[Form 2 (to be reported to Committee on Countermeasures for Contaminated Water Treatment and to be disclosed to public)

Technology Information	
Area	5 (Select the number from "Areas of Technologies Requested")
Title	Management measures to block groundwater from flowing into the site
Submitted by	Shaw Global Services, LLC

1. Overview of Technologies (features, specification, functions, owners, etc.)

Shaw Global Services is responding to the request for the information on management measures to block groundwater from flowing into the site as follows.

Objectives and Requested Technologies

The natural flow of groundwater from the hillsides surrounding the nuclear plant goes underneath the plant and out to sea. This groundwater is mixing with radioactively contaminated water that has seeped into the ground under the damaged reactors. Approximately 300 tonnes of this mildly radioactive groundwater is flowing into the sea every day.

TEPCO and the Government of Japan wish to (1) isolate the ground beneath the reactors from the flowing groundwater by installing an impermeable barrier(s) and (2) decrease the volume of ground water that must be collected for storage by reducing the radioactive strontium content in the groundwater. Specifically, the objectives are to:

- Reduce groundwater levels surrounding nuclear reactor buildings
- Reduce groundwater inflow into the buildings – currently about 400 m^3/day flows into the building
- Reduce the amount of contaminated water in buildings and reduce the concentration of radioactive strontium (Sr) in the groundwater surrounding the plant and potentially around the storage tanks.

The RFI requested information on the following areas:

- Install impermeable walls at OP+35M and/or OP+10m
- Extensive facing/surface covering to reduce rainwater permeation
- Collect/stabilize radioactive Sr in the ground

1.0 Installation of Impermeable Walls at O.P.35+M and/or O.P.+10 M.

Shaw Global Services recommends installation of an impermeable groundwater barrier wall at the O.P.+35M area. This wall may be approximately 820 meters or longer. Please see Exhibit 1 below for one alternative for the location of the wall.

