6. SUMMARY AND CONCLUSIONS

The objective of this RI is to establish an understanding of the geology, hydrology, and the nature and extent of contamination in surface water, soils, and groundwater for the Westinghouse Hematite Site, located near the town of Hematite in Jefferson County, Missouri. Data obtained during this investigation will be used to facilitate development of a Feasibility Study for selection of appropriate alternatives for remediation. Coupled with process knowledge for the Hematite Facility and known potential source areas for contaminants, this evaluation has led to the development of a Conceptual Site Model (CMS) from which the fate and transport of contaminants in groundwater have been assessed. Finally, the CSM has become the basis from which a groundwater flow and transport model has been constructed and calibrated against empirical data.

The Hematite Facility was originally constructed as the Mallinckrodt Chemical Works in 1955. The Facility became operational in July 1956, producing uranium metals for the nuclear fuel program of the U.S. Navy. Throughout its history, the manufacture of uranium metal and compounds from natural and enriched uranium was the primary activity at the Facility. Operations included the conversion of UF₆ gas of various ²³⁵U enrichments to uranium oxide, uranium carbide, uranium dioxide pellets, and uranium metal. Although uranium material production was the primary function at the Hematite Facility, records indicate secondary activities such as uranium scrap recovery and a limited amount of work with thorium compounds as part of early research into the use of thorium in the fuel cycle.

In addition to the nuclear materials used at the Hematite Facility, there were a variety of non-nuclear chemical products stored on-Site and used in many of the processes. Those with the greatest potential for contaminating surface water, soils, and groundwater at the Hematite Facility because of leaks (from storage tanks or process pipelines) or waste disposal activities (e.g., the Evaporation Ponds and the Burial Pits) include strong mineral acids (hydrochloric, hydrofluoric, and nitric) and chlorinated organic solvents (PCE and TCE). A number of AOCs have been identified at the Hematite Site and include those locations where these (and other) potential contaminants were stored, used, and/or disposed.

6.1 SUMMARY OF GEOLOGIC AND HYDROLOGIC CONDITIONS

The geologic framework of the Hematite Site is dominated by two key bedrock formations, the Jefferson City-Cotter Dolomite and the Roubidoux Formation that underlie the site. These formations dip gently toward the northeast. The regional landscape is highly dissected by streams yielding topographic relief in excess of 150 ft. The Hematite Facility is built upon terrace/alluvial flood plain sediments overlying bedrock within the valley carved by Joachim Creek. These sediments include 10 to 20 ft of fine-grain material underlain by 5 to 20 ft of coarser-grain sands and gravels.

In the unconsolidated overburden, groundwater flow is chiefly confined to the basal, coarse-grain unit and is in a southeastward direction from the Hematite Facility toward Joachim Creek where it discharges. A groundwater mound is associated with the Hematite Facility and has a significant impact on the potentiometric surface. Groundwater flow in the upper Jefferson City-Cotter Dolomite appears to be affected by the mounding, and components of flow radiate from the Hematite Facility toward the northeast (along bedding planes) and toward the southeast (in a transmissive zone) within this bedrock unit. Below the Jefferson City-Cotter Dolomite, the current direction of groundwater flow appears to reflect a northeasterly trajectory, which is consistent with the regional groundwater flow direction in the Roubidoux Formation. In this RI report, several HSUs in bedrock have been tentatively defined that conform to the orientation of bedding. In descending order of depth, these are the Jefferson City-Cotter, Jefferson City-Roubidoux contact zone, and Roubidoux HSUs, respectively.
Vertical head gradients are downward from the shallow to deep overburden. Between the deep overburden, and Jefferson City-Cotter HSU, gradients are downward in the vicinity of the Hematite Facility and upward near Joachim Creek. Vertical gradients tend to be upward from the Jefferson City-Cotter HSU and deeper HSUs. However, until approximately mid-2004, this gradient was reversed (i.e., downward) as a result of the significant lowering of heads in the Roubidoux Formation. A possible reason for lower heads in the deeper HSUs was the pumping of groundwater from the Roubidoux Formation by water supply wells in the city of Festus.

6.2 SUMMARY OF CONTAMINATION AT THE SITE

Most contamination (radionuclides, metals, and organics) in soil at the Hematite Site is closely associated with the footprint of the Hematite Facility and disposal sites within the Facility. The distribution of contamination in groundwater, however, is significantly different among these potential contaminants. Summary conclusions for all contaminants and media are described in the following subsections.

