WORKPLAN

EVALUATION OF LICENSED MATERIALS MIGRATION VIA GROUNDWATER PATHWAYS

CUSHING, OKLAHOMA REFINERY SITE

Kerr-McGee Corporation

Oklahoma City, Oklahoma

and

Grant Environmental, Inc.

Englewood, Colorado

CONTROLLED DOCUMENT

Date: November 12, 1996

Signature:

October 1996

TABLE OF CONTENTS

TABLE OF CONTENTS
(continued)

LIST OF TABLES

LIST OF FIGURES

1. INTRODUCTION

Kerr-McGee Corporation (KMC) owns a closed refinery facility (Site) approximately two miles north of the City of Cushing, Oklahoma, as shown in Figure 1. A portion of the Site was occupied by a facility licensed for the production of radioactive materials for industrial use. During operating and subsequent years, radiologically contaminated waste was placed in several locations on the Site. In 1990, Kerr-McGee entered into a consent order with the Oklahoma State Department of Health (now the Oklahoma Department of Environmental Quality, or ODEQ) to clean up the refinery site. The consent order addressed both the radiological and non-radiological (refinery-related) cleanup of the Site. In 1993, Kerr-McGee received license SNM-1999, issued by the U.S. Nuclear Regulatory Commission (NRC), to decommission the Site radiologically.

Radiological surveys of the Site conducted since 1990 have identified 16 areas where decommissioning may be required. These areas have been designated Radioactive Materials Areas, or RMAs. Knowledge about the disposal history of the RMAs indicates that only three of the 16 might contain contamination that could affect groundwater.

This workplan was developed to assess the possible impact to groundwater from licensed radioactive materials present in all 16 RMAs. The workplan describes actions planned to complete the radiological groundwater assessment, including:

- Evaluation of historical radiological groundwater data,
- Determination of background radiological groundwater quality,
- Soil sampling to identify possible impact to groundwater from some RMAs,
- Installation of groundwater monitoring wells where impact to groundwater from licensed materials is suspected,
- Sampling and analysis of groundwater from selected monitoring wells, and
- Evaluation of groundwater quality data to determine impact where present.

The first step in this groundwater evaluation, evaluation of historical radiological groundwater data, is included in this workplan. The rest of the steps listed above will be performed after ODEQ and NRC approve this workplan. Upon completion of all field work, analysis, and data evaluation, a report will be prepared describing the work performed and presenting the results of the groundwater evaluation.

2. REGULATORY CRITERIA

There are no regulatory criteria that dictate the scope of the groundwater evaluation. However, federal and state regulations do identify groundwater information that is pertinent. The federal regulations establishing maximum contaminant levels (MCLs) for community water systems are contained in 40 CFR 141.15 and 141.16. Oklahoma promulgates MCLs in Oklahoma Administrative Code (OAC) 785:45-7-2(a)(2)(B). Pertinent MCLs are:

- The MCL for radium-226 and radium-228 (combined total concentration) is 5 picoCuries per liter (pCi/l);
- The MCL for gross alpha particle activity (including radium-226, excluding radon and uranium) is 15 pCi/l; and
- For beta particle and photon radioactivity (from man-made radionuclides), the annual dose equivalent to the total body or any internal organ is not to exceed 4 millirem per year (mrem/yr).

Additional pertinent information is contained in the August 22, 1994 "Proposed Rule on Radiological Criteria for Decommissioning" (59 FR 43220). The proposed rule includes the following criteria regarding groundwater quality at decommissioned facilities.

- Residual radioactivity will not cause exceedance of MCLs (40 CFR 141) in current or potential drinking water sources.
- Residual radioactivity, as distinguishable from background, will not result in a total effective dose equivalent (TEDE) exceeding 15 mrem/yr.

3. BACKGROUND EVALUATION

This section summarizes groundwater information currently available for the Site. Much of this information is presented in greater detail in the Phase I Remedial Investigation Report and other reports. Referenced reports are listed in Section 6. This section also discusses background water quality, and describes the rationale for determining background water quality.

3.1 REGIONAL HYDROGEOLOGY

The regional geology of the Cushing, Oklahoma, area is typified by alternating sequences of mudstones and shales with thin sandstone and limestone lenses. Approximately 2,200 feet of late Pennsylvanian and early Permian rock underlie the region, with Pennsylvanian carbonates and shales forming the majority of the bedrock found directly beneath the unconsolidated surface soil.

Groundwater is present in near-surface alluvium and unconsolidated soil, water-bearing sandstones and limestones within the Vanoss Group, and the deeper Vamoosa-Ada aquifer. The most favorable areas for groundwater development are the alluvial floodplains and terraces of the major rivers and larger tributaries. Groundwater also is obtained from wells screened in sandstone and limestone zones within the Vamoosa-Ada aquifer. Regionally, groundwater flow is likely down-dip to the west, however, local influences might alter this general flowpath.

Groundwater chemical data for the unconsolidated soil and Vanoss Group were collected as part of the Phase I Remedial Investigation. These water-quality samples were collected hydraulically up-gradient from the RMAs, and are presumed to be similar to regional water quality. These data are discussed later in this section.

3.2 SITE HYDROGEOLOGY

3.2.1 Site Geology

The surface of the Site is underlain by unconsolidated materials, which are underlain by the Vanoss Group. The Vanoss is underlain by the Ada Group and then the Vamoosa Formation, which are collectively referred to as the Vamoosa-Ada aquifer.

3.2.1.1 Unconsolidated Soil

The soil beneath the Site is residual, derived primarily from weathering of the underlying mudstone and shale bedrock. Limited areas of alluvial materials are present along Skull Creek and its tributaries. Soil typically is 10 feet or less thick, and has been

significantly disturbed by cut and fill activities related to past oil refining, such as the construction of tank dikes, roads, buildings, and drainages.

3.2.1.2 Vanoss Group

The Vanoss Group beneath the Site typically is composed of thick beds of reddish-brown mudstone with interbeds of siltstone, shale, sandstone, and limestone. The sandstone interbeds occur as discontinuous lenticular bodies within the mudstone and shale matrix of the Vanoss Group. Borings at the Site indicate the sandstone bodies range in thickness from 0.5 to 12 feet. The limestone interbeds occur as thin and discontinuous, competent stringers. Borings at the Site indicate the limestone bodies range in thickness from 0.5 to 5 feet (Burns & McDonnell Waste Consultants, Inc., 1993).

3.2.1.3 Vamoosa-Ada

The Vamoosa-Ada aquifer is the uppermost continuous aquifer at the Site. The aquifer consists of a sequence of fine- to very fine-grained sandstones, siltstones, shales, and conglomerates. The top of the Vamoosa-Ada is about 175 feet below ground surface beneath the north part of the Site. Typically, the uppermost 80 feet of the aquifer is comprised of sandstone.

3.2.2 Site Groundwater

There are three hydrogeologic zones: the unconsolidated soil and the upper portion of the Vanoss Group, the lower portion of the Vanoss Group, and the Vamoosa-Ada aquifer.

The uppermost water-bearing zone in the area is in the unconsolidated soil and the upper portion of the Vanoss Group. Previous reports indicate that up to 20 to 30 feet of the Vanoss Group mudstone is hydraulically connected to the unconsolidated soil. Monitoring wells screened in these upper zones indicate that the water levels are less than 10 feet below the ground surface. A potentiometric surface map has been developed using data from shallow wells, and is included in Figure 2. Estimates of the direction and hydraulic gradient of groundwater movement used in this workplan are determined from this map.

Groundwater movement in the uppermost water-bearing zone is a reflection of the Site topography. Recharge occurs along the crests and flanks of topographic highs, and the shallow groundwater discharges to Skull Creek and its tributary drainages.

The hydraulic gradient in the unconsolidated soil and upper Vanoss Group varies because of changes in the hydraulic conductivity of the upper zone, and local topographic and cultural features that alter the natural groundwater regime. Altered tributaries and drainage channels, pit excavations and ponds, and the french drain west of Pit 5 are man-made influences that affect the groundwater flow.

The lower portion of the Vanoss Group is a hydrogeologically complex unit. Wells installed in this zone show widely different piezometric levels, depending on whether the well is screened in a more permeable or less permeable zone. Piezometric measurements in the lower Vanoss Group suggest large vertical gradients in isolated areas. Flow direction and gradients are difficult to extrapolate. Groundwater movement in the lower portion of the Vanoss Group is influenced by the orientation of the more hydraulically conductive lenses of sandstone and limestone within the mudstone. The discontinuous nature of these lenses contributes to the complex groundwater flow in this unit. Regionally, groundwater flow is likely down-dip, to the west.

The Vamoosa-Ada aquifer is the regional groundwater regime beneath the Site. Groundwater movement in the Vamoosa-Ada is controlled by large-scale recharge and discharge conditions that are not influenced by the Site. Age-dating by tritium analysis of groundwater collected at the Site indicates that the Vamoosa-Ada aquifer is isolated from the uppermost water-bearing zone by low-permeability strata within the Vanoss, and is unaffected by surface activities.

Site monitoring wells have been installed in the three hydrogeologic zones - the shallow water-bearing zone (unconsolidated soil and the upper Vanoss), the lower Vanoss, and the upper part of the Vamoosa-Ada aquifer. Table 1 lists the monitoring wells, the zone in which each well is screened, and whether the well is part of the regular monitoring program. The well locations are indicated on Figure 2.

3.2.3 Site Groundwater Quality

Site groundwater quality reflects natural influences and, potentially, radiological and non-radiological impacts from previous Site activities. To determine the impact of previous Site activities, it is necessary to separate naturally-occurring conditions from conditions related to Site activities. The comparison of groundwater chemistry of up-gradient or background wells with wells that are within or down-gradient from source areas can aid in the interpretation of the effects of Site activities. In some instances, examination of the concentration ratios of isotopes in the uranium and thorium decay chains might allow dissolved radionuclides derived from processed radioactive materials to be differentiated from radionuclides leached from native radioactive materials.

Groundwater samples for radiological analysis were collected once in 1990 and twice in 1994. Samples were collected from 41 monitoring wells in 1990. These samples were analyzed for Ra-226, Ra-228, Th-230, Th-232, and uranium. The concentration of Ra-226 was analyzed by two different methods to compare U. S. Environmental Protection Agency (EPA) Method 903.0 and the EPA-approved KMC Technical Center method. EPA Method 903.0 measures Ra-226 together with Ra-223 and Ra-224, while the KMC method is specific for Ra-226 only. The concentrations of Ra-226, as analyzed by the EPA and Kerr-McGee methods, are referred to in this report as Ra-226 and Ra-226-K, respectively, and yield distinctly different concentrations. In the 1990 results, the

radium and thorium isotopes were reported in pCi/L and uranium was reported in mg/L. These values are presented in Appendix A.

Nine monitoring wells were sampled in March and November 1994. These samples were analyzed for Th-228, Th-230, Th-232, U-234, U-235, and U-238. The values were reported in pCi/L. These values are presented in Appendix A.

The locations for each of the sampled wells, the zones in which the wells are screened, and the proximity of the wells to potential influences, such as RMAs or acid sludge pits, are presented in Table 2. Most of the sampled wells are located near acid sludge pits 1, 2, 3, and 4. Some of the wells near acid pits 1, 2, and 3 are within Unaffected Area 1, an area designated, on the basis of gamma spectrometer soil surveys, to be unaffected by radiological materials (Morton Associates, 1994). These areas also are indicated in Table 2.

3.3 BACKGROUND CHEMISTRY

3.3.1 Background Soil Chemistry

The developed soil layer, or "A" horizon, normally is present in undisturbed off-site areas. In on-site areas, the "A" horizon often has been disturbed (e.g. either is covered with fill, is absent because of excavation, or otherwise has been modified as a result of refinery land uses). Where a normal "A" horizon is present, it has been naturally leached and weathered, and radionuclide and other constituent concentrations are different than in the underlying, less weathered soil. Where the "A" horizon has been disturbed (as is the case in most RMAs and many other Site areas), shallow soil chemistry might be different than where it has not been disturbed. Also, the application of fertilizers in agricultural areas will alter soil chemistry. Consequently, radionuclide measurements in undisturbed off-site "A" horizon surface soil might not be similar to the same measurements in the disturbed surface soil in on-site areas.

Because of this, KMC believes that on-site, disturbed areas that were not affected by facility waste disposal operations, and have not been recently farmed, provide more representative "background" soil samples for comparison to soil from on-site disturbed areas affected by facility operations than do off-site areas. In general, on-site surface soil, not affected by historic radioactive waste management, is present in unaffected areas. Under this groundwater evaluation workplan, background soil samples will be collected from these areas for comparison to samples from the RMAs.

3.3.2 Background Water Quality

The solubility, ion-exchange, and adsorption characteristics of radionuclides control their movement in the groundwater. Small solubility values and large distribution coefficients, a measure of chemical affinity of dissolved elements for a soil matrix, combine to reduce leaching from soil and mobility in groundwater. Uranium, thorium, and radium normally have limited to very low solubility in groundwater, respectively, and

are not expected to migrate far from local source areas. Of the radionuclides that are monitored at the Site (uranium, radium, and thorium), uranium is the most mobile, radium is the next most-mobile, and thorium is the least mobile (Ivanovich and Harmon, 1992). The differences in mobility will affect the distance from a source at which these elements could be present, as well as the relative concentrations of the elements in groundwater.

The uranium processed at the Site was enriched in U-235, and hence, soil contamination derived from the processed uranium could be enriched in U-235.

Radioactivity in groundwater might result either from natural sources or from leaching of contamination from licensed materials that were used at the Site. Naturally-occurring uranium, or uranium from licensed sources, would produce variations in the concentrations of different uranium isotopes in the groundwater. Isotopic disequilibrium frequently is observed in the concentrations of U-234 and U-238 in groundwater. Reported ratios of U-234:U-238 concentrations range from 0.7 to 32 in groundwater sampled in the United States, with arithmetic mean of 4.4 and geometric mean of 2.7 (EPA, 1985). Isotopic ratios less than one are atypical. Therefore, in background water quality, U-234:U-238 ratios of 4.4 or higher would not be unexpected, and, alone, would not suggest the influence of licensed materials.

Radium and thorium are far less soluble in groundwater than uranium, and the influences from natural or licensed sources might be distinguished on the basis of elevated concentrations. The isotopes Th-232 and Ra-228 should be in secular equilibrium in natural soil. However, differences in the solubilities of these two nuclides should yield far greater amounts of radium in the groundwater than thorium. Typically, this difference is on the order of 100 to 1,000 times more radium than thorium (Hem, 1985).

The 1990 and 1994 groundwater data are plotted in Figures 3 through 8 to show the relationships between various radionuclides. These radionuclides come from the uranium-238 series and the thorium-232 series, and were plotted as follows:

- U-238 was compared to U-234, and
- Th-232 was compared to Ra-228.

If the source of the dissolved uranium is natural, then the ratio of U-234 to U-238 should be within the range described above (i.e. average U-234:U-238 ratio less than 4.4). Ratios outside this range might be indications of the presence of licensed materials, or reflect uncertainty in the concentration measurements.

If the sources of the dissolved thorium and radium-228 are natural, then the radium concentration should be larger than the thorium concentration, since the radium and thorium activities in soil should be equal, and radium is more soluble than thorium. However, other aspects of groundwater chemistry also can affect the solubility of the

different radionuclides. In Site data, there are groundwater samples where thorium exceeds radium in samples from several locations, including presumed background locations. The occurrence of elevated thorium in background locations suggests a solubility, sampling, or analysis issue, rather than influence from licensed materials.

Graphs of the concentrations of these radionuclides at several wells presented in Figures 3 through 8 identify the locations of wells based on their proximity to RMAs and Other Industrial Waste (OIW) pits, or if a well is proposed as a background monitoring well. There does not appear to be a consistent pattern between well locations and the concentrations and ratios of the radionuclides in the groundwater. This suggests that groundwater quality is not affected by licensed materials, and the natural variability of radionuclides in soil and their relative leaching characteristics are responsible for observed concentration differences in groundwater.

The material outside the well screen (e.g. permeable material, such as sandstone or limestone, or less permeable material, such as mudstone) also appears to influence the concentration of radionuclides in the groundwater. Wells screened in less permeable materials appear to have higher radionuclide concentrations, suggesting an association between natural radionuclide occurrence and the fine-grained material, or an analytical problem related to suspended solids in the samples. This could result from a combination of several factors. The water in wells in low permeability soil stays in the wellbore longer, and consequently water chemistry might be affected by contact with air or by prolonged contact with slow-leaching radionuclides. The longer contact time between groundwater and radionuclides in the soil or rock matrix in low permeability materials could contribute to increased leaching of radionuclides. Also, water samples from wells completed in fine-grained soil are more prone to contamination by fine suspended soil particles. The presence of even a small amount of suspended material can completely obscure the actual dissolved concentrations of radionuclides (Law Engineering, 1976).

The groundwater data also were examined to determine if typical concentrations can be established for radionuclides in background wells or for other wells, based on their proximity to RMAs. It might be expected that radionuclide concentrations in the groundwater in background wells would be lower than radionuclide concentrations in wells within or down-gradient from RMAs. However, no such general relationship was identified.

The following observations and interpretations can be made about the background water-quality data:

1. The groundwater data generally indicate low concentrations of uranium, thorium and radium.

2. There does not appear to be a consistent relationship between well location and radionuclide concentrations.

3. Radium and thorium analyses for several samples do not conform to the expectations described above, and instead indicate the presence of more thorium than radium. Because this occurs in some monitoring wells located in background areas, this can be attributed to the influence of other aspects of groundwater chemistry on radionuclide solubility, or to the uncertainty of the analyses at the low radionuclide concentrations found in the groundwater, rather than to the presence of licensed materials.