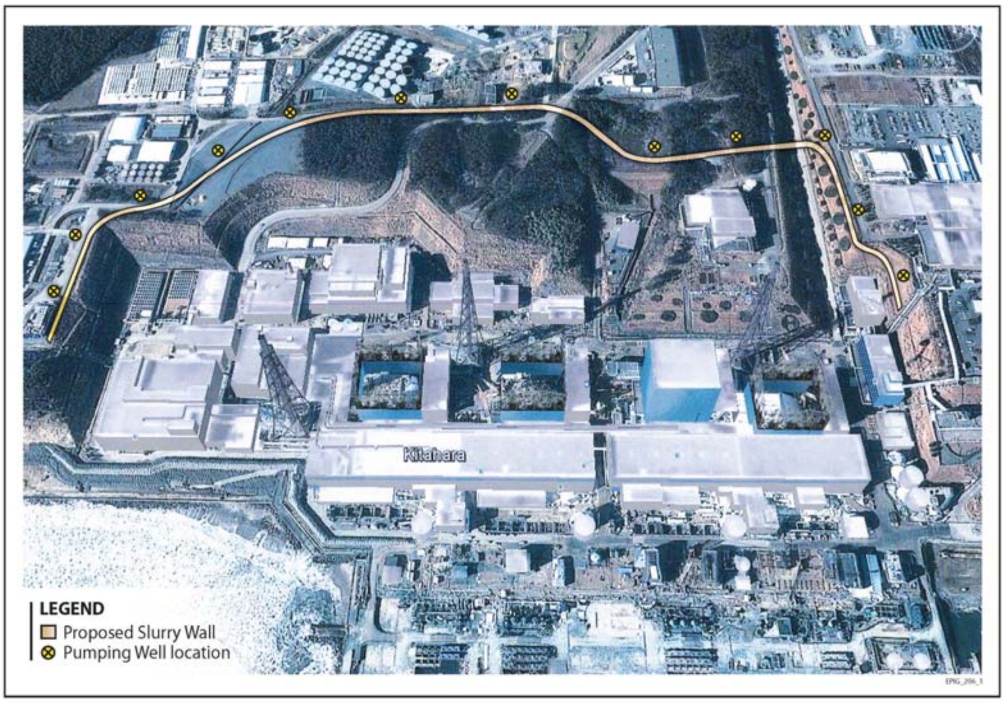

Exhibit 1. Proposed Barrier Wall Location

Bypass pumping wells as noted in the RFI are shown on the landward side of the barrier wall. actual number and positions of the wells will be based on the site's hydrology and groundwater modeling results. This combination of barrier wall and extraction wells will divert most of the groundwater away from the plant area. When a long barrier wall is built, water will mound behind it. With walls of shorter length, the water may flow around the ends of the wall to relieve the pressure. The water pressure behind the planned long wall will build up and the water will be released somewhere taking the path of least resistance, for example seeping under the wall and flowing out the sides of the hill. It is therefore critical that a groundwater extraction system (groundwater bypass pumping wells), be installed upgradient of wall (i.e. on the landward side of the wall) to relieve this pressure. Shaw Global Services does not recommend using barriers to divert groundwater at the O.P.10+M location for several reasons. These include that the new barrier will be very close to the facility, the wall will be near the cryogenic wall, and its location will be at the bottom of the hill where higher hydraulic pressure may build up behind the wall.

Before a barrier wall is installed within at the O.P.35+M area, it is recommended that additional information be obtained. As an example, soil core samples will be collected for geotechnical testing that includes soil classification and drained and undrained triaxial measurements. Data from these tests will be used to analyze the site for slope stability and subsidence characteristics. Groundwater analysis including, but not limited to, pH, total dissolved solids, groundwater anion and cation concentrations, turbidity and Sr and Cs concentrations, are recommended.

Shaw Global Services has installed barrier walls and other subsurface barriers (e.g. sheet piling) throughout the United States. For example, Shaw Global Services installed a 12-km, 15-meter-deep cement and soil/bentonite wall to contain leachate from the Fresh Kills Landfill on Staten Island, NY (this is the landfill where the World Trade Center 9/11 debris was placed). At the time, it was the largest installation of its kind. Exhibit 2 lists some of our experience designing and installing barrier walls. Shaw Global Services also installed one of the first direct-pass-through (no funnel and gate or confining unit) “permeable reactive barrier” (PRB) walls, completing the conceptual design through installation within 8 months. PRB walls allow groundwater to pass through, but contain materials (such as zeolites, red mud, activated carbon, etc.) that adsorb the contaminants from the groundwater.

1.1 Slurry Walls

We have a business relationship with a barrier wall subcontractor, with specific experience in deep bentonite barrier wall construction similar to that proposed for Fukushima. This firm has installed more than 250 subsurface barriers using the barrier trench method. These barrier walls have consisted of soil-bentonite, concrete, plastic concrete, soil-attapulgite, Impermix, and other impermeable materials. In addition, RECON has installed more than 30 treatment systems using the biopolymer trench method. A few examples of their experience are provided below:

- **Deep Barrier Wall, Rocanville, Saskatchewan.** Constructing 11 km of 1-meter width bentonite mix barrier wall to a depth of 25 to 55 meters around the perimeter of a tailings management unit at a potash mine. They are using hydraulic excavators, pre-trench excavators, and cranes with both hydraulic and mechanical clam buckets.

- **B47 Block Containment System, Freeport, TX.** Installed 3.1 km of 1-meter wide soil-attapulgite barrier to encapsulate n 80-hectare landfill area at a former chemical production plant. The trench was keyed into underlying clay at an average depth of 27 meters, and extending to more than 31 meters.
- **Bofors-Nobel Superfund Site, Muskegon, MI.** Constructed a 600-meter cut-off and containment wall to a depth of up to 38 meters down-gradient of abandoned sludge lagoons.

Conventional slurry wall installation has limitations where there are underground utilities and piping. As noted above, Shaw Global Services does not recommend using conventional slurry walls at the O.P.+10M locations. During construction at the O.P.+35M level, there will be a temporary need to handle significant quantities of soil and cuttings, some of which may be radioactively contaminated (from leaking tanks). As shown in the supplied RFI materials, there are discontinuous mud layers (“stringers”) within the sandstone and there are two aquifers separated by varying thicknesses of mudstone. Care will be taken to ensure that the mudstone layer is not breached to allow mixing of the two aquifers. In addition, excavation with large soil cutting equipment may cause cutting through the stringers that may allow some mixing of water from different depths in the upper sandstone layer.

Shaw Global Services also has another business relationship with a company that uses a different approach to install cut-off-walls and PRBs. Their technology does not required large quantities of soil to be excavated. This technology enables installation at sites where trenching is not an optimum option, such as deep cut-off-wall installations exceeding 30 meters or shallow sites with complexities such as congestion aboveground or having utilities underground.

