SITE INVESTIGATION REPORT

FOR THE

CIMARRON CORPORATION FACILITY
LOGAN COUNTY, OKLAHOMA

Prepared for

KERR-MCGEE CORPORATION
AND
CIMARRON CORPORATION
OKLAHOMA CITY, OKLAHOMA

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1. EXECUTIVE SUMMARY

Cimarron Corporation (Cimarron), a wholly-owned subsidiary of Kerr-McGee Corporation (Kerr-McGee), operated a facility near Crescent, Oklahoma for the fabrication of mixed oxide (plutonium and uranium) and enriched uranium fuel elements. The facility was closed in 1975 and decommissioning, which commenced in 1979, is continuing at present. These activities are conducted under NRC Special Nuclear Materials Licenses SNM-928 and SNM-1174.

Decommissioning activities consist of dismantling the former production facilities and management of any waste materials related to production and decommissioning activities. Management of waste materials includes off-site disposal of equipment and soils and on-site stabilization of soils which contain either or both uranium and thorium at concentrations meeting Options 1 and 2 of the Nuclear Regulatory Commission Branch Technical Position (46 Federal Register 52061, October 23, 1981). Approximately 370 cubic yards of greater than Option 2 limit soil materials will be disposed at a licensed commercial radioactive waste disposal facility.

Approximately 14,800 cubic yards of Option 2 limit materials will be buried on-site at least four feet below the ground surface in a designated landfill. In addition, approximately 96,300 cubic yards of soil that meets Option 2 limits and which is already four or more feet deep will be left in place under the uranium plant yard. These volume estimates are based on results of a facility area soil boring program, logging of boreholes with a counter and comparison of count rates to reference standards of known radiological content. These data were then processed using a computer program. The volumes are believed to be conservative and samples will be taken during excavation to provide final volume definition.

As part of planning for the disposition of Option 2 limit materials, Cimarron has conducted site studies to characterize the local hydrogeologic system, establish a system for ground-water monitoring, evaluate current ground-water quality, and estimate the long-term effect on ground-water quality which on-site burial of Option 2 limit soil might have. This report summarizes the field investigation, laboratory analyses, and data evaluation conducted for the site characterization.

The facility is located south of the Cimarron River in an area of low, rolling hills and incised drainages. Local elevations range between about 940 along the river to 1010 feet at the plant. Subsurface materials at the site include one to eight feet of soil covering the Garber Sandstone. The rock strata in the upper 140 feet of the Garber include alternating sandstones and mudstones. The sandstone layers, which are between 30 and 55 feet thick, have been designated Sandstones A, B, and C. The three sandstones are separated by mudstone layers. The mudstones are designated Mudstones A and B and are between 6 and 20 feet thick.

Shallow ground water occurs in Sandstone A under water table conditions. Most of the site monitoring wells are completed in this zone. The depth to water is between 10 and 30 feet below ground surface. Ground-water flow is to the north-northwest where discharge to the surface or to Cimarron River alluvium is likely. The hydraulic conductivity of Sandstone A is 1.03×10^{-3} cm/sec. Ground water also occurs in Sandstones B and C. Four of the site wells are completed in Sandstone C. The hydraulic conductivity in the deeper unit is about 1.27×10^{-4} cm/sec. Flow in this stratum is toward the northwest where discharge to the Cimarron river alluvium is likely.

Current ground-water quality in Sandstone A indicates that past operations might have affected the water in the immediate vicinity of certain facility units. The units where down-gradient ground-water impacts may have occurred include: wastewater ponds #1 and 2, the former burial area, and the area between the plutonium and uranium buildings. Since closure, ground-water sampling around these units shows water quality has improved. No definite effects are apparent in the deeper Sandstone C stratum.

Soil and rock samples from the unsaturated and saturated zones were chemically analyzed. Radionuclides were not detected in significant concentrations and facility operations do not appear to have affected soil and rock in the subsurface.

The results of soil, rock, and water analyses have been analyzed to estimate effects which could result from infiltration of water through Option 2 limit materials buried on-site. The solubility and mobility of radionuclides in the subsurface have been estimated using infiltration models and measurements of aquifer properties, water chemistry, and elemental partition coefficients.

The calculations demonstrate that the Option 2 limit materials which will remain at the site after decommissioning will not present a real or potential threat to ground-water or surface-water use.

2. INTRODUCTION

2.1 Report Purpose and Scope

This report presents the results of a site investigation program conducted by James L. Grant and Associates (JLGA) during early 1989. The purpose of the investigation was to determine the possible impacts that facility production and decommissioning operations may have had on the hydrogeologic system underlying the site. The geotechnical characteristics of selected site materials that may be used in construction of the permanent repository for site soils that contain low levels of uranium and thorium were evaluated.

A "Work Plan for Site Investigation Program" (Work Plan) was submitted January 4, 1989 to Kerr-McGee Corporation and Cimarron Corporation. The Work Plan specified procedures for drilling, sampling soil and rock, well installation, ground-water sampling, conducting aquifer tests and cleaning drilling and sampling equipment. Procedures specified in the Work Plan were adhered to during the site investigation. The Work Plan is included in this report as Appendix A.

The report emphasis is on the local ground-water system and assesses the impacts facility operations may have had on this system. The anticipated behavior of radionuclides in the shallow subsurface of the site is addressed, as are the engineering properties of materials to be used in the permanent soil repository planned at the site. Data have been obtained that permit the following:

- o Characterization of stratigraphy and lithology of the soils and bedrock strata at the site;
- o Characterization of aquifer properties including hydraulic conductivity, ground-water flow direction, and gradient;
- o Characterization of ground-water quality and determination of the effects that facility operations may have had on ground-water quality;
- o Determination of the mobility of radionuclides, particularly uranium, in the subsurface and the ability of subsurface materials to retard migration;
- o The suitability of selected site soil and rock for cover materials of the planned landfill.

2.2 Description of the Facility

Cimarron Corporation (Cimarron), a wholly-owned subsidiary of Kerr-McGee Corporation (Kerr-McGee), manages the decommissioning activities at the Cimarron Facility in Logan County, Oklahoma. Figure 2.1 shows the location of the facility. The facility was operational from 1965 to 1975. The principal operations at the facility involved the fabrication of fuel elements from plutonium and enriched uranium. Production ceased in 1975; decommissioning commenced in 1979 and is continuing at present. Figure 2.2 is a detailed map of the facility.

Enriched uranium fuel was produced from 1965 to 1975. In general, the process is described by the following steps:

- Uranium hexafluoride gas was passed through an ammonia solution, producing solid ammonium diuranate.
- Ammonium diuranate was calcined to produce uranium oxide powder (UO_3).
- Uranium oxide powder was pressed into pellets.
- The pellets were converted into ceramic-grade uranium dioxide (UO_2) in reduction furnaces.

Mixed-oxide fuel also was produced from 1970 to 1975 in the plutonium plant. Additional operations at the facility included a solvent extraction process to recover uranium from the processing of scrap and from material that did not meet contract specifications.

Liquid wastes from uranium processing were passed through an ion-exchange system for the recovery of uranium. The treated effluent was discharged to the Cimarron River under permit from 1965 to 1971. From 1971 to 1975, the treated effluent was pumped to wastewater evaporation ponds. Contaminated sludges that accumulated in the ponds were excavated in 1976 and 1977 and shipped to a licensed commercial low-level radioactive waste disposal facility. The ponds were subsequently reclaimed, inspected, and released for unrestricted use.

Sanitary water and laundry water from the uranium and plutonium operations was sent to the sewage lagoons. Contaminated sediments that accumulated were removed from the lagoons. The sediments contained up to 1300 pCi/g uranium and 11 pCi/g plutonium. These sediments were shipped off-site to a commercial disposal facility. Sediments that have accumulated since those shipments are from decommissioning activities and will be analyzed, excavated and disposed off-site if activity levels warrant.

Contaminated solid wastes generated from uranium plant activities were buried at a designated location on-site from 1966 to 1970. These solid wastes have since been excavated and shipped to a commercial disposal facility. Since 1970, all contaminated solid wastes were shipped off-site to a commercial disposal facility.

Thorium was present at the former burial site as drummed waste materials from the decommissioning of the Kerr McGee Corporation Cushing facility. Equipment from the Cushing facility also was stored at the uranium plant yard. The equipment and excavated drummed waste was shipped to a commercial disposal facility. Thorium has not been detected in soils or ground water at the Cimarron facility above background levels indicating there has been no impact from these materials. No plutonium waste was disposed on-site.

Only purified uranium and plutonium were used in the production processes. The concentrations of daughter products were negligible. Radium and thorium detected in ground-water and soil samples represent natural background levels and not the effects of facility activities.

Facility operations ceased in 1975 and Cimarron staff are presently decommissioning the facilities. Certain soil materials associated with the decommissioning activities will be left on-site, either in a designated, engineered site or in-situ, in accordance with the Nuclear Regulatory Commission's (NRC) Branch Technical Position (46 Federal Register 52061, October 23, 1981). The soils to be left on-site contain enriched uranium and thorium that meet the Branch Technical Position Options 1 and 2 concentration limits and conditions for disposal.

- NRC Branch Technical Position Option 1:

  This Option places no restrictions on the method of disposal or on-site storage of soils that contain up to 30 pCi/g enriched uranium, 35 pCi/g depleted uranium, and 10 pCi/g natural thorium (Th-232 plus Th-228).

- NRC Branch Technical Position Option 2:

  This Option permits the burial of soils containing low levels of uranium with no subsequent restrictions on land use or continued NRC licensing of the material. To meet this disposal criterion, soils must not contain more than 100 pCi/g soluble enriched uranium, 250 pCi/g insoluble enriched uranium, 100 pCi/g soluble depleted uranium, 300 pCi/g insoluble depleted uranium, or 50 pCi/g natural thorium. A minimum burial depth of four

> feet is required, and the proposed burial site must have acceptable hydrogeologic, meteorologic and topographic characteristics to mitigate against transport.

Cimarron plans to leave in place soils that contain Option 2 levels of uranium that are deeper than four feet below the ground surface. Soils that are shallower than four feet and meet the Option 2 disposal criterion will be excavated and transported to a designated on-site landfill.

The hydrologic, meteorologic and topographic characteristics of the Cimarron facility and the engineered on-site landfill are addressed in this report.

