Mitigation of the Contaminated Groundwater Plume at the West Valley Demonstration Project, New York, USA – 10409

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ABSTRACT

The Main Plant Process Building (MPPB, Main Plant) at the present site of the West Valley Demonstration Project (WVDP, the Project) was used to reprocess irradiated nuclear fuel from 1966 to 1972. During routine groundwater sampling, groundwater contamination was detected down-gradient from the Main Plant and was traced to a leak in the process piping that occurred during the commercial fuel reprocessing era. Since the contamination was first discovered, a number of studies and actions have been undertaken to identify the configuration of the plume and the extent of contamination present in the groundwater, and to mitigate the off-premises flow of contaminated water. In 2008, the U.S. Department of Energy (DOE) decided to better define the plume and mitigate the spread of contamination.

A Geoprobe® study conducted after the contamination was first detected determined the primary contaminant to be Strontium-90 (Sr-90) and delineated the general leading edge of the plume and path of migration. Two steps were taken to slow the expansion of the leading edge of the plume. A pump and treat system was installed along one lobe of the plume to extract and treat some of the contaminated groundwater through a series of ion-exchange columns. A small test permeable treatment wall (PTW) was installed near the leading edge of another lobe of the plume for in situ capture of the Sr-90. The pump and treat system slowed expansion along one section of the plume's leading edge, but requires treating several million gallons of groundwater annually with the generation of low-level waste ion-exchange resin. The test PTW did not significantly slow plume expansion, due to restricted flow of groundwater through the wall.

In 2007, Project Managers and involved state and federal agencies identified the installation of a more comprehensive and passive contamination barrier to mitigate the migration of the Sr-90 as a best management practice. To prepare for more extensive mitigative measures, the WVDP conducted a Triad-type investigation in late 2008 consisting of more than 80 soil borings and microwells to more closely define the leading edge of the plume. The data collected from those wells, combined with historical data, has been useful in defining the characteristics of the plume and developing a mitigation strategy to reduce radiological migration.

The WVDP is preparing to install a passive in situ PTW near the 10,000 pCi/l isopleth of the plume to capture the Sr-90 through a cation exchange reaction. In 2009, laboratory testing of simulated and actual groundwater from the plume were conducted at the University at Buffalo (UB) and the WVDP to determine the cation exchange capabilities of two potential zeolite compounds proposed for the 213-244 meter (700-800 feet) long wall. Using field

characterization and zeolite study data, design of the PTW is progressing, with installation of the PTW planned for 2010.

INTRODUCTION

DOE has evaluated and is in the process of designing and subsequently installing a passive groundwater treatment technology to mitigate the spread of Sr-90-affected groundwater beneath the North Plateau portion of the WVDP. The WVDP comprises approximately 200 acres within the 3,300 acre Western New York Nuclear Service Center (WNYNSC). A northeast portion of the WVDP known as the "North Plateau" contains the MPPB where commercial nuclear fuel reprocessing occurred from 1966 to 1972. The plume area is depicted in Figure 1.

During routine groundwater sampling, groundwater contamination was detected down gradient from the MPPB and was traced to a leak in the process piping that occurred during the fuel reprocessing era. A Resource Conservation and Recovery Act (RCRA) Facility Investigation (RFI) of the WVDP was initiated in the early 1990s and identified elevated gross beta concentrations in groundwater samples collected from the subsurface near the MPPB. In 1993, sampling and analysis of surface water in a ditch known as the "swamp ditch" identified elevated gross beta activities near the edge of the North Plateau. A Geoprobe®

