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GEOLOGIC SETTING OF THE NEW PRODUCTION REACTOR REFERENCE SITE
WITHIN THE SAVANNAH RIVER SITE (U)

VAN PRICE ¹

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EXECUTIVE SUMMARY

The Department of Energy (DOE) is preparing an environmental impact statement (EIS) on the Siting, Construction, and Operation of New Production Reactor (NPR) Capacity. The EIS will describe the environmental effects of siting, constructing, and operating one of three reactor types (heavy water reactor, light water reactor, and modular high-temperature reactor) at one of three sites (the Hanford Reservation, the Idaho National Engineering Laboratory, and the Savannah River Site [SRS]). This report has been prepared to document the geologic setting of the reference NPR site at SRS. The reference site will be described in the NPR EIS as the proposed NPR site at SRS.

The geology and hydrology of the reference NPR site at SRS have been summarized using the available information from the NPR site and areas adjacent to the site, particularly the away from reactor spent fuel storage site (AFR site). The NPR site is underlain by a succession of unconsolidated and semiconsolidated sediments that are approximately 1100 ft thick. This sequence is underlain by a Precambrian to Paleozoic crystalline basement complex composed of folded and faulted metamorphic rocks similar to those exposed north of the Fall Line in South Carolina and Georgia.

Lithologic and geophysical logs from wells drilled near the NPR site do not indicate any faults in the upper several hundred feet of the Coastal Plain sediments. However, the Pen Branch Fault is located about 1 mile south of the site and extends into the upper 100 ft of the Coastal Plain sequence. Subsurface voids, resulting from the dissolution of calcareous portions of the sediments, may be present within 200 ft of the surface at the NPR site. This condition has been observed at the AFR site. Similar voids in the subsurface have been successfully grouted at other facilities on SRS.

The water table at the NPR site is located within 30 to 70 ft of the surface. Locally at the site there are areas containing perched water zones. The NPR site is located on a groundwater divide, and groundwater flow for the shallowest hydraulic zones is predominantly toward local streams. Groundwater flow in deeper Tertiary sediments is north to Upper Three Runs Creek or west to the Savannah River Swamp. Groundwater flow in the Cretaceous sediments is west to the Savannah River.

INTRODUCTION

There are several areas within the Savannah River Site (SRS) suitable for construction of new production reactor (NPR) facilities. One of these, referred to as the "reference NPR site," will be discussed in this report. This reference site was selected through a lengthy process, beginning with the entire SRS area and systematically eliminating potential sites based on environmental, safety, security, engineering, long-term disposition, and other considerations. For example, major drainage valleys were eliminated for both safety and environmental reasons. The selection process has been reviewed in Bean and Olson (1990).

The reference NPR site (Figure 1), hereafter referred to as the NPR site, is immediately adjacent to a site considered for storage of spent reactor fuel in the late 1970s. The away from reactor spent fuel storage facility site (AFR site) was proposed as a potential NPR site as early as 1984 (Figure 1). A subsurface investigation was conducted when the area was under consideration as the spent fuel storage site (D'Appolonia, 1980). Data analysis was curtailed when the storage project was terminated. Subsequently, the engineering firm of Mueser, Rutledge, Johnston, and DeSimone (MRJD) reviewed the data and determined that engineering properties of the soils were similar to other areas of SRS and that there was no danger of liquefaction from seismic shock (MRJD, 1984). A summary from the MRJD report is attached as Appendix A.

Portions of the following text are keyed to headings prepared by Argonne National Laboratory (ANL) as an outline for the NPR environmental impact statement. This outline is attached as Appendix B. Information applicable to the entire SRS, such as regional geology, is included in WSRC (1989).

GEOLOGY OF THE SAVANNAH RIVER SITE (ANL Section 3.3.1)

Geologic Setting of the Savannah River Site (ANL Section 3.3.1.1)

Regional and local geologic settings are discussed in WSRC (1989, beginning at p. 3A-194).

Stratigraphic Units at the NPR Site (ANL Section 3.3.1.2.1)

There are no detailed surficial geologic maps for the NPR site; however, reconnaissance field examination and drill data indicate that surface sediments at the NPR area are represented by a relatively thick section of the "Upland" unit. A soil map of the NPR site is presented in Figure 2.

Figure 1. NPR and AFR site locations and cross-section lines A-A' and B-B'.

Figure 2. Soils at the NPR site.

The NPR area is in the Upper Atlantic Coastal Plain and is underlain by a sedimentary wedge approximately 1100 ft thick. The Coastal Plain wedge consists of unindurated and semi-indurated fluvial, deltaic, and marine sediments that dip gently to the southeast and range in age from Late Cretaceous to Holocene (Table 1, Figures 3, 4, and 5). The stratigraphy in the NPR area has been delineated primarily through lithologic and downhole geophysical logging of boreholes located in adjacent areas. An example of the geophysical logs for four boreholes is presented in Figure 6, which illustrates the geophysical signature of the stratigraphic contacts in the upper portion of the Coastal Plain sediments and their correlation between holes.

The sedimentary sequence is underlain by a Precambrian/Paleozoic basement complex composed of folded and faulted metamorphic rocks similar to those exposed in the Piedmont north of the Fall Line in South Carolina and Georgia. Within the basement complex is a Newark-type basin (the Dunbarton Basin) which contains sedimentary rock of Triassic age (Marine and Siple, 1974).

Pre-Cretaceous Basement (ANL Section 3.3.1.1.1.1)

Under the NPR area, the basement surface is at an elevation of about 760 to 770 ft below mean sea level (msl), strikes approximately north 60 degrees east, and dips approximately 40 ft/mile to the southeast. The crystalline rocks beneath SRS include granitic intrusives, hornblende gneisses, and chlorite-hornblende schists that are similar to Charlotte and Kiokee belt lithologies of the Appalachian Piedmont. Figure 7 is a map showing rock types encountered in SRS wells that extend through the Coastal Plain. The sub-Coastal Plain basement under most or all of the NPR area is composed of crystalline rock, whereas farther south the basement is dominated by Triassic sedimentary rocks.

Figure 8 is a contour map showing the elevation (msl +/-) of the sub-Coastal Plain surface. This map is based on lithologic data from wells that reached basement rocks; thus, it is a standard by which interpretations of geophysical data can be judged. Based upon drill and seismic reflection data, two fault displacements are apparent in the surface: the east-west trending Pen Branch fault and an unnamed north-south trending fault.

An aeromagnetic survey of the area in 1958 by the U. S. Geological Survey identified the presence of a magnetic low that may coincide with the distribution of the Triassic rocks. Based on the magnetic data and cored wells, the Dunbarton Triassic Basin was defined as being approximately 30 miles long (Marine and Siple, 1974). The strike of the basin's long axis is approximately north 63 degrees east and parallels the regional trend of Appalachian structures (WSRC, 1989). Several wells in the southeastern part of SRS have penetrated maroon siltstones, feldspathic sandstones, and conglomerates that are similar to Triassic deposits of

Table 1. Stratigraphy of sediments in the NPR area^a

<u>Stratigraphic Unit</u>	<u>Age</u>
"Upland" unit	Miocene(?)
Barnwell Group	
Tobacco Road Sand	Late Eocene
Dry Branch Formation	Late Eocene
Irwinton Sand Member	
Griffins Landing Member	
Clinchfield Formation	Late Eocene
Orangeburg Group	
Santee Limestone	Middle Eocene
Congaree Formation	Middle Eocene
Black Mingo Group	
Fourmile Member of Fishburne Formation	Early Eocene
Snapp Member of Williamsburg Formation	Late Paleocene
Ellenton Member of Rhems Formation	Early and Late Paleocene
Lumbee Group	
Steel Creek Member of Peedee Formation	Late Cretaceous
Black Creek Formation	Late Cretaceous
Middendorf Formation	Late Cretaceous
Cape Fear Formation	Late Cretaceous
Newark Supergroup	Late Triassic

^a Minor revisions to the above stratigraphic sequence were suggested by Fallaw et al. in the proceedings of the Second Bald Head Island Conference, November 6-11, 1990. The abstract of this presentation is included as Appendix C.

Figure 3. Coastal Plain sediments at SRS (see the revisions described in Appendix C).

A

- SAND
- CLAY
- LIMESTONE
- FOSSILS
- PEBBLES

0 4000
FEET

V.E. = 44.3X

P 18

CPC 1

NPM 1A

Figure 4. Cross section A-A' illustrating the sedimentological relationships between the lithostratigraphic units above the base of the Peedee Formation. Well PBF 3 is located at the southern end of the AFR site; well M12 1A is located west of the AFR site (see Figure 1 for location of the cross-section line).

Figure 5. Cross-section B-B' illustrating offset across the Pen Branch Fault. Horizontal lines represent the tops of the Dry Branch Formation and the Santee Limestone. E wells = AFR series (see Figure 1 for the location of the cross-section line).

Figure 6. Geophysical logs for wells AFR 26, AFR 24, AFR 4, and PBF 3.

Figure 7. Sub-Coastal Plain basement lithologies at SRS (modified from Cumbest and Price, in press).

Figure 8. Contour map of the top of the sub-Coastal Plain basement, derived from drill data. Note basement faults and the location of the Dunbarton Basin.

the Newark Supergroup. The maximum thickness of the Triassic rocks is not known but has been estimated at 5000 to 7000 ft by interpretation of gravity and electromagnetic (TEM) survey data (Price et al., in review). One well drilled at SRS in 1969 penetrated 1593 ft of Triassic sediments before encountering metamorphic rocks. Another well drilled in 1972 penetrated 2250 ft of Triassic sediments; then the drilling was terminated. Figure 9 shows the configuration of the basement surface based on the TEM data.

Stratigraphy of Coastal Plain Sediments

Late Cretaceous Cape Fear Formation

The Cape Fear Formation is composed of light to dark gray, yellow, red, and purple sands interbedded with gray, purple, red, and yellow clays. Bedding thickness of the sands is up to 30 ft and of the clays is up to 15 ft. The sands are fine to coarse, pebbly, silty, clayey, and poorly to moderately sorted. Many of them are micaceous, and some fine upward. Induration is moderate to high. The unit has been interpreted as an upper delta plain deposit. The high clay content of the Cape Fear Formation at SRS makes it an aquitard. The top of the unit is about 600 to 640 ft below msl in the NPR area, and the formation is about 130 to 150 ft thick. Pollen dated as possibly Turonian or Coniacian (late Cretaceous) has been obtained from Cape Fear samples at SRS.

Late Cretaceous Lumbee Group

Quartz sands and clays that are assigned to the Lumbee Group are present beneath the NPR area. The formations of the Lumbee are the Middendorf, the Black Creek, and the Steel Creek Member of the Peedee Formation. The upper surface of the Lumbee is about 90 to 120 ft below msl in the NPR area, and the group is approximately 650 ft thick.

Middendorf Formation. The Middendorf Formation overlies the Cape Fear Formation along a sharp, unconformable contact; the contact is marked in most SRS wells by a coarse, pebbly zone and a distinct change in lithology. The Middendorf is made up mostly of tan and gray, fine to coarse, loose to slightly indurated, moderately and well-sorted quartz sands. In the upper third of the unit, interbedded gray clays up to 6 ft thick are common. Some of the sands fine upward, and muscovite, lignite, and iron sulfides are fairly abundant in parts of the section. Thin clay laminae are locally interbedded with the sands. The sands are loose to slightly indurated, and the clays are moderately indurated. The Middendorf has the characteristics of a fluvial or upper delta plain deposit.

In the NPR area, the top of the Middendorf Formation is approximately 470 to 500 ft below msl, and the unit is about 140 to 150 ft thick. The lower sandy part has

Figure 9. Configuration of the sub-Coastal Plain basement surface at SRS, derived from TEM data. Areas outside of the SRS boundary not covered by the TEM survey are shown at datum elevation of the figure.

high permeability, whereas the upper clayey zone may be an aquitard. The Middendorf has been dated as Santonian (late Cretaceous).