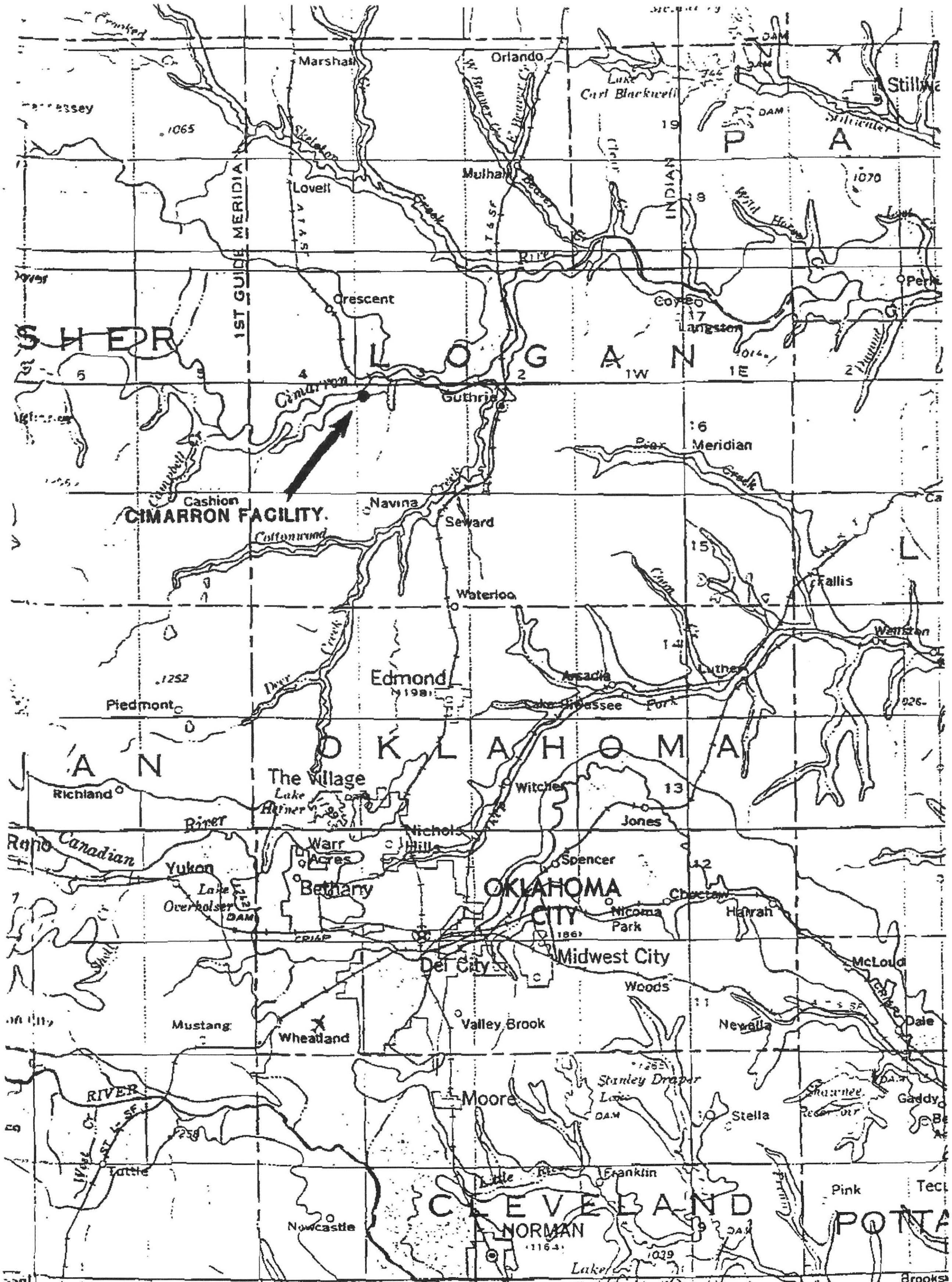

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FIGURE 2.1

CIMARRON FACILITY LOCATION

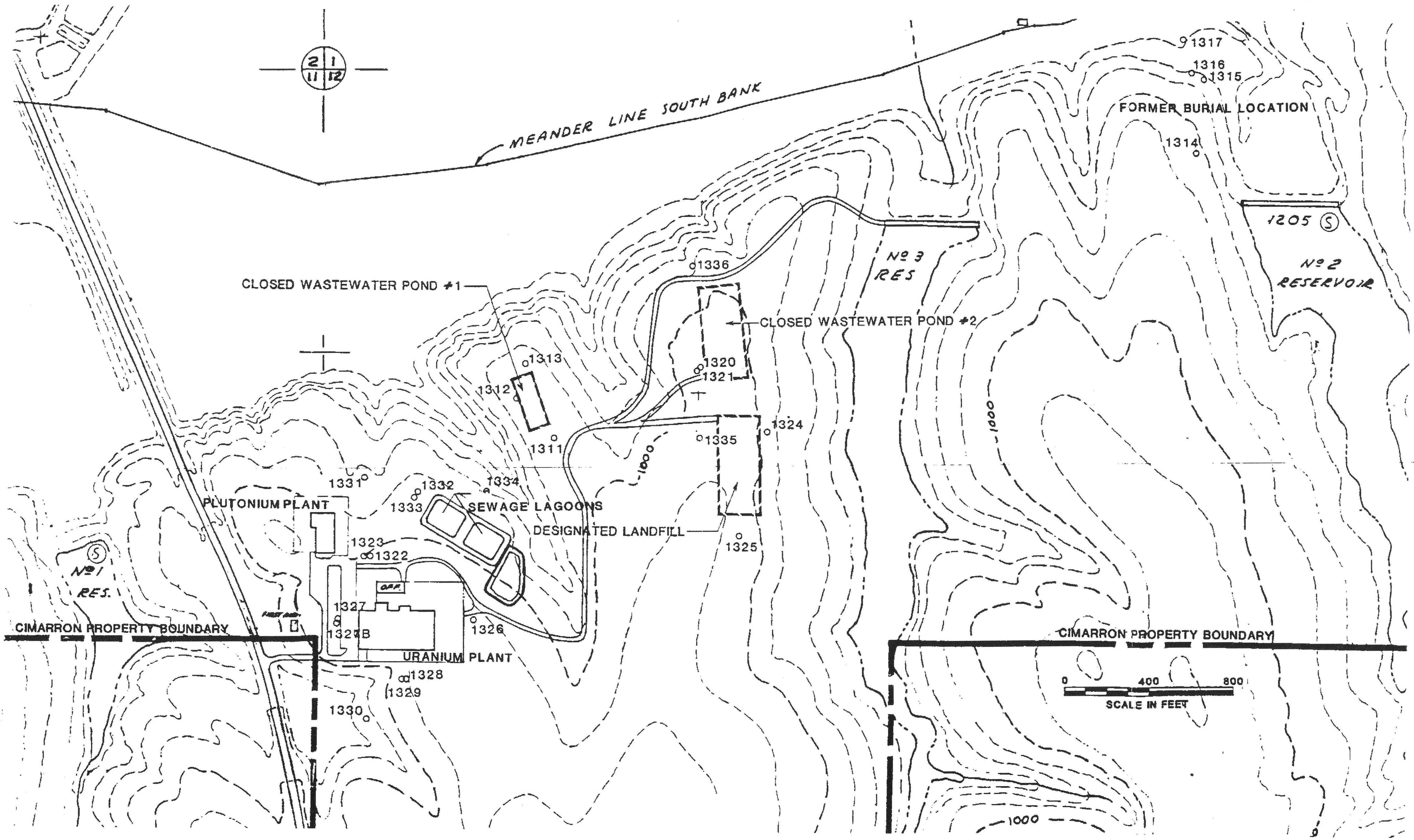

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FIGURE 2.2

CIMARRON FACILITY SITE MAP

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3. SITE INVESTIGATIONS

3.1 Previous Cimarron Investigations

The Cimarron facility has an extensive and continuous environmental monitoring program to determine the impacts of facility activities on the environment. This program consists of routinely collecting and analyzing air, surface water, ground water, soil and vegetation samples from the site and adjacent areas.

The environmental program includes many monitoring wells installed throughout the facility area for collection of groundwater samples from the shallow, unconfined aquifer which occurs at depths less than 50 feet below ground surface. Wells no. 1311 through 1317 shown on Figure 2.2 were installed during previous site investigations. Boring logs and well completion information were available for these wells; hydrologic and geologic data, and analyses of ground water collected from these wells have been incorporated into the JLGA investigation.

Cimarron also has conducted a detailed soil boring survey and sampling program to provide semi-quantitative information on the extent of facility-related radionuclide contamination in the shallow subsurface. The survey consisted of lowering a sodium iodide (NaI) probe into borings and measuring gamma radiation at one-foot intervals. The probe was calibrated against standards of known concentrations of uranium and thorium. Measurements of total gamma activity were recorded and concentrations of radionuclides were estimated by comparing counts in the boreholes with the standards.

The quantities of soils meeting the Option 1 and 2 disposal criteria have been conservatively estimated from the borehole gamma survey. Cimarron estimates that 14,800 cubic yards of soil at depths less than four feet meet the Option 2 on-site disposal criteria. This soil will be excavated and placed in the designated on-site landfill. An estimated 96,300 cubic yards of soil and rock that meets the Option 2 limits occurs at depths greater than four feet. Cimarron plans to leave this material in place.

3.2 JLGA Investigation

James L. Grant and Associates (JLGA) was retained by Cimarron to conduct a supplemental site characterization investigation. The field investigation was conducted between January 16 and April 1, 1989.

3.2.1 Drilling and Sampling.

A total of eighteen wells were installed during the field investigation. The wells were drilled using air rotary, water rotary and coring techniques. Drilling was conducted by Kerr-McGee and Jim Winnek, Inc. of Tulsa, Oklahoma. The equipment decontamination procedures presented in the Work Plan (Appendix A) were used to minimize the potential for introduction of contaminants into intervals penetrated by drilling. All drilling and sampling activities were observed by a JLGA geologist and descriptive sample logs were maintained.

The majority of wells were sampled by continuous coring. Both diamond and Criss bits were used. The cores are NX size and are stored in waxed cardboard boxes. The diamond bits cut a 1-7/8 inch diameter core and the Criss bits cut a 2-1/8 inch diameter core. Upon completion of coring to the designated depth, the bore holes were reamed to a 6 inch diameter using water rotary techniques.

Rock was sampled by continuous coring or rotary techniques. For the intervals drilled by air or water rotary, cuttings were collected and composited over 24-inch intervals. The cuttings were logged and stored in plastic bags. Descriptions are recorded on the monitoring well records in Appendix B.

Soil was sampled with split-spoon samplers following the procedures specified in ASTM 1586. Each sample represented a 24-inch interval except at the top of bedrock where refusal of the sampling tool resulted in a smaller sample collected. Samples were stored in plastic bags. Descriptions of the samples and the interval sampled are indicated on the monitoring well records included in Appendix B.