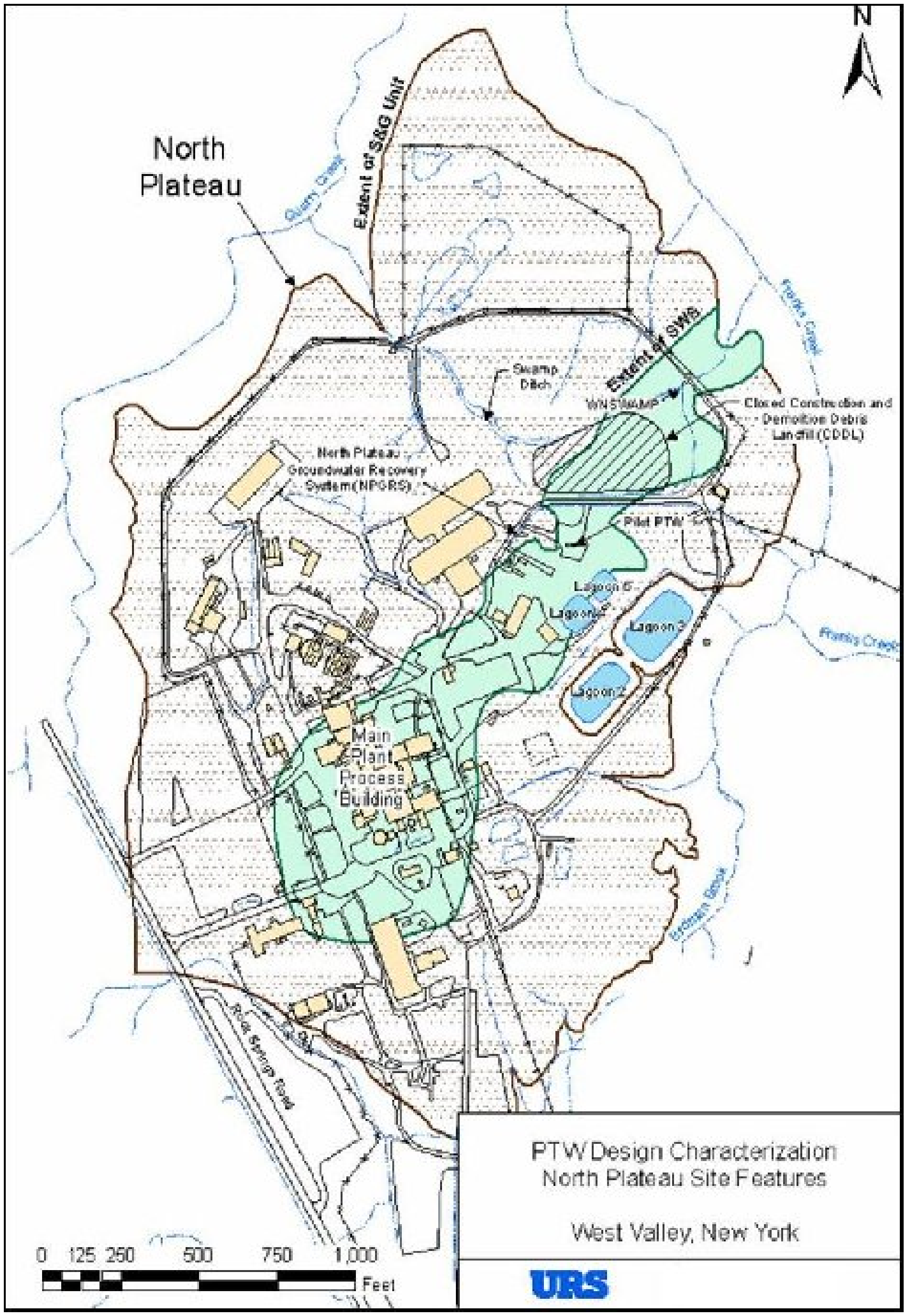

Fig. 1. The WVDP comprises approximately 200 acres within the 3,300-acre Western New York Nuclear Service Center. The Sr-90 plume extends in a northerly direction from the southeast corner of the MPPB.

subsurface soil and groundwater sampling program was subsequently conducted in 1994 to characterize the lateral and vertical extent of the elevated gross beta activities on the North Plateau and identify the contributing radioisotopes. Sr-90 was found to be the primary contributor to the measured gross beta activities.

