Thermal Removal of Tritium from Concrete and Soil to Reduce Groundwater Impacts – 13197

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ABSTRACT

Legacy heavy-water moderator operations at the Savannah River Site (SRS) have resulted in the contamination of equipment pads, building slabs, and surrounding soil with tritium. At the time of discovery the tritium had impacted the shallow (< 3-m) groundwater at the facility. While tritium was present in the groundwater, characterization efforts determined that a significant source remained in a concrete slab at the surface and within the associated vadose zone soils. To prevent continued long-term impacts to the shallow groundwater a CERCLA non-time critical removal action for these source materials was conducted to reduce the leaching of tritium from the vadose zone soils and concrete slabs. In order to minimize transportation and disposal costs, an on-site thermal treatment process was designed, tested, and implemented.

The on-site treatment consisted of thermal detritiation of the concrete rubble and soil. During this process concrete rubble was heated to a temperature of 815 °C (1,500°F) resulting in the dehydration and removal of water bound tritium. During heating, tritium contaminated soil was used to provide thermal insulation during which it's temperature exceeded 100°C (212°F), causing drying and removal of tritium. The thermal treatment process volatiles the water bound tritium and releases it to the atmosphere. The released tritium was considered insignificant based upon Clean Air Act Compliance Package (CAP88) analysis and did not exceed exposure thresholds. A treatability study evaluated the effectiveness of this thermal configuration and viability as a decontamination method for tritium in concrete and soil materials. Post treatment sampling confirmed the effectiveness at reducing tritium to acceptable waste site specific levels.

With American Recovery and Reinvestment Act (ARRA) funding three additional treatment cells were assembled utilizing commercial heating equipment and common construction materials. This provided a total of four units to batch treat concrete rubble and soil. Post treatment sampling verified that the activity in the treated soil and concrete met the treatment standards for each medium which allowed the treated concrete rubble and soil to be disposed of on-site as backfill. During testing and operations a total of 1,261-m^3 (1,650-yd^3) of contaminated concrete and soils were treated with an actual incurred cost of $3,980,000. This represents a unit treatment cost of $3,156/$m^3$ ($2,412/$yd^3$). In 2011 the project was recognized with an e-Star Sustainability Award by DOE's Office of Environmental Management.

INTRODUCTION

This remedial activity pioneered the use of thermal heating to remove tritium from concrete rubble and soil materials to satisfy on-site disposal requirements. Characterization efforts had determined that tritium was present in a concrete slab that was associated with a former reactor moderator handling facility. Tritium levels as high as 1,680,000 pCi/g were identified in the concrete slab and were related to distinct processing areas (WSRC, 2006). The characterization also determined that the soil beneath the concrete slab contained tritium (maximum value of 251,000 pCi/g) that decreased significantly with depth (WSRC, 2008a). The tritium served as a long-term source of contamination to the underlying groundwater system. The purpose of the removal action was to eliminate the continued leaching of tritium from the contaminated materials that were impacting the groundwater. Waste site specific leeching analysis had determined that the maximum contaminant level necessary to prevent exceeding the maximum contaminant level (MCL) for tritium in the groundwater was 120 pCi/g for the soil and 68,000 pCi/g for the concrete (WSRC, 2008a).

The thermal detritiation process removes tritium as a water vapor by heating the concrete rubble and soil in batch treatment cells. For the concrete rubble this removal requires both drying and dehydration of the material. Previous laboratory scale investigations have demonstrated that tritium removal from concrete is a function of temperature with higher temperatures removing higher amounts of tritium (Wang et.al. 2004; EFDA, 2005). Based upon this information complete removal of tritium is expected to occur at temperatures between 700°C and 1000°C (1292°F and 1832°F). These observations were coupled with the maximum contaminant migration levels to establish a target temperature of the concrete rubble of 800°C (1,472°F). Based upon reported observations this temperature would result in a minimum of 92% removal of the tritium that was present in the concrete material and would be sufficient to achieve concentrations below migration thresholds for concrete (WSRC, 2008b). Figure 1 illustrates the relationship of the established target temperature for the concrete rubble with literature reported cumulative recovery. Since the soils are inorganic, removal of the tritium requires drying only which occurs when soils reach temperatures near 100°C (212°F). For both the concrete rubble and soil all of the removed tritium was released to the atmosphere as water vapor. CAP88 analysis was performed to determine dose to the site worker and offsite individual as well to demonstrate National Emission Standards for Hazardous Air Pollutants (NESHAP 40CFR61) compliance. The evaluation determined that the tritium released to the atmosphere would represent a maximum dose to the site worker of 1.88E-02 mrem, and the maximum dose to the offsite individual would be approximately 2.37E-04 mrem. The analysis further concluded that the source was insignificant (WSRC, 2008b).