3.2.2 Well Installation.

Monitoring well installation procedures are described in the Work Plan (Appendix A). A 2.5 feet long sump was installed below the well screen to provide a repository for fines that accumulate during well development and evacuation prior to sampling. Figure 3.1 shows the relative placement of well screen, sand pack, and sealed sections of the well. Table 3.1 lists the pertinent completion details for the monitoring wells. Well completion information also is shown on the monitoring well records presented in Appendix B. The locations of the monitoring wells are indicated on Figure 2.2 and in Table 3.1.

At borings where wells were completed, the well casing was installed after completion of drilling to the desired depth. Two-inch diameter, flush-joint, threaded, schedule 80 PVC well casing and screen was used for all the monitoring wells (1320 through 1336).

3.2.3 Borehole Abandonment.

Sample recoveries were inadequate at two borings. These borings were abandoned and redrilled using drilling and sampling techniques suitable for the materials encountered. Wells 1323 and 1330 were constructed in the redrilled borings. The abandoned borings were backfilled to ground surface with a portland cement/sodium bentonite grout. A shallow concrete cap was placed on top of the hardened grout.

Two additional 10 feet deep borings were advanced adjacent to Well 1325 at the request of Cimarron personnel. These borings were drilled to obtain a continuous core sample from 5 to 10 feet. These additional borings were also backfilled with a portland cement/sodium bentonite grout.

3.2.4 Well Development.

The ground-water monitoring wells were developed soon after they were completed. Each of the wells was developed to remove fines and drill cuttings from the screened interval. Well development was accomplished by the air-lift method or by bailing with a cleaned PVC bailer. The wells developed by bailing were Nos. 1320 and 1322. The remainder were developed via air-lift. The air-lift method is described in the Work Plan (Appendix A). Development was terminated when the turbidity of the discharge water stabilized and a minimum of ten well volumes had been removed.

Water removed from each well during development was discharged to the ground surface. The volume of water removed was estimated by periodically measuring the quantity discharged into a bucket per unit of time. For the wells developed by bailing, water was discharged into buckets and the quantities recorded. The volume, color, odor, and clarity of water evacuated from each of the wells during development was established by visually noting these characteristics. Table 3.2 provides a summary of well-development data.

3.2.5 Field Tests.

3.2.5.1 Well Surveying.

Locations, datum and ground-surface elevations for wells and surface water elevations of the three reservoirs at the site were determined by R. E. Heinz and Associates of Guthrie, Oklahoma. The wells were surveyed between March 20 and March 27, 1989

All elevations and horizontal locations are based on the Cimarron Facility plant datum located due west of the the uranium building. The elevation of the datum was determined from facility construction plans. It is believed that the elevation of the plant datum is tied to the U. S. Geological Survey mean sea level datum since it corresponds to elevations noted on the U.S. Geological Survey topographic quadrangle of the area; however, no established benchmarks were located within several miles of the facility for verification. Horizontal coordinates for the wells are based upon a north-aligned grid system established at the plant datum. The elevations and coordinates for each well are noted on the monitoring well records in Appendix B and in Table 3.1.

3.2.5.2 Water-Level Measurements.

Water levels were measured at the site monitoring wells after installation and development. The levels were measured over a relatively short time interval so that the data are comparable. Measurements were made on March 21, 1989, and again on March 31, 1989. Additional measurements were made periodically during the drilling program to anticipate the depth ground water would be encountered at subsequent wells.

The depth to water below the measurement datum was recorded to the nearest 1/8 inch (0.01 feet). The ground-water levels measured during the investigation are included in Table 3.1.

3.2.6 Slug Tests.

In-situ field tests using the slug insertion and withdrawal procedure to obtain measures of hydraulic conductivity were conducted at all wells installed during this investigation. These tests were conducted by quickly inserting a weighted slug of known volume into the well and recording changes in head as a function of time as the water in the aquifer adjusts to the presence of the slug. After the water level in the well has stabilized, the slug is quickly withdrawn, and the resulting drawdown and recovery are recorded.

The water level in the wells recovered too quickly for head fluctuations to be measured manually. Head fluctuations were measured using an In-Situ Model SE-1000B Hermit Environmental Data Logger and a 10.13 psi down-hole pressure transducer. This unit allowed accurate measurement of rapid water level changes over very short time intervals. Recovery and drawdown data were recorded using a pre-programmed logarithmic sampling rate with very frequent measurements during the first 20 seconds and less frequent measurements during the remaining portion of the test.

The test data were interpreted using techniques described in Bouwer and Rice (1976), Cooper, Bredehoeft and Papadopulos (1967) and Hvorslev (1951). The results of these aquifer tests are presented in Table 3.3. The test data are presented in Appendix C. The three different analytical techniques were employed for comparison and to ensure that reliable estimates of hydraulic conductivity were obtained.

Hydraulic conductivities and transmissivities were calculated for both the slug insertion (falling head) and slug withdrawal (rising head) portions of the tests. From past experience the calculations based on rising head data are believed more representative of the aquifer since it partially removes the effects of the greater permeability of the sand packs around the well screens. Since the sand pack around the well screen has a greater permeability than the adjacent aquifer, it is believed that upon insertion of the slug, the water level will initially rise more rapidly and to a higher level in the sand pack than in the aquifer. The initial stages of the subsequent water-level recovery therefor reflect ground water reentering the well from the sand pack rather than the aquifer.

The rising head portion of the slug test serves to remove the effects of the sand pack. When the slug is withdrawn, the water level in the well drops an amount equivalent to the volume displaced by the slug. The subsequent recovery to the initial water level is due to ground water entering the well from the aquifer. The amount of water stored in the sand pack and available to enter the well after the slug is withdrawn is negligible. The calculations for both the falling and rising head portions of

the test showed slightly higher values for hydraulic conductivity and transmissivity for the falling head tests.

According to Bouwer & Rice (1976), their method is applicable for partially or fully penetrating wells in unconfined aquifers, or for wells in leaky confined aquifers. Cooper, Bredehoeft & Papadopulus (1967) state their method is applicable to wells fully or partially screened in confined aquifers. The Hvorslev method (1951) is applicable to wells installed in unconfined aquifers. A comparison of the three methods is presented in Table 3.3 and shows reasonable agreement among the three methods.

The hydraulic conductivity of the shallow aquifer is best approximated by the Bouwer & Rice and Hvorslev methods since it is under water table conditions. The results of these two methods were averaged geometrically to arrive at an approximation for the hydraulic conductivity and transmissivity Geometric averages are more appropriate than arithmetic averages for data that differs by orders of magnitude. The hydraulic conductivity of the shallow aquifer ranges from 2.41 x 10^{-4} cm/sec to 5.7 x 10^{-3} cm/sec. The geometric mean of the measured values is 1.03 x 10^{-3} cm/sec. The transmissivity of this aquifer ranges from 10.3 ft sq/day to 108 ft sq/day, with a geometric mean of 33.4 ft sq/day.

The hydraulic conductivity and transmissivity of the confined aquifer screened in the deep wells is best approximated by the Cooper et. al. method. The results from those analyses were averaged geometrically. The hydraulic conductivity of the deep aquifer ranges from 1.39 x 10^{-5} cm/sec to 7.06 x 10^{-4} cm/sec, with a geometric mean of 1.27 x 10^{-4} cm/sec. The transmissivity ranges from .67 ft sq/day to 50 ft sq/day, with a geometric mean of 7.96 ft sq/day.

3.2.7 Ground-Water Sampling.

Monitoring wells installed during this program were sampled during the week of March 19, 1989. Cimarron sampled existing wells at the same time to provide a full-facility range of comparable data for the evaluation of ground-water quality. All samples were analyzed for the same constituents.

The ground-water samples were collected using the procedures described in the Work Plan (Appendix A). Specific conductance and pH were measured in the field for each sample collected. The ground-water samples were placed in containers provided by the laboratory and by Cimarron Corporation. Both one-gallon and one-quart plastic cubitainers were filled at each well. An additional one quart glass jar was filled for the samples requiring TOC and TOX analyses.

A label was placed on each sample container. This label contained the well number, date, type of sample, name of collector, and any special instructions. The ground-water samples were kept chilled and delivered to the laboratory within hours of collection. Chain of custody documentation was maintained for all the samples and is included in Appendix D. The analyses conducted are described in the following section.

3.2.8 Laboratory Tests.

3.2.8.1 Ground-Water Analyses.

Ground-water analyses were conducted by the Kerr-McGee Technical Center Laboratory. The samples were analyzed for nitrate, fluoride, gross alpha and beta activity, Pu-239, Ra-228, Ra-226, Th-232, Th-228, U-238, U-235, and U-234 in accordance with standard EPA methods. Four samples were also selected for Total Organic Carbon (TOC) and Total Organic Halide (TOX) analyses in accordance with standard EPA methods. Standard ground-water quality analyses for major cations and anions were performed in conjunction with the distribution coefficient (Kd) tests. Table 3.4 provides a summary of the ground-water analyses. Documentation of the analyses and the chain of custody documentation are included as Appendix D to this report.

3.2.8.2 Soil and Rock Analyses.

Selected soil and rock samples were submitted to the Kerr-McGee Technical Center laboratory for analysis. The samples were analyzed for parameters related to facility activities. The parameters analyzed for include nitrate, fluoride, gross alpha and beta activity, Pu-239, Ra-228, Ra-226, Th-232, Th-228, U-238, and U-234 in accordance with standard EPA methods. Table 3.5 provides a summary of the results. Documentation of these analyses and the chain of custody documentation are included as Appendix E.

The samples selected for site-specific parameter analyses are representative of the different strata encountered and different locations around the site. Sample selection was not random, but emphasized stratigraphic intervals where migration of contaminants may be restricted, such as at the top of less permeable, confining strata, or adsorbed in strata of favorable chemistry. The well number, interval sampled and lithologic description of the rock or soil also are indicated in Table 3.5.

Prior to submission to the laboratory, Cimarron measured the uranium activity in the samples by gamma spectrometry. The Cimarron gamma spectrometry analysis utilizes the EG&G Ortec ADCAM computer analysis program. The samples were analyzed inside a lead-shielded box to minimize background interference. These results also are presented in Table 3.5.

3.2.8.3 Physical Property Analyses.

Samples were submitted to Standard Testing, Inc. of Oklahoma City for physical property analyses. These analyses included characterization tests (grain size and Atterberg Limits), standard Proctor tests and compacted permeabilities. The Proctor and compacted permeability tests were performed on samples of borrow material from the designated landfill site which are representative of materials that may be used to construct the landfill cover. The results of these tests are presented in Table 3.6 and documentation is included in Appendix F.

3.2.8.4 Soil and Rock Mineralogical Analyses.

Samples were submitted to the Department of Agronomy and Soils at Auburn University for analysis of selected properties. The tests performed included cation exchange capacity (CEC), exchangeable cation (EXC), mineralogy, grain size and matric potential. The well number, interval sampled, lithologic description and analytical results are presented in Table 3.7. Documentation of the results are presented in Appendix G. The samples submitted are representative of the different strata encountered during this investigation.

