1.4.3 GEOLOGY

1.4.3.1 Regional Geology (320 km [200 mile] Radius)

The following discussion on the regional geology is based on DOE-STD-1022-94 (Ref. 139). The area of interest is a radius of about 320 km (200 miles) from the site. The information also provides the basis for understanding the regional tectonics as applied to SRS.

SRS has conducted many investigations and used extensive literature review to reach the conclusion that there are no geologic threats affecting the SRS, except the Charleston Seismic Zone and the minor random Piedmont earthquakes. These topics are discussed in greater technical detail in Section 1.4.4. Possible threats to groundwater contamination are discussed in Section 1.4.2.

The southeastern continental margin, within a 320-km (200-mile) radius of SRS, contains portions of all the major divisions of the Appalachian orogen (mountain belt) in addition to the elements that represent the evolution to a passive margin.

Within the Appalachian orogen, several lithotectonic terranes that have been extensively documented include the foreland fold belt (Valley and Ridge) and western Blue Ridge Precambrian-Paleozoic continental margin; the eastern Blue Ridge-Chauga Belt-Inner Piedmont terrane; the volcanic-plutonic Carolina Terrane; and the geophysically defined basement terrane beneath the Atlantic Coastal Plain (see Figure 1.4-30) (Ref. 140, 141). These geological divisions record a series of compressional and extensional events that span the Paleozoic. The modern continental margin includes the Triassic-Jurassic rift basins that record the beginning of extension and continental rifting during the early to middle Mesozoic. The offshore Jurassic-Cretaceous clastic-carbonate bank sequence covered by younger Cretaceous and Tertiary marine sediments, and onshore Cenozoic sediments represent a prograding shelf-slope (Ref. 140) and the final evolution to a passive margin. Other offshore continental margin elements include the Florida-Hatteras shelf and slope and the unusual Blake Plateau basin and escarpment (Ref. 142-144).

From the Cumberland Plateau and the Valley and Ridge provinces to the offshore Blake Plateau basin, the regional geology records the complete cycles of opening and closing of Paleozoic oceans and the opening of a new ocean (Atlantic) (Ref. 140). Late Proterozoic rifting is recorded in rift-related sediments at the edge of the frontal Blue Ridge province and the Ocoee and Tallulah Falls basins in the western and eastern Blue Ridge, respectively. Passive margin conditions began in the middle Cambrian and persisted through early Ordovician. The Cambro-Ordovician sedimentary section in the Valley and Ridge reflects this condition. The

collision-accretionary phase of the Appalachians began in the middle Ordovician and persisted with pulses through the early Permian. Mesozoic rifting of the continents led to the creation of Triassic rift basins on the modern eastern continental margin and ultimately to the creation of the Atlantic Ocean basin. The evolution to a passive margin is recorded in the Cretaceous through Holocene Coastal Plain sediments and offshore carbonate bank and shelf sequences.

The two predominant processes sculpting the landscape during this tectonically quiet period included erosion of the newly formed highlands and subsequent deposition of the sediments on the coastal plain to the east. The passive margin region consists of a wedge of Cretaceous and Cenozoic sediments that thicken from near zero at the Fall Line to about 335 meters (1,100 feet) in the center of SRS, and to approximately 1,220 meters (4,000 feet) at the South Carolina coast. The fluvial to marine sedimentary wedge consists of alternating sand and clay with tidal and shelf carbonates common in the downdip Tertiary section.

VALLEY AND RIDGE PROVINCE

The Valley and Ridge Province (see Figure 1.4-30) includes Paleozoic sedimentary rocks consisting of conglomerate, sandstone, shale, and limestone. The shelf sequence was extensively folded and thrust faulted during the Alleghanian collisional event. The physiography is expressed as a series of parallel ridges and valleys that are a result of the erosion of breached anticlines with the oldest layers exposed in the valleys and the younger layers forming the ridges. The topographic expression of the folds is best expressed in the central and southern Appalachians. In the central and northern Appalachians the folded structure is dominant and thrust faults are not as numerous or expressed at the surface. The eastern boundary with the Blue Ridge province is formed by the Blue Ridge-Piedmont thrust. This boundary is distinct in most places along the strike of the Appalachians and marks the change from folded rocks that are not penetratively deformed to rocks that are penetratively deformed.

BLUE RIDGE PROVINCE

The Blue Ridge geologic province is bounded on the southeast by the Brevard fault zone and on the northwest by the Blue Ridge-Piedmont fault system (see Figure 1.4-30) (Ref. 145-147). The province is a metamorphosed basement/cover sequence that has been complexly folded, faulted, penetratively deformed, and intruded. These rocks record multiple late Proterozoic to late Paleozoic deformation (extension and compression) associated with the formation of the Iapetos Ocean and the Appalachian orogen (Ref. 145, 148-151). The province consists of a series of westward-vergent thrust sheets, each with different tectonic histories and different lithologies (including gneisses, plutons, metavolcanic, and metasedimentary rift sequences), as well as continental and platform deposits (Ref. 140, 145). The Blue Ridge-Piedmont fault system thrust the entire Blue Ridge province northwest over Paleozoic sedimentary rock of the Valley and Ridge province during the Alleghanian orogeny (Ref. 149-154). The Blue Ridge geologic province reaches its greatest width in the southern Appalachians.

The Blue Ridge is divided into a western and an eastern belt separated by the Hayesville-Gossan Lead fault. Thrust sheets in the western Blue Ridge consist of a rift-facies sequence of clastic sedimentary rocks deposited on continental basement, whereas thrust sheets in the eastern Blue

Ridge consist of slope and rise sequences deposited in part on continental basement and in part on oceanic crust (Ref. 145, 149). Western Blue Ridge stratigraphy consists of basement gneisses, metasedimentary, metaplutonic, and metavolcanic rocks, whereas Eastern Blue Ridge stratigraphy consists of fewer lithologies, more abundant mafic rocks, and minor amounts of continental basement. These divisions of the Blue Ridge are discussed in more detail below.

Western Blue Ridge

The western Blue Ridge consists of an assemblage of Middle Proterozoic continental (Grenville) basement nonconformably overlain by Late Proterozoic to Early Paleozoic rift and drift facies sedimentary rock (Ref. 140, 155, 156). The basement consists of various types of gneisses, amphibolite, and gabbroic and volcanic rock and metasedimentary rock. All basement is metamorphosed to granulite or uppermost amphibolite facies (Ref. 140). The calculated ages of these rocks generally range from 1000-1200 Ma (mega annum or millions of years) (Ref. 157-159).

The rifting event during the Late Proterozoic through Early Paleozoic that formed the Iapetos Ocean is recorded in the rift-drift sequence of the Ocoee Supergroup and Chillhowie Group (Ref. 160, 161). These rocks, basement and sedimentary cover, were all later affected by Taconic and possibly Acadian deformation and metamorphism. The entire composite thrust sheet was transported west as an intact package during the Alleghanian collision event on the Blue Ridge-Piedmont thrust.

Eastern Blue Ridge

The eastern Blue Ridge is located southeast of the western Blue Ridge and is separated from that province by the Hayesville-Gossan Lead fault. The Brevard fault zone forms the southeastern boundary with the Inner Piedmont (see Figure 1.4-31). Lithologically, the eastern Blue Ridge is composed of continental slope, rise, and ocean floor metasedimentary rocks in association with oceanic or transitional to oceanic crust (Ref. 140, 162). This contrasts with the western Blue Ridge, which contains metasedimentary rocks suggesting continental rift-drift facies of a paleomargin setting. The eastern Blue Ridge is structurally complex with several major thrust faults, multiple fold generations, and two high-grade metamorphic episodes (Ref. 140). Metamorphism took place during the Taconic and possibly Acadian orogenies.

The stratigraphy within the eastern Blue Ridge includes rare Grenville (Precambrian) gneisses, metasedimentary rocks of the Tallulah Falls Formation and the Coweeta Group, metamorphosed Paleozoic granitoids, and mafic and ultramafic complexes and rocks of the Dahlonega Gold Belt. The Paleozoic granitoids are a part of a suite of similar granites that are found in the western Inner Piedmont suggesting a common intrusive history. Metasedimentary rock sequences in the eastern Blue Ridge are correlated along strike as well as across some thrust fault boundaries also suggesting a commonality in the original depositional history. Based on geochemical data, the mafic and ultramafic complexes that are found in particular thrust sheets in the eastern Blue Ridge have oceanic as well as continental affinities. However, exact tectonic origin is not clear because the contacts with the host metasedimentary rock are obscure.

PIEDMONT PROVINCE

The Piedmont province in northwestern South Carolina consists of variably deformed and metamorphosed igneous and sedimentary rocks ranging in age from Middle Proterozoic to Permian (1100-265 Ma). The province consists of the Western Piedmont and the Carolina terrane (see Figure 1.4-32). This designation is made because of different tectonic origins for the western and eastern parts of the province. The province can also be subdivided into seven distinctive tectonostratigraphic belts, separated by major faults (e.g., Towaliga fault), contrasts in metamorphic grade, or both. From northwest to southeast, these are the Chauga, Inner Piedmont, Kings Mountain, Charlotte, Carolina Slate, Kiokee, and Belair belts. The metamorphic grade of these belts alternates between low grade (Chauga, Kings Mountain, Carolina Slate, and Belair) and medium to high grade (Inner Piedmont, Charlotte, and Kiokee). The Charlotte and Carolina Slate belts are combined and discussed as the Carolina Terrane. The rocks of the Piedmont have been deformed into isoclinal recumbent and upright folds, which have been refolded and are contained in several thrust sheets or nappes. These metamorphic rocks extend beneath the Coastal Plain sediments in central and eastern South Carolina. The southeastern extent of the Piedmont province underneath the Coastal Plain is unknown.

Western Piedmont

The Western Piedmont encompasses the Inner Piedmont block, the Smith River Allochthon, and the Sauratown Mountains Anticlinorium (see Figure 1.4-31) (Ref. 163). It is separated from the Blue Ridge province on the northwest by the Brevard Fault zone. It is separated from the Carolina Terrane on the southeast by a complex series of fault zones approximately coincident with the Central Piedmont suture (Ref. 149). These faults include Lowndesville, Kings Mountain, Eufola, Shacktown, and Chatham fault zones (Ref. 163). The province is a composite stack of thrust sheets containing a variety of gneisses, schists, amphibolite, sparse ultramafic bodies and intrusive granitoids (Ref. 146, 164, 165). The protoliths are immature quartzo-feldspathic sandstone, pelitic sediments, and mafic lavas.

The Sauratown Mountains Anticlinorium is a complex structural window of four stacked thrust sheets that have been exposed by doming and subsequent erosion. Each sheet contains Precambrian basement with an overlying sequence of younger Precambrian to Cambrian metasedimentary and metaigneous rocks (Ref. 163). The Smith River Allochthon contains two predominantly metasedimentary units and a suite of plutonic rocks. It is a completely fault-bounded terrane, as is the Sauratown Mountains anticlinorium. The Inner Piedmont block is a fault-bounded, composite thrust sheet with metamorphic complexes of different tectonic affinities (Ref. 163). There is some continental basement within the block (Ref. 165) and scattered mafic and ultramafic bodies and complexes (Ref. 166) suggesting the presence of oceanic crustal (Ref. 163). The rest of the block contains a coherent though poorly understood stratigraphy of metasedimentary rock, metavolcanic gneisses, and schists (Ref. 163). The eastern Blue Ridge and Inner Piedmont contain some stratigraphically equivalent rocks (Ref. 167).

The western Piedmont reflects the effects of a complex tectonic history from the Precambrian Grenville through Late Paleozoic Alleghanian orogenies. Metamorphism affected the basement rocks of the Sauratown Mountains anticlinorium at least twice: during the Precambrian Grenville

and later during the Paleozoic. The metasedimentary cover sequence as well as the Smith River allochthon and the Inner Piedmont block were affected by one metamorphic event (prograde and retrograde) in the Paleozoic (Ref. 163). The Alleghanian continental collision is reflected in the thrust and dextral strike slip fault systems such as the Brevard and Bowens Creek fault zones. A few late Paleozoic granites were emplaced in the Inner Piedmont block; however, most lie further east in the Carolina Terrane. Early Mesozoic extension resulted in the formation of rift basins (Dan River and Davie County basins).

Carolina Terrane

The Carolina Terrane is part of a late Precambrian-Cambrian composite arc terrane, exotic to North America (Ref. 168, 169), and accreted sometime during the Ordovician to Devonian (Ref. 170, 171). It consists of felsic to mafic volcanic rock and associated volcanoclastic rock. Middle Cambrian fossil fauna indicate a European or African affinity (Ref. 168).

The northeastern boundary of the Carolina terrane is formed by a complex of faults that comprise the Central Piedmont suture (see Figure 1.4-31) and separate the terrane from rocks of North American affinity (Ref. 172-177). This structure was reactivated during the later Alleghanian collisional events as a dextral shear fault system (Ref. 178). Subsequent investigators have further established understanding of the complicated structure (Ref. 173, 179-185) suggested that the Central Piedmont suture is a low-angle normal fault. The Carolina terrane is bounded on the southeast by the Modoc fault zone and the Kiokee belt (see Figure 1.4-32).

The Carolina terrane is the combination of the earlier Charlotte and Carolina slate belts. The belts were initially distinguished by metamorphic grade (Ref. 147) and were later recognized as the same protolith and thus were combined (Ref. 140). Metamorphic grade increases to the northwest from lower greenschist facies to upper amphibolite facies. Pre-Alleghanian structure is dominated by large northeast trending folds with steeply dipping axial surfaces. All country rock of the Carolina terrane has been penetratively deformed, thereby producing axial plane cleavage and foliation (Ref. 140).

The Charlotte belt contains numerous intrusions and moderate- to high-grade metamorphic rock. Much of the belt was metamorphosed to amphibolite grade during the Taconic orogeny (Ref. 182), but retrograde metamorphism is also widespread. The oldest rocks are amphibolite, biotite gneiss, hornblende gneiss, and schist and probably were derived from volcanic, volcanoclastic, or sedimentary protoliths.

The Carolina Slate belt is characterized by thick sequences of metasedimentary rocks derived from volcanic source areas and felsic to mafic metavolcanic rocks. The oldest rocks within the Carolina Slate belt consist of intermediate to felsic ashflow tuff and associated volcanoclastic rocks. These rocks are overlain by a sequence of mudstone, siltstone, sandstone, greywacke, and greenstone with some interbedded volcanic tuff and flows. The belt was subjected to low- to medium-grade regional metamorphism and folding from 500-300 Ma and was intruded subsequently by granitic and gabbroic plutons about 300 Ma.

Kiokee Belt

The Kiokee belt is located between the Carolina terrane and the Belair belt in Georgia and South Carolina (see Figure 1.4-32). It is referred to as the Savannah River terrane in some of the recent literature (Ref. 186, 187). The Kiokee belt is bounded on the northwest by the Modoc fault zone and on the southeast by the Augusta Fault. It is a medium- to high-grade metamorphic belt with associated plutonism . Snoke (Ref. 188) recognized the Kiokee belt as the Alleghanian metamorphic core. The faults are mylonite zones that overprint the amphibolite facies infrastructure of the core of the belt (Ref. 140). The core was deformed and metamorphosed prior to the development of the plastic shear zones bounding it (Ref. 182, 183).

The Kiokee belt is an antiformal structure that strikes northeast. The interior is a migmatitic complex of biotite amphibole paragneiss, leucocratic paragneiss, sillimanite schist, amphibolite, ultramafic schist, serpentinite, feldspathic metaquartzite, and granitic intrusions of Late Paleozoic age (Ref. 189). Some of the lithologic units found in the Carolina slate belt may occur at higher metamorphic grade in the Kiokee belt (Ref. 140).

From extensive field studies and geochronological dating a complex Alleghanian history can be derived from the studies of the Kiokee belt (Ref. 188, 190-193). The pre-Alleghanian structure and stratigraphy are only partially known. The nature of the crustal rock that played a part in the metamorphism, deformation, and intrusion is still unknown. The possible role of a Precambrian basement in the Kiokee belt is an essential question proposed by Hatcher et al. (Ref. 140). No rock in the Kiokee belt has been identified at this time as Precambrian basement. However, Long (Ref. 194) suggested, based on gravity data, that a large rifted block of continental crust underlies the Kiokee belt.

Belair Belt

The Belair belt (also Augusta terrane) (Ref. 191, 195) is locally exposed in the Savannah River valley, near Augusta, GA (see Figure 1.4-32). It is largely concealed beneath the Atlantic Coastal Plain with several small erosional windows through the Coastal Plain sediments in eastern Georgia (Ref. 196). The Belair belt consists of intermediate to felsic volcanic tuffs and related volcanoclastic sediments penetratively deformed and metamorphosed to greenschist facies (Ref. 186, 188, 195-201). The Belair belt contains similar characteristics to the Carolina terrane (Ref. 202). Geophysical and well data indicate that the Belair belt extends beneath the Atlantic Coastal Plain (Ref. 202).

MESOZOIC RIFT BASINS

Mesozoic age rift basins are found along the entire eastern continental margin of North America from the Gulf Coast through Nova Scotia (see Figure 1.4-33). The basins formed in response to the continental rifting episode that broke up the super continent, Pangea, and led to the formation of the Atlantic ocean basin. Rift basins are exposed in the Piedmont province as well as buried beneath Cretaceous and younger Coastal Plain sediments. Many underlie offshore regions. Structurally, the basins are grabens or half grabens, elongated in a northeast direction and are

bounded by normal faults on one or both sides (Ref. 203). Several basins were localized along reactivated Paleozoic ductile or brittle fault zones (Ref. 204-207).

There are two belts of basins that trend northeastward along the continental margin from the Carolinas to Pennsylvania (Ref. 208). In North and South Carolina the Deep River, Elberbe and Crowburg basins are included in the eastern belt, and the Dan River and Davie County basins are in the western belt (Ref. 208). The Dunbarton, Florence, Riddleville, and South Georgia basins are buried beneath Coastal Plain sediments in the eastern belt (see Figure 1.4-34). The basins are generally filled with lacustrine sedimentary and igneous rock.

Strata within the basins consist mainly of non-marine sandstone, conglomerate, siltstone, and shale. Carbonate rocks and coal are found locally in several basins. Igneous rocks of basaltic composition occur as flows, sills, and stocks within the basins and as extensive dike swarms within and outside the basins (Ref. 209). These basin fill strata have been described and named the Newark Supergroup (Ref. 208, 210, 211). In general, the stratigraphy can be broken out into three sections. The lower section is characteristically fluvial (Ref. 211, 212) and contains reddish-brown, arkosic coarse-grained sandstone, and conglomerate. The middle section mainly includes sediments of lacustrine origin (Ref. 211). These sediments include grey-black fossiliferous siltstone, carbonaceous shale, and thin coal beds (Ref. 208). The upper section is a complex of deltaic, fluvial, and lacustrine environments (Ref. 213. 214). These sediments include red-brown siltstone, arkosic sandstone, pebbly sandstone, and red and grey mudstone and conglomerate (Ref. 208).

In North Carolina, there are two exposed major basins, the Dan River and Deep River basins. There are many similarities between the two basins as well as significant differences (Ref. 208). Both basins exhibit half-graben geometry, bounded on one side by a major normal fault zone. Basin strata typically dip towards the border fault. However, the border faults on the two basins are on opposite flanks of the basin: Dan River's Chatham Fault dips to the southeast. Deep River's Jonesboro fault zone is located on the basin's southeast flank and dips northwest (Ref. 208). There are also significant differences in the internal stratigraphy and component of basalt intrusion.

The Dunbarton basin beneath SRS has a master border fault dipping to the southeast (Ref. 215), and so does the Riddleville basin in Georgia (Ref. 208). The Dunbarton basin is not known to contain any basalt sills. The South Georgia Rift, in Georgia and South Carolina, is a much larger, deeper and more complex basin than either the Riddleville or Dunbarton basins. The basin is as wide as 100 km and as deep as 7 km (Ref. 216). It is not a single basin but is a complex of isolated synrift grabens with limited to major crustal extension. The major border fault dips northward (Ref. 216) as opposed to southeastward for the master faults bounding Riddleville and Dunbarton basins.

ATLANTIC COASTAL PLAIN STRATIGRAPHY, LITHOLOGY, AND STRUCTURE

The information in this section is based largely on Aadland et al., Hydrogeologic Framework of West Central South Carolina (Ref. 100). (Text excerpts and figures from that document are included here with permission of the authors.)

The sediments of the Atlantic Coastal Plain in South Carolina are stratified sand, clay, limestone, and gravel that dip gently seaward and range in age from Late Cretaceous to Recent. The sedimentary sequence thickens from essentially zero at the Fall Line to more than 1,219 meters (4,000 feet) at the coast. Regional dip is to the southeast, although beds dip and thicken locally in other directions because of locally variable depositional regimes and differential subsidence of basement features such as the Cape Fear Arch and the South Georgia Embayment. A map depicting these regional features and the study area discussed in the following sections is presented in Figure 1.4-35.

The Coastal Plain sedimentary sequence near the center of the region (i.e., SRS) consists of about 213 meters (700 feet) of Late Cretaceous quartz sand, pebbly sand, and kaolinitic clay, overlain by about 18 meters (60 feet) of Paleocene clayey and silty quartz sand, glauconitic sand, and silt. The Paleocene beds are in turn overlain by about 107 meters (350 feet) of Eocene quartz sand, glauconitic quartz sand, clay, and limestone grading into calcareous sand, silt, and clay. The calcareous strata are common in the upper part of the Eocene section in downdip parts of the study area. In places, especially at higher elevations, the sequence is capped by deposits of pebbly, clayey sand, conglomerate, and clay of Miocene or Oligocene age. Lateral and vertical facies changes are characteristic of most of the Coastal Plain sequence, and the lithologic descriptions below are therefore generalized. A surface geologic map for SRS is presented in Figure 1.4-36. The stratigraphic section, which delineates the coastal plain lithology (see Figure 1.4-18), is divided into several formations and groups based principally on age and lithology.

Geology of the Coastal Plain Sediments - General

The following sections describe regional stratigraphy and lithologies, with emphasis on variations near the SRS. The data presented are based upon direct observations of surface outcrops; geologic core obtained during drilling of bore holes; microfossil age dating; and borehole geophysical logs. Several key boring locations within the SRS boundaries and in the adjacent regions (presented in Figure 1.4-21) are referenced throughout the following discussions.

Rocks of Paleozoic and Triassic ages have been leveled by erosion and are unconformably overlain by unconsolidated to poorly consolidated Coastal Plain (Ref. 217-219). This erosional surface dips approximately 7 m/km (37 ft/mile) toward the southeast. The Atlantic Coastal Plain sediments in South Carolina are stratified sand, clay, limestone, and gravel that dip gently seaward and range in age from Late Cretaceous to Recent. Near the coast, the wedge is approximately 1,219 meters (4,000 feet) thick (Ref. 220).

Upper Cretaceous Sediments

Upper Cretaceous sediments overlie Paleozoic crystalline rocks or lower Mesozoic sedimentary rocks throughout most of the study area. The Upper Cretaceous sequence includes the basal Cape Fear Formation and the overlying Lumbee Group, which is divided into three formations (see Figure 1.4-18). The sediments in this region consist predominantly of poorly consolidated, clay-rich, fine- to medium-grained, micaceous sand, sandy clay, and gravel (Ref. 100), and is

about 213 meters (700 feet) thick near the center of the study area. Thin clay layers are common. In parts of the section, clay beds and lenses up to 21 meters (70 feet) thick are present. Depositional environments were fluvial to prodeltaic.

Cape Fear Formation

The Cape Fear Formation rests directly on a thin veneer of saprolitic bedrock and is the basal unit of the Coastal Plain stratigraphic section at SRS. The saprolite ranges from less than 3 meters (10 feet) to more than 12 meters (40 feet) in thickness and defines the surface of the crystalline basement rocks and sedimentary rocks of the Newark Supergroup (Middle to Upper Triassic age). The thickness of the saprolite reflects the degree of weathering of the basement prior to deposition of the Cape Fear Formation. The Cape Fear is encountered at about 61 meters (200 feet) msl just south of well C-3 in the north and at about 366 meters (1,200 feet) msl at well C-10 (see Figure 1.4-21) in the south. The Cape Fear does not crop out in the study area, and its northern limit is north of the C-1 and P-16 wells and south of wells C-2 and C-3. The unit thickens to more than 70 meters (230 feet) at well C-10 and has a maximum known thickness of about 213 meters (700 feet) in Georgia (Ref. 221). The top of the Cape Fear Formation dips approximately 5 m/km (30 ft/mile) to the southeast across the study area.

