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TECHNICAL APPROACH TO FINALIZING SENSIBLE SOIL CLEANUP LEVELS AT THE FERNALD ENVIRONMENTAL MANAGEMENT PROJECT

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WASTE MANAGEMENT'96 SUMMARY

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ABSTRACT

The remedial strategy for addressing contaminated environmental media was recently finalized for the U.S. Department of Energy's (DOE) Fernald Environmental Management Project (FEMP) following almost 10 years of detailed technical analysis. The FEMP represents one of the first major nuclear facilities to successfully complete the Remedial Investigation/Feasibility Study (RI/FS) phase of the environmental restoration process. A critical element of this success was the establishment of sensible cleanup levels for contaminated soil and groundwater both on and off the FEMP property. These cleanup levels were derived based upon a strict application of Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) regulations and guidance, coupled with positive input from the regulatory agencies and the local community regarding projected future land uses for the site. The approach for establishing the cleanup levels was based upon a Feasibility Study (FS) strategy that examined a bounding range of viable future land uses for the site. Within each land use, the cost and technical implications of a range of health-protective cleanup levels for the environmental media were analyzed. Technical considerations in deriving these cleanup levels included: direct exposure routes to viable human receptors; cross-media impacts to air, surface water, and groundwater; technical practicality of attaining the levels; volume of affected media; impact to sensitive environmental receptors or ecosystems; and cost. This paper will discuss the technical approach used to support the finalization of the cleanup levels for the site. The final cleanup levels provide the last remaining significant piece to the puzzle of establishing a final site-wide remedial strategy for the FEMP, and positions the facility for the expedient completion of site-wide remedial activities.

INTRODUCTION

The Fernald Environmental Management Project (FEMP) is nearing the conclusion of the Remedial Investigation/Feasibility Study (RI/FS) process, with Records of Decision (RODs) for all five operable units at the facility due to be completed by July 1996. With the conclusion of the RI/FS process, the attention of the facility is now being directed to the safe and efficient implementation of remedial actions.

Operable Unit 5 at the FEMP represents all of the environmental media (soil, sediment and groundwater) that have been impacted by past uranium production operations and waste disposal practices at the site. A ROD was recently issued for Operable Unit 5, completing over 10 years of intensive environmental investigations into the conditions at the site. The ROD established final cleanup levels for all of the environmental media and defined a strategy for the permanent disposal of contaminated soil and sediment in an on-property engineered facility. This paper is focused on the approach applied to finalize cleanup levels for soil; however, the methods were similar for the other environmental media. These cleanup levels and the associated waste management approach provide the last component to a comprehensive site-wide remedial strategy for the FEMP.

The strategy for finalizing these cleanup levels involved a process of consensus building with local residents, the Ohio Environmental Protection Agency (OEPA), the U.S. States Environmental Protection

Agency (EPA) and DOE, and in marrying the CERCLA decision process with the deliberations of a citizens task force formed to make recommendations on cleanup levels and final land use.

A key objective of the RI/FS decision-making process was to arrive at final cleanup levels that were protective to existing and future human and ecological receptors as well as cost effective and implementable. Characterization data collected during the RI phase of the study revealed that small changes (i.e., reductions) in cleanup levels for the principal contaminants of concern would yield large increases in projected soil excavation volumes. With these large increases in the volume of contaminated media requiring excavation, equally dramatic shifts in remedial costs were predicted. Thus, the stakes were high at the FEMP to arrive at cleanup levels for soil that satisfied stakeholder concerns regarding long-term protectiveness and were economically sensible.

BACKGROUND

The FEMP, formerly known as the Feed Materials Production Center, is a 1050-acre DOE facility located approximately 18 miles northwest of Cincinnati. The FEMP is situated in a rural setting near the village of Fernald, Ohio. The FEMP operated from 1952 until 1989 as a large-scale production facility extracting uranium from ores and ore concentrates to yield high-purity metal products in support of U.S. defense programs. During the 38-year production history of the facility over 500 million pounds of uranium metal products were shipped from the FEMP to other DOE sites across the country. In 1989, with a decline in product demand and increasing environmental concerns, production operations were permanently shut down. In August 1991 the site was officially declared closed and the facility renamed to reflect its new mission.

The topography of the area includes gently rolling uplands with steep hillsides along major streams, such as the Great Miami River. Surface drainage on the FEMP is from east to west and south into Paddys Run, with the exception of the northeast corner which drains east toward the Great Miami River. Groundwater beneath the FEMP is found in two principal geologic units: the glacial overburden (ranging in thickness between zero and 50 feet) and the sand and gravel of the Great Miami Aquifer. Groundwater occurring in the glacial overburden is considered "perched," in that it is contained within silty sand lenses residing within a low-permeability, clay-rich soil. The underlying Great Miami Aquifer is the principal drinking water supply for the region and is regulated as a sole-source aquifer under the Safe Drinking Water Act.

In December 1984 the release of approximately 200 pounds of uranium from a plant dust collector was reported to the National Response Center. This release notification focused nationwide attention on the environmental issues at the facility and produced increased oversight by the DOE, EPA and OEPA. Local residents at the site formed a watchdog group entitled the Fernald Residents for Environment, Safety and Health. The high public and political profile surrounding activities at the FEMP has remained relatively unchanged since this initial release in 1984.

The RI/FS process was initiated at the FEMP under a Federal Facility Compliance Agreement between EPA and the DOE. The work plan for the study, prepared by DOE in 1988, identified 39 site areas for investigation. To enhance implementation of the RI/FS, the 39 areas were grouped into five "operable units" by combining similar waste areas or related environmental concerns. The operable unit concept was incorporated into the April 1990 Consent Agreement between EPA and the DOE. The RI/FS and any required cleanup of specific operable units at the FEMP are guided by the Consent Agreement as amended in September 1991, and associated work plans. These documents provide procedures and schedules to ensure investigations are conducted in compliance with federal and state environmental laws. Due to confirmed contaminant releases to the environment identified during the initial stages of the RI, the FEMP was placed on the National Priorities List in November 1989.