Their process does not produce walls as thick as conventional slurry wall installations. Shaw Global Services thus recommends considering that two walls separated by three or more meters be installed. Having two walls provides additional protection if another earthquake causes one of the walls to crack. This process will have minimal impact on the mud stringers within the sandstone layer. With collection of a few borings at the beginning of the project, the process can be designed to complete the barrier wall one meter or less into the mudstone layer thus the possibility of mixing of the two aquifers. Compared to conventional slurry wall and large diameter auger barrier installation, the only soil collected will be soil cuttings; thus, there will be much less potentially-contaminated soil to handle. The equipment footprint is smaller than any other barrier wall installation systems, except jet grouting. If there are pipes and underground utilities present, the process can work around these obstructions.

Besides slurry walls described above there are several other types of impermeable wall construction technologies that Shaw Global Services has used and considered for Fukushima Daiichi.

1.2 Freeze Walls

The basic method of circulating cooled brine through underground tubing is described in the 1883 patent as the "Poetsch Process," and remains the basic process in use today. The primary use and development of the freezing method has been in the mining industry, and the construction industry has been using this method more often during the past 25years. Essentially, the process of ground freezing involves removing the heat from the ground to cause a drop of subsurface temperature below the freezing point of moisture in the pore spaces. The frozen moisture acts as a cementing agent, binding the soil particles together and providing a structural support network in the soil mass. Heat is removed by circulating coolants through pipes installed from the surface into the zone to be frozen, and subsequently is transferred into the atmosphere. In practice, a designed pattern of freezing pipes or "probes" is emplaced in the zone to be frozen. The probes are typically two pipes of different sizes, one within the other, so that the coolant can be pumped into one and extracted or allowed to escape from the other. Freezing progresses radially outward from the probe location, forming a frozen cylinder along the length of the probe. Adjoining cylinders eventually coalesce between probes to form a continuous impervious barrier wall.

Shaw Global Services has experience with freeze walls as currently proposed to isolate the soil beneath the reactor buildings. For example, Shaw Global Services constructed a freeze wall to eliminate groundwater infiltration during the excavation of PCB-contaminated soil, and we
in the design of the City of Boston Central Artery (underground highway) which used freeze walls prevent groundwater infiltration during excavation. We have observed that as the soil is freezing expands and there can be vertical expansion and significant horizontal pressure applied to the soil surrounding the freezing soil column. Based on the information supplied with the RFI, it appears that the aquifer may be partially-cemented sandstone that has been vibrated during the earthquake. This soil has also been saturated and dewatered multiple times. Therefore, this

may be prone to fracture formation and subsidence. Shaw Global Services would perform a geotechnical testing and engineering analysis to select the exact location of the freeze wall to minimize the potential impact of the soil expanding during the cryogenic treatment. Shaw Global Services has also observed subsidence near the freeze area if the wall is allowed to thaw.
in order to control water flow through the wall there will be on-going O&M costs to ensure that the wall stays frozen.

1.3 Jet-Grouted Barrier Walls

In a jet grouting application, a hole, typically about 10 cm diameter, is bored separately or by a jet grouting monitor or bit. Then a special hollow drill rod, equipped with a monitor containing a horizontal jet nozzle at the tip, is lowered into the hole. Grout is pumped down the drill rod at very high pressure, up to about 9,000 psi (620 bars), while the drill rod and monitor are simultaneously rotated and withdrawn. The grout, which exits the jet nozzles at high velocity, disintegrates the soil and mixes with it to form an impermeable barrier. The effective radius depends on the properties of the soil and the jet grouting parameters used. Column diameters on the order of 0.6 m are typically obtained in clay soils, and diameters up to about 1.2 m can be achieved in granular materials. Shaw Global Services has used jet-grouting techniques in various construction applications to stabilize sidewalls or prevent groundwater seepage.

Depending on the soil stability and degree of cementation, jet grouting may be applicable at Fukushima.

1.4 Deep Soil Mixing (DSM) Barriers

DSM barriers consist of overlapping columns of solidified soil created by a series of large diameter counter-rotating augers mixing in situ soils with additives, usually bentonite or cement grout, which is injected through the augers (auger diameters 0.9 to1.5 meter each, installation to depths of up to 45 meters). Shaw Global Services installed two deep soil mixing barrier walls at a confidential-client site in Bay City, Michigan with a total length of 1.3 km, using four side-by-side augers. The augers rotated down through the soil while a cement, bentonite, and water slurry mixture was injected into the soil from ports at the bottom of each auger. The rotation of the augers mixed the slurry into the soil to create an impermeable vertical wall section.