Black Creek Formation. The Black Creek Formation overlies the Middendorf along a probable unconformity and is composed of four parts: a lower sandy zone, an interbedded sand and clay zone, an upper sandy zone, and an upper clay. The lower part is composed of tan, brown, and gray, poorly to moderately sorted, and fine to coarse quartz sand. Pebbles, lignite clasts, and iron sulfides are common, and muscovite is abundant. Thin clayey and lignitic laminae occur in places. The interbedded sand and clay zone contains dark to light gray and brown sands, with interbedded dark, silty, lignitic, pyritic clays up to 25 ft thick. The overlying sands are medium to coarse, moderately to well sorted, and contain abundant muscovite and lignite. Pebbles, thin clay beds, and iron sulfides occur in places. The upper clay is silty, dark to light gray, with orange and red mottling. Lignite and iron sulfides occur in places. The upper clay varies from about 40 to 50 ft in thickness in the NPR area. Sands of the Black Creek are loose to slightly indurated, and many of the sand beds fine upward. The clays are moderately indurated. The Black Creek was probably deposited in a deltaic environment.

The top of the Black Creek is about 470 to 500 ft below msl, and the formation is about 290 to 310 ft thick. The lower and upper sands have high permeability, and the interbedded sand and clay zone may be an aquitard. The upper clay, if it is continuous across the area, is an aquitard. Campanian and early Maestrichtian fossils occur in the Black Creek.

Steel Creek Member of the Peedee Formation. The Steel Creek Member unconformably overlies the Black Creek and is composed of a lower sand that is about 20 to 50 ft thick and an upper clay that is about 25 to 60 ft thick. The sand, composed of fining upward cycles, is loose, medium to coarse, poorly to well sorted, and slightly pebbly. It is colored orange, gray, and tan. Muscovite is abundant in the sand, and iron sulfide occurs locally. The clay is light gray, red, purple, and yellow. Muscovite and iron sulfide are locally common. The Steel Creek was probably deposited in a deltaic environment.

The top of the Steel Creek Member is approximately 90 to 120 ft below msl in the NPR area, and the unit is about 70 to 85 ft thick. The lower sand has moderate to high permeability, and the upper clay is an aquitard. The age is Maestrichtian (late Cretaceous).

Paleocene-Eocene Black Mingo Group

The Black Mingo Group at SRS consists of the early and late Paleocene Ellenton Member of the Rhems Formation, the late Paleocene Snapp Member of the Williamsburg Formation, and the early Eocene Fourmile Member of the Fishburne

Formation. Quartz sands and clays are the dominant lithologies. In the NPR area, the top of the group is about 10 to 40 ft above msl, and the group is about 140 ft thick.

Ellenton Member of the Rhems Formation. The Ellenton Member of the Rhems Formation lies unconformably on the Steel Creek Member. It is composed of dark gray, moderately and well-sorted micaceous sand, with interbedded, light to dark silty clays up to about 10 ft thick in the lower part. Lignite and iron sulfide are present in places. The sediments were probably deposited in a deltaic environment. The Ellenton sands have moderate to low permeabilities, and the clays are aquitards.

The top of the formation is about 30 to 70 ft below msl, and the unit is 60 to 70 ft thick. Midwayan (early Paleocene) and early Sabinian (late Paleocene) dates have been obtained from the Ellenton.

Snapp Member of the Williamsburg Formation. The Snapp Member of the Williamsburg Formation lies unconformably(?) on the Ellenton. It consists of a fine- and medium-grained, slightly indurated, lower sandy zone and a moderately indurated upper clay. The sand is about 15 to 30 ft thick, light to dark gray, moderately to well sorted, with abundant muscovite. Lignite clasts and iron sulfides are locally common in the sand. The clay is light to dark gray, fissile, micaceous, and moderately indurated. Iron sulfides are locally common in the clay. The Snapp was probably deposited in a deltaic environment.

The top of the member varies from 0 to 40 ft below msl, and the unit is about 30 ft thick. The sand probably has moderate permeability, and the clay is an aquitard if it has lateral continuity. The age is middle Sabinian (late Eocene).

Fourmile Member of the Fishburne Formation. The Fourmile Member of the Fishburne Formation unconformably overlies the Snapp. It is composed almost entirely of loose to slightly indurated, medium and coarse, moderately sorted, gray and orange sand. It is slightly pebbly, and small amounts of glauconite occur in places. Clay layers up to 30 ft thick occur in the Fourmile Member, especially in the lower part of the unit. The sediments were deposited in shallow marine and lagoonal environments.

The top of the Fourmile is about 10 to 40 ft above msl, and the thickness of the member is from 35 to 50 ft in the NPR area. Permeability is high. The age is late Sabinian (early Eocene).

Orangeburg Group

The Orangeburg Group contains quartz sands, clays, and limestones of the early middle Eocene Congaree Formation and the late middle Eocene Santee Limestone. The top of the group is from 110 to 150 ft above msl, and the thickness of the group is approximately 110 ft.

Congaree Formation. The Congaree Formation overlies the Fishburne; these two formations may be separated by an unconformity. They are almost lithologically identical, but the Congaree lacks clay layers. Grain size is fine to coarse, and the unit is moderately to well sorted. The sands are rather loose, and the dominant colors are orange, green, and tan. The environment of deposition was shallow marine.

The top of the Congaree is from about 55 to 90 ft above msl, and the thickness is about 40 to 45 ft. Permeability is high. The age is early Claibornian (early middle Eocene). Much of what was previously mapped as Congaree at SRS is now assigned to the Fourmile Member of the Fishburne Formation.

Santee Limestone. The Santee Limestone is composed of several lithostratigraphic units. The basal unit of the formation is a fine to coarse, poorly to well-sorted orange sand, approximately 6 ft thick. This unit is overlain by a glauconitic, poorly sorted, fine to medium sand up to 5 ft thick or by a glauconitic, green clay about 1 or 2 ft thick. In the western part of the NPR area, the glauconitic zone is overlain by the calcareous McBean Member of the Santee Limestone. The McBean Member is 20 ft thick and includes calcarenite, calcilutite, highly indurated, biomoldic limestone, and shelly calcarenite. In the central and eastern part of the area, where no carbonate has been found, a loose, very fine to medium, well-sorted orange sand is present. The Santee was deposited in a shallow marine environment. See Appendix C for revisions to the stratigraphic nomenclature of the Santee Limestone.

The top of the formation is about 120 to 130 ft above msl, and the Santee is approximately 50 ft thick. Permeability may be high except in the glauconitic zone and in the calcilutite. The age is late Claibornian (late middle Eocene).

Barnwell Group

The Barnwell Group is composed of quartz sands, clays, and limestones of the Clinchfield, Dry Branch, and Tobacco Road formations. The group probably crops out at lower elevations near the NPR area. Its thickness is highly variable, probably as much as 190 ft in places. The age of the Barnwell Group is Jacksonian.

Clinchfield Formation. The basal unit of the Barnwell, the Clinchfield Formation, lies unconformably on the Santee. In the western part of the NPR area, the Clinchfield consists of a calcareous, shelly, moderately sorted quartz sand about 8 ft thick. No carbonate is reported from the central and eastern part of the area, but quartz sand is present. The environment of deposition was shallow marine.

The top of the Clinchfield is about 140 ft above msl in the NPR area, and the unit is from 5 to 15 ft thick. Permeability should be high. The age is early Jacksonian (early late Eocene).

Dry Branch Formation. In the western part of the NPR area, the Clinchfield is overlain by the Griffins Landing Member of the Dry Branch Formation. This member is composed of calcilutite, calcarenite, and shelly limestone. In the central and eastern parts of the area, the Clinchfield is overlain by the Irwinton Sand Member, described below. In the west, the Griffins Landing is overlain by a green and tan clay, about 10 ft thick, that is in turn overlain by the Irwinton Sand Member. The clay is very thin or missing in the central and eastern parts of the area. The Irwinton Sand is loose, moderately and well sorted, and medium grained. Colors are orange, yellow, tan, and brown. The environment of deposition was shallow marine. The top of the Dry Branch is from 100 to 180 ft above msl, and it is from 60 to 70 ft thick. Permeability should be high except in the calcilutite and clay in the western part of the area. The age of the Dry Branch is middle Jacksonian (middle late Eocene).

Tobacco Road Sand. The Dry Branch is conformably overlain by the Tobacco Road Sand. The Tobacco Road is composed of slightly to moderately indurated, poorly to well-sorted, medium and coarse sand. Some of the sands are quite clayey. Pebbles and muscovite are locally abundant. Colors are purple, yellow, white, orange, and red. Burrows are salient in outcrop. The formation is probably of shallow marine origin.

The top of the Tobacco Road is from 240 below to 260 ft above msl, and the formation is from 40 to 80 ft thick. The thickness is quite variable because the upper part was incised before deposition of the overlying unit. Permeabilities vary from high to low.

"Upland" unit

The Tobacco Road Sand is unconformably (?) overlain by the informally named "Upland" unit, which occurs at the surface in the NPR area. It is composed of fine to coarse, pebbly, silty, clayey, micaceous sand, conglomerate, and clay. Clay beds up to 35 ft thick occur in the area, but bedding is not laterally continuous. The environment of deposition was fluvial. The thickness may be 75 ft or more in the NPR area. Permeability is low.

Geologic Structures (ANL Section 3.3.1.3)

Regional Geologic Structures (ANL Section 3.3.1.3.1)

Regional geology is discussed in section 3.6 of WSRC (1989). Mapped and postulated faults are shown in Figures 3.6-24, 3.6-26, 3.6-32, 3.6-33, and 3.6-34 and are discussed in section 3.6.1.7 of WSRC (1989). All of the faults shown on these figures are related to Paleozoic compressional or Mesozoic extensional tectonism. As indicated in Figure 3.6-5 (WSRC, 1989, p. 3A-202), the Atlantic margin has exhibited very little tectonic subsidence in the past 25 million years. Thus, the faults are likely to be inactive at the present time.

The Dunbarton Triassic Basin is probably bounded on the northwest by a normal fault dipping southeast. Movement occurred during Late Triassic time, and displacement was probably thousands of ft. The Pen Branch fault cuts Coastal Plain strata of Cretaceous, Paleocene, and Eocene age. Its position has recently been determined by drilling (Figure 10), and it overlies and appears to be directly related to the northwestern border of the Dunbarton Basin. The fault strikes northeast-southwest, dips almost vertically, and is downthrown on the northwestern side. At its closest approach to the NPR area, the Pen Branch fault runs approximately along SRS coordinate N 56,000. Subsurface mapping indicates displacement of approximately 100 ft on the basement surface, 50 ft on the top of the Cretaceous Steel Creek Member, and about 30 ft on the top of the upper Eocene Dry Branch Formation (Figure 11). There is no subsurface evidence that movement on the fault has occurred since Eocene time. The Eocene epoch ended approximately 36 million years ago. The fault appears to have offset aquitards within the Coastal Plain section, perhaps allowing lateral and vertical communication between some aquifers. A summary of the evolution of the Pen Branch Fault is presented in Cumbe and Price (in review).

Figure 11 is a model showing the Pen Branch Fault as a reactivation fault near or on the Dunbarton Basin border fault. In this model, the Pen Branch Fault is proposed as an antithetic fault accommodating extensional movement on deeper faults. A typical antithetic fault in this setting would have a northerly dip. However, a pre-existing zone of weakness at the Dunbarton Basin Border may control the dip direction of the Pen Branch Fault. This model is suggested by Cumbe and Price (in press), who named an hypothesized deeper fault the Upper Three Runs Fault and describe its relation to the Augusta Fault of Hatcher et al. (1977). Extensional movement, as required by this model, would not occur under present-day stress conditions (Zoback et al., 1986), requiring the Pen Branch Fault to be currently inactive.

Figure 10. Drill hole control for location of the Pen Branch Fault.

Figure 11. Representative cross section showing the offset of Coastal Plain sediments along the Pen Branch Fault and the relationship of Pen Branch Fault to other basement faults.

Lineaments (ANL Section 3.3.1.3.1.2)

Many faults located in crystalline rocks in the southeastern U.S. form topographic and photo-lineaments. Conversely, many lineaments that are persistent on aerial photographs are not faults. In the Coastal Plain, very few photo-lineaments have been observed with the exception of short (ca. 1 mile or less) stream channels. Aerial photography, including false-color infrared photography, is periodically conducted at SRS to support forest management. Inspection of these photographs along the inferred trace of the Pen Branch Fault has not revealed any lineaments that can be associated with the fault.