Operable Units 1-4 are termed "source" operable units and include the former production area and associated waste management areas that were the initial points of contaminant release to the environment. Operable Unit 5 addresses all environmental media on and off the FEMP property impacted by contaminants released from the facility. Each operable unit is being managed in accordance with the schedules set in the Amended Consent Agreement, with RODs for all operable units due to be completed by July 1996.

To foster community input into the decision process, the DOE chartered the Fernald Citizens Task Force. The Task Force, which is comprised of local government officials and residents, labor leaders, FEMP employees and community leaders, focused on making recommendations to decision makers on preferred cleanup levels, waste disposition strategies and future land uses for the FEMP property. Throughout the development of the Operable Unit 5 FS and the ROD, DOE has attempted to consider the evolving deliberations of the Task Force.

The RI identified widespread contamination of surface soil, sediment and groundwater both on and adjacent to the facility as a legacy of the 38-year production mission. The RI identified over 90 contaminants of concern in the various environmental media and uranium as the predominant contaminant. The following is a brief discussion of the findings of the RI as it pertains to soil at the site. Additional information on soil contamination and the findings for other media are available within the Remedial Investigation Report for Operable Unit 5.

Contamination of surface and subsurface soils occurs within and beyond the FEMP property boundaries. The highest concentrations of uranium in surface soil were found in the former production area at the location of the scrap metal pile (greater than 8000 parts per million [ppm]). Contamination in subsurface soil appears limited to the FEMP property with levels of uranium, up to a hundred times background levels, found in soil at depths as great as 20 feet. Some of the highest subsurface contaminant levels (greater than 400 ppm of total uranium) were found near the former processing facilities where acidic uranium solutions were handled in large quantities.

Concentrations of approximately 20 ppm of uranium (about five times background) were identified in surface soil samples collected offproperty immediately adjacent to the eastern and northeastern boundary of the FEMP. Uranium was detected at above-background concentrations (generally less than two times background) in a widespread area off the FEMP property; up to 11 square miles of surface soil are projected to have been impacted at these low concentrations. The source of these low concentrations is emissions of dust particles to the atmosphere from plant stacks over the FEMP's 38-year production history.

Radium, thorium, fission and uranium activation products, and inorganic and organic contaminants were also observed in surface and subsurface soils on the FEMP property. The areas affected by these contaminants are localized, with the highest concentrations typically found in association with areas exhibiting the highest uranium concentrations.

TECHNICAL APPROACH TO ESTABLISHING CLEANUP LEVELS

As is the case at many Superfund sites, remediation at the FEMP requires the removal, treatment, and disposal of hazardous source-area materials and the cleanup of environmental media (soil and groundwater) contaminated by the migration of materials from the source areas. There is little dispute over the need to remove, treat, and/or dispose of the source materials themselves; likewise, there is little dispute over the need to restore the Great Miami Aquifer (a protected sole-source aquifer) to full beneficial use, including use as a drinking water supply. Rather, as noted by the Fernald Citizens Task Force in their deliberations, it is the cleanup of the contaminated soil that poses a difficult management problem because: 1) there are large volumes of contaminated material with associated high costs of cleanup; 2) the risk presented by contaminated soil is real but the harm is seldom imminent; 3) the technology for treating contaminated soil is often imperfect; and 4) the materials that are removed during cleanup must be disposed of somewhere and no place is eager to host them.

At the FEMP, the environmental cleanup question can be summarized as: how much contaminated soil must be removed from the site to make it acceptably safe for persons on or near it? The answer to this question is, in turn, driven by two considerations: protection of the groundwater aquifer under the site, and evaluation of risks to persons in contact with the surface soil.

In this section, the major steps in establishing safe, land-use specific, cost-effective cleanup levels for soil are described. From these levels, estimates of the volumes and areal extent of affected soil are derived for a range of potential risk levels under consideration. The volumes and areas of affected soil serve as the foundation for the development and evaluation of remedial alternatives. They are used throughout the process to judge the viability of remedial technologies and process options, as well as to size and estimate the cost for specific remedial alternatives. To develop cleanup levels that ultimately would achieve regulatory agency concurrence, DOE employed a multistep process (summarized in Figure 1) "Place Fig. 1 here" that began with the identification of a range of viable potential future land uses for the site, referred to in the FEMP's FS process as land use objectives. For each respective land use objective, the process began with the development of risk- and receptor-based preliminary remediation goals (PRGs) and ended with the identification of preliminary remediation levels (PRLs). PRLs differ from PRGs in their derivation in that PRLs consider the site-specific, naturally occurring background concentrations of the constituents. PRLs also consider analytical limits that affect the ability to detect the constituent in environmental media, and soil-based applicable or relevant and appropriate requirements (ARARs) and to be considered (TBC) criteria that establish maximum regulation-based concentration levels for the constituents in the environment. These PRLs are then used as the contaminant-specific remediation goals to develop and evaluate remedial alternatives for soil. The PRLs are adopted as legally binding final remediation levels for the selected remedy following public concurrence with the Proposed Plan and the issuance of a signed ROD by EPA and DOE. Each of the specific steps comprising this process is described in the subsections that follow.

Definition of Land Use Objectives and Associated Receptor Scenarios

A range of potential future land uses was used as the foundation for the identification, initial screening, and detailed evaluation of viable remedial action alternatives. The same potential future uses also provided the framework for identifying risk-based exposure scenarios and the hypothetical reasonable maximally exposed (RME) individuals for which land use-specific remediation levels were established.

The land use objectives were developed to take into consideration the progressive deliberations of the Fernald Citizens Task Force. The prevailing land use of the region, residential farming, was used as the point of departure for establishing the following land use objectives:

- **Land Use Objective 1** examined the viability of returning the entire on-property area to full unrestricted use following cleanup, including the potential for establishing a hypothetical family farm on any portion of the property. For this and all of the other land use objectives, affected off-property areas were examined only in context of the existing land use in the region, residential farming. A hypothetical resident farmer was, therefore; used as the target receptor for both the on- and off-property affected areas. For this this receptor, the exposure pathways considered in the setting of soil cleanup levels included: incidental ingestion; dermal contact; direct radiation; fruit and vegetable products; meat and milk products; inhalation of suspended solids; and leaching to groundwater.