The Cape Fear Formation consists of firm to indurated, variably colored, poorly sorted, silty, clayey sand and sandy silt and clay. Bedding thickness of the sand, silt and clay ranges from about 1.5 meters (5 feet) to 6 meters (20 feet), with the sand beds generally thicker than the clay beds. The sand grains are typically coarse-grained with common granule and pebble. The sand is arkosic with rock fragments common in the pebbly zones.

The Cape Fear Formation is more indurated than other Cretaceous units because of the abundance of cristobalite cement in the matrix. The degree of induration decreases from north to south across the area. In the northern part of the area, the formation is represented on geophysical logs as a zone of low resistivity. In the southern part of the study area, the unit is more sandy, and is noted on geophysical logs by increased electrical resistivity (wells ALL-324 and C-10 on Figure 1.4-21). The transition from the more indurated clayey sand in the north to the poorly consolidated cleaner sand in the south may be due to deeper fluvial incisement and erosion of the Cape Fear section to the north. This may bring the deeper, more cristobalite-rich part of the section into proximity with the overlying unconformity that caps the formation. Clark et al. (Ref. 121) attribute the differences between updip and downdip lithologies to changes in source material during deposition or to the southern limit of the cristobalite cementation process.

The lithologic characteristics and the paucity of marine fossils are indicative of a high-energy environment close to a sediment source area. Thus, these sediments may represent deposition in fluvial-deltaic environments on the upper parts of a delta plain (Ref. 221), grading downdip to marginal marine (Ref. 222). The Cape Fear Formation was erosionally truncated prior to deposition of the overlying Middendorf Formation, resulting in a disconformity between the two formations.

Lumbee Group

Three formations of the Late Cretaceous Lumbee Group (Ref. 223) are present in the study area (Ref. 124). These are, from oldest to youngest, the Middendorf, Black Creek, and Steel Creek Formations (see Figures 1.4-18).

The Lumbee Group consists of fluvial and deltaic quartz sand, pebbly sand, and clay in the study area. The sedimentary sequence is more clayey and fine-grained downdip from the study area, reflecting shallow to deep marine shelf sedimentary environments. Thickness ranges from about 122 meters (400 feet) at well C-3 (see Figure 1.4-21) in the north, to about 238 meters (780 feet) near well C-10 in the south. At least part of the group crops out in the northern part of the study area but it is difficult to distinguish the individual formations. Consequently, the Lumbee Group was mapped as undifferentiated Upper Cretaceous by Nystrom and Willoughby (Ref. 224). The dip of the upper surface of the Lumbee Group is to the southeast at approximately 4 m/km (20 ft/mile) across the study area.

The Middendorf Formation unconformably overlies the Cape Fear Formation with a distinct contact. The contact is marked by an abrupt change from the moderately indurated clay and clayey sand of the underlying Cape Fear to the slightly indurated sand and lesser clayey sand of the Middendorf. The basal zone is often pebbly. The contact is unconformable and is marked by a sudden increase in electrical resistivity on geophysical logs. Thickness of the formation ranges from approximately 37 meters (120 feet) in well C-2 (see Figure 1.4-21) in the north, to 73 meters (240 feet) in well C-10 in the south. It has a maximum known thickness of about 158 meters (520 feet) in Georgia (Ref. 121). The top of the formation dips to the southeast at about 4.9 m/km (26 ft/mile) across the study area. Fossil data for the Middendorf are sparse and the formation is not well dated in the study area.

The sand of the Middendorf Formation is medium to very coarse grained, typically angular, slightly silty, tan, light gray, and yellow in color. It is much cleaner and less indurated than the underlying Cape Fear sediments. Sorting is generally moderate to poor. Pebble and granule zones are common in updip parts of the study area, whereas clay layers up to 3 meters (10 feet) thick are more common downdip. Clay clasts are abundant in places. Some parts of the unit are feldspathic and micaceous, but not as micaceous as in the overlying Black Creek Formation. Lignitic zones are also common.

Over much of the study area, a zone of interbedded sand and variegated clay up to 18 meters (60 feet) thick is present at or near the top of the Middendorf Formation. The interbedded sand is upward fining in places. This lithology and the marine microfauna found in core samples indicate that the unit was deposited in lower delta plain and delta front environments under some marine influence (Ref. 225). In the northern part of the study area, the formation is variably colored, composed of tan, red, and purple sand. Here, the sediments have the characteristics of fluvial and upper delta plain deposits.

Near Bamberg, SC, the Middendorf Formation consists of poorly sorted, gray, medium- to very coarse-grained, angular to subangular quartz sand with quartz pebbles and sparse feldspar grains (Ref. 222). Silt and fine-grained sand are present. The angularity and large overall grain size of the quartz and the presence of feldspar indicate that deposition occurred relatively close to the

source area, most likely in an upper delta plain environment. In southeastern Georgia, the Middendorf includes some shallow shelf sediments. Farther downdip, sediments of the Middendorf become finer grained. In Allendale County, SC, near Millet, the unit consists of light gray to colorless, fine- to coarse-grained quartzose sand, clayey sand, and silty clay. The sand is unconsolidated and poorly to moderately sorted. Trace amounts of heavy minerals and lignite are present. Deposition most probably occurred on a lower delta plain (Ref. 222).

Paleontological control for the Black Creek is poor updip in South Carolina and Georgia. Prowell et al. (Ref. 225), citing Christopher (Ref. 226) and Sohl and Christopher (Ref. 227), suggested a Late Cretaceous age for the Black Creek Formation as indicated by various paleontological data from the unit. Sediments assigned to the Black Creek Formation in the vicinity of the SRS yield Late Cretaceous paleontological ages and unconformably overlie the Middendorf Formation (see Figure 1.4-18) (Ref. 222).

The Black Creek Formation is penetrated at virtually all well-cluster sites in the study area. The unit ranges in thickness from approximately 46 meters (150 feet) at well C-2 in the north to 91 meters (300 feet) near the center of the study area in well PBF-3 and to 113 meters (370 feet) at well C-10 in the south. The unit dips approximately 4 m/km (22 ft/mile) to the southeast.

The Black Creek is distinguished from the overlying and underlying Cretaceous units by its better sorted sand, fine-grained texture, and relatively high clay content. It is generally darker, more lignitic, and more micaceous, especially in the updip part of the section, than the other Cretaceous units. In much of the study area, the lower one-third of the formation is mostly sand that is separated from the upper two-thirds of the unit by clay beds. These beds are 6 meters (20 feet) to 12 meters (40 feet) thick in the northern part of the region and more than 46 meters (150 feet) at well C-10 in the south. In general, the top of the Black Creek Formation is picked at the top of a clay bed that ranges from 3 meters (10 feet) to 8 meters (25 feet) in thickness. The clay bed is exceptionally thick but not laterally extensive. For example, it is essentially absent in wells P-21, CPC-1, P-26, and P-29. This suggests lagoonal back barrier bay deposition associated with nearby shorelines. Often the thick clay beds flank the areas where shoaling is suggested owing to uplift along the Pen Branch and Steel Creek Faults, which was contemporaneous with deposition. Overall, the Black Creek consists of two thick, fining-upward sequences, each capped by thick clay beds. The lower sequence is predominantly silty, micaceous sand in the area of SRS, while the upper sequence is mostly clay and silt.

Where the Black Creek Formation is present north of SRS, it consists of clayey, micaceous, poorly to moderately well sorted, fine to medium-grained, subangular to subrounded quartz sand beds and silty clay beds. Pebbly beds are present throughout the unit. This sandy lithology is indicative of fluvial to upper delta-plain environments; the clay beds that cap the upward-fining sandy sequences are typical of lower delta plain depositional environments. Near Millet, SC, the basal beds of the Black Creek consist of sand and silty clay and are similar to underlying Middendorf sediments. Here, deposition occurred on a lower delta plain. Fossils recovered from the unit suggest marine influences during deposition of the sediments, especially the clay (Ref. 225).

In the central and downdip part of the study area (wells P-22, ALL-324, C-6, C-10), the unit grades into gray-green clayey silt, micritic clay, and fine- to medium-grained, upward fining sand

that is moderately well sorted, micaceous, carbonaceous, and locally glauconitic. The sequence suggests deposition in a delta front or shallow shelf environment, as indicated by the lithology and an abundance of marine macrofauna and microfauna (Ref. 225). The transition from fine-grained, prodelta or delta front deposits in the southern part of the study area to coarser-grained, more landward deltaic deposits in the northern part of the area is reflected in the general increase in electrical resistivity noted on geophysical logs in the wells in the north, especially in the upper part of the Black Creek section.

The Peedee Formation was previously considered by some investigators to be absent in the study area (Ref. 220); however, recent paleontological evidence provides dates of Peedee age from sediment samples in the southern part of SRS (Ref. 222). Because there is a considerable difference in lithology between the type Peedee (Ref. 228) and the sediments in the SRS region, Peedee-equivalent sediments in the vicinity of SRS were referred to as the "Steel Creek Member" of the Peedee Formation (Ref. 115). Raising the Steel Creek Member to formational status was recommended by Aadland et al. (Ref. 100) and it is so used in this document. The type well for the Steel Creek Formation is P-21, located near Steel Creek. The top of the Steel Creek is picked at the top of a massive clay bed that ranges from 1 meter (3 feet) to more than 9 meters (30 feet) in thickness. The formation dips approximately 4 m/km (20 ft/mile) to the southeast.

The unit ranges in thickness from approximately 18 meters (60 feet) at well P-30 (see Figure 1.4-21) to 53 meters (175 feet) at well C-10 in the south. It has a maximum known thickness of 116 meters (380 feet) in Georgia (Ref. 120). The Steel Creek section thins dramatically between the ALL-324 and the P-22 wells due to truncation by erosion at the Cretaceous-Tertiary unconformity. The Steel Creek Formation overlies the Black Creek Formation and is distinguished from it by a higher percentage of sand, which is represented on geophysical logs by a generally higher electrical resistivity and lower natural gamma radiation count.

The formation consists of yellow, tan, and gray, medium to coarse, moderately sorted sand interbedded with variegated clay. The lower part of the unit consists of medium- to coarse-grained, poorly to well-sorted, quartz sand, silty sand, and off-white to buff clay that contains thin beds of micaceous and carbonaceous clay. Pebbly zones are common, as are layers with clay clasts. Fining-upward sand is interbedded with the clay and silty clay beds in some areas. It is difficult to differentiate the Steel Creek from the underlying Black Creek in the northwestern part of the study area. The unit appears to have been deposited in fluvial environments in updip areas and upper to lower delta plain environments in the south. The massive clay that caps the unit suggests lower delta plain to shallow shelf depositional

environments. The presence of certain microfossils indicates some marine influence in parts of the Steel Creek (Ref. 225). A pebble-rich zone at the base of the unit suggests a basal unconformity.

Tertiary Sediments

Tertiary sediments range in age from Early Paleocene to Miocene and were deposited in fluvial to marine shelf environments. The Tertiary sequence of sand, silt, and clay generally grades into highly permeable platform carbonates in the southern part of the study area and these continue southward to the coast. The Tertiary sequence is divided into three groups, the Black Mingo

Group, Orangeburg Group, and Barnwell Group, which are further subdivided into formations and members (see Figure 1.4-18). These groups are overlain by the ubiquitous Upland unit.

The Tertiary sedimentary sequence deposited in west-central South Carolina has been punctuated by numerous sea level low stands and/or affected by subsidence in the source areas (which reduced or eliminated sediment availability) resulting in a series of regional unconformities. Four such regionally significant unconformities are defined in the Tertiary stratigraphic section in A/M Area (Ref. 229). From base upwards they include the "Cretaceous-Tertiary" unconformity, the "Lang Syne/Sawdust Landing" unconformity, the "Santee" unconformity and the "Upland" unconformity. Based on these unconformities, four sequence stratigraphic units (unconformity bounded sedimentary units) have been delineated (Figure 1.4-18). Work is currently underway to place the units in the global sequence stratigraphic framework.

Sequence stratigraphic unit I includes the sediments deposited between the "Cretaceous-Tertiary" unconformity and the "Lang Syne/Sawdust Landing" unconformity, and includes the Lang Syne/Sawdust Landing formations undifferentiated of the Black Mingo Group. Sequence unit II lies between the Lang Syne/Sawdust Landing unconformity and the Santee unconformity, and includes from oldest to youngest the Fourmile/Congaree formations undifferentiated, the Warley Hill Formation, the Tinker/Santee Formation of the Orangeburg Group and the carbonates (Utley Member) of the Clinchfield Formation. The Santee unconformity that caps the sequence is a major erosional event in the SRS region. Sequence unit III lies between the Santee unconformity and the "Upland unit" unconformity, and includes the Dry Branch and Tobacco Road formations of the Barnwell Group. Sequence unit IV includes all the fluvial sediments overlying the "Upland unconformity".

Black Mingo Group

The Black Mingo Group consists of quartz sand, silty clay, and clay that suggest upper and lower delta plain environments of deposition (Figure 1.4-37) generally under marine influences (Ref. 225). In the southern part of the study area, massive clay beds, often more than 50 feet (15 meters) thick, predominate. Downdip from the study area, thin red to brown sandy clay beds, gray to black clay beds and laminated shale dominate the Black Mingo Group and suggest deposition in clastic shelf environments. At the South Carolina coast, carbonate platform facies-equivalents of the updip Black Mingo clastic sediments first appear. The carbonate units are all referred to as "unnamed limestones" by Colquhoun et al. (Ref. 220). These are equivalent to the thick beds of anhydrite and dolomite of the Paleocene Cedar Keys Formation (Ref. 108, 111) and the lower Eocene glauconitic limestone and dolomite of the Oldsmar Formation. Both carbonate units are delineated and mapped in coastal Georgia and northeastern Florida.

Basal Black Mingo sediments were deposited on the regional "Cretaceous-Tertiary" unconformity of Aadland (Ref. 229) that defines the base of Sequence Stratigraphic unit I. There is no apparent structural control of this unconformity. Above the unconformity, the clay and clayey sand beds of the Black Mingo Group thin and often pinch out along the traces of the Pen Branch and Crackerneck Faults. This suggests that coarser-grained materials were deposited preferentially along the fault traces, perhaps due to shoaling of the depositional surface. This, in

turn, suggests movement (reactivation) along the faults. This reactivation would have occurred during Black Mingo deposition, that is, in Paleocene and lower Eocene time.

The upper surface of the Black Mingo Group dips to the southeast at 3 m/km (16 ft/mi.), and the group thickens from 18 meters (60 feet) at well C-2 in the north, to about 52 meters (170 feet) near well C-10 in the south. The group is about 213 meters (700 feet) thick at the South Carolina coast (Ref. 220). Throughout the downdip part of the South Carolina Coastal Plain, the Black Mingo Group consists of the Rhems Formation and the overlying Williamsburg Formation.

The Rhems Formation contains four members, each representing a depositional facies. They are the Sawdust Landing Member, an upper delta plain fluvial deposit which unconformably overlies the Cretaceous Peedee Formation; the Lang Syne Member, a lower delta-plain deposit of estuarine and littoral origin; the Perkins Bluff Member, a shallow shelf deposit; and the Browns Ferry Member, a deep-water shelf deposit. Additionally, an unnamed unit represents the carbonate-shelf facies (Ref. 220).

In the updip part of the South Carolina Coastal Plain, the Black Mingo Group consists of the Sawdust Landing and Lang Syne Formations (Ref. 118), which are equivalent to the Ellenton Formation of Siple (Ref. 123); the Snapp Formation (Ref. 118), which is the updip equivalent of the Williamsburg Formation of Colquhoun et al. (Ref. 220); and the Fourmile Formation (Ref. 118), which is the updip equivalent of the Fishburne Formation of Gohn et al. (Ref. 230).

Lang Syne/Sawdust Landing Formations. Siple proposed the name Ellenton Formation for a subsurface lithologic unit in the SRS area consisting of beds of dark, lignitic clay and coarse sand, which are equivalent to the Sawdust Landing and Lang Syne Members of the Rhems Formation of Colquhoun et al. (Ref. 220). Fallaw and Price (Ref. 118) suggested that the Sawdust Landing Member and the overlying Lang Syne Member of the Rhems Formation be raised to formational status and replace the term Ellenton in the study area

In the absence of detailed paleontological control, the Sawdust Landing Formation and the overlying Lang Syne Formation could not be systematically separated for mapping in this region. Thus, they are treated as a single unit; the Lang Syne/Sawdust Landing undifferentiated, on all sections and maps. This is consistent with the approach taken by Fallaw and Price (Ref. 231). The sediments of the unit generally consist of two fining-upward sand-to-clay sequences, which range from about 12 meters (40 feet) in thickness at the northwestern boundary of SRS to about 30 meters (100 feet), near the southeastern boundary. The unit is mostly dark gray to black, moderately to poorly sorted, fine to coarse-grained, micaceous, lignitic, silty and clayey quartz sand interbedded with dark gray clay and clayey silt. Pebbly zones, muscovite, feldspar, and iron sulfide are common. Individual clay beds up to 6 meters (20 feet) thick are present in the unit. Clay and silt beds make up approximately one-third of the unit in the study area. The dark, fine-grained sediments represent lower delta plain, bay-dominated environments (Figure 1.4-37). Tan, light gray, yellow, brown, purple, and orange sand, pebbly sand, and clay represent upper delta plain, channel-dominated environments.

In the southern part of the study area, dark, poorly sorted, micaceous, lignitic sand and silty sand containing a diverse assemblage of pollen and microfauna of early and middle Paleocene

(Midwayan) age are present (Ref. 225). This is the Perkins Bluff Member of the Rhems Formation, which was deposited in lower delta plain or shallow marine shelf environments.

Toward the coast, the Rhems Formation includes shallow to increasingly deeper water clastic shelf facies sediments (Browns Ferry Member) that ultimately pass into a shallow carbonate platform facies at the South Carolina coastline. Colquhoun et al. (Ref. 220) referred to the carbonate platform facies equivalent as "unnamed limestone." The carbonate platform sequence is correlative with the anhydrite- and gypsum-bearing dolomitized limestone and finely crystalline dolomite of the lower part of the Cedar Keys Formation (Ref. 111) that is mapped in coastal Georgia and northeastern Florida. The carbonate sequence is about 76 meters (250 feet) thick at the South Carolina coastline (Ref. 220). The Cedar Keys Formation has a maximum thickness of 130 meters (425 feet) in coastal areas of Georgia (Ref. 232). The carbonate platform sediments of the Cedar Keys Formation are generally impermeable, and the unit acts as the underlying confining unit of the Floridan Aquifer System in the coastal areas of South Carolina and Georgia.

Snapp Formation (Williamsburg Formation). Sediments in the study area that are time equivalent to the Williamsburg Formation differ from the type Williamsburg and have been designated the "Snapp Member of the Williamsburg Formation" (Ref. 233). Fallaw and Price (Ref. 231) have suggested that the "Snapp Member" of the Williamsburg be raised to formational status. The Snapp Formation is used in this report. The unit is encountered in well P-22 (see Figure 1.4-21) in the southeastern part of SRS near Snapp Station. The basal contact with the underlying Lang Syne/Sawdust Landing undifferentiated is probably unconformable. The Snapp Formation appears to pinch out in the northwestern part of SRS and thickens to about 15 meters (50 feet) near the southeastern boundary of the site.

The Snapp Formation (Williamsburg Formation) crops out in Calhoun County. The sediments in the upper part of the unit consist of low-density, fissile, dark-gray to black siltstone and thin layers of black clay interbedded with sand in the lower part. These and similar sediments in Aiken and Orangeburg Counties were probably deposited in lagoonal or estuarine environments (Figure 1.4-37). Within and near SRS, the Snapp sediments typically are silty, medium- to coarse-grained quartz sand interbedded with clay. Dark, micaceous, lignitic sand also occurs, and all are suggestive of lower delta plain environments. In Georgia, the unit consists of thinly laminated, silty clay locally containing layers of medium- to dark-gray carbonaceous clay. This lithology is indicative of marginal marine (lagoonal to shallow shelf) depositional environments. Clayey parts of the unit are characterized on geophysical logs as zones of low electrical resistivity and a relatively high-gamma ray response. In the southernmost part of the study area, the Snapp (Ref. 120) consists of gray-green, fine to medium, well-rounded, calcareous quartz sand and interbedded micritic limestone and limey clay that is highly fossiliferous and glauconitic. This lithology suggests deposition in shallow shelf environments somewhat removed from clastic sediment sources.

Farther south toward the coast, the Williamsburg Formation (Snapp equivalent) exhibits deeper-water, clastic facies, which give way to the carbonate-platform facies that were first established in early Paleocene time. Colquhoun et al. (Ref. 220) referred to the carbonate platform sediments, which are about 350 feet (106 meters) thick at the coast, as "unnamed limestone." The unit is equivalent to the anhydrite- and gypsum-bearing dolomitized limestone

and finely crystalline dolomite of the upper part of the Cedar Keys Formation mapped in southeastern Georgia and northeastern Florida (Ref. 111, 234). The carbonate platform expanded dramatically during upper Paleocene time, reaching as far north as Bamberg County, South Carolina (Ref. 220).

The upper surface of the Williamsburg Formation is defined by the "Lang Syne/Sawdust Landing" unconformity (Ref. 229) and defines the upper boundary of Sequence Stratigraphic Unit I (Figure 1.4-18). The surface has been offset by normal faulting as noted in A/M Area (Ref. 229)

Fourmile Formation. Early Eocene ages, derived from paleontological assemblages, indicate that the sand immediately overlying the Snapp Formation in the study area is equivalent to the Fishburne (Ref. 231). These sediments were deposited on the "Lang Syne/Sawdust Landing" unconformity (Ref. 229) and constitute the basel unit of Sequence Stratigraphic Unit II (Figure 1.4-18). The Fishburne is a calcareous unit that occurs downdip near the coast. The sand was initially designated the Fourmile Member of the Fishburne Formation (Ref. 233). Owing to the distinctive difference in lithology between the type, Fishburne Formation and the time-equivalent sediments observed in the study area, Fallaw and Price (Ref. 231) have recommended that the Fourmile Member of the Fishburne be raised to formational rank. The term Fourmile Formation is used in this report.

The Fourmile Formation averages 9 meters (30 feet) in thickness, is mostly tan, yellow-orange, brown, and white, moderately to well-sorted sand, with clay beds a few feet thick near the middle and at the top of the unit. The sand is very coarse to fine grained, with pebbly zones common, especially near the base. Glauconite, up to about 5%, is present in places, as is weathered feldspar. In the center and southeastern parts of SRS, the unit can be distinguished from the underlying Paleocene strata by its lighter color and lower content of silt and clay. Glauconite and microfossil assemblages indicate that the Fourmile is a shallow marine deposit (Figure 1.4-37).

Overlying the Fourmile Formation in the study area is 9 meters (30 feet) or less of sand similar to the Fourmile. This sand is better sorted, contains fewer pebbly zones, less muscovite and glauconite, and in many wells is lighter in color. Microfossil assemblages indicate that the sand is correlative with the early middle Eocene Congaree Formation. In some wells a thin clay occurs at the top of the Fourmile, separating the two units; however, the difficulty in distinguishing the Fourmile Formation from the overlying Congaree Formation has led many workers at SRS to include the entire 293 meters (960 feet) section in the Congaree Formation.