Supporting Geophysical Data (ANL Section 3.3.1.3.1.3)

Gravity, magnetic, and seismographic surveys have been performed at SRS. The Pen Branch Fault was evident on seismic lines that crossed it (Figures 12 and 13). Several other faults appear on seismic lines, but only the Pen Branch Fault and a north-south trending fault with small displacement are substantiated by subsurface data (Figure 8). Figure 3.6-27 of WSRC (1989) presents a possible interpretation of a gravity profile along SRS coordinate E 60,000.

Local Geologic Structures (ANL Section 3.3.1.3.2)

Faults (ANL Section 3.3.1.3.2.1)

Figure 14 is a site north-south cross section made as part of the foundation engineering studies for the AFR spent fuel storage facility. It is slightly oblique to the line between holes M12 1A (NPM 1A) and PBF 3 (Figure 4) and crosses that line at about the location of piezometer TP-11. This figure shows that lithologic units to the base of the Congaree Formation are traceable as horizons from hole to hole and are not displaced by measurable faults. Also, note that no faults are mapped on Figure 4. Thus, available data indicate that there are no local-scale faults in the upper 300 ft at the NPR site.

D'Appolonia conducted seismic reflection surveys as part of the AFR study (Figure 15). The east-west seismic sections (Figures 16, 17, 18, and 19) display evidence of faults between 0.2 and 0.3 seconds. These structures appear to represent a set of conjugate faults. The faults are apparent only in what is likely the Cretaceous section and do not appear in the higher Coastal Plain units. The trend of the faults is approximately north 45 degrees west, and they may be related to other northwest trending faults described at SRS.

Figure 12. Location of seismic reflection lines used to delineate Pen Branch Fault.

Figure 13. Interpretive cross section of a portion of seismic reflection line 7 showing the offset of Coastal Plain sediments along Pen Branch Fault.

Figure 14. Cross section through the NPR area (AFR site). See Figure 15 for location of cross-section line. T.R. = Tobacco Road Sand; D.B. = Dry Branch Formation; CLF. = Clinchfield Sand; CONG. = Congaree Formation; FSHB. = Fishburne Formation; WMSB. = Williamsburg Formation. E series wells correspond to AFR series.

Figure 15. Location of seismic reflection lines and cross sections for the NPR area (AFR site).

UNINTERPRETED SECTION-LINE B-1

INTERPRETED SECTION-LINE B-1

B-1 POINT OF INTERSECTION
WITH OTHER LINE

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WILMINGTON, DELAWARE

Figure 16. Seismic reflection line B-1.

UNINTERPRETED SECTION-LINE B-2

INTERPRETED SECTION-LINE B-2

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 INCORPORATED
 WILMINGTON, DELAWARE

Figure 17. Seismic reflection line B-2 with fault location.

UNINTERPRETED SECTION-LINE B-3

INTERPRETED SECTION-LINE B-3

B-1
POINT OF INTERSECTION
WITH OTHER LINE

PREPARED FOR
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WILMINGTON, DELAWARE

Figure 18. Seismic reflection line B-3.

UNINTERPRETED SECTION - LINE B-4

INTERPRETED SECTION - LINE B-4

Figure 19. Seismic reflection line B-4 with fault location.

Fracture Traces (ANL Section 3.3.1.3.2.2)

Soil fractures ascribed to a pedogenic origin are discussed in WSRC (1989), section 3.6.1.8.3. These fractures may be observed in outcrop near the NPR reference site. No systemic study has been made of their length, depth, or orientation; however, cursory examination of exposures indicates these to be highly variable. Soil fractures exposed in trenches at Chem-Nuclear burial ground just east of SRS were described in support of a proposed nuclear fuel reprocessing facility (Bechtel Corporation, 1968). These data may be available.

Subsurface Voids

The MRJD summary of the engineering properties of the soils at the NPR site note that voids or leached zones are present in some of the calcareous sands underlying portions of the site (Appendix A). The voids were located between 80 and 90 ft msl, which corresponds to the Santee Limestone. Further evidence of voids in the subsurface is indicated by acoustic logs from borehole PBF 3, which record low velocity zones at depths near 200 ft (Figure 20). These low velocity zones suggest that calcareous portions of the strata have been dissolved at these elevations. Standard penetrometer testing was undertaken during the installation of boreholes by D'Appolonia. The calcareous sands record low penetration resistance in many of the boreholes, further suggesting that local voids may underlie some areas of the NPR site. However, MRJD noted that voids have been encountered in many areas of SRS and have posed no engineering problems. Subsurface voids in other areas have been successfully grouted and have supported heavy, critical structures.

Volcanism (ANL Section 3.3.1.4)

There is no documentation of post-Eocene volcanic activity in the southeastern U.S.

Seismicity (ANL Section 3.3.1.5)

Regional and local seismicity are reviewed in WSRC (1989). Standard penetrometer testing, summarized in Figure 21, demonstrates that there is no potential for liquefaction within the NPR site.

GROUNDWATER HYDROLOGY

Regional and Area Groundwater Use

Most municipal and industrial water supplies in Aiken County are developed from the Upper Cretaceous formations, which occur at shallower depths as the Fall Line

Figure 20. Acoustic log from the upper portion of well PBF 3. Note the low velocity zone at 200 ft depth.

Figure 21. Standard penetrometer test results from the NPR area showing limits of liquefaction failure criteria.

is approached. Domestic water supplies are developed primarily from the Barnwell Group and the Santee and Congaree formations. In Barnwell and Allendale counties, the Upper Cretaceous formations occur at increasingly greater depths; some municipal users are supplied from the shallower Congaree and Santee formations or from their limestone equivalents. In these counties, domestic supplies are developed from the Barnwell Group and the Santee Formation.

Approximately 39 municipalities and industries were identified that each use over 5000 gpd from groundwater sources (Tables 2 and 3). Total pumpage for these users is at least 26,109,000 gpd. The largest user is the town of Barnwell, about 15 miles from SRS, which uses 4,000,000 gpd, some of which is supplied to local industry.

Total municipal pumpage from the Upper Cretaceous is at least 5,232,000 gpd. Total municipal pumpage is 10,000 gpd from the Santee Formation by the town of Elko and 4,000,000 gpd from the Congaree Formation by the town of Barnwell. The town of Williston uses water from both the Santee Formation and the Upper Cretaceous formations for a total pumpage of 700,000 gpd.

Seventeen industrial users were identified. The largest users are the Sandoz Company, located approximately 17 miles from the site, and the Vogtle Electric Generating Plant in Georgia, across the Savannah River from SRS. Each pumps groundwater at an average of 2,880,000 gpd. Total industrial pumpage from the Upper Cretaceous formations is greater than 14,573,000 gpd.

In addition to the large municipal and industrial users, 25 small communities and mobile home parks, 4 schools, and 11 small commercial interests are listed in files from the South Carolina Department of Health and Environmental Control (SCDHEC) as using groundwater. Wells serving these users generally produce from shallow aquifers and are equipped with 10-gpm to 60-gpm pumps that do not draw large quantities of water. Two South Carolina state parks are within the survey area: Aiken State Park has seven wells (all flowing at several gallons per minute), and Barnwell State Park has two wells. The Edisto Experimental Station at Blackville pumps an average of 19,000 gpd from the Congaree Formation. Several shallow wells produce small quantities of water for guardhouses at SRS.

Geohydrology of the Sub-Coastal Plain Basement

The hydrology of the buried Paleozoic and Triassic rocks was studied intensively (Marine, 1966, 1967a, 1967b, 1974; Webster et al., 1970) to assess the safety and feasibility of storing radioactive waste in these rocks. Water injection and removal tests on packed-off sections of rock indicated that two kinds of fractures exist in the Paleozoic bedrock. The first consists of minute fractures that pervade the entire rock mass but transmit water extremely slowly. Rocks containing only

Table 2. Groundwater pumpage by municipalities near SRS

<u>User</u>	<u>Distance From SRS Center (miles)</u>	<u>Number of People Served</u>	<u>Average Daily Use (gpd x 10⁶)</u>	<u>Water- Bearing Formation^a</u>	<u>Type of Source</u>
Aiken County, SC					
Aiken	22	28,000	2.0	"Tuscaloosa" ^b	Springs
Jackson	10	3,152	0.175	"Tuscaloosa"	2 Wells
New Ellenton	11	4,000	0.300	"Tuscaloosa"	2 Wells
Langley	19	1,330	0.130	"Tuscaloosa"	2 Wells
College Acres	15	1,264	0.065	"Tuscaloosa"	3 Wells
Bath Water Dist.	19	1,239	0.325	"Tuscaloosa"	2 Wells
Beech Island	18	4,500	0.300	"Tuscaloosa"	3 Wells
Talatha	10	1,260	0.040	"Tuscaloosa"	2 Wells
Breezy Hill	22	4,500	0.233	"Tuscaloosa"	4 Wells
Burnettown	20	1,200	0.150	"Tuscaloosa"	2 Wells
Montmorenci	17	4,232	0.423	"Tuscaloosa"	2 Wells
Warrenville	19	788	0.300	"Tuscaloosa"	4 Wells
Johnstown	18	1,560	0.144		
Howlandville	18	1,232	0.100	"Tuscaloosa"	1 Well
Gloverville	18	1,440	0.144		
Belvedere	24	6,300	0.362	"Tuscaloosa"	5 Wells
Barnwell County, SC					
Barnwell	15	6,500	4.0	Congaree	11 Wells
Williston	15	3,800	0.700	Santee	4 Wells
				"Tuscaloosa"	
Blackville	22	2,975	0.300	"Tuscaloosa"	3 Wells
Hilda	22	315	0.009	"Tuscaloosa"	1 Well
Elko	17	315	0.010	Santee	1 Well
Burke County, GA					
Girard	16	210	0.020	"Tuscaloosa"	3 Wells

^a Many of these wells are gravel packed from the bottom of the well to the free water table; thus, the water-bearing formation may not be clearly defined.

^b "Tuscaloosa" should be read "Cretaceous undifferentiated."

Reference: Dukes, 1977; Siple, 1967; South Carolina Water Resources Commission, 1971.

Table 3. Groundwater pumpage by industries near SRS

<u>User</u>	<u>Distance From SRS Center (miles)</u>	<u>Number of Users Served</u>	<u>Average Daily Use (gpd x 10⁶)</u>	<u>Water- Bearing Formation^a</u>	<u>Type of Source</u>
Aiken County, SC					
SRS A Area	8	2,131	1.605	"Tuscaloosa" ^b	4 Wells
F Area	4	800	1.800	"Tuscaloosa"	5 Wells
H Area	2	825	1.470	"Tuscaloosa"	4 Wells
U Area	6	110	0.005	"Tuscaloosa"	1 Well
Central Shops	2	600	1.09 ^c	"Tuscaloosa"	1 Well
CMX-TNX	8	50	0.108 ^c	ND ^d	1 Well
Class. Yd.	5	35	0.108 ^c	ND	1 Well
U.S. Forest Service	7	70	ND	"Tuscaloosa"	1 Well
Graniteville Co.	23	2,156	ND	"Tuscaloosa"	1 Well
J. M. Huber Co.	18	ND	2.23	"Tuscaloosa"	1 Well
Augusta Sand & Gravel	21	ND	0.95	"Tuscaloosa"	1 Well
Cyprus Mines Corp.	24	ND	0.375	"Tuscaloosa"	1 Well
Florida Steel Corp.	19	ND	0.02	"Tuscaloosa"	1 Well
Valchem	20	ND	0.108	"Tuscaloosa"	1 Well
Allendale County, SC					
Sandoz Co., Inc.	17	ND	2.88	"Tuscaloosa"	1 Well
Barnwell County, SC					
E. T. Barwick Ind.	16	400	0.25	"Tuscaloosa"	2 Wells
Burke County, GA					
A. W. Vogtle NPS	12	ND	2.880	"Tuscaloosa"	2 Wells
Future User					
Barnwell NFP	9	450	4.032 ^e	"Tuscaloosa"	2 Wells

^a Many of these wells may be gravel packed from the bottom of the well to the free water table; thus, the water-bearing formation may not be clearly defined.

^b "Tuscaloosa" should be read "Cretaceous undifferentiated."

^c Pump capacity, not groundwater use.