At the Fukushima plant, the mudstone layer between the two aquifers is sloped and thickness varies between about 1 to 10 meters. It may be difficult to key into this mudstone layer without mixing the two aquifers. Alternatively, the wall could be extended to the second mudstone layer temporary mixing the two aquifers is acceptable. During installation, there will be moderate amounts of soil and cutting that will have to be handled. The equipment footprint will be in size.

2.5 Sheet Piles

Installation of sheet piles consists of driving metal plates into the ground while overlapping adjacent plates to form a solid barrier to stop groundwater flow. The metal sheets are typically keyed into a confining layer to keep the water from flowing under the sheetpiles. For most soils types, it is difficult to drive sheet piles 35 – 40 meters or greater depth without partial separation of the sheets. The more the sheets separate, the greater the water flow through the sheetpiles. As with deep soil mixing barriers, it may be difficult to key into mudstone layer between the two aquifers. At the Fukushima Daiichi site, there may be significant issues with mixing the two aquifers when sheet piles are used.

Shaw Global Services has installed sheet piles at multiple locations. At the Hunters Point Shipyard site, Shaw Global Services characterized subsurface conditions, installed a sheet pile wall and restored the surface at the site. The site characterization confirmed that the lithology was favorable for driving sheet piling adjacent to the shoreline and delineated the depth to the bay mud/artificial that the sheet piles were to be keyed. The sheet pile wall were driven to a depth which penetrated the bay mud sediments to a minimum of 2 feet to ensure water would not seep beneath the wall.

2.0 Extensive Facing (Covering) to Reduce Rainwater Permeation

Shaw Global Services has covered/sealed soil, landfills and roadways to limit water permeation. For example at the Willow Run site, to improve product quality of the curing material it was necessary to minimize rain infiltration. Shaw Global Services successfully sprayed foams and a form of hydroseeding to seal the surface. In addition, at the U.S. Department of Energy (DOE) Nevada Test Site, soil surfaces were treated by spraying or mixing various road stabilization chemicals into the soil or roadbed.

For long-term treatment of open areas without much debris or equipment on top of the soil, Shaw Global Services recommends application of gunite (a cement-based material) or asphalt. Both materials have successfully been used in the United States to cap or seal soils to stop water infiltration.

For areas around buildings or where there is equipment or debris present, a spray application system is preferred. For long-term treatment, gunite may be sprayed onto the soil. This will seal the soil and become hard. This hard surface may not be optimal for locations where groundwater or soil samples may be taken or where equipment or debris may need to be moved. In locations where a hard surface coating is unacceptable, other options are available. Two of multiple treatment options include spraying polyurea foam or road stabilization chemicals. Polyurea generates less foam than polyurethane applications and it adheres well to surfaces. In addition, polyurea can be modified with a proprietary agent to form a partial shield for gamma radiation.

Shaw Global Services has shown that application of road stabilization products can lower dust, lower permeability of the soil with minimal to no apparent swelling. If needed, the treatments can be selected to provide moderate unconfined compressive strength and high resistance to shear forces. These products may contain one or more of the following: plastic (e.g., latex, acrylic and vinyl acetate polymers), bitumen, plant byproducts (e.g., corn or wood pulp) and other agents. The components may be mixed in with other additives such as CaCl2, MgCl2, and Portland cement to provide the various structural properties.

3.0 Collect/Stabilize Radioactive Strontium in the Ground

There are several options to remove Sr from groundwater in the ground (in situ), or to selectively treat Sr in water that has been pumped out of the ground. We understand that TEPCO/METI are looking for methods to remove Sr in situ, without having to pump Cs-contaminated water is from the ground for treatment. Shaw Global Services is experience with technologies that have the potential to successfully perform in situ removal of Sr. Shaw Global Services also has developed effective methods to remove Sr from water in above-ground treatment systems. The presence of Cs in the groundwater is complicating factor for treatment, however, if Cs is not present in the groundwater, there will be additional options available for treatment reagents. The reagents include an iron-based solid material that has been successfully used to treat radium, uranium and other metal cations. The other reagents are phosphate-based.

3.1 Removal of Sr from Groundwater in the Subsurface

Radioactive Sr can be removed from the groundwater in situ by injection of a reagent into the ground that adsorbs Sr into an insoluble matrix, immobilizing it. Sr can also be removed into a permeable reactive barrier (PRB) using reagents that are selective for Sr but not Cs. With both in-situ options, if desired, the treated soil may be excavated and disposed at some future date. Testing will be required to optimize the formulation to the site conditions.

