		**7515**	137258	11180	204181
^{51}Cr		**9203**	3329	17923	6440		**1160**	3292	2226	6318
^{52}Mn		**0**	2519	0	2519		**0**	5039	0	0
^{54}Mn	7800	**34880**	39398	57346	70340	3070	**29750**	12057	40097	16251
^{55}Fe	5900	**48191**	111749	67252	175354	8040	**19953**	65737	59387	195653
^{86}Rb		**1074**	3235	2067	6225		**1057**	3196	2045	6184
^{88}Y		**0**	77509	0	0		**0**	0	0	0
^{131}Cs		**162**	1027	572	23872		**12**	1012	558	45790
^{181}Hf		**2770**	7942	5688	16308		**2744**	7871	5588	16028
beta	40000					51600				

REMEDIATION OF BLIP CONTAMINATION

Several corrective actions have been implemented at the BLIP facility in response to the detection of the tritium. Actions to improve surface water management at the BLIP have included the connection of storm water down spouts to the storm sewer system and the installation of a gunite cap around the BLIP building to minimize water flow beneath the BLIP and through the activated soil.

In 1999, an Engineering Evaluation/Cost Analysis for the BLIP remediation was completed. It recommended the design and installation of a Viscous Liquid Barrier (VLB) to contain the activated BLIP site soil and prevent future leaching of tritium and Na-22 from the soils surrounding the BLIP target area into the groundwater. The VLB technology was developed at Lawrence Berkeley National Laboratory (see Moridis, et al) with funding from the U.S. Department of Energy (EM-50). It uses low-pressure permeation grouting to deliver a colloidal-silica grout to the subsurface.

MSE Technologies Applications, Inc. (MSE) has been tasked by the Office of Science and Technology Subsurface Contaminants Focus Area (OST-SCFA) with implementing the VLB technology at a contaminated site. The BLIP site at BNL with its activated soil problem was selected as a suitable site to deploy the technology. The "barrier" would consist of solidifying the contaminated soils around the target dump with a colloidal silica (CS) grout. The liquid grout is pumped into the soil where it fills the interstitial voids in the soil. The grout then sets in place to become a gel and relatively impermeable to water. Any future contamination would be formed inside the grouted soil and also be contained and immobile. The VLB will act in conjunction with the gunite cap to minimize the volume of surface water percolating through the contaminated soils. By reducing the flow through the activated soils, the contaminant flux to the groundwater will be minimized.

The VLB technology can reduce the hydraulic conductivity of the grouted area and provide interim and/or long-term containment. Other benefits that the VLB technology provides include:

- The ability to contain waste material in situ, decreasing the mobility of waste through the unsaturated soils, and preventing the waste from entering the groundwater.

- Cost-effective technology.

- The viscous liquid is compatible with multiple waste forms (i.e., radioactive waste, organics, and inorganics) and is not degraded biologically or chemically, resulting in a long-term containment system.

- The viscous liquid containment system can be emplaced around areas of a sensitive nature (i.e., around piping, under storage tanks and infrastructure) for source control purposes because the low-energy emplacement method allows nondestructive emplacement, limiting surface disruption and reducing worker exposure.

DESIGN AND INSTALLATION OF THE BARRIER

The 95% Design Document has been developed to address the contamination problem resulting from the activated soil zone at the BNL BLIP site. The VLB design was developed to fully encapsulate the BLIP soil activation zone with CS grout (see Figure 3). Barrier installation will be completed in May of 2000.

MSE tested nine colloidal silica variants using BNL soil samples taken from around the BLIP. The soil samples were primarily sand and will be referred to as BNL sand in this paper. The tests determined which colloidal silica most effectively reduced the permeability of the BNL sand. The CS variants ranged in colloid particle size and solids content. Based on permeability results, a single variant was selected for procurement. In addition, large sand tank injection tests were conducted to optimize the grout bulb size for the design effort.

Twenty-two injection locations (see Figure 3) will be grouted to deliver the CS necessary to encapsulate the activation zone. Each injection string will consist of one to seven adjoining grout bulbs.