6.2.1 Inorganics

Cyanide was not detected in any of the surface water, sediment, surface and subsurface and groundwater samples. This is clearly not a constituent of concern at the Site.

Fluoride was detected in one surface water sample collected from the Northeast Site Creek (part of AOC #2). The measured concentration, 0.67 mg/L, was only slightly higher than the reporting limit (0.5 mg/L). Fluoride was not detected in any of the surface water samples from the Site Pond, Site Creek, and Joachim Creek.

The highest fluoride levels in the surface soil samples were measured in samples from the Evaporation Ponds area (AOC #4), Deul's Mountain area (AOC #13), next to the buildings and adjacent outdoor areas (AOC #8). The highest fluoride result (170 mg/kg) is still below the geometric mean of regional values (270 mg/kg) reported by Tidball (1984).

The majority of the subsurface soil samples did not contain fluoride above the reporting limit of ~7 mg/kg. Elevated fluoride concentrations were measured in soil samples in localized areas within the Facility including the Evaporation Ponds (AOC #4), under the buildings (AOC #6) and near Deul's Mountain (AOC #13). However, even the highest fluoride level (190 mg/kg in EP-13-06-SL) is below the geometric mean of regional values (270 mg/kg) reported by Tidball (1984). Note that Deul's Mountain will have been removed and packaged in shipping containers for disposal off-Site by the time this Report is published. Fluoride was not measured in the groundwater because the subsurface soil fluoride data was present in localized areas, suggesting that migration via groundwater is probably minimal.

A number of metals were not detected above reporting limits in the surface water samples. These include antimony, beryllium, cadmium, selenium, silver, thallium, and mercury. The only Site surface water sample which contained metals at levels suggesting contamination was SW-01-SW collected from the Site Pond (AOC #2). Surface water samples from the Northeast Site Creek and Joachim Creek were not contaminated with any of the inorganics.

Some of the inorganics are elevated in a number of sediment samples from the Site Pond, Site Creek, and Northeast Site Creek. Highest concentrations were measured in SW-06-SS from the Site Pond. This sample had the highest mercury result (1.1 mg/kg), highest aluminum result (13,000 mg/kg) and is one of the two highest samples in iron and manganese. These data suggest either an accumulation zone where
Oxyhydroxides of aluminum, iron, and manganese have scavenged metals from the surface water or where some metal scrap may be present. With the exception of SW-15-SS, which was collected near the bridge on Joachim Creek, concentrations of inorganics in sediment samples from Joachim Creek are comparable to the upstream and site-specific background concentrations (Table 4.12). The elevated metals concentrations from the sediment sample near the bridge across Joachim Creek may be due to use of this area as an adhoc household dumping site.

Although some metals are present in the Site sediments, the data from the surface water suggests that there is minimal to no migration of inorganics through the surface water at the Site.

A majority of the surface soil samples that had elevated metals concentrations relative to Site and regional background values were collected from the Evaporation Ponds area (AOC #4), and outdoor areas adjacent to buildings (AOC #8).

Data from subsurface soil samples suggest low-level metals contamination in two locations: under one of the process buildings (BD-02, under Bldg. 253, AOC #6) and next to the Site Pond (SW-02). Most of the remainder of the highest results were sporadically distributed and not indicative of significant contamination.

The following metals were not detected above reporting limits in any of the groundwater samples: antimony, beryllium, mercury, and silver. The other metals were detected in groundwater samples mostly from wells installed under the buildings (AOC #6) and Burial Pits (AOC #3). Because the elevated metals concentrations in the groundwater are localized, this suggests that groundwater migration of inorganics is limited and not as extensive as that of chlorinated solvents. There was no indication of metals contamination in the bedrock groundwater.

### 6.2.2 Radionuclides

Surface water and sediment data from the Site Pond indicate elevated uranium activity relative to upstream values. A limited amount of discharge into the Site Pond from the outfalls is allowed by the NPDES permit (refer to Figure 1.2 for outfall locations). Uranium activities both in surface water and sediment decrease in the Site Creek downstream of the Site Pond dam.

Uranium activities in the surface water and sediment samples from the Northeast Site Creek are slightly elevated relative to the upstream samples (Appendix H.7 and H.9 for data). The data suggests that uranium known to be present in the Burial Pits based on disposal records (Sect. 1.4) has had a minimal impact on the Northeast Site Creek that runs adjacent to the Burial Pits area.

Uranium activities in surface water and sediment samples from Joachim Creek are comparable to upstream values.