^d ND = no data.

^e Anticipated pumpage.

this kind of fracture are called virtually impermeable rocks (Marine, 1966). The second kind of fractures has larger openings that transmit water more quickly. The fractures are vertically restricted but can be traced laterally. Rocks containing these fractures are called hydraulically transmissive rocks (Marine, 1966).

Marine (1967a, 1975) reported representative hydraulic conductivity values of 3×10^{-4} gpd/ft² for the virtually impermeable rocks and 0.8 gpd/ft² for the hydraulically transmissive rocks. Analysis of a two-well tracer test indicated a fracture porosity of 0.08% in a hydraulically transmissive fracture zone (Webster et al., 1970). Laboratory analyses of cores indicated an average intergranular porosity of 0.13% (Webster et al., 1970).

Groundwater occurs in the primary porosity of the Triassic sedimentary rock. However, the hydraulic conductivity is extremely low, and water movement is almost nonexistent. The hydraulic conductivity of the Triassic sedimentary rock as determined from field tests ranged from 10^{-4} to 10^{-7} gpd/ft² (Marine, 1974). The average total porosity was 8.0% for sandstones and 3.3% for mudstones. The average effective porosity was 7.0% for sandstones and 0.53% for mudstones.

Because of the large amount of groundwater in the prolific aquifers of the Coastal Plain sediments, the Paleozoic bedrock will probably not be used as a water source at SRS. No water is pumped from the Dunbarton Triassic basin, nor is there likely to be any pumped in the future because of the poor water quality and the low permeability of the rocks.

Geohydrology of the Coastal Plain Sediments

Provisional hydrostratigraphic units for SRS have been outlined previously (WSRC, 1989) based upon hydrologic characteristics, such as hydraulic conductivity and effective porosity (Figure 22). These zones do not necessarily correspond to stratigraphic units, and some of the zones corresponding to aquitards may not necessarily be impervious everywhere at SRS. Hydrostratigraphic zones above the Santee Limestone have been modified herein for the NPR site.

Piezometric data collected September 1990 from AFR and ATP series wells installed by D'Appolonia for the AFR study were used to determine the groundwater characteristics at the AFR site. Groundwater elevation data collected September 1990 from six wells of the NPM series, located along the western edge of the AFR area, were also used in the study. Five NPM wells are water-table wells screened in the Tobacco Road Sand or the "Upland" unit, and one is screened in the Fourmile Member of the Fishburne Formation. Well logs from well PBF 3 were used to outline the stratigraphy and lithology of units at the NPR site (Figure 4).

Figure 22. Coastal Plain stratigraphy from well P 24 and hydrologic units at the NPR area.

Piezometric surface contour maps of the NPR site for some hydrologic zones are incomplete due to the paucity and limited distribution of measurements. However, syntheses of groundwater data for SRS (e.g., Looney et al., 1988) may be used in conjunction with local data as a reference for the groundwater gradients at the site.

Hydrologic Zones in Cretaceous Sediments

The saprolite overlying the unweathered crystalline rocks and the Cape Fear Formation (zone 1, Figure 22) form an aquitard. Marine (1973) reported vertical hydraulic conductivities for materials from two wells in the Cape Fear as 0.0065 and 0.036 gpd/ft² and porosity as 38%. For the upper zone of the saprolite, the reported vertical hydraulic conductivities averaged 0.001 gpd/ft², and the porosity averaged 29.6%. Water levels within the Cape Fear are not monitored.

The Cretaceous sediments comprise two water-bearing zones and an intervening aquitard. The uppermost and lowermost Cretaceous sedimentary units are also aquitards. The lower water-bearing zone corresponds to sands of the Middendorf Formation and the lower Black Creek Formation (zones 2a and 2b, Figure 22).

Interbedded sand and clay layers in the middle of the Black Creek Formation form effective aquitards and appear to be continuous across the site. The thick Cretaceous and Paleocene clays form a barrier to prevent fluid migration between Cretaceous and Eocene sands. A sample between 410 and 412 ft deep in well P 18 yielded both vertical and horizontal permeabilities of 3×10^{-8} cm/sec.

Sand layers at the top of the Black Creek and the majority of the Peedee Formation form a second major water-producing zone in the Cretaceous sediments at the site (zone 3a, Figure 22). This zone is overlain by an aquitard that corresponds to a clay layer at the top of the Peedee Formation as well as clay layers in the Black Mingo Group. These clay layers are impervious over much of SRS. Lithologic data from holes PBF 3 and CPC 1 (Figure 4) indicate that clay beds at the top of the Steel Creek Member of the Peedee Formation are continuous across the NPR area and likely form an aquitard.

The sand beds in the Cretaceous sediments (zones 2a, 2b, and 3a, Figure 22) are the principal aquifers at SRS, and they are an important source of water for neighboring wells. Industrial wells in these sands commonly yield more than 1000 gpm of good quality water.

Hydrologic data for these zones are listed in Table 4. Transmissivity values and storage coefficients were determined from the results of pumping tests made in 1951 and 1952 (Siple, 1967). The Theiss nonequilibrium and the Cooper-Jacob straight-line methods were used to analyze the data from the tests in which

Table 4. Hydrologic data for the Upper Cretaceous formations and the Paleocene Ellenton/Upper Cretaceous Peedee

<u>Zone^a</u>	<u>Date Sampled</u>	<u>Area</u>	<u>Well Pumped</u>	<u>Well Observed</u>	<u>Average Pumping Rate (gpm)</u>	<u>Sand Thickness (ft)</u>	<u>Hydraulic Transmissivity (gpd/ft)</u>	<u>Hydraulic Conductivity (gpd/ft²)</u>	<u>Storage Coefficient</u>
3 + 4	09/20/51	P	25-P	25-P	540	219	63,000	290	-
3 + 4	11/03/51	P	30-P	30-P	540	144	52,000	361	-
3 + 4	08/10/52	R	27-R	105-R	440	103	90,000	874	0.0004
3	12/31/51	K	33-K	33-K	578	154	109,000	708	-
3	05/26/52	C	51-C	51-C	589	-	95,000	-	-
3	06/16/52	C	52-C	52-C	567	136	140,000	1,029	-
3	08/03/52	P	25-P	105-P	370	219	46,000	210	0.0004
3	11/28/51	L	29-L	29-L	525	124	71,000	573	-
3	04/23/51	M	15-M	15-M	450	160	33,500	209	-
2	04/28/52	F	49-F	49-F	562	267	105,000	393	-
2	11/16/51	F	21-F	24-F	1,870	237	252,000	1,065	0.0007
2	05/08/52	H	35-H	35-H	1,350	273	196,000	720	-
2	01/03/52	H	35-H	35-H	560	273	198,000	725	-
2	02/23/52	H	43-H	43-H	560	277	204,000	736	-
2	05/06/52	H	48-H	48-H	600	260	198,000	762	-
2	03/17/52	H	44-H	44-H	570	239	375,000	1,569	-
2	02/29/52	F	37-F	37-F	589	213	178,000	836	-
2	01/19/52	M	31-M	4-M, 20-M	1,500	181	147,000	812	0.0003

^a See Figure 22.

Reference: Siple (1967).

measurements were obtained in one or more observation wells (Siple, 1967). The Theiss recovery formula was used to analyze the data from the tests in which measurements were made only in the pumped well (Siple, 1967). The storage coefficients are within the range of 10^{-5} to 10^{-3} for confined aquifers (Driscoll, 1986).

Table 5 lists porosity and hydraulic conductivity estimates of representative samples of loose sands from the Cretaceous sediments based on the sieve analysis method of Beard and Weyl (1973). With this method, the mean grain diameters and sorting coefficients of sand samples were determined, and the porosities and permeabilities (in darcys) were estimated from the first two parameters. The hydraulic conductivity values were obtained by multiplying the darcy values by 18.2 (Fetter, 1988).

Flow velocities for zones 2a and 2b can be obtained using $K = 846 \text{ gpd/ft}^2$ and a porosity of 31.9%. Along the northern side of SRS where the hydraulic gradient is 8 ft/mile, the velocity is calculated as 0.531 ft/day or 194 ft/year. Along the western side of SRS where the gradient decreases to 3 ft/mile, the velocity is calculated as 0.21 ft/day or 78 ft/year. For zone 3a, K is 546 gpd/ft^2 and the porosity is 29%. In the northern part of SRS where the gradient is about 11 ft/mile, the velocity is calculated as 0.5 ft/day or 184 ft/year. Along the western side of SRS, the gradient is about 3 ft/mile, which yields a velocity of about 0.15 ft/day or 55 ft/year.

The potentiometric surface map for zone 3 (Figure 23) is similar to maps compiled previously (WSRC, 1989). Groundwater gradients in the Cretaceous sediments over most of SRS are predominantly sloping towards the Savannah River where the aquifers discharge. Thus, groundwater in the Cretaceous sediments does not flow between South Carolina and Georgia to any appreciable extent at SRS. Gradients in Georgia also indicate flow toward the Savannah River (Siple, 1967).

Hydrologic Zones in Tertiary Sediments

Zone 4

Hydrologic zone 4 (Figure 22) encompasses sands in the Ellenton Member of the Rhems Formation and the Snapp Member of the Williamsburg Formation, which are water-bearing but have moderate to low permeability. At the NPR site, the Ellenton contains interbedded sand and clay layers at the lower and middle portions of the section; these layers are overlain by sand. The top of the Williamsburg is predominantly represented by sand layers with thin beds of clay. The clay zones in the Ellenton may not be continuous enough to form an aquitard at the NPR site. Only one well, AFR 9, is screened in zone 4 at the NPR site. This well exhibits an unusually high piezometric head of 207.6 ft (Table 6). Piezometric data from well

Table 5. Porosity and hydraulic conductivity (K) of loose sands from zones 2, 3, and 4 determined by the sieve analysis method of Beard and Weyl (1973)

<u>Well</u>	<u>Depth (ft)</u>	<u>Zone^a</u>	<u>Median Grain Size (mm)</u>	<u>Sorting^b</u>	<u>Porosity (%)</u>	<u>K (gpd/ft²)</u>
P 24	457	4	0.50	2.08	29.5	655
P 24	477	4	0.18	2.50	29.0	45
P 24	592	3	0.73	2.60	27.8	673
P 28	367	3	0.68	2.48	28.1	673
P 24	657	3	0.55	1.67	33.0	1,274
P 28	440	3	0.75	1.89	31.0	1,692
P 29	555	3	0.74	2.19	29.2	1,201
P 29	615	3	0.4	2.65	27.0	200
P 24	777	2	0.10	1.85	34.0	36
P 24	802	2	0.54	1.81	31.5	1,001
P 24	851	2	0.63	1.53	34.0	1,820
P 24	860	2	0.12	1.86	33.5	46
P 28	533	2	0.55	1.53	34.0	1,365
P 28	628	2	0.47	1.64	33.0	910
P 28	702	2	0.45	1.88	31.0	673
P 28	709	2	0.28	2.03	30.3	200
P 29	634	2	0.52	1.59	32.5	1,238
P 29	655	2	0.46	2.41	27.9	346
P 29	700	2	0.98	2.18	29.6	1,820
CPC 1	710	2	0.44	1.44	35.0	1,001
CPC 1	719	2	0.62	1.69	33.0	1,547
CPC 1	728	2	0.64	1.58	34.0	1,784
CPC 1	742	2	0.44	1.44	35.0	1,001
CPC 1	749	2	0.28	1.62	33.5	328
CPC 1	761	2	0.52	1.43	35.0	1,365

^a See Figure 22.

^b Trask sorting coefficient; sorting decreases with increasing numbers.

Figure 23. Potentiometric map for zone 3, data from 1988 (after Looney et al., 1988). Elevations in ft msl.