4. Uranium concentration ratios in Site groundwater samples are greater than one and less than the expected isotopic ratio for U-234:U-238 (e.g. the U.S. average value of 4.4), regardless of well location. This suggests that the uranium in the groundwater samples collected at the Site is background, and not attributable to the presence of licensed materials.

The low mobility of radionuclides in normal groundwater suggests that any impacts from licensed materials would not migrate far from the source, and only groundwater samples collected near those areas would detect the influence, if any, of licensed materials. Greater radionuclide movement might be possible where groundwater pH has been altered, such as near sludge pits. However, if the radionuclides were present in an acidic groundwater, migration distances would be limited by the combination of dilution and the buffering of the soil matrix. The pH measurements in wells down-gradient of possible source areas indicate that neutralization occurs near the pits. At Pit 4, groundwater immediately down-gradient from the pit has a low pH that is attributed to the presence of the pit, but the pH returns to near-neutral levels before reaching the next down-gradient monitoring well, about 300 feet from the pit. These observations suggest that additional data should be collected as the groundwater evaluation progresses to further evaluate radionuclide mobility. These data should be collected in the areas most likely to be influenced by licensed materials. Areas where no impacts are observed should be eliminated from further study.

3.3.2.1 Background Water-Quality Sampling Locations

An assessment of background water quality is necessary for identifying possible Site impacts to the groundwater. Wells located either hydraulically up-gradient from specific RMAs or distant from all RMAs should provide background water-quality information. Also, wells located south and east of Skull Creek should provide background water-quality information, since shallow groundwater flows toward the creek and the RMAs are located north and west of creek.

Based on these characteristics, a list has been compiled of wells that could be expected to provide the necessary background water quality for radiological analysis. These wells are identified in Table 3 and Figure 9, and represent an initial estimate of the background sampling set.

3.3.2.2 Analysis of Background Water-Quality Data

Twenty-three existing wells, listed in Table 3, are proposed for obtaining background water-quality samples. The distribution of these wells in the different flow zones is as follows:

Unconsolidated Soil/Upper Vanoss	8 Wells
Lower Vanoss	14 Wells
Vamoosa-Ada	1 Well

One additional sampling event is planned for these existing wells under this workplan. The water quality between the different hydrogeologic units will be examined for possible influences on radionuclide concentrations, or indications of contamination (e.g. pH, total dissolved solids, carbonate/bicarbonate, dissolved oxygen and specific conductance). If groundwater analyses from Site monitoring wells provide evidence of seasonal fluctuation in radionuclide concentrations, additional sampling will be performed in the future.

3.3.2.3 Additional Sampling Locations

Examination of the RMA locations, existing well locations, and the groundwater flow path in the upper zone indicates that additional sampling points are needed to refine the analysis of background groundwater quality. Possible locations for new background water-quality wells are identified on Figure 9. Well clusters screening the unconsolidated soil and Upper Vanoss Zone are planned at these locations.

Deeper background wells could be installed if soil samples collected during drilling or groundwater sampling at down-gradient locations indicate the presence of radionuclide concentrations above background in the shallower zones. The necessity of installing deeper background monitoring wells will be determined from the results of sampling proposed in this workplan from existing wells and new proposed wells.

4. PROPOSED INVESTIGATION

4.1 OBJECTIVES

Accurate and detailed analysis of potential groundwater pathways is important to KMC cleanup efforts. Groundwater investigation for the Site has been performed to develop the "Phase I Remedial Investigation Report" (Burns & McDonnell, 1993). This workplan for analysis of licensed materials migration is planned to supplement the prior groundwater work in specific parts of the Site.

The primary objectives for use of data to be collected using this workplan are:

1. to determine the range of background concentrations of natural radionuclides in groundwater;

2. to evaluate the potential migration of radionuclides by sampling soil and/or groundwater, as necessary, at selected RMAs;

3. to identify whether a completed contaminant pathway occurs for each RMA to groundwater; and

4. to establish groundwater monitoring system improvements in areas where migration of licensed materials via the groundwater pathway is considered feasible.

These primary objectives will be achieved through the following processes:

1. collect and analyze groundwater samples, and evaluate background water quality;

2. establish background water-quality monitoring points, using existing wells where possible;

3. perform additional analyses at selected RMAs by sampling soil and/or groundwater to identify subsurface radiological contamination; and

4. install additional monitoring wells at RMAs where potential radiological impact to groundwater is anticipated based on the results of the soil sampling.

The following sections identify the rationale and approach to collecting data for the pathway analysis and achieving these objectives. The rationale is presented for the selection of sampling locations. The approach includes a description of data to be collected, and how data will be used to guide the investigation.

4.2 EXISTING SOURCE CHARACTERIZATION

The boundaries of the RMAs have been established by prior surveys to identify areas where radioactive materials are present in surface soil. These areas are shown on Figure 10. In delineating the RMAs, KMC included a significant buffer area surrounding the confirmed impacted areas so that RMA limits are conservative representations of the entire area where contamination is likely.

The controlling premise in development of the sampling program approach for most RMAs is that contamination is the result of intentional surface placement of radioactive materials containing the relatively insoluble and immobile radionuclide thorium. Subsurface contamination might be present beneath these RMAs as a result of the leaching of radionuclides, and downward transport of radionuclides with infiltrating water. However, the low solubility of the radionuclides is expected to minimize the depth of penetration of these contaminants. Sampling and analysis is planned to determine if subsurface soil or groundwater is affected.

Intentional subsurface placement of radioactive materials containing uranium occurred at only a few RMAs. The controlling premise in development of the sampling program approach for these RMAs is that some radioactive materials might have been placed near the groundwater level and uranium, a relatively soluble radionuclide, might be present in groundwater at the RMA. At these locations, groundwater sampling and analysis is planned to measure whether groundwater is affected.

Existing surface gamma survey data and shallow soil data are discussed in Section 4.2.1. Investigation at most of the RMAs will consist of confirming shallow, near-surface contamination by soil sampling, and is discussed in Sections 4.3 and 4.4. Areas where former Site activities and disposal practices might have caused deeper contamination have been identified as localized disposal areas associated with RMA-3 and RMA-11, and the building areas and debris piles of RMA-10. These areas are discussed in greater detail in Sections 4.2.4, 4.2.6, and 4.2.5, respectively.

4.2.1 Existing Survey Data

The RMA boundaries shown on Figure 10 were established using surface gamma surveys and soil sampling. Gamma survey procedures are described in detail in the Site Decommissioning Plan (Morton Associates, 1994). Areas containing licensed materials were identified by a series of surveys that began with a Site-wide 10-meter grid. Additional surveys using tighter grid spacings were done in areas where initial survey results indicated gamma readings exceeded background. Soil samples in RMAs were collected from selected locations on a five-meter (or less) grid. The locations

where Option 1 concentrations were exceeded provide the starting points for the soil sampling described in this workplan.

4.2.2 Background Soil Characteristics

As is discussed in Section 3.3.1, soil samples from unaffected areas will be obtained for comparison to samples from the RMAs. Samples from the unaffected areas will be taken at similar depths, by similar sampling methods, and analyzed by the same methods as samples from RMAs.

4.2.3 RMAs 1, 2, 4 Through 9, and 12 Through 16

At RMAs 1, 2, 4 through 9, and 12 through 16, general Site waste disposal activities resulted in surface and shallow soil contamination. The RMA boundaries encompass the extent of affected area within which isolated areas of elevated surface gamma values have been recorded.

4.2.4 RMA-3

At RMA-3, sulfuric acid sludges were disposed in Pit 4. Thorium-contaminated waste was disposed in the northwest corner of the pit. Near the sludge pit, the more acidic environment could increase the solubility of thorium, and increase its mobility. The possibility that the acidic environment could increase radionuclide migration near Pit 4 provides the basis for KMC to evaluate shallow groundwater impacts in this area. Water from Pit 4 could discharge to the surface in the area south of the pit. Thorium that might be dissolved in groundwater would precipitate as pH rises when groundwater mixes with surface water. This would cause thorium to adsorb to surface soil particles.

Additionally, thorium-contaminated material was placed in burial trenches located in the northern portion of RMA-3. These trenches were excavated to depths of 12 to 14 feet (Morton Associates, 1994). Soil sampling performed in the vicinity of the trenches indicated that this soil contains relatively low levels of uranium and thorium, with average concentrations below Option 1 concentrations. Only thorium has been observed at concentrations exceeding Option 1 concentrations in Pit 4.

4.2.5 RMA-10

At RMA-10, thorium and uranium were detected (Morton Associates, 1994). The contamination is present in process structures that are still standing and in the adjacent area. Uranium often is more soluble and more mobile than other radionuclides. As a result, KMC considers that radionuclide migration through soil to groundwater might be more likely in this area than in some others.

4.2.6 RMA-11

Disposal of debris and associated soil at the trash dump in RMA 11 involved excavation and backfill operations, which could lead to deeper deposition of materials containing radionuclides. This area contains the most variable uranium and thorium concentrations on the Site (Morton Associates, 1994). Contamination in this area includes Option 2 and Option 4 materials. Since subsurface waste placement might have occurred, KMC considers that the potential for radionuclide migration though soil and into groundwater might be greater here than at other RMAs.

4.3 SAMPLING RATIONALE

4.3.1 RMAs 1, 2, 4 Through 9, and 12 Through 16

RMAs are considered the only probable sources for groundwater contamination from licensed materials. The investigation approach planned for RMAs 1, 2, 4 through 9, and 12 through 16 will systematically examine soil as a function of depth below ground surface, and use the shallow soil results to determine the need for deeper sampling. This process eliminates deeper sampling at those areas with minor surface or near-surface contamination.

The process of soil sampling at RMAs 1, 2, 4 through 9, and 12 through 16 is illustrated on Figure 11. This process is divided into the following steps.

1. The prior surveys were used to establish RMA boundaries and provide the starting point for this investigation. The survey locations or soil sampling locations with the highest values will be used as the starting locations for this analysis.

2. Surface and near-surface sampling of areas at each RMA will be done using mechanized or hand-operated equipment. Samples will be analyzed at the on-site laboratory to identify impacted soil.

3. If near-surface impacts are confirmed, deeper samples will be obtained. If sampling beyond the depth of hand-sampling is necessary, deeper samples will be obtained using mechanical equipment.

4. Groundwater grab samples will be collected if soil impacts extend to the water table.

5. If groundwater grab samples indicate that radionuclides might have migrated to groundwater, investigation in these areas will include installation and sampling of monitoring wells.

Within each RMA, KMC plans to obtain samples from five-meter square grid areas where the results of previous soil sample analyses exceeded the method detection limit.

A minimum of one such sample location will be selected in each RMA and a minimum of two samples will be taken at each location. These will include the 0 to 0.5 feet deep and 0.5 to 1.0 feet deep samples. The maximum number of surface locations to be sampled in a single RMA is 10. Where the RMA includes more than 10 five-meter square grids where the method detection limit was exceeded, the 10 grids with the highest measured activities will be selected for sampling.

4.3.2 RMAs 3, 10, and 11

Conditions at RMA-3, RMA-10 and RMA-11 suggest the possibility that radionuclides could have migrated in the soil to the groundwater. As a result, a different approach to determine if radionuclide migration has occurred is planned for these RMAs.

4.3.2.1 RMA-3

The mobility of the thorium contained in materials disposed in this RMA could be increased because sludge acidity in Pit 4 locally affects the pH of shallow groundwater. Thorium mobility will decrease dramatically as groundwater pH rises as it moves away from the pit and mixes with unaffected groundwater or surface water. As pH rises, thorium will sorb to surface or subsurface soil near Pit 4 where shallow groundwater discharges to a tributary to Skull Creek.

The sequence of sampling at RMA-3 will be as follows.

- First, groundwater samples will be taken from the three existing monitoring wells completed in the unconsolidated zone or upper Vanoss. These are wells 14.1, 16.1, and 17.1. If these wells show reduced pH and/or elevated thorium concentrations, then the next sampling step will be taken.

- Shallow surface soil samples will be taken for analysis to determine if radionuclide concentrations are similar to background values. Samples will be taken at four locations from 0.5 to 1.0 feet deep and 2.0 to 2.5 feet deep. Samples will not be taken from below groundwater level.

- If soil sample analyses confirm that radionuclide concentrations are similar to background, then no groundwater sampling will be necessary.

- If soil sample analyses confirm radionuclide concentrations are different from background, then additional groundwater samples might be determined to be necessary. Such additional samples probably would be taken further down-gradient from Pit 4 and RMA-3.

Figure 12 shows a plan view of the first two sampling steps. Figure 13 is a schematic cross-section showing typical sample locations.

4.3.2.2 RMA-10

Thorium and uranium are present in RMA-10. Since uranium often is more soluble and mobile than other radionuclides, and groundwater is relatively shallow in this area, KMC considers that uranium migration through soil to groundwater could have occurred. In RMA-10, the investigation to determine if radionuclides have migrated to groundwater will focus immediately on groundwater quality. KMC will install two new up-gradient and three new down-gradient wells at the locations indicated on Figure 14 to determine if groundwater-quality impacts directly attributable to this RMA have occurred. All five wells will be shallow wells to monitor the first water-bearing interval in either the unconsolidated soil or upper Vanoss zones. KMC plans to sample these new wells four to six times over a six- to eight-month period to quickly assemble the data necessary to make this determination.

4.3.2.3 RMA-11

Thorium and uranium are present in RMA-11. Locations of greater contamination within the RMA will be identified with a NaI detector surface scan. Subsurface placement of radioactive materials in RMA-11 increases the potential for radionuclide impacts to groundwater. As at RMA-10, the RMA-11 investigation will focus on groundwater quality to determine if radionuclides have migrated to groundwater. KMC will install one new shallow up-gradient well and sample the new well and four existing wells (MW-2, 3, 8, and 9) to determine if groundwater-quality impacts directly attributable to this RMA have occurred. These well locations are indicated on Figure 14. KMC plans to sample these wells four to six times over a six- to eight-month period to quickly assemble the data necessary to make this determination.

4.4 SAMPLING PROCESS

The soil beneath and down-gradient from the RMAs will be sampled and analyzed to identify the potential for impacts to shallow groundwater associated with the RMAs. This sampling process addresses two primary media: soil and groundwater.

The need to collect groundwater data at specific RMAs will depend on the results of the soil analysis. If the soil analyses indicate that radionuclide concentrations are similar to background values or that affected soil does not extend to the water table, no groundwater sampling will be performed at that location. Also, if shallow groundwater is not present in the unconsolidated zone or upper part of the Vanoss, then the pathway to groundwater is not complete, and groundwater sampling is not necessary.

Each of these components is described in greater detail below. Procedures to be used during field data collection are included in the Kerr-McGee Site Sampling and Analysis Plan. Other industry-standard procedures might be used when necessary.

4.4.1 Soil Sampling and Analysis Process

4.4.1.1 Soil Sampling

Surface soil sampling will be performed at RMAs 1, 2, 4 through 9, and 12 through 16 at locations previously identified as having the highest surveyed gamma values, and at selected locations in RMA-3. One or more locations will be sampled in each RMA. At least two samples will be taken at each surface soil location. Except at RMA-3, the first sample will be collected from 0 to 0.5 feet deep and the second sample will be collected from 0.5 to 1.0 feet deep. At RMA-3, the first sample will be taken from 0.5 to 1.0 feet deep, and the second sample will be taken from 2.0 to 2.5 feet deep.

At RMAs 1, 2, 4 through 9, and 12 through 16, the 0 to 1.0 feet deep samples are to compare with previous data, and assess that sampling is occurring at the correct location. A hand auger will be used to obtain deeper samples at two-feet intervals until sampling ceases. Sampling will cease when:

- hand augering refusal occurs,
- uncontaminated soil is reached, or
- the water table is reached.

The deepest soil sample will be taken at the depth at which groundwater is encountered. If groundwater is not present in the unconsolidated zone or upper portion of the Vanoss, the deepest soil sample will be taken from a depth considered to be stratigraphically equivalent to the depth of shallow groundwater elsewhere in the investigated area.

At RMA-3, the same sampling procedures will be used, but only two soil samples will be obtained. If both samples show elevated thorium levels, then additional down-gradient groundwater sampling will be done.

The thickness of unconsolidated soil underlying the Site is expected to be about 10 feet or less in most areas. Where shallow groundwater is present, its depth ranges from near surface to about 10 feet deep. In other areas of the Site, shallow groundwater is not present. Hand augers can be used to obtain samples from depths to about 10 feet, depending on soil conditions and the presence of groundwater. If the sampling depth must exceed the limit of hand-augering, and field and laboratory analyses indicate that radionuclide concentrations above background still are present, mechanical drilling and sampling techniques will be used. The general approach to this sampling and analysis of soil samples will be similar to that used for manual sampling.

After sampling has been completed, the borehole either will be used for groundwater grab sampling, monitoring well installation, or will be backfilled in accordance to Site abandonment procedures. Boreholes in which monitoring wells are not installed will be backfilled with cuttings if the borehole is 10 feet deep or less, or grout if the borehole is more than 10 feet deep.