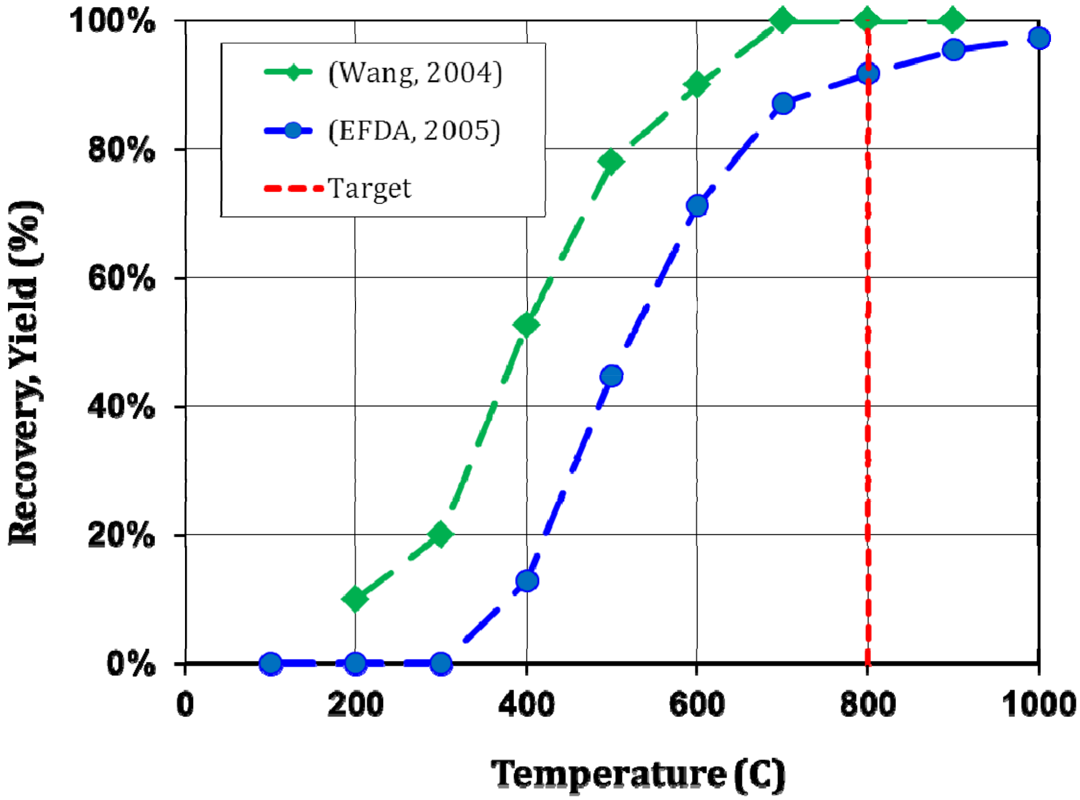

Figure 1: Target Temperature for Thermal Detritiation Process Compared with Cumulative Tritium Recovery from Literature Reports.