- **Land Use Objective 2** provided for the establishment of an on-property, consolidated management area for contaminated soil, with unrestricted use of all remaining areas of the property. This land use objective considered the potential for establishing a hypothetical family farm, following cleanup, on any portion of the FEMP property outside the area where the contaminated materials are consolidated. A hypothetical resident farmer was used as the target receptor for the on- and off-property areas outside the consolidation area. For the consolidation area, a hypothetical trespasser is used as the target receptor. For the trespasser receptor, the exposure pathways considered in the setting of soil cleanup levels include: incidental ingestion; dermal contact; direct radiation; and inhalation of suspended solids.

- **Land Use Objective 3** also provided for the consolidation of contaminated soil in a central area, but restricted potential uses of the remaining areas of the property through the application of institutional controls. This objective considered the potential for establishing recreational, commercial/industrial, or undeveloped open space on any portion of the FEMP property outside the area where the contaminated materials are consolidated. For the hypothetical receptors that represent these land uses, the exposure pathways considered in the setting of soil cleanup levels included: incidental ingestion; dermal contact; direct radiation; and inhalation of suspended solids. For the area of consolidation, a hypothetical trespasser receptor was used in a manner similar to Land Use Objective 2.

- **Land Use Objective 4** provided for minimum consolidation of contaminated soil with access and future use of the Fernald property restricted. This land use objective contemplated maintaining the entire 1050-acre property under restricted access for waste management purposes. For this land use, a hypothetical trespasser was used to guide the development of cleanup levels, similar to the use of this target receptor for the consolidation area designated in Land Use Objectives 2 and 3.

By using the land use objectives approach to formulate remedial action alternatives, decision-makers are provided with a comprehensive but manageable array of alternatives. From this array, decision-makers are provided with the required information from which to evaluate technical site constraints, required administrative controls, and the overall cost implications of moving from totally restricted to progressively less restricted land use possibilities.

Identification of Constituents of Concern

The Operable Unit 5 baseline risk assessment evaluated constituents of potential concern (CPCs) and exposure pathways to ascertain their present and potential future impacts on human health. Not all CPCs identified in the baseline risk assessment pose significant health risks, and many need not be considered in future remedial activities. Contaminants of concern (COCs) are those constituents that remain a concern following evaluation in the baseline risk assessment process. Only those contaminants identified as posing a concern at the site need to be considered in the development and evaluation of remedial alternatives. The purpose of restricting the number of COCs is to focus on the contaminants that require implementation of remedial actions to ensure the protection of human health and the environment.

The National Contingency Plan establishes a point of departure for acceptable risk as one in a million (10^{-6}) for carcinogenic compounds, including radionuclides. The acceptable limit for noncarcinogenic effects is a hazard index (HI) of 1.0. A HI of greater than 1.0 is considered indicative of a potential toxic effect. However, because multiple contaminants are considered, the screening point for selection of COCs for the FEMP was set at an incremental lifetime cancer risk (ILCR) of 10^{-7} and an individual HI of 0.1 to the hypothetical on-property farmer to ensure no significant COCs were ignored. Any contaminant with a risk level or HI less than this screening point is not considered further. For soil contaminants, this screening point considered both direct exposure to contaminated soil as well as the potential impact to groundwater through cross-media pathways.

Using this screening process, 89 soil-based COCs were identified at the FEMP site. Based on the site's uranium-processing history, uranium was found to be the primary COC with the remaining soil COCs generally falling within the concentration-based contamination envelope represented by uranium.

Risk-Based Preliminary Remediation Goals (PRGs)

For each of the COCs discussed in the previous subsection, land-use-scenario-specific PRGs were calculated for each target receptor, using a target HI of 0.2 for noncarcinogenic effects and/or the selected target risk for carcinogenic effects (ILCRs of 10^{-6}, 10^{-5}, and 10^{-4}). The risk-based PRGs were calculated using the equations and parameters for all exposure pathways as detailed in the site's EPA-approved Risk Assessment Work Plan Addendum. The PRGs that are calculated through the process yield health-based contaminant concentration levels for surface contact-related exposure pathways that are protective at each of the target risk levels considered.

Screening of PRGs to Ensure Protection of Groundwater

For purposes of reducing the number of target risk levels and associated risk-based PRGs requiring consideration in the development of remedial alternatives, a screening process was adopted for affected soil. The premise behind this screening process was to determine the maximum uranium concentration that could reside within the soil and still ensure the continued protection of the Great Miami Aquifer (i.e., for a performance period of up to 1000 years into the future, as required by the federal Uranium Mill Tailings Radiation Control Act). For this screening process a cross-media protectiveness goal was adopted to ensure that groundwater concentrations of uranium resulting from the leaching of soil constituents to groundwater do not exceed drinking water quality requirements following completion of remedial actions.

Using a one-dimensional groundwater solute transport model (ECTran) and average hydrogeologic conditions at the site, a maximum soil total uranium concentration of 154 ppm was calculated as the upper-bound value above which undesirable groundwater impacts would be anticipated. This screening-level cross-media-based PRG (i.e., "CPRG") thus represents the upper limit from which to assess the protectiveness of the risk-based PRGs calculated in the previous step. All PRGs with a higher value than the screening-level CPRG would be dropped from further consideration.

To illustrate the results of risk-based PRG development and CPRG screening, the following table summarizes the risk-based soil PRGs for uranium for each of the receptor scenarios under consideration. The land-use specific, risk-based PRGs that fall in the shaded area of the table exceed the screening-level CPRG of 154 ppm, and thus would not be expected to be protective of groundwater at the FEMP site (and are therefore eliminated from further consideration).