A PRB is an in-situ treatment where a reagent bed is installed at a 90-degree angle to groundwater flow to immobilize or destroy the contaminant in groundwater. A PRB is usually built by digging a long, narrow trench and adding treatment reagents or injecting the reagents into the path of contaminated groundwater flow. The trench is filled with a reactive material, such as zeolite, activated carbon, granulated iron, crushed limestone, or organic material (mulch), to adsorb or chemically alter contamination in the groundwater. Side walls filled with an impermeable material (e.g. a slurry wall) may be constructed at an angle to the PRB to help funnel the flow of contaminated groundwater toward the reactive materials. The filled trench is covered with soil, and is not usually visible at the ground surface. Shaw Global Services has installed PRBs at over 20 hazardous and radioactive waste sites around the US including six US Department of Energy Sites (Exhibit 3). In addition, Shaw Global Services has experience successfully applying and mixing multiple treatment reagents that include, polysulfides, phosphates, and ferrous sulfate within the subsurface to immobilize multiple metals..

3.2 Extracting Groundwater Containing Radioactive Sr with Above-Ground Treatment

Groundwater containing Sr is pumped up and passed through a reactive media the sorbs Sr strongly but has minimal effectiveness with Cs removal. This should remove the majority of the Sr from the extracted groundwater. Depending on the contact time and the media used, this treated water may need additional treatment to achieve the residual Sr level. Secondary treatment may include the use of SARRY units, precipitation process that has been successfully used with other radioactive metal cations or a proprietary process ion exchange/sorption media process. If needed, once the Sr is removed, this water may be treated through the Cs removal system.

Geochemically, Sr typically sorbs to soil by reactions with carbonate minerals such as $CaCO_3$ and cation exchange sites (typically iron-based) on clay minerals. If desired, Shaw Global Services can modify the in-situ conditions (e.g. adjust the pH) to allow release of Sr that is adsorbed to the soil so it can also be removed from the subsurface.

Shaw Global Services has significant experience with pump and treat operations; in-situ metal and organic treatment; treatment of groundwater and process waters for radionuclides, metals and organic compounds; groundwater management and groundwater modeling. At the DOE Brookhaven National Laboratory facility, Shaw Global Services conducted treatability studies; evaluated alternatives, and designed an ion exchange/sorption media treatment system to treat 682 liters per minute of Sr-90 and Cs-137 contaminated groundwater. The pump and treat operation treated over eleven million liters of water to meet the New York state drinking water standard of 0.296 Bq/L. This same design was subsequently used at other sites. Experience with ex-situ treatment of radioactively contaminated water includes design and building the system as well as implementing water treatment at various DOE sites. During the SARRY development process, Shaw Global Services analyzed multiple sorption, fixation and ion media for Cs and Sr removal. With the SARRY development, besides removal efficiencies by the media, Cs and Sr loading on the media and the subsequent heat generation were major consideration in selecting the media chosen for the project. With the current situation addressed in this RFI, Shaw Global Services will have more latitude in its selection of treatment media. Global Services, for DOE projects, has investigated other Sr removal media that were not for the SARRY project.

- Notes (Please provide following information if possible.)
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- Technology readiness level (including cases of application, not limited to nuclear industry, time line for application)

The proposed technologies are all commercially available and have been demonstrated. The exhibits below show examples of Shaw Global Services Experience with Barrier Walls (Exhibit 2) and Permeable Reactive Barriers (Exhibit 3).