DESCRIPTION

The equipment necessary for on-site thermal treatment includes an enclosure configured to contain the material during heating and reduce heat losses to the surrounding environment and a heat source with appropriate temperature control and monitoring system. The treatment cell was fabricated using standard construction materials and commercial heating equipment. The objective was to provide a cost-effective system that was re-usable, scalable, and can be readily disposed of. To facilitate these requirements the treatment cell was fabricated using inexpensive, commercially available industrial retaining wall blocks (V-Interlock Blocks from World Block Duluth, MN). The heating equipment consisted of an array of thirty-six (36) heating elements that were connected to a control cabinet. The individual heating elements were 277-V, single-phase and rated at 7,778 watts each and provided a total of 280 kilowatts. The elements were manufactured by Watlow Electric Manufacturing Company and are distributed under the Multicell® trade name and have a maximum operating temperature of 2200°F (1204°C). For long-term, reliable performance the manufacturer recommends operating temperatures between 1800 and 2000°F (982 - 1093°C). The overall cost of the heating equipment for one treatment cell was on the order of $75,000, which included the control cabinet, one set (36) of heating elements, control thermocouples, and retaining wall blocks.

A critical aspect of the design involved how the materials were loaded into the treatment cell. Since the concrete rubble requires a treatment temperature much higher than that of the soil, it was loaded first into the bottom of the treatment cell. Concrete from the contaminated slab was excavated in small boulder/large cobble size (12-15 inch) portions. Once excavated the small boulder/large cobble size pieces were irregularly placed on the grid formed by the heating elements. The remaining volume of the cell was then filled with soil. This configuration allows the concrete rubble to be in direct proximity to the heat source while the soil serves as an insulation layer to reduce heat losses. The insulating factor from the soil allows the internal portions of the concrete rubble to reach the desired target temperature. The overall arrangement of the treatment cell, the location of the heating elements, and the positioning of the rubble and soil material is presented in Figure 2.

For operations and control the heating elements were grouped into four (4) zones of nine (9) elements each. The temperature of each zone was controlled by an integrated temperature controller and an independent limit controller. The integrated temperature controller received input from a thermocouple integral to the central element of each zone. This allowed the integrated temperature controller to regulate the power to all elements in that zone based upon the operational set points. High limit thermal protection of the heating elements was provided by an independent limit controller within each zone with independent thermocouples to prevent overheating. Additional thermal monitoring was provided in the concrete rubble and soil via an independent monitoring system. This system consisted of rubble monitoring thermocouples and soil monitoring thermocouples that were interfaced to a commercial data logger. The rubble monitoring thermocouples were cast in concrete mold samples that allowed monitoring internal rubble temperatures. Figure 3 illustrates how the power was distributed to the four heating zones and temperature controls associated with each zone and the associated soil and rubble temperature monitoring.

The treatment cell was located on an adjacent, uncontaminated, concrete slab and assembled on a base layer of coarse stone. The base of coarse stone is considered an important feature as this allows ambient air to flow in from the perimeter, through the heated rubble, and exit through the top. This airflow provides a vector for the removal of tritium from the concrete rubble and soil material during a heating cycle. A typical heating cycle involved increasing the temperature of the elements from ambient to 927°C (1,700°F) over a week long period. Once the heating elements were at the operating temperature the rubble and soil were allowed to heat soak under these conditions. During the heat soak the temperature in the concrete rubble and soil increased and tritium was released as water vapor. During the soak period temperatures were monitored to determine if target temperatures were obtained. The soak period allowed sufficient time to provide heat transfer necessary to increase the internal temperature of the concrete rubble followed by advective gas transport of the water vapor through the soil. Figure 4 illustrates the treatment cell during early phase of construction. As shown in Figure 5, following construction and loading the completed treatment cell was covered with a simple roof structure to eliminate infiltration during heating.