In 1995 a three-well groundwater recovery system ("North Plateau Groundwater Recovery System") was installed within the Sr-90 plume to minimize contaminated groundwater from discharging to the ground surface in the area of the western lobe of the Sr-90 plume. The recovered groundwater continues to be treated at the onsite Low Level Waste Water Treatment Facility (LLW2). The groundwater recovery system has removed approximately 9 curies of Sr-90 from approximately 54.7 million gallons of processed groundwater since 1995. However, the recovery system does not completely mitigate migration of the western portion of the plume.

In 1999, a pilot small-scale, approximately 9 meters (approximately 30 feet) long innovative PTW was constructed within the plume to test in situ fixation (as promoted by ion-exchange) as a passive groundwater mitigation technology. The pilot PTW is a subsurface trench backfilled with clinoptilolite, a zeolite mineral selected as a treatment medium due to its ability to adsorb Sr-90 ions (through ion-exchange) from groundwater. The objective of the pilot PTW was to assess whether the technology could successfully remove Sr-90 from the contaminated North Plateau groundwater and identify those design and construction issues important for implementing a potential full-scale system. Evaluations of groundwater monitoring data indicated that the PTW technology was effective in removing Sr-90 from groundwater through ion-exchange.

FULL SCALE REMEDIAL ALTERNATIVE EVALUATION

In 2007, Project Managers and involved state and federal agencies identified the installation of a more comprehensive and passive contamination barrier to mitigate the migration of the North Plateau Sr-90 plume as a best management practice.

A focused analysis of remedial alternatives for the minimization of Sr-90 plume expansion in groundwater on the North Plateau was conducted in 2007. Evaluated alternatives included:

- Maintain current approach (continued operation of groundwater recovery system and natural attenuation through radioactive decay and plume retardation),
- Interceptor trench drain,
- Groundwater extraction wells,
- Far down-gradient interceptor trench drain,
- Far down-gradient groundwater extraction wells,
- In situ plume treatment with passive zeolite PTW (similar to pilot PTW),
- In situ plume treatment with active zeolite PTW, and
- Far down-gradient in situ plume treatment with passive zeolite PTW.

The alternatives were evaluated with respect to the following criteria:

- Implementability,
- Ability to minimize future expansion of plume,
- Passivity,

- Ensure technology does not preclude any strategies for addressing plume during site decommissioning,
- Additional data requirements, and
- Cost of implementation.

Based on the alternative evaluation, the recommended remedial alternative included in situ treatment of the Sr-90 plume using a full-scale passive zeolite PTW similar to the pilot PTW. (See Figure 2.)

Relative to the PTW groundwater remediation technology, since 1995, the use of PTWs has evolved from innovative to an accepted standard practice for the containment and treatment of a variety of groundwater contaminants. The most common PTWs are constructed with zero valent iron or granular iron (for the mitigation of chlorinated solvent contamination) with more than 67 full-scale systems in operation in the United States. The first full-scale zeolite-based PTW used for the mitigation of Sr-90 contaminated groundwater was installed in Ontario, Canada in 1998 with remediation goals continuing to be realized.

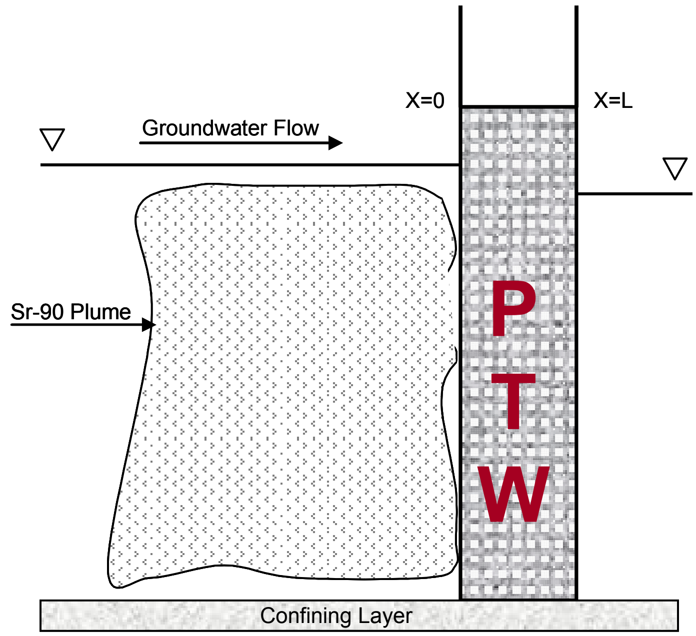

Fig. 2. Illustration of the proposed WVDP PTW.