3.2.8.5 Distribution Coefficient Analyses.

Five samples of site soils, rock and ground water were analyzed by the Kerr-McGee Technical Center to determine equilibrium distribution coefficients (Kd) for uranium and thorium. This test provides a measure of the affinity of the selected elements for soil and rock and the solubility of the material in the rock/ground-water system. The tests were conducted according to the batch test procedures included in Appendix H. Kd test results are summarized in Table 3.8 and documentation of the results is included in Appendix H.

The samples for Kd determinations were selected after the soil and rock mineralogical and chemical analyses were completed. The aquifer matrix materials can be broadly classified into one of four major groups: low clay (<18%), low calcite (<3%) content; high clay (>30%), low calcite content; low clay, high calcite (>3%) content; and high clay, high calcite content. For the aquifer matrix materials underlying the Cimarron facility, clay and calcite content were the important constituents affecting the distribution coefficients. The matrix samples submitted for Kd

determinations are representative of the four groups identified, including "reduced" and "non-reduced" samples. The reduced samples are representative of iron-deficient intervals where ferric oxides have been reduced to ferrous oxides and removed by ground water.

Two distribution coefficient tests were conducted for each sample submitted for both uranium and thorium. The first test used 20 milliliters (ml) of site ground water spiked to a uranium concentration of 850 pCi/l and a thorium concentration of 850 pCi/l. This solution was applied to 5 gram samples of site aquifer matrix materials for a total concentration of 3.40 pCi/g uranium and 3.40 pCi/g thorium. After reaching equilibrium with the matrix materials, final concentrations of uranium in solution ranged from 1.2 pCi/l to 9.3 pCi/l. Final concentrations of thorium ranged from 0.6 to 1.2 pCi/l.

The second test used 100 ml of site ground water spiked to a uranium concentration of 850 pCi/l and a thorium concentration of 850 pCi/l. This solution was applied to 5 gram samples of matrix materials for a total concentration of 17 pCi/g uranium and 17 pCi/g thorium. After reaching equilibrium, final concentrations of uranium in solution ranged from 1.5 to 9.9 pCi/l. Final concentrations of thorium ranged from 0.6 to 1.3 pCi/l.

The experimentally derived Kd values for uranium range from 339 ml/g to 2829 ml/g. Experimental Kd values for thorium range from 2262 ml/g to 5662 ml/g. The experimentally derived values for both elements are within published value ranges. Isherwood (1981) reports Kd values for uranium in soil at near neutral pH that range from 4,400 ml/g to 62,000 ml/g. Kd values for thorium at near neutral pH are reported to range from 40 ml/g to 400,000 ml/g. The experimental Kd values did not exhibit a direct correlation with either the clay mineral or calcite content of the site soils.

Approximations of distribution coefficients can also be made by comparing the amount of uranium detected on the aquifer material with the amount detected in ground water from that interval. Six of the aquifer material samples submitted to the laboratory for uranium analyses represent screened intervals in monitoring wells. Comparing the uranium values found in the rock samples with the ground-water samples yield approximate Kd values ranging from 10 ml/g to 192 ml/g.

The difference between the approximated Kd values and those from the laboratory tests may be attributable to precipitation of uranium in the batch test. The laboratory Kd tests are conducted under controlled conditions using ground water spiked to a concentration greater than that typically found at the site. Precipitation of uranium during the test will result in higher Kd values than if adsorption were the sole mechanism removing

uranium from ground water.

The distribution coefficient (Kd) tests demonstrate that uranium will have limited solubility in the subsurface ground water. Final concentrations of uranium in the test solutions ranged from 1.2 to 9.9 pCi/l. These concentrations are consistent with naturally occurring uranium concentrations in ground-water samples from most of the monitoring wells. The combined effects of uranium precipitation and adsorption on the aquifer matrix materials appear to produce equilibrium concentrations of uranium in ground water less than 10 pCi/l.

Water from certain wells sampled had uranium concentrations greater than the above equilibrium concentration. These wells are located adjacent to and immediately down-gradient from the closed wastewater ponds and the former solid-waste burial area, where the chemistry of the ground water probably was changed by the materials stored in these areas. The higher uranium concentrations probably result from the differences in water chemistry, especially the presence of nitrate and fluoride ions. As discussed in Section 7.3, uranium concentrations in the ground water decrease rapidly with distance from such a source as the concentrations of ions is reduced through dilution and sorption.

TABLE 3.1

Well Completion Details

WELL NO.	INSTALLED BY	DATUM ELEVATION (feet msl)	GROUND ELEVATION (feet msl)	COORDINATES EAST	COORDINATES NORTH	WELL DEPTH	DEPTH TO SCREEN TOP	DEPTH TO SCREEN BOTTOM	GROUND WATER LEVELS 3/31/89 DEPTH	GROUND WATER LEVELS 3/31/89 ELEVATION	GROUND WATER LEVELS 3/21/89 DEPTH	GROUND WATER LEVELS 3/21/89 ELEVATION
1311	Cimarron	995.69	993.9	11087.15	10949.24	80.00	25.00	40.00	28.28	967.41	28.07	967.62
1312	Cimarron	992.17	989.6	10917.11	11133.08	36.00	21.00	35.00	26.50	965.67	25.50	966.67
1313	Cimarron	994.70	992.4	10955.19	11278.42	38.00	23.00	38.00	28.95	965.75	28.70	966.00
1314	Cimarron	983.02	980.0	14093.26	12266.33	80.00	30.00	45.00	27.82	955.20	27.40	955.62
1315	Cimarron	955.98	953.0	14126.89	12610.52	27.00	12.00	27.00	13.64	942.34	13.92	942.06
1316	Cimarron	951.31	949.9	14066.96	12637.28	32.00	17.00	32.00	10.60	940.71	10.65	940.66
1317	Cimarron	946.62	943.9	14026.01	12798.60	18.00	3.00	18.00	10.30	936.32	10.95	935.67
1320	JLGA	998.14	995.6	11755.70	11266.69	41.30	28.50	38.50	27.66	970.48	27.01	971.13
1321	JLGA	998.38	996.0	11743.26	11261.76	124.40	111.60	121.60	59.85	938.53	60.25	938.13
1322	JLGA	1001.48	998.6	10238.93	10386.13	37.90	25.00	35.00	32.12	969.36	31.76	969.72
1323	JLGA	1001.85	998.9	10224.06	10387.37	129.60	116.80	126.80	57.20	944.65	57.48	944.37
1324	JLGA	997.58	995.2	12075.48	10972.36	35.00	25.00	35.00	25.58	972.00	25.03	972.55
1325	JLGA	1008.32	1005.9	11951.47	10494.65	48.30	35.50	45.50	33.08	975.24	32.49	975.83
1326	JLGA	1009.33	1006.5	10719.85	10112.93	45.10	32.30	42.30	37.62	971.71	37.11	972.22
1327	JLGA	1009.17	1006.2	10100.10	10103.73	41.80	29.00	39.00	dry		dry	
1327-B	JLGA	1008.42	1006.2	10100.10	10090.43	51.80	39.00	49.00	41.03	968.14	40.93	967.49
1328	JLGA	1008.44	1006.0	10411.70	9830.36	137.80	125.00	135.00	55.35	953.09	55.54	952.90
1329	JLGA	1008.55	1005.9	10405.36	9835.39	47.80	35.00	45.00	38.79	969.76	38.86	969.69
1330	JLGA	997.70	995.3	10231.32	9657.06	41.50	28.70	38.70	26.60	971.10	26.17	971.53
1331	JLGA	978.00	975.3	10202.71	10751.13	25.00	12.20	22.20	10.51	967.49	9.81	968.19
1332	JLGA	989.54	987.1	10457.35	10686.36	118.80	106.00	116.00	46.97	942.57	47.05	942.49
1333	JLGA	989.77	986.8	10442.73	10662.97	34.80	22.00	32.00	20.75	969.02	20.62	969.15
1334	JLGA	980.26	977.6	10776.31	10688.14	22.80	10.00	20.00	12.33	967.93	12.60	967.66
1335	JLGA	1002.50	1000.2	11758.09	10944.05	42.80	30.00	40.00	28.91	973.59	28.20	974.30
1336	JLGA	986.02	984.0	11722.31	11738.39	30.80	18.00	28.00	25.34	960.68	25.14	960.88

NOTE: DATUM IS TOP OF CASING FOR ALL WELLS.
ELEVATION OF WATER IN RESERVOIR 1: 959.3' 3/26/89
ELEVATION OF WATER IN RESERVOIR 2: 966.3' 3/26/89
ELEVATION OF WATER IN RESERVOIR 3: 971.0' 3/26/89

TABLE 3.2

Well Development Summary

WELL NO.	DATE	WELL TD (BTOC)	DEPTH TO WATER BEFORE (BTOC)	DEPTH TO WATER AFTER (BTOC)	GALLONS REMOVED	CLARITY AFTER DEVELOPMENT	COMMENTS
1320	3/14/89	41.2	26.88	34.65	30	Clear, with orange tint	Develop. by bailing
1321	3/16/89	128.4	60.2	74.91	130	Clear and colorless	
1322	2/16,22/89	40.8	29.9	30.56	20	Clear and colorless	Develop. by bailing & air-lift
1323	2/22-24/89	129.2	54.58	85.9	130	Clear, v. faint orange tint	
1324	3/15/89	34.95	24.17	27.9	30	Clear, pale orange tint	
1325	3/15/89	50.5	32.78	33.97	75	Clear, v. pale orange tint	
1326	3/16/89	47.9	N/M	N/M	>40	Colorless	Develop. by Kerr-McGee
1327		NOT DEVELOPED					
1327-B	3/20/89	N/M	N/M	N/M	40	Clear, pale orange tint	
1328	3/16/89	139.15	55.34	64.02	250	Clear, v. pale orange tint	Well made >4 gpm during devel.
1329	3/13/89	49.5	38.7	41.3	35	Clear, v. pale orange tint	
1330	3/16/89	43.7	26.21	27.1	80	Clear, pale orange tint	
1331	3/15/89	27.9	10.1	13.35	80	Clear, colorless	
1332	3/16/89	121.1	46.8	59.25	240	Clear, colorless	Well made about 4 gpm
1333	3/14/89	37.6	20.7	N/M	30	Clear, colorless	Well made about 1 qt/m
1334	3/16/89	25.1	9.85	N/M	30	Clear, pale orange tint	
1335	3/15/89	45.1	28.65	31.25	50	Clear, v.pale orange tint	
1336	3/15/89	32.7	25.18	N/M	20	Clear, colorless	Very slow flow rate