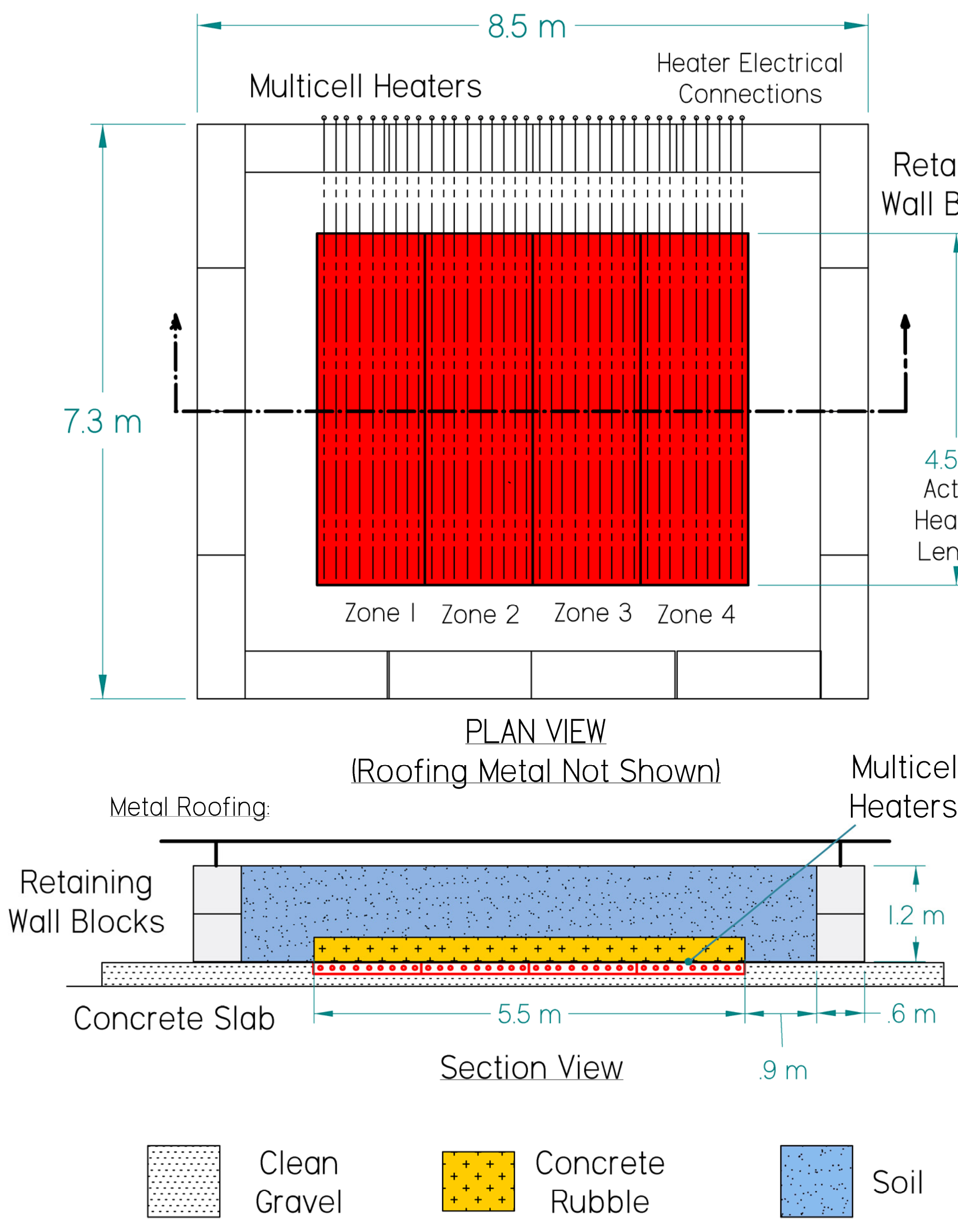

Figure 2: Arrangement of Enclosure Blocks, Heating Elements, Rubble and Soil Material used for Thermal Removal of tritium from Concrete Rubble and Soil.