ACTIVITIES TO SUPPORT ENGINEERING LEVEL DESIGN

Field Characterization Activities

To facilitate engineering-level design and exact placement of the PTW, in late 2008 extensive field investigations were undertaken of the geologic, hydrogeologic, and geochemical conditions in the northern portion of the North Plateau to supplement existing information. Periodic sampling continued through August 2009. The characterization study strategy employed a modified Triad investigation approach to allow work scope flexibility (ability to supplement the planned field work with additional field activities, as necessary) that would satisfy investigation objectives. The Triad approach involved the use of real-time data collection including rapid Sr-90 analysis (24-hour proportional counting). Based on real-time data, additional soil borings and monitoring wells were installed and additional environmental samples (soil, surface water, and groundwater) were collected and analyzed. The supplemental field work improved plume delineation and site characterization in support of PTW design.

The following field activities were conducted as part of the investigation:

- Direct push borings and microwell installation with statigraphic and hydrochemical data collection,
- Depth discrete groundwater sampling,

- Soil sampling,
- Short-term pumping tests, and
- Surface water sampling in the swamp ditch and drainage areas in the study area.

Approximately 80 borings were advanced with hundreds of soil and groundwater samples collected and analyzed. Additionally, a geophysical survey of the area was conducted to evaluate the potential presence of any significant subsurface anomalies. No significant anomalies were detected. Data generated through August 2009 provide an overview of the topography, geology, hydrogeology, and geochemistry of the proposed PTW alignment.

On the North Plateau, the ground surface across is relatively flat and slopes gently to the northeast. The WVDP is located within the Buttermilk Creek drainage basin, which is part of the Cattaraugus Creek watershed. Stream valleys incised by Quarry Creek, Franks Creek, and Erdman Brook, respectively, form the western, northern, and eastern boundaries of the North Plateau. A geologic cross-section in the area of the planned alignment of the PTW is shown in Figure 3.