4.4.1.2 Soil Laboratory Analyses

The radionuclides for which soil samples will be screened are listed in Table 4. The number of such analyses will be determined as the investigation progresses. The KMC on-site laboratory will be used for these analyses. The advantage of using an on-site laboratory is the quick turn-around times possible during field activities.

In addition to radionuclide concentration analyses, one or more samples representing the major subsurface soil types will be selected for distribution coefficient analysis. Since these analyses will be used in the evaluation of the potential for radionuclide migration, the samples to be submitted for laboratory analysis typically will be from among the deeper soil samples collected. Distribution coefficient (K_d) testing will be conducted using the batch test methods of B. F. Hajek (Hajek, 1981) or ASTM Method D-4319. These samples will be collected, but not analyzed. If no groundwater impacts are identified from this program, then the distribution coefficient of the soil samples do not need to be analyzed.

4.4.2 Groundwater Sampling Process

The interaction between source areas and groundwater is dependent on the intersection of affected soil with the water table. The radionuclide migration pathway through soil considers leaching and convective transport as the primary transport mechanism for radionuclides from the source to groundwater. Along this pathway, strong sorption of radionuclides to soil is expected to limit radionuclide mobility.

Where groundwater is encountered during soil sampling at RMAs 1, 2, 4 through 9, and 12 through 16, and affected soil extends to the depth of groundwater, groundwater analysis will consist of a two-step process.

1. One-time grab samples of water will be obtained from open soil borings if groundwater is present at the time the boring is made. The groundwater grab sample will be submitted for analysis of soluble radionuclides.

2. If radiological impacts are observed in deep soil or rock, or in the grab groundwater sample, a monitoring well might be installed to allow representative groundwater samples to be obtained.

The advantage of performing the work in two steps is that a general screening (grab sample) can be performed over a large area, and more detailed sampling information (monitoring wells) can be performed where a well is determined to be necessary.

Information gathered during the grab sampling phase will allow the need for a well and its appropriate location and screen depth to be determined.

If groundwater is not present in the unconsolidated soil or upper Vanoss, no groundwater grab sampling or well installation will occur.

At RMAs 3, 10, and 11, groundwater samples will be obtained from existing monitoring wells and new monitoring wells installed to investigate these RMAs.

4.4.2.1 Grab Sampling

Groundwater grab sampling will be used to identify areas where potential radiological effects are observed in groundwater. Grab sample data will be compared to background water quality. This screening step will identify where monitoring wells are necessary. This sampling will consist of measurement of groundwater level at the time of drilling, if groundwater is present, and collection of a grab groundwater sample from the open borehole. The sample will be submitted for radiological analyses as discussed in Section 4.4.2.4. Analytical results from grab samples will be used to compare groundwater in that location with background water quality.

4.4.2.2 Monitoring Well Installation

Groundwater monitoring wells will be drilled and installed in areas down-gradient from RMAs where impact is suspected in grab sample analyses. The three areas where monitoring wells have been determined to be needed include:

- down-gradient from RMA-3,
- up- and down-gradient of RMA-10, and
- up- and down-gradient of RMA-11.

Proposed locations for monitoring well installations at RMA-3, 10, and 11 are presented in Figure 14. These locations are approximate, and might be moved based on additional information gathered during the implementation of this workplan. Soil sampling at RMAs 1, 2, 4 through 9, and 12 through 16 also could indicate the need to install and sample additional down-gradient monitoring wells. This determination will be made on the basis of soil analysis results.

In all RMAs, wells might be installed in borings drilled for collection of soil and grab groundwater samples, or in separate borings. Monitoring wells will be completed with two-inch inside diameter (ID) PVC casing and screen. Screen lengths will be limited to a maximum of 10 feet. Shorter screen lengths will be used where the stratum or zone to be monitored is less than 10 feet in thickness. Monitoring wells will be completed with a one-foot sump.

Monitoring wells less than 20 feet deep will be completed without centralizers. Monitoring wells deeper than 20 feet will be completed with centralizers placed at the bottom of the casing string, at a location 10 feet from the top, and with intermediate centralizers as necessary. During completion, casing strings will be hung about one-half foot off the bottom to maintain tension on the casing.

Filter pack will be washed in through a tremie tube to the screened interval and to two feet above the top of the screen. Bentonite pellets will be placed on top of the filter pack to form a seal about five feet in thickness above the completed interval. If the bentonite is above the water table, it will be hydrated with potable water prior to grouting. The monitoring well will be completed with cement-bentonite grout to within two feet of the surface. The remaining annulus will be filled with concrete. Where shallow wells are installed and the top of the well screen is less than seven feet below ground surface, filter pack, bentonite seal, grout, and concrete thicknesses will be modified.

The monitoring wells will be completed as permanent installations. The well heads will be completed with casing protectors and concrete pads.

Well installation and development will be conducted according to procedures in the KMC Sampling and Analysis Plan (SAP) for the Site.

4.4.2.3 Groundwater Monitoring Well Sampling

The groundwater monitoring wells installed at RMA-3, 10, and 11, and (if necessary) at other RMAs, will be sampled frequently to build a database of information. KMC plans to sample these wells four to six times in the six to eight months following their installation.

4.4.2.4 Groundwater Laboratory Analyses

A list of radionuclides and field parameters for which groundwater will be analyzed is presented on Table 5. Radionuclide analyses will be performed at an off-site analytical laboratory selected by KMC.

The use of filtered versus unfiltered samples is important in groundwater sampling. Filtered samples provide information on the actual dissolved radionuclide concentration in the groundwater, and eliminate the influences of well installation and sampling that might cause analytical results to yield higher concentrations in unfiltered groundwater samples than actually are present in groundwater. Because this is an investigative program to examine the impact of possible leaching and transport of dissolved radionuclides in the groundwater near the RMAs, only filtered samples will be collected and analyzed. Future sampling and monitoring techniques might be adjusted depending on the results from the filtered samples.

5. DATA EVALUATION

Data collected during this investigation will supplement existing Site data to support and refine KMC's understanding of Site hydrogeology, particularly in the vicinity of RMAs. Date evaluation will yield the following results:

- Determination of vertical extent of radiologically impacted soil,
- Determination of background groundwater quality,
- Identification of the presence and movement of groundwater near RMAs,
- Estimation of the extent of radiologically impacted groundwater near RMAs, and
- Summary report of investigation results.

Methods to be used to address these features are discussed in the following sections.

5.1 VERTICAL EXTENT OF RADIOLOGICALLY IMPACTED SOIL

The vertical extent of radiologically impacted soil will be estimated from the soil sampling performed in the RMAs. Information collected as part of this groundwater pathways analysis will be combined with previous analyses to estimate a lower vertical extent of licensed materials migration. The estimated depths will be mapped or contoured for the RMAs examined as part of this analysis. The estimated or measured depth to groundwater will be included on the illustrations of vertical extent to identify those areas where the pathway to groundwater appears to be completed.

5.2 BACKGROUND WATER QUALITY

Background water-quality samples will be collected in areas selected to identify naturally occurring radionuclides in the groundwater, and to separate Site impacts from natural concentrations. Background water-quality values will be determined as described in Section 3.3.2. The output from these analyses will be statistical parameters that provide an accurate description of background water quality. A values table will be compiled for background water quality to be used in comparison with additional Site monitoring data.

5.3 PRESENCE AND MOVEMENT OF GROUNDWATER

Potentiometric maps of the unconsolidated zone and Upper Vanoss Group will be refined with the addition of data from soil borings and new monitoring wells. Maps for areas near the RMAs will show the presence or absence of shallow groundwater, and will be used to refine the estimates of hydraulic gradient, direction of flow, and water-quality impacts related to RMAs. The refined interpretation of recharge and discharge zones will provide additional information about movement of groundwater to be used in subsequent pathways analyses.

Water-quality data collected as part of this workplan will be combined with previously collected data to estimate any confirmed impacts to groundwater quality. The data will be analyzed and presented to show potential flowpaths and rate of groundwater movement, and influence of recharge, discharge, and dilution on the groundwater flow system.

5.4 EXTENT OF IMPACTED GROUNDWATER

The extent of impacted groundwater will be related to the mapped areas of the RMAs. Additionally, shallow geologic cross-sections for the vicinity of RMAs will be generated from boring logs. The correlation of sandstone and limestone lenses in the Upper Vanoss Group between borings will be interpreted. Understanding the correlation of these zones is expected to be important in monitoring rate and direction of groundwater flow and movement of radionuclides that could be present in groundwater.

5.5 SUMMARY REPORT OF RESULTS

The data collected under this groundwater evaluation will be used to refine the understanding of the groundwater regime in the vicinity of the 16 RMAs. The information that is expected to be contained in the report of this investigation includes the following:

- Vertical extent of contamination at possible radionuclide source areas;
- Background water quality for naturally occurring radionuclide concentrations and ranges;
- Groundwater impacts related to source areas; and
- Groundwater monitoring system improvements.

Each of these major conclusions will be addressed in the report that presents data gathered during implementation of this workplan.

6. REFERENCES

American Society for Testing and Materials, 1993, "Annual Book of ASTM Standards," Section 4, Construction, Volume 04.08 Soil and Rock, Building Stones; Geotextiles."

Burns & McDonnell Waste Consultants, Inc., 1993, "Phase I Remedial Investigation Report, Kerr-McGee Cushing Refinery Site, Cushing, Oklahoma," April 1, 1993.

Hajek, B.F., 1981, "Equilibrium Distribution Coefficients - Batch Determination Techniques," submitted to Kerr-McGee Tech Center, Oklahoma City, Oklahoma, February 19, 1981.

Hem, J.D., 1985, "Study and Interpretation of the Chemical Characteristics of Natural Water," 3rd edition, U.S. Geological Survey Water Supply Paper 2254.

Ivanovich, M. and R. S. Harmon, 1992, "Uranium-Series Disequilibrium: Applications to Earth, Marine, and Environmental Sciences," 2nd edition, Clarendon Press.

Kerr-McGee Corporation, Sampling and Analysis Plan for the Cushing, OK Facility.

Law Engineering, 1976, Report on Maxey Flats Geohydrologic Investigation.

Morton Associates, 1994, "Cushing Refinery Site, Site Decommissioning Plan," April 25, 1994.

NRC, 1981, Disposal or Onsite Storage of Thorium or Uranium Wastes from Past Operations, Federal Register, Vol. 48, No. 205, October 23, 1981.

U.S. Environmental Protection Agency, 1985, "Nationwide Occurrence of Radon and Other Natural Radioactivity in Public Water Samples," Eastern Radiation Facility, Montgomery, AL, 520/5-85-008.

TABLES

TABLE 1

EXISTING GROUNDWATER MONITORING SYSTEM

Unconsolidated Soil	Upper Vanoss Group	Lower Vanoss Group		Vamoosa-Ada
CMW-4.1	CMW-2.1	CMW-1.1*	CMW-13.2	CMW-29.1
CMW-5.1	CMW-5.2	CMW-2.2	CMW-14.2*	
CMW-6.1	CMW-12.1	CMW-2.3	CMW-15.1	
CMW-7.1	CMW-13.1	CMW-2.4	CMW-15.2	
CMW-8.1	CMW-14.1	CMW-2.5	CMW-16.3*	
CMW-9.1	CMW-16.2	CMW-3.1*	CMW-18.1	
CMW-10.1	CMW-21.1	CMW-5.3	CMW-18.2	
CMW-11.1	CMW-22.1	CMW-6.2	CMW-19.1*	
CMW-16.1	CMW-24.1	CMW-7.2	CMW-20.1	
CMW-17.1	CMW-25.1	CMW-9.2*	CMW-20.2*	
CMW-27.1	CMW-26.1*	CMW-10.2	CMW-23.1	
	CMW-28.1	CMW-10.3	CMW-23.2	
	CMW-30.1	CMW-11.2*	CMW-30.2	
	CMW-33.1	CMW-11.3	CMW-30.3	
		CMW-12.2	CMW-31.1	
		CMW-12.3	CMW-31.2	
		CMW-12.4	CMW-32.2	

* - indicates wells that are part of the regular groundwater monitoring program.

TABLE 2

SAMPLED WELL LOCATIONS

Well	Formation	Location*	Comment
CMW 4.1	Unconsolidated Soil	Unaffected Area 1	Down-gradient of Pit 2
CMW 5.1	Unconsolidated Soil	Unaffected Area 1	Down-gradient of Pit 3
CMW 6.1	Unconsolidated Soil	Unaffected Area 1	Adjacent to Pit 1
CMW 7.1	Unconsolidated Soil	Unaffected Area 1	Adjacent to Pit 2
CMW 8.1	Unconsolidated Soil	Unaffected Area 1	Down-gradient of Pit 2
CMW 9.1	Unconsolidated Soil	Unaffected Area 1	Down-gradient of Pit 3
CMW 10.1	Unconsolidated Soil	Unaffected Area 1	Down-gradient of Pit 3
CMW 11.1	Unconsolidated Soil	Undesignated Area	Up-gradient of RMA-3
CMW 16.1	Unconsolidated Soil	RMA-3	Down-gradient of Pit 4
CMW 17.1	Unconsolidated Soil	RMA-3	Down-gradient of Pit 4
CMW 2.1	Upper Vanoss	Undesignated Area	Adjacent to Pit 1
CMW 12.1	Upper Vanoss	RMA-3	Up-gradient of Pit 4
CMW 13.1	Upper Vanoss	RMA-3	Up-gradient of Pit-4
CMW 14.1	Upper Vanoss	RMA-3	Down-gradient of Pit 4
CMW 21.1	Upper Vanoss	Undesignated Area	No associated RMA
CMW 22.1	Upper Vanoss	Undesignated Area	No associated RMA
CMW 24.1	Upper Vanoss	Unaffected Area 2	Up-gradient of Pit-5
CMW 26.1	Upper Vanoss	Undesignated Area	Up-gradient of Pit-5
CMW 1.1	Lower Vanoss	Unaffected Area 1	Down-gradient of RMA-4, Up-gradient of Pit-1
CMW 2.3	Lower Vanoss	Undesignated Area	Down-gradient of RMA-4 and 5, Up-gradient of Pit 1
CMW 3.1	Lower Vanoss	Undesignated Area	Adjacent to Pit 2
CMW 5.3	Lower Vanoss	Unaffected Area 1	Down-gradient of Pit 3
CMW 6.2	Lower Vanoss	Unaffected Area 1	Adjacent to Pit 1
CMW 7.2	Lower Vanoss	Unaffected Area 1	Adjacent to Pit 2
CMW 9.2	Lower Vanoss	Unaffected Area 1	Down-gradient of Pit 3

* Unaffected area locations as delineated in Site Decommissioning Plan, April 1994.

TABLE 2

SAMPLED WELL LOCATIONS
(continued)

Well	Formation	Unaffected Area *	Comment
CMW 10.2	Lower Vanoss	Unaffected Area 1	Adjacent to Pit 3
CMW 10.3	Lower Vanoss	Unaffected Area 1	Adjacent to Pit 3
CMW 11.2	Lower Vanoss	Undesignated Area	Up-gradient of RMA-3
CMW 11.3	Lower Vanoss	Undesignated Area	Up-gradient of RMA-3
CMW 12.2	Lower Vanoss	RMA-3	Up-gradient of Pit-4
CMW 12.3	Lower Vanoss	RMA-3	Up-gradient of Pit 4
CMW 14.2	Lower Vanoss	RMA-3	Up-gradient of Pit 4
CMW 15.1	Lower Vanoss	RMA-3	Up-gradient of Pit 4
CMW 15.2	Lower Vanoss	RMA-3	Up-gradient of Pit 4
CMW 16.3	Lower Vanoss	RMA-3	Down-gradient of Pit 4
CMW 18.1	Lower Vanoss	Undesignated Area	Up-gradient of RMA-3
CMW 18.2	Lower Vanoss	Undesignated Area	Up-gradient of RMA-3
CMW 19.1	Lower Vanoss	Undesignated Area	Down-gradient of Pit 4
CMW 20.1	Lower Vanoss	Undesignated Area	No associated RMA
CMW 20.2	Lower Vanoss	Undesignated Area	No associated RMA
CMW 23.1	Lower Vanoss	Unaffected Area 1	Up-gradient of Pit 3
CMW 23.2	Lower Vanoss	Unaffected Area 1	Up-gradient of Pit 3

* Unaffected area locations as delineated in Site Decommissioning Plan, April 1994.

TABLE 3

WELLS FOR BACKGROUND MONITORING

Well	Unit	Rationale
CMW-11.1	Unconsolidated Soil	Located hydraulically up-gradient of RMAs
CMW 21.1	Upper Vanoss	Separated from RMAs by local discharge to Skull Creek
CMW-22.1	Upper Vanoss	Separated from RMAs by local discharge to Skull Creek
CMW 24.1	Upper Vanoss	Separated from RMAs by local discharge to Skull Creek
CMW 25.1	Upper Vanoss	Separated from RMAs by local discharge to Skull Creek
CMW 26.1	Upper Vanoss	Separated from RMAs by local discharge to Skull Creek
CMW 30.1	Upper Vanoss	Separated from RMAs by local discharge to Skull Creek
CMW 33.1	Upper Vanoss	Located hydraulically up-gradient of RMAs
CMW-11.2	Lower Vanoss	Located hydraulically up-gradient of RMAs
CMW-11.3	Lower Vanoss	Located hydraulically up-gradient of RMAs
CMW-18.1	Lower Vanoss	Located hydraulically up-gradient of RMAs
CMW-18.2	Lower Vanoss	Located hydraulically up-gradient of RMAs
CMW 20.1	Lower Vanoss	Separated from RMAs by local discharge to Skull Creek
CMW 20.2	Lower Vanoss	Separated from RMAs by local discharge to Skull Creek
CMW-23.1	Lower Vanoss	Located hydraulically up-gradient of RMAs
CMW-23.2	Lower Vanoss	Located hydraulically up-gradient of RMAs
CMW 30.2	Lower Vanoss	Separated from RMAs by local discharge to Skull Creek
CMW 30.3	Lower Vanoss	Separated from RMAs by local discharge to Skull Creek
CMW 31.1	Lower Vanoss	Separated from RMAs by local discharge to Skull Creek
CMW 31.2	Lower Vanoss	Separated from RMAs by local discharge to Skull Creek
CMW 32.1	Lower Vanoss	Separated from RMAs by local discharge to Skull Creek
CMW 32.2	Lower Vanoss	Separated from RMAs by local discharge to Skull Creek
CMW 29.1	Vamoosa-Ada	Located hydraulically up-gradient of RMAs

TABLE 4

SOIL SAMPLE ANALYTICAL PROCEDURES

Radionuclides	Analytical Procedure
Uranium-235, 238	Gamma Spec.
Thorium-232	Gamma Spec.
Radium-226	Gamma Spec.