Downdip from the study area, the clean, shallow shelf sand of the Fourmile Formation passes into silt, massive clay, siltstone, and mudstone suggestive of a deep clastic shelf facies (Ref. 111) (see Figure 1.4-37). Toward the coast, the stratigraphic interval is composed of calcareous, glauconitic sand and clay and sandy glauconitic, fossiliferous limestone indicative of deep shelf to carbonate platform environments (Figure 1.4-37). The carbonate facies equivalent of the Fourmile is correlative with the glauconitic, micritic limestone and interbedded fine to medium, commonly vuggy, crystalline dolomite platform facies of the Oldsmar Formation in coastal Georgia and northeastern Florida (Ref. 111, 234). The Oldsmar Formation equivalents in South Carolina unconformably overlie clastic sediments of the Rhems Formation downdip in South Carolina and the correlative Clayton Formation in Georgia. The unit signals the rapid northward

advance of the leading edge of the carbonate platform first established in lower Paleocene time near the South Carolina coast. The early Eocene carbonate sediments reach 241 meters (800 feet) in thickness in coastal Georgia (Ref. 234).

Orangeburg Group

The Orangeburg Group consists of the lower middle Eocene Congaree Formation (Tallahatta equivalent) and the upper middle Eocene Warley Hill Formation and Santee Limestone (Lisbon equivalent) (see Figure 1.4-18). Over most of the study area, these post-Paleocene units are more marine in character than the underlying Cretaceous and Paleocene units; they consist of alternating layers of sand, limestone, marl, and clay.

The group crops out at lower elevations in many places within and near SRS. The sediments thicken from about 26 meters (85 feet) at well P-30 near the northwestern SRS boundary to 61 meters (200 feet) at well C-10 (see Figure 1.4-21) in the south. Dip of the upper surface is 2 m/km (12 ft/mile) to the southeast. Downdip at the coast, the Orangeburg Group is about 99 meters (325 feet) thick (Ref. 220) and is composed of shallow carbonate platform deposits of the Santee Limestone.

In the extreme northern part of the study area, the entire middle Eocene Orangeburg Group is mapped as the Huber Formation (Ref. 224). The micaceous, poorly sorted sand, abundant channel fill deposits and cross bedding, and carbonaceous kaolin clay in the Huber is indicative of fluvial, upper delta plain environments (Figure 1.4-37).

In the central part of the study area the group includes, in ascending order, the Congaree, Warley Hill, and Tinker/Santee Formations (Ref. 233) (see Figure 1.4-18). The units consist of alternating layers of sand, limestone, marl, and clay that are indicative of deposition in shoreline to shallow shelf environments (Figure 1.4-37). From the base upward, the Orangeburg Group passes from clean shoreline sand characteristic of the Congaree Formation to shelf marl, clay, sand, and limestone typical of the Warley Hill and Santee Limestone. Near the center of the study area, the Santee sediments consist of up to 30 vol% carbonate. The sequence is transgressive, with the middle Eocene Sea reaching its most northerly position during Tinker/Santee deposition.

Toward the south, near wells P-21, ALL-324, and C-10 (see Figure 1.4-21), the carbonate content of all three formations increases dramatically. The shoreline sand of the Congaree undergoes a facies change to interbedded glauconitic sand and shale, grading to glauconitic argillaceous, fossiliferous, sandy limestone. Downdip, the fine-grained, glauconitic sand, and clay of the Warley Hill become increasingly calcareous and grades imperceptibly into carbonate-rich facies comparable to both the overlying and underlying units. Carbonate content in the glauconitic marl, calcareous sand, and sandy limestone of the Santee increases towards the south. Carbonate sediments constitute the vast majority of the Santee from well P-21 southward.

Toward the coast, the sediments of the entire Orangeburg Group grade into the pure white to creamy-yellow fossiliferous and partly glauconitic Santee Limestone (Ref. 220) that was deposited on the shallow carbonate platform first established in early Paleocene time. The Santee is correlative with the chalky or indurated pelloidal to micritic limestone interbedded with

fine to medium, crystalline, slightly vuggy dolomite of the Avon Park Formation in coastal sections of Georgia and northeastern Florida (Ref. 111, 234). The Avon Park Formation unconformably overlies the Oldsmar Formation, and reaches a thickness of about 305 meters (1,000 feet) in coastal Georgia.

The carbonate platform reached its maximum northern extent during middle Eocene time when the leading edge extended into Allendale County north of well ALL-19. The three largely clastic formations that constitute the Orangeburg Group in the study area are the updip clastic equivalents of the platform carbonate rocks of the Santee to the south.

Congaree Formation. The early middle Eocene Congaree Formation has been traced from the Congaree valley in east central South Carolina into the study area. It has been paleontologically correlated with the early and middle Eocene Tallahatta Formation in neighboring southeastern Georgia by Fallaw et al. (Ref. 233).

The Congaree is about 9 meters (30 feet) thick near the center of the study area and consists of yellow, orange, tan, gray, green, and greenish gray, well-sorted, fine to coarse quartz sand, with granule and small pebble zones common. Thin clay laminae occur throughout the section. The quartz grains tend to be better rounded than those in the rest of the stratigraphic column are. The sand is glauconitic in places suggesting deposition in shoreline or shallow shelf environments (Figure 1.4-37). To the south, near well ALL-324, the Congaree Formation consists of interbedded glauconitic sand and shale, grading to glauconitic, argillaceous, fossiliferous sandy limestone suggestive of shallow to deeper shelf environments of deposition. Farther south, beyond well C-10 (Ref. 220), the Congaree grades into platform carbonate facies of the lower Santee Limestone (see Figure 1.4-37).

The equivalent of the Congaree northwest of SRS has been mapped as the Huber Formation (Ref. 224). At these locations it becomes more micaceous and poorly sorted, indicating deposition in fluvial and upper delta plain environments. On geophysical logs, the Congaree has a distinctive low gamma ray count and high electrical resistivity.

Warley Hill Formation. Unconformably overlying the Congaree Formation are 3 meters (10 feet) to 6 meters (20 feet) of fine-grained, often glauconitic sand and green clay beds that have been referred to respectively as the Warley Hill and Caw Caw Members of the Santee Limestone. The green sand and clay beds are referred to informally as the "green clay" in previous SRS reports. Both the glauconitic sand and the clay at the top of the Congaree are assigned to the Warley Hill Formation (Ref. 233). In the updip parts of the study area, the Warley Hill apparently is missing or very thin, and the overlying Tinker/Santee Formation rests unconformably on the Congaree Formation.

The Warley Hill sediments indicate shallow to deeper clastic shelf environments of deposition in the study area, representing deeper water than the underlying Congaree Formation (Figure 1.4-37). This suggests a continuation of a transgressive pulse during upper middle Eocene time. To the south, beyond well P-21, the green silty sand, and clay of the Warley Hill undergo a facies change to the clayey micritic limestone and limey clay typical of the overlying Santee Limestone. The Warley Hill blends imperceptibly into a thick clayey micritic limestone that divides the Floridan Aquifer System south of the study area. The Warley Hill is correlative with the lower

part of the Avon Park Limestone in southern Georgia and the lower part of the Lisbon Formation in western Georgia.

In the study area, the thickness of the Warley Hill Formation is generally less than 6 meters (20 feet). In a part of Bamberg County, South Carolina, the Congaree Formation is not present, and the Warley Hill rests directly on the Williamsburg Formation (Ref. 222).

Tinker/Santee Formation. The late middle Eocene deposits overlying the Warley Hill Formation consist of moderately sorted yellow and tan sand, calcareous sand and clay, limestone, and marl. Calcareous sediments dominate downdip, are sporadic in the middle of the study area, and are missing in the northwest (Figure 1.4-38). The limestone represents the farthest advance to the northwest of the transgressing carbonate platform first developed in early Paleocene time near the South Carolina and Georgia coasts (Figure 1.4-37).

Fallaw et al. (Ref. 233) divided the Santee into three members in the study area: the McBean, Blue Bluff, and Tims Branch Members. The McBean Member consists of tan to white, calcilutite, calcarenite, shelly limestone, and calcareous sand and clay. It dominates the Santee in the central part of the study area and represents the transitional lithologies between clastics in the north and northwest (Tims Branch Member), and fine-grained carbonates in the south (Blue Bluff Member).

The carbonates and carbonate-rich clastics are restricted essentially to three horizons in the central part of, the Griffins Landing Member of the Dry Branch Formation, the McBean Member of the Tinker/Santee Formation and the Utley Limestone member of the Clinchfield Formation (Figures 1.4-18, 1.4-39, 1.4-40). The uppermost horizon includes the carbonates of the Griffins Landing Member of the Dry Branch Formation found below the "tan clay" interval that occurs near the middle of the Dry Branch. The isolated carbonate patches of the Griffins Landing are the oyster banks that formed in the back barrier marsh zone behind the barrier island system (Figures 1.4-37 and 1.4-40). Underlying the Dry Branch, directly below the regionally significant Santee Unconformity (Figure 1.4-39), is the Utley Limestone Member of the Clinch Field Formation. Without the benefit of detailed petrographic and paleontological analysis, the Utley carbonates cannot be systematically distinguished from the carbonates of the underlying Tinker/Santee Formation. Thus the carbonate-rich sediments between the Santee Unconformity (Figure 1.4-39), and the Warley Hill Formation are referred to as the Tinker/Santee (Utley) sequence in this report.

Approximately 40-50% of the wells that drilled through the Tinker/Santee (Utley) interval in the GSA penetrated quantities of carbonate ranging from 5-78% of the sediment sampled (Figure 1.4-38). The calcareous sediment in the GSA consists of calcareous sand, calcareous mud, sandy limestone, muddy limestone, and sandy muddy limestone. Viewing the Tinker/Santee (Utley) sedimentary package parallel to the shoreline (Figure 1.4-37), the carbonate-rich sediments would be concentrated in the areas furthest removed from the tidal inlets at the shore face where clastic sediments supplied by riverine input is concentrated. The clastic-rich on the other hand would concentrate opposite the tidal inlet areas where clastic sediment is more readily available. The lateral facies transition of the sediments in the subtidal shelf environment from carbonate-rich to clastic-rich lithologies is therefore gradual and measures in the thousands of feet. Shifting

locations of the tidal inlets at the shoreline has resulted in a complex sedimentary package where facies gradually transition from one lithology to another both laterally and vertically.

The GSA is in that part of the mixed clastics/carbonate zone where the clastic sediments generally constitute a greater percentage of the section than the carbonates (Figure 1.4-38). Figure 1.4-40 illustrates the environments of deposition of the Tinker/Santee (Utley) sediments in the SRS region. In northern SRS the Tinker/Santee (Utley) sediments are mostly sands and muddy sands (Tims Branch Member) deposited in shoreline to lesser lagoonal and tidal marsh environments (Figure 1.4-37). In the central SRS the sequence was deposited in middle marine shelf environments resulting in a varied mix of lithologies from carbonate-rich sands and muds to sandy and muddy limestones. In southern SRS the Tinker/Santee (Utley) sediments were deposited further offshore, further removed from riverine clastic input into the shelf environment resulting in deposition of carbonate muds (Blue Bluff Member).

The Blue Bluff Member consists of gray to green, laminated micritic limestone. The unit includes gray, fissile, calcareous clay and clayey micritic limestone and very thinly layered to laminated, clayey, calcareous, silty, fine sand, with shells and hard, calcareous nodules, lenses, and layers. Cores of Blue Bluff sediments are glauconitic, up to 30% in places. The Blue Bluff lithology suggests deposition in offshore shelf environments. Blue Bluff sediments tend to dominate the formation in the southern part of the study area and constitute the major part of the "middle confining unit" that separates the Upper and Lower Floridan aquifers south of the study area.

Fallaw et al. (Ref. 233) described the Tims Branch Member of the Santee as the siliciclastic part of the unit, consisting of fine- and medium-grained, tan, orange, and yellow, poorly to well sorted, and slightly to moderately indurated sand. The clastic lithologies of the Tims Branch Member dominate the Santee in the northern part of the study area. Because the clastic lithologies differ so markedly from the type Santee, Fallaw and Price (Ref. 118) raised the Tims Branch Member of the Santee to formational rank, namely the Tinker Formation. Because the clastic and carbonate lithologies that constitute the Tinker/Santee sequence in the upper and middle parts of the study area are hydrologically undifferentiated, the units are not systematically separated, and they are designated Tinker/Santee Formation on maps and sections. The thickness of the Tinker/Santee Formation is variable due in part to displacement of the sediments, but more commonly to dissolution of the carbonate resulting in consolidation of the interval and slumping of the overlying sediments of the Tobacco Road and Dry Branch Formations into the resulting lows (Figure 1.4-41).

The Tinker/Santee (Utley) interval is about 21 meters (70 feet) thick near the center of SRS, and the sediments indicate deposition in shallow marine environments (Figure 1.4-40). The top of the unit is picked on geophysical logs where Tinker/Santee (Utley) sediments with lower electrical resistivity are overlain by the more resistive sediments of the Dry Branch Formation (Figure 1.4-39). In general, the gamma-ray count is higher than in surrounding stratigraphic units.

Often found within the Tinker/Santee (Utley) sediments, particularly in the upper third of the interval, are weak zones interspersed in stronger carbonate-rich matrix materials. The weak zones, which vary in apparent thickness and lateral extent, were noted where rod drops and/or

lost circulation occurred during drilling, low blow counts occurred during SPT pushes, etc. The weak zones have variously been termed as "soft zones", the "critical layer", "underconsolidated zones", "bad ground", and "void". For this report, the preferred term used to describe these zones will be "soft zones."

The initial Corps of Engineers (COE) characterization in 1952 identified soft zones as being the major concern for foundation design. This initial study made many important observations concerning the formation, geometry, distribution, and physical attributes of soft zones (and potential associated voids) within the Santee Formation. Some of the soft zone observations and hypotheses set forth by the COE report have remained unchanged to this day. However, several important aspects of early soft zone analyses run counter to current thinking on this subject (Ref. 235)

Barnwell Group

Upper Eocene sediments of the Barnwell Group (see Figure 1.4-18) represent the Upper Coastal Plain of western South Carolina and eastern Georgia (Ref. 222). Sediments of the Barnwell Group are chronostratigraphically equivalent to the lower Cooper Group (late Eocene) of Colquhoun et al. (Ref. 220). The Cooper Group includes sediments of both late Eocene and early Oligocene age and appears downdip in the Lower Coastal Plain of eastern South Carolina.

Sediments of the Barnwell Group overlie the Tinker/Santee Formation and consist mostly of shallow marine quartz sand containing sporadic clay layers. Huddleston and Hetrick (Ref. 236) recently revised the upper Eocene stratigraphy of the Georgia Coastal Plain, and their approach has been extended into South Carolina by Nystrom and Nystrom and Willoughby (Ref. 224, 237). These authors elevated the Eocene "Barnwell Formation" to the "Barnwell Group." In Burke County, Georgia, the group includes (from oldest to youngest) the Clinchfield Formation, and Dry Branch Formation, and the Tobacco Road Formation. The group is about 21 meters (70 feet) thick near the northwestern boundary of SRS and 52 meters (170 feet) near its southeastern boundary. The regionally significant Santee Unconformity that defines of boundary between Sequence Stratigtraphic units II and III (Figure 1.4-18) separates the Clinchfield Formation from the overlying Dry Branch Formation. The Santee Unconformity is a pronounced erosional surface observable throughout the SRS region (Figures 1.4-18 and 1.4-39).

In the northern part of the study area, the Barnwell Group consists of red or brown, fine to coarse-grained, well-sorted, massive sandy clay and clayey sand, calcareous sand and clay, as well as scattered thin layers of silicified fossiliferous limestone. All are suggestive of lower delta plain and/or shallow shelf environments (Figure 1.4-37). Downdip, the Barnwell undergoes a facies change to the phosphatic clayey limestone that constitutes the lower Cooper Group. The lower Cooper Group limestone beds indicate deeper shelf environments.

Clinchfield Formation. The basal late Eocene Clinchfield Formation consists of light colored quartz sand and glauconitic, biomoldic limestone, calcareous sand, and clay. Sand beds of the formation constitute the Riggins Mill Member (Ref. 236) of the Clinchfield Formation and are composed of medium to coarse, poorly to well sorted, loose and slightly indurated, tan, clay, and green quartz. The sand is difficult to identify unless it occurs between the overlying carbonate layers of the Griffins Landing Member and the underlying carbonate layers of the Santee

Limestone. The Clinchfield is about 8 meters (25 feet) thick in the southeastern part of SRS and pinches out or becomes unrecognizable at the center of the site.

The carbonate sequence of the Clinchfield Formation is designated the Utley Limestone Member (Ref. 231). It is composed of sandy, glauconitic limestone and calcareous sand, with an indurated, biomoldic facies developed in places. In cores, the sediments are tan and white and slightly to well indurated. Without the benefit of detailed petrographic and paleontological analysis, the Utley carbonates cannot be systematically distinguished from the carbonates of the underlying Tinker/Santee Formation. Thus the carbonate-rich sediments between the Santee Unconformity (Figures 1.4-18 and 1.4-39), and the Warley Hill Formation are referred to as the Tinker/Santee (Utley) sequence in this report.

Dry Branch Formation. The late Eocene Dry Branch Formation is divided into the Irwinton Sand Member, the Twiggs Clay Member, and the Griffins Landing Member (Ref. 231). The unit is about 18 meters (60 feet) thick near the center of the study area. The top of the Dry Branch is picked on geophysical logs where a low gamma-ray count in the relatively clean Dry Branch sand increases sharply in the more argillaceous sediments of the overlying Tobacco Road Sand.

The Dry Branch sediments overlying the Tinker/Santee (Utley) interval in the central portion of SRS were deposited in shoreline/lagoonal/tidal marsh environments (Figure 1.4-40). The shoreline retreated from its position in northern SRS during Tinker/Santee (Utley) time to the central part of SRS in Dry Branch time. Progradation of the shoreline environments to the south resulted in the sands and muddy sands of the Dry Branch being deposited over the shelf carbonates and clastics of the Tinker/Santee (Utley) sequence.

The Twiggs Clay Member does not seem to be mappable in the study area. Lithologically similar clay is present at various stratigraphic levels in the Dry Branch Formation. The tan, light-gray, and brown clay is as thick as 4 meters (12 feet) in SRS wells but is not continuous over long distances. This has been referred to in the past as the "tan clay" in SRS reports (Figure 1.4-39). The Twiggs Clay Member, that predominates west of the Ocmulgee River in Georgia, is not observed as a separate unit in the study area.

The Griffins Landing Member is composed mostly of tan or green, slightly to well indurated, quartzose calcareous micrite and sparite, calcareous quartz sand and slightly calcareous clay (Ref. 233). Oyster beds are common in the sparry carbonate facies (Figure 1.4-40). The unit seems to be widespread in the southeastern part of SRS, where it is about 15 meters (50 feet) thick, but becomes sporadic in the center and pinches out. Carbonate content is highly variable. In places, the unit lies unconformably on the Utley Limestone Member, which contains much more indurated, moldic limestone. In other areas, it lies on the noncalcareous quartz sand of the Clinchfield. Updip, the underlying Clinchfield is difficult to identify or is missing, and the unit may lie unconformably on the sand and clay facies of the Tinker/Santee Formation. The Griffins Landing Member appears to have formed in lagoonal/marsh environments (Figure 1.4-40).

The Irwinton Sand Member is composed of tan, yellow and orange, moderately sorted quartz sand, with interlaminated and interbedded clay abundant in places (Ref. 233). Pebbly layers are present, as are clay clast-rich zones (Twiggs Clay lithology). Clay beds, which are not continuous over long distances, are tan, light gray, and brown in color, and can be several feet

thick in places. These are the "tan clay" beds of various SRS reports. Irwinton Sand beds have the characteristics of shoreline to shallow marine sediments (Figures 1.4-37 and 1.4-40). The Irwinton Sand crops out in SRS. Thickness is variable, but is about 12 meters (40 feet) near the northwestern site boundary and 21 meters (70 feet) near the southeastern boundary.

Tobacco Road Formation. The Late Eocene Tobacco Road Formation consists of moderately to poorly sorted, red, brown, tan, purple, and orange, fine to coarse, clayey quartz sand (Ref. 233). Pebble layers are common, as are clay laminae and beds. Ophiomorpha burrows are abundant in parts of the formation. Sediments have the characteristics of lower Delta plain to shallow marine deposits (Figure 1.4-37). The top of the Tobacco Road is characterized by the change from a comparatively well-sorted sand to the more poorly sorted sand, pebbly sand, and clay of the "Upland unit." Contact between the units constitutes the "Upland" unconformity (Ref. 229). The unconformity is very irregular due to fluvial incision that accompanied deposition of the overlying "Upland unit" and later erosion. As stated previously, the lower part of the Cooper Group (upper Eocene) is the probable downdip equivalent of the Tobacco Road Formation.

"Upland Unit"/Hawthorn/Chandler Bridge Formations. Deposits of poorly sorted silty, clayey sand, pebbly sand, and conglomerate of the "Upland unit" cap many of the hills at higher elevations over much of the study area. Weathered feldspar is abundant in places. The color is variable, and facies changes are abrupt. Siple (Ref. 123) assigned these sediments to the Hawthorn Formation. Nystrom et al. (Ref. 237), who mapped it as the "Upland unit", discuss evidence for a Miocene age. The unit is up to 18 meters (60 feet) thick. The environment of deposition appears to be fluvial, and the thickness changes abruptly owing to channeling of the underlying Tobacco Road Formation during "Upland" deposition and subsequent erosion of the "Upland" unit itself. This erosion formed the "Upland" unconformity (Ref. 229). The unit is up to 18 meters (60 feet) thick (Ref. 237).

Lithologic types comparable to the "Upland" unit but assigned to the Hawthorn Formation overlie the Barnwell Group and the Cooper Group in the southern part of the study area. In this area, the Hawthorn Formation consists of very poorly sorted, sandy clay, and clayey sand, with lenses of gravel and thin beds of sand very similar to the "Upland unit". Farther downdip, the Hawthorn overlies the equivalent of the Suwanee Limestone and acts as the confining layer overlying the Floridan Aquifer System. It consists of phosphatic, sandy clay and phosphatic, clayey sand and sandy, dolomitic limestone interbedded with layers of hard, brittle clay resembling stratified fuller's earth.

Colquhoun et al. (Ref. 238) suggest that the "Upland unit", Tobacco Road Formation, and Dry Branch Formation are similar in granularity and composition, indicating that they might be similar genetically, that is that they are part of the same transgressive/regressive depositional cycle. The "Upland unit" represents the most continental end member (lithofacies) and the Dry Branch Formation represents the most marine end member. Thus, the "Upland unit" is the result of a major regressive pulse that closed out deposition of the Barnwell Group/Cooper Group depositional cycle. Colquhoun et al.(Ref. 238) suggested that the "Upland unit" is correlative with the Chandler Bridge Formation downdip toward the coast. This hypothesis is significant because it implies that there was no major hiatus between the "Upland unit" and the underlying

Tobacco Road and Dry Branch Formations. The existence of a hiatus between the units has been reported by numerous studies of the South Carolina Coastal Plain (Ref. 118, 123, 222, 237).

Quaternary Surfaces and Deposits

Determining fault capability requires assessing the potential for Quaternary (1.6 - 0.01 Ma) deformation (Ref. 239). The Quaternary and neotectonic studies conducted at SRS during 1991-1992 by Geomatrix were designed to span the geologic record between deposition of the "Upland unit" and the present, and to determine if deformation has affected Quaternary-age deposits or surfaces (Ref. 239, 240). The Quaternary record in the SRS area is preserved primarily in fluvial terraces along the Savannah River and its major tributaries and in deposits of colluvium, alluvium, and eolian sediments on upland interfluve areas (see Figure 1.4-36).

SRS lies within the interfluve area between the Savannah and the Salkahatchie Rivers. The drainage systems within the site consist entirely of streams that are tributary to the Savannah River. A series of nested fluvial terraces are preserved along the river and major tributaries. Fluvial terraces are the primary geomorphic surface that can be used to evaluate Quaternary deformation within SRS. However, there is limited data available for the estimation of ages of river terraces in both the Atlantic and Gulf Coastal Plains (Ref. 241-245).

Major stream terraces form by sequential erosional and depositional events in response to tectonism, isostasy, and climate variation. Streams respond to uplift by cutting down into the underlying substrate in order to achieve a smooth longitudinal profile that grades to the regional base level. Aggradation or deposition occurs when down-cutting is reversed by a rise in base level. The stream channel is elevated and isolated from the underlying marine strata by layers of newly deposited fluvial sediments. Down-cutting may resume and the aggraded surface is abandoned. The result is a landform referred to as a fill terrace.