	Total Uranium PRG (ppm)			
Receptor Scenario	10^{-6}	10^{-5}	10^{-4}	HI=1
RME farmer/child	1.3	13	130	44
Groundskeeper (industrial user)	12	120	1200	250
Developed park user	33	330	3300	1100
Undeveloped park user	77	770	7700	1250
Trespasser	120	1200	12000	1000

Development of Cross-Media PRGs

Following the initial screening process, a more detailed, location-specific analysis was conducted to further evaluate the potential for cross-media impacts, including impacts to media other than groundwater. Cross-media impacts occur when contaminants from waste or an environmental medium, such as soil, are transported into another medium and result in the potential for secondary exposure to a receptor. When this occurs, receptors can be exposed to these contaminants by an exposure pathway indirectly related to the contaminant source.

The PRGs that passed the groundwater CPRG screening in the previous step were evaluated further using location-specific modeling that considered actual (rather than average) hydrogeologic conditions present within 125- by 125- foot grids across the 1050-acre FEMP property. The detailed evaluation also considered the location-specific potential for contaminants to enter the air and surface water resources as well as groundwater. Reverse-modeling fate and transport simulations were used to ascertain the concentration in the source medium necessary to yield the critical concentration in the receptor medium over a 1000-year performance period.

The results of the simulations were used to further screen the risk-based PRGs to those that are fully protective through both direct contact and indirect (i.e., cross-media) exposure routes. To facilitate the development and presentation of PRGs for soil which could be implemented in the field as part of a remedial action, the mapping of the common physical attributes of the FEMP property discussed above were simplified into three zones, established on the basis of similarities in the hydrogeologic and geochemical characteristics of the soil. The most restrictive physical and geochemical conditions and the controlling transport pathway within each of the individual zones were applied to the entire zone for each individual COC. The derived CPRGs for each of these zones were then arrayed and the most restrictive value identified for each COC was considered. Finally, for uranium, the simulations also considered the varying leaching potentials of the several geochemical forms of uranium that exist in the FEMP environment. The limiting values derived from the evaluations were then used in the development of modified PRGs that fully consider cross-media impacts to groundwater, surface water, and air.

For uranium, the principal COC at the site, the results of the detailed CPRG evaluations indicated the need to further adjust downward the risk-based PRGs developed in the previous step. The simulations indicated that in those areas where more-leachable uranium species are present (primarily in the 135-acre former processing area at the site), a maximum allowable soil concentration of 20 ppm total uranium is necessary to fully protect the Great Miami Aquifer over the full duration of the 1000-year simulation period. In the remaining areas of the site where less-leachable uranium species are present, a maximum allowable soil concentration of 100 ppm total uranium is necessary to fully protect surface water resources in the site area, and ultimately to protect the aquifer from surface water infiltration. Therefore, the 20 ppm and 100 ppm CPRG values provide thresholds that the risk-based PRGs cannot exceed and remain protective of the aquifer.

Identification of Chemical-Specific ARARS and TBCs

CERCLA does not provide for one set of cleanup criteria for universal application to waste sites, but requires that sites attain, or seek a waiver of, federal and state environmental laws and regulations (i.e., ARAR), and meet the intentions of other pertinent considerations (TBCs). Therefore, in addition to meeting the risk-based remediation levels established for each land use objective, all the viable alternatives must satisfy ARARs specified in federal and state environmental laws and regulations. Over 100 individual ARARs and TBCs were identified that affect the design and implementation of the cleanup at the FEMP. However, the primary ARARs for soil are:

- State of Ohio siting criteria for solid waste disposal facilities
- Resource Conservation and Recovery Act requirements for treatment of contaminated media and the design of engineered containment facilities
- State of Ohio rules for control of particulate emissions and dust
- Uranium Mill Tailings Radiation Control Act regulations regarding the management of materials at inactive uranium processing facilities.

Most of the identified requirements address the design and execution of the remedial alternatives, rather than specifying specific concentration-based cleanup levels for soil. The ARARs also govern the handling of residual materials that may be generated during treatment processes.

Establishment of Modified PRGs

Modified PRGs represent an intermediate product in the derivation of PRLs. They are established for each COC by comparing, for the land use scenario and risk level of interest, the risk-based PRGs with available ARARS/TBCs and the appropriate CPRGs, and then selecting the lowest of the values. At this juncture, the lowest value is termed a modified PRG and is carried forward to the next step.

Establishment of COC Background Levels

For each of the naturally occurring and anthropogenic COCs that are present at the FEMP, the 95th percentile of the background distribution of the COC in environmental media was determined through a statistical analysis of contaminant concentration data gathered as part of the Operable Unit 5 RI. These background concentrations were used in the development of PRLs primarily when the modified PRGs fell below the background concentrations.

For uranium, the FEMP's key COC, a 95th percentile background concentration in soil of 3.7 ppm was established.

Analytical Detection Limit Considerations

The final element in the development of PRLs was the establishment of the lowest reasonable and achievable analytical detection limits for the 89 soil COCs. These detection limits were used in the PRL development process for those COCs with modified PRGs that fell below analytical detection limits. The detection thresholds were based on experience at the FEMP regarding actual instrument detection limits reported by subcontract laboratories for requested analyses at analytical support levels C and D. For soil, a 25 percent moisture content was assumed in the detection level development; for sediment, a 60 percent moisture content was assumed.

Development of PRLs

PRLs differ from modified PRGs in that PRLs consider the practicality of obtaining and verifying the attainment of a remediation goal. This differentiation is important to allow the development of cost-effective alternative remedial actions.

PRLs for nonradiological COCs were developed in a two-step process. First, all modified PRGs were reviewed against the routinely achievable analytical detection limits. For PRGs below this limit, the analytical detection limit was substituted as the PRL. Next, the modified PRGs were compared to background concentrations in the local environment. In the event the modified PRG was less than the 95th percentile of the background distribution for that constituent, the PRL was considered indistinguishable from background concentrations and the target PRL was set at the 95th percentile background value.

Based on EPA Region 5 policy, a slightly altered approach to developing PRLs for radiological constituents was adopted. First, the 95th percentile background concentration was added to the modified PRG. This value was then compared to the analytical detection limit and the higher of the two values was adopted as the PRL. In two instances background was not added to the modified PRGs for radiological COCs to derive PRLs: if the modified PRG was based directly on an ARAR/TBC or if the modified PRG was based upon a CPRG derived on the basis of attaining an ARAR/TBC in the aquifer.