Gamma spec. analyses by KMC on-site counter.

TABLE 5

GROUNDWATER ANALYTICAL PROCEDURES

Radionuclides	Analytical Procedure	MRL
Gross Alpha/Beta	900.0	N/A
Uranium-234, 235, 238	HASL-300	N/A
Thorium-228, 230, 232	HASL-300	N/A
Radium-226	903.0 or KMTC-205-RA-7	N/A
Radium-228	904.0	N/A
Radon-222*	913.0	N/A

Water-Quality Parameters	Analytical Procedure	MRL (mg/l)
Chloride	300.0	0.02
Fluoride	340.2	0.02
Nitrate	300.0	0.02
Phosphate	365.3	0.01
Sulfate	300.0	0.02
Total Dissolved Solids	160.1	5
Total Suspended Solids	160.2	5
Aluminum	200.7	0.05
Calcium	200.7	0.05
Iron	200.7	0.02
Magnesium	200.7	0.01
Potassium	200.7	2
Sodium	200.7	0.1
Ammonium	350.3	0.05
Carbonate Bicarbonate	SM2320B	20

Field Parameters	Procedure	MRL
pH	Probe	N/A
Temperature	Probe	N/A
Specific Conductivity	Probe	N/A
Dissolved Oxygen	Probe	N/A
Eh	Probe	N/A

Analytical procedures from SW-846 or Standard Methods for the Examination of Water and Wastewater (SM).

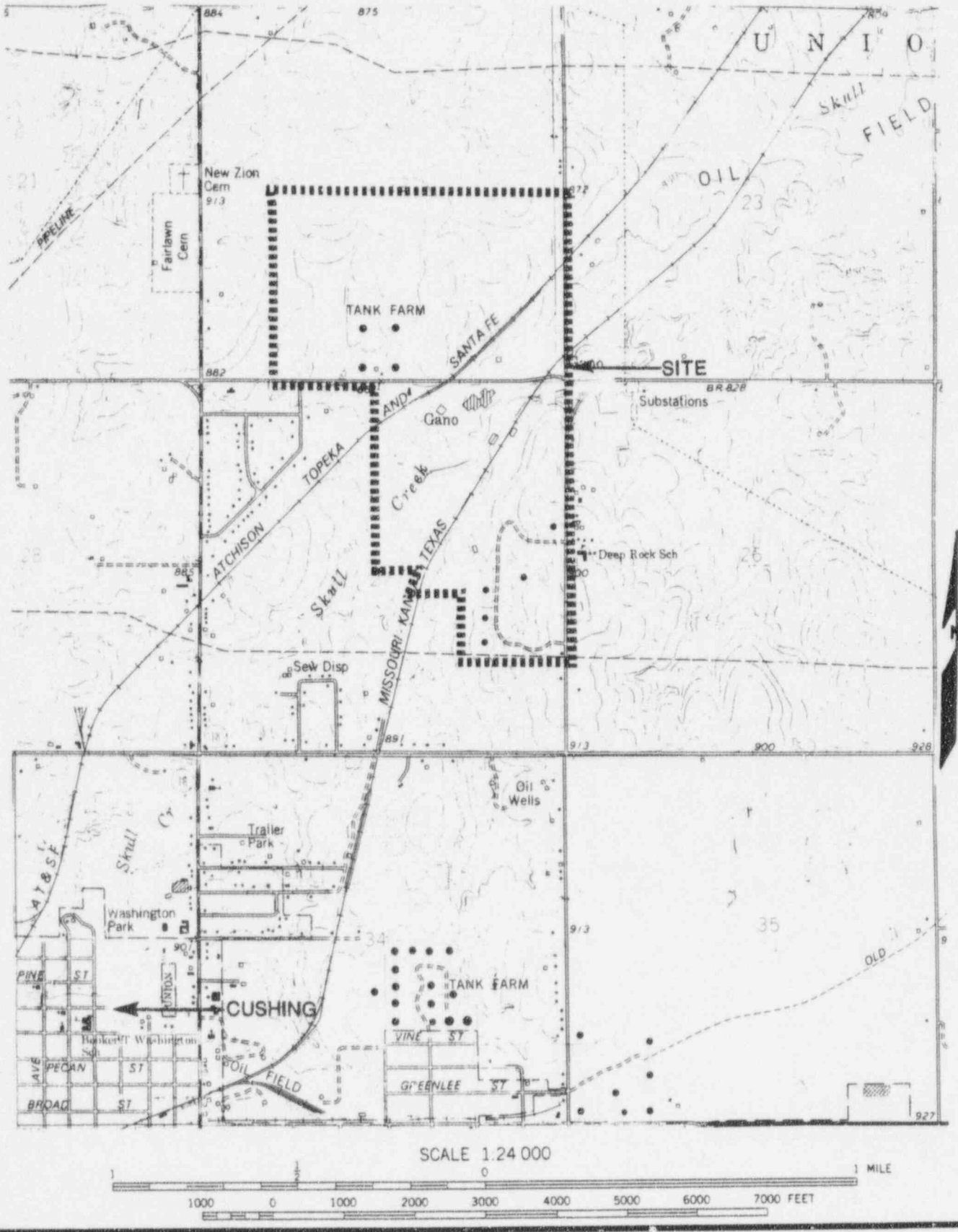
MRL - Method Reporting Limit (detection limits for volatile and semi-volatile organic compounds vary depending on compound analyzed).

mg/l = milligrams/liter

N/A = Not Applicable

*Necessity for radon analyses dependent on gross alpha results.

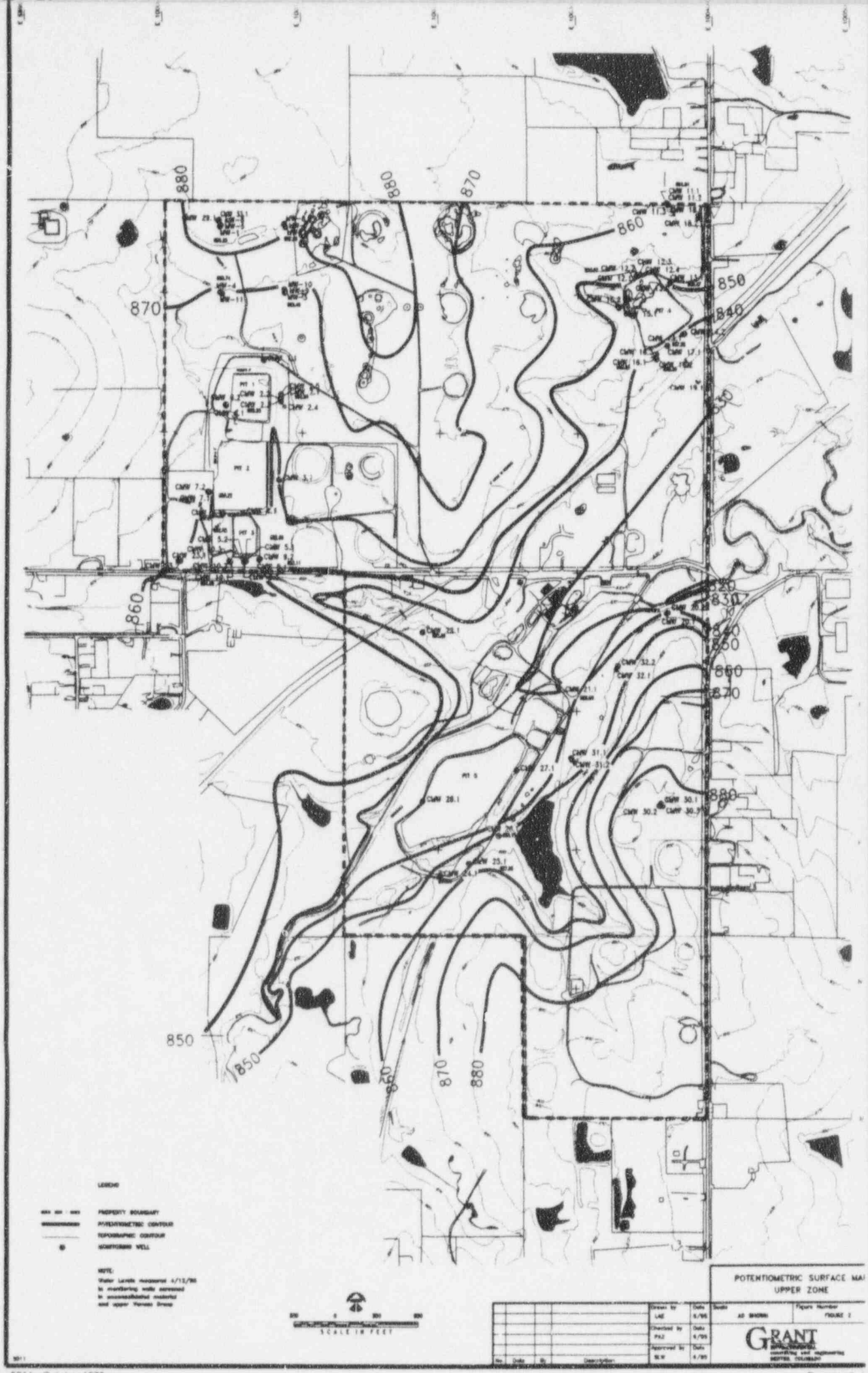
FIGURES

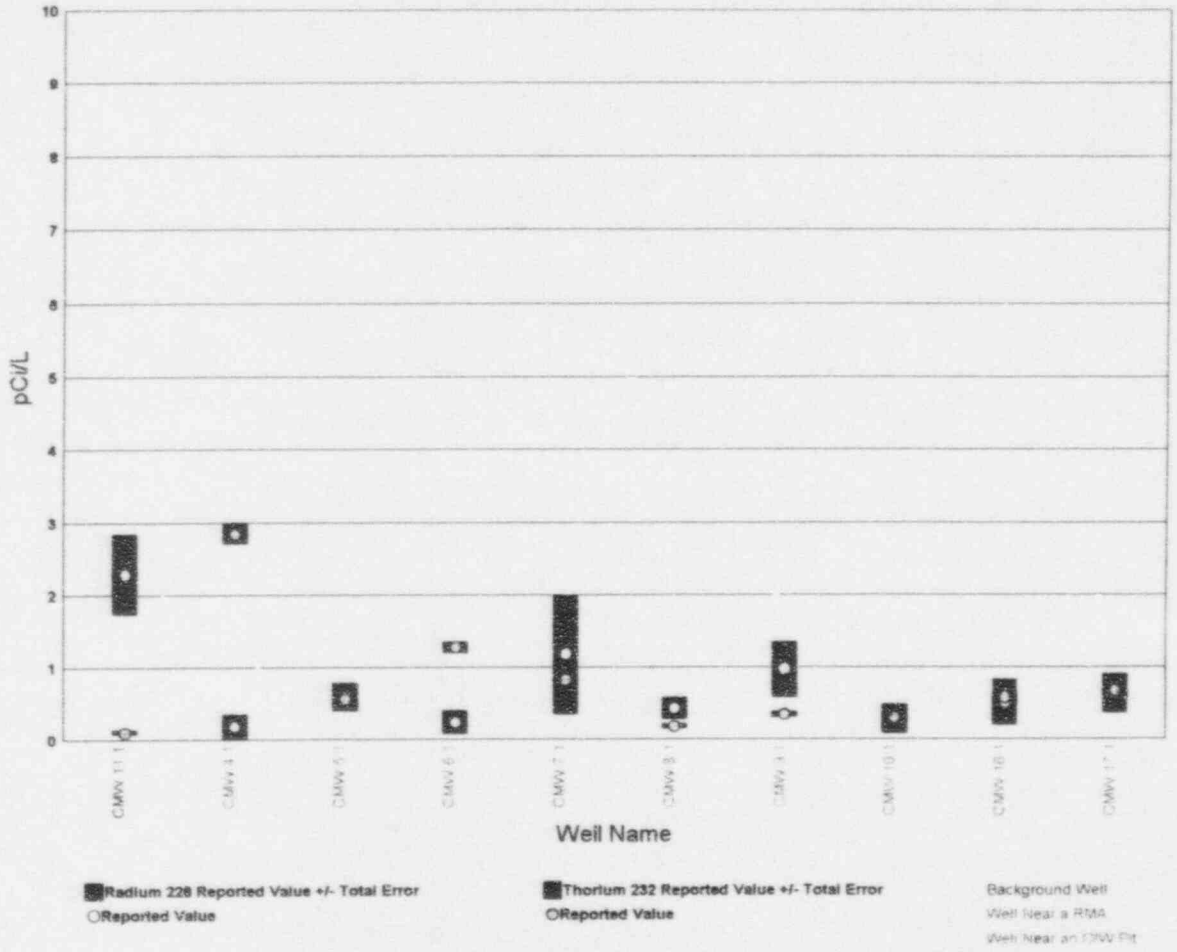


GRANT ENVIRONMENTAL
consulting and engineering
DENVER, COLORADO

FIGURE 1

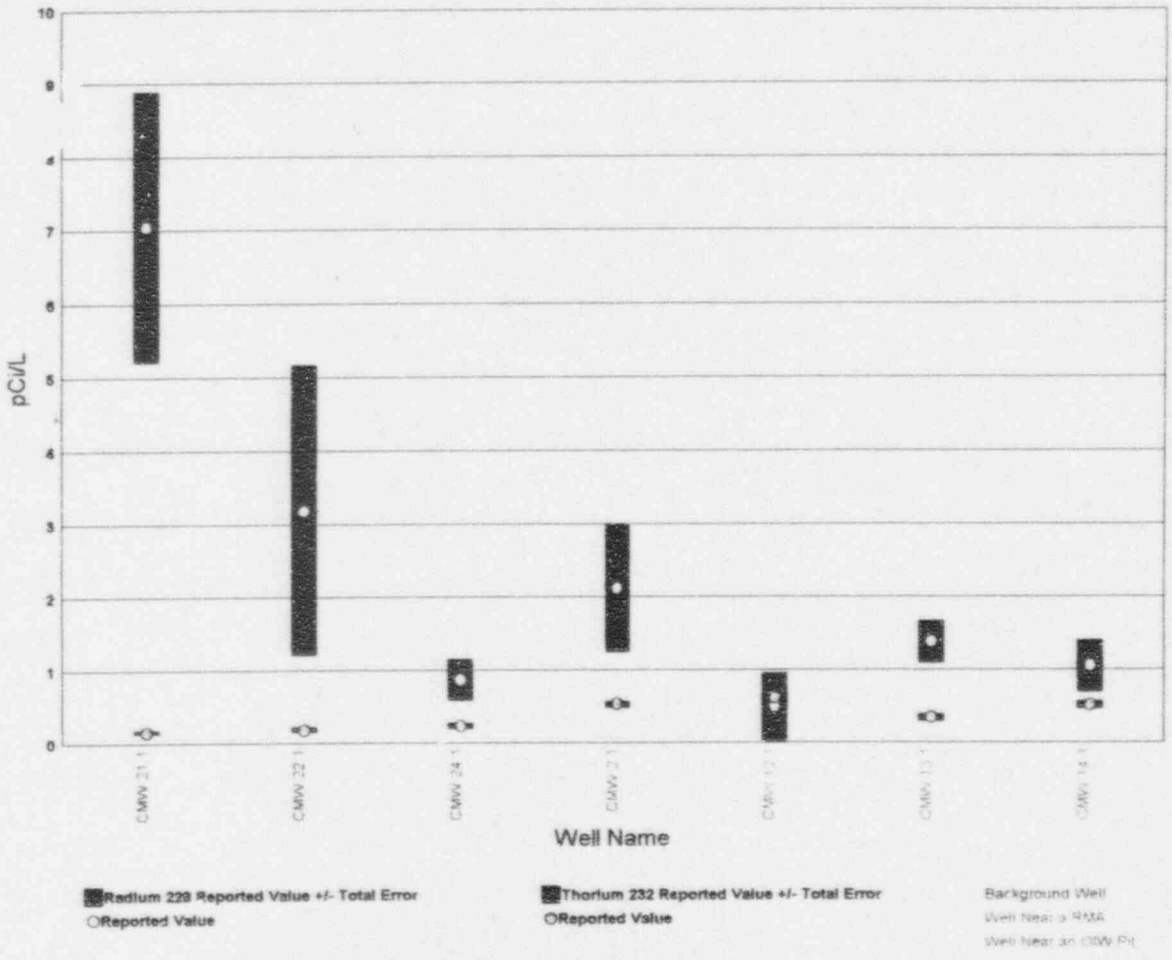
FACILITY LOCATION MAP


880
880
870
860
870
850
840
860
820
830
840
850
860
870
880
850
850
870
880
LEGEND
PROPERTY BOUNDARY
POTENTIOMETRIC CONTOUR
TOPOGRAPHIC CONTOUR
MONITORING WELL
NOTE:
SCALE IN FEET
POTENTIOMETRIC SURFACE MA
UPPER ZONE
GRANT