At the SRS there are two prominent terraces above the modern floodplain (Qal (see Figure 1.4-36). These designations are based on morphology and relative height above local base level. Local base level is the present elevation of the Savannah River channel. In addition, there are other minor terraces: one lower and several higher, older terrace remnants.

The terraces of Upper Three Runs and Steel Creeks were mapped on false color, infrared aerial photography, and field checked. Although exposures of fluvial deposits are extremely limited, these terraces are laterally continuous. Upper Three Runs terraces are of interest to SRS because of their position over the Atta and Upper Three Runs Faults. The terraces along Steel Creek represent a family of seven sets of well-defined fluvial terraces, one of the best sequences of terraces at SRS. These terraces range from less than 1 meter to 30 meters (3 to 100 ft) above local base level. The lower terraces appear to be fill terraces whereas the higher terraces appear to be strath terraces that cut into Tertiary strata. The Steel Creek drainage parallels the trace of the subsurface Steel Creek Fault.

Estimated ages of the terraces are based on several techniques including radiometric carbon-14 dates, soil chronosequences, relative position above base level and correlation to other dated river or marine terraces. The modern floodplain is as old as the latest Pleistocene to Holocene (Ref. 240). Others have indicated a much younger age of 4,000 years (Ref. 244). Based on soil

chronosequences, it is at least 400 ka to perhaps 1 Ma. Brooks and Sassaman (Ref. 246) conclude early to middle Holocene (less than 10 ka) based on geoarchaeological studies. The terraces on Upper Three Runs range from 11 ka for the lower (0.5 to 4.5 meters) terrace to 38 to 47 ka for the higher (greater than 6 meters [30 ft]) terrace. Overall, the terraces at SRS represent ages from middle Holocene (less than 10 ka) to late Pleistocene (1 Ma).

Carolina Bays

Carolina bays are shallow, elliptical depressions with associated sand rims that are found on the surface of the Coastal Plain sediments. They are found from southern New Jersey to northern Florida with the greatest occurrence in the Carolinas (Ref. 247). One hundred ninety-seven confirmed or suspected Carolina bays have been identified at SRS (see Figure 1.4-42). The long axes of the bays are oriented S50°E (Ref. 248) and the sand rims are observed on the east and southeast flanks. Numerous authors have provided several hypotheses for the timing and mode of origin for these bays (Ref. 70, 249-253). Theories regarding the origin of bays include meteorite impact, sinks, wind, and water currents. The origin of these features continues to be studied.

Soller and Mills (Ref. 247) suggest that the work done by Savage (Ref. 254) and Kaczorowski (Ref. 253) provides the most likely explanation of formation. They suggest that the bays were formed by action of strong unidirectional wind on water ponded in surface depressions. The resulting waves caused the formation of the sand rims as shoreline features, and the sand rims formed perpendicular to the wind direction. Therefore, the wind that formed the bays we observe today was a southwesterly wind (Ref. 247).

The Carolina bays are surficial features that have no effect on the subsurface sediments. Based on subsurface core data, Gamble et al. (Ref. 249) demonstrated that a clay layer mapped beneath the bays and beyond had no greater relief beneath the bays than beyond them. Additional evidence of the surficial character of Carolina bays is povided by Thom (Ref. 252). In these studies certain identified strata could be mapped and found continuous and undeformed beneath bay and interbay areas. In Horry and Marion Counties, South Carolina, there was no evidence of solution-related subsidence of the Carolina bays, in spite of the presence of carbonate-rich strata in the subsurface and some localized sink holes of irregular shape with depths on the order of 6 meters (20 feet).

Gamble et al. (Ref. 249) indicated that there are two types of bay rims, a primary, and a secondary. They may have a cross cutting relationship with each other or exist as rims within a rim. Bays may have secondary rims, but it is not a necessary condition. Formation of secondary bay rims as a consequence of wind and water action along the shores of a shallow body of water can account for the development of multiple bay rims and bays within bays. Receding water levels could alter the shape of the shoreline and cause one or more subsequent secondary rims to develop inside the confines of the first one. The altered shape of the water body could cause the new secondary rim to truncate and obliterate part of the old secondary rim.

The age of the bays is based on Soller (Ref. 245) and Thom (Ref. 252). A minimum age was set at middle to late Wisconsinian based on radiocarbon dating (Ref. 252). The maximum age can be relatively determined by examination of the formations on which the bays rest. If one

assumes a single generation of formation for all bays, then the bays formed after deposition of the Socastee Formation and before the Wando Formation (Ref. 243). This places bay formation between 100 and 200 ka. If there is more than one generation, then the bays could be as old as the formations on which they rest.

Carbonate and Soft Zones

Often found within the Tinker/Santee (Utley) sediments, particularly in the upper third of this section, are weak zones interspersed in stronger carbonate-rich matrix materials. These weak zones, which vary in apparent thickness and lateral extent, were recorded where rod drops and/or lost circulation occurred during drilling, low blow counts occurred during SPT pushes, etc. They have variously been termed as "soft zones", "the critical layer", "underconsolidated zones", "bad ground", and "void". The preferred term used to describe these zones is "soft zones".

The initial Corps of Engineers (COE) characterization in 1952 (Ref. 255) identified soft zones as being the major concern for foundation design. This initial study made many important observations concerning the formation, geometry, distribution, and physical attributes of soft zones (and potential associated voids) within the Santee Formation. Some of the soft zone observations and hypotheses set forth by the COE report have remained unchanged to this day. However, several important aspects of early soft zone analyses run counter to current thinking on this subject.

Historically, the soft zones were grouted as an expedient way of resolving any potential foundation stability issues. This method continued through the restart of the K-reactor where the project chose to grout the Santee formation beneath the cooling water lines to resolve a potential foundation stability issue. The results of that effort were carefully studied and it was found that the grout was not having the desired effect on the subsurface soft zones. The results showed that the grout traveled in thin sheets along preferential pathways. Soft zones that existed prior to grouting still existed after grouting was completed. The grouting provided limited benefit in reducing the potential settlement from the soft zones.

More recently, technology improvements have allowed sampling and testing which have resulted in additional insight to the properties of the soft zone soils. With these properties, advanced analytical techniques have been used to resolve the foundation stability issues without requiring soil remediation. The information provided herein allows for a clearer understanding of the geologic underpinnings that established the carbonates and the attendant soft zones.

In general, where carbonates are found (Figures 1.4-38 and 1.4-39) soft zones are likely to be found as well. This conclusion is based on a significant study of soil samples from borings, boring logs, geophysical logs, and cone penetration test soundings throughout the GSA (Ref. 235). This review was instrumental in delineating the extent of both carbonates and soft zones. The data were studied in many different ways but resulted in the simple conclusion that although carbonates and soft zones are not found in every drill hole or CPT, they are generally found in every area that was investigated in the GSA.

Isopach maps (Ref. 235) reveal that carbonate thickness and concentration is directly related to the isopach thickness of the Tinker/Santee (Utley) interval. Where the Santee-Utley interval is

thick, carbonate is more concentrated, where the interval is thin, carbonate thickness and concentration is reduced. It is further observed that where carbonate is concentrated in the Santee-Utley section the overlying "upland unit", Tobacco Road/Dry Branch section (Figure 1.4-41) is generally structurally high, and where the carbonate content is reduced or absent the overlying "upland unit," Tobacco Road/Dry Branch section is generally structurally low. This indicates that the removal (dissolution) of carbonate and the thinning of the Santee-Utley interval occurred in post Tobacco Road time

Since the thickness and distribution of soft zones is closely linked to the thickness and distribution of carbonate, those areas where clastic sediments were initially concentrated and in structurally low areas where a great deal of carbonate has been removed would be areas where soft zones may not be present. This however would not reduce the need to investigate these areas for potential siting of new facilities but would aid in siting and land use issues.

Origin of Carbonates and Soft Zones. The origin of the carbonates in the Tinker/Santee (Utley) interval is fairly clear. The carbonate content ranges from zero to approximately 90 percent. The presence of glauconite along with a normal marine fauna including foraminifers, molluscs, bryozoans, and echinoderms, indicates that the limestones and limy sandstones were deposited in clear, open-marine water of normal salinity on the inner to middle shelf (Figures 1.4-37 and 1.4-40). The abundance of carbonate mud (micrite) in the limestones suggests deposition in quiet water below normal marine wave base. The presence of abraded and well-worn skeletal grains indicates that bottom transport by currents or storm-generated waves alternated with quiet-water conditions in which the sediments accumulated.

Viewing the Santee sedimentary package parallel to the shoreline, the carbonate-rich sediments would be concentrated in the areas furthest removed from the tidal inlets at the shore face where clastic sediments supplied by riverine input is concentrated (Figure 1.4-37). The clastic-rich sediments on the other hand would concentrate opposite the tidal inlet areas where clastic sediment is more readily available. The lateral facies transition of the sediments in the subtidal shelf environment from carbonate-rich to clastic-rich lithologies is therefore gradual and measures in the thousands of feet. Shifting locations of the tidal inlets at the shoreline has resulted in a complex sedimentary package where facies gradually transition from one lithology to another both laterally and vertically. Therefore, both vertical and lateral lithologic variability in the Tinker/Santee (Utley) sequence is the rule rather than the exception. Locally the contact between carbonate sediments and laterally comparable clastic sediments is often sharply drawn, occurring over distances of only a few feet.

The original thoughts were that the soft zones were the result of the dissolution of the shell debris concentrated in bioherms (oyster banks). This premise has since been proven to be false. Significant study of the deposition of the Tinker/Santee (Utley) sediments precludes the formation of bioherms. Several hypotheses exist concerning the origin of the soft zones: one being that these zones consisted of varying amounts of carbonate material that has undergone dissolution over geologic time leaving sediments that are now subjected to low vertical effective stresses due to arching of more competent soils above the soft zone intervals.

A second hypothesis is based on recent studies that indicate that soft zones occur where silica replacement/cementation of the carbonate occurred. The silicification (by amorphous opaline

silica) of the enclosing carbonate sediment would follow and spread along bedding planes, along microfractures of varied orientations and along corridors of locally enhanced permeability (Figure 1.4-43). The resulting "soft zone" could be in the form of irregular isolated pods, extended thin ribbons or stacked thin ribbons separated by intervening unsilicified parent sediment. Careful observations of the grouting programs conducted by the COE in the early 1950s, and more recently for the restart of K Reactor, corroborate these recent findings. They observed that the grout was not having the desired effect on the subsurface soft zones as was previously thought. The results showed that the grout traveled in thin sheets along preferential pathways. Soft zones that existed prior to grouting still existed after grouting was completed. Soft zones encountered in one cone penetrometer test (CPT) sounding could be absent in the neighboring CPT only a few feet away. Only where silicification has spread far enough away from the bedding planes and/or fractures along which the silica replacement has taken place, where all the intervening sediment is replaced, would the soft zones be large enough and coherent enough to pose a question for the siting of new facilities. In all likelihood this would be a most uncommon event.

Geotechnical investigation programs are performed routinely for new facilities at SRS. Detection of soft zones will not prevent the siting of new facilities in these areas. Exploration to locate soft zones should include soil borings and cone penetration test (CPT) soundings. Our experience indicates that the CPT is the best tool to determine the presence of soft zones. However, exploration programs for critical facilities include combinations of soil borings, CPT soundings, surface and down-hole geophysical measurements, compression and shear wave velocity determinations, and sampling for laboratory testing. It is recommended that initial soft zone identification be determined using the CPT tip resistance and the SPT N-value. For depths between 100 and 150 feet below the ground surface, the CPT criteria would be tip stress less than 1.44 Mpa (15 tons per square foot) and the SPT criteria would be an N-value less than 5. The exploration program depth must be designed to penetrate through the layer where soft zones occur. In the GSA, that translates to depths of approximately 55 meters (180 feet) below ground surface.

For critical facilities it is recommended that a phased investigation program be performed. This could be done in combination with a site selection program, if warranted. The phased program allows for determination of stratigraphy (particularly soft zones) early in the program, then targeting those critical layers that require sampling and laboratory testing. Generally, the initial phase relies heavily on the CPT, and the second phase relies heavily on drilling, sampling and laboratory testing. Because of the depth of the soft zones (30 meters [100 ft] to 46 meters [150 ft] in the GSA) there is no static stability issue. Dynamic settlement, on the other hand, requires evaluation. Analyses include dynamic settlement determinations from partial liquefaction and consolidation from load transfer due to a seismic event.

More recently, technology improvements have allowed sampling and testing which have resulted in additional insight to the properties of the soft zone soils. With these properties, advanced analytical techniques have been used to resolve the foundation stability issues without requiring soil remediation. The information provided herein allows for a clearer understanding of the geologic underpinnings that established the carbonates and the attendant soft zones.

REGIONAL PHYSIOGRAPHY

The site region, defined as the area within a 320-km (200-mile) radius of the center of SRS, includes parts of the Atlantic Coastal Plain, Piedmont and Blue Ridge physiographic provinces. SRS is located on the upper Atlantic Coastal Plain, about 50 km (30 miles) southeast of the Fall Line.

The Atlantic Coastal Plain extends southward from Cape Cod, Massachusetts, to south central Georgia where it merges with the Gulf Coastal Plain. The surface of the Coastal Plain slopes gently seaward. Colquhoun and Johnson (Ref. 218) divided the South Carolina Coastal Plain into three physiographic belts: Upper, Middle, and Lower Coastal Plain. The Upper Coastal Plain slopes from a maximum elevation of 200 meters (650 feet) msl at the Fall Line to about 75 meters (250 feet) msl on its southeastern boundary (see Figure 1.4-44). Primary depositional topography of the Upper Coastal Plain has been obliterated by fluvial erosion. The Upper Coastal Plain is separated from the Middle Coastal Plain by the Orangeburg scarp, which has a relief of approximately 30 meters (100 feet) over a distance of a few miles. The Orangeburg scarp is the locus of Eocene, Upper Miocene, and Pliocene shorelines (Ref. 218). The Middle Coastal Plain, separated from the Lower Coastal Plain by the Surry scarp, is characterized by lower elevations and subtle depositional topography that has been significantly modified by fluvial erosion (Ref. 256). The Lower Coastal Plain is dominated by primary depositional topography that has been modified slightly by fluvial erosion.

Siple (Ref. 118) and Cooke (Ref. 219) previously divided the Upper Coastal Plain of South Carolina into the Aiken Plateau and Congaree Sand Hills. The Aiken Plateau, where SRS is located, is bounded by the Savannah and Congaree Rivers and extends from the Fall Line to the Orangeburg scarp. The plateau's highly dissected surface is characterized by broad interfluvial areas with narrow, steep-sided valleys. Local relief is as much as 90 meters (295 feet) (Ref. 123). The plateau is generally well drained, although many poorly drained sinks and depressions exist, especially on the topographically high (above 76 meters [250 feet] msl) "Upland unit". The Congaree Sand Hills trend along the Fall Line northeast and north of the Aiken Plateau. The sand hills are characterized by gentle slopes and rounded summits that are interrupted by valleys of southeast-flowing streams and their tributaries (Ref. 123).

The site region contains Carolina bays. (Carolina bays are discussed in detail in the previous section.)

The Piedmont province extends southwest from New York to Alabama and lies adjacent to the Atlantic Coastal Plain. It is the eastern-most physiographic and structural province of the Appalachian Mountains. The Piedmont is a seaward-sloping plateau whose width varies from about 10 miles (16 km) in southeastern New York to almost 125 miles (200 km) in North Carolina; it is the least rugged of the Appalachian provinces. Elevation of the inland boundary ranges from about 60 meters (200 feet) msl in New Jersey to over 550 meters (1,800 feet) msl in Georgia.

The Blue Ridge province extends from Pennsylvania to northern Georgia. It varies from about 48 km (30 miles) to 120 km (75 miles) wide north to south. Elevations are highest in North Carolina and Georgia, with several peaks in North Carolina exceeding 1,800 meters (5,900 feet)

msl. Mount Mitchell, North Carolina, is the highest point (2,000 meters , 6,560 feet) msl in the Appalachian Mountains. The Blue Ridge front, with a maximum elevation of 1,200 meters (4,000 feet) msl in North Carolina, is an east-facing escarpment between the Blue Ridge and Piedmont provinces in the southern Appalachians.

GENERAL GEOLOGIC SETTING AT SAVANNAH RIVER SITE (40 km RADIUS)

The 40-km (25-mile) radius study area is taken from DOE-STD-1022-94 (Ref. 139) as the area in which to conduct geoscience investigations to locate possible seismogenic sources and surface deformation or to demonstrate that such features do not exist.

The SRS is located on the Atlantic Coastal Plain, which is an essentially flat-lying, undeformed wedge of unconsolidated marine and fluvial sediments. The sediments are stratified sand, clay, limestone, and gravel that dip gently seaward and range in age from Late Cretaceous to Holocene. The sedimentary sequence thickens from zero at the Fall Line to more than 4,000 feet (1,200 meters) at the coast. Several investigations have provided a great deal of data and insight into the evolution of the southeastern United States Coastal Plain, including Cook (Ref. 219), Siple (Ref. 118), Huddlestun and Hetrick (Ref. 257), Colquhoun and Steele (Ref. 258); Prowell et al. (Ref. 259), Dennehy et al. (Ref. 260), Fallaw and Price (Ref. 231), Fallaw et al. (Ref. 233), Nystrom et al. (Ref. 261), and Bledsoe et al. (Ref. 103). The Coastal Plain section is divided into several rock-stratigraphic groups, based principally on age and lithology (see Figure 1.4-45). The details of Coastal Plain stratigraphy have been discussed in the preceding section.

Beneath the Coastal Plain sedimentary sequence and below a pre-Cretaceous unconformity are two geologic terranes: (1) the Dunbarton basin, a Triassic-Jurassic Rift basin, filled with lithified terrigenous and lacustrine sediments with possible minor amounts of mafic volcanic and intrusive rock (Ref. 262-266); and (2) a crystalline terrane of metamorphosed sedimentary and igneous rock that may range in age from Precambrian to late Paleozoic (see Figure 1.4-46). The Paleozoic rocks and the Triassic sediments were leveled by erosion, forming the base for Coastal Plain sediment deposition. The erosional surface dips southeast approximately 8 m/km (42 ft/mile).

Information about the Dunbarton basement and crystalline terrane comes primarily from deep borings. The U.S. Army Corps of Engineers drilled a single hole into basement rock in 1950 for the startup of the plant (Ref. 267). In 1961, The Bedrock Waste Storage Project rock exploration program was conducted to determine the feasibility of long-term storage of radioactive waste in mined rock chambers . Twelve deep rock borings, the DRB well series, were completed into basement to various depths greater than 300 meters (980 feet) to accomplish this goal. This information is also augmented by deep borings used to constrain seismic reflection informationboth in the early 1970s (P-R series) and more recently acquired information (MMP and GCB series). The topography of the crystalline basement is shown on Figure 1.4-47.

In addition to the direct information furnished by the deep borings, information about the composition, extent and structure of crystalline terrane and the Dunbarton basin are also provided by potential field geophysical methods. Detailed gravity information concerning SRS and vicinity exists (Ref. 268, 269) and has been used to provide a detailed gravity map of the site (Figure 1.4-48). In addition high resolution aeromagnetic data are available from the U.S. Geological

Survey (Ref. 202) and have been used to produce a high resolution aeromagnetic map of SRS and vicinity (Ref. 270) (Figure 1.4-49). Several recent studies have been the focus on integrating this geophysical information with the boring information listed above to evolve a fairly detailed model of the crystalline terrane and Dunbarton Basin (Ref. 266, 272-277).

Crystalline Terrane

The studies mentioned above have determined that the lithologies and structures in the crystalline terrane are basically similar to that seen in the eastern Piedmont province as exposed in other parts of the southeastern United States. The crystalline rocks form a volcanic – intrusive sequence of calc-alkaline composition, portions of which record both ductile and brittle deformational events. These relationships indicate that these rocks are the metamorphosed and deformed remnants of an ancient volcanic arc that are interpreted to be Carolina Terrane equivalents.

The crystalline rocks were mapped as three formations (Ref. 275) (Figure 1.4-46). The Crackerneck formation consists of weakly to unmetamorphosed and mildly to undeformed volcanic rocks of intermediate to felsic composition with minor amounts of mafic material. The rocks in this formation are represented mainly by tuffs and lapilli tuffs (extrusive volcanic rocks).

The DRB Formation (named after the Deep Rock Borings in which it is found) consists of moderately metamorphosed and highly to moderately deformed volcanic and plutonic rocks of mafic to intermediate compositions. The DRB Formation is cut by deformed amphibolite dikes and by undeformed dikes of basaltic and rhyolitic compositions, indicating that these rocks were intruded both before deformation and after the major episode of deformation had ceased. The DRB Formation may also contain a minor amount of quartz-rich sedimentary rock. However, the identification of this material is uncertain.

The PBF Formation (named after the Pen Branch Fault borings in which it is found) occurs as a thin slice between the Dunbarton Basin to the south and the DRB Formation to the north. This formation contains strongly metamorphosed gneisses and amphibolites that have experienced relatively high thermal effects and appear to be deeper equivalents of the DRB Formation. The plutonic rocks of both the DRB Formation and PBF Formation have radiometerically dated crystallization ages of 620 Ma. Based on the association of these rocks with the Carolina Terrane, the metavolcanic rocks of the Crackerneck Formation are interpreted to have been deposited unconformably on the DRB formation at about 620 Ma.

Subsequent to the formation of this volcanic stratigraphy these rocks underwent multiple deformational episodes and chemical changes. The rocks of the DRB formation record highly developed deformational fabrics that indicate that these rocks have undergone significant amounts of ductile shearing at moderately high temperatures. These fabrics, in association with the superposition and juxtaposition of the higher temperature PBF formation indicate that this deformation resulted from thrust and strike-slip faulting, which placed the PBF formation over the DRB formation. Based on radiometric age dating of biotite in the fault zone, this deformation is Paleozoic in age (approximately 300 Ma). In addition to ductile deformation features, the sub-Cretaceous basement rocks also record the effects of brittle deformation episodes characterized by fractures, brittle faults, and frictional melting. The presence of

mineralized veins associated with these fractures and brittle faults indicate that the brittle faulting was often accompanied by the movement of hot waters. Radiometric dating of these effects suggest that at least one phase of brittle deformation occurred around 220 Ma. This age would make this phase of brittle deformation most likely associated with formation of the Dunbarton basin. Other younger brittle deformation features are also present, and are most likely associated with Tertiary deformation in the basement such as the Pen Branch Fault. Radiometric dating of fracture filling yielded an age of 23 Ma. However, the radiometric systematics of the mineral dated are not well known so the geologic meaning of this age is uncertain.

Dunbarton Triassic Rift Basin

The Dunbarton basin underlies the southeastern portion of SRS and was first identified based on aeromagnetic and well data (Ref. 264). Subsequent seismic reflection surveys, potential field surveys, and additional well data have led to the current understanding of the basin (Ref. 262-266, 268, 269, 271, 272, 277-279). The structure is currently interpreted as an asymmetric graben approximately 50 km (30 miles) long and 10 to 15 km (6 to 9 miles) wide. The axis of the basin strikes north 63° east, which is parallel to the regional strike of crystalline basement (Ref. 264). The basin extends 8 km (5 miles) southwest of the Savannah River and 40 km (24 miles) to the northeast of SRS, where it terminates against a granite body interpreted from magnetic data (Ref. 220, 264, 268, 272). The master border fault, named the Pen Branch Fault, is on the northwest boundary of the basin and dips to the southeast.

The southeast boundary of the basin is poorly constrained but is interpreted as a fault (Ref. 124, 265). Southeast of the Dunbarton basin aeromagnetic and gravity data indicate a terrane heavily influenced by basalt flows and sills. The magnetic data contain numerous high-frequency, closed-contour features indicative of shallow structures, and lower frequency features indicative of deeper-seated features. The host rock is perhaps crystalline metamorphosed rock similar to what is found further to the northwest beneath SRS. In addition, Madabhushi and Talwani (Ref. 440) suggest that this terrane separates the Piedmont orogeny from crust of a different affinity further to the southeast. In effect, the mafic intrusions define the southeastern boundary of the Dunbarton basin and the northern boundary of the South Georgia Rift basin (Ref. 215).