Estimation of Excavation Area Footprints and Volumes of Contaminated Soil

In order to estimate the volume of contaminated soil at the FEMP site requiring excavation, a solid block model of the top 30 feet of soil was developed. The model consisted of a three-dimensional representation of the FEMP extending to a depth of 30.5 feet. The total model volume was divided into discrete volumes, or solid blocks. Subsurface blocks represented a volume of soil 125 feet by 125 feet by 1 foot deep. Surface soil blocks were 6-inches deep to support a more refined estimate of contaminated soil at shallower depths where contamination is more prevalent.

The solid block model was based upon the results of soil samples collected from various locations and depths across the FEMP site. These sampling results provided uranium concentrations only at the point from which the samples were collected. A geostatistical analysis technique known as kriging was used to establish contaminant concentrations between sampling locations at the center of each model block.

The kriging program employed an ellipsoidal search, using a distance of 16 feet in the vertical direction and 275 feet in the horizontal direction. In other words, when estimating the concentration of uranium within a block, the model searched 16 feet in the vertical direction and 275 feet in the horizontal direction for sampling points with which to establish a spatial relationship for calculation of the contaminant concentration within a block. If no sampling points were found within the search ellipsoid, no estimate of concentration was made for that block.

The resulting uranium concentrations from kriging the solid block model were used to estimate the soil volumes above the maximum contaminant level that require excavation. Furthermore, since the average concentration in each block was known, the excavated soil could be classified as to its ultimate disposition.

Proposed remediation areas (referred to as footprints) and volumes of affected media were estimated for those actions required to achieve each of the four land use objectives over a range of potentially viable PRLs. The PRLs considered under each of the land use objectives were developed to bound the range of potential cleanup levels deemed practical for the site. Volume estimates were performed for a total of nine cases.

A summary of the relationship between uranium soil concentration and affected soil volume is presented in Figure 2. "Place Fig. 2 here"

FORMATION AND EVALUATION OF REMEDIAL ALTERNATIVES

There were many remedial technologies and process options initially considered for the cleanup of each of the affected media at the FEMP site. Arraying these process options together produced in excess of 2000 remedial alternatives that could be applied at the site. Using the four land use objectives as a guide, 10 viable remedial alternatives were identified from the long list for further consideration in the initial screening step of the FS. The alternatives were first compared with one another to identify meaningful differences and then evaluated with respect to implementability, effectiveness, and cost. Only the alternatives judged as most promising on the basis of these evaluation factors were retained for further consideration and analysis. The screening process resulted in the selection of seven remedial alternatives that were sufficiently distinct, yet potentially implementable and effective. Each of the seven alternatives, along with the no-action alternative, is listed below (the number accompanying the alternative corresponds to its land use objective):

- **No-Action Alternative** — This alternative was retained to provide a baseline for comparison in accordance with regulatory requirements.

- **Alternative 1 — Excavation and Off-Site Shipment** - Under this alternative, soil with contamination exceeding final remediation levels would be excavated and shipped to an off-site licensed disposal facility. Excavated areas would be regraded to reach a predetermined final surface grade that would allow for use of the property as a family farm. Two differing remediation levels were considered; the first case had as an objective the protection of future receptors (in this case a hypothetical on- and off-property farmer) at an ILCR of 10^{-6} and a HI of less than 1.0. The second case was designed to provide protection to these same receptors at a 10^{-5} level and a HI of less than 1.0. This alternative would result in the excavation and off-site disposal of 9.6 million cubic yards of soil (10^{-6} risk level) at a present worth cost of $4.2 billion, and 2.7 million cubic yards (10^{-5} risk level) at a present worth cost of $1.1 billion. At the 10^{-6} risk level, approximately 11 square miles of off-property farmland would be disturbed for remedial purposes, and approximately 1 square mile at the 10^{-5} risk level.

- **Alternative 2A — Engineered Disposal Facility** - Under this alternative, a consolidated waste management area would be established and the remaining areas of the property would be made available for unrestricted use. Contaminated soil exceeding final remediation levels would be excavated and placed in an engineered above-grade disposal facility. The facility would be situated in an on-property area displaying the best available geologic conditions. Contaminated soil not meeting waste acceptance criteria for the facility would be shipped to an off-site licensed disposal facility, unless a more economical technology emerged that was deemed more prudent to apply to this soil to attain the acceptance criteria. As in Alternative 1, two different remediation levels were considered for the area outside the disposal facility and for the off-property area: ILCR levels of 10^{-6} and 10^{-5} for a hypothetical on- or off-property farmer, and HI values less than 1.0. For all COCs, the waste acceptance criteria for the disposal facility were set at values that would protect neighboring populations and the drinking water quality of the Great Miami Aquifer for a performance period of up to 1000 years. This alternative would result in the excavation and disposal of 9.6 million cubic yards of soil (10^{-6} risk level) at a present worth cost of $2.1 billion, and 2.7 million cubic yards (10^{-5} risk level) at a present worth cost of $560 million. At the 10^{-6} risk level, approximately 11 square miles of off-property farmland would be disturbed for remedial purposes, and approximately 1 square mile at the 10^{-5} risk level.

- **Alternative 2C — Consolidation with Off-Site Shipment** - Under this alternative, contaminated soil exceeding remediation levels would be excavated and, depending on contaminant concentration levels, dispositioned either in an on-property earthen-covered, revegetated consolidation area or at an off-site licensed disposal facility. Two risk and cleanup levels, consistent with the receptor scenarios of Alternative 2A, were evaluated for this alternative. The waste acceptance criteria for the consolidation area would be established to ensure protection of neighboring populations and the underlying Great Miami Aquifer, and the consolidation area would be managed as an off-limits area to the public. This alternative allows a direct comparison of the cost of off-site shipment to the cost of on-site disposal in an engineered disposal facility (Alternative 2A). This alternative would result in the excavation and disposal of 9.6 million cubic yards of soil (10^{-6} risk level) at a present worth cost of $4.2 billion, and 2.7 million cubic yards (10^{-5} risk level) at a present worth cost of $750 million. At the 10^{-6} risk level, approximately 11 square miles of off-property farmland would be disturbed for remedial purposes, and approximately 1 square mile at the 10^{-5} risk level.