The highest uranium activity in surface soil was measured in samples collected from the Deul's Mountain area (AOC #13). In addition, most of the surface soil samples potentially contaminated with uranium were collected from the Evaporation Ponds (AOC #4) and outdoor areas adjacent to buildings (AOC #8), Red Room Roof Burial Area (AOC #11), in the Pipeline area (AOC #10), near the Site Pond (AOC #2), and the Cistern Burn Pit Area (AOC #14).

Subsurface soil data indicate that shallow subsurface soil samples associated with the process buildings (AOC #6), the Site Pond (AOC #2) and a low-lying area where drainage from the Site collects, and DM-02 collected at Deul’s Mountain show significant uranium contamination.
The RI groundwater data suggest that uranium has not migrated to the same extent as the chlorinated VOCs, and the elevated activities are present in the overburden groundwater in localized areas within the Facility. These areas include: Deul's Mountain, the Burial Pits Area, the Evaporation Ponds and under the process buildings. The groundwater data from the bedrock wells do not indicate uranium contamination in the bedrock formations underlying the Hematite Site. The potential for downward migration may exist, but retention in surface soils of uranium by adsorption appears to dominate.

$^{99}$Tc was not detected in any of the surface water samples from the Site (Sect. 4.3.1).

$^{99}$Tc was detected in the sediment samples from the Site Pond, but activities decreased significantly in the Site Creek sediments. $^{99}$Tc was not detected in any of the surface water or sediment samples from the Northeast Site Creek and Joachim Creek.

The highest $^{99}$Tc activities in surface soils were in samples collected near the Evaporation Ponds (AOC #4), outdoor areas adjacent to buildings and the limestone storage area (AOC #6, AOC# 7, AOC #8).

$^{99}$Tc activities detected in a number of subsurface soils were generally lower than concentrations found in surface soils. The significantly lower concentrations in the subsurface suggest that although downward migration of $^{99}$Tc is occurring, most of the mass is retained in the surface soils.

$^{99}$Tc activity was only detected in the overburden groundwater in localized areas in the Facility including the Evaporation Ponds (AOC #4), under the buildings (AOC #6), in the Leach Field Area (AOC #5), and in outdoor areas adjacent to buildings (AOC #8). Similar to uranium, $^{99}$Tc has not migrated in the groundwater to the same extent as the chlorinated solvents.

$^{232}$Th was not detected in any of the surface water or sediment samples from the Site. The RI also included sample collection and analysis for radium isotopes and for $^{237}$Np, $^{241}$Am, and for plutonium isotopes. There was no evidence of contamination from these species.

6.2.3 Organics

With the exception of infrequent, low concentrations of PCE and TCE at several locations along Joachim Creek, there is no surface water contamination at the Site.

The only elevated organics in sediment samples above reference levels was observed for a variety of PAHs. A number of PAHs were also commonly found in on-Site surface soil samples. Dioxins, PCBs, and petroleum contamination was found in some samples.

The most significant contamination in subsurface soil is PCE and TCE. Contaminated samples appear to reflect a source area associated with the Hematite Facility and nearby disposal areas, although contaminated soils extend southeastward from the Hematite Facility toward Joachim Creek and probably reflect migration of contaminated groundwater from which sorption to soil organic matter has occurred. DNAPL was confirmed at one location under a building at the Hematite Facility based on elevated levels of PCE concentrations. A few PAHs also are common contaminants; dioxins are occasionally detected above reference concentrations.

Groundwater in the overburden and Jefferson City-Cotter bedrock formation is contaminated with VOCs; there is also contamination in groundwater from the underlying Roubidoux Formation. PCE, TCE, their degradation products, and several additional chlorinated VOCs are commonly observed. A number of locations have sufficiently elevated PCE or TCE concentrations to suggest the nearby presence of
DNAPL. PCE and TCE plumes in overburden originate at the Hematite Facility and extend southeastward toward Joachim Creek. One component of contamination in the Jefferson City-Cotter HSU has migrated in a southeasterly direction beneath Joachim Creek; a second component has migrated down dip from the Hematite Facility to the northeast toward BR-04. Deeper contamination in bedrock only has been observed in association with private wells PW-19, PW-16, and PW-06 in a residential community to the southeast of the Hematite Facility and with PW-03 located near BR-04. PW-06, PW-16, and PW-17 are no longer used as domestic supply wells, and have been converted to dual-completion groundwater monitoring wells as part of this RI.