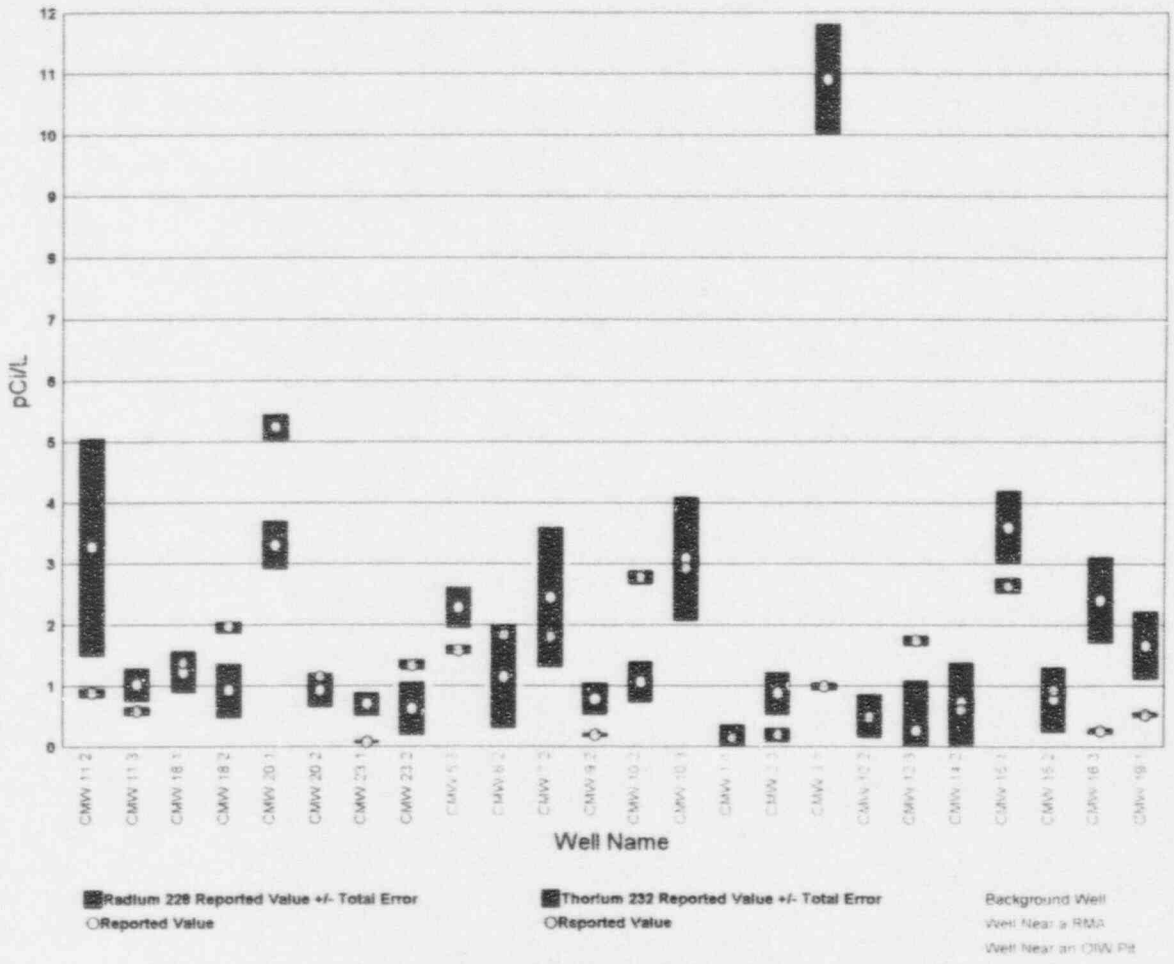
GRANT ENVIRONMENTAL
consulting and engineering
DENVER, COLORADO

FIGURE 3
1990 GROUNDWATER DATA -
UNCONSOLIDATED SOIL ZONE



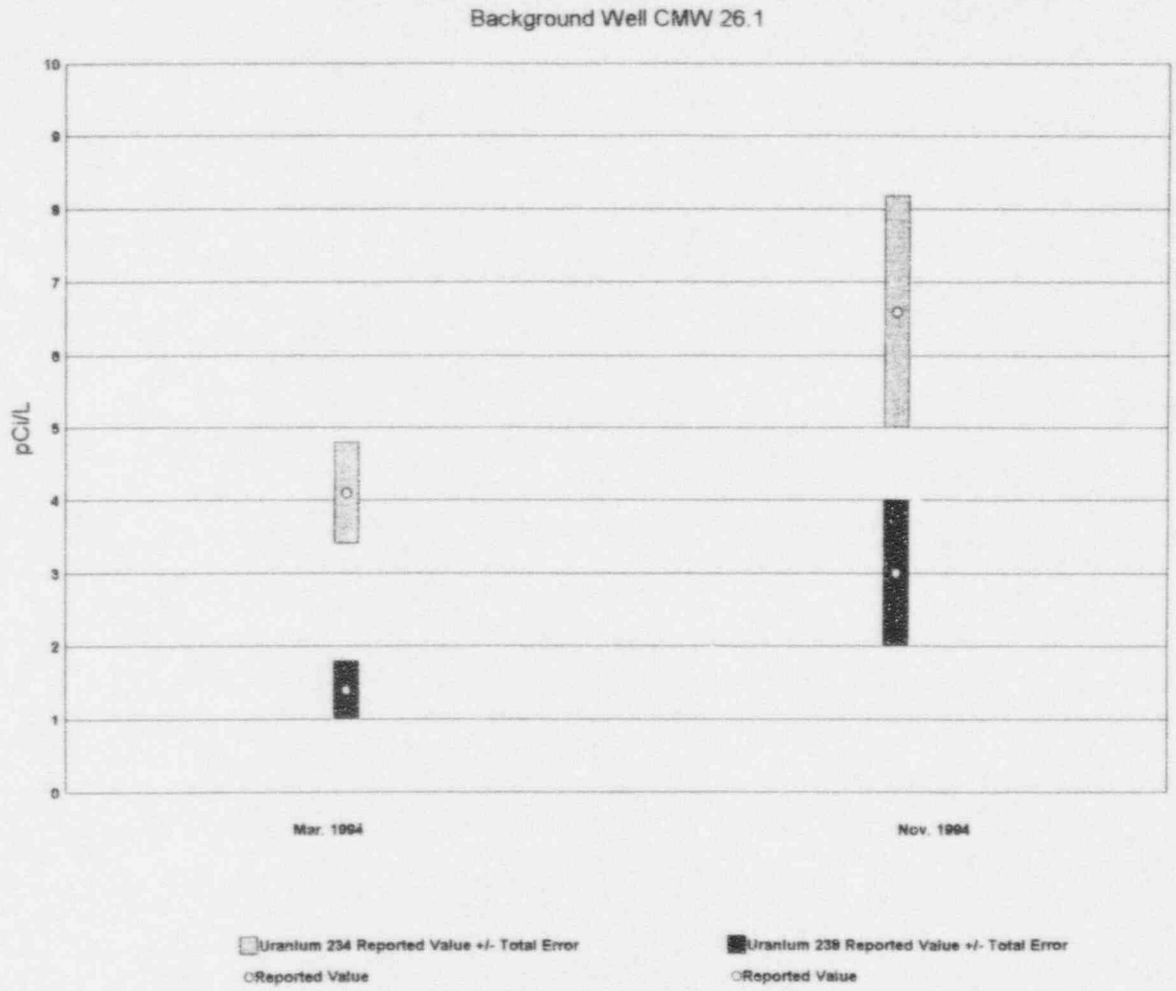
GRANT ENVIRONMENTAL
consulting and engineering
DENVER, COLORADO

FIGURE 4
1990 GROUNDWATER DATA - UPPER VANOSS ZONE



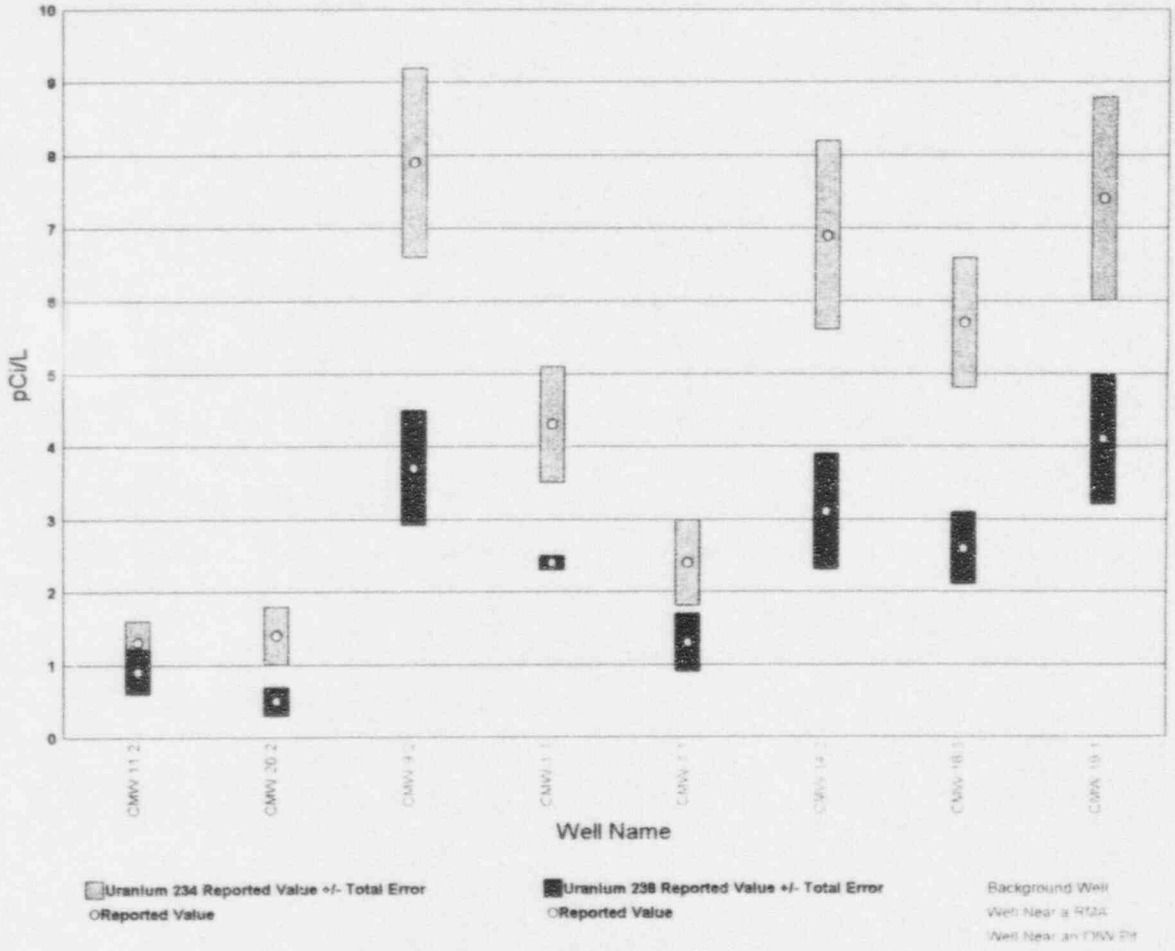
GRANT ENVIRONMENTAL
consulting and engineering
DENVER, COLORADO

FIGURE 5
1990 GROUNDWATER DATA -
LOWER VANOSS ZONE



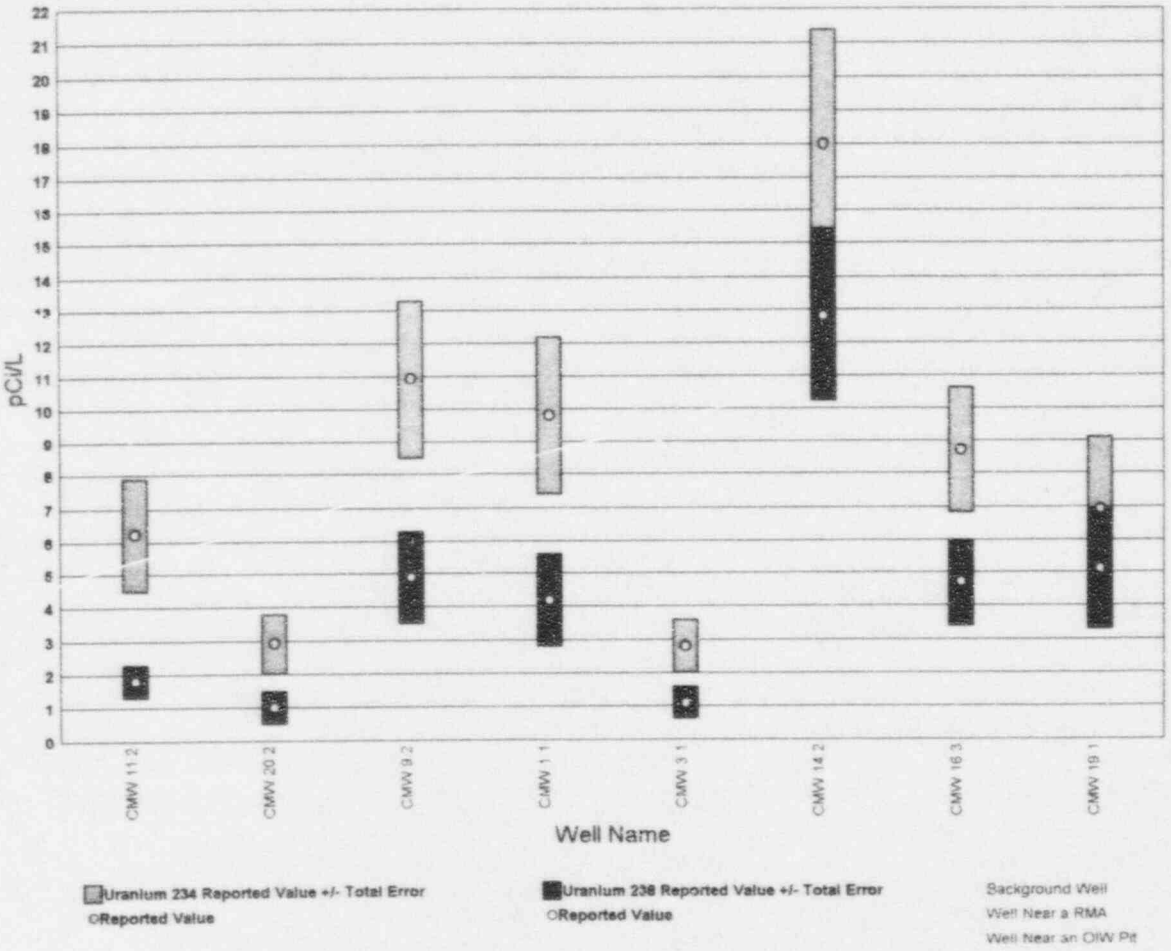
GRANT ENVIRONMENTAL
consulting and engineering
DENVER, COLORADO