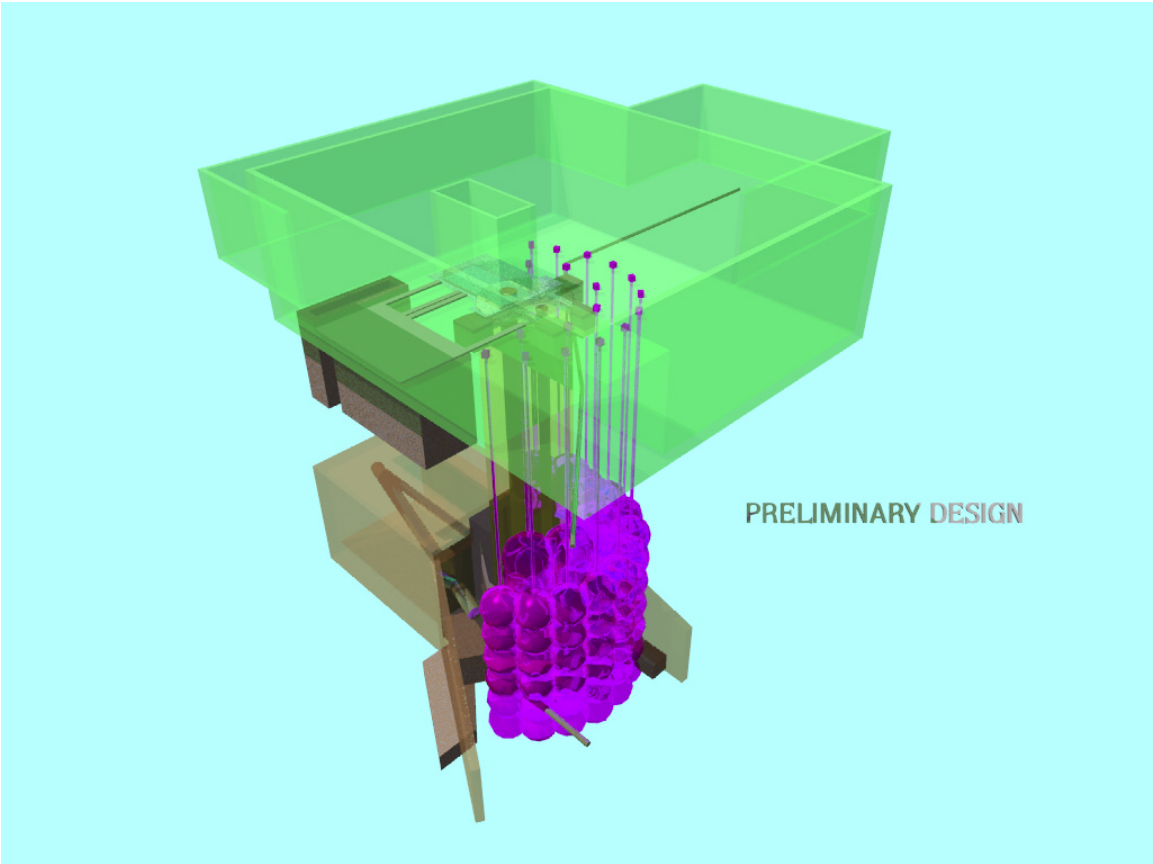

Figure 3 Visualization of preliminary design of colloidal silica barrier

The grout bulbs will range in size from 1.3 M to 2 M ft in diameter resulting in 260 to 370 liters of grout being injected at each injection point. The vertical and horizontal grout bulb overlap is

30%. Each grout bulb will be injected with flow rates ranging from 3.7 liters per minute (lpm) to 11 gpm and an expected pressure range from 5 to 50 psi. Each grout bulb will be injected with CS having a State 2 gel time (initiation of viscosity increase) of 90 minutes ± 20% and a State 9 gel time (Rigid gel) of 180 minutes ± 20%.

An ®Advance 66DT Geoprobe soil-probing machine (Advance 66) will be used for grout emplacement during the VLB demonstration at BNL. The Advance 66 is a diesel powered track mounted direct push rig that is capable of driving up to 3.25-inch diameter probe rods. The Geoprobe unit is equipped with a Kubota 4-cylinder turbo diesel engine with 54 horsepower at 2800 rpm. The rig relies on a hydraulic hammer system to drive the rods and a hydraulic pullback system to remove the rods. The unit provides a retraction force of 42,000 pounds (lb), a maximum down force of 32,000 lb and a maximum hydraulic pressure of 3000 psi. A Schematic is depicted in Figure 4. The GeoProbe rig was selected due to its relatively compact size and configuration allowing it to maneuver inside the BLIP building during grout emplacement.