NOTE: N/M means not measured

TABLE 3.3

Aquifer Test Results

	BOUWER AND RICE METHOD		COOPER ET.AL. METHOD		HVORSLEV METHOD	
WELL NO.	Conductivity cm/sec	Transmissivity ft sq/day	Conductivity cm/sec	Transmissivity ft sq/day	Conductivity cm/sec	Transmissivity ft sq/day
			SHALLOW WELLS			
1320	2.34E-04	1.03E+01	2.30E-04	6.50E+00	2.57E-04	7.44E+00
1322	1.29E-03	2.10E+01			1.88E-03	3.09E+01
1324	5.19E-04	1.74E+01				
1325	9.66E-04	4.19E+01			2.72E-03	1.04E+02
1326	5.01E-04	1.06E+01			7.45E-04	1.70E+01
1327-B	8.98E-04	2.85E+01			2.41E-03	7.53E+01
1329	3.03E-03	1.02E+02			5.70E-03	1.94E+02
1330	8.60E-04	6.36E+01	7.40E-04	5.46E+01	1.41E-03	1.03E+02
1331	1.08E-03	4.34E+01	1.13E-03	4.00E+01		
1333	2.46E-04	9.92E+00				
1334	8.52E-04	2.50E+01			5.96E-04	5.76E+00
1335	4.11E-04	2.72E+01				
1336	2.28E-03	1.08E+02			4.61E-03	1.05E+02
			DEEP WELLS			
1321	2.25E-04	4.76E+01	4.41E-05	5.00E+00	1.09E-04	1.55E+01
1323	2.00E-05	4.58E+00	1.39E-05	6.70E-01	1.59E-05	5.90E-01
1328	1.03E-03	2.54E+02	7.06E-04	5.00E+01	1.06E-03	4.49E+01
1332	4.66E-04	1.03E+02	6.05E-04	2.40E+01		

TABLE 3.6

Physical Property Analyses

SAMPLE NO.	PP-1	PP-2	PP-3	PP-4	PP-5	PP-6	PP-7	PP-8	PP-9	PP-10
WELL NO.	Landfill Borrow	Landfill Borrow	Landfill Borrow	1328	1328	1323	1332	1332	1334	1327
SAMPLE INTERVAL				6-8'	15-15.5'	2-4'	20-20.4'	10.5-11'	13.5-14	16.5-17'
ATTERBERG LIMITS										
LIQUID LIMIT	24.0	23.0	23.0	26.0	34.0	NP	NP	25.0	36.0	NP
PLASTIC LIMIT	10.0	9.0	8.0	8.0	9.0	NP	NP	8.0	13.0	NP
PERCENT PASSING SIEVE										
#10	93.8	98.3	97.3	100.0	100.0	100.0	100.0	100.0	100.0	95.9
#40	90.0	95.4	93.5	94.8	95.6	99.9	99.2	99.9	98.5	71.8
#200	70.5	73.3	72.9	62.8	87.7	39.2	89.2	94.6	94.1	44.7
STANDARD PROCTOR TEST ASTM D698										
% MOISTURE	13.1	13.0	14.0							
DRY DENSITY	119.7	120.5	117.8							
PERMEABILITY TEST ASTM STP-479										
% MOISTURE	13.4	15.3	16.9							
% COMPACTION	80.8	77.9	77.1							
PERMEABILITY cm/sec	1.02E-04	1.98E-05	1.38E-04							
% MOISTURE	12.8	14.7	15.5							
% COMPACTION	89.6	88.2	87.7							
PERMEABILITY cm/sec	1.18E-05	2.99E-06	1.60E-05							
% MOISTURE	14.3	14.6	16.0							
% COMPACTION	96.1	97.4	97.1							
PERMEABILITY cm/sec	3.00E-07	3.08E-08	2.48E-08							

TABLE 3.7

Rock and Soil Mineralogical Analyses

UMPLE NO.	BORING NO.	SAMPLED INTERVAL	ABBREVIATED FIELD DESCRIPTION	GRAIN SIZE DISTRIBUTION % FRACTION < 2mm Sand	Silt	Clay	pH	CEC meq/100g	EXCHANGEABLE CATIONS (meq/100g) Ca	Mg	K	Na	MINERALOGICAL COMPOSITION (wt. percent) Kaolinite	Fe Oxides/ Hydroxides	Expanding Silicates	Feldspar + mica	Calcite	Quartz	Adsorbed Water
CH-1	1323	37.9-38.4'	VFG sandy mudstone	0.70	78.74	20.56	8.43	10.83	6.96	3.29	0.32	0.30	15	4	12	17	<1	48	1.63
CH-2	1323	34.3-37.9'	Comp. of red. zones	15.50	64.94	19.56	8.72	7.96	17.25	2.78	0.23	0.28	12	2	8	17	<1	56	2.25
CH-3	1326	2-4'	Silty sand	57.70	27.82	14.48	6.87	7.71	5.01	1.61	0.16	0.11							
CH-4	1328	20-20.4	Slightly sandy mudstone	18.70	47.22	34.08	8.53	18.56	27.37	6.62	0.47	0.30							
CH-5	1328	37.2-38'	Sandstone conglomerate	82.40	10.48	7.12	9.18	2.55	18.84	1.14	0.08	0.21	1	3	3	5	29	58	0.5
CH-6	1336	15.3-15.7	VFG sandy mudstone	2.50	58.18	39.32	8.18	22.75	26.26	5.97	0.48	0.35	27	8	23	27	<1	12	3.63
CH-7	1321	25.5-26	VFG sandy mudstone	39.60	45.56	14.84	7.91	4.59	8.35	1.62	0.11	0.33							
CH-8	1321	25-25.3	FG-VFG sandstone	80.00	13.08	6.92	8.30	3.37	10.93	1.43	0.07	0.33	1	<1	3	3	1	90	0.38
CH-9	Landfill	borrow	silt, sand, rock frags.	37.50	39.66	22.84	8.76	9.93	21.14	2.94	0.25	0.21	8	3	10	14	3	59	1.63
CH-10	1324	20-22'	Sandy mudstone	74.20	16.12	9.68	5.99	2.96	10.50	1.36	0.10	0.17							
CH-11	1325	24-26'	Sandy mudstone	56.40	25.56	18.04	8.86	6.00	17.82	5.71	0.22	0.29							
CH-12	landfill		Grab - gray red. zone	47.00	43.44	9.56	8.69	6.20	9.29	4.03	0.50	0.27	7	1	6	9	3	72	1
CH-13	1332	4-5.5'	Silty sand	25.50	55.34	19.16	8.89	8.02	20.24	4.95	0.34	0.47							
CH-14	1334	16.4-16.7'	Gray, silty red. zone	59.20	24.16	16.64	8.95	6.87	17.71	4.2	0.50	0.21	1	1	7	11	12	59	1.25
CH-15	1334	15.6-15.9'	Sandy mudstone	21.90	51.94	26.16	8.62	11.32	12.35	5.18	0.58	0.15	10	4	11	17	3	52	1.88

TABLE 3.8

Distribution Coefficient Analyses

Sample No.	Initial Water Conc. (pCi/ml)	Total Spike (pCi)	Initial pH	Final pH	Equilibrium Water Conc. (pCi/ml)	Soil Conc. (pCi/g)	Distribution Coefficient (ml soln/g soil)
TEST 1 - Uranium-232							
CH-1R	0.85	17.00	7.45	7.90	1.20E-03	3.40	2829.333
CH-5R	0.85	17.00	7.45	7.76	2.70E-03	3.39	1255.259
CH-6R	0.85	17.00	7.50	7.82	9.30E-03	3.36	361.591
CH-8R	0.85	17.00	7.49	7.75	1.20E-03	3.40	2829.333
CH-14R	0.85	17.00	7.50	7.82	3.00E-03	3.39	1129.333
- Thorium-228							
CH-1R	0.85	17.00	7.45	7.90	6.00E-04	3.40	5662.667
CH-5R	0.85	17.00	7.45	7.76	9.00E-04	3.40	3773.778
CH-6R	0.85	17.00	7.50	7.82	6.00E-04	3.40	5662.667
CH-8R	0.85	17.00	7.49	7.75	1.20E-03	3.40	2829.333
CH-14R	0.85	17.00	7.50	7.82	1.20E-03	3.40	2829.333
TEST 2 - Uranium-232							
CH-1R	0.85	85.00	7.11	7.38	7.50E-03	3.37	449.333
CH-5R	0.85	85.00	7.22	7.46	3.60E-03	3.39	940.444
CH-6R	0.85	85.00	7.19	7.40	9.90E-03	3.36	339.434
CH-8R	0.85	85.00	7.20	7.42	1.50E-03	3.39	2262.667
CH-14R	0.85	85.00	7.23	7.46	2.10E-03	3.39	1615.048
- Thorium-228							
CH-1R	0.85	85.00	7.11	7.38	1.50E-03	3.39	2262.667
CH-5R	0.85	85.00	7.22	7.46	9.00E-04	3.40	3773.778
CH-6R	0.85	85.00	7.19	7.40	9.00E-04	3.40	3773.778
CH-8R	0.85	85.00	7.20	7.42	9.00E-04	3.40	3773.778
CH-14R	0.85	85.00	7.23	7.46	6.00E-04	3.40	5662.667