- **Alternative 3A — Engineered Disposal Facility** - This alternative is identical in concept to Alternative 2A, except the area outside the disposal area footprint is made available for restricted (nonresidential and nonfarming) land use. The alternative considers use of the on-property area for commercial/industrial, developed park, and undeveloped park land uses, and a 10^{-6} risk level for these on-property, nonfarming land uses was used to guide the analysis of this alternative. For the off-property area, two risk levels were considered: an ILCR of 10^{-5} for the residential farmer (consistent with Alternatives 1, 2A, and 2C above) and an ILCR of 3.5×10^{-5} for the residential farmer, which corresponds to a HI set at its maximum permissible value of 1.0. This alternative would result in the excavation and disposal of soil ranging from 2.4 million cubic yards (industrial land use paired with a 10^{-5} ILCR for the off-property residential farmer) at a present worth cost of $530 million, to 1.8 million cubic yards (undeveloped park land use paired with a HI of 1.0 for the off-property residential farmer) at a present worth cost of $420 million. At the 10^{-5} risk level for the off-property area, approximately 1 square mile of farmland would be disturbed for remedial purposes, and approximately 1 acre or less would be disturbed at the HI = 1.0 risk level.

- **Alternative 3C — Consolidation with Off-Site Shipment** - This alternative is identical in concept to Alternative 2C, except for the changes in land use and the receptor scenarios described for Alternative 3A. The same quantities of soil would require excavation as in Alternative 3A; however, the costs resulting from the need for off-site disposal in this alternative would range from $720 million (industrial land use example) to $610 million (undeveloped park land use example).

- **Alternative 4A — Engineered Disposal Facility** - This alternative is identical in concept to Alternative 2A, except the area outside the disposal area footprint is not made available for productive use following remediation; i.e., the entire 1050-acre site is rendered off-limits to the general public. For this alternative, a trespasser receptor scenario (at an ILCR of 10^{-6}) is used to guide the development of cleanup levels. For the off-property area, the same risk levels for residential farming as described under Alternatives 3A and 3C were used. This alternative would result in the excavation and disposal of soil ranging from 2.2 million cubic yards (trespasser scenario paired with a 10^{-5} ILCR for the off-property residential farmer) at a present worth cost of $450 million, to 1.8 million cubic yards (trespasser scenario paired with a HI of 1.0 for the off-property residential farmer) at a present worth cost of $420 million.

- **Alternative 4C — Consolidation with Off-Site Shipment** - This alternative is identical in concept to Alternative 2C, except for the changes described above for Alternative 4A. The same quantities of soil would require excavation as in Alternative 4A; however, the costs resulting from the need for off-site disposal would range from $640 million (using a 10^{-5} ILCR for the off-property area) to $620 million (using a HI of 1.0 [3.5×10^{-5} ILCR] for the off-property area).

IDENTIFICATION OF LEADING ALTERNATIVE AND SITE-WIDE RISK ANALYSIS

Of the five operable units at the FEMP, Operable Unit 5 is chronologically the fourth to identify and issue a preferred remedy for the site. Each of the operable units is expected to provide a progressive evaluation of the projected site-wide remedy, using the best available information at the time, to predict the acceptability of postremediation conditions. This projected site-wide remedy incorporates the selected (identified in a ROD), preferred (identified in a Proposed Plan), or leading remedial alternative for each operable unit, as appropriate. The intent of the analysis is to progressively monitor the interfaces among the operable units to ensure that the final site-wide remedy is well thought out, cost effective, and ensures the long-term protection of human health and the environment. The site-wide risk analysis that accompanies the evaluation, termed a Comprehensive Response Action Risk Evaluation (CRARE), also provides for a comprehensive assessment of the impact of multiple carcinogenic and noncarcinogenic compounds, multiple exposure pathways, and the incremental risks due to background levels of contaminants on human health. To conduct the risk analysis of the adopted site-wide remedy, a hypothetical undeveloped park user was the target on-property receptor.

The results of the risk analysis indicate that the adopted site-wide remedy would result in a 90.7 percent reduction in carcinogenic risk to an undeveloped park user of the Fernald property following remediation. Of the carcinogenic risk projected to remain following remedy implementation, 80 percent is due to the presence of naturally occurring background constituents. The estimated residual carcinogenic risk from all constituents and pathways, inclusive of natural background risk, is estimated to be 2.1×10^{-5} following remediation. Similarly, the risk analysis projects a 96.5 percent reduction in noncarcinogenic health effects (i.e., HI) for the undeveloped park user following implementation of the site-wide remedy. Naturally occurring background constituents will account for approximately 69 percent of this residual noncarcinogenic risk. The residual HI from all constituents and pathways, inclusive of natural background contributions, is estimated to be 0.059.

OVERVIEW OF THE SELECTED REMEDY AND CORRESPONDING CLEANUP LEVELS

In conjunction with the Fernald Citizens Task Force recommendations, DOE, EPA, and OEPA selected Alternative 3A, excavation of contaminated soil and placement in an engineered on-property engineered disposal facility, as the preferred remedy for contaminated soil at the FEMP site. This alternative was selected because it provides a remedy that is reliable over the long term, yields the lowest overall short- term risks, is less costly when compared to the other alternatives, and employs proven technologies which are implementable.

During the solicitation of community and stakeholder input for the remedy decision, it became clear that virtually no stakeholders or members of the public were interested in seeing the on-property area of the FEMP site returned to residential farming following remediation. From this basis, and on the recommendations of the Fernald Citizens Task Force, DOE, EPA, and OEPA collectively agreed to adopt Land Use Objective 3 (i.e., the restricted, nonfarming land use objective) for the setting of on-property cleanup levels. Individual constituent PRG values for the undeveloped park receptor were then set at an ILCR of 10^{-6} and a HI of 0.2, recognizing that at these target values other nonforming land uses (commercial, industrial, developed park, etc.,) would be possible for the site while meeting the corresponding land use-specific risk range targets (1×10^{-4} to 1×10^{-6} ILCR and HI=1) considered acceptable by EPA in the National Contingency Plan. PRLs were therefore developed for the selected remedy from this PRG target risk level, using the sequence of steps outlined in this paper. As indicated by the CRARE evaluation, the individual constituent PRLs are fully health protective when considered collectively from a multiple constituent/multiple exposure pathway perspective. These PRLs also protect the Great Miami Aquifer from cross-media transport pathways.