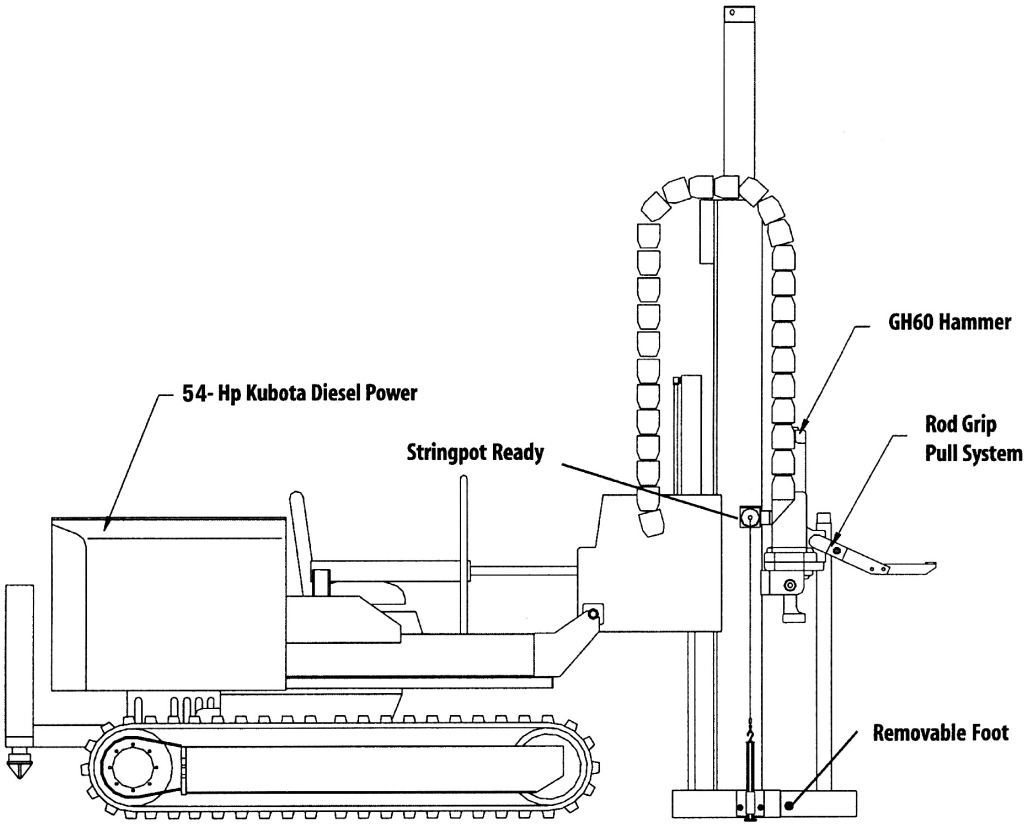

Figure 4 Schematic of Advance 66 Geoprobe unit

The Advance 66 GeoProbe rig will use 5.4 cm outside diameter (OD) by 1.6 M long injection rods to emplace the CS grout. The inside diameter (ID) of the rod is 3.8cm, allowing room for a 2.5 cm diameter deviation tool. The injection tip placed on the bottom end of the injection string will deliver the grout to the specified depth.

The top end of the direct push rod system will use a specially designed drive cap that will allow the rod to be advanced into the ground while injecting grout. The drive cap will thread directly onto the drive rod and form a seal, not allowing grout to leak. The drive cap has a threaded port on the side to receive a grout supply hose for the injection of grout down the inside of the rod system.

A skid–mounted, hydraulically-driven, variable-ratio grout pump will be used to supply the activated colloidal silica grout to the injection rods. The pump has a ratio accuracy of ± 2% and can pump volumes up to 26 liters per minute at pressures ranging from 50 to 350 psig. The pump system will be set to mix the grout to a 5:1 ratio by volume, with five parts colloidal silica to one part electrolyte. The grout pump system will receive CS from one tank and electrolyte solution ($CaCl_2$) from another tank and thoroughly mix them in a static mixer at a mixer manifold.

Two grout injection control stations will be used to control, monitor, and record grout injection volumes, pressures and flow rates at separate locations. The control stations will consist of a flow meter/totalizer and a pressure measurement device allowing project personnel to record flow rate, total liters injected, and injection pressure.

A 2.5cm OD Slope Indicator inclinometer will be used to determine the deviation of the injection rods in the subsurface after grout bulb emplacement. The inclinometer will be fixed to a torque-rod system to ensure proper orientation within the injection rods. Measurements will be taken every 0.5 meters when advancing the tool down the injection rods until total depth is achieved.

A laptop computer will be used to produce near-time 3-D construction drawings using injection data and deviation data to determine grout bulb placement. If the construction as-built drawings indicate that deviation has occurred, more grout will be injected at the affected injection horizons or other injection locations will be added to the injection design to compensate for the deviation. The creation of the near-time as-built drawings provides for a QC check of the constructed VLB and allows for addition of grout to fill any void spaces created by injection rod deviation.