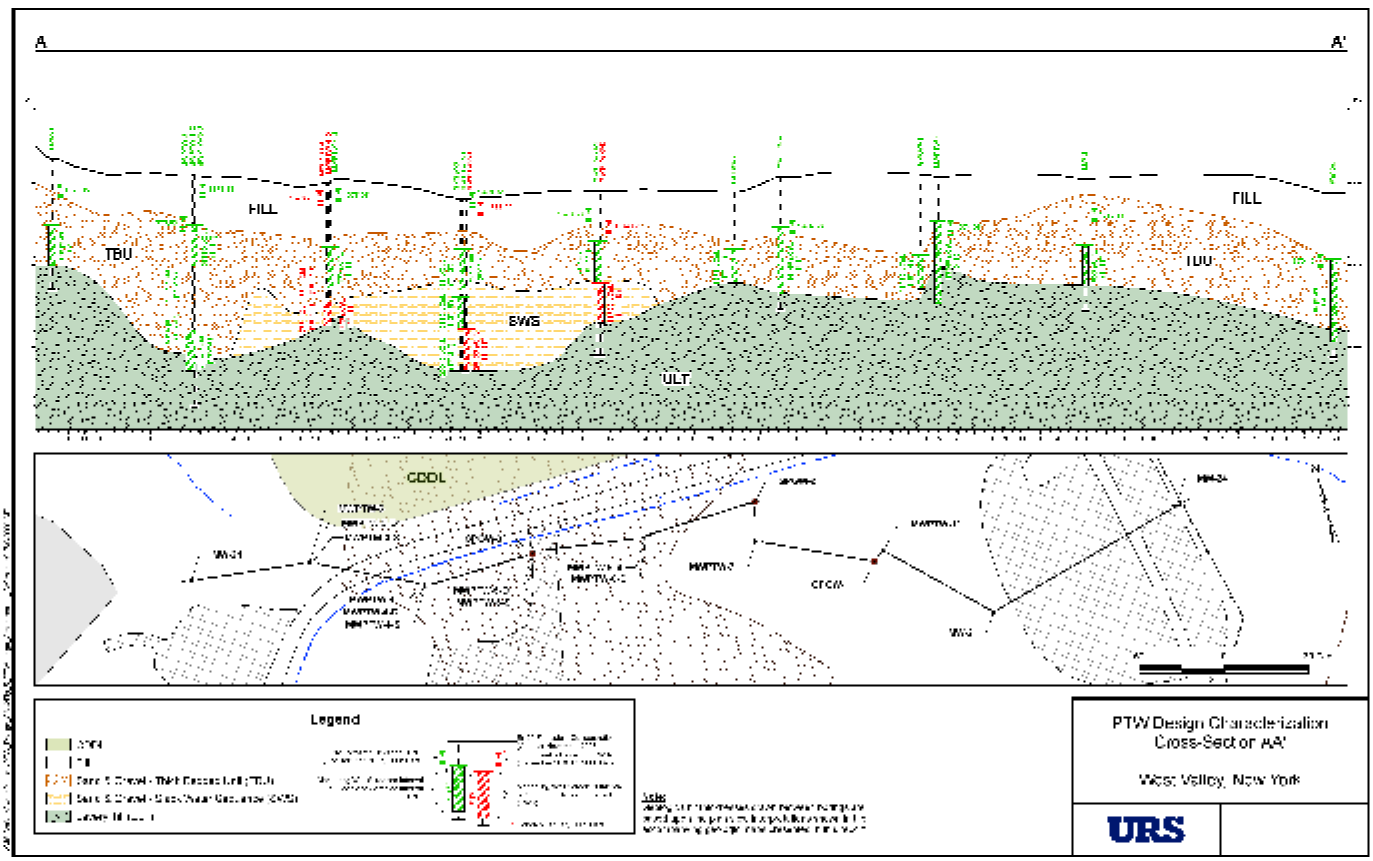

Fig. 3. Geologic cross-section of the planned PTW.

The cross-section identifies:

- Fill (reworked sand and gravel excavated from the site) ranging in thickness from 61 cm to 2.7 m (2 to 9 feet);
- Thick Bedded Unit (TBU) (poorly sorted, massive, silty sand and gravel layer that is best described as “muddy gravel”) ranging in thickness from 1.5m - 6 m (5 to 19 feet);
- Slack Water Sequence (SWS) (differentiated from the overlying TBU primarily by its interbedded stratigraphy and well-sorted materials) ranging in thickness from being absent to 3 meters (10 feet); and
- Till (composed of silt and clay) that occurs at a depth below the ground surface of 7.6 meters (25 feet) or less.

The results of grain size distribution testing for the TBU and SWS will be considered in the detailed design with respect to PTW constructability. In particular, the SWS is relatively coarse grained and has the potential to collapse or “run” during trenching activities, potentially displacing the treatment media, thereby reducing the design width of the PTW. The trench stability is a key constructability concern in the detailed design.

The underlying till surface was found to undulate in the area of the proposed PTW with as much as 3 meters (0 – 10 feet) of variation in the elevation of the contact with the sand and gravel. Effectively keying the PTW to the undulating till will be considered in the design and construction methods, taking into consideration waste (excavated soils) minimization goals.

Three hydrostratigraphic units were identified in the study area:

- Unconfined groundwater in the TBU/fill,
- Confined or semi-confined groundwater in the SWS, and
- Underlying Lavery till aquitard.

Groundwater flow direction is generally to the north-northeast toward the edge of the sand and gravel unit.