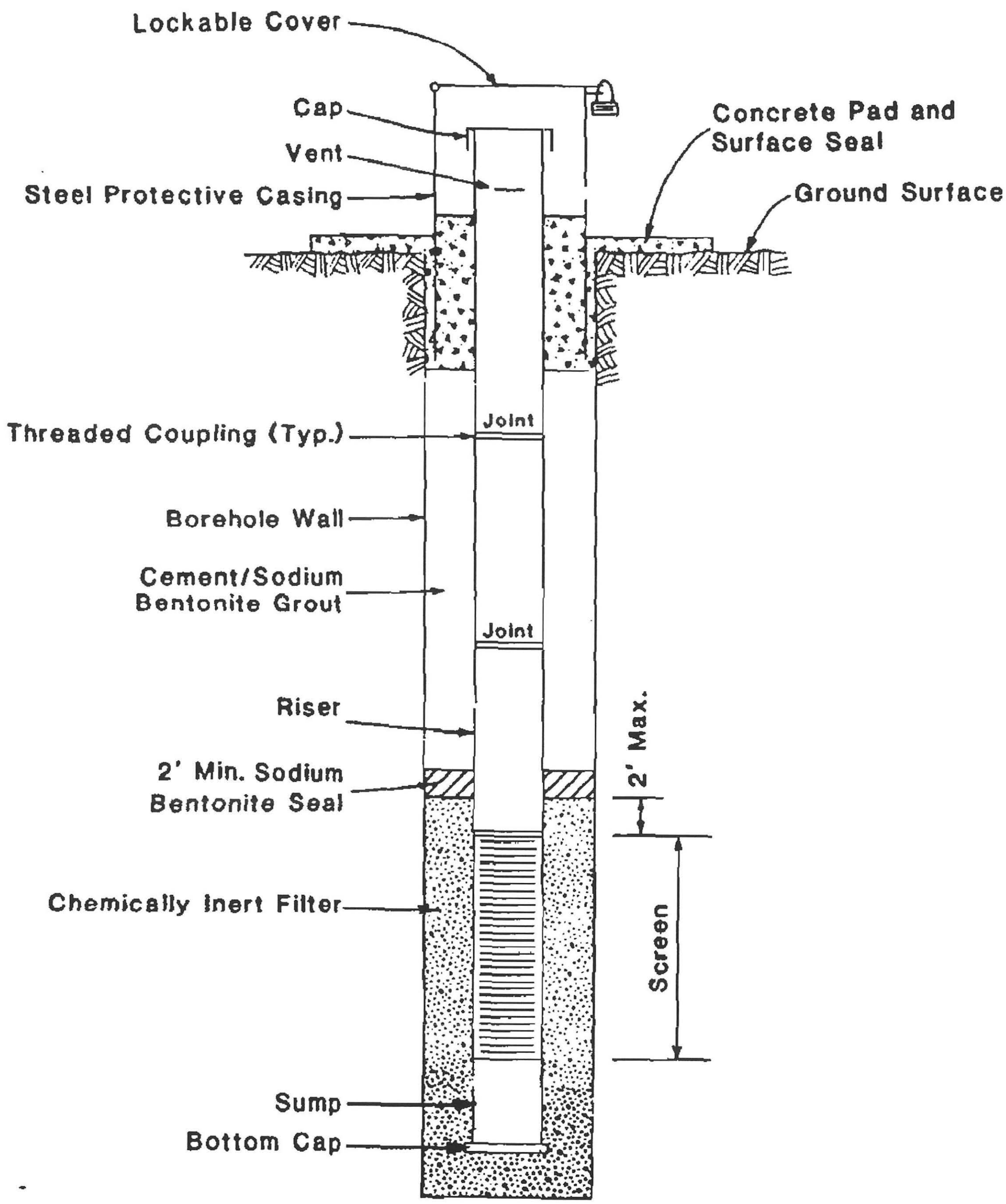

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FIGURE 3.1

MONITORING WELL DESIGN

4. REGIONAL HYDROGEOLOGY

4.1 Regional Structure and Stratigraphy

Subsurface rock units in the central Oklahoma region range in age from Precambrian through Permian. Outcropping bedrock in the area consists of Permian and Pennsylvanian strata. Near drainages and flood plains the rocks are capped with unconsolidated Quaternary alluvium and terrace deposits. Figure 4.1 is a geologic map of the region.

The principal structural feature in the central Oklahoma region is the Nemaha ridge or uplift, a north-northwest trending subsurface uplift formed during the Mississippian. Figure 4.2 is a map of Oklahoma showing the tectonic provinces.

The Phanerozoic (Cambrian and younger) geologic history of central Oklahoma is characterized by periods of marine and non-marine sedimentation punctuated by periods of extensive erosion. Four widespread unconformities have been identified marking periods of uplift, erosion, and subsequent deposition. These unconformities occur at the top of the Ordovician Arbuckle formation, at the base of the Mississippian system, at the base of the Pennsylvanian system, and during the Tertiary Period.

Of particular importance to the central Oklahoma region is a period of uplift and erosion that occurred between the Mississippian and Pennsylvanian systems. This period of activity produced the north-northwest trending normal faults and anticlinal structures that comprise the Nemaha ridge. Early Pennsylvanian strata onlap and thin over the structures signifying continued uplift into the Pennsylvanian. Reactivation of the faults is not documented after early to middle Pennsylvanian time.

The Nemaha ridge controlled sedimentation during part of the Pennsylvanian by partially subdividing the existing basin. Sediments east of the ridge are generally representative of shallow marine and non-marine deposition, while strata west of the ridge were deposited from essentially shallow and deeper marine environments. The axis of the Nemaha ridge or uplift lies west of the site.

By Permian time, the central Oklahoma region lay along the eastern shelf of a shallow sea. The Permian strata underlying the Cimarron facility area are the Garber and Wellington formations. These formations consist of interbedded sandstones, siltstones and shales primarily and were deposited from a west-flowing deltaic system. These clastic units are characteristically interbedded and of limited areal extent with rapid facies changes.

A widespread unconformity has truncated all pre-Quaternary formations in the region. This has produced the characteristic north-trending outcrop pattern indicated in Figure 4.1.

Along rivers and streams, Quaternary terrace and alluvial deposits have formed. These deposits consist of unconsolidated gravels, sands, silts and clays. The deposits generally range in thickness from 10 to 50 feet. Locally, they may be as much as 100 feet thick. In the vicinity of the Cimarron facility, the Cimarron terrace is Pleistocene in age and is the result of glacial outwash.

4.2 Regional Ground-Water Occurrence

Ground water in the central Oklahoma region occurs principally in the Permian-aged Garber/Wellington aquifer. The Oklahoma Geological Survey groups the Garber and Wellington formations together as a single hydrologic unit on the basis of similar lithologies and water-bearing characteristics (Bingham and Moore, 1975).

The water-bearing sandstones are fine grained and friable, with numerous interbedded siltstones and shales. The matrix of the sandstones is frequently a fine red mud. Sandstones are generally thin and the percentage of sandstone versus shale increases from north to south in the central Oklahoma region. The combined thickness of the Garber and Wellington formations is approximately 600 to 800 feet.

Carr and Marcher (1977) have identified differences in ground-water flow patterns within the Garber/Wellington aquifer. The shallow ground water generally flows laterally towards streams and springs where it discharges to the surface. A minor component of flow is vertical and leakage partially recharges deeper confined aquifers. The authors also note that shallow ground water occasionally flows upward where rivers or streams have deeply entrenched the bedrock and the potentiometric surface is higher than the surface-water elevation.

Ground water in the deeper portion of the Garber/Wellington aquifer flows primarily to the southwest along the regional dip. The points of discharge of the deeper ground water are outside the central Oklahoma region. Figure 4.3 shows the potentiometric surface of the Garber/Wellington aquifer in southern Logan and northern Oklahoma counties.

Recharge of the Garber/Wellington aquifer is accomplished through precipitation and infiltration in areas of outcrop. Infiltration through overlying porous and permeable strata also provides considerable recharge. Johnson (1983) identified the principal recharge area for the Garber/Wellington aquifer as an area lying generally north of the Canadian River, south of Guthrie, east of the Canadian County line, and west of Shawnee. Figure 4.4 shows the recharge area.

Bingham and Moore (1975) estimated the amount of water available for recharge of ground water in the central Oklahoma region. Average annual precipitation ranges from 28 inches per year near Kingfisher to about 41 inches per year near Holdenville. Approximately 24 to 30 inches per year is returned to the atmosphere through evaporation and transpiration. Runoff ranges from 2.5 to 8 inches per year. The authors estimate that 1.5 to 3.5 inches per year is subsequently available for recharge.

In addition to the Garber/Wellington aquifer, Quaternary-aged terrace and alluvial deposits are locally important sources of ground water. These deposits consist of lenticular unconsolidated gravels, sands, silts, and clays. Alluvium refers to sediments deposited along modern stream channels and flood plains. Terrace deposits are older alluvial deposits that remain after rivers shift position, or may represent previous flood plains. Figure 4.1 shows the extent of the surficial alluvium and terrace deposits in the area near the Cimarron facility.

According to Bingham and Moore (1975), well yields of 200 to 250 gallons per minute (gpm) are common and that up to 500 gpm have been reported locally from these deposits. Engineering Enterprises (1973) reports that ground water in the terrace deposits near the town of Crescent flows southward towards the Cimarron River and contributes to its base flow. Recharge of the terrace and alluvial aquifers also occurs through precipitation and infiltration; however, water levels in the alluvial aquifers are commonly maintained by streams and rivers.

4.3 Ground-Water Use

The principal source of ground water in the area near the Cimarron facility is the Garber/Wellington formation. Well fields supply water to the towns of Edmond, Cashion, and others from this aquifer. North of the Cimarron River, domestic and agricultural users frequently obtain ground water from the Cimarron terrace deposits. Engineering Enterprises (1973) reports that well density in the terrace is approximately three wells per square mile. The river alluvium in the vicinity of the Cimarron facility is not used for ground water or drinking water supplies because of the salinity of the Cimarron River.

4.4 Regional Ground-Water Quality

Bingham and Moore (1975) discuss ground-water quality in the region encompassed by the Oklahoma City quadrangle. Previously published water quality data were combined with samples collected by the authors to characterize ground-water quality in the region. A summary of their results is presented in Table 4.1. Table 4.2 is a summary of ground-water quality analyses compiled by the U.S. Geological Survey for wells in the Garber/Wellington aquifer in Logan County.

In general, the water from bedrock aquifers is of good quality although the water usually is hard to very hard. Ground water from terrace deposits is also of good quality. Water from the alluvium along the Cimarron, North Canadian and Canadian Rivers is generally fair to poor because of the poor quality of the river water (Bingham and Moore, 1975). Engineering Enterprises (1973) reports that the Cimarron River has elevated naturally occurring chlorides derived from the Big Salt plains area approximately 100 miles upstream from the Cimarron facility.

The Garber/Wellington aquifer generally has good water. Bingham and Moore (1975) report that in the central Oklahoma region, hardness ranges from 4 ppm to 538 ppm, with a median value of 156 ppm; sulfate ranges from 3 ppm to 1450 ppm with a median of 17 ppm; chlorides range from 0.2 ppm to 458 ppm, with a median of 14 ppm; and nitrate ranges from 0 ppm to 100 ppm with a median of 1 ppm. Generally, hardness and dissolved solids tend to increase with depth. These data are presented in Table 4.1.

Table 4.2 presents data compiled by the U.S. Geological Survey for wells screened in the Garber/Wellington aquifer at depths less than 200 feet below ground surface in the area near the Cimarron facility. The data represents wells located in an area defined by Township 15 North, Range 2 West on the southeast to Township 16 North, Range 4 West on the northwest. In this area, hardness ranges from 130 ppm to 1300 ppm, with an average of 381 ppm; sulfate ranges from 7 ppm to 1900 ppm, with an average of 245 ppm; chlorides range from about 5 ppm to 110 ppm, with an average of about 32 ppm; and nitrates plus nitrite ranges from 0.3 to 63 ppm, with an average of about 15 ppm.