Grout samples will be collected downstream of the in-line static mixing system. These samples will be tested with a viscometer to measure the viscosity of the CS grout during emplacement; this will document the gel times achieved during injection. This QC check will allow gel times to be measured and adjusted, if necessary, and will ensure that the proper gel times for the injected grout bulbs are maintained.

COST AND SCHEDULE

The following cost estimates are based on the necessary labor and equipment to complete a project at a contaminated site; the actual costs of this project will be higher, due the project being a first time hot site demonstration for the VLB technology. These costs do not include all the planning documents required at a DOE site. This emplacement estimate does not include the costs for rad support or sample analyses, these services/costs would be provided by the host site.

Activity	Cost ($)
Additional Site Characterization (including drilling and sample collection)	25K
Grout/Soil Compatibility and Grout Optimization Testing	35K
Design and Modeling	40K
Emplacement (including labor and equipment for mobilization, field prep, test injections, CS material, QA/QC, construction as-builting, etc. in rad-contaminated environment)	225K
Barrier Integrity Verification (including planning, design, well installation, baseline measurements & post-emplacement testing)	50K
Total Cost	$ 375K

The VLB emplacement at the BLIP site, scheduled to begin in the spring, is anticipated to take about four weeks from start to finish. This schedule accounts for the field preparation and mobilization, the test injections, emplacement of the VLB and verification test columns, and demobilization. The site characterization activities, as well as the grout testing and design and modeling tasks, are all completed in advance and are not included in this schedule. In addition, the baseline verification measurements are completed in advance of the emplacement, while the post-testing will be performed several weeks to a month after the VLB emplacement has been completed.

CONCLUSIONS

The BLIP produces radioisotopes through reactions with a high-energy proton beam. These isotopes are crucial in nuclear medicine for both research and clinical use. The BLIP also supports research on diagnostic and therapeutic radiopharmaceuticals. Operation of the BLIP has caused activation of the soil in a small subsurface region (85 m^3) surrounding the structure that contains the radiopharmeceutical target material. This contamination beneath the BLIP facility at BNL poses a threat to the groundwater. BNL has taken action to reduce this possibility. In particular, the VLB technology is being used to control water flow and minimize releases from the activated zone. In addition, surface water management features including storm water down spouts and the installation of a gunite cap around the BLIP facility have been installed to reduce water flow beneath the BLIP facility.

Data collection, numeric modeling of soil activation, and numeric modeling of release and transport of contaminants to the aquifer have been used to define the nature and extent of contamination and the potential impacts on the sole source aquifer. This information formed the basis for designing the size and shape of the viscous liquid barrier. Independent testing has been performed to select the optimum colloidal silica gel for forming the barrier in the activated soil surrounding the BLIP. The 95% design has been completed and the installation of the VLB is scheduled for May 2000.

The VLB technology is an innovative approach that can reduce the hydraulic conductivity of the soil beneath BLIP. The reduction in conductivity will reduce water flow through the activated soils and reduce the mobility of contaminants. Other benefits that the VLB technology provides include:

- The ability to contain waste material in situ at depth.

- Cost-effective technology.

- The viscous liquid barrier is compatible with multiple waste types (i.e., radioactive waste, organics, and inorganics) and is not degraded biologically or chemically, resulting in a long-term containment system.

- The viscous liquid containment system can be emplaced around areas of a sensitive nature (i.e., around piping, under storage tanks and infrastructure) for source control purposes because the low-energy emplacement method allows nondestructive emplacement, limiting surface disruption and reducing worker exposure.

REFERENCES

1. Moridis, G.J., Persoff, P., Holman, H.Y., Muller, S.J., Pruess, K., and Radke, C.J., New Barrier Fluids for Subsurface Containment of Contaminants, in Proceedings of ER93 Environmental Remediation Conference, pp 941-948, Oct. 24-28, 1993, Augusta, GA

2. Brookhaven LINAC Isotope Producer, Engineering Evaluation/Cost Analysis, Brookhaven National Laboratory, September 17, 1999.

3. MSE Technology Applications, Work Plan for the BLIP Site VLB Demonstration at the BNL, September, 1999.

FOOTNOTES

[a] Brookhaven National Laboratory, Environmental & Waste Management Group
[b] MSE Technologies Applications, Inc.
[c] U.S. Department of Energy, Brookhaven Group
[d] Brookhaven National Laboratory, Environmental Restoration Division