The leading edge of the plume is characterized by three Sr-90 “lobes.” The western leading edge lobe is coincident with a north-flowing drainage swale and the swamp ditch. The center leading edge lobe extends to the central portion of the Construction Demolition and Debris Landfill (CDDL) along the orientation of the SWS. The CDDL is a closed landfill with a natural soil cover. The eastern leading edge lobe occurs north of Lagoon 3 southeast of the CDDL; a more eastward groundwater flow direction is noted in this area. See Figure 4 for an illustration of the three lobes.

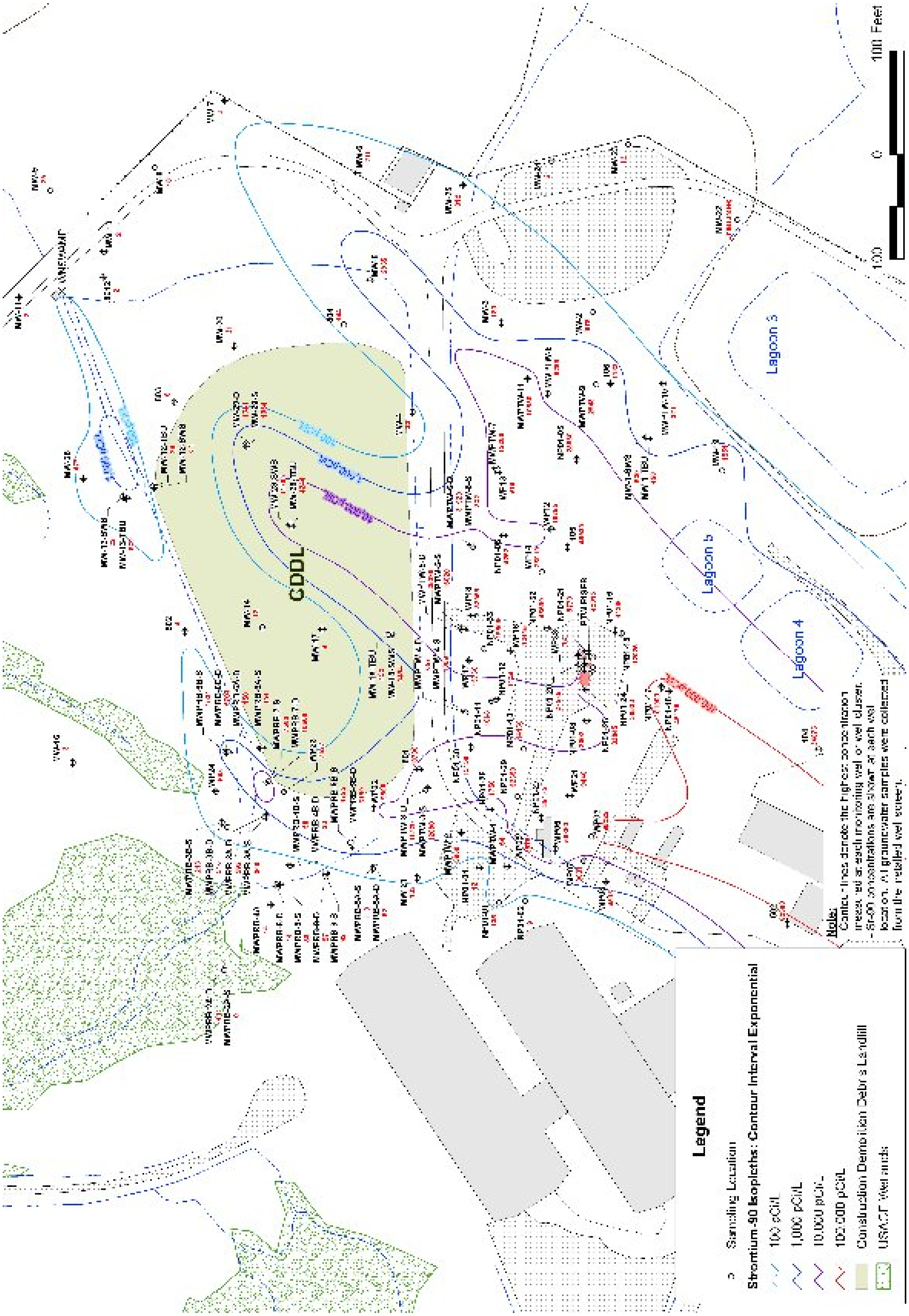

Fig. 4. The leading edge of the plume is characterized by three Sr-90 lobes; PTW Design Characterization Sr-90 Concentration in Groundwater, March 2009.