Exhibit 2. Shaw Global Services Barrier Wall Experience

Project	Work Scope
Panoche Landfill Closure, Solano County, CA	As part of the closure for two landfills encompassing 100 acres, Shaw Global Services designed, permitted, and constructed a barrier wall and a groundwater recovery system to minimize pressure against the barrier wall. Containment was accomplished by keying the wall into shale bedrock underlying the site and providing a 1-meter- wide soil-bentonite barrier wall. The wall was 210 meters long and extended to a depth of 18 meters below the construction platform.
Waste Containment At Bulldog Mountain, Creede, CO	To mitigate contaminant migration caused by seepage of a 28-meter-high earth dam that retained tailings generated from silver mining operations, Shaw Global Services designed and constructed a barrier trench cutoff wall, drainage collection trenches, and pumpback system. The soil-bentonite wall was 426 meters long and up to 30 meters deep. Excavation to 18 meters was accomplished with an extended backhoe, and excavation below 18 meters was accomplished with a crane-mounted, 13-ton clamshell.
Helen Kramer Landfill Superfund Site, Mantua Township, NJ	Shaw Global Services designed and constructed a 1-meter wide, 2.6 km long soil-bentonite barrier wall to prevent contaminant migration from a hazardous waste landfill. The barrier wall was keyed 1 meter into the underlying low permeability layer, at a depth of up to 23 meters below grade.
Closure of Vine Hill Complex, Martinez, CA	To accomplish closure of the Vine Hill Complex, a 70-hectare parcel containing 38 hectares of unlined surface impoundments, Shaw Global Services installed 6.1 km of 6- to 8-meter-deep barrier walls and extraction trenches to contain groundwater flow.
Landfill Closure At Brunswick Naval Air Station, Brunswick, ME	Shaw Global Services installed a 700-meter barrier wall around a 6.5-hectare landfill to a maximum depth of 20 meters. A 9-meter-wide working platform and 6-meter-wide construction access road was installed along the alignment of the barrier wall trench to ensure stability for construction equipment. The wall was keyed 1 meter into a low-permeability clay formation.
Fresh Kills Landfill Remediation, Staten Island, NY	Shaw Global Services designed and constructed a leachate containment and collection system, a methane abatement system, a 4.5 million liter-per-day water treatment facility, and over 13.7 km of soil/bentonite cutoff walls. The project encompassed excavation and landfilling of 760,000 cubic meters of wastes and 3.8 million cubic meters of fill material.
Soil-Bentonite Cutoff For Existing Landfill, Lansing, MI	Shaw Global Services designed and constructed a barrier wall to encapsulate an existing landfill. Site conditions included restricted access and steep (2 horizontal to 1 vertical) grades on alignment. Clamshell excavation was performed to a depth of 29 meters, and the barrier wall was placed within 3 meters of an active railway.

Exhibit 3. Shaw Global Services Permeable Reactive Barrier Wall Experience for US DOE

Project	Work Scope
DOE, Los Alamos National Lab	Shaw Global Services designed and installed a PRB at Los Alamos National Lab to intercept and treat surface water and subsurface alluvial groundwater contaminated with plutonium, americium, uranium, Sr, nitrate, and perchlorate. Water sequentially passed through four chambers of the multi-barrier system to meet the performance criteria.
DOE, S-3 Pond, Oak Ridge, Tennessee	Designed and installed a funnel-and-gate reactive barrier system consisting of HDPE membrane walls, a treatment module containing porous media, and groundwater collection piping. Barrier was installed using modular shoring and biopolymer slurry. The treatment module is designed to allow for the testing of various treatment media.
DOE Rocky Flats Environmental Technology Site, Colorado	Installed a funnel-and-gate reactive barrier system consisting of HDPE membrane walls, two treatment cells containing zero valent iron, and a groundwater collection system. The treatment cells are designed such that the treatment media can be easily placed and retrieved to allow regeneration or replacement of the media. The barrier was installed using an open trench method with a track-mounted hydraulic excavator.
DOE, East Trenches Plume, Rocky Flats Environmental Technology Site, Colorado	Designed and constructed a funnel-and-gate permeable reactive wall consisting of HDPE membrane walls and a subsurface groundwater collection system. The wall was constructed using an open-ended trench box pinned with H-pile to shore the excavation. Treatment media is granular zero-valent iron which can be easily placed and retrieved from cell.
DOE, Solar Ponds, Rocky Flats Environmental Technology Site, Colorado	Designed and constructed a funnel-and-gate permeable reactive wall consisting of a subsurface collection system and a two-stage treatment module. Stage 1 contains organic media and granular iron to induce denitrification and reduce nitrate. Stage 2 contains granular iron to remove radioisotopes by chemical reduction. The system was installed using a track-mounted hydraulic excavator.
DOE, Monticello, Utah	Constructed in a funnel-and-gate permeable reactive wall consisting of two impermeable bentonite/soil slurry wing walls and a zero-valent iron reactive section. Installed using steel sheet pile cofferdam construction.

- Challenges

The major challenges are access to locations on steep slopes or covered with debris or structure, and minimizing worker exposure. We believe that the technologies proposed provide solutions to both of these problems.

- Others (referential information on patent if any)

【Areas of Technologies Requested】

(1) Accumulation of contaminated water (Storage Tanks, etc.)

(2) Treatment of contaminated water (Tritium, etc.)

(3) Removal of radioactive materials from the seawater in the harbor

(4) Management of contaminated water inside the buildings

(5) Management measures to block groundwater from flowing into the site

(6) Understanding the groundwater flow