Ten wells drilled in the southeastern half of SRS penetrated sedimentary rocks of the Dunbarton basin (see Figure 1.4-46). Recovered core is clastic rock (Ref. 264, 280). Conglomerate, fanglomerate, sandstone, siltstone, and mudstone are the dominant lithologies. These rocks are similar to the clastic facies in other Newark Supergroup basins. In addition, four of the Pen Branch fault series wells penetrated Triassic rock. Conglomerate and red clayey siltstone are the dominant lithologies in these cores. Parsons et al. (Ref. 280) conclude that the lithology and stratigraphy identified in these core indicate that the proximal side of the basin is to the northwest. There is a larger component of coarse-grained rock types on the proximal side than on the southeast side of the basin. Marine and Siple (Ref. 264) found an upward increase of total fines in each core. Further, the sediments fine upward in each core. A detailed study of the Dunbarton Basin core that integrated the above observations with some new information (Ref. 266) grouped the sediments in the basin into four lithofaces:

1. A proximal fan facies occurs near the hanging wall of the Pen Branch Fault (see Figure 1.4-50) and consists mainly of poorly sorted, matrix-supported conglomerates dominated by debris flows.
2. A distal fan facies includes silty and sandy mudstones interbedded with massive immature sandstones and wackes.
3. A fringe fan facies which is dominated by mudstones but also contains intervals with bioturbation, roots, and caliches, which indicate periods of flooding overprinted during periods of nondeposition by burrowing and soil formation.
4. A braided plain facies includes cross-stratified channel sandstones erbedded with bioturbated mudstones and fine sandstones containing caliches.

The facies relationships described above suggest an asymmetric basin that subsided faster to the northwest than to the southeast. The asymmetry led to greater local relief along the northern boundary, where high-energy fluvial processes dominated, and the resulting sediments were more coarse grained than farther out in the basin. The predominance of alluvial fan facies with abundant mud and debris flows, and caliches in paleosols suggests that the basin and surrounding areas were poorly vegetated, and an arid to semi-arid climate.

Gravity and magnetic modeling suggests that the Triassic section in the Dunbarton basin averages about 2 km (1.2 miles) thick. Boreholes have encountered up to 899 meters (3,000 feet) of Triassic fill, but the base of the Dunbarton was not encountered (Ref. 264). Seismic reflection data do not unequivocally constrain the base of the basin, as the transition between the Triassic rock and the crystalline terrane is unclear. However, interpreted Triassic reflectors are at least as deep as 1,188 meters (3,900 feet) to 3,688 meters (12,100 feet) (Ref. 269).

SITE GEOLOGIC MAP

A geologic map of the SRS was completed by the USGS and provided to SRS in 1994 (Ref. 281) (see Figure 1.4-36). This map shows the Coastal Plain formations that crop out at the surface. Other, deeper Coastal Plain formations may not be observed at the surface within the boundaries of the site, however, these formations are known to exist in the subsurface based on drill core data and outcrops in nearby regions.

Erosion by the Savannah and Edisto Rivers and tributaries have truncated the uppermost stratigraphic units such as the Upland unit and the Tobacco Road Sand. This gives the geologic map its characteristic dendritic pattern and indicates that the strata are sub-horizontal. Deeper and older formations are exposed in stream valley walls Paleocene and Cretaceous formations crop out in nearby regions and are mapped on the USGS Barnwell sheet (Ref. 281).

Superposed on the Coastal Plain sediments are a variety of alluvial and colluvial deposits that have resulted from streams cutting the valleys they occupy. The alluvial deposits are located in the stream valleys and on terraces and are indicated on the map (see Figure 1.4-36) as Qal 1, Qal 2, and Qt. The reworked sediments are derived from the uppermost Coastal Plain sediments and effectively cover up the deepest formations exposed in the stream valley bottoms.

Contacts separating the geological formations were mapped by examination of natural and manmade surface exposures and from subsurface drill core. Original compilation of field data was done at 1:100,000 scale. The subsequent SRS map is presented at 1:48,000 scale.

1.4.3.2 Tectonic Features

DEFINITION OF PLATE TECTONICS

Plate tectonics is the concept that the earth's crust is broken into large blocks with portions of each block being continually renewed or destroyed. The theory integrates the concepts of rift zone/sea-floor spreading, continental collision/subduction zone, and seismic/volcanic zones into a unified theory. Plate tectonics within the 320-km (200-mile) radius of the SRS would provide the description of the major structural or deformational features of the region, as well as the origins, evolution, and interrelationship of these features.

The implementation of Natural Phenomena Hazards Mitigation requires that the tectonic elements of the site region should be understood and described in sufficient detail to allow an evaluation of the safety of a proposed or existing facility. The major issue with respect to the tectonic framework and site suitability is concern for tectonic features influencing the seismicity of the region.

Based on previous studies at SRS and elsewhere, there are no known capable or active faults within the 320-km radius of the site that influence the seismicity of the region with the exception of the blind, poorly constrained faults associated with the Charleston seismic zone (see Section 1.4.4).

DEFINITION OF SEISMOGENIC FAULTS

Various definitions have been established to evaluate the issues of describing the deformational features and relating specific features to seismicity. These definitions are derived from classical geology and regulatory geology. In some cases, the same concept is defined with different terminology. The definitions that follow are taken from the NRC and DOE.

The NRC provided their definition in 10 CFR Part 100, Appendix A, as follows (Ref. 282):

Capable fault: a fault, which has one or more of the following characteristics:

1) Movement at or near the ground surface at least once in the past 35,000 years or repeatedly within the past 500,000 years.

2) Macro-seismicity instrumentally determined with records of sufficient precision to demonstrate a direct relationship with the fault.

3) A structural relationship to a capable fault according to characteristics 1 or 2 such that movement on one could be reasonably expected to be accompanied by movement on the other.

The NRC has proposed the following definition in amendments to 10 CFR Part 100 (Section 100.23).

Capable tectonic source: a tectonic structure that can generate both vibratory ground motion and tectonic surface deformation such as faulting or folding at or near the earth's surface in the present seismotectonic regime. Characterized by the attributes defining a capable fault in the 1973 regulations.

The NRC is also defining a seismogenic source as a portion of the earth that has uniform earthquake potential (same expected maximum earthquake and frequency of recurrence) distinct from other regions. A seismogenic source will generate vibratory ground motion but is not assumed to cause surface displacement. Seismogenic sources cover a wide range of possibilities from a well-defined tectonic structure to simply a large region of diffuse seismicity (seismotectonic province) thought to be characterized by the same earthquake recurrence model. A seismogenic source is also characterized by its involvement in the current tectonic regime (the Quaternary, or approximately the last 2 million years).

The DOE, in DOE-STD-1022-94 (Ref. 139) provides fault terminology as follows:

Fault: a geologic feature which demonstrates deformation or/and rupture of geologic deposits.

Active fault: a capable tectonic structure which demonstrates surface or near surface deformation of geologic deposits of a recurring nature within approximately the last 500,000 years or once in the last 50,000 years or/and associated with one or more large earthquakes or sustained instrumentally recorded earthquake activity.

Seismic source: seismic events, which contribute significantly (more than 5% to the total seismic hazards) to a probabilistic ground motion assessment.

SRS currently works to DOE-STD-1022-94 Natural Phenomena Hazards Site Characterization Criteria (Ref. 139). At this time, there are no faults classified as active or capable at SRS (Ref. 283).

Crustal geometry of the region and SRS area

Thickness of the Crust

Along continental margins the nature of the crust changes from continental-type crust to oceanic-type crust. Continental crust is generally thicker, less dense, and chemically distinct from ocean crust. The boundary at the base of either continental or oceanic crust also marks a fundamental change in physical parameters and is referred to as the Mohorovicic discontinuity. Density and P-wave velocity is significantly greater below this layer than above.

With the onset of continental rifting, the North American continent began to break away from Africa. Continental crust was stretched and thinned and was intruded with mafic magmas. At the point that one spreading center became dominant, the continental crust ceased to stretch and ocean crust was generated at the spreading center. This marked the initiation of a passive margin along the Atlantic continental margin.

In general, the thickness of continental crust thins from west to east across the eastern U.S. continental margin. The zone of transition from continental crust to oceanic crust is thought to underlie the offshore Carolina Trough and the Blake Plateau basin (see Figure 1.4-35) (Ref. 142, 284). Sheridan and Grow (Ref. 285) provide a cross-section through the continental margin and Baltimore trough (offshore New Jersey) (see Figure 1.4-51). This is a typical Atlantic-type margin showing the geometry of oceanic crust to the east and continental crust to the west. The Moho deepens from east to west from about 15 km (9 miles) to about 40 km (25 miles), respectively. The continental crust along the margin has been extended and intruded during Mesozoic rifting and is described as rift stage crust. Further east in the middle of the cross section is a complicated zone of transition from continental crust to oceanic crust. The data that support this interpretive model come largely from seismic reflection and refraction surveys and potential field surveys. Offshore South and North Carolina show a similar geometry of thinning crust (see Figure 1.4-52) (Ref. 143).

Further inland, the base of crust is discerned by following the configuration of the Moho on seismic refraction or reflection lines. From seismic reflection data collected at SRS (Ref. 278), the Moho is interpreted at about 30.0 to 31.5 km (18.6 to 19.6 miles) depth (Ref. 269). On the deep seismic profiles, a wide ban of reflections (200 to 300 milliseconds wide) at 10.5 to 11.05 seconds are interpreted to be the Moho (Ref. 269). Luetgert et al. (Ref. 279) report crustal thickness changes along a survey from SRS southeast to Walterboro, SC. They find a crust that thins from 37 km (23 miles) beneath the Dunbarton basin to 32 km (19.9 miles) near Walterboro, SC. This interpretation is based on long seismic refraction and wide-angle seismic reflection data and constrained by gravity and aeromagnetic data (see Figures 1.4-48 and 1.4-49). The effect of continental extension and thinning during the Mesozoic rifting event is thus observed in the configuration of the Moho as well as the geologic evidence from the existence of the Dunbarton basin.

TECTONIC STRUCTURES: FAULTING, FOLDING, AND RIFT BASINS

Tectonic structures of interest in the SRS region include faults, folds, arches, basins (rift and post-rift) and paleoliquefaction features from earthquakes. The various structural features in this section are discussed in terms of the age of the feature, starting with the oldest structures. The age of the structure is to be distinguished from the age of the rock in which the structure formed. The primary interest is on how the age of the feature can be discerned with greater or lesser confidence with respect to the definitions of active and capable features in the previous section.

Paleozoic and Precambrian Structures

Modoc Fault Zone

The Modoc fault zone (see Figure 1.4-32), located in South Carolina and Georgia, separates greenschist facies metamorphic rocks of the Carolina Terrane (Carolina Slate and Charlotte belts) from the amphibolite facies migmatitic and gneissic rocks of the Kiokee belt (Ref. 182, 189). The Modoc fault zone is an east-northeast trending ductile shear zone that can be traced from central Georgia to central South Carolina based on geological and geophysical data. The Modoc fault zone dips steeply to the northwest and contains quartzites, phyllite, paragneiss, and button schists correlative with units in the Asbill Pond Formation of the Carolina terrain. The lower grade Carolina terrane rocks underwent significant granitic sheet intrusion, prograde metamorphism, and penetrative strain during the Alleghanian orogeny (Ref. 182, 188, 189). Fabric in the fault zone is characterized by brittle and ductile deformation produced by ductile shear during an early phase of the Alleghanian orogeny (315 Ma) (Ref. 177, 286). The Modoc zone is overprinted by the Irmo antiform near Columbia, SC. Extension of the Modoc fault zone further to the northeast is uncertain but there are shear zones in North Carolina and Virginia that may be of the same deformational phase (Ref. 178, 287). Sacks and Dennis (Ref. 288) report an important normal-sense component in the Modoc zone on the northwest flank of the Kiokee belt. The significance of the age of myonitic fabric on this fault at 315 Ma is that the fault is very old and therefore not in the realm of active or capable in terms of regulatory guidance.

Augusta Fault

The Augusta fault zone (see Figure 1.4-32) is located near Augusta, GA, and juxtaposes amphibolite grade rocks of the Kiokee belt against the greenschist facies rocks of the Belair belt (Ref. 191). The fault trends east-northeast and dips approximately 45° southeast. The fault contains two distinct deformation fabrics: a mylonite about 250 meters (820 feet) thick is overprinted by a brittle fabric. Kinematic analysis within the mylonite zone reveals a hanging wall down component during the movement history (Ref. 191). Furthermore, the hanging wall consists of lower greenschist facies while the footwall contains upper amphibolite facies. Lower grade rocks structurally positioned above higher grade rocks in combination with shear sense indicators suggests a low-angle normal fault movement for the Augusta fault zone. This is a new view of the Augusta fault zone, which previously had been considered a ductile-to-brittle thrust fault or a strike-slip fault (Ref. 181, 188, 289). It now appears that ductile faults with a normal

sense component were an important aspect of late Alleghanian deformational history (Ref. 140). Recently Maher et al. (Ref. 186) reported $^{40}Ar/^{39}Ar$ ages from samples along a traverse across the Modoc fault and Augusta fault zones. They concluded that a 274 Ma cooling age closely dates initiation of extensional movement on the Augusta fault zone. This cooling age indicates the time when the ductile fabric was generated and therefore when the fault moved. This fault does not fall into the capable or active fault definitions of the regulatory guides.

Near Augusta, GA, the Augusta Fault and the southeast edge of the Kiokee belt are offset by the north-northeast trending Belair Fault (see Figure 1.4-32). Bramlett et al. (Ref. 196) suggest that the Belair Fault was a tear fault linking two segments of the Augusta fault zone. Within the Atlantic Coastal Plain province sediments, the final stage of movement on the Belair fault occurred during the Cenozoic as high angle reverse faulting that offset the Late Cretaceous uniformity by 30 meters (100 feet) and the Early Eocene uniformity by 12 meters (40 feet).

Hatcher et al. (Ref. 198) suggested that the Modoc shear zone, the Irmo shear zone, and the Augusta Fault are part of the proposed Eastern Piedmont Fault System, an extensive series of faults and splays extending from Alabama to Virginia. Aeromagnetic, gravity, and seismic data indicate that the Augusta fault zone continues in the crystalline basement beneath the Coastal Plain province sediments.

Paleozoic Basement Beneath SRS

Information concerning structural features in the basement beneath Savannah River Site is mainly derived from analysis of structural fabrics recorded in core samples from deep borings and at larger scales from geophysical techniques such as gravity and magnetic surveys and seismic reflection profiles. Seismic reflection surveys were conducted onsite in 1972 and 1987 to 1988 to image the basement reflector. In 1972, Seismograph Services Incorporated did a seismic reflection survey as part of the Bedrock Waste Storage Project. Approximately 60 line miles of survey were completed. This was the first survey that indicated the presence of basement faults, some of which disturbed Coastal Plain sediments. Offset reflectors were interpreted as basement faults. No official report was written for the survey.

During the period 1987 to 1988, Conoco, Inc. (Ref. 278) completed a more thorough seismic reflection survey of SRS (see Figure 1.4-53). The program consisted of two phases, which covered approximately 134 line miles distributed over much of the SRS. These data were used to further define basement faults and to image any shallower or deeper structures. Subsequent seismic reflection and field potential geophysical data have led to various basement fault interpretations (Ref. 265, 269, 270).

These data were reprocessed and re-interpreted at Virginia Polytechnic and State University Regional Geophysical Laboratory (Ref. 269, 290). The overall goal was to produce improved images of the Coastal Plain section and faults known to deform Coastal Plain sediments. Recovery of the shallow time section (40-200 milliseconds) in conjunction with recovery of the deep section (7-14 seconds) led to the discovery of additional faults clearly rooted in the midcrust and deforming Coastal Plain sediments.

An integrated analysis of the structural fabric in the basement core in addition to the geophysical data (Ref. 276, 273) concluded that at least two regional scale ductile faults are present in the basement beneath Savannah River Site and vicinity, the Upper Three Runs fault and the Tinker Creek Fault. These faults are expressed in the aeromagnetic data as lineaments and are interpreted to be associated with a thrust duplex that emplaces the rocks of the PBF Formation (Tinker Creek Nappe) over the DRB formation (Figure 1.4-46). The age of the faulting is constrained by a radiometric age on biotite that dates the movement at about 300 Ma, which would indicate that these faults are part of the Paleozoic Eastern Piedmont Fault System.

In order to resolve faulting that deform Coastal Plain sediments, the topography of the basement surface was mapped utilizing the data listed above along with more recently acquired seismic reflection profiles (Ref. 270). The map of basement topography indicates that offsets of the basement surface that range from approximately 30 meters (100 ft) in magnitude down to the resolution limits of the data are present on the basement surface. However most of these offsets are of relatively small magnitude and have limited lateral extents. Faults that involve Coastal Plain sediments that are considered regionally significant based on their extent and amounts of offset (i.e., Atta, Crackerneck, Martin, Pen Branch, and Tinker Creek) are shown on Figure 1.4-54. The Crackerneck and Pen Branch Faults are relatively well constrained with borings. The other faults are projected from geophysical data only and their parameters are less well known. Of these faults the Pen Branch fault has been extensively studied and found to be not capable or not active (see Section 1.4.3.2).

Mesozoic: Extensional Tectonics and Rift Basins

A broad zone of extended (rifted) continental crust formed along the eastern continental margin of the U.S., especially the southeastern portion during the early Mesozoic when North America broke away from Africa and South America. This region extends from Florida to Newfoundland and includes the area where the SRS exists. The Eastern Seaboard domain as it is identified in Kanter (Ref. 291) encompasses this extended crust and is a sub-domain of the North American stable continental crust. Its significance is that within stable continental crust, areas of extended crust potentially contain the largest earthquakes. The Eastern Seaboard domain is bounded on the west by the western-most edge of Triassic-Jurassic onshore rift basins or the boundaries of the structural blocks in which they occur (see Figure 1.4-34) (Ref. 143, 291, 292). The eastern boundary is the continental/ oceanic boundary which is coincident with the East Coast magnetic anomaly (see Figures 1.4-35) (Ref. 291). Rifted crust is crust that has been stretched, faulted, and thinned slightly by rifting but is still recognizable as continental crust. The faulting is extensional or normal and down-dropped blocks form rift basins.

Geometric and kinematic arguments suggest that early Mesozoic normal faults may have been reactivated Alleghanian faults (Ref. 293, 294). Studies of exposed and buried rift basins in the eastern U.S. show that the faults controlling basin formation are complex, with border faults of variable dip, antithetic faults of variable displacement, and cross or transfer faults that fragment the basin into sub-basins (Ref. 293, 294). Within the SRS region, there is the Dunbarton rift basin (see Section 1.4.3.1), which is part of this tectonic setting. The fault that controls the basin

formation, the Pen Branch fault, initially moved as a normal fault during the Triassic. However, it may have been a reactivated Paleozoic fault, and it has moved since the rifting episode (Ref. 215, 276, 295).

One locus of major extension during early stages was in the South Georgia rift, which extends from Georgia into South Carolina (see Figure 1.4-33). The Dunbarton basin, underlying the SRS, is most likely structurally related to that rift basin (see Figure 1.4-34) (Ref. 215). During the later stage of rifting (early Jurassic), the focus of extension was shifted eastward to the major marginal basins that would become the site of the Atlantic Ocean basin. The extension in the onshore, western-most basins, such as the Dunbarton, Florence, and Riddleville, waned. Eventually, rifting of continental crust ceased as sea floor spreading began in the Atlantic spreading center sometime around 175 Ma (Ref. 143). The oldest ocean crust in contact with the eastern continental margin is late middle Jurassic (Ref. 296). The significance of the age of transition from rifting to seafloor spreading is that the tectonic regime of rifting is no longer acting on the crust in the Eastern seaboard domain. The basins are not continuing to form and for the most part, the crust is quiescent. The modern tectonic environment is partly based on ridge push from the Atlantic spreading center, and recent crustal stress measurements indicate a compressive northeast directed stress for the region (Ref. 297).

Post-Rift and Cenozoic Structures

The following discussion includes tectonic features that have formed on the continental margin since the end of the Mesozoic rift stage (post-rift stage). Therefore, the discussion will include the late Mesozoic, as well as Cenozoic, tectonic elements. Post-rift tectonism is expressed along the eastern continental margin in a variety of structures originating in the crystalline basement and affecting the deposition of sediments and deformation of Coastal Plain sediments from the Cretaceous through the Cenozoic. These structures include offshore sedimentary basins, such as the Carolina trough and the Blake Plateau basin; transverse arches and embayments, such as the Cape Fear arch and the Southeast Georgia Embayment; Coastal Plain faulting; and paleoliquefaction features that provide information on the recurrence of the Charleston earthquake.

Outer Margin Basins

Sedimentary basins along the continental margin (offshore) have formed in response to subsidence in the outer continental margin crust. Outer margin subsidence resulted from 1) the extension and thinning of the crust during early Mesozoic rifting followed by thermal contraction as the lithosphere cooled, and (2) from sediment loading on the lithosphere (Ref. 298-300). The outer margin sediment basins formed on this transitional crust (see Figure 1.4-52). Toward the continent, continental crust was less altered and thicker. This portion of the margin subsided at a slower rate than the outer margin. Because of the differing rates and total amount of subsidence, a hinge zone developed all along the continental margin (Ref. 298). Seaward of the hinge zone the crust is rift-stage continental crust. The crust here has subsided to greater depths. This is also the location of the outer margin basins (see Figures 1.4-35 and 1.4-52). Landward of the hinge zone, the crust is the thicker, unaltered crust. The depth to crust in this region is significantly shallower with a corresponding thinner veneer of post-rift sediments (see

Figures 1.4-35 and 1.4-52). The Atlantic Coastal Plain is located landward of the hinge zone and has been affected by the outer margin subsidence. For detailed discussion on the evolution and structure of the East Coast outer margin basins and the effects within the Atlantic Coastal Plain, see Sheridan and Grow (Ref. 285).

Folding and Arching

Not all tectonism along the continental margin is due to outer margin subsidence. Lithospheric cooling and sediment loading were dominant processes during Middle Jurassic through early Cretaceous. The sediments now present in the outer margin basins are mostly Jurassic and early Cretaceous. Compressional faults, folds and thickness variations in the late Cretaceous and Cenozoic are due to intraplate stress fields rather than margin subsidence (Ref. 200, 301, 302). These latest features are seen as highs and lows in the crust that control Coastal Plain sedimentation and are oriented perpendicular to the hinge zone. They are thought to be indicative of continued, episodic, differential crustal movements (tectonic) from Cretaceous through Pleistocene (Ref. 303). The sedimentary sections are thinner, incomplete on the highs, or arches, and thicker with complete sections in the lows or embayments. The most prominent arch is the Cape Fear arch near the North Carolina-South Carolina border (see Figure 1.4-55). Other arches in the region include the Norfolk arch near the North Carolina-Virginia border, and the Yamacraw arch near the South Carolina-Georgia border (see Figure 1.4-56).

The Cape Fear arch has a variable history, receiving sediments during the Late Cretaceous and then acting as a sedimentary divide or arch from Latest Cretaceous through Late Tertiary (Ref. 298, 304). Upper Cretaceous Santonian sediments are the oldest strata to completely cover the Cape Fear arch (see Figure 1.4-56) (Ref. 298). Paleocene, Eocene, and Oligocene strata comprise 640 meters (2,100 feet) of marine carbonate in the southeast Georgia embayment and thin to the northeast, toward the Cape Fear arch. The sediments become largely terrigenous on the flank of the arch and are completely missing over the crest of the arch; thus suggesting the arch was acting as a sedimentary divide beyond the Oligocene (Ref. 142, 143). Uplift on the arch may have continued through the Pleistocene (Ref. 304).