Groundwater typically is present five feet or more below the ground surface, however, near the CDDL access road, groundwater occurs within a few feet of the ground surface. This high water table condition allowed groundwater to occasionally seep to the ground surface in drainage swales paralleling the road. Storm water from an area northeast of the Main Plant Process Building is conveyed northward and discharges to the drainage swale south of the access road. Stormwater infiltration is a source of groundwater recharge in this area.

Relative to design considerations, the PTW may need to extend nearly to ground level in areas where the water table is near the surface. The high water table condition also raises the possibility that wet conditions could develop on the ground surface on the upgradient side of the PTW.

Horizontal hydraulic gradients in the area of the planned alignment of the PTW range from 0.011 to 0.026 (TBU) to 0.03 (SWS). The upper range of horizontal hydraulic gradients in the TBU occurs on the western side of the Sr-90 plume as groundwater flows toward the swamp ditch. Vertical gradients for paired wells in the TBU are downward in the area of the planned PTW. Vertical gradients in the SWS are upward. Upward vertical gradients exist between the SWS and TBU.

Hydraulic conductivity values in the area of the planned alignment of the PTW were estimated by evaluating the results of pumping tests. Values from pumping tests in the TBU completed in 2009 range from 2.87×10^{-4} centimeters per second (cm/s) to 2.63×10^{-2} cm/s. TBU slug test results average 1.94×10^{-3} cm/s. For the SWS, hydraulic conductivity estimates in the area of the planned alignment of the PTW range from 3.12×10^{-4} cm/s to 1.23×10^{-2} cm/s. The highest hydraulic conductivity values are associated with the area around the North Plateau groundwater recovery system and in the eastern end of the planned alignment of the PTW.

Table I illustrates the average horizontal groundwater flow velocities calculated for the TBU and SWS in the area of the PTW, presented for the discrete areas that correlate with plume lobes.

Table I. Average Horizontal Groundwater Flow Velocity.

	Average Horizontal Groundwater Flow Velocity
TBU Eastern Lobe	193 meters/year (642 feet/year)
TBU Central Lobe	82 meters/year (270 feet/year)
TBU Western Lobe	79 meters/year (259 feet/year)
SWS Central Lobe	173 meters/year (569 feet/year)

Relative to design considerations, the Sr-90 distribution along the proposed alignment of the PTW suggests some areas of relatively high activity (i.e., groundwater contributing to the western and central leading edge lobes) are also associated with relatively high hydraulic conductivity. The high activity coupled with increased velocity (i.e., less residence time in the treatment media) is an important design consideration. Furthermore, the loading rate of Sr-90 and other cations (i.e., calcium and magnesium) to the PTW is expected to be much higher in these areas than in portions of the wall spanning lower hydraulic conductivity zones, due primarily to the higher groundwater flow rate.

Zeolite Evaluation Activities

Laboratory evaluations of candidate naturally-occurring zeolites were also considered necessary for furthering the design of the groundwater PTW. The evaluations included batch testing to assess the removal of Strontium by cation exchange, mechanical testing to evaluate the grain size and hydraulic conductivity of the candidate materials, and column tests to further assess potential long-term efficacy of the ion-exchange process by the candidate zeolites and provide the basis for predictive modeling as part of the PTW design phase.