Table 6. Piezometer data from the NPR and AFR areas (September 1990)^a

<u>Piezometer Name</u>	<u>Well Point Elev. (ft msl)</u>	<u>Stratigraphic Unit</u>	<u>Piezometric Head (ft msl)</u>	<u>Site North Coordinate</u>	<u>Site East Coordinate</u>
NPM 4DD	296.2 - 306.2	Upland	303.7	60886	57238
ATP 6	284.6 - 287.1	Upland	< 285 (dry)	60160	59610
ATP 7	285.5 - 288.0	Upland	< 286 (dry)	60090	59610
UNK 3 ^b		Upland	283	59250	61120
UNK 2		Upland	278	60830	60230
NPM 1	276.9 - 296.9	Upland	268.6	62146	56872
ATP 8	275.7 - 278.2	Upland	279.4	59890	59610
AFR 12A	271.2 - 273.7	Upland	274	60543	59513
UNK 1		Upland	274	60910	59400
AFR 31	268.2 - 270.7	Upland	272	61326	59549
AFR 21A	267.9 - 270.4	Upland	273.6	60666	59862
AFR 4		Upland	273.0	58760	60434
AFR 27	261.8 - 266.8	Upland	272.6	61725	59551
AFR 29	260.5 - 263.0	Upland	271.4	61526	59751
AFR 17A	259.6 - 262.1	Upland	272.6	61128	59610
NPM 4	256.4 - 276.4	Upland/Tobacco	267.5	60876	57235
NPM 3	247.1 - 267.1	Tobacco Road	259.0	62102	55437
NPM 2	241.7 - 261.7	Tobacco Road	255.1	63049	58272
AFR 7A	188.9 - 191.4	Upper Dry Branch	266.8	58737	61701
AFR 10A	176.7 - 179.2	Upper Dry Branch	265.2	60428	59766
AFR 3A	150.8 - 153.3	Lower Dry Branch	261.1	60216	59206
ATP 2	151.1 - 153.6	Lower Dry Branch	261.8	60190	59550
ATP 3	151.1 - 153.6	Lower Dry Branch	261.5	60190	59490
ATP 1	99.0 - 101.5	Santee	255.1	60250	59600
AFR 11	93.7 - 96.2	Santee	254.6	60428	59623
AFR 5A	92.5 - 95.0	Santee	250.1	61675	60449
AFR 19	89.2 - 91.7	Santee	246.8	60740	59610
AFR 2	60.0 - 62.5	Santee/Congaree	238.2	61641	59199
ATP 10	43.1 - 45.6	Congaree	187.3	60160	59590
ATP 9	42.6 - 45.1	Congaree	186.5	60090	59590
ATP 11	39.4 - 41.9	Congaree	186.6	59890	59590
AFR 8B	18.1 - 20.6	Fourmile	187.1	61649	61669
NPM 1A	9.3 - 19.3	Fourmile	204.0	62163	56840
AFR 16	-13.8 - -11.3	Fourmile	186	61115	59486
ATP 4	-28.3 - -25.8	Fourmile/Snapp	186.5	60200	59700
ATP 5	-32.2 - -29.7	Fourmile/Snapp	188.1	60200	59800
AFR 1	-31.7 - -29.2	Snapp/Fourmile	186.8	58751	59200
AFR 6B	-34.8 - -32.3	Snapp/Fourmile	186.6	60213	60458
AFR 9	-45.3 - -42.8	Snapp	207.6	60200	61700

^a All water elevations measured September 12, 1990, except NPM series wells (September 20, 1990) and wells AFR 1 and 4 (August 10, 1990).

^b Wells listed as UNK are water-table wells with metal casing; the well identification is not known.

NPM 1A suggest that overlying units may be locally hydraulically connected to upper portions of the Williamsburg. There are no piezometric data from lower portions of the Williamsburg at the NPR site. It is, therefore, possible that clay layers in lower portions of the unit may form aquitards.

Hydrologic data for zone 4 are listed in Table 4. Porosity and hydraulic conductivity estimates based on sieve analysis data are listed in Table 5.

Three hydraulic conductivity measurements on clays from zone 4 at SRS have been reported. Bledsoe (1987) recorded a vertical hydraulic conductivity (K_v) of 1.4×10^{-8} cm/sec for a clay sample from well P 19 and $K_v = 5 \times 10^{-8}$ cm/sec and $K_v = 3.6 \times 10^{-7}$ cm/sec for two clays from well P 22. These data are consistent with the interpretation that the clays of this zone are confining layers. However, the potentiometric surface map (Figure 23) indicates that water flowing beneath SRS in Upper Cretaceous sediments discharges into the Savannah River along the southwestern boundary of the site. Modeling the Savannah River valley along the southwestern boundary of SRS as a rectangular discharge area and using the discharge for the Cretaceous hydrologic zones as previously calculated, the effective thickness of the aquitard in this area can be calculated as 0.27 ft. This result suggests that in the Savannah River valley and vicinity this zone is not as effective an aquitard as it is at other SRS locations.

Sieve analysis data (Table 5) are available on two Rhems Formation sand samples from well P 24. One sand sample was fine grained ($Q_{50} = 0.18$ mm) and poorly sorted ($S_o = 2.50$). The other sand sample was coarse grained ($Q_{50} = 0.50$ mm) and poorly sorted ($S_o = 2.08$). Porosity estimates (Beard and Weyl, 1973) were 29% for both samples, and hydraulic conductivity estimates (Beard and Weyl, 1973) were 45 gpd/ft² for the fine sand and 655 gpd/ft² for the coarse sand.

Sieve analysis data from hole PBF 3 are available from the Snapp Member of the Williamsburg Formation. The sample from the Snapp is coarse grained ($Q_{50} = 0.865$ mm) and has an estimated porosity of 32.5% (Table 7). Hydraulic conductivity is estimated at 2457 gpd/ft².

Zone 5

Hydrologic zone 5 (Figure 22) can be subdivided into two distinct hydrologic components. The lower (zone 5a) corresponds to the Fourmile Member of the Fishburne Formation and the Congaree Formation, which are predominantly water-bearing sands with thin beds of discontinuous clay. This water-bearing zone has been referred to as the Lower Tertiary Zone in Looney et al. (1988). These formations are overlain by a clay that corresponds to the basal portion of the Santee Limestone (zone 5b). This clay, referred to as the "green clay" in older SRS publications, forms an effective aquitard in the area of the NPR site. The

Table 7. Sieve analysis results of sands from well PBF 3

Formation	Depth (Ft.)		Q ₂ (mm)	Q ₆₀ (mm)	Q ₅₀ (phi)	Q ₁ (mm)	Sorting	Porosity(%)	K(D)	K(m/s)	K(gpd/ft ²)
	Top	Base									
Upland ^a	14.0	15.0	0.265	0.138	2.86	0.004	8.52	25.0	0.1	9.66E-07	1.8
Upland ^a	47.0	48.0	0.074	0.010	6.64	0.001	8.60	25.0	0.1	9.66E-07	1.8
Upland	59.0	60.0	0.210	0.148	2.76	0.034	2.49	29.8	2.0	1.93E-05	36.4
Upland	69.0	70.0	0.225	0.152	2.72	0.032	2.65	29.0	1.5	1.45E-05	27.3
T. Road	79.0	80.0	0.210	0.140	2.84	0.020	3.24	29.0	0.8	7.24E-06	13.6
T. Road	87.0	88.0	1.050	0.680	0.56	0.380	1.66	33.0	100.0	9.66E-04	1820.0
T. Road	97.0	98.0	1.300	0.800	0.32	0.300	2.08	29.5	80.0	7.73E-04	1456.0
T. Road	105.0	106.0	0.800	0.540	0.89	0.375	1.46	35.0	80.0	7.73E-04	1456.0
T. Road	110.0	111.0	0.300	0.210	2.25	0.132	1.51	35.0	12.0	1.16E-04	218.4
T. Road	119.0	120.0	0.428	0.282	1.83	0.210	1.43	35.0	22.0	2.13E-04	400.4
Irwinton	126.0	127.0	0.685	0.460	1.12	0.310	1.49	34.0	55.0	5.31E-04	1001.0
Irwinton	135.0	136.0	0.540	0.430	1.22	0.350	1.24	39.0	80.0	7.73E-04	1456.0
Irwinton	144.0	145.0	0.468	0.395	1.34	0.292	1.27	38.3	65.0	6.28E-04	1183.0
Irwinton	148.0	149.0	0.448	0.300	1.74	0.208	1.47	35.0	24.0	2.32E-04	436.8
Irwinton	157.0	158.0	0.600	0.258	1.95	0.202	1.72	33.0	15.0	1.45E-04	273.0
Irwinton	165.0	166.0	0.560	0.335	1.49	0.198	1.68	33.0	30.0	2.90E-04	546.0
Irwinton	175.0	176.0	0.500	0.390	1.36	0.315	1.26	39.0	65.0	6.28E-04	1183.0
Irwinton	184.0	185.0	0.482	0.320	1.64	0.198	1.56	34.0	25.0	2.41E-04	455.0
Irwinton	194.0	195.0	0.525	0.370	1.43	0.255	1.43	35.0	40.0	3.86E-04	728.0
Santee	196.0	197.0	0.218	0.182	2.46	0.138	1.26	39.5	17.0	1.64E-04	309.4
Santee	203.0	204.0	0.668	0.420	1.25	0.308	1.47	34.5	48.0	4.64E-04	873.6
Santee	209.0	210.0	0.308	0.248	2.01	0.210	1.21	39.8	27.0	2.61E-04	491.4
Santee	219.0	220.0	0.290	0.215	2.22	0.110	1.62	34.0	10.0	9.66E-05	182.0
Santee	228.0	229.0	0.280	0.210	2.25	0.150	1.37	36.5	15.0	1.45E-04	273.0
Santee	237.0	238.0	0.160	0.128	2.97	0.079	1.42	36.5	4.5	4.35E-05	81.9
Santee	247.0	248.0	0.122	0.095	3.40	0.065	1.37	38.5	3.5	3.38E-05	63.7
Santee	253.0	254.0	0.580	0.315	1.67	0.165	1.87	31.5	19.0	1.84E-04	345.8
Congaree	256.0	257.0	0.325	0.172	2.54	0.110	1.72	34.0	6.0	5.80E-05	109.2
Congaree	260.0	261.0	0.180	0.138	2.86	0.100	1.34	37.5	6.5	6.28E-05	118.3
Congaree	269.0	270.0	0.330	0.240	2.06	0.170	1.39	36.0	19.0	1.84E-04	345.8
Congaree	279.0	280.0	0.540	0.400	1.32	0.310	1.32	37.0	65.0	6.28E-04	1183.0
Congaree	289.0	290.0	0.315	0.220	2.18	0.158	1.41	35.0	15.0	1.45E-04	273.0
Congaree	297.0	298.0	0.700	0.480	1.06	0.288	1.56	34.0	65.0	6.28E-04	1183.40
Fourmile	299.0	300.0	0.610	0.310	1.69	0.190	1.79	32.0	20.0	1.93E-04	364.0
Fourmile	305.0	306.0	0.500	0.318	1.65	0.238	1.45	34.5	27.0	2.61E-04	491.4
Fourmile	315.0	316.0	1.020	0.840	0.25	0.560	1.35	36.5	195.0	1.88E-03	3549.0
Fourmile	321.0	322.0	0.760	0.420	1.25	0.265	1.69	32.5	40.0	3.86E-04	728.0
Fourmile	326.0	327.0	0.740	0.540	0.89	0.310	1.55	34.0	75.0	7.24E-04	1365.0
Fourmile	338.0	339.0	1.620	0.795	0.33	0.365	2.11	32.5	125.0	1.21E-03	2275.0
Fourmile	346.0	347.0	0.540	0.370	1.43	0.250	1.47	34.5	75.0	7.24E-04	1365.0
Snapp	349.0	350.0	1.420	0.865	0.21	0.464	1.75	32.5	135.0	1.30E-03	2457.0

^a Q₅₀(phi) and sort are off scale for these depths; therefore, the values for porosity and K(D) in Table 7 are minimum values.

^b 9.66 E-07 = 9.66x10⁻⁷.

difference in piezometric head between the Santee and Congaree formations at the NPR site is 40 to 60 ft (Table 6).

The "Congaree" aquifer (zone 5a, Figure 22) is capable of large yields at SRS and in nearby municipal wells. Siple (1967) reported yields of 660 gpm from some SRS wells that probably were pumping the Congaree Formation. Some municipal wells that draw water from the Congaree Formation at Barnwell, South Carolina, yield 400 gpm.