Faulting

The most definitive evidence of crustal deformation in the Late Cretaceous through Cenozoic is the reverse sense faulting found in the Coastal Plain section of the eastern U.S. Under the auspices of the Reactor Hazards Program of the late 1970s and early 1980s, USGS conducted a field mapping effort to identify and compile data on all young tectonic faults in the Atlantic Coastal Plain (Ref. 305). Consequently, many large, previously unrecognized Cretaceous and Cenozoic fault zones were found (Prowell, 1983). Of 131 fault localities cited, 26 were within North and South Carolina (see Figure 1.4-57). The identification of Cretaceous and younger faults in the eastern United States is greatly affected by distribution of geologic units of that age. Many of the faults reported by Prowell (Ref. 306) are located in proximity to the Coastal Plain onlap over the crystalline basement. This may be due to the ease of identifying basement lithologies in fault contact with Coastal sediments (Ref. 305).

Prowell and Obermeier (Ref. 305) characterized the faults as mostly northeast trending reverse slip fault zones with up to 100 km (62 miles) lateral extent and up to 76 meters (250 feet) vertical displacement in the Cretaceous. The faults dip 40° to 85°. Offsets were observed to be progressively smaller in younger sediments. This may be due to an extended movement history from Cretaceous through Cenozoic (Ref. 305). Based on their similar characteristics Prowell (1988) was able to associate Cretaceous and younger faulting in the Coastal Plain into several Fault Provinces. The Savannah River Site falls in to Prowell's (1988) Atlantic Coast Fault Province. A comparison of Cretaceous and younger faulting in the Savannah River Site (Cumbest and others, 2000) found that faulting on Savannah River Site shared similar characteristics with the faults in the Atlantic Coastal Fault Province including orientation and offset history. This comparison concluded that Cretaceous and younger faulting on Savannah River Site was not unique in comparison to The Atlantic Coast Fault Province in general and as a result shared the same seismic hazard.

Offset of Coastal Plain sediments at SRS includes all four Tertiary unconformities (Ref. 229). Following deposition of the Snapp Formation some evidence indicates oblique-slip movement on the existing faults (Ref. 136). The offsets involve the entire Cretaceous to Paleocene sedimentary section. In A/M Area, this faulting formed a serious of horsts and grabens bounded by subparallel faults that truncate at the fault intersections. The strike orientations of the individual fault segments vary from N 11°E to N 42°E, averaging about N 30°E. Apparent vertical offset varies from 4.5 to 18 meters (15 to 60 feet), but throws of 9 to 12 meters (30 to 40 feet) are most common.

This faulting was followed by erosion and truncation of the Paleocene section at the Lang Syne/Sawdust Landing unconformity. Subsequent sediments were normal faulted following deposition of the Santee Formation. Typically, the offset is truncated at the Santee unconformity, and the overlying Tobacco Road/Dry Branch formations are not offset (Ref. 229). Locally, however, offset of the overlying section indicates renewed movement on new or existing faults after deposition of Tobacco Road/Dry Branch sediments.

In conjunction with these observations of Coastal Plain faults, modern stress measurements provide an indication of the likelihood of Holocene movement. Moos and Zoback (Ref. 307, 308) report a consistent northeast-southwest direction of maximum horizontal compressive stress (N 55-70°E) in the southeast U.S. Their determination is based on direct in situ stress measurements, focal mechanisms of recent earthquakes, and young geologic indicators. Shallow seismicity in the area, within crystalline terranes, is predominantly reverse character (Ref. 309). Moos and Zoback (Ref. 307) conclude that the northeast directed stress would not induce damaging reverse and strike-slip faulting earthquakes on the Pen Branch fault, a northeast striking Tertiary fault in the area. These same conclusions may be implied for the other northeast trending faults mapped by Prowell (Ref. 306).

In A/M Area at SRS, faulting appears to have been episodic and to have varied in style during the Tertiary (Ref. 229). Oblique-slip faulting dominated the Cretaceous/Paleocene events, with a local north-south stress orientation. Subsequently, left-lateral shear on the pre-existing faulting and normal faulting occurred, with a corresponding shift in the direction of maximum compressional stress oriented N 20°E to N 30°E.

Pen Branch Fault

The Pen Branch fault has been regarded as the primary structural feature at SRS that has the characteristics necessary to pose a potential seismic risk. As stated below, studies have indicated that, despite this potential, the fault is not capable.

The Pen Branch fault (see Figures 1.4-46 and 1.4-57) is an upward propagation of the northern boundary fault of the Triassic Dunbarton basin that was reactivated in Cretaceous/Tertiary time. The fault dips steeply to the southeast. In the crystalline basement, slip was originally down to the southeast, resulting in the formation of the Dunbarton rift basin. However, movement during Cretaceous into Tertiary time was reverse movement, that is, up to the southeast (Ref. 310). There could also be a component of strike-slip movement (Ref. 311).

The bulk of evidence collected for the Pen Branch Fault Program supports the conclusion that the most recent faulting on the Pen Branch fault is older than 500,000 years. Therefore, the Pen Branch fault is not a capable fault per 10 CFR 100, Appendix A. In a study designed to examine only the sediments with an age of 1 Ma or less, deformation was not found to exist (Ref. 239).

The Pen Branch Fault was identified in the subsurface at SRS in 1989. It was interpreted from seismic reflection surveys and other geologic investigations (Ref. 126, 278, 295, 312). A program was initiated at that time to determine the capability of the fault to release potentially damaging seismic energy as defined in NRC regulatory guidelines, 10 CFR 100, Appendix A (Ref. 278). Separate actions completed under this program title include the following:

- Shallow drilling of Coastal Plain sediments with eight paired drill holes to bracket the location and the amount of displacement on the Pen Branch fault (Ref. 126, 313)
- Formation of the Earth Science Advisory Committee for independent assessment and verification of the data gathered
- A deep drilling program into the fault zone in basement underlying Coastal Plain sediments
- A high-resolution, shallow seismic reflection survey over the fault trace (Ref. 126, 313, 314)
- Reprocessing Conoco seismic reflection data by geophysicists at Virginia Polytechnic Institute to enhance the shallow portions of the data and then the deeper portions of the data under separate processing protocols (Ref. 269, 271, 283, 290)
- Quaternary geology investigation by Geomatrix to examine the youngest surfaces and deposits onsite for indications of neotectonism (Ref. 239, 240).
- Confirmatory Drilling Project: The final investigation carried out under the 1989 Pen Branch Fault Program. The investigation focused on a small zone over the fault where seismic reflection data had been collected previously and indicated that the fault deforms the subsurface reflector at 200 milliseconds two-way travel time. Eighteen drill holes, two to basement and the others to a depth of 300 feet, were arranged to adequately define the configuration of the layers deformed by the

fault. Boreholes were spaced over a zone of 245 meters (800 feet), north to south. Results suggest that deformation by the fault is limited to the Lang Syne/Sawdust Landing unconformity (~50 Ma) (Ref. 283). Other interpretations may be offered (Ref. 135, 136) where offset on the Pen Branch Fault involved the Tobacco Road and Dry Branch Formations. However, based on presently available data, the Pen Branch fault is not capable.

WSRC thus concludes that the Pen Branch fault is not a capable fault per 10 CFR 100, Appendix A (Ref. 126, 283, 315).

Belair Fault Zone

The Belair fault is a Cenozoic fault located on the inner margin of the Coastal Plain near Augusta, GA (see Figure 1.4-32). The fault was first documented by O'Connor et al. (Ref. 316) and has been further investigated by USGS and others (Ref. 196, 199, 201, 317). The fault is really a set of en echelon faults extending at least 24 km (15 miles) and trending northeast (Ref 199). Individual fault segments are 2 to 5 km (1.25 to 3 miles) long. The fault zone places Late Precambrian phyllites of the Belair belt over Middle Tertiary Coastal Plain sediments. All the faults show oblique-reverse slip movement and as much as 30 meters (100 feet) of vertical offset has taken place since the deposition of the Barnwell Group sediments. Bramlett et al. (Ref. 196) reported that the Belair fault zone has a protracted history of movement in that it initiated as a tear fault on the Augusta fault during the late Alleghanian (Hercynian). The fault was later reactivated as an oblique-reverse slip fault during the Cretaceous. The age of latest movement on the Belair fault zone can only be determined based on available stratigraphic marker horizons. The age of last movement can be bracketed between the age of the sediment that is offset and the age of the stream terrace that caps this strata and is not deformed. The age of the deformed strata can be as young as 40 Ma and the age of the stream fill terrace is between 26,000 and 1,550 years based on carbon-14 dates of peat (Ref. 199). This makes the age determination on the fault uncertain because the age of undeformed deposits capping the deformation is poorly defined and because the fault age can only be bracketed based on deposits that precede a large time period unconformity. However, it has been concluded that the Belair fault zone records movement from late Early Cretaceous through at least Eocene (Ref. 318), which makes the fault approximately 40 Ma.

Buried or Blind Faulting in the Charleston Seismic Zone

Seismic activity in the southeastern U.S. has been dominated by the 1886 Charleston, SC, earthquake, aftershocks, and the continuing low-level seismic activity that persists in the area today. The search for structures to explain seismicity near Charleston has been complicated by the absence of surface faulting, fault scarps, or other fault-generated topographic features. Because the seismic zone is buried in the subsurface, the presence of possible causal geologic structures at depth must be inferred through geophysical methods. Many geologic, geophysical, and seismic studies have been completed by a number of researchers since the mid-1970s resulting in the emergence of some widely diverse models and hypotheses (Ref. 319). A review of the more recent models reveals that uncertainty still exists on details of the causal relationship

between local geologic structures and seismic activity in the region (Ref. 320, 321). However, significant progress has been made.

Most hypotheses relating southeast U.S. seismicity to geologic structure assume activity to occur along preexisting zones of weakness favorably oriented with respect to the ambient stress field. Understanding the regional stress is an essential element in the formation of causative models.

Models developed in the early 1980s involved possible slip along a master decollement located under the coastal plain at a depth of 10-12 km (6.2 – 7.5 miles). This was primarily based on interpretations of deep seismic reflection profiling coupled with an inferred orientation of the regional maximum horizontal stress axes in a northwest-southeast direction (Ref. 289, 321). The implications of this model were that the observed seismicity near Charleston was not particularly unique to that region and that similar large events could potentially occur anywhere east of the Appalachians. However, there were problems associated with this model. They stem primarily from (a) lack of consensus on the existence of a master decollement and (b) subsequent data gathered over the years that establishes the preferred regional maximum horizontal stress axis in a northeast direction, making movement along a decollement unlikely.

Spatial association of buried plutons and seismicity has also been noticed in the Charleston region (Ref. 322, 323). Stress amplification due to rigidity contrasts between plutons and the country rock near these plutons has also been suggested as a mechanism where the mafic or ultramafic plutons lying deep below the ground surface are inferred from localized gravity highs. However, it is unknown if the large contrasts required exist for this model. An alternative explanation suggests that the plutons are symptomatic of a zone of weakness (Ref. 320). Thus, any seismic response to the stress field would occur at the zones of weakness. A problem with this scenario is that mafic bodies defined by gravity highs occur throughout the southeastern U.S., but Charleston remains the only location to show evidence of historical earthquake activity.

Recent Models. Tarr et al. (Ref. 324) noted that eastern U.S. coastal plain seismic activity occurred in distinct zones superposed on a regional background of very low level seismicity. The most active of these zones and the one assumed likely to be associated with the 1886 Charleston event is the Middleton Place-Summerville Seismic Zone (MPSSZ). The MPSSZ lies some 20 km (12 miles) northwest of Charleston well within the mesoseismal area of the 1886 Charleston earthquake. It was in this area that Talwani identified the delineation of two possible intersecting faults when relocating instrumentally recorded earthquakes from 1974 to 1980 (see Figure 1.4-58) (Ref. 325). The first was a shallow, northwest-trending fault defined by hypocenters 4 to 8 km (2.5 to 5 miles) deep striking parallel to the Ashley River. This he named the Ashley River fault. The second fault was labeled the Woodstock fault. The Woodstock fault trends north-northeasterly and is defined by planar distribution of hypocenters with depths between 9 and 13 km 5.6 – 8.1 miles). It intersects and appears deeper than the Ashley River fault. Recent studies by Madabhushi and Talwani (Ref. 279) refine and complement the 1982 effort by utilizing 58 additional well-recorded events located in the MPSSZ from 1980 to 1991 (Ref. 279). Fault-plane solutions from the new data reinforce the northeast-southwest maximum horizontal stress direction of previous studies. However, the epicentral distribution of this new data displayed no obvious pattern of association with the Ashley River fault or the Woodstock fault. Therefore, the seismicity was divided into sets according to focal mechanism in an attempt to infer a structural cause of the earthquakes. Results of this breakout revealed:

- The first set of data favored a northwest-southeast strike and southwest dip direction, suggesting compatibility with the Ashley River fault zone. Solutions were found to have components of mostly strike-slip and/or reverse faulting mechanisms.
- The second set of data was further divided into two subsets with the first displaying mainly vertical fault planes striking north-south and the second subset striking north northeast-south southwest with shallower dips to the southwest. These two subsets were classified as belonging to the Woodstock fault zone. Solutions of these events revealed mostly strike-slip motion on the vertical fault with a strong thrust component on the shallower dipping events.

Results indicated that the Ashley River and the Woodstock faults are not simple planar features, but resemble zones composed of short segments of varying strike and dip. When location was factored into the analyses, it was found that events associated with all sets of data occurred in the same area. From these observations, Madabhushi and Talwani (Ref. 279) conclude that the seismicity in the MPSSZ defines the intersection of two fault zones, which they infer to be the Ashley River fault zone and the Woodstock fault zone.

Paleoseismic Data. Estimating seismic recurrence intervals of moderate to large earthquakes within the southeastern U.S. is difficult. These difficulties stem from the relatively short (300 years) historical record coupled with an absence of surface faulting, offset features, or prehistoric ruptures.

Geologic field study methods developed to extend the seismic record assess both the temporal and spatial distribution of past moderate and large earthquakes. This assessment is carried out through identification and dating of secondary deformation features resulting from strong ground shaking. In the southeast, this extension of the seismic record has been accomplished through field search for earthquake-induced liquefaction flowage features called "sand blows" associated with prehistoric earthquake-induced paleoliquefaction features.

These features are attributed to prehistoric earthquake induced liquefaction as defined by the transformation of sediments from solid to liquid state caused by increased pore water pressure (Ref. 326). The increased pore pressure is caused during or immediately after an earthquake. "Sand blows" are features formed where earthquake shaking causes liquefaction at depth followed by the venting of the liquefied sand and water to the surface.

The following section summarizes paleoliquefaction studies in the southeastern United States. Aspects that are of particular importance to SRS include the following:

- No conclusive evidence of large prehistoric earthquakes originating outside of coastal South Carolina has been found.
- Young fluvial terraces at or slightly above the level of the modern floodplain and Carolina bays are the most likely depositional environments for potentially liquefiable deposits in the SRS region.

Paleoliquefaction Studies in the Eastern United States. Dutton originally reported the widespread occurrence of earthquake-induced sand blows throughout the meizoseismal area of

the 1886 Charleston, SC, earthquake (Ref. 327). Excavation and detailed analyses of these liquefaction flow features provided the first insight into the pre-history of the Charleston earthquake (Ref. 328, 329). Other pre-1886 liquefaction flow features (mostly sand blows) were discovered and investigated near the town of Hollywood, about 25 km (15 miles) west of Charleston (Ref. 330, 331). Searches for sand blows were continued throughout the Charleston area and expanded to the remaining coastal South Carolina areas. Eventually, areas of study were broadened to include Delaware, Virginia, North Carolina, and Georgia (Ref. 332). The objective was to identify other epicentral regions, if they existed, and to estimate the sizes of pre-1886 earthquakes assuming the areal extent of sand blows caused by an earthquake are a function of earthquake intensity in areas of similar geologic and groundwater settings. Figure 1.4-58 shows the study region of current paleoliquefaction areas of interest (Ref. 333). To date, no conclusive evidence of large prehistoric earthquakes originating outside of coastal South Carolina have been found (Ref. 332).

In coastal South Carolina investigations, identification of paleoliquefaction features generally adheres to specific local geologic criteria. Some specific relations between liquefaction susceptibility and subsequent formation of liquefaction features (sand blows) are summarized below (Ref. 332, 333):

- A water-table very near the ground surface greatly increases susceptibility to liquefaction (depth <1 m (<3 feet).
- Virtually all seismically induced liquefaction sites are located in either beach-ridge, backbarrier, or fluvial depositional environments. Of these, beach-ridge deposits were found to be the most favorable for the generation and preservation of seismically induced liquefaction features.
- Due primarily to the effects of chemical weathering, materials older than about 250 ka were less susceptible to liquefaction than were younger deposits. This indicates that the probabilities of sand blows forming in deposits of late Pleistocene and early Holocene age are extremely low.
- The liquefied materials are generally fine-grained, well-sorted (i.e., uniformly graded), clean beach sand. The principal properties of sand that control liquefaction susceptibility during shaking are degree of compaction (measured as relative density by geotechnical engineers), sand-grain size and sorting, and cementation of the sand at grain-to-grain contacts. Fine grained well-sorted sand of ancient and modern beaches are much more susceptible to liquefaction than standard sand used for engineering analyses (Ref. 333).
- Features large enough to be interpreted as possibly having an earthquake origin in the low country were found only in sand deposits having total thickness greater than 2 to 3 meters (7 to 10 feet).
- The depth of the probable source beds at liquefaction sites is generally less than 6 to 7 meters (20 to 23 feet), and the groundwater table is characteristically less than 3 meters (10 feet) beneath present ground surface.

Liquefaction features that typify the coastal South Carolina area have been described as sand blow explosion craters and sand-vents/fissures (Ref. 332).

Sand Blow Explosion Craters or Filled Sand-blow Craters. Following the onset of seismic loading from a moderate to large earthquake, development of sand blow craters can be described by four sequential phases: (a) an explosive phase, (b) a flowage phase, (c) a collapse phase, and (d) a filling phase. These were first described by Gohn et al. based on historical accounts and the internal morphology of exhumed features (Ref. 330). Figure 1.4-59 is a vertical section of a filled sand-blow that is representative of the type observed at most study sites. This feature illustrates characteristics consistent with earthquake-induced liquefaction origin. The soil horizon is cut by an irregular crater and filled with stratified to nonstratified and graded sediments. The fill materials are fine-to medium-grained sand and clasts from the original soil profile, as well as sand from source beds at depths below the exposed C horizon (Ref. 333). Sand-blow explosion craters were found primarily on beach deposits, and are notably absent in fluvial settings (Ref. 332).

Sand-Vents/Fissures or Sand Volcanoes. Sand volcanoes vent to the surface and leave relict sand mounds. These features generally form in circumstances where the liquefying source zone, at depth, is overlain by a cohesive, finer grained, non-liquefiable layer, or "cap". The thickest part of the mound ranges from a few centimeters to as much as 25 centimeters (10 inches). The mounds are generally thickest directly above source feeder vents that extend downward through clay-bearing stratum (Ref. 333). This type of liquefaction feature was rare in beach settings, but commonly found within backbarrier marine sediments and in interbedded fluvial deposits (Ref. 332).

Dating paleoliquefaction episodes can be accomplished either qualitatively or quantitatively. Qualitative methods include degree of staining and weathering of sands within the feature, thickness of overlying profiles, and cross cutting relations of one feature compared to another. A more quantitative approach involves radiometric dating of organic material within or cut by the liquefaction feature. An example of a minimum age constraint is dating of roots that have grown into the feature. A maximum constraint can be determined from roots cut by the feature or by dating organic materials recovered from the collapsed area of the crater during the liquefaction episode. The most accurate estimates for the age of a liquefaction episode are obtained from radiometric dating of leaves, pine needles, bark or small branches that were washed or blown into the liquefaction crater following formation (Ref. 332).

Utilizing the above methods, Amick, and Amick and Gelinas described at least four pre-1886 liquefaction episodes at approximately 580 +104 (CH-2), 1311+ 114 (CH-3), 3250+ 180 (CH-4), and 5124+ 700 (CH-5) years before the present (Ref. 332, 334). CH refers to Charleston source with CH-1 designated as the 1886 earthquake. An even older episode (CH-6) was found to be cut by a CH-5 feature.

Changes in hydrologic conditions (groundwater levels) play an important role in determining an area's susceptibility to liquefaction. On the basis of published sea-level curves, groundwater levels in the southeastern U.S. have been assumed at or near present levels for only the past 2,000 years. Consequently, the paleoliquefaction record is probably most complete for this period (Ref. 334). However, beyond the 2,000-5,000 year range, knowledge of groundwater conditions is considerably less reliable, making gaps in the paleoseismic record much more probable.

Paleoliquefaction at the Savannah River Site. Amick and Gelinas carried out reconnaissance surveys in search of paleoliquefaction sites as far as 65 km (40 miles) inland along the Savannah River (Ref. 354). However, no South Carolina paleoliquefaction surveys or studies have yet been performed as far inland as SRS. Several factors suggest that it would be difficult to locate and evaluate the origin of potential liquefaction features within the geomorphic and geologic environment of the SRS. Investigations elsewhere in South Carolina have shown that aerial photographs are useless for locating 1886 and pre-1886 sand blows (Ref. 332, 333). The SRS region has no Pleistocene beach ridges for sand-blow crater formation. Young fluvial terraces at or slightly above the level of the modern floodplain and Carolina bays are the most likely depositional environments for potentially liquefiable deposits in the SRS region. However, the search for liquefaction features in these areas is severely limited by the lack of access, high water-table conditions, dense vegetative cover, and few exposures.

Existing exposures in the Savannah River fluvial terraces above the modern floodplain were examined by Geomatrix for evidence of liquefaction (Ref. 240). Extensive reconnaissance of the Bush Field and Ellenton terraces on the SRS revealed few exposures of adequate depth and extent to evaluate the presence or absence of liquefaction. Terrace alluvium associated with these terraces contains a high percentage of sand, but based on the degree and depth of pedogenic modification and probable depth to the water-table, these terraces were judged to have had a relatively low susceptibility to liquefaction during the late Pleistocene and Holocene. In this fluvial environment, the most likely liquefaction features are sand vents or fissures. No evidence of sand vents, fissures, or other liquefaction features were observed in any of the available exposures examined by Geomatrix (Ref. 240). Recognition of paleoliquefaction features in the pre-Quaternary deposits at SRS would be extremely difficult, if not impossible.

A paleoliquefaction assessment of SRS was prepared by WSRC in 1996 (Subcontract C001015P). This investigation indicated that several hydrologic, sedimentological, and logistical conditions must be met for seismically induced liquefaction (SIL) to occur and be identified. These included: (1) the presence of Quaternary-age deposits; (2) the presence of a shallow groundwater table; (3) proximity to potential seismogenic features; (4) geologic sections of several different types of unconsolidated deposits; and (5) quality and extent of exposure.

Based on these considerations, the floodplains of the Savannah River and its tributaries were identified as the areas on the SRS with the highest potential for generating and recording Holocene SIL features. The terraces of the Savannah River and tributaries were also considered potential areas for recording Quaternary SIL features, though these features would likely be older than ones in the floodplains. The upland areas on the SRS have a low potential for recording Quaternary SIL because they are pre-Quaternary in age, partially indurated, and generally high above the water table. Paleoliquefaction investigations in the SRS uplands, therefore, only targeted those sites postulated by previous workers as containing evidence of SIL.

Conclusions from this paleoliquefaction assessment fell into two categories: (1) field studies of floodplain deposits along the Savannah River, and (2) evaluation of previously reported paleoliquefaction and neotectonic features located in pre-Quaternary sediments. A brief summary of findings in these two areas follows.

Investigation of banks along 110 km (68 miles) of the Savannah River adjacent to the SRS revealed a large number of excellent exposures of floodplain deposits. Most of the exposed deposits were clay and silt, and had a low liquefaction potential. Locally however, clean sand deposits with a high liquefaction potential were present. Given the extensive amount of exposure and the local presence of liquefiable materials, SIL features would likely be present in these deposits if strong earthquakes had occurred after they were deposited. However, the presence of buried historical objects and radiocarbon dates from these materials illustrated that most or all of the exposed floodplain deposits were historical in age. As no strong ground motions have occurred in historical times in the SRS area, SIL features could not exist in these deposits. Furthermore, the fact that they date to historical times precludes them from providing any information of earlier earthquake history.