FIGURE 6
1994 GROUNDWATER DATA -
UPPER VANOSS ZONE



GRANT ENVIRONMENTAL
consulting and engineering
DENVER, COLORADO

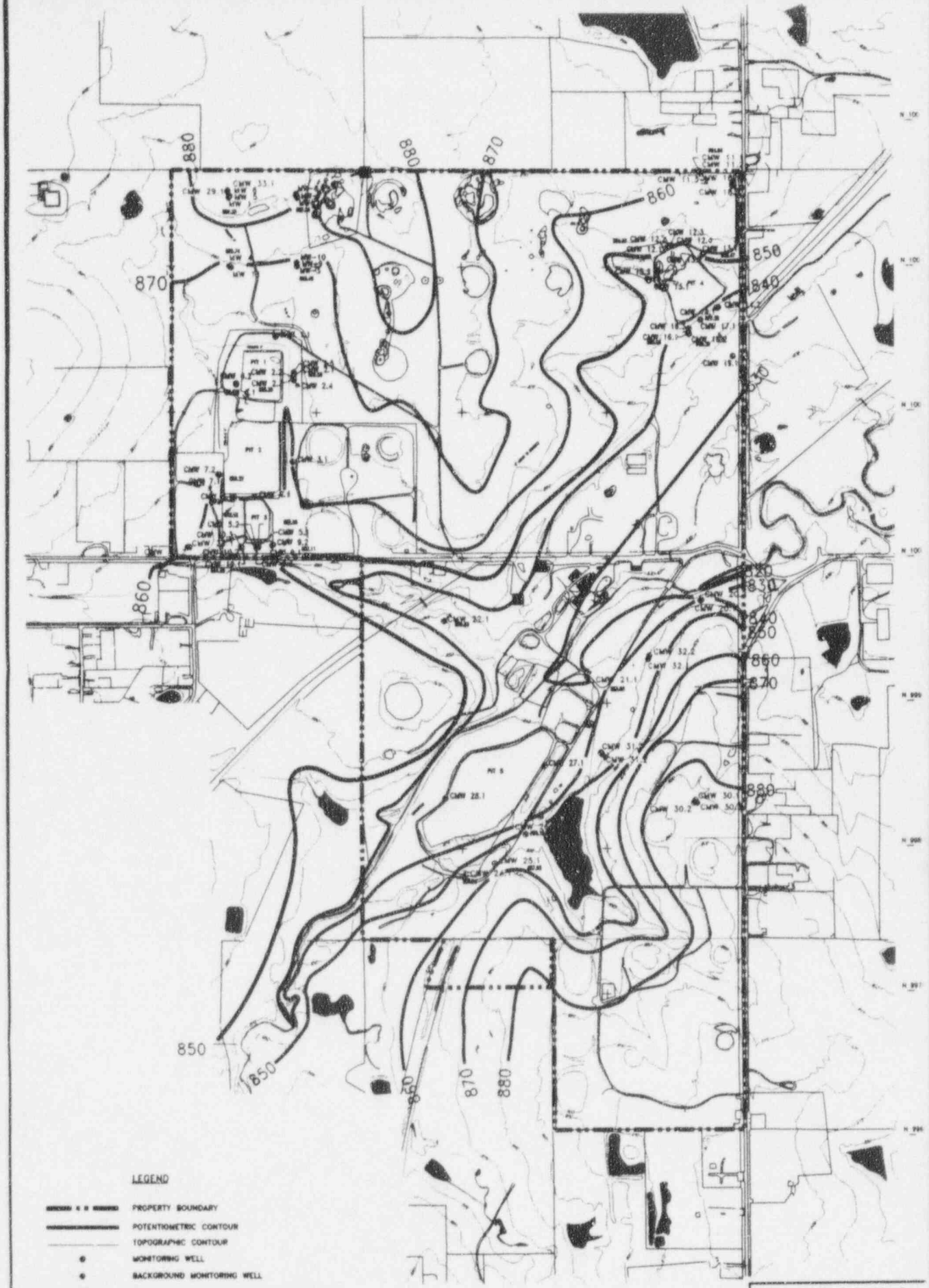
FIGURE 7
MARCH 1994 GROUNDWATER DATA - LOWER VANOSS ZONE

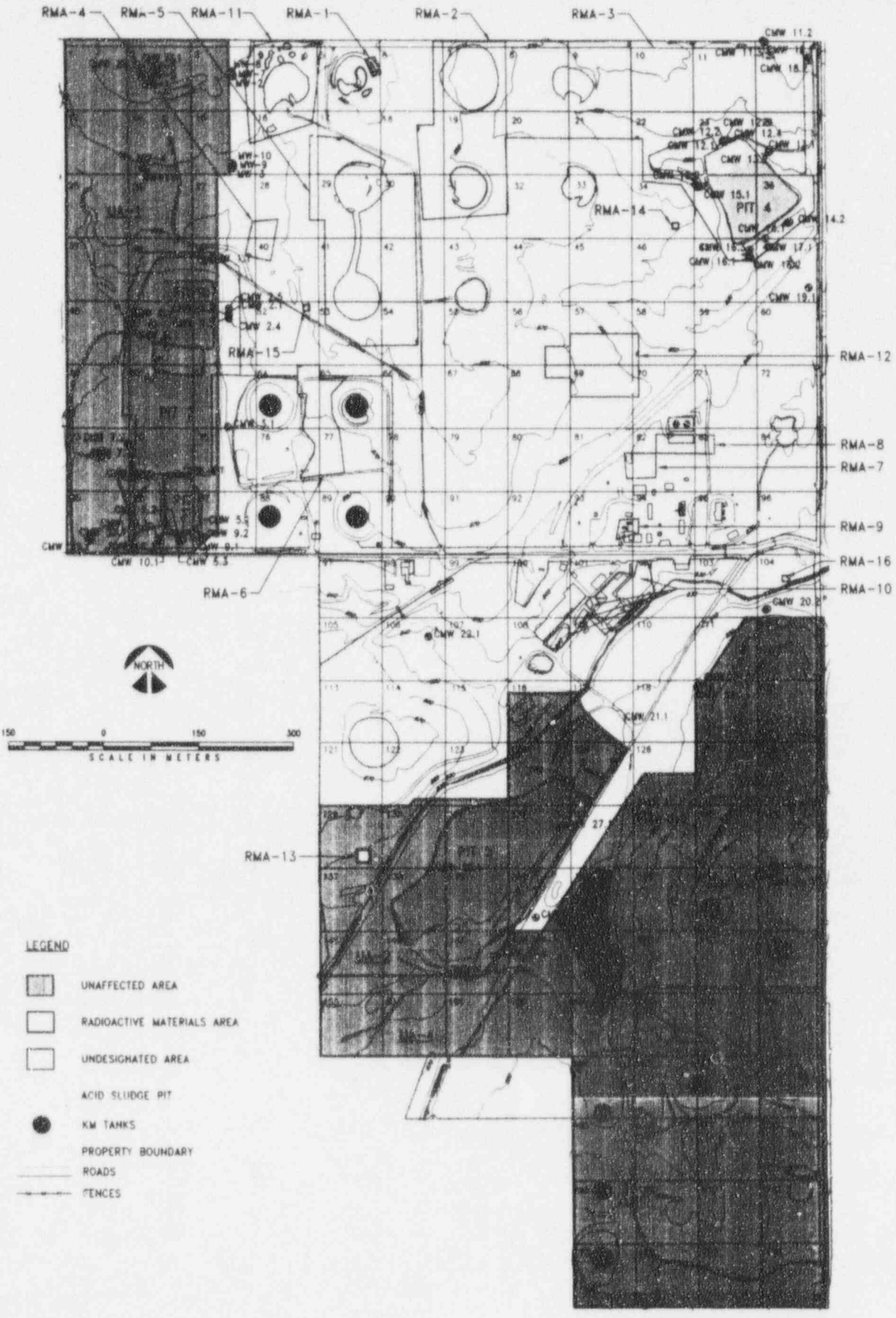


GRANT ENVIRONMENTAL
consulting and engineering
DENVER, COLORADO

FIGURE 8

NOVEMBER 1994 GROUNDWATER DATA - LOWER VANOSS ZONE


880
880
870
860
850
840
870
860
850
840
830
860
870
880
850
850
860
870
880
LEGEND
PROPERTY BOUNDARY
POTENTIOMETRIC CONTOUR
TOPOGRAPHIC CONTOUR
MONITORING WELL
BACKGROUND MONITORING WELL
PROPOSED UPGRADIENT MONITORING WELL CLUSTER
NOTE:
Water Levels measured 4/12/95
in monitoring wells screened
in unconsolidated material
and upper Yahoola Group
SCALE IN FEET
PROPOSED BACKGROUND
MONITORING WELLS
GRANT



GRANT ENVIRONMENTAL
consulting and engineering
DENVER, COLORADO

FIGURE 10

RADIOACTIVE MATERIALS AREAS

FIGURE 11

CONCEPTUAL MODEL: SOIL SAMPLING AT RMAS

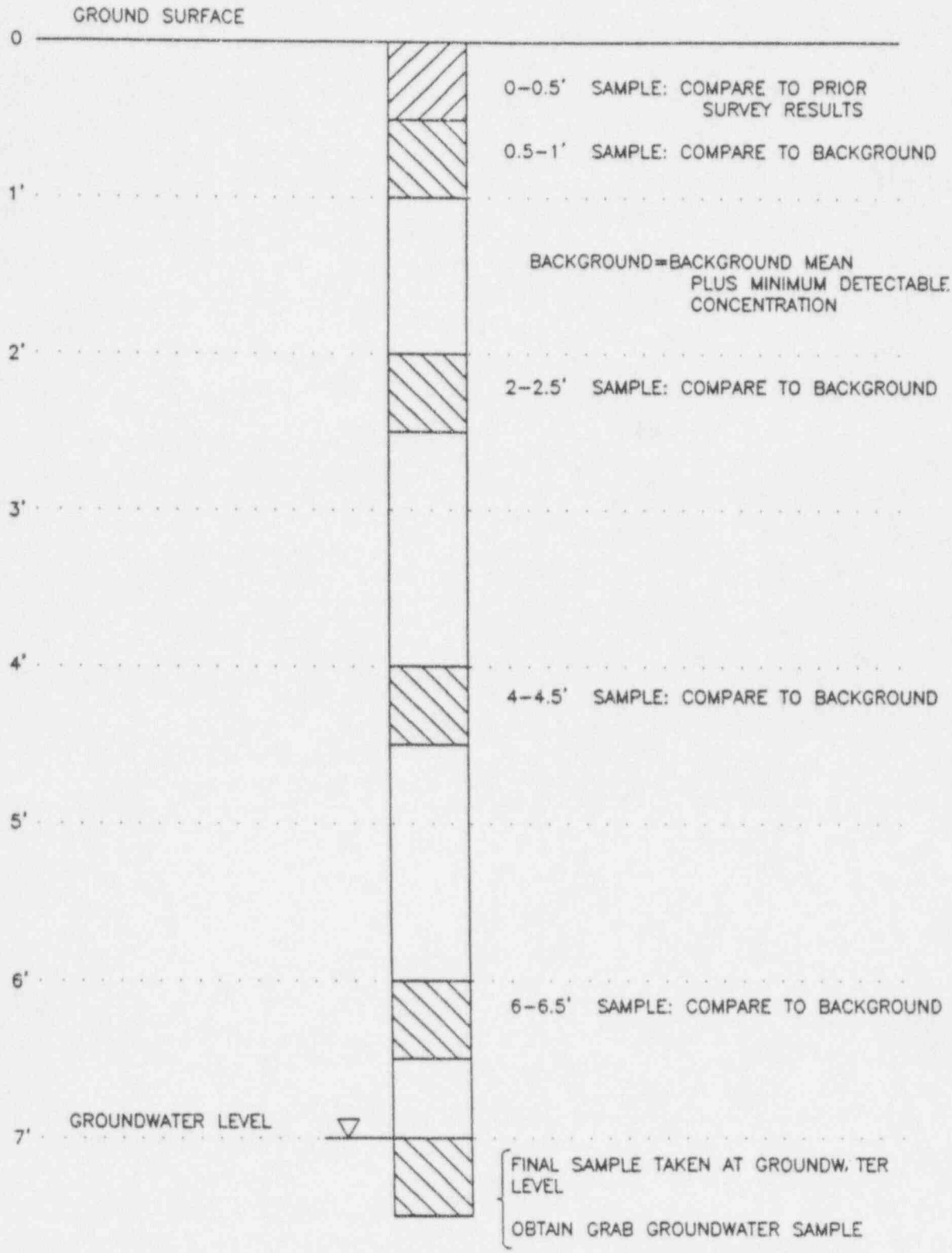


FIGURE 12

CONCEPTUAL MODEL: RMA-3 / PIT-4 PLAN VIEW

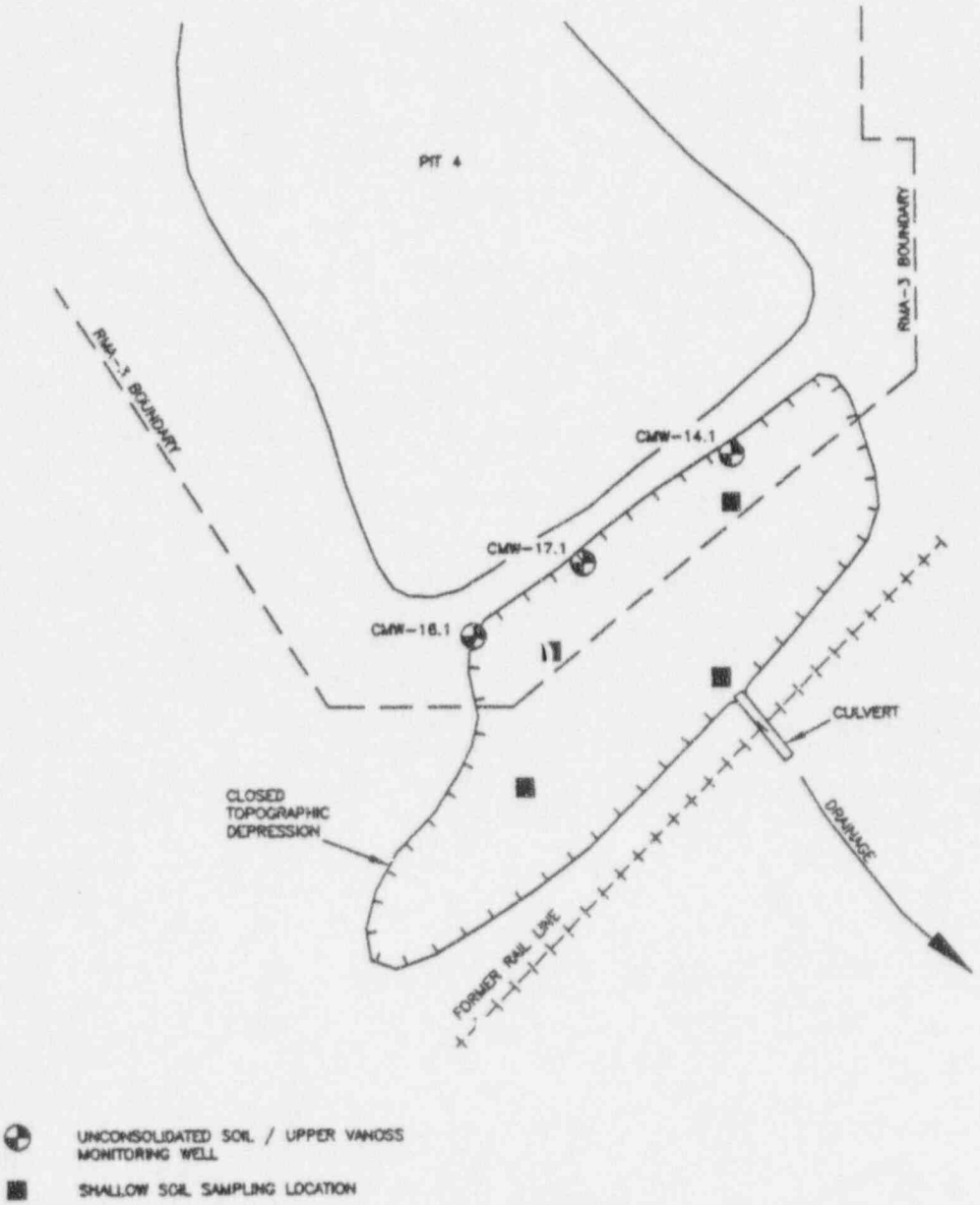
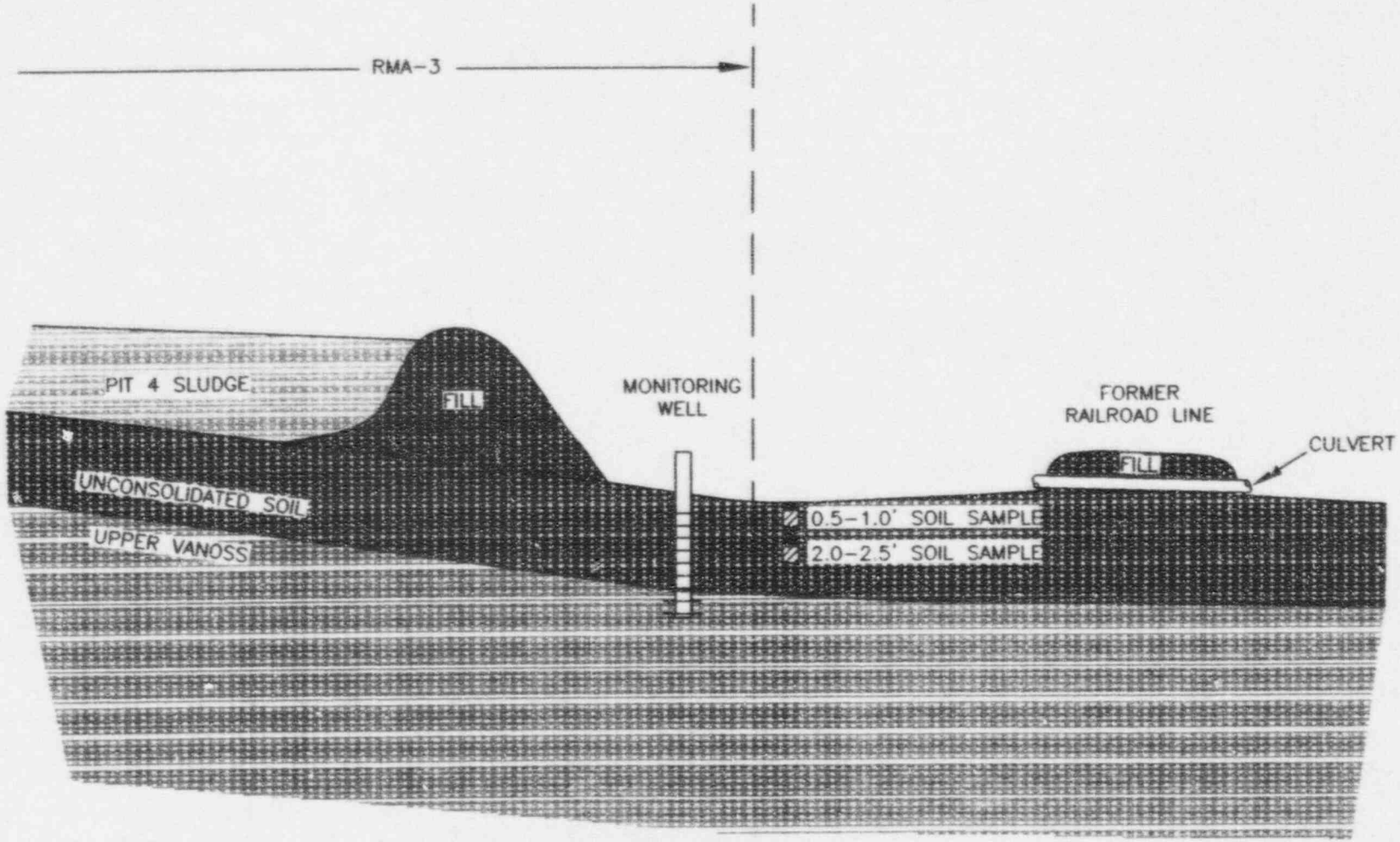
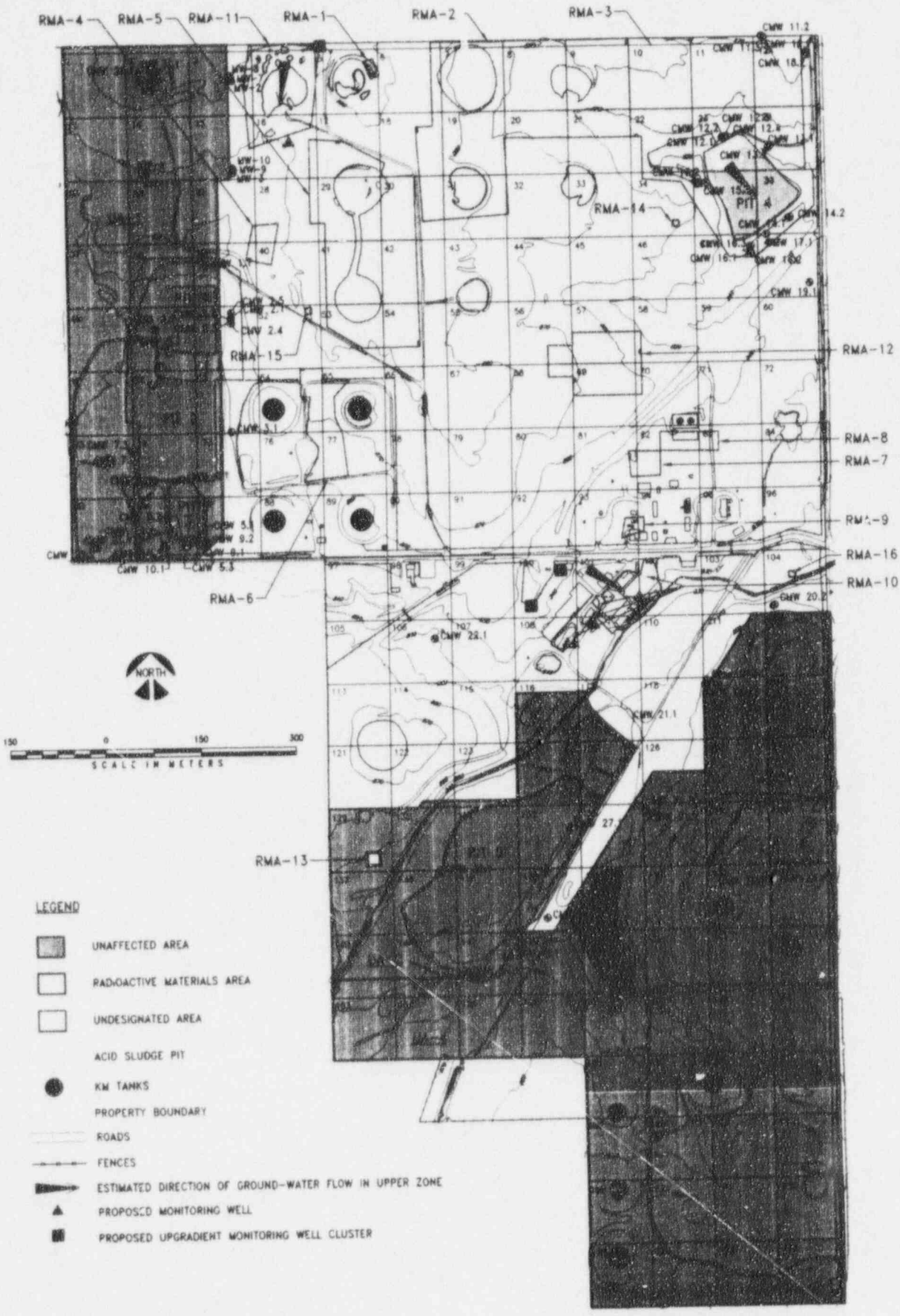