In addition to conducting column testing using simulated North Plateau groundwater (formula determined during the 2008 field investigations) at the University at Buffalo (UB), supplemental column tests were also performed at the WVDP using Sr-90. The experimental program, which was completed in October 2009 generated a considerable amount of new information on the performance of zeolitic materials for removing Strontium from groundwater. These data are significant both in terms of their scope (multiple material combinations, multiple tests) and for the extended duration of column tests – some greater than 200 days. Of particular importance for design, the extended column experiments provide more robust estimates of cation exchange selectivity coefficients, and the batch testing has provided a more complete picture of the initial distribution of zeolite cations, an important component of simulation modeling.

Taken as a whole, the zeolite tests confirmed the ability of the candidate zeolites to remove Strontium by the process of cation exchange. For both candidate zeolites, approximately 90 percent Strontium removal was consistently observed through the entire duration of the 200-day study for columns with 100 percent zeolite. Although significant Strontium breakthrough did not occur during the study period, the high-quality data set supports the estimation of cation exchange parameters for use in design simulations.

For both candidate zeolites, columns constructed of uniform zeolite/soil mixtures began to exhibit a gradual increase in effluent Strontium concentrations after approximately 100 days of operation. In general, the Strontium increases are attributable to the lower overall cation exchange capacity (CEC) associated with the mixture, lower effective porosity due to the less uniform particle size distribution (resulting in higher velocity), and a possible "masking" of zeolite exchange sites by fine soil particles. The inclusion of zeolite/soil mixtures was intended to provide insight into possible mixing that would occur during PTW construction using a trencher apparatus. Because field mixing is likely to occur at the outer edges of an installed PTW rather than uniformly throughout its cross section, the zeolite/soil mixture column configurations represent an unrealistic "worst case" mixing environment, applicable to only a small portion of an installed system. From a PTW construction standpoint, zeolite emplacement should be conducted in a manner that reduces the potential for mixing of native soil into the treatment zone.

Considering the full suite of mechanical, batch, and column tests, in comparing the candidate zeolites, two clear advantages of one of the materials was evident:

- One material is less friable and contains a relatively lower percentage of particles finer than the design specification. The inclusion of fine particles is potentially problematic because it could lead to reduced porosity and hydraulic conductivity in the field.

- One material has a higher clinoptilolite fraction and, as would be expected, consistently exhibits a 20-30 percent higher CEC. The range of CEC values reported by the supplier (1.5 –1.8 meq/g) is reasonably consistent with measurements from the UB study. Hence the material exhibits a clear advantage in terms of expected Strontium removal capacity.

For a PTW system constructed of the selected candidate zeolite, the experimental program has provided estimated values for important geochemical parameters including the total CEC, the initial distribution of sorbed cations, and the Gaines-Thomas selectivity coefficients. Other important design variables include:

- Treatment zone thickness;
- Effective porosity and zeolite bulk density of the installed PTW;
- Local groundwater flow rates; and
- Time-dependent concentration of Sr-90 entering the treatment zone, and the target effluent concentration.

A limited set of PTW simulations based on hypothetical but realistic field conditions suggest that the local groundwater flow velocity is probably the most important factor influencing the longevity of the zeolite at a particular PTW cross-section. In general, the expected time-to-Sr-90-breakthrough is approximately proportional to the local flow velocity, although the influence of Sr-90 decay will increase as the local residence time within the PTW increases (as the groundwater velocity is decreased). Similarly, the estimated PTW life is approximately proportional to the effective zeolite CEC, but the expected range of variation is much smaller than the local groundwater velocity.

DESIGN AND INSTALLATION OF PTW

The PTW is currently envisioned to be approximately 0.9 meters (3 feet) wide by 7.6 meters (25 feet) deep by approximately 213-244 meters (700- 800 feet) long. Installation is anticipated to occur using a single-pass continuous trencher such that, as soil is removed, the zeolite is immediately loaded into the void space.

The conceptual 30 percent design of the PTW was completed in December 2009. The final design of the PTW is scheduled to be completed in the spring of 2010. To support the final design, trencher demonstrations have been conducted and additional field investigation activities are planned (e.g., borings along PTW alignment to confirm depth to till). The installation of the PTW is targeted for fall of 2010.