The absence of SIL features in the bank exposures does not preclude the possibility that SIL features exist deeper in the section or on the older, higher terraces. In fact, the local presence of liquefiable materials in the Modern floodplain deposits suggests that, if strong prehistoric earthquakes had occurred, SIL features are probably present at depth in the floodplain deposits or on the older/higher terraces. These key areas were not investigated, and exposure is limited.

The upland areas of the SRS were considered to have a low potential for recording Quaternary SIL because the deposits are old (pre-Quaternary), generally high above the water table (>10 meters [>30 feet]), and are indurated. However, previous investigators described several features in the Tertiary section as clastic dikes, and attributed them to SIL and/or neotectonic activity. The sites were evaluated to determine if they have the diagnostic characteristics that have recently been documented for true SIL.

Four types of post-depositional features were identified: (1) irregularly shaped cutans; (2) structurally controlled cutans; (3) joints; and (4) faults. Cutans are a modification of the texture, structure, or fabric of the host material by pedogenic (soil) processes, either by a concentration of particular soil constituents or in-situ modification of the matrix. These features were interpreted through the process of elimination procedure of multiple working hypotheses. None were thought to be the result of SIL. Summary observations of these four elements are given below.

Irregularly Shaped Cutans. The absence of offset on irregularly shaped cutans eliminated the possibility that they were faults, and the undisrupted bedding within and across the feature eliminated the possibility that they were clastic dikes, SIL features, or ice wedges. The higher density of these features near the ground surface and their similarity in appearance to the zone of more intense geochemical alteration at the top of each exposure suggested these features were pedogenic in origin. They were interpreted as an in-situ, pedogenic modification of the texture, structure, and fabric of the host material, and therefore were referred to as "irregularly shaped cutans".

Structurally Controlled Cutans. There was no evidence of rapid injection of liquefied material into structurally controlled cutans. The similarity of the material within the features and that of the host material, as well as undisrupted pebbly horizons within and across the features, demonstrated the features were not clastic dikes, ice wedges, or SIL features. The absence of offset across virtually all of the features demonstrated that they did not develop as faults. They were interpreted to have developed through pedogenic processes based on: (1) the similarity and

relationships that illustrate the features formed concomitantly with the sub-horizontal zone of more intense geochemical alteration at the top of each exposure, and (2) an overall downward thinning and local pinch-out of the features. Strong preferred orientations at most exposures, parallelism with adjacent joints, and their occurrence along fault planes at one locality, suggested that the orientation of most of the features was controlled by pre-existing structures, and were therefore referred to as "structurally controlled cutans".

Joints. Joints are common on the SRS and vicinity. Though their mechanism of formation is not well understood, their age was determined to be constrained by interpretation that cutans often developed along pre-existing joints. The joints, therefore, pre-dated the pedogenic processes that formed the cutans. Highly variable orientations of cutans suggested that the orientation of joints on the SRS was also highly variable. A gradual and consistent change in orientation of cutans over 30 to 60 meters (100 to 200 feet) at some outcrops suggested the orientation of joints also locally changed gradually and consistently. A lack of consistent preferred orientations of joints across the SRS did not favor a tectonic origin for these features. Furthermore, no clear relationship existed between the joint-controlled cutans and the local topography. The joints, therefore, were probably not related to slope mass wasting. A local, gradual change in orientation over several hundred feet, and the common occurrence of closed depressions on the SRS, are consistent with differential settling from subsurface dissolution. This hypothesis was not addressed directly during this study.

Faults. Small scale faults were clearly present at several locations on and adjacent to the SRS. Most faults had normal separations, though one small, sub-vertical feature had a component of reverse motion. All separations observed were less than 1 meter (3 feet). The amount of horizontal slip was not determined for any of the faults. Low, medium, and high angle faults were also present. The presence of cutans on several faults suggested that these faults were older than the pedogenic processes that formed the cutans. A 0.6 meter (2 feet) thick Pliocene loess deposit overlies one fault zone, indicating these faults are probably older than Pliocene. One fault zone was of particular interest because it was located at the approximate upward projection of the Pen Branch fault. Furthermore, the faults in outcrop trended northeast, sub-parallel to the Pen Branch fault. The relationship between the faults in outcrop and the Pen Branch fault, if any, was not investigated.

1.4.4 SEISMOLOGY

1.4.4.1 Earthquake History of the General Site Region

This section includes a broad description of the historic seismic record (non-instrumental and instrumental) of the southeastern U.S. and SRS. Aspects that are of particular importance to SRS include the following:

- The Charleston, SC, area is the most significant seismogenic zone affecting the SRS.
- Seismicity associated with the SRS and surrounding region is more closely related to South Carolina Piedmont-type activity. This activity is characterized by

occasional small shallow events associated with strain release near small scale faults, intrusive bodies, and the edges of metamorphic belts.

HISTORIC RECORD

The earthquake history of the southeastern U.S. (of which the SRS is a part) spans a period of nearly three centuries, and is dominated by the catastrophic Charleston earthquake of August 31, 1886. The historical database for the region is essentially composed of two data sets extending back to as early as 1698. The first set is comprised of pre-network, mostly qualitative data (1698-1974), and the second set covers the relatively recent period of instrumentally recorded or post-network seismicity (1974-present). Sibol and Bollinger created a comprehensive catalog that successfully merged macroseismic, historical pre-network data with instrumental, mostly microseismic, post-network data (Ref. 335). Table 1.4-26 lists significant earthquake locations within 200 miles (327 km) of SRS excerpted from this catalog. Today seismic monitoring results from all southeastern seismic networks are cataloged annually in the Southeast U.S. Seismic Network bulletins. Figure 1.4-60 shows both pre-network and post-network locations of activity for the southeastern U.S., from 1568 to the present within a 200-mile (327-km) radius of SRS.

The information chronicled on earthquakes within the Southeast and the SRS region during the pre-network period consists of intensity data. Intensity refers to the measure of an earthquake's strength by reference to "intensity scales" that describe, in a qualitative sense, the effects of earthquakes on people, structures, and land forms. A number of different intensity scales have been devised over the past century, but the scale generally used in North America and many other countries is the modified Mercalli (MMI) Scale (Table 1.4-27). Using this intensity scale, it is possible to summarize the macroseismic data for an earthquake by constructing maps of the affected region that are divided into areas of equal intensity. These maps are known as isoseismal maps. It was through construction of isoseismal maps that epicenters of pre-network earthquakes were located at or near centers of areas experiencing highest ground shaking intensity. There is considerable uncertainty (up to several tens of miles) in locating the epicenters with this method because it depends heavily upon population density of the region in which the earthquake occurred.

The Charleston, SC, area is the most significant source of seismicity affecting SRS, in terms of both the maximum historical site intensity and the number of earthquakes felt at SRS. The greatest intensity felt at the SRS has been estimated at MMI VI-VII and was produced by the intensity X earthquake that struck Charleston, SC, on August 31, 1886, at 9:50 p.m. local time (see Figure 1.4-61). An earthquake that struck Union County, South Carolina (about 100 miles [160 km] north-northeast of SRS), on January 1, 1913, is the largest event located closest to SRS outside of the Charleston area. It had an intensity greater than or equal to MMI VII. This earthquake was felt in the Aiken-SRS area with an intensity of MMI II-III. Several other earthquakes, including some aftershocks of the 1886 Charleston event, were felt in the Aiken-SRS area with intensities estimated to be equal to or less than MMI IV.

Several large earthquakes outside the region were probably felt at SRS, including the earthquake sequence of 1811 and 1812 that struck New Madrid, Missouri (about 535 miles west-northwest of SRS) and the earthquake that struck Giles County, Virginia (about 280 miles north of SRS),

on May 31, 1897. Bollinger et al. (Ref. 336) judged the temporal completeness of the existing earthquake catalog to be complete for recent network data to mb = 2.5, historical period between 1939 and 1977 complete to mb = 4.5 and the historical period between 1870 and 1930 to mb = 5.7 level.

SRS Activity (within 50 mile radius)

The SRS is located within the Coastal Plain physiographic province of South Carolina. However, seismic activity associated with SRS and the surrounding region displays characteristics more closely associated with the Piedmont province, that is, a marked lack of clustering in zones. The activity is more characteristic of the occasional energy strain release occurring through a broad area of central Piedmont of the state. Epicentral locations for events near (within 50 miles from center of site) SRS are presented in Table 1.4-28. Figure 1.4-62 shows the distribution of earthquake epicenters within 50 miles (80 km) of SRS.

A description of each historical event is presented below. The numbers in parentheses refer to numbers on Figure 1.4-62 and Table 1.4-28.

1897, May 06, 24, and 27 (1,3,4): These three small earthquakes were reported to have occurred around the farming community of Blackville, SC. They were lightly felt by residents of the town and surrounding farms. No intensity values have been assigned to these events as they have only been mentioned as being felt (Ref. 337). When researching local newspapers of the area, the only reference found to any of these small events appeared as a small sentence in the May 13 issue of the *Barnwell People* from Blackville, which said, "Quite an earthquake shock was felt here on last Friday evening at 8:10." No mention of the 24th or 27th events was found in newspapers published shortly following those dates.

1897, May 09 (2): This has been documented as a small "lightly" felt event in the area of Batesburg, SC (Ref. 337). No intensity values have been assigned to this event.

1945, July 26: This event was felt most in the Columbia and Camden, SC areas. Historically it has been more closely associated with Lake Murray, near Columbia, SC. However, Dewy (Ref. 338) relocated it using some instrumental recordings at regional and teleseismic distances. Dewy's relocation moved the epicenter some 50 km to an area southwest of Columbia and to within the 80-km radius of interest for this study. This location, though instrumental, seems extremely questionable. An isoseismal map for this event prepared by Vivanathan ((Ref. 337) defined the area of greatest intensity (VI) to be near Camden, SC. Newspaper reports from Aiken, Columbia and Camden, SC the day following the event tend to confirm this original location. In this case, the location indicated from the intensity felt reports is favored over the Dewy instrumental location.

1972, August 14 (5): Felt reports for this earthquake were reported at Barnwell, Bowman, Cordova, Horatio, North, Springfield, and Summerton, SC with an intensity of between I and III (Ref. 337). Location of this earthquake also seems tenuous. Although the event was instrumentally located, the location can only be assumed approximate because the nearest station was over 100 km northeast of the computed epicenter. It may possibly have occurred closer to the Bowman area and outside the area of interest for this study.

1974, October 28 (6), **and November 5** (7): These two events were estimated to have occurred in McCormick and southern Edgefield counties, South Carolina. Magnitudes of 3.0 and 3.7 respectively were assigned on the basis of felt reports collected at the time. An isoseismal map constructed by Talwani (Ref. 339) for the October event shows an elongated isoseismal roughly following the Fall Line with a maximum felt intensity of III-IV. No instrumental locations are available for either of these events.

INSTRUMENTAL RECORD (POST-NETWORK SEISMICITY)

By the middle of the 20th century, instrumental recordings from a few regional seismographic stations (less than ten for the entire southeastern U.S.) reduced uncertainty in locating epicenters to fewer than 10 miles (16 km). However, it was not until the early 1970s that the detection and location of earthquakes in the region greatly improved with the installation of seismic networks in South Carolina as well as other regions of the eastern U.S.

The first seismic network in the region was deployed by the USGS and the University of South Carolina in 1974. Operation continues today under the management of the University of South Carolina and is known as the South Carolina Seismic Network (SCSN). It currently consists of some 28 stations strategically located throughout the state. By 1976, a three-station short-period vertical component network was also established at SRS to monitor potential earthquake activity near the SRS. A fourth station, consisting of a vertical and two horizontal instruments, was added to the network in 1986. Figure 1.4-63 shows the current station configuration of the SRS short-period seismic recording stations.

With the advent of modern seismic network installation, it was possible to estimate local magnitudes from collected data. Magnitudes are more quantitative estimates of an earthquake's size using instrumentally recorded data. They are based on the amplitude of motion on a standard instrument (seismograph) normalized to account for the separation of the instrument and the earthquake. Within South Carolina and the SRS region, the University of South Carolina developed a duration magnitude scale normalized to the world-wide seismic station in Atlanta, GA, that has been commonly employed since the mid-1970s within South Carolina and the SRS region. Magnitudes reported using the duration scale are approximately equivalent to body wave magnitude. The uncertainty in the instrumentally determined duration magnitudes is about +0.3 magnitude units.

In addition to more accurate determinations of epicenters and magnitudes, a major benefit of instrumentation has been the ability to determine focal depths and focal mechanisms of locally recorded earthquakes. Bollinger et al. (Ref. 336) and Bollinger (Ref. 340) noted that there is a systematic difference between the depths of earthquakes occurring in the Appalachian highlands and those occurring in the Piedmont and Coastal Plain. In the Appalachian highlands, the 90% depth (i.e., the depth above which 90% of all foci lie) is 12 miles (19 km), with a peak in the focal depth distributions at 6 to 7 miles (9.6 to 11.3 km). The corresponding depths for Piedmont and Coastal Plain earthquakes are 8 miles (13 km) and 4 to 5 miles (6.4 to 8 km), respectively. Bollinger et al. (Ref. 336) argue that these depth variations indicate a significant difference in the thickness of the seismogenic crust between the adjacent provinces. Details of this focal depth study can be found in Bollinger et al. (Ref. 336).

Focal mechanism data for the region have been presented by many researchers through the years. A summary of current results can be found in Bollinger et al. (Ref. 336). Madabhushi and Talwani (Ref. 440) present some of the most recent Charleston area data with event relocations and 58 focal mechanism solutions for coastal South Carolina. Most focal mechanisms for the South Carolina-SRS region can be summarized to indicate thrust or strike-slip faulting, with the direction of the P-axis (inferred to be the direction of maximum horizontal compressive stress, oriented in a northeast southwest to east-northeast, west-southwest direction. An updated summary of existing fault mechanism result presented in Figure 1.4-64 is modified from Bollinger et al. (Ref. 336).

INSTRUMENTAL LOCATIONS (POST-NETWORK)

A detailed review of all existing data pertaining to instrumentally located earthquake activity within 50 miles of SRS has recently been completed. The purpose of the review was to refine as much as possible the locations of reported event locations -- both historical and instrumental. Historical activity was addressed above in the previous section and with the exception of the 1945 event the number of reported occurrences and locations did not change. Examination of data associated with instrumentally obtained epicenters revealed that many of the reported events would benefit from using a more detailed velocity model developed since the locations were originally noted. Additionally, waveform data not employed in some of the original locations was added from old records of the SRS network and incorporated into the location algorithm. All new locations were derived using HYPOELLIPSE (Ref. 341). Repeated trial runs revealed that the most stable locations were obtained when P and discernible S arrivals were used from stations within a 100-km radius of the computed hypocenter. HYPOELLIPSE provides a multiple crustal structure option for refinement of locations by allowing the use of varying velocity structure models for groups of stations according to their proximity to geologically differing areas of South Carolina. Varying velocity models have been developed using 20 years of seismic refraction surveys completed throughout South Carolina (Ref. 279, 309). A total of five velocity models covering the entire state of South Carolina were developed from this data. These five velocity models change from one physiographic province to another and have been applied to each recording station accordingly. Further refinement to reflect the structure of a buried Triassic basin (Dunbarton Basin) lying beneath two SRS stations has also been provided.

Relocation results are presented in Table 1.4-28 and plotted on Figure 1.4-62. The solid triangles represent old locations and solid circles represent the new locations. Four events – 26 July 1945, 15 November 1978, 16 January 1979, and 07 January 1992 -- have no circles associated with them because their revised locations either plotted out of our 50-mile (80-km) radius (26 July 1945, and 07 January 1992) or upon closer inspection were discovered not to be real events at all (15 November 1978 and 16 January 1979). Consequently these four events have been removed from consideration as reflected in Table 1.4-28. All relocations showed improvement in quality estimates. The revised locations show few if any changes between triangles and solid circles. The depth estimate parameter returned by the HYPOELLIPSE on all relocated events remained less than 12 km. However, no relocated event had a depth of less than 2.3 km, where original estimates had some events with depths at less than 1 km.

The largest felt event to have occurred within a 50-mile radius of SRS is the August 8, 1993 (09:24 UCT, 5:24 a.m. EDST), Couchton earthquake near Aiken, SC (approximately 40 miles [65 km] north of SRS). It was widely felt throughout the region in Williston, New Ellenton, and the SRS. The MMI intensity for this event was estimated at IV-V with a duration magnitude of 3.2. No alarms were triggered. The location of this event plotted on the flanks of a localized gravity low indicating relation to Piedmont-type activity associated with the boundary of a buried intrusive rather than a large-scale regional feature.

Recorded Activity (Regional)

The distribution of eastern U.S. instrumentally located epicenters essentially coincides with pre-network, historical seismicity. That is, the pattern of historical activity, which is based on larger-magnitude, felt events, is reproduced in the pattern of smaller, instrumentally located events. Bollinger noted a non-random spatial distribution of epicenters with patterns that lie parallel as well as transverse to the northeasterly tectonic fabric of the Appalachians (Ref. 336, 342). Appreciable seismic activity is displayed trending along the Appalachian highlands (i.e., the Blue Ridge) with other broad trends of activity seen primarily in the Piedmont and Coastal Plain provinces of Virginia, South Carolina and Georgia. These apparent trends led Bollinger to a zonal interpretation of southeast regional seismicity that includes the Appalachian zone, Virginia zone, and the South Carolina-Georgia zone (Ref. 342). However, Bollinger modified his earlier interpretation by presenting a broader and simpler zonation concept that includes the dominant regional trend (along Appalachian highlands) and specific zones defined by areas of concentrated activity (see Figure 1.4-60) (Ref. 340).

Results obtained from network data within the South Carolina-SRS region also allowed Tarr et al. (Ref. 324) to identify the Piedmont and Coastal Plain physiographic provinces as two diffuse areas of seismic activity. Through these studies, the Coastal Plain was further divided into three distinct clusters of seismicity that include the Bowman Seismogenic Zone, the MPSSZ, and the Jedburg-Adams Run Seismogenic Zone. The most active zone is the MPSSZ, which is the only one to coincide with the meizoseismal area of the 1886 Charleston earthquake. (Refer to Section 1.4.4.2 for more details on this zone.) Earthquake activity within the Piedmont not associated with reservoir-induced activity can best be characterized by occasional small shallow events associated with strain release near small-scale faults, intrusives, and edges of metamorphic belts.

SRS, On-Site Earthquake Activity

Three earthquakes of MMI III or less have occurred with epicentral locations within the boundaries of SRS. On June 9, 1985, an intensity III earthquake with a local duration magnitude of 2.6 occurred at SRS (Ref. 343). Felt reports were more common at the western edge of the central portion of the plant site. Figure 1.4-65 shows the resulting isoseismal intensity map, and Figure 1.4-66 shows a fault plane solution for this event (Ref. 311, 343). Another event occurred at SRS August 5,1988, with an MMI I-II and a local duration magnitude of 2.0. A survey of SRS personnel who were at the plant during the 1988 earthquake indicated that it was not felt at SRS (Ref. 344). Neither of these earthquakes triggered the seismic alarms (set point 0.002g) at SRS

facilities (Ref. 311, 344). These earthquakes were of similar magnitude and intensity as several recent events with epicenters southeast of SRS (Table 1.4-28).

On the evening of May 17, 1997, at 23:38:38.6 UTC (7:38 pm EDST) an MD ~ 2.3 (Duration Magnitude) earthquake occurred within the boundary of the Savannah River Site. It was reported felt by workers in K-Area and by Wackenhut guards at a nearby barricade. An SMA (strong motion accelerograph) located 3 miles southeast of the epicenter at GunSite 51 was **not** triggered by the event. The SMA located approximately 10 miles (16 km) north of the event in the seismic lab building 735-11A was **not** triggered. The closest instrument to the epicenter (GunSite 51) is set at a trigger threshold of 0.3% of full scale where full scale is 2.0g (0.006g). The more distant lab SMA is set to trigger at a threshold of 0.1% of full scale where full scale is 1.0g (0.001g).

SEISMIC NETWORKS

Local

As discussed above, a short-period seismic network was established at SRS in 1976 with the installation of three single-component vertical stations. In 1987, digital recording capability and a fourth three-component (one vertical and two horizontal) site were added to the network. Other short-period instrumentation has been added through the years to more completely cover the site with the total number of short-period stations currently at eight. In addition to the short-period network a ten station strong motion accelerometer (SMA) network was more recently (1998, 1999) installed throughout the SRS complex.

SMA Network

Ten new SMAs have been installed in selected mission-critical structures at foundation level, other selected elevations and in the free-field. In the event of an earthquake of sufficient size to trigger the installed instrumentation, free-field instrumentation data will be used to compare measured response to the design input motion for the structures and to determine whether the OBE has been exceeded. The instruments located at the foundation level and at elevation in the structures will be used to compare measured response to the design input motion for equipment and piping, and will be used in long-term evaluations. In addition, foundation-level instrumentation will provide data on the actual seismic input to the mission critical structures and will be used to quantify differences between the vibratory ground motion at the free-field and at the foundation level. All instruments are Kinemetrics Etna Strong Motion Accelerographs with dial-up modem data download capability. All SMA instrumentation is set to trigger at 2.0% full scale with full scale being 1g (i.e. trigger set at 0.02g). Figure 1.4-67 shows the current station configuration with specific instrument locations. Numbered locations on the figure correspond to the numbers in parentheses appearing just before location description described below.

A-Area (1) One free-field SMA is located on floor of seismic laboratory.

F-Area	(2) One SMA is located in close proximity to top of tanks in F-tank farm. (3) One SMA is located at foundation level in F-Canyon.
H-Area:	(4,5) Two SMAs are located near H-Tank farm. One at the top of the tanks and one at the bottom. (6,7) Two SMAs are located at H-Canyon. One at elevation on the roof and one at the foundation level. (8) One SMA is located in Replacement Tritium Facility (RTF) at foundation level
K-Area	(9) One SMA is located in K-Reactor building at foundation level
L-Areal	(10) One SMA is located in L-Reactor building at foundation level.
S-Area	(11) One SMA is located at Defense Waste Processing Facility (DWPF)
Other	Two additional SMAs are located in remote field locations at: (12) PAR Pond and (13) Gun Site 51

Short-Period Seismic Monitoring Network (1991-Present)

From 1991 to the present, the following short-period instrumentation has been operated and maintained onsite (see Figure 1.4-63):

- Vertical short-period digital seismic array. This consists of geophones (sensors) placed at different levels within a deep borehole located near the center of SRS to monitor effects of soil column for engineering analysis and design.
- Seven-station continuous-recording short-period telemetered seismic monitoring network for location and depth determination of locally occurring seismic activity.

Regional

To address the regional seismic issues within 150 to 200 miles (240 to 320 km) of the SRS, supplemental support has been provided to the University of South Carolina. This assistance is for operation and maintenance of the SCSN, which includes regional state-wide stations located east of the SRS as well as a small network of stations surrounding the most significant seismic source zone affecting SRS: the Charleston, SC, region. Figure 1.4-68 depicts the station locations for the SRS and surrounding region. This program serves to complement current ongoing local SRS seismic data and studies by providing access to important regional data and reliable independent sources of data and expertise.

1.4.4.2 Relationship of Geologic Structure to Seismic Sources in the General Site Region

Within the southeastern United States, seismicity generally occurs in distinct zones superimposed on a regional background of very low level seismicity. These distinct zones of epicentral distribution are both parallel and oblique to the general northeastern trend of the tectonic

structures in the region. As a general result, the relationship between the observed tectonic structures and seismic activity in the region remains unknown. Therefore, in most instances, the seismic sources are inferred rather than demonstrated by strong correlation with geologic structure. This diffuse characteristic of foci suggests the presence of multiple rather than specific seismogenic structural elements such as small-scale faults, intrusive bodies and edges of metamorphic belts.

In this region, only about 65 percent of the instrumentally recorded earthquakes have focal depth determined, and only then with modest accuracy of about +/- 5 km (3 miles) (Ref. 345). Bollinger et. al. (Ref. 336) estimate that about 90 percent of these earthquakes occur above a depth of 19 km (11 miles) and that this depth defines the thickness of the brittle seismogenic crust (Ref. 345). In the SRS region, the foci peak at about 5 km (3 miles) depth, although there is a smaller peak at about 8 km (5 miles).