FIGURE 13

CONCEPTUAL MODEL: RMA-3 / PIT-4 CROSS-SECTION





GRANT ENVIRONMENTAL
consulting and engineering
DENVER, COLORADO

FIGURE 14

PROPOSED
MONITORING WELL LOCATIONS

EXISTING WATER QUALITY DATA

March 1990 Groundwater Sampling

Well Number	Isotope	Total	Total Uncertainty (+/-)	Units	Method
Monitoring Wells Screened in Unconsolidated Materials					
CMW 4.1	Ra 226	7.40	---	pCi/L	903.0
	Ra 226 -K	0.00	0.15	pCi/L	KMTC-205-RA-7
	Ra 228	0.18	0.17	pCi/L	904.0
	Th 230	2.80	0.12	pCi/L	KMTC-162-TH-3
	Th 232	2.83	0.12	pCi/L	KMTC-162-TH-3
	U	0.015	NA	mg/L	KMTC-229-U-19
CMW 5.1	Ra 226	3.29	---	pCi/L	903.0
	Ra 226 -K	0.24	0.12	pCi/L	KMTC-205-RA-7
	Ra 228	0.58	0.19	pCi/L	904.0
	Th 230	1.08	0.07	pCi/L	KMTC-162-TH-3
	Th 232	0.55	0.05	pCi/L	KMTC-162-TH-3
	U	0.005	NA	mg/L	KMTC-229-U-19
CMW 6.1	Ra 226	2.43	---	pCi/L	903.0
	Ra 226 -K	0.67	0.18	pCi/L	KMTC-205-RA-7
	Ra 228	0.23	0.16	pCi/L	904.0
	Th 230	1.49	0.07	pCi/L	KMTC-162-TH-3
	Th 232	1.27	0.07	pCi/L	KMTC-162-TH-3
	U	0.054	NA	mg/L	KMTC-229-U-19
CMW 7.1	Ra 226	5.98	---	pCi/L	903.0
	Ra 226 -K	0.71	0.68	pCi/L	KMTC-205-RA-7
	Ra 228	1.17	0.82	pCi/L	904.0
	Th 230	0.93	0.06	pCi/L	KMTC-162-TH-3
	Th 23[illegible]	0.81	0.05	pCi/L	KMTC-162-TH-3
	U	0.062	NA	mg/L	KMTC-229-U-19
CMW 8.1	Ra 226	0.96	---	pCi/L	903.0
	Ra 226 -K	0.20	0.15	pCi/L	KMTC-205-RA-7
	Ra 228	0.43	0.15	pCi/L	904.0
	Th 230	0.19	0.03	pCi/L	KMTC-162-TH-3
	Th 232	0.18	0.03	pCi/L	KMTC-162-TH-3
	U	0.012	NA	mg/L	KMTC-229-U-19
CMW 9.1	Ra 226	1.99	---	pCi/L	903.0
	Ra 226 -K	0.41	0.33	pCi/L	KMTC-205-RA-7
	Ra 228	0.96	0.38	pCi/L	904.0
	Th 230	0.12	0.02	pCi/L	KMTC-162-TH-3
	Th 232	0.34	0.03	pCi/L	KMTC-162-TH-3
	U	0.005	NA	mg/L	KMTC-229-U-19

LLD = Lower Limit of Detection

Analyzed by Kerr-McGee Technical Center, LLD information archived

pCi/g = picocuries per liter --- = uncertainty value not provided

mg/L = milligrams per liter NA = not applicable

EXISTING WATER QUALITY DATA

March 1990 Groundwater Sampling

Well Number	Isotope	Total	Total Uncertainty (+/-)	Units	Method
Monitoring Wells Screened in Unconsolidated Materials					
CMW 10.1	Ra 226	0.68	---	pCi/L	903.0
	Ra 226 -K	0.12	0.18	pCi/L	KMTC-205-RA-7
	Ra 228	0.28	0.20	pCi/L	904.0
	Th 230	0.33	0.03	pCi/L	KMTC-162-TH-3
	Th 232	0.29	0.03	pCi/L	KMTC-162-TH-3
	U	0.02	NA	mg/L	KMTC-229-U-19
CMW 11.1	Ra 226	6.82	---	pCi/L	903.0
	Ra 226 -K	1.28	0.40	pCi/L	KMTC-205-RA-7
	Ra 228	2.28	0.56	pCi/L	904.0
	Th 230	0.08	0.02	pCi/L	KMTC-162-TH-3
	Th 232	0.10	0.02	pCi/L	KMTC-162-TH-3
	U	<.005	NA	mg/L	KMTC-229-U-19
CMW 16.1	Ra 226	3.27	---	pCi/L	903.0
	Ra 226 -K	0.14	0.15	pCi/L	KMTC-205-RA-7
	Ra 228	0.51	0.31	pCi/L	904.0
	Th 230	0.48	0.05	pCi/L	KMTC-162-TH-3
	Th 232	0.58	0.05	pCi/L	KMTC-162-TH-3
	U	<.005	NA	mg/L	KMTC-229-U-19
CMW 17.1	Ra 226	2.50	---	pCi/L	903.0
	Ra 226 -K	0.006	0.017	pCi/L	KMTC-205-RA-7
	Ra 228	0.63	0.27	pCi/L	904.0
	Th 230	0.48	0.05	pCi/L	KMTC-162-TH-3
	Th 232	0.66	0.05	pCi/L	KMTC-162-TH-3
	U	0.005	NA	mg/L	KMTC-229-U-19
Monitoring Wells Screened in Upper Vanoss Zone					
CMW 2.1	Ra 226	5.49	---	pCi/L	903.0
	Ra 226 -K	1.55	0.76	pCi/L	KMTC-205-RA-7
	Ra 228	2.11	0.89	pCi/L	904.0
	Th 230	0.52	0.04	pCi/L	KMTC-162-TH-3
	Th 232	0.52	0.04	pCi/L	KMTC-162-TH-3
	U	<.005	NA	mg/L	KMTC-229-U-19
CMW 12.1	Ra 226	2.36	---	pCi/L	903.0
	Ra 226 -K	0.19	0.25	pCi/L	KMTC-205-RA-7
	Ra 228	0.49	0.46	pCi/L	904.0
	Th 230	0.75	0.05	pCi/L	KMTC-162-TH-3
	Th 232	0.61	0.05	pCi/L	KMTC-162-TH-3
	U	<.005	NA	mg/L	KMTC-229-U-19

Analyzed by Kerr-McGee Technical Center, LLD information archived

pCi/g = picocuries per liter --- = uncertainty value not provided

mg/L = milligrams per liter NA = not applicable

EXISTING WATER QUALITY DATA

March 1990 Groundwater Sampling

Well Number	Isotope	Total	Total Uncertainty (+/-)	Units	Method
Monitoring Wells Screened in Upper Vanoss Zone					
CMW 13.1	Ra 226	3.63	---	pCi/L	903.0
	Ra 226 -K	0.75	0.26	pCi/L	KMTC-205-RA-7
	Ra 228	1.37	0.29	pCi/L	904.0
	Th 230	0.22	0.03	pCi/L	KMTC-162-TH-3
	Th 232	0.34	0.04	pCi/L	KMTC-162-TH-3
	U	0.02	NA	mg/L	KMTC-229-U-19
CMW 14.1	Ra 226	13.6	---	pCi/L	903.0
	Ra 226 -K	0.39	0.21	pCi/L	KMTC-205-RA-7
	Ra 228	1.04	0.36	pCi/L	904.0
	Th 230	0.40	0.04	pCi/L	KMTC-162-TH-3
	Th 232	0.51	0.05	pCi/L	KMTC-162-TH-3
	U	<.005	NA	mg/L	KMTC-229-U-19
CMW 21.1	Ra 226	8.50	---	pCi/L	903.0
	Ra 226 -K	7.48	1.96	pCi/L	KMTC-205-RA-7
	Ra 228	7.05	1.84	pCi/L	904.0
	Th 230	0.15	0.03	pCi/L	KMTC-162-TH-3
	Th 232	0.15	0.03	pCi/L	KMTC-162-TH-3
	U	0.008	NA	mg/L	KMTC-229-U-19
CMW 22.1	Ra 226	4.56	---	pCi/L	903.0
	Ra 226 -K	- - -	- - -	pCi/L	KMTC-205-RA-7
	Ra 228	3.18	1.99	pCi/L	904.0
	Th 230	0.10	0.02	pCi/L	KMTC-162-TH-3
	Th 232	0.18	0.03	pCi/L	KMTC-162-TH-3
	U	<.005	NA	mg/L	KMTC-229-U-19
CMW 24.1	Ra 226	1.24	---	pCi/L	903.0
	Ra 226 -K	0.77	0.30	pCi/L	KMTC-205-RA-7
	Ra 228	0.86	0.29	pCi/L	904.0
	Th 230	0.25	0.03	pCi/L	KMTC-162-TH-3
	Th 232	0.23	0.03	pCi/L	KMTC-162-TH-3
	U	0.005	NA	mg/L	KMTC-229-U-19
Monitoring Wells Screened in Lower Vanoss Zone					
CMW 1.1	Ra 226	0.38	---	pCi/L	903.0
	Ra 226 -K	0.22	0.15	pCi/L	KMTC-205-RA-7
	Ra 228	0.15	0.21	pCi/L	904.0
	Th 230	0.06	0.02	pCi/L	KMTC-162-TH-3
	Th 232	0.13	0.02	pCi/L	KMTC-162-TH-3
	U	0.007	NA	mg/L	KMTC-229-U-19

Analyzed by Kerr-McGee Technical Center, LLD information archived

pCi/g = picocuries per liter --- = uncertainty value not provided

mg/L = milligrams per liter NA = not applicable

EXISTING WATER QUALITY DATA

March 1990 Groundwater Sampling

Well Number	Isotope	Total	Total Uncertainty (+/-)	Units	Method
Monitoring Wells Screened in Lower Vanoss Zone					
CMW 2.3	Ra 226	18.1	---	pCi/L	903.0
	Ra 226 -K	0.36	0.30	pCi/L	KMTC-205-RA-7
	Ra 228	0.87	0.35	pCi/L	904.0
	Th 230	1.70	0.10	pCi/L	KMTC-162-TH-3
	Th 232	0.19	0.11	pCi/L	KMTC-162-TH-3
	U	0.011	NA	mg/L	KMTC-229-U-19
CMW 3.1	Ra 226	15.3	---	pCi/L	903.0
	Ra 226 -K	5.26	0.60	pCi/L	KMTC-205-RA-7
	Ra 228	10.9	0.90	pCi/L	904.0
	Th 230	0.70	0.05	pCi/L	KMTC-162-TH-3
	Th 232	0.98	0.06	pCi/L	KMTC-162-TH-3
	U	0.01	NA	mg/L	KMTC-229-U-19
CMW 5.3	Ra 226	23.9	---	pCi/L	903.0
	Ra 226 -K	1.63	0.33	pCi/L	KMTC-205-RA-7
	Ra 228	2.28	0.34	pCi/L	904.0
	Th 230	1.91	0.08	pCi/L	KMTC-162-TH-3
	Th 232	1.58	0.07	pCi/L	KMTC-162-TH-3
	U	0.017	NA	mg/L	KMTC-229-U-19
CMW 6.2	Ra 226	7.18	---	pCi/L	903.0
	Ra 226 -K	0.39	0.64	pCi/L	KMTC-205-RA-7
	Ra 228	1.13	0.83	pCi/L	904.0
	Th 230	1.57	0.16	pCi/L	KMTC-162-TH-3
	Th 232	1.84	0.14	pCi/L	KMTC-162-TH-3
	U	< 005	NA	mg/L	KMTC-229-U-19
CMW 7.2	Ra 226	13.5	---	pCi/L	903.0
	Ra 226 -K	1.43	0.92	pCi/L	KMTC-205-RA-7
	Ra 228	2.44	1.15	pCi/L	904.0
	Th 230	1.63	0.06	pCi/L	KMTC-162-TH-3
	Th 232	1.79	0.07	pCi/L	KMTC-162-TH-3
	U	0.015	NA	mg/L	KMTC-229-U-19
CMW 9.2	Ra 226	2.05	---	pCi/L	903.0
	Ra 226 -K	0.38	0.24	pCi/L	KMTC-205-RA-7
	Ra 228	0.77	0.26	pCi/L	904.0
	Th 230	0.12	0.02	pCi/L	KMTC-162-TH-3
	Th 232	0.19	0.03	pCi/L	KMTC-162-TH-3
	U	0.005	NA	mg/L	KMTC-229-U-19