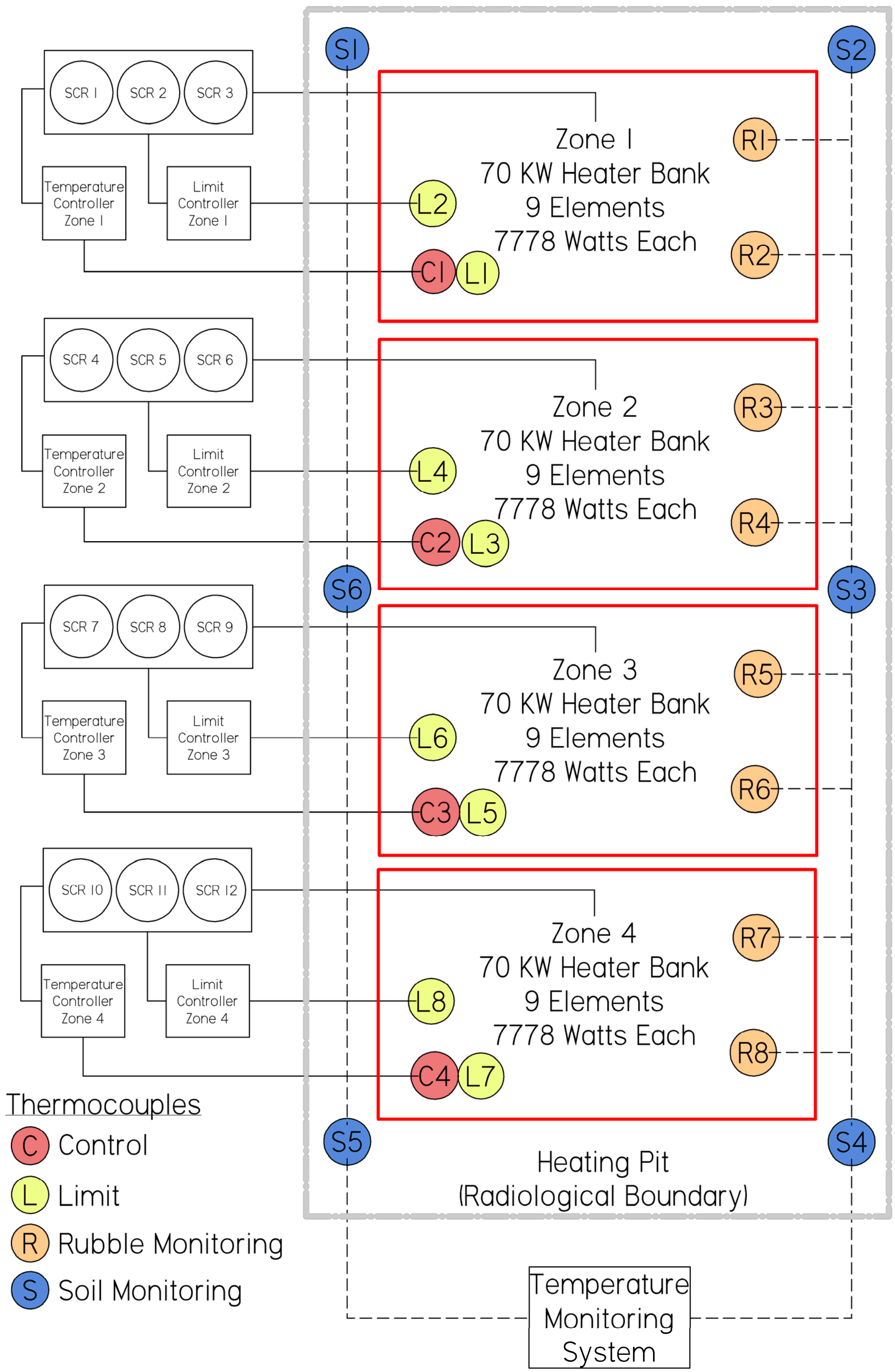

Figure 3: Arrangement of Control, Limit, Rubble, and Soil Monitoring Thermocouples.

Figure 4: Initial assembly of treatment cell used during the treatability study.

Figure 5: Final assembly of treatment cell used during the treatability study.

DISCUSSION

Initial testing of the treatment modality began on March 9, 2009 using approximately 54.3 m^3 (71 yd^3) of contaminated soil and concrete rubble. The rubble and soil were sourced from those areas containing highest levels of tritium. The objective during the campaign was to heat the rubble to 815°C (1500°F) and maintain this temperature for 30 days during which the soil temperature would exceed 100°C (212°F). Following minor adjustments in the temperature control scheme the target temperature were obtained on April 3, 2009, less than 30 days after heating was initiated. During the soak period the average temperature of the elements was maintained in excess of 927°C (1,700°F) which resulted in a rubble temperature of 833°C (1,531°F). During this period the temperature in the soil increased to over 350°F (177°C), providing adequate drying for the soil (SRNL, 2009).