Biological degradation of PCE and TCE is occurring at the Hematite Site, but appears not to have proceeded past the production of 1,1-DCE; cis-1,2-DCE; and trans-1,2-DCE, except in relatively few samples.

6.3 CONCEPTUAL SITE MODEL

The CSM that was developed for this RI focuses on the following key conclusions:

- Flow and transport in a southeasterly direction within the overburden is dominated by a hydraulic gradient caused by groundwater mounding under the Hematite Facility and discharge to the surface in Joachim Creek.

- With increasing depth below the surface, flow/transport directions gradually shift from southeasterly (overburden), to a blend of southeasterly and a regionally imposed northeasterly component (Jefferson City-Cotter HSU), and finally to a regional northeasterly direction (Jefferson City-Roubidoux contact zone and Roubidoux HSUs).

- Contaminant transport in all geologic units projects back to the footprint of the Hematite Facility (and surrounding disposal areas) as the ultimate source area.

Flow and contaminant migration in bedrock at the Hematite Site has potentially been impacted by pumping in deep production wells operated by the city of Festus. These wells were operational until August 2003 and caused regionally extensive drawdown in the Roubidoux Formation of up to 50 ft in the vicinity of the Hematite Site. In the residential community southeast of the Hematite Facility, a number of private wells were completed open hole, which provided a hydraulic connection between the Jefferson City Dolomite and Roubidoux Formation. Pumping of the city of Festus wells impacted contaminant distribution at the Hematite Site in several ways. First, hydraulic stresses in the Roubidoux Formation were transferred to the upper Jefferson City-Cotter Dolomite through these wells (e.g., PW-06, PW-16, and PW-19) and facilitated flow and contaminant migration in the Jefferson City-Cotter HSU from the Hematite Facility to the location of the wells. Secondly, downward flow of groundwater and contaminants in these wells spread contaminants to deeper zones at lower heads imposed by pumping of the Festus production wells.

Once the Festus wells were shut down, rebound of water levels in the Roubidoux Formation occurred rapidly and the potential for downward flow through the private wells declined. The changes in the hydrologic regime since shutdown of the Festus production wells eventually will likely eliminate future downward vertical migration of contamination once water levels stabilize in the Roubidoux Formation.

A similar mechanism is responsible for vertical migration of contaminants at PW-03.
6.4 NUMERICAL MODELING

A numerical model was constructed by using the CSM to identify hydraulic boundaries, defining a suite of five layers corresponding to the shallow and deep overburden and the three HSUs in bedrock, and establishing the geometric (e.g., thickness and orientation) and hydraulic properties for each layer. The flow model was calibrated against water level data obtained during the RI (i.e., following shutdown of the Festus wells). The principal conclusions from the modeling investigation include:

- The shallow groundwater mound underlying the Hematite Facility plays a major role in flow/transport in both layers of the overburden, as well as in the Jefferson City-Cotter HSU.

- The assignment of reasonable downhole flow rates to the open boreholes in the vicinity of PW-19 is essential for creating the observed transport to the southeast in the Jefferson City-Cotter HSU and is supportive of the CSM.

- Particle tracking suggests that contaminant transport directions for layers responding to either the locally imposed or regional flow systems can be rationalized with observed contaminant distribution patterns. Backward particle tracking from contaminated bedrock wells (BR-08-JC, BR-09-JC, and BR-04-JC) suggests that the Burial Pits are the source of contamination in these wells. Particle travel times vary depending on the location of their release points within the Hematite Facility. Particles “released” within the southwestern part of the Hematite Facility (i.e., BD-02) tend to have longer travel times towards their discharge point (Joachim Creek) when compared to particles “released” within the northeastern part of the Hematite Facility (i.e., the Burial Pits). This is due to the mounding in the northeastern corner of the Hematite Facility that causes downward migration in this area to transmissive bedrock formations that are conductive, and probably have lower porosities than the overburden.

- Contaminant transport modeling of PCE and TCE in groundwater indicates that sorption and degradation can significantly attenuate contaminant migration such that organic contaminant levels can decrease by one to two orders of magnitude within close proximity of the source areas.

- Contaminant transport modeling of uranium in groundwater indicates very limited spreading of contamination from source areas, consistent with what was observed in groundwater sample data. The site-specific partition coefficient for uranium is two orders of magnitude higher than the sorption coefficient for organics, resulting in significantly less migration for uranium in groundwater at the Hematite Site when compared to PCE and TCE.