Analyzed by Kerr-McGee Technical Center, LLD information archived

pCi/g = picocuries per liter --- = uncertainty value not provided

mg/L = milligrams per liter NA = not applicable

EXISTING WATER QUALITY DATA

March 1990 Groundwater Sampling

Well Number	Isotope	Total	Total Uncertainty (+/-)	Units	Method
Monitoring Wells Screened in Lower Vanoss Zone					
CMW 10.2	Ra 226	16.1	---	pCi/L	903.0
	Ra 226 -K	0.46	0.22	pCi/L	KMTC-205-RA-7
	Ra 228	1.05	0.34	pCi/L	904.0
	Th 230	2.45	0.10	pCi/L	KMTC-162-TH-3
	Th 232	2.77	0.11	pCi/L	KMTC-162-TH-3
	U	0.005	NA	mg/L	KMTC-229-U-19
CMW 10.3	Ra 226	11.1	---	pCi/L	903.0
	Ra 226 -K	1.51	0.67	pCi/L	KMTC-205-RA-7
	Ra 228	3.07	1.01	pCi/L	904.0
	Th 230	2.61	0.10	pCi/L	KMTC-162-TH-3
	Th 232	2.91	0.10	pCi/L	KMTC-162-TH-3
	U	0.008	NA	mg/L	KMTC-229-U-19
CMW 11.2	Ra 226	17.2	---	pCi/L	903.0
	Ra 226 -K	4.05	1.87	pCi/L	KMTC-205-RA-7
	Ra 228	3.27	1.79	pCi/L	904.0
	Th 230	0.47	0.05	pCi/L	KMTC-162-TH-3
	Th 232	0.87	0.07	pCi/L	KMTC-162-TH-3
	U	0.009	NA	mg/L	KMTC-229-U-19
CMW 11.3	Ra 226	4.02	---	pCi/L	903.0
	Ra 226 -K	0.61	0.21	pCi/L	KMTC-205-RA-7
	Ra 228	1.01	0.27	pCi/L	904.0
	Th 230	0.55	0.06	pCi/L	KMTC-162-TH-3
	Th 232	0.57	0.06	pCi/L	KMTC-162-TH-3
	U	<.005	NA	mg/L	KMTC-229-U-19
CMW 12.2	Ra 226	4.30	---	pCi/L	903.0
	Ra 226 -K	0.49	0.35	pCi/L	KMTC-205-RA-7
	Ra 228	0.50	0.36	pCi/L	904.0
	Th 230	0.39	0.04	pCi/L	KMTC-162-TH-3
	Th 232	0.48	0.04	pCi/L	KMTC-162-TH-3
	U	0.007	NA	mg/L	KMTC-229-U-19
CMW 12.3	Ra 226	12.5	---	pCi/L	903.0
	Ra 226 -K	0.77	0.12	pCi/L	KMTC-205-RA-7
	Ra 228	0.25	0.83	pCi/L	904.0
	Th 230	2.22	0.09	pCi/L	KMTC-162-TH-3
	Th 232	1.73	0.08	pCi/L	KMTC-162-TH-3
	U	0.012	NA	mg/L	KMTC-229-U-19

Analyzed by Kerr-McGee Technical Center, LLD information archived

pCi/g = picocuries per liter --- = uncertainty value not provided

mg/L = milligrams per liter NA = not applicable

EXISTING WATER QUALITY DATA

March 1990 Groundwater Sampling

Well Number	Isotope	Total	Total Uncertainty (+/-)	Units	Method
Monitoring Wells Screened in Lower Vanoss Zone					
CMW 14.2	Ra 226	2.56	---	pCi/L	903.0
	Ra 226 -K	0.28	0.87	pCi/L	KMTC-205-RA-7
	Ra 228	0.71	0.67	pCi/L	904.0
	Th 230	0.71	0.05	pCi/L	KMTC-162-TH-3
	Th 232	0.59	0.05	pCi/L	KMTC-162-TH-3
	U	0.027	NA	mg/L	KMTC-229-U-19
CMW 15.1	Ra 226	12.9	---	pCi/L	903.0
	Ra 226 -K	2.22	0.42	pCi/L	KMTC-205-RA-7
	Ra 228	3.59	0.60	pCi/L	904.0
	Th 230	[illegible]	0.13	pCi/L	KMTC-162-TH-3
	Th 232	6	0.12	pCi/L	KMTC-162-TH-3
	U	0.[illegible]	NA	mg/L	KMTC-229-U-19
CMW 15.2	Ra 226	5.28	---	pCi/L	903.0
	Ra 226 -K	0.72	0.42	pCi/L	KMTC-205-RA-7
	Ra 228	0.77	0.53	pCi/L	904.0
	Th 230	0.75	0.05	pCi/L	KMTC-162-TH-3
	Th 232	0.91	0.06	pCi/L	KMTC-162-TH-3
	U	<.005	NA	mg/L	KMTC 229-U-19
CMW 16.3	Ra 226	3.14	---	pCi/L	903.0
	Ra 226 -K	1.15	0.44	pCi/L	KMTC-205-RA-7
	Ra 228	2.40	0.71	pCi/L	904.0
	Th 230	0.31	0.04	pCi/L	KMTC-162-TH-3
	Th 232	0.26	0.04	pCi/L	KMTC-162-TH-3
	U	0.018	NA	mg/L	KMTC-229-U-19
CMW 18.1	Ra 226	5.39	---	pCi/L	903.0
	Ra 226 -K	1.05	0.29	pCi/L	KMTC-205-RA-7
	Ra 228	1.21	0.34	pCi/L	904.0
	Th 230	1.11	0.07	pCi/L	KMTC-162-TH-3
	Th 232	1.38	0.08	pCi/L	KMTC-162-TH-3
	U	0.006	NA	mg/L	KMTC-229-U-19
CMW 18.2	Ra 226	7.90	---	pCi/L	903.0
	Ra 226 -K	0.48	0.34	pCi/L	KMTC-205-RA-7
	Ra 228	0.91	0.45	pCi/L	904.0
	Th 230	2.24	0.09	pCi/L	KMTC-162-TH-3
	Th 232	1.95	0.09	pCi/L	KMTC-162-TH-3
	U	0.006	NA	mg/L	KMTC-229-U-19

Analyzed by Kerr-McGee Technical Center, LLD information archived

pCi/g = picocuries per liter --- = uncertainty value not provided

mg/L = milligrams per liter NA = not applicable

EXISTING WATER QUALITY DATA

March 1990 Groundwater Sampling

Well Number	Isotope	Total	Total Uncertainty (+/-)	Units	Method
Monitoring Wells Screened in Lower Vanoss Zone					
CMW 19.1	Ra 226	1.17	---	pCi/L	903.0
	Ra 226 -K	1.19	0.54	pCi/L	KMTC-205-RA-7
	Ra 228	1.65	0.56	pCi/L	904.0
	Th 230	0.31	0.03	pCi/L	KMTC-162-TH-3
	Th 232	0.52	0.04	pCi/L	KMTC-162-TH-3
	U	0.009	NA	mg/L	KMTC-229-U-19
CMW 20.1	Ra 226	20.2	---	pCi/L	903.0
	Ra 226 -K	1.96	0.38	pCi/L	KMTC-205-RA-7
	Ra 228	3.30	0.40	pCi/L	904.0
	Th 230	2.10	0.14	pCi/L	KMTC-162-TH-3
	Th 232	5.23	0.21	pCi/L	KMTC-162-TH-3
	U	0.011	NA	mg/L	KMTC-229-U-19
CMW 20.2	Ra 226	1.36	---	pCi/L	903.0
	Ra 226 -K	0.69	0.27	pCi/L	KMTC-205-RA-7
	Ra 228	0.91	0.28	pCi/L	904.0
	Th 230	0.72	0.06	pCi/L	KMTC-162-TH-3
	Th 232	1.13	0.07	pCi/L	KMTC-162-TH-3
	U	0.005	NA	mg/L	KMTC-229-U-19
CMW 23.1	Ra 226	0.39	---	pCi/L	903.0
	Ra 226 -K	0.54	0.12	pCi/L	KMTC-205-RA-7
	Ra 228	0.69	0.19	pCi/L	904.0
	Th 230	0.06	0.02	pCi/L	KMTC-162-TH-3
	Th 232	0.07	0.02	pCi/L	KMTC-162-TH-3
	U	0.012	NA	mg/L	KMTC-229-U-19
CMW 23.2	Ra 226	4.57	---	pCi/L	903.0
	Ra 226 -K	0.53	0.40	pCi/L	KMTC-205-RA-7
	Ra 228	0.61	0.44	pCi/L	904.0
	Th 230	1.49	0.08	pCi/L	KMTC-162-TH-3
	Th 232	1.34	0.08	pCi/L	KMTC-162-TH-3
	U	<.005	NA	mg/L	KMTC-229-U-19

Analyzed by Kerr-McGee Technical Center, LLD information archived

pCi/g = picocuries per liter --- = uncertainty value not provided

mg/L = milligrams per liter NA = not applicable

EXISTING WATER QUALITY DATA

March 1994 Groundwater Sampling

Well Number	Isotope	Total	Total Uncertainty (+/-)	Total LLD	Units	Method
Monitoring Wells Screened in the Upper Vanoss Zone						
CMW 26.1	Th 228	1.1	0.3	0.1	pCi/L	907.0
	Th 230	0.6	0.3	0.5	pCi/L	907.0
	Th 232	0.4	0.2	0.1	pCi/L	907.0
	U 234	4.1	0.7	0.2	pCi/L	908.0
	U 235	ND	0.1	0.2	pCi/L	908.0
	U 238	1.4	0.4	0.2	pCi/L	908.0
Monitoring Wells Screened in the Lower Vanoss Zone						
CMW 1.1	Th 228	0.4	0.3	0.2	pCi/L	907.0
	Th 230	0.3	0.3	0.5	pCi/L	907.0
	Th 232	0.3	0.2	0.2	pCi/L	907.0
	U 234	4.3	0.8	0.3	pCi/L	908.0
	U 235	0.1	0.1	0.1	pCi/L	908.0
	U 238	2.4	0.1	0.2	pCi/L	908.0
CMW 3.1	Th 228	0.4	0.2	0.2	pCi/L	907.0
	Th 230	0.1	0.2	0.4	pCi/L	907.0
	Th 232	0.1	0.1	0.1	pCi/L	907.0
	U 234	2.4	0.6	0.1	pCi/L	908.0
	U 235	0.1	0.1	0.1	pCi/L	908.0
	U 238	1.3	0.4	0.1	pCi/L	908.0
CMW 9.2	Th 228	0.5	0.2	0.4	pCi/L	907.0
	Th 230	0.5	0.3	0.4	pCi/L	907.0
	Th 232	0.2	0.1	0.2	pCi/L	907.0
	U 234	7.9	1.3	0.3	pCi/L	908.0
	U 235	0.1	0.1	0.3	pCi/L	908.0
	U 238	3.7	0.8	0.2	pCi/L	908.0
CMW 11.2	Th 228	0.3	0.2	0.3	pCi/L	907.0
	Th 230	ND	0.1	0.4	pCi/L	907.0
	Th 232	ND	0.1	0.2	pCi/L	907.0
	U 234	1.3	0.3	0.2	pCi/L	908.0
	U 235	ND	0.1	0.2	pCi/L	908.0
	U 238	0.9	0.3	0.2	pCi/L	908.0
CMW 14.2	Th 228	0.4	0.2	0.4	pCi/L	907.0
	Th 230	0.5	0.3	0.4	pCi/L	907.0
	Th 232	0.2	0.1	0.1	pCi/L	907.0
	U 234	6.9	1.3	0.3	pCi/L	908.0
	U 235	ND	0.1	0.2	pCi/L	908.0
	U 238	3.1	0.8	0.3	pCi/L	908.0

Analyzed by Core Laboratories
LLD = Lower Limit of Detection
pCi/g = picocuries per liter
mg/L = milligrams per liter

EXISTING WATER QUALITY DATA

March 1994 Groundwater Sampling

Well Number	Isotope	Total	Total Uncertainty (+/-)	Total LLD	Units	Method
Monitoring Wells Screened in the Lower Vanoss Zone						
CMW 16.3	Th 228	0.7	0.2	0.3	pCi/L	907.0
	Th 230	0.4	0.3	0.5	pCi/L	907.0
	Th 232	0.4	0.2	0.2	pCi/L	907.0
	U 234	5.7	0.9	0.2	pCi/L	908.0
	U 235	0.2	0.1	0.2	pCi/L	908.0
	U 238	2.6	0.5	0.2	pCi/L	908.0
CMW 19.1	Th 228	1.0	0.3	0.3	pCi/L	907.0
	Th 230	0.2	0.3	0.5	pCi/L	907.0
	Th 232	0.1	0.1	0.2	pCi/L	907.0
	U 234	7.4	1.4	0.5	pCi/L	908.0
	U 235	0.1	0.1	0.3	pCi/L	908.0
	U 238	4.1	0.9	0.4	pCi/L	908.0
CMW 20.2	Th 228	0.9	0.3	0.3	pCi/L	907.0
	Th 230	1.0	0.3	0.5	pCi/L	907.0
	Th 232	0.6	0.3	0.3	pCi/L	907.0
	U 234	1.4	0.4	0.2	pCi/L	908.0
	U 235	ND	0.1	0.1	pCi/L	908.0
	U 238	0.5	0.2	0.2	pCi/L	908.0

November 1994 Groundwater Sampling

Well Number	Isotope	Total	Total Uncertainty (+/-)	Total LLD	Units	Method
Monitoring Wells Screened in the Upper Vanoss Zone						
CMW 26.1	Th 228	2.5	1.5	1.8	pCi/L	HASL-300
	Th 232	1.9	1.3	1.5	pCi/L	HASL-300
	U 234	6.6	1.6	0.6	pCi/L	HASL-300
	U 235	1.3	0.6	0.3	pCi/L	HASL-300
	U 238	3.0	1.0	0.5	pCi/L	HASL-300
Monitoring Wells Screened in the Lower Vanoss Zone						
CMW 1.1	Th 228	0.4	0.4	0.6	pCi/L	HASL-300
	Th 232	0.4	0.4	0.7	pCi/L	HASL-300
	U 234	9.8	2.4	0.6	pCi/L	HASL-300
	U 235	2.1	0.9	0.3	pCi/L	HASL-300
	U 238	4.2	1.4	0.3	pCi/L	HASL-300

Analyzed by Core Laboratories
LLD = Lower Limit of Detection
pCi/g = picocuries per liter
mg/L = milligrams per liter

EXISTING WATER QUALITY DATA

November 1994 Groundwater Sampling

Well Number	Isotope	Total	Total Uncertainty (+/-)	Total LLD	Units	Method
Monitoring Wells Screened in the Lower Vanoss Zone						
CMW 3.1	Th 228	1.4	1.0	1.4	pCi/L	HASL-300
	Th 232	0.7	0.9	1.7	pCi/L	HASL-300
	U 234	2.8	0.8	0.5	pCi/L	HASL-300
	U 235	0.4	0.3	0.2	pCi/L	HASL-300
	U 238	1.1	0.5	0.2	pCi/L	HASL-300
CMW 9.2	Th 228	0.7	0.8	1.5	pCi/L	HASL-300
	Th 232	1.2	0.8	0.9	pCi/L	HASL-300
	U 234	10.9	2.4	0.8	pCi/L	HASL-300
	U 235	2.3	0.9	0.6	pCi/L	HASL-300
	U 238	4.9	1.4	0.7	pCi/L	HASL-300
CMW 11.2	Th 228	2.4	1.1	0.7	pCi/L	HASL-300
	Th 232	2.0	1.1	1.0	pCi/L	HASL-300
	U 234	6.2	1.7	0.5	pCi/L	HASL-300
	U 235	1.1	0.6	0.3	pCi/L	HASL-300
	U 238	1.8	0.5	0.5	pCi/L	HASL-300
CMW 14.2	Th 228	ND	0.1	1.6	pCi/L	HASL-300
	Th 232	0.5	0.5	1.0	pCi/L	HASL-300
	U 234	18	3.4	0.9	pCi/L	HASL-300
	U 235	5.3	1.4	0.5	pCi/L	HASL-300
	U 238	12.8	2.6	0.9	pCi/L	HASL-300
CMW 16.3	Th 228	1.2	1.0	1.5	pCi/L	HASL-300
	Th 232	2.3	1.2	1.0	pCi/L	HASL-300
	U 234	8.7	1.9	0.7	pCi/L	HASL-300
	U 235	1.9	0.8	0.5	pCi/L	HASL-300
	U 238	4.7	1.3	0.5	pCi/L	HASL-300
CMW 19.1	Th 228	1.1	0.8	1.1	pCi/L	HASL-300
	Th 232	1.7	1.0	0.9	pCi/L	HASL-300
	U 234	6.9	2.2	0.9	pCi/L	HASL-300
	U 235	1.8	1.0	0.8	pCi/L	HASL-300
	U 238	5.1	1.8	0.9	pCi/L	HASL-300
CMW 20.2	Th 228	1.6	1.0	1.0	pCi/L	HASL-300
	Th 232	2.5	1.2	0.5	pCi/L	HASL-300
	U 234	2.9	0.9	0.3	pCi/L	HASL-300
	U 235	0.1	0.1	0.3	pCi/L	HASL-300
	U 238	1.0	0.5	0.3	pCi/L	HASL-300

Analyzed by Core Laboratories
LLD = Lower Limit of Detection
pCi/g = picocuries per liter
mg/L = milligrams per liter

APPENDIX A

EXISTING WATER-QUALITY DATA