Siple (1967) tabulated the results of three pumping tests. An examination of his data indicates that one of the tests was on the lower Congaree Formation and Fourmile Member, and a second test was on the lower Congaree Formation, Fourmile Member, and the Snapp Member. He reported a hydraulic conductivity of 980 gpd/ft² for the lower Congaree/Fourmile and 950 gpd/ft² for the Congaree/Fourmile/Snapp. No other pumping test data have been reported; however, the results of three slug tests were reported by INTERRA (1986) from Z Area (Table 8). Two of the tests were on sandy layers that had hydraulic conductivities of 89 gpd/ft² and 594 gpd/ft². The other test, conducted on a clayey zone near the base of the formation, had a hydraulic conductivity of 0.6 gpd/ft².

Table 9 lists porosity and permeability estimates of loose Congaree sands based on sieve analyses (Beard and Weyl, 1973). Hydraulic conductivities were obtained by multiplying the permeability values (in darcys) by 18.2 (Fetter, 1988). The sands were fine to coarse, loose, moderately well to well sorted, and porous. The median-grain size was medium sand. Porosities varied from 31.6% to 41.0%, and the median was 35%. The hydraulic conductivities varied from 66 to 3185 gpd/ft², and the median was 590 gpd/ft².

Sieve analysis of sands from the Congaree Formation and the Fourmile Member of the Fishburne Formation taken from hole PBF 3 are presented in Table 7. Most samples from these strata were fine sands with an average porosity of 35.6%. Estimated hydraulic conductivity ranged from 109.2 to 1183 gpd/ft². Several samples of the Fourmile Member were analyzed and ranged from medium to coarse grained. The average porosity was 33.8%. Estimated hydraulic conductivity ranged from 364 to 3549 gpd/ft².

Estimated hydraulic conductivities based upon sieve analysis are similar to the hydraulic conductivities determined from pump tests. Looney et al. (1990) used a value of 972 gpd/ft² for the horizontal hydraulic conductivity in a calibrated flow model of the NPR area.

Piezometric maps encompassing SRS are included in Looney et al. (1988, 1990). The map of the "Lower Tertiary zone" (Figure 24) was used to estimate a hydraulic

Table 8. Hydraulic conductivity (K) of zone 5 sediments obtained from slug tests performed by INTERRA Technologies, Inc. (1986)

<u>Formation</u>	<u>Area</u>	<u>Well</u>	<u>K (m/s)</u>	<u>K (gpd/ft²)</u>
Fishburne	Z	SDS 7A ^a	2.8×10^{-7}	0.6
Congaree	Z	SDS 21A	4.2×10^{-5}	89.0
Congaree	Z	SDS 20A	2.8×10^{-4}	594.0

Note: The method of Cooper et al. (1967) was used to analyze the data.

^a Test performed on a clayey zone near the base of the Fishburne Formation.

Table 9. Porosity and permeability of loose Congaree and Fishburne sands determined by the sieve analyses method of Beard and Weyl (1973)

<u>Well</u>	<u>Depth (ft)</u>	<u>Q₅₀ (mm)</u>	<u>Sorting^a</u>	<u>Porosity (%)</u>	<u>Permeability (darcys)</u>	<u>K (gpd/ft²)</u>
FSB 96A	283.5	0.14	1.27	38.5	8.7	158
FSB 98A	188	0.14	1.85	33.0	3.6	66
FSB 99A	187.2	0.16	1.44	35.0	79.0	1,438
FSB 100A	178	0.50	1.19	40.2	140.0	2,548
FSB 100A	182-183	0.48	1.31	37.5	85.0	1,547
FSB 101A	185	0.61	1.14	41.0	175.0	3,185
HSB 117A	125	0.20	1.55	35.0	11.0	200
HSB 117A	130	0.12	1.24	40.0	7.0	127
HSB 117A	148.5	0.30	1.23	39.7	43.0	783
HSB 118A	146.0-146.5	0.29	1.85	31.6	17.0	309
HSB 118A	147.5-148.0	0.45	1.62	33.3	50.0	910
HSB 119A	152.5-153.0	0.14	1.46	36.5	5.5	100
HSB 119A	158.8-159.0	0.54	1.39	35.8	88.0	1,602
HSB 119A	163.5-163.7	0.15	1.57	35.6	6.3	114
HSB 120A	166.0-168.0	0.31	1.59	33.7	24.0	437
HSB 120A	175.5	0.41	1.37	36.0	53.0	965
HSB 121A	179	0.32	1.39	36.0	30.0	546
HSB 122A	183.0	0.41	1.48	34.8	47.0	855
HSB 123A	160-170	0.29	1.42	35.6	26.0	473
HSB 124A	162-162.5	0.32	1.31	37.6	35.0	637
P 24	299	0.46	1.66	33.0	50.0	910
P 28	193	0.30	1.58	33.8	22.0	400

^a Trask sorting coefficient.

Figure 24. Potentiometric map for zone 5, data from 1988 (after Looney et al., 1988). Elevations in ft msl.

gradient of 16 ft/mile in zone 5a (Congaree/Fourmile) at the site. Using the material with the highest hydraulic conductivity and a porosity of 37%, the maximum horizontal flow velocity is 1.32 ft/day or 483.7 ft/year.

The piezometric surface for zone 5 (Congaree/Fourmile) is influenced by Upper Three Runs Creek and the Savannah River, where the overlying aquitard is breached (Figure 24, Table 6). However, the groundwater gradient in this zone is not affected by Four Mile Creek or Pen Branch near the NPR site because the streams have not dissected the top of the Congaree. Thus, groundwater in zone 5 at the NPR area discharges north into Upper Three Runs Creek and west to the Savannah River Swamp. The unusually high piezometric head in wells AFR 9 and NPM 1A may indicate a head reversal between the upper Williamsburg and overlying units (Figure 25). This possibility should be investigated, especially in terms of its relationship to lithologic units and geologic structures in the area.

Regional studies indicate that in the central portion of SRS there is a head reversal between zones incorporating the Cretaceous sediments and zone 5, although there are no data for the deeper aquifers to confirm this relationship at the NPR site. However, the Pen Branch Fault is located just south of the site. It has been documented that the fault affects the stratigraphic section into the Eocene units (Snipes et al., 1989). Thus, it is likely that the fault disrupts aquitards to the south of the site, promoting hydraulic communication between different hydrologic zones. Looney et al. (1990) stated that the Pen Branch Fault does not represent a regional hydrologic feature and probably affects only the water table. However, there is no good piezometric control near the fault to establish precise gradients near the structure, which limits their model. A program is underway to determine the location of the fault with exploratory borings, then install piezometer clusters along the fault in order to determine the hydrologic effects of the Pen Branch Fault (Figure 26).

The Congaree and Fishburne Formations provide water to SRS (tens to hundreds of gallons per minute) and to the rural population around SRS. These users will probably increase as the region develops, but most users who require thousands of gallons per minute will develop their wells from the Cretaceous zones. Thus, the total quantity pumped from the Congaree will probably increase more slowly than the total quantity pumped from the Cretaceous. Because streams such as the Savannah River, Upper Three Runs Creek, and Hollow Creek cut through the Congaree, water use on one side of a stream has no bearing on water availability or flow in the Congaree on the other side of the stream.

Zone 6

Hydrologic zones corresponding to middle and upper portions of the Santee Limestone (zone 6a, Figure 22) are represented by calcareous sediments in the

Figure 25. Piezometric heads for the tops of zone 4 and zone 5 (Upper Williamsburg, Fishburne, and Congaree formations) at the NPR area. Data from September 1990.

Figure 26. North-south cross section illustrating the location of borings and piezometers required to determine the hydrologic influence of Pen Branch Fault. Stippled areas represent tops of Dry Branch Formation and Santee Limestone.

western portion of the NPR site and by well-sorted sand in the central and eastern portions. The Santee is overlain by sands of the Clinchfield and Dry Branch formations. Head differences of 8 to 10 ft over a vertical separation of 60 ft indicate that the Santee is semiconfined and is not hydraulically separate from the Clinchfield and lower Dry Branch (zone 6b, Figure 22, Table 6).

Siple (1967) reported pumping tests from one well screened in the lower Dry Branch Formation. He reported a hydraulic conductivity of 140 gpd/ft² for this well.

Groundwater in zone 6 at the NPR area is recharged through downward and lateral groundwater migration. Piezometric data from this zone are inconsistent (Figure 27, Table 6), making it difficult to determine the groundwater gradient. The piezometric head in zone 6 is 250 to 260 ft. The groundwater in this zone likely discharges into Pen Branch and Four Mile Creek where the stream level is at about 210 ft msl.

Zone 7

A 10-foot layer of clay, which likely acts as a local aquitard, occurs in the middle of the Dry Branch section in the western portion of the NPR site. However, there is not enough well control at the NPR site to determine if the upper Dry Branch and the lower Dry Branch are hydraulically connected. On the basis of the clay bed and similar relationships in other areas of SRS, the upper Dry Branch is assigned to hydrologic zone 7 (Figure 22).

Zone 7 also includes most or all of the Tobacco Road Sand. There are no piezometers located in the Tobacco Road Sand at the AFR site, and the thickness and areal extent of the unit is variable and not well delineated in the AFR area. At the AFR site, the saturated zone generally starts in zone 8. Some piezometers at the NPR site were installed in the Tobacco Road Sand where the saturated zone starts. Head differences between zone 7 and zone 8 (Figure 22), which corresponds to the "Upland" unit, indicate that these two zones are not connected in the AFR area and that zone 7 is at least partially confined. A persistent clay- and silt-rich unit between 250 and 270 ft msl (Figure 14) likely hydraulically separates zone 7 from zone 8.

There is insufficient piezometric data to determine groundwater gradients in zone 7 at the AFR site. This hydrologic zone is probably recharged mostly by water migrating downward through the "Upland" unit. Piezometric head for this zone at the site is 255 to 268 ft (Figure 28, Table 6), and it likely discharges into Four Mile Creek north of the site and southward into Pen Branch.

Figure 27. Piezometric heads for zone 6 at the NPR area. Data from September 1990.

Figure 28. Piezometric heads for zone 7 at the NPR area. Data from September 1990.

Material from hole PBF 3 was used to obtain sieve analysis data for the Tobacco Road Sand (Table 7). The range of estimated hydraulic conductivities derived from this data is 13.6 to 1820 gpd/ft².

The water-table piezometric map was used to obtain the hydraulic gradient for the Tobacco Road Sand (zone 7). Using the interval with the highest hydraulic conductivity and a porosity of 33%, the maximum horizontal flow velocity is estimated at 6.9 ft/day or 2503 ft/year.

Zone 8

Zone 8 is largely unsaturated at the NPR site and in the upper 40 ft of the AFR site. This zone is recharged from water migrating downward from the unsaturated zone, and it discharges to Four Mile Creek to the north and Pen Branch to the south in areas where it is underlain by clay. Groundwater gradients are predominantly to the northwest and southwest because there is an east-west trending groundwater divide located in the middle of the AFR and NPR sites (Figure 29). A clay layer occurs between 280 and 290 ft msl at the AFR site. There appears to be a local perched water zone above this clay, as evidenced by the Carolina bay at the northern end of the site.

Sieve analysis data of "Upland" unit material from hole PBF 3 yield horizontal hydraulic conductivity estimates (1.8 to 36.4 gpd/ft²) similar to values for the "water-table aquifer" used by Looney et al. (1990) in their calibrated hydrologic model of the NPR area.

Sieve analysis data on material from hole PBF 3 (Table 7) were used as a basis to estimate groundwater flow velocity in the water table. The average hydraulic gradient of the water table is about 49 ft/mile (Figures 29 and 30). Using the interval in the "Upland" unit with the highest hydraulic conductivity and porosity of 29.8%, the maximum horizontal flow velocity is estimated as 0.15 ft/day or 55.5 ft/year.

Figure 29. Water-table map at the NPR area. Data from September 1990.

WATER TABLE NEAR REFERENCE NPR SITE

Figure 30. Water-table map near the NPR area (after Looney et al., 1988). Elevations in ft msl.

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APPENDIX A

SUMMARY FROM MRJD REPORT ON AFR SITE

The results of a subsurface investigation performed by D'Appolonia in 1980 were reviewed and the data used for evaluation of foundation conditions at the proposed New Production Reactor at the Savannah River Site. Foundation analyses comprised bearing capacity, settlement, elevation of groundwater, presence of subsurface voids, and the liquefaction potential.