Near the town of Crescent, ground water from the terrace deposits above the Cimarron River is generally of good quality. Engineering Enterprises (1973) reports that wells screened in the terrace deposits near Crescent have a hardness ranging from 100 ppm to 200 ppm; total dissolved solids range from 400 ppm to 1000 ppm; and chlorides average about 50 ppm. They also report, however, that the terrace aquifer is locally impacted by brines that were disposed in unlined pits in the Crescent oilfield. Chlorides have been measured up to 17,000 ppm in this area.

According to Engineering Enterprises (1973), the water quality in the alluvial aquifers is similar to the terrace aquifers where the alluvium is recharged by the terrace ground water. In general, however, the alluvial aquifers are of poor quality because they are recharged by the Cimarron River which contains high chlorides that result from water from the natural salt springs about 100 miles upstream.

4.4.1 Background Nitrate and Fluoride Concentrations.

In the Garber/Wellington aquifer in the central Oklahoma region, Bingham and Moore (1975) report nitrate concentrations of 0 ppm to 100 ppm. Carr and Havens (1976) report nitrate concentrations of 1 ppm to 32 ppm from six wells in the Garber/Wellington aquifer near the Cimarron facility. The average nitrate concentration for the six wells is 12 ppm.

Carr and Havens (1976) also sampled one well in section 29, Township 15 North, Range 4 West for fluoride. The fluoride concentration was 0.9 ppm. At the Cimarron facility, twenty of the twenty four wells sampled had fluoride levels less than 0.5 mg/l. Regional fluoride concentrations in the Garber/Wellington aquifer are believed similar to these values.

4.4.2 Background TOC and TOX Concentrations.

Total organic carbon (TOC) and total organic halides (TOX) are general indicators of ground-water impacts from organic origins. At the Cimarron facility, three of the four wells sampled had TOC concentrations less than the laboratory detection limit of 10 mg/l. A fourth sample had a TOC content of 12 mg/l. These are equivalent to regional background concentrations in the Garber/Wellington aquifer.

Regional TOX concentrations in the Garber/Wellington aquifer probably are similar to values in the shallow ground water at the facility. These values range from 62 ug/l to 130 ug/l.

4.4.3 Background Radionuclide Concentrations.

Cimarron personnel installed monitoring wells approximately one-half mile south of the facility near the intersection of State Highways 33 and 74 to provide background data. These wells are up-gradient from the facility. Samples have been collected and analyzed for radionuclides since 1971. The data indicates that background values of U-238 are generally less than 0.7 pCi/l; Pu-239 is generally less than 0.010 pCi/l; gross alpha activity is less than 10 pCi/l; and gross beta activity is less than 20 pCi/l.

TABLE 4.1

Regional Ground-Water Quality

(from Bingham and Moore, 1975)

AQUIFERS	HARDNESS (ppm)			SULFATE (ppm)			CHLORIDE (ppm)			NITRATE (ppm)			TDS (ppm)		
	minimum	maximum	median	minimum	maximum	median	minimum	maximum	median	minimum	maximum	median	minimum	maximum	median
Alluvium and Terrace deposits	14	1320	297	3.3	1320	64	2.0	1450	40	0.0	189	5.8	82	3060	520
Garber/Wellington	4.0	538	156	3.0	1450	17	0.2	458	14	0.0	100	1.0	101	2110	320
Other Permian Formations	40	1670	310	12	5350	73	9.0	945	40	0.0	175	14	246	5900	577
Vamoosa Formation	36	600	200	3.5	796	28	4.0	320	13	0.0	214	0.8	113	1540	357
Other Pennsylvanian Formations	9.0	2760	164	4.8	4850	35	3.0	2100	38	0.0	160	2.0	77	9580	416

TABLE 4.2

GARBER/WELLINGTON AQUIFER GROUND-WATER QUALITY
LOGAN COUNTY WELLS
Townships 15N-R2W to 16N-R4W
(From Carr & Havens, 1976)

PARAMETER	HIGH (ppm)	LOW (ppm)	AVERAGE (ppm)	STD. DEVIATION
Calcium	370	29	108.7	100.9
Chloride	110	4.8	31.7	32.6
Dissolved Solids				
- residue on evaporation	3260	215	758.2	907.5
Hardness	1300	130	381.2	316.2
Bicarbonate	420	136	293.2	74.8
Magnesium	89	15	35.2	22.6
Sodium	690	22	104.2	187.7
Nitrate	32	1	12	11.4
Nitrate + Nitrite	63	0.3	14.9	21.9
pH	8.1	7.2	7.8	0.3
Sulfate	1900	7	245.4	562.6
Depth (feet)	200'	41'	121.7'	

5. SITE HYDROGEOLOGY

5.1 Site Physiography

The Cimarron facility lies in the Central Lowlands portion of the Great Plains physiographic province. The topography is characterized by low, rolling hills and incised drainages and floodplains. The elevation of the site above sea level ranges from about 940 to 1010 feet. The principal geomorphic feature at the site is the Cimarron River floodplain which is approximately one-half mile in width and trends east-west.

Vegetation in the site area is mainly native grasses with well developed tree stands in the drainages and along the bluff overlooking the Cimarron River.

Precipitation averages about 39 inches per year. Table 5.1 shows average monthly precipitation at the Cimarron facility. The majority of the precipitation occurs during the spring and fall months.

5.2 Site Geology

5.2.1 Site Stratigraphy.

A veneer of soil, one to eight feet thick, covers most of the site. The shallow rock at the site consists of sandstones and siltstones of the Garber formation (Garber Sandstone). The Garber Sandstone is relatively thick in the facility area and no other formations were penetrated by drilling conducted during this investigation to depths of up to 140 feet. Figures 5.1 and 5.2 are geologic cross-sections showing the shallow subsurface stratigraphy underlying the site.

The deeper stratigraphic units in the area were penetrated by a proposed deep disposal well that was completed in 1969. This well is the deepest borehole known to have been drilled in the immediate vicinity of the site. The deep well is on Cimarron facility property near the uranium plant. The depth of the well is 2078 feet. The top of the unit immediately underlying the Garber, the Wellington formation, was identified at 200 feet below the ground surface. The Wellington consists of 960 feet of red shale with several thin siltstone beds. The top of the Wolfcampian age Stratford formation was found at 1160 feet. It is 870 feet thick and consists of red and gray shale with thin anhydrite beds in the upper part. The lower part of the Stratford

is predominately red and gray sandy shale with three porous sandstone members.

Process wastes were planned to be injected into one of the sandstone members of the Stratford; however, no injection into the well ever was conducted. The injection well will be plugged and abandoned in accordance with State regulations as part of the site decommissioning activities.

5.2.1.1 Shallow Stratigraphic Units.

SOIL LAYER:

The soil layer ranges from one to eight feet thick and is chiefly a reddish-brown silty sand. This soil type predominates and is present where the underlying rock type is sandstone. A very fine sandy silt/clay also occurs at the site where the underlying bedrock is a sandy siltstone or mudstone. The silt/clay type soils are less abundant than the silty sand soils.

ROCK LAYERS:

The upper portion of the Garber Sandstone at the site consists primarily of sandstone layers separated by relatively continuous siltstone and mudstone layers. For the purposes of this report, the lithologically similar sandstones are designated, from shallowest to deepest, Sandstones A, B, and C. Similarly, the intervening siltstones and mudstones are designated Mudstones A and B. The discussion of the stratigraphy and lithology of these strata, and later references to hydrogeologic and chemical properties, are keyed to this arbitrary nomenclature.

- SANDSTONE A: The first or uppermost sandstone is up to 35 feet thick. The bottom of this sandstone occurs at an elevation of about 970 feet (msl).

- MUDSTONE A: The mudstone stratum separating Sandstones A and B ranges from about 6 to nearly 20 feet thick.

- SANDSTONE B: The second or intermediate sandstone is up to about 30 feet thick and lies roughly between the 925 and 955 feet elevations (msl).

- MUDSTONE B: The mudstone stratum separating Sandstones B and C ranges from about 6 to 14 feet thick.

- SANDSTONE C: The third significant sandstone may not have been fully penetrated during this investigation. The presence of a basal siltstone or mudstone layer was not verified at the depth penetrated by the site wells; but, Sandstone C appears to be at least 55 feet thick and contains interbedded siltstones.

These strata are inferred to have been deposited in a fluvial/upper deltaic system. Lateral facies changes are frequent and correlations over long distances are difficult, perhaps as a result of shifting channel locations. Each of the major strata identified above has interbedded, thin and discontinuous sandstones and siltstones. Patterson (1933) interprets the Garber as originating from a deltaic system that entered the Permian sea from the east.

5.2.1.2 Description of Sandstones:.

All three sandstones encountered during this investigation can be described as generally fine to very fine grained with well sorted subangular to rounded grains. Variable silt content was observed in the sandstones. The estimated silt content ranges from less than 10 to up 50 percent. Where the silt content is high, distinction between sandstone and siltstone is difficult. The sand grains are virtually all quartz, with minor amounts of potassium feldspar and occasional mafic grains such as magnetite. Micas are minor constituents. Intergranular porosity is generally good, though obviously varies with silt content.

The sandstones typically are weakly cemented and friable. The cementing agents appear to be calcite and hematite; however, silt and clay-sized fractions in the matrix may also contribute to cementation. Thin intervals are present occasionally that are well cemented and hard. These intervals are frequently conglomeratic with gypsum and possibly barite providing additional intergranular cement.

The sandstones often are cross-stratified with thin, silty laminae. The cross-stratification is planar and might be indicative of bar deposition in fluvial systems. Cross stratification was usually found near the middle of the sandstone intervals.

Conglomeratic intervals were encountered in most of the borings. These intervals are associated with the sandstone strata although, in some instances, the matrix materials are mudstones. The conglomeratic intervals are 2.5 feet or less in thickness. The matrix is either sandstone or mudstone and the clasts are predominately mudstone. Patches of sandstone clasts also are present. These conglomeratic intervals commonly possess a vuggy porosity. The vugs probably formed through dissolution of lithic clasts. The presence of vugs is not attributed to drilling fluids

because the vugs often are lined with euhedral calcite, gypsum and barite crystals.

The origin of the conglomeratic sandstones and mudstones might be related to an influx of more rapidly moving water, such as a flood. The influx could have caused the pre-existing rocks and sediments to be torn up and re-transported. Transport distance probably was minimal as the weakly-cemented clasts would have disintegrated if they were agitated for prolonged periods. In all cases, a fining upward sequence in grain size accompanies the conglomeratic intervals, as is typical in fluvial and deltaic systems.

5.2.1.3 Description of Mudstone:.

Separating the sandstones are fine-grained, silty and shaley beds. These beds were identified in the field as mudstones, a genetic description inferring their origin. Dessication cracks in the mudstones were observed in several borings and these beds might represent flood plain deposits. Stratification within the mudstones is largely absent and they lack the fissile nature characteristic of shales.