During the heating campaign the exterior temperature of the treatment cell was routinely monitored. This monitoring indicated that the construction of the cell provided adequate insulation to allow heating of the concrete rubble to the target temperature. While elevated above ambient temperature of 15°C (60°F), the exterior temperature of the treatment cell did not present any recognized hazards to personnel or equipment.

Previous characterization had determined that tritium levels in the concrete slab that was excavated and treated were as high as 1,680,000 pCi/g (WSRC, 2006) and tritium in the soil beneath the concrete slab was as high as 251,000 pCi/g and decreased significantly with depth (WSRC, 2008a). Following heating soil and concrete rubble samples were collected for tritium analysis. Samples were split and sent to two analytical laboratories for analysis. Following the treatment all of the soil samples (n=4) were well below the soil contaminant migration level of 120 pCi/g for soil and all of the concrete samples (n = 10) were below the concrete contaminant migration level of 68,000 pCi/g for concrete.

The configuration of the treatment cell was effective in heating the different materials to the target temperature of each material. An important aspect of this was the arrangement of the materials within the treatment cell. The geometry of the cell was such that the concrete material, which required the highest treatment temperature, was placed immediately on top of the heating elements. Soil was them used an insulation of top of the concrete rubble. The entire treatment cell was fabricated on a layer of coarse gravel which enhanced the effectiveness of the design. The coarse gravel bed allowed ambient air to serve as process air during heating. The application of heat coupled with the fresh air inflow enabled convective transport of tritium in the form of water vapor from the contaminated material to the atmosphere.

Following the success of the treatability study the configuration of the treatment unit was scaled-up and three additional treatment cells were assembled to treat the tritium contaminated material associated with the waste unit. Figure 6 provides an aerial view of the waste unit. Cell

#1 is the original cell used during the treatability study and Cells #2 through #4 are the larger cells that were constructed. The operational paradigm consisted of excavation of contaminated soil/concrete and batch treatment in one of the four cells. Following treatment the material was sampled to verify that tritium levels were below the contaminant migration levels required. The treated material was then used to backfill the excavation areas. A total of 17 heating campaigns were completed between March of 2009 and September 2011 and approximately 1,260 m^3 (1,650 yd^3) of tritium-contaminated soil and concrete was processed. This material is observed as the stockpiles above Cells #3 and #4 in Figure 5. This material was first excavated, then thermally treated, tested, and then used to backfill the area of the original contaminated concrete slab and soil. As a result of on-site management and treatment over $1.6 million in transportation cost savings and avoidance of over 400,000 truck miles were realized while accelerating site cleanup by six years. The actual cost incurred for the project was $3,980,000 (SRNS, 2011), representing a unit treatment cost of $3,156/$m^3$ ($2,412/$yd^3$).

Figure 6: Thermal Detritiation Units used to remove tritium from concrete rubble and soil.

CONCLUSIONS

This treatability study demonstrated that tritium can be effectively removed from concrete rubble and soil using thermal heating. Reusable treatment cells were readily fabricated using common, inexpensive construction materials and commercially available heating equipment. Effective treatment requires consideration of the temperature requirements for concrete rubble and soil as well as insulating capacity of soil when configuring material within the treatment cell. An important aspect associated with thermal treatments is the need for reliable and consistent temperature monitoring throughout the treatment cell. The configuration of the equipment was effective in heating both concrete rubble and soil materials as well as heating only soil to the necessary target temperatures. As a result of the heating activity, residual tritium was released from the concrete and removed via air currents within the treatment cell.

The removal action served as source zone removal for an existing groundwater plume. The purpose of the action was to reduce future leaching of tritium from vadose zone soils and concrete slabs. This action should result in a future decrease of tritium concentrations in the groundwater. Since completion of the removal action ongoing management of the area includes groundwater monitoring with land use controls that prevent unrestricted land use.

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