Our conclusion and recommendations are as follows:

1. The subsoils at the [AFR] Site are complexly interbedded clayey sand, sand, and stiff sandy clay. The clayey soils are generally heavily preconsolidated to stresses above anticipated foundation loads. Low preconsolidation stresses may occur in a silty clay layer encountered at the contact of the Barnwell and McBean formations. Undisturbed samples of that clay should be retrieved in subsurface investigations made for final NPR design and tested to confirm the clay's preconsolidation.
2. The subsurface conditions at the NPR site are similar to H and S areas. Therefore, the soil properties, foundation design parameters, and liquefaction criteria from previous investigations are applicable to the NPR site.
3. The average groundwater table is approximately 40 ft below the existing ground surface and averages Elev. 285 in the area of plant coordinates N 60,000 and E 60,000. As presently planned, the top of the foundation mat supporting the NPR coincides with the average groundwater table.
4. There is some evidence of leaching of calcareous sand at the NPR site. Voids or leached zones of limited lateral extent were defined between elevations 80 and 90 in one area of the site, and other zones may be present. In subsequent subsurface investigations, accurate and detailed records of all very loose zones, loss of drilling fluid, and quantity of grout required to fill the boring should be maintained. Furthermore, all samples retrieved from the McBean formation should be tested with dilute HCL.
5. Voids or leached zones do not preclude the siting of the NPR in the investigated area. Subsurface voids of much larger extent than indicated at the NPR site have been successfully grouted in other areas of Savannah River Plant, and heavy, critical structures are supported above the grouted zones.

No structural problems have ever developed within the plant because of the presence of these voids or leached zones.

6. The recommended allowable bearing capacity of the subsoils, for footings greater than 3 ft in width and for mats is 3 tsf. The allowable bearing at this site was determined by settlement limitations, and not by the strength of the subsoils.
7. Estimated settlement of the NPR, assuming a mat supported structure bearing 40 ft below ground surface exerting an area load of 3 tsf is three to five inches. Most of this settlement will occur during construction of the reactor. Long term settlement is estimated as less than one inch.
8. Comparison of the data from the 1980 subsurface investigation at the NPR site and liquefaction failure criteria developed during a recent investigation in S-Area indicates that soils at the NPR site are not susceptible to liquefaction from seismic shocks.

APPENDIX B

Section #: 3.3.1

Title: Geology of the Savannah River Site

Author(s): Site

Date:

Max. # of Pages: 14.5 # of Figures: # of Tables: 11

Description of Contents:

This section is an introductory paragraph summarizing the topics discussed in the subsequent sections.

Section Outline:

3.3.1.1	Geologic Setting of the Savannah River Site
3.3.1.2	Lithostratigraphy
3.3.1.2.1	Regional
3.3.1.2.2	Local
3.3.1.3	Geologic Structures
3.3.1.3.1	Regional Geologic Structures
3.3.1.3.1.1	Faults
3.3.1.3.1.2	Lineaments
3.3.1.3.1.3	Supporting Geophysical Data
3.3.1.3.2	Local Geologic Structures
3.3.1.3.2.1	Faults
3.3.1.3.2.2	Fracture Traces
3.3.1.3.2.3	Supporting Geophysical Data
3.3.1.4	Volcanism
3.3.1.5	Seismicity
3.3.1.5.1	Regional
3.3.1.5.2	Local
3.3.1.6	Soils
3.3.1.7	Natural Radioactivity

Section #: 3.3.1.1

Title: Geologic Setting of the Savannah River Site

Author(s): Site

Date:

Max. # of Pages: 2

of Figures:

of Tables:

Description of Contents:

This section is a discussion of the regional and local geologic setting of the Savannah River site. First, the reader will be oriented with a regional-scale discussion including location of site with respect to physiographic provinces and a summary geologic history of the region. Zooming in on the local scale, the reader will be oriented by a local geographic site location map. Local geologic history will be discussed. This discussion will include chronostratigraphic identification of locally significant igneous, metamorphic, and sedimentary events, to the extent that the data are available.

Section Outline:

3.3.1.1.1	Regional Geologic Setting
3.3.1.1.1.1	Physiographic provinces of the United States
3.3.1.1.1.2	Chronostratigraphy of regional igneous, metamorphic, and sedimentary events
3.3.1.1.2	Local Geologic Setting
3.3.1.1.2.1	Local Surficial Geology
3.3.1.1.2.2	Chronostratigraphy of local igneous, metamorphic, and sedimentary events

Figures:

3.3.1.1.1.2-1	Physiographic Provinces of the United States
3.3.1.1.1.2-2	Regional surficial geology
3.3.1.1.2.2-1	Local surficial geology

Tables:

3.3.1.1.1.3-1	Chronology of regional igneous, metamorphic, and sedimentary events
3.3.1.1.2.3-1	Chronology of local igneous, metamorphic, and sedimentary events

Section #: 3.3.1.2

Title: Lithostratigraphy of the Savannah River Site

Author(s): Site

Date:

Max. # of Pages: 2

of Figures:

of Tables:

Description of Contents:

Regional scale lithostratigraphy will be discussed and summarized in a generalized stratigraphic column. A brief discussion of "clastic dikes" of the type identified at the site will be included. Local lithostratigraphy will be examined and characterized with particular attention paid to variability of individual rock units on the local scale. Depending on the degree of variability found at the site, 1-2 local lithostratigraphic column figures will be included.

Section Outline:

3.3.1.2	Lithostratigraphy
3.3.1.2.1	Regional Lithostratigraphy
3.3.1.2.2	Local Lithostratigraphy

Figures:

3.3.1.2-1	Schematic diagram of basalt cooling structures
3.3.1.2.1-1	Generalized regional lithostratigraphic column
3.3.1.2.2-1..n	Lithostratigraphic column showing geologic configuration of area (1..n)

Section #: 3.3.1.3

Title: Geologic Structures

Author(s): Site

Date:

Max. # of Pages: 5

of Figures:

of Tables:

Description of Contents:

See sections 3.3.1.3.1 and 3.3.1.3.2 for descriptions of Regional Geologic Structures of the Savannah River Site and Local Geologic Structures of the Savannah River Site, respectively.

Section Outline:

3.3.1.3	Geologic Structures
3.3.1.3.1	Regional Geologic Structures
3.3.1.3.1.1	Regional-scale faults: number of, location, description
3.3.1.3.1.2	Lineaments: occurrence, frequency, spacing/density, azimuthal orientation
3.3.1.3.1.3	Supporting Geophysical Data
3.3.1.3.2	Local Geologic Structures
3.3.1.3.2.1	Local-scale faults: number of, location, description
3.3.1.3.2.2	Fracture traces: occurrence, frequency, spacing/density, azimuthal orientation
3.3.1.3.2.3	Supporting Geophysical Data

Section #: 3.3.1.3.1

Title: Regional Geologic Structures of the Savannah River Site

Author(s): Site

Date:

Max. # of Pages: 2

of Figures:

of Tables:

Description of Contents:

This section is a discussion of existing regional and local geologic structures at the Savannah River site. At the regional scale, any extant faults will be characterized as to their type (e.g., Strike-Slip, Normal, Thrust, etc.), location, number, and extent. In addition, lineaments which occur will be characterized by their location, frequency of occurrence, spacing/density, and azimuthal orientation. This section also includes a discussion of supporting geophysical data. Deep seismic profiles will be included in an appendix.

Section Outline:

- 3.3.1.3.1 Regional Geologic Structures
 - 3.3.1.3.1.1 Faults: type, location, number of, extent
 - 3.3.1.3.1.2 Lineaments: location, frequency of occurrence, spacing/density, primary/secondary azimuthal orientation
 - 3.3.1.3.1.3 Supporting Geophysical Data

Figures:

- 3.3.1.3.1.1-1 Areal locations of major faults and lineaments on geologic map
- 3.3.1.3.1.1.2..n Cross-sectional views of major faults

Tables:

- 3.3.1.3.1.1-1 Names and types of major faults in regions
- 3.3.1.3.1.3-1 Supporting geophysical data; type, how used, source

Section #: 3.3.1.3.2

Title: Local Geologic Structures of the Savannah River Site

Author(s): Site

Date:

Max. # of Pages: 3

of Figures:

of Tables:

Description of Contents:

This section is a discussion of existing local geologic structures at the Savannah River site. Any extant faults will be characterized as to their type (e.g., Strike-Slip, Normal, Thrust, etc.), location, number, and extent. In addition, lineaments which occur will be characterized by their location, frequency of occurrence, spacing/density, and azimuthal orientation. This section also includes a discussion of supporting geophysical data.

Section Outline:

- 3.3.1.3.2 Local Geologic Structures
 - 3.3.1.3.2.1 Faults: type, location, number of, extent
 - 3.3.1.3.2.2 Fracture Traces: location, frequency of occurrence, spacing/density, primary/secondary azimuthal orientation
 - 3.3.1.3.2.3 Supporting Geophysical Data

Figures:

- 3.3.1.3.1.1-1 Areal locations of major faults and lineaments on geologic map
- 3.3.1.3.1.1.2..n Cross-sectional views of major faults
- 3.3.2.3.1.3-1..n Shallow seismic profiles

Tables:

- 3.3.1.3.1.1-1 Names and types of major faults in regions
- 3.3.1.3.1.3-1 Supporting geophysical data; type, how used, source

Section #: 3.3.1.4

Title: Volcanism

Author(s): Site

Max. # of Pages: 2

of Figures:

Date:

of Tables:

Description of Contents:

This section will enumerate the type, location, areal extent, duration, and frequency of volcanic events on and about the Hanford site. One to two figures will show the areal extent and timing of selected flow events.

Section Outline:

3.3.1.4	Volcanism
3.3.1.4.1	Type
3.3.1.4.2	Location
3.3.1.4.3	Extent
3.3.1.4.4	Duration
3.3.1.4.5	Frequency

Figures:

3.3.1.4-1..n	Areal distribution of major volcanic flows (shown on one map, if possible)
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Tables:

3.3.1.4-1-	Major flow events, type of rock, areal extent (km**2), chronology
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Section #: 3.3.1.5

Title: Seismicity

Author(s): Site

Max. # of Pages: 2

of Figures:

Date:

of Tables:

Description of Contents:

Regionally, historical seismic events will be enumerated as to spatial (epicenter) and temporal locations, magnitude, and frequency/ recurrence interval. This exercise will be repeated at the local scale for any on-site historical seismicity. In situ (borehole) stress tests, when available, will be incorporated into the analyses.

Section Outline:

3.3.1.5	Seismicity
3.3.1.5.1	Regional Seismicity
3.3.1.5.1.1	Locations-Spatial and Temporal
3.3.1.5.1.2	Magnitude
3.3.1.5.1.3	Frequency/Recurrence
3.3.1.5.2	Local Seismicity
3.3.1.5.2.1	Locations-Spatial and Temporal
3.3.1.5.2.2	Magnitude
3.3.1.5.2.3	Frequency/Recurrence

Figures:

3.3.1.5-1	Relationships of historical seismicity to structural/tectonic environment
3.3.1.5-2	Spatial distribution of epicenters of regional and local historical seismic and microseismic events

Tables:

3.3.1.5-1	Historical seismicity; Name, Epicenter, Magnitude
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Section #: 3.3.1.6

Title: Soils

Author(s): Site

Max. # of Pages: 1

of Figures:

Date:

of Tables:

Description of Contents:

Because soils may have either a high or a low capacity to retard the movement of contaminants in the subsurface, an in depth characterization of soils present at the site is critical. This characterization will include a map showing the distribution of various soil types at the site, and a classification and description of these soils. The four characteristics which will be described are thickness, erosion potential, water content at field capacity, and hydraulic conductivity. In addition, where significant weathered rock (saprolite) horizons exist, these will be characterized.

Section Outline:

3.3.1.6	Soils
3.3.1.6.1	Locations
3.3.1.6.2	Classification & Description
	Thickness
	Erosion Potential
	Water Content at Field Capacity
	Hydraulic Conductivity
3.3.1.6.3	Subsoil/Unconsolidated Units Characterization

Figures:

3.3.1.6-1	A local scale soils map
3.3.1.6-2	Cross-sectional view of soil and unconsolidated units

Tables:

3.3.1.6-1	Classifications and descriptions of soils
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Section #: 3.3.1.7

Title: Natural Radioactivity

Author(s): Site

Max. # of Pages: 0.5 # of Figures:

Date:

of Tables:

Description of Contents:

If any parent rocks or soils at the site produce radioactivity, they will be identified as to their distribution, radioactive products, and typical activity levels.