For the affected off-property area, all parties agreed that a residential farming land use scenario should guide the selection of cleanup levels, as this is the predominant land use in the area. It was agreed that the cleanup levels should not exceed a 10^{-4} ILCR level or a HI of 1 for any site contaminant present outside the FEMP property boundary. Because uranium is considered to be the only site-related constituent in soil that resides outside the property boundary, the cleanup level was set at 50 ppm (inclusive of background), which corresponds to a HI of 1.0 and an ILCR of 3.5×10^{-5}. The most striking consideration in selecting this level was the volume of soil that would require excavation beyond the FEMP property boundary if a 1×10^{-6} residential scenario were chosen: a total of 5,200,000 cubic yards of soil would be removed and up to 11 square miles of farmland would be disturbed, with considerable loss of vital topsoil. The tradeoffs to achieve a 10^{-6} risk level were found by all parties to be disproportionate to the benefits achieved. A key ingredient to the stakeholders' understanding of the tradeoffs and benefits of the various cleanup levels under consideration was the highly successful public-forum deliberations and presentations conducted by the Fernald Citizens Task Force.

Summary of Key Accomplishments

The strategy for establishing health-protective soil cleanup levels, as outlined in this paper, has led to a cost-effective, environmentally sound approach to site remediation at the FEMP. Most notably, through the cross-media impact considerations adopted in this strategy, the site's top environmental priority -- the long-term protection of the Great Miami Aquifer -- will be realized, resulting in the unrestricted availability of groundwater from the aquifer for the foreseeable future following the cessation of remedial operations. Recognition and ultimate achievement of this priority remains absolutely critical to maintaining the outstanding public stakeholder support for the remedy that is currently enjoyed by the FEMP.

By shipping the most contaminated soil off site, and keeping the lightly-contaminated materials on site in an engineered disposal facility, the remedy represents a balanced, fair approach to site remediation. It is estimated that this element of the remedy, in conjunction with the realistic cleanup levels that were selected, results in a cost savings of over \$3.6 billion when compared to the cost impacts of adopting the most stringent cleanup levels (i.e., those corresponding to a 10^{-6} incremental lifetime cancer risk) and adopting a full offsite shipment and disposal alternative. The selected cleanup levels also eliminate the need for significant physical disturbance to off-property wetlands, habitats, cultural resources, natural vegetative communities and cultivated croplands. Over 11 square miles of off-property disturbance to such resources would be required to achieve a 10^{-6} incremental lifetime cancer risk, which in the view of the Fernald decision team represents only a marginal improvement in an already acceptable set of off-property risks that exist under current conditions. Removal of soil to the 10^{-6} level would remove tremendous quantities of topsoil from currently productive agricultural lands.

The soil cleanup levels that were established through the process are each individually health-protective, satisfy ARARs, consider the incremental health risks attributable to naturally occurring background concentration levels, and, when considered collectively through all exposure pathways, fall within the acceptable risk range required for CERCLA sites by EPA's National Contingency Plan regulations. By arriving at the selection of these levels in an open public forum, in concert with the deliberations of the Fernald Citizen's Task Force, citizen trust and understanding of DOE's top cleanup objectives and priorities was gained. DOE cannot be successful at Fernald — or anywhere else for that matter — without the continuing dialogue and understanding that was displayed among the various stakeholder groups during the Operable Unit 5 remedy selection process.

As the final chapter in the effort, the PRLs that were developed through the Operable Unit 5 FS became legally binding final remediation levels in January, 1996, when the ROD for Operable Unit 5 was signed. This ROD brought to completion the 10-year RI/FS process for addressing environmental impacts at the FEMP site, and set in motion a comprehensive remedial design and construction program to aggressively implement the successful remedy decisions reached collectively and cooperatively by the decision team.