The mudstone units typically are poorly consolidated as indicated by the tendency for core samples to deteriorate rapidly. The mudstone cores have a consistency more like a very stiff to hard sandy silt or clay than rock, even at depths greater than 100 feet below ground.

Encapsulating the mudstone layers were thin, bluish-gray zones or layers that ranged from less than 0.1 inches to over 4 inches in thickness. These layers tentatively were identified in the field as "reduction zones." Reduction spots were also observed. This phenomenon is common in red bed formations and is not unique to the site. In the subsurface at the facility, the thickness of the bluish-gray layers is directly proportional to the thickness of the silt and clay-rich layers they bound.

The reduction zones might represent intervals where ferric oxides have been reduced to ferrous compounds. Ferrous iron is soluble and is removed by ground water. Al-Shaieb et.al. (1977) attribute the reduction of ferric iron to a reaction with hydrogen sulfide produced either by the contact of sulfate with hydrocarbons, or hydrogen sulfide released directly from naturally occurring hydrocarbons.

5.2.2 Structure.

The strata underlying the Cimarron facility are largely undeformed. Dip is westerly to southwesterly and has been described by various authors as ranging from 20 to 40 feet per mile. Measurements at outcrops at the facility indicate the sandstones strike to the northwest and dip very slightly to the southwest. The site lies to the east of the Nemaha ridge, a narrow, subsurface north-northwest trending uplift formed during the Mississippian.

The Nemaha ridge or uplift is characterized by a series of en-echelon, parallel normal faults which are down-thrown on the west side, with anticlinal folding across the top. Some reactivation of the faults occurred during the early Pennsylvanian; however, movement has not been described since that time. Regional dip is to the southwest into the Anadarko basin and is the result of post-Paleozoic uplift and erosion.

5.2.3 **Mineralogy and Rock Chemistry.**

Analysis of selected samples for mineralogy and chemical parameters including cation exchange capacity and exchangeable cation were performed by Auburn University. These tests were performed to verify the field classification of soils and rocks, and to provide information useful for determining the capacity of selected rock units to adsorb radionuclides and inhibit their migration. Table 3.7 summarizes the results of these analyses.

5.2.3.1 Mineralogy.

5.2.3.1.1 Testing

Site representative samples were analyzed via X-ray diffraction at Auburn University for major mineral constituents. X-ray diffraction is one of the more effective analytical methods for identifying clay minerals in rock material. The mineral constituents of the samples analyzed are listed in Table 3.7.

5.2.3.1.2 Discussion

The mineralogical analyses indicate that quartz and feldspar are the predominant minerals of the larger sized fractions. Kaolinite and 2:1 expanding layer clay minerals (montmorillonites) dominate the fine fraction in nearly equal proportions. Minor amounts of calcite, iron oxides and iron hydroxides are identified and are probably the cementing agents.

The particle size distributions reflect the field descriptions listed in Table 3.7. The rock units identified as mudstones and sandy mudstones are composed predominantly of silt-size particles. The sandstones are dominated by particle sizes in the 0.25 to 0.05 mm range, which corresponds to the fine and very-fine grained descriptions assigned in the field.

Samples from the "reduction zones", Nos. CH-2, CH-12, and CH-14, are of particular interest. The distinction between these samples and the "non-reduced" samples is subtle. Samples CH-1 and CH-2 are from essentially the same interval and are nearly identical in gross mineralogy. The principal difference between the two samples is that the iron content of sample CH-2 is about one-half that of CH-1. Samples CH-12 and CH-14 had low iron values compared to non-reduced samples as well.

5.2.3.2 Soil and Rock Chemistry.

5.2.3.2.1 Testing

In addition to mineralogy, the samples submitted to Auburn University were analyzed for cation exchange capacity (CEC) and exchangeable cation (EXC). These results are presented in Table 3.7.

5.2.3.2.2 Discussion

Cation exchange capacity ranges from 2.96 to 22.75 meq/l. The majority of samples had CEC's less than 10 meq/l. The clay minerals responsible for the cation exchange capacity of the samples are identified as montmorillonites.

The most prevalent exchangeable cations are divalent. Calcium and magnesium are the significant exchangeable cations. Potassium and sodium are also present but their concentrations are about an order of magnitude less than calcium and magnesium.

5.2.3.3 Chemical Interactions.

The hydrogeologic environment underlying the site is composed of physical and chemical systems. The physical system is characterized by lithologies, structures, hydraulic conductivities, and flow gradient and directions. The chemical system is characterized by the interaction between ground-water chemistry and the enclosing strata.

5.2.3.3.1 Chemical Environments

The chemical environment underlying the site is characterized by the chemistry of the unsaturated and saturated zones. The unsaturated zone environment will be dominated by the chemistry of the soils and rock strata. The saturated zone will be dominated by the chemistry of the ground water.

Ground water at the site is oxygenated and slightly alkaline. The strata appear oxidized and have a relatively low cation exchange capacity. The organic content of the strata is negligible.

5.2.3.3.2 Site-Related Elements

Elements targeted in this investigation that may interact with the subsurface environment include fluoride, nitrate, plutonium, uranium, thorium and radium. Thorium and radium were not used in the facility processes; however analyses were conducted to determine background concentrations. The availability of plutonium for interaction with the environment is considered negligible. Plutonium was only present within the plutonium plant and in very small concentrations in the sewage lagoon sediments.

Thorium was present as drummed waste in the former burial location. The drums containing thorium were removed and disposed in a commercial disposal facility. Some thorium processing equipment from the Cushing facility was stored at the uranium facility yard; however thorium has not been detected above natural background levels. Radium was not used in the facility production processes and there is no source for radium to enter the environment. Consequently, thorium and radium encountered in this investigation are considered to be representative of background sources, and not derived from materials processed by the Cimarron facility.

5.3 Surface-Water Hydrology

5.3.1 Local Surface-Water Bodies.

The principal surface-water bodies at the site are the three reservoirs indicated on the site map and the Cimarron River.

The water elevation of the three reservoirs was determined at the time the monitoring wells were surveyed. The water elevations for reservoirs 1,2 and 3 are 959.3, 966.3, and 959.7 feet above mean sea level, respectively. The average stage for the Cimarron River near the facility is approximately 940 feet above mean sea level.

5.3.2 Influence on Ground-Water System.

The three reservoirs appear to influence shallow ground-water flow at the site. Reservoirs 1 and 3 have water levels significantly below the water table in the nearest wells indicating that shallow ground water maintains the water level of these reservoirs and hence provides the base flow for the streams that exit the reservoirs.

5.4 Site Ground-Water Hydrology

5.4.1 Ground-Water Occurrence.

Shallow ground water occurs under water table and partially confined conditions at the site. The depth to water in the shallow wells ranges from about 10 to 30 feet below ground level. The shallow wells constructed during this investigation are all screened at about the same stratigraphic interval. This interval is approximately the base of the first major sandstone (sandstone A). Figure 5.4 is a map of the potentiometric surface of the shallow ground water.

The water table shows a strong influence exerted by topography and the surface-water bodies. Seepage faces were observed along the slope above the Cimarron River floodplain. In the vicinity of Well 1334, seepage occurs at an elevation of about 964 feet with standing water occurring in a marshy area at an elevation of about 960 feet.

All the rocks below the water table are saturated. The deep wells were screened in a confined sandstone that occurs approximately 80 to 100 feet below the ground surface. This interval was subsequently identified as the third major sandstone (sandstone C) underlying the site. Figure 5.5 is a map of the potentiometric surface defined by the deep wells.

5.4.2 Ground-Water Flow System.

Shallow ground water is strongly influenced by topography and the surface-water bodies. Flow direction is primarily north-northwest toward the Cimarron River. The incised drainages and bluff overlooking the river's floodplain exert local influences. The gradient averages approximately 0.025 except where it steepens as a result of proximity to discharge areas.

Ground water from the confined aquifer screened in the deep wells also flows to the north-northwest. The gradient is approximately 0.014. This deeper ground-water interval probably recharges the Cimarron alluvium and contributes to the base flow of the Cimarron River.

5.4.3 Hydraulic Properties of Water-Bearing Strata.

Hydraulic conductivities of the Garber Formation sandstones generally are moderate. The primary hydraulic conductivity control is the good intergranular porosity observed in the core samples. The sandstones are poorly cemented and show few diagenetic effects, thus the primary porosity restrictions are the variable amounts of fines present in the sandstones. Inspection of outcrops at the site and core samples revealed minimal jointing indicating that the effect of fractures on hydraulic conductivities is expected to be low.

The hydraulic conductivities of the sandstones that are screened in both the deep and shallow wells have been measured by slug test methods. Descriptions of the test methods and analytical techniques was presented in Section 2.2.6.

The hydraulic conductivity of the shallow aquifer ranges from 2.41×10^{-4} cm/sec to 5.7×10^{-3} cm/sec. The geometric mean of the measured values is 1.03×10^{-3} cm/sec. The transmissivity of this aquifer ranges from 10.3 x 10 ft sq/day to 108 ft sq/day, with a geometric mean of 33.4 ft sq/day.

The hydraulic conductivity of the deep aquifer ranges from 1.39×10^{-5} cm/sec to 7.06×10^{-4} cm/sec, with a geometric mean of 1.27×10^{-4} cm/sec. The transmissivity ranges from .67 ft sq/day to 50 ft sq/day, with a geometric mean of 7.96 ft sq/day. Slug test results are included in Table 3.3.

5.5 Ground-Water Quality

A standard water quality analysis was performed on a sample of ground water from Well 1324. This well is up-gradient from all facility components and is representative of background presence of major cations and anions in the shallow ground water. Shallow ground-water quality at the site is consistent with the regional average concentrations of major ions reported by Bingham and Moore (1975) and Carr and Havens (1976). The results are presented in Table 3.4.

5.5.1 pH and Conductivity.

At the time of sampling, pH and specific conductance were measured for all ground-water samples collected. In general, the ground water at the site is near neutral to slightly alkaline. Ground water from the deep wells is similar in pH to the shallow, but has significantly higher specific conductance.

Ground water from the shallow wells has a pH ranging from 6.99 to 7.71. Specific conductance ranges from 400 to 1590 micromhos per centimeter (umho/cm) and averages 646 umho/cm. The highest value indicated for the shallow wells, 1590 umho/cm, is from Well 1330. Ground water from the deep wells has a pH ranging from 6.91 to 7.39. Specific conductance ranges from 1910 to 3190 umho/cm, and averages 2480 umho/cm.

Specific conductance values are higher in the deeper ground water as a result of limited infiltration and mixing of precipitation, according to Bingham and Moore (1975).