Section Outline:

3.3.1.7	Natural Radioactivity
3.3.1.7.1	Natural Radioactivity of lithologic units
3.3.1.7.2	Natural Radioactivity of soils units

Tables:

3.3.1.7.1-1	Lithologic sources of natural radioactivity with typical activity levels
3.3.1.7.2-1	Soil sources of natural radioactivity with typical activity levels

APPENDIX C

STRATIGRAPHY OF THE SAVANNAH RIVER SITE, SOUTH CAROLINA

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INTRODUCTION

The Savannah River Site (SRS) covers approximately 300 sq mi (780 sq km) in Aiken and Barnwell counties, South Carolina, with the northwestern boundary being about 20 mi (32 km) southeast of the Fall Line. The last detailed, published study of the Site is that of Siple (1967). The present description is based on data accumulated in the last few years from numerous wells, geophysical logs, paleontological studies, reflection seismic surveys, and observations of outcrops on and in the vicinity of SRS.

The Coastal Plain section, a wedge of Cretaceous and Cenozoic sediments, thickens from about 700 ft (213 m) at the northwestern boundary to about 1400 ft (430 m) at the southeastern boundary. Regional dip is to the southeast at about 50 ft/mi (9 m/km) on the sub-Cretaceous unconformity and decreases upward. Over most of the site, the Coastal Plain sediments lie on Crystalline rocks of the Appalachian orogen. In the southeastern part of the Site, they lie on Mesozoic sediments of the Newark Supergroup which were deposited in the Dunbarton basin (Marine and Siple, 1974). Another major structural feature is the Pen Branch fault, which parallels the Dunbarton border fault and cuts Cretaceous, Paleocene, and Eocene strata (Snipes et al., this volume).

The Coastal Plain section is mostly quartz sand and pebbly sand. Clay beds and lenses occur throughout, and calcareous strata are common throughout, and calcareous strata are common in the middle and upper parts of the Eocene section in downdip parts of SRS. Most of the formations appear to be separated by unconformities. Lateral and vertical facies changes are characteristic of most of the section, and the lithologic descriptions below, therefore, are broad generalizations.

Table C-1. Stratigraphic Column

Miocene (?)
"upland unit"
Upper Eocene
Tobacco and Sand
Dry Branch Formation
Irwinton Sand Member
Griffins Landing Member
Clinched Formation
Utley Limestone Member
Riggins Mill Member
Middle Eocene
"Orangeburg District beds"
Santee Limestone
McBean Member
Blue Bluff Member
Tims Branch Member
Warley Hill Formation
Lower Eocene
Congaree Formation
Fourmile Member of Fishburne
Formation
Paleocene
Snapp Member of Williamsburg
Formation
Ellenton Formation
Upper Cretaceous
Steel Creek Member of Peedee
Formation(?)
Black Creek Formation
Middendorf Formation
Cape Fear Formation

UPPER CRETACEOUS

The Cretaceous section, assigned to the Tuscaloosa Formation by Siple (1967), is about 650 ft (198 m) thick at the center of SRS and consists mostly of sand, usually pebbly and micaceous. Thin clay layers are common, and in parts of the section clay beds and lenses up to 70 ft (21 m) thick occur. Some of these appear to cover tens of square miles. Environments of deposition appear to be fluvial to prodelta.

The basal Cretaceous deposits are a distinctive unit consisting of a very clayey, silty, poorly sorted sands with numerous interbedded clays. Pebbly beds and feldspathic zones are common. Induration is relatively high, and resistivity is very low on geophysical logs. The thickness is about 140 ft (43 m) at the center of the Site. A few palynological dates from this unit appear to center around a Santonian age. We assign this basal unit to the Cape Fear Formation.

Overlying the Cape Fear is the Middendorf Formation, composed of moderately sorted, yellow, tan and gray quartz sand. A zone of interbedded sands and variegated clays occurs at the top. A few palynological dates centering around Santonian have been reported. The unit is about 140 ft (43 m) thick at the center of the Site.

Sediments which we assign to the Black Creek Formation overlie the Middendorf and are about 300 ft (91 m) thick near the center of SRS. They consist mostly of tan and gray sand. A thick, variegated clay lens occurs in the lower part in places, and a more extensive bed occurs at the top. In the central and downdip part of SRS, a southeastwardly-thickening wedge of dark, fissile, lignitic, micaceous clay with dark, interbedded sands occurs in the middle and upper part of the section. We have many Campanian palynological dates from this unit. Dinoflagellates are abundant, in contrast to the other Cretaceous sediments.

Overlying the Black Creek is a section of yellow, tan, and gray, moderately sorted sand and interbedded sand and variegated clay, about 70 ft (21 m) thick, which we refer to informally as the Steel Creek member of the Peedee Formation. There are a few palynological dates of Maestrichtian age. It may later be assigned to the Black Creek.

PALEOCENE

The Paleocene section consists of interbedded clay. It is about 60 ft (18 m) thick in the center of the Site, and the environment of deposition was probably delta plain and prodelta.

Siple (1967) described and named the Ellenton Formation at SRS, observing that it lay between the Cretaceous Tuscaloosa and the Eocene Congaree(?) Formation. It consists mostly of interbedded light gray-to-black, poorly sorted sand and dark clay and is about 50 ft (15 m) thick in the center of SRS. Lignite, glauconite, iron, sulfide, and muscovite are abundant in places. Feldspar is common in some wells. Prowell et al. (1985) reported early Paleocene fossils from the lower part of the Ellenton.

We have obtained many dinoflagellate dates of early Paleocene age from the lower part and a few late Paleocene dates from the upper part. Siple's Ellenton may later be subdivided. It appears to correlate with the Clayton, Porters Creek, Naheola and Nanafalia formations of the Gulf Coastal Plain.

In the downdip part of the Site, overlying the dark sediments of the Ellenton are about 60 ft (18 m) of lighter-colored, very micaceous, very poorly sorted, silty sands, and interbedded light-colored clays. The unit appears to pinch out near the center of SRS. Two palynological dates of late Paleocene age have been reported. We are referring to it informally as the Snapp member of the Williamsburg Formation and correlate it with the Tusahoma Formation of the Gulf Coastal Plain.

LOWER EOCENE

Sediments of the early Eocene age are approximately 60 ft (18 m) thick at the center of SRS and consist of moderately and well sorted sands with a few interbedded, green, black, and tan clays. The environment of deposition appears to be shallow marine and lagoonal. Siple (1967) assigned this part of the section to the Congaree Formation(?).

The basal Eocene unit, approximately 30 ft (9 m) thick, is mostly tan, yellow, orange, and green, moderately sorted sand with clays a few feet thick in the middle and at the top in places. It is glauconitic in some wells. We have obtained numerous early Eocene age dates from palynological assemblages, some indicating its equivalence to the Fishburne Formation (Gohn et al., 1983), a calcareous unit which occurs downdip near the coast. We are informally referring to the sediments on the site as the Fourmile member of the Fishburne and correlate it with the Bashi and Hatchitigbee of the Gulf Coastal Plain.

Overlying the Fourmile is a section approximately 30 ft (9 m) thick similar to the underlying unit. It is better sorted, contains fewer pebbly zones, less muscovite and glauconite, and is lighter in color in many wells. There are a few early Eocene age dates from dinoflagellate assemblages which appear to be different from and slightly younger than those in the underlying unit. The upper part may be middle Eocene. We consider the unit to be the Tallahatta of the Gulf Coastal Plain.

MIDDLE EOCENE

The middle Eocene section, a shallow marine deposit, consists of moderately sorted, yellow and tan sand, calcareous sands and clays, several types of carbonates, and clay. The calcareous deposits are much more abundant downdip, sporadic in the middle of the Site, and missing along the updip boundary.

At the base of the middle Eocene, a sand approximately 10 ft (3 m) thick which is glauconitic in places has yielded a palynological date which suggests a lower Lisbon correlation. The unit is probably the Warley Hill "phase" of Sloan (1908) (see also Willoughby and Nystrom, this volume).

Siple (1967) referred to the section overlying the Warley Hill as the McBean Formation, but we are using the term Santee for the unit as a whole because of priority (Sloan, 1908) and informally referring to the light-colored, calcareous part of the section as the McBean member, the gray and green, laminated, calcareous part as the Blue Bluff member, and the siliciclastic part as the Tims Branch member. A green, gray, or tan clayey zone occurring in the lower part of the formation in many wells is useful in correlation. Glauconite is common in places within the Santee. The units about 80 ft (24 m) thick in the center of SRS. There are numerous dates from dinoflagellates, calcareous nannofossils, and other taxa indicating a late middle Eocene age, equivalent to the upper Lisbon of the Gulf Coastal Plain.

One ostracode assemblage from a well has indicated the presence of sediments equivalent to the Gosport Formation of the Gulf Coastal Plain. The fossils occur in sediments very similar to that of the McBean member, and its distribution at SRS, therefore, is uncertain at this time. It appears to correlate with the "Orangeburg District beds" of Dockery and Nystrom (this volume) (see also Nystrom et al, this volume).

UPPER EOCENE

The upper Eocene section is approximately 120 ft (37 m) thick in the center of the Site and consists of sand, calcareous sand and clay, various kinds of carbonates, and thin clay beds. The environment of deposition is probably shallow marine and lagoonal. Siple (1967) assigned the lower part of the section to the McBean Formation and the upper part to the Barnwell and Hawthorn formations. We are using the stratigraphic terminology of Huddlestun and Hetrick (1985) for the upper Eocene.

The basal upper Eocene unit is the Clinchfield Formation which consists of glauconitic, biomoldic limestone, calcareous sand and clay, and tan and yellow

sand. The sand is probably the Riggins Mill Member. The calcareous part is the Utley Limestone Member. The Clinchfield is about 25 ft (8 m) thick in the southeastern part of the plant and pinches out or becomes unrecognizable in the center of the plant. It appears to correlate biostratigraphically with the "*Scutella*" abundance zone of the Gulf Coastal Plain (Gosport or Moodys Branch).

The Clinchfield is overlain by the Dry Branch Formation which is about 60 ft (18 m) thick in the center of SRS. The Dry Branch consists of the Irwinton Sand Member, a unit of tan, yellow, and orange, poorly to well-sorted sand with interbedded tan and gray clays near the bottom (Twiggs Clay lithology), and the Griffins Landing Member, consisting of calcareous sands and clays and various types of carbonates. The Griffins Landing appears to be widespread in the southeastern part of SRS where it is about 50 ft (15 m) thick but becomes sporadic in the center where it pinches out. We have several late Eocene dates from the Dry Branch, mostly from the Griffins Landing, indicating a correlation with the lower part of the Yazoo Formation of the Gulf Coastal Plain.

The Tobacco Road Formation overlies the Dry Branch and consists of red, purple, and orange poorly-to-well sorted sand and clayey sand. Clay laminae are abundant. Its thickness is about 50 ft (15 m) in the middle of SRS but is extremely variable because of erosion preceding deposition of the overlying unit. We do not have fossil dates from the Tobacco Road, but it has been dated as late Eocene in Georgia (Huddleston and Hetrick, 1985) and is probably correlative to the upper part of the Yazoo Formation of the Gulf Coastal Plain.

MIocene(?)

At higher elevations over much of the Site is a deposit of very poorly sorted, silty, clayey sand, pebbly sand, and conglomerate with sporadic clay lenses. Weathered feldspar is abundant in places. The color is quite variable, and facies changes are abrupt. The environment of deposition appears to be fluvial, and the thickness changes rapidly because of channeling of the underlying Tobacco Road and because of Quaternary erosion. Thicknesses of at least 60 ft (18 m) have been observed in places. Siple (1967) assigned the sediments to the Hawthorn Formation. We do not have fossil dates from the unit. Nystrom et al. (1986), who map it as the "upland unit," have discussed the evidence for a Miocene age, suggesting a correlation with the Altamaha Formation of Georgia.

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