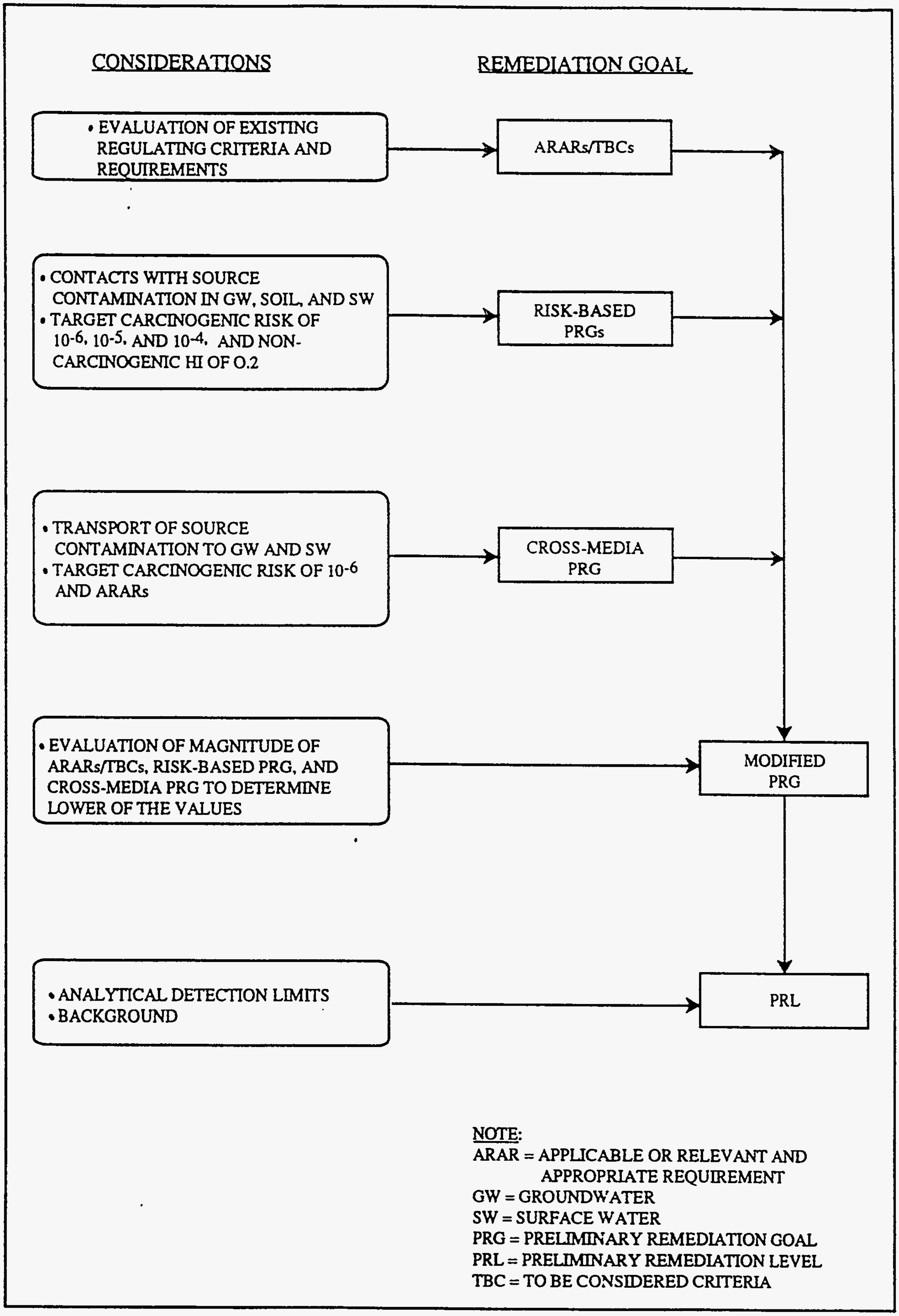

FIGURE 1. REMEDIATION LEVEL DETERMINATION PROCESS

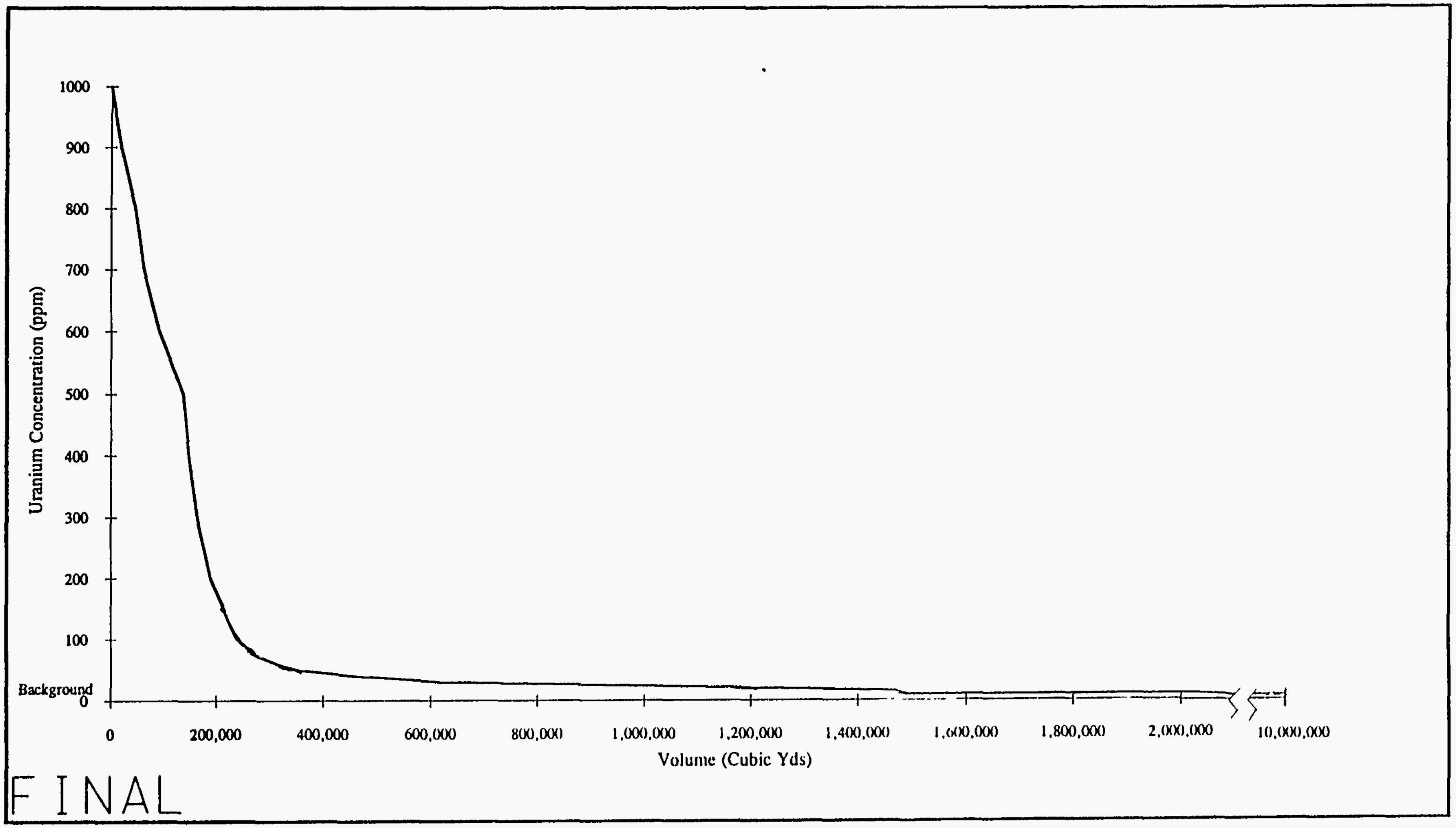

FIGURE 2.

COMPARISON OF AFFECTED SOIL VOLUME FOR VARIOUS URANIUM SOIL CONCENTRATIONS