For this discussion, we have defined a seismic zone to extend from the Brevard zone in northwest South Carolina to just northwest of Charleston, SC, where another seismic zone has been defined. The length of the zone is about 400 km (250 miles), and the width is 150 km (93 miles) on each side of the Savannah River. This places the SRS in about the center of the zone and includes the COCORP seismic reflections lines in Georgia .

The SRS seismic reflection data reprocessed by Virginia Polytechnical Institute present a remarkably high-resolution image of the crust from within 20 meters of the surface to the Moho. The upper crust is highly reflective and is dominated by southeast dipping bands of laminar reflective packages that are correlatable across the SRS (Ref. 346). Two of the most prominent of these packages appear to correspond to reflections identified in COCORP lines 5 and 8 in Georgia as the Augusta fault and a mid-crustal detachment (Ref. 289, 347). The midcrustal detachment at SRS is a discrete mappable southeastern dipping reflection that occurs at 14-22 km (8.7-13.7 miles) (Ref. 346). The Augusta fault is denoted by a distinct laminar southeast dipping reflector at 3.6-12 km (2.2-7.4 miles) depth (see Figure 1.4-32) (Ref. 346). In the southeastern portion of SRS, reflections from deformed Triassic-Jurassic strata are evident. These reflections are truncated by a complex southeast dipping package of reflections that may mark the detachment along which the Dunbarton basin formed (Ref. 346).

The quality of the reflection seismic data outside of the SRS is not as good except for the ADCOH data at the north northwestern end of the Savannah River Corridor and the COCORP lines 1, 5, and 8 obtained on the Georgia side on the Savannah River. The ADCOH data clearly imaged highly reflective strata of lower Paleozoic age beneath the Blue Ridge allochthon. This interpretation now appears to be generally accepted by most workers in the area. A similar seismic signature has also been imaged on COCORP line 5, suggesting that the lower Paleozoic platform rock extend southeastward at least as far as COCORP line 5 (Ref. 346). If these interpretations are correct, then the master decollement must lie above the highly reflective shelf strata.

Studies of the seismotectonics in central Virginia by Coruh et al. (Ref. 348) have shown a correlation between the distribution of hypocenters and seismic reflectors. They suggest that the earthquake activity might be associated with reactivation along existing faults above a major decollement. The seismic reflection data in the Savannah River Corridor also suggest that not

only is the seismicity similar to that in central Virginia, but it may be related to the seismic reflection data in a similar manner. That is, the seismicity is related to reactivation of existing faults above major detachments (Blue Ridge master decollement and August fault), but in general, does not penetrate below the midcrustal reflections until one approaches the East Tennessee seismic zone at the northwestern end of the corridor.

Although there are uncertainties in the determination of hypocentral depths, the earthquakes in the zone do appear to be localized above what is interpreted to be lower Paleozoic platform rock, which is separated by the master decollement from the overlying allochthon. It is reasonable to suggest that the earthquakes have been localized in the more brittle crystalline allochthon rather than in the more ductile underlying Paleozoic platform shelf strata. Indeed, this is generally the case for all of the seismic zones in the eastern U.S. as pointed out by Bollinger et al. (Ref. 349). Thus, there does appear to be an association of the seismicity with pre-existing structure in the upper 12 km of the brittle crust, which forms the seismogenic zone. This is important in that for earthquakes with a moment magnitude M>5.5, the main shock usually occurs near the base of the seismogenic zone (Ref. 350-352). This may then represent the largest earthquakes that possibly could occur in the SRS region due to the limits on size created by the depth of the seismogenic zone.

1.4.4.3 Development of Design Basis Earthquake

This section describes the basic approach to the development of the Design Basis Earthquake (DBE) spectra for the SRS. Probabilistic hazard, deterministic ground motion prediction methodologies, and the DBE history for the SRS are described. The summary of the evolution of the SRS design basis provides the necessary background for facility construction that spans four decades. This section also describes the DOE seismic criteria. A description of ground motion prediction methodologies is presented in Section 1.4.4.4. Discussions of current design guidance are contained in Section 1.4.4.5.

For engineering design of earthquake-resistant structures, empirically derived seismic response spectra are most commonly used to characterize ground motion as a function of frequency. These motions provide the input parameters used in the analysis of structural response and/or geotechnical evaluation. Response spectra are described in terms of oscillator damping, amplitude, and frequency and are defined as the maximum earthquake response of a suite of damped single degree-of-freedom oscillators. The response spectra are related to earthquake source parameters, the travel path of the seismic waves, and local site conditions. Over the last two decades, SRS response spectra have evolved from the use of a single scaled record of a western US earthquake to a composite spectra that may represent the response of more than one earthquake. In the latter approach, controlling DBEs represent a suite of earthquake magnitude and distance pairs that provide the maximum oscillator response in discrete frequency bands. The basis for controlling earthquakes is derived from detailed geologic and seismologic investigations conducted in accordance with 10 CFR 100 Appendix A and taking into consideration proposed changes as described in Draft 10 CFR 100, Appendix B (Ref. 282). This approach is typically labeled the "deterministic" approach. The primary disadvantage of this approach is that the selection of controlling earthquakes does not explicitly incorporate the rate of seismicity or the uncertainty in earthquake source parameters and ground motion.

An important alternative to the deterministic approach is the Probabilistic Hazards Assessment (PHA). The PHA incorporates the source zone definition and ground motion prediction assessments required for the deterministic approach, but also considers the estimated rates of occurrence of earthquakes, and explicitly incorporates the uncertainties in all parameters. This approach predicts the probability of exceeding a particular ground motion value at a location during a specified period of time. This approach is essential for hazard mitigation of spatially distributed facilities having different risk factors. The current DOE criteria are probabilistic based.

For SRS, design spectral shapes are employed for earthquakes of different magnitudes and travel paths. The following principal spectra have been developed for the SRS using deterministic methodologies or combinations of deterministic methodologies:

- Housner (Ref. 353)
- Blume (Ref. 354)
- Geomatrix (Ref. 355)
- WSRC (Ref. 356)
- WSRC (Ref. 357)
- WSRC (Ref. 358)

Each of these portrays a step in the evolution of the understanding of the seismic process. Because no one facility SAR portrays the evolution of the scientific and technical basis for the DBE, background for development of the DBE is described herein.

The Housner spectra was the response of a single record, the Taft record, from the 1952 Tehachippi earthquake. In contrast, the Blume study developed a composite free-field spectrum that enveloped three postulated events: (1) a random local (<25 km [<15 mile)]), (2) a large earthquake originating near Bowman, SC, and (3) a repeat of the 1886 Charleston, SC, earthquake (Ref. 354). Although different methodologies were used to develop response spectra, the Geomatrix study used the same three earthquake sources except that the 1886 Charleston earthquake was increased slightly in magnitude and moved a few tens of km closer to the site (Ref. 355). In both Geomatrix and Blume investigations, the postulated Bowman earthquake did not control motions at any spectral frequency; consequently, only two controlling events were modeled: the random local earthquake and the larger, more distant, Charleston event.

The Housner and Blume spectra were based on western U.S. strong motion data, because strong motion data were unavailable at that time in the eastern U.S. for earthquake magnitudes and distances necessary for design. Since the Blume study was conducted, ground motion studies have shown that seismic path and site properties are very different between the eastern U.S. and western U.S. Current analytical approaches directly estimate spectra by using SEUS Coastal Plain conditions to model path effects on wave propagation (Ref. 357).

Current design basis spectra are based on a hybrid of deterministic and probabilistic approaches. Some analyses (e.g., RTF and H-Area facilities) have required site-specific design basis motion for determination of liquefaction susceptibility and structural integrity.

CRITERIA

Seismic design criteria for nonreactor DOE facilities are contained in DOE Order 420.1 and DOE-STD-1020-94 and DOE-STD-1024-92 (Ref. 59, 359, 361). Additionally, criteria can be found in DOE STD-1022-94 (Ref. 139).

Earlier estimates of ground motion for SRS critical facilities have generally adopted U.S. NRC regulatory guidance provided in 10 CFR 100, Appendix A (Ref. 282). This deterministic guidance was applied, for example, at K-Reactor. However, the more recent seismic evaluations have employed the probabilistic guidance contained in DOE-STD-1024-94 and DOE-STD-1023-95 (Ref. 361, 362).

DOE Order 420.1 provides requirements for mitigating natural phenomena hazards that include seismic, wind, flood, and lightning (Ref. 359).

DOE-STD-1020-94 defines the performance goals for seismic, wind, tornado, and flood hazards (Ref. 59).

DOE-STD-1021-93 provides guidelines for selecting performance categories of Systems, Structures, and Components (SSCs), for the purpose of Natural Phenomena Hazard (NPH) design and evaluation (Ref. 363). This standard recommends general procedures for consistent application of DOE's performance categorization guidelines.

DOE-STD-1020-94 and DOE-STD-1024-92 require the use of median input response spectra that are determined from site-specific geotechnical studies and anchored to Peak Ground Accelerations (PGAs) determined for the appropriate facility-use annual rate of exceedance (Ref. 59, 361). Guidance regarding the specific characterization of seismic hazard is found in the Systematic Evaluation Program guidance and DOE-STD-1022-94 (Ref. 139).

DOE-STD-1024-92 was an interim standard which requires deterministic and probabilistic methodologies be used for hazard evaluation, and superseded by DOE-STD-1023-95 (Ref. 361, 362). The guidelines for probabilistic hazard analyses are: (1) sites can use a combined Electric Power Research Institute (EPRI) and Lawrence Livermore National Laboratory (LLNL) result if applicable, or (2) complete a new estimate using site-specific data including definition of source zones, earthquake recurrence rates, ground motion attenuation, and computational methodologies that are spelled out in the Systematic Evaluation Program.

DOE-STD-1023-95 provides guidelines for developing site-specific probabilistic seismic hazard assessments, and criteria for determining ground motion parameters for the design earthquakes (Ref. 362). It also provides criteria for determination of design response spectra. Five performance categories are specified, from Performance Category 0 (PC0) for SSCs that require no hazard evaluation, to design of PC4, a desired performance level comparable to commercial nuclear power plants. These criteria address weaknesses in prior guidance by specifying Uniform Hazard Spectrum (UHS) controlling frequencies, requiring a site-specific spectral shape and a historic earthquake check, to assure that the DBE contains sufficient breadth to accommodate anticipated motions from historic earthquakes above moment magnitude (Mw) 6.

The fundamental elements of the criteria for higher hazard nuclear facilities (PC3 and PC4) are as follows:

1. A probabilistic seismic hazard assessment (PSHA) must be conducted for the site (or use an existing PSHA that is less than 10 years old).
2. A target DBE response spectrum is defined by the mean UHS.
3. Mean UHS shapes are checked by median site-specific spectral shapes, which are derived from de-aggregated PSHA earthquake source parameters. The median site-specific spectral shapes are scaled to the UHS at two specific frequencies (average 1-2.5, and 5-10 Hz).
4. Estimated site-specific ground motions from historical earthquakes (significant felt or instrumental with Mw > 6) are developed using best estimate magnitude and distance.
5. Spectral shapes are adjusted until DBE response spectra have a smooth site-specific shape.
6. Probabilistic assessment of ground failure should be applied if necessary (i.e., wherever there may be instances of liquefaction or slope failure).

Recently, NEHRP-97 (Ref. 364) criteria have been adopted by WSRC and DOE for evaluation of spectra for PC1 and PC2 facilities and structures (Ref. 358). DOE-STD-1023-95 (Ref. 362) allows the use of building codes and/or alternate design criteria for PC1 and PC2 design. The NEHRP design criteria is defined as 2/3 of the maximum considered earthquake ground motion (i.e., 2/3 of the 2500 year UHS).

HISTORICAL PERSPECTIVE ON DESIGN BASIS EARTHQUAKES AT THE SAVANNAH RIVER SITE

Because maximum potential causative fault structures within the Coastal Plain, Piedmont, and Blue Ridge provinces are not clearly delineated by lower-level seismicity or geomorphic features, past regulatory guidance prescribes the use of an assumed local earthquake. The magnitude/intensity is conservatively assumed to be a repeat of the largest historic event in a given tectonic province located at that province's closest approach to the site. Application of this guidance has resulted in the definition of two controlling earthquakes for the seismic hazard at SRS. One earthquake is a local event comparable in magnitude and intensity to the Union County earthquake of 1913 but occurring within a distance of about 25 km (15 miles) from the site. The other controlling earthquake represents a potential repeat of the 1886 Charleston earthquake. Selection of these controlling earthquakes for design basis spectra has not changed significantly in over 20 years. However, the assumed maximum earthquake moment and magnitude estimates have increased in the more recent assessments of the 1886 Charleston earthquake. In addition, the assumed distance to a repeat of the 1886 Charleston-type earthquake has slightly decreased.

Until the late 1980s, investigations performed for the NRC focused on the uniqueness of the location of the Charleston earthquake, due to a lack of knowledge of a positive causative

structure at Charleston. At issue was the possibility of a rupture on any one of the numerous northeast-trending basement faults located throughout the eastern seaboard. Further, there were no obvious geomorphic expressions that might suggest large repeated faulting.

Evidence that defines the Charleston Seismic Zone (CSZ) is as follows:

- The detailed analyses of isoseismals following the 1886 Charleston earthquake (Ref. 327, 365).
- Instrumental locations and focal mechanisms of seismicity defining the 50-km long Woodstock fault lineament, which closely parallels the north-northeast trending Dutton isoseismals
- The remote-sensed 2.5-meter high, 25-km long lineament that also parallels the Woodstock fault (Ref. 366, 367).

Paleoliquefaction investigations along the Georgia, North and South Carolina coasts (Ref. 332, 333) have identified and dated multiple episodes of paleoliquefaction that have constrained the latitude of the episodes (Section 1.4.3.2). Crater frequency and width are greatest in the Charleston area, and decrease in frequency and width with increased distance along the coast, away from Charleston. This evidence led the NRC in 1992 to its position that a repeat of the Charleston earthquake was assumed to be restricted to the Charleston, Middleton Place region. NRC guidance for the nearby VEGP commercial nuclear power plant has, therefore, been based on an assumed recurrence of the 1886 Charleston earthquake in the Summerville-Charleston area (Ref. 355). Sporadic and apparently random low level seismicity is characteristic of the Coastal Plain and Piedmont geologic provinces (excepting clusters of seismicity in Bowman and Middleton Place). Regulatory guidance has prescribed a design basis local event to occur at a random location within a specified radius of the site.

The following sections contain, for historical reasons, brief summaries of the important deterministic and probabilistic seismic hazard investigations that have been conducted at or applied to various facilities at the SRS.

Housner

The earliest spectra used at SRS were developed by Housner who used a 5% damped response from the 1952 Taft earthquake (Ref. 353, 368). For a repeat of the Charleston earthquake, Housner predicted 0.1g at SRS and conservatively recommended 0.2g for the DBE. These spectra were used in an early evaluation of the seismic adequacy of production reactors at the site, but are no longer considered acceptable for design basis analysis.

Blume

Recommended site acceleration and spectra in the Blume analysis were based on conservative assumptions for the occurrence of specific earthquakes (Ref. 354). The anticipated ground motions from those events were developed from recorded earthquakes and synthetic seismograms for those postulated events. A probabilistic hazard evaluation was also done. Two

hypothetical earthquakes consistent in size with earthquakes that have occurred in similar geologic environments were found to control SRS spectra and peak ground motion: (1) a hypothesized site MM intensity VII local earthquake of epicentral intensity VII causing an estimated site PGA of 0.10g; and (2) a hypothetical intensity X (1886 Charleston-type), occurring at a distance of 145 km causing an estimated site PGA of <0.1g. For added conservatism, the site PGA was increased to 0.2g, this corresponded to a site intensity of VIII (see Figure 1.4-61).

The PHA indicated that the mean annual rate of exceedance of $2x10^{-4}$, corresponding to 0.2g, was comparable to those probabilistic hazard studies developed for nearby nuclear power plants. The spectra also compared well to LLNL report UCRL 53582.

In the Blume study, the following three seismogenic source regions were considered for ground motion assessment:

- Appalachian Mountains including the Piedmont and Blue Ridge geologic provinces assessed at a maximum intensity VIII.
- Atlantic Coastal Plain, including SRS, assessed at a maximum intensity VII.
- The CSZ with an epicentral intensity of X. A hypothetical Charleston event was also assumed to occur at Bowman for the purposes of estimating the distance for the attenuation of ground motion.

The length of the 1886 Charleston seismogenic zone was estimated as 50 km based on the elongation of the highest intensity isoseismal and on the length and location of the inferred Woodstock fault as determined by instrumental location and mechanisms of earthquakes (Ref. 327, 366). A displacement of 200 cm was estimated for the Charleston event based on the source dimension and the seismic moment. The source mechanism was assumed to be similar to the mechanisms recorded along the Woodstock fault: steeply dipping right lateral strike-slip fault oriented N10°E.

The estimated PGAs for postulated maximum events were based on the following:

- A local earthquake of MMI VII as a maximum credible earthquake (MCE) for the Atlantic Coastal Plain.
- A Fall Line event, MMI VIII with distance > 45 km, is an MCE for the Piedmont.
- A Middleton Place event of MMI X, a repeat of the Charleston 1886 earthquake
- A Bowman, MMI X, a postulated and considered extremely unlikely occurrence of a 1886 type-event at closest credible distance of 95 km.

Blume applied a confidence margin of one intensity unit to the estimates in Table 1.4-29, resulting in a site intensity of VIII with a corresponding doubling of the estimated PGA (to 0.2g). Using the PHA, Blume noted that a doubling of the PGA results in an approximate order of magnitude smaller probability of exceedance.

Local and distant earthquake response spectral shapes were derived from statistical analysis of primarily western U.S. (western) data. The recommended response spectra were computed from the envelope of the mean spectral shapes (see Figure 1.4-69).

Geomatrix (K-Reactor)

In a manner similar to Blume, Geomatrix performed a deterministic analysis following NRC SRP 2.5.2 for K-Reactor (Ref. 355). The resulting spectra were developed for a distant Charleston source and a local source. The Charleston source was modeled for a moment magnitude (Mw) 7.5 using the Random Vibration Theory (RVT) model. Site-specific soil data were used to address the impact of local conditions of the spectral content. The local source assumed a Mw 5 and used empirical western U.S. deep soil strong motion data corrected for eastern U.S. soil and rock conditions. The 5% damped spectra for the two hypothetical controlling earthquakes are illustrated in Figure 1.4-69.

The primary uncertainty related to the 1886 Charleston earthquake moment magnitude estimate was the interpretation of intensity, which was derived from Dutton's damage patterns (Ref. 369). The fault rupture width was estimated to be 20 km based on a range of deepest Coastal Plain hypocenters (Ref. 355). The rupture length was determined from regressions of world-wide M_O vs. rupture area. From the rupture dimensions and moment, Geomatrix estimated a stress-drop of 65 bars and an average displacement of 400 cm.

The Bowman seismicity zone, located in the Coastal Plain province, consists of M3.5-4.0 events occurring along a northwest trend from Charleston. Because of the timing and mechanisms of events, they are not believed to be associated with the CSZ. The largest historical earthquake in the Piedmont Province was the 1913 Union County earthquake having an epicentral intensity of VI-VII. Based on Johnston isoseismal areas, that earthquake was estimated to be Mw 4.5. The largest Appalachian province earthquake was the 1875 Central Virginia event of MMI VII and Mw = 4.8. These earthquakes suggest Mw_{max} of 5.0 for Bowman, but because it was part of a diffuse north-west trend, Geomatrix used 6.0 for conservatism. The Bowman earthquake did not control site motions (similarly to the Blume study) and consequently was not used in specification of design basis motions.

For the local earthquake, the occurrence of a random earthquake within 25 km of K-Reactor was assumed. With the largest site vicinity events limited to magnitude range 2–3, regulatory guidance suggests using largest historical events in the Piedmont Province: $M_{wmax} = 5.0$.

Geomatrix developed 5% damped response of the horizontal component from an Mw 7.5, 150 bar stress drop Charleston-type earthquake using the parameters described above (see Figure 1.4-69). The vertical component of motion was estimated to be half the horizontal. Table 1.4-30 summarizes the source parameters and predicted motions from these earthquakes.

Statistics for the Geomatrix local earthquake were selected following the approach outlined by Kimball using strong motion records from earthquakes of Mw 5.0 ± 0.5 within 25 km of epicenter (Ref. 370). The Geomatrix local earthquake spectral shape was scaled per DOE-STD-1024-92 guidance (Ref. 361).

Evaluation Basis Earthquake Spectra

For the 1993 liquefaction studies at RTF, the design basis envelope spectra contained in the Blume report were not recommended because the spectra were not representative of a specific earthquake (Ref. 371). Seismic hazard results show that the site can be characterized by local events with R <25 km, controlling the PGA. Larger events, at some distance from the site, controlled peak ground velocity at SRS. These results compared favorably with the deterministic analyses performed for the site by Blume and Geomatrix.

The controlling earthquakes used in the liquefaction study at RTF were selected to be consistent with the DOE probabilistic acceptance criteria (Ref. 59, 371). A spectral shape was taken from the local event spectra developed for K-Reactor (Ref. 355). The distant event spectra were recommended unscaled (see Figure 1.4-69). The results were then compared to the past deterministic study of Blume and the disaggregated LLNL and EPRI hazard analyses. Induced stresses were calculated for the liquefaction analysis based on the two controlling earthquakes. Separate analysis is warranted based on the difference in shape of the two spectra.

The RTF spectra were later named the Evaluation Basis Earthquake (EBE), and used to support initial geotechnical evaluations for the ITPF and H-Area Tank Farms. The EBE spectra were used until site-specific spectra could be developed to judge adequacy. The EBE spectra, which account for local and distant earthquakes, were consistent with DOE criteria, and were used for the initial geotechnical evaluation.

WSRC (H-Area Spectrum)

Following initial site-specific evaluations done for the ITPF and H-Area, a revised spectrum (84^{th} percentile deterministic spectrum) was developed and recommended for structural engineering and geotechnical analysis of facilities in H-Area (Ref. 356). The geotechnical analysis utilized the basement results in a convolution analysis and the structural engineering groups developed an envelope for use in analysis of SSCs. The resulting structural design spectrum envelope is shown in 1.4-70.

The fundamental change was to the distant earthquake component. The parameters used to develop a 50^{th} and 84^{th} percentile spectra were site-specific soil and revised stress drop for a Charleston earthquake.

EPRI and LLNL hazard spectra were used to estimate the probability of exceedance of the spectra. The local event spectrum was unchanged from the EBE. The resulting local and distant spectra were then enveloped into a surface design spectrum 1.4-70.

WSRC (PC-3 And PC-4 Site-Wide Design Spectra)

The site-wide design spectra fully implement DOE-STD-1023-95 (Ref. 357, 362). DOE-STD-1023-95 specifies a broadened mean-based UHS representing a specified annual probability of exceedance (for an SSC performance category) and a historical earthquake deterministic spectrum that ensures breadth of the UHS. For the SRS, the deterministic spectrum

is represented by a repeat of the 1886 Charleston earthquake. The development of the SRS design basis spectra uses a statistical methodology to verify that a mean-based response is achieved at the soil free surface.

The design spectra were intended for simple response analysis of SSCs and are not appropriate for soil-structure interaction analysis or geotechnical assessments. The design basis spectra for PC3 and PC4 are given in Figures 1.4-71 and 1.4-72, respectively.

The EPRI and LLNL bedrock level uniform hazard spectra were averaged and broadened per DOE-STD-1023-95 (Ref. 362). Available SRS soil data were used to parameterize the soil shear-wave velocity profile. The parameterization was used to establish statistics on site response for ranges of soil column thickness present at the SRS. The mean soil UHS was obtained by scaling the bedrock UHS by the ground motion dependent mean site amplification functions.

The soil data used to develop the sitewide spectra incorporate the available SRS velocity and dynamic property database available to about mid-1996. The spectra are based on soil properties and stratigraphy from specific locations at the SRS, and are parameterized to represent the variability in measured properties. Because of the potential for variation of soil properties in excess of what have been measured at the SRS, the design basis spectra are issued as "committed" in accordance with the WSRC Quality Assurance Manual 1Q (Ref. 372). The open item is the soil column variability used in the calculations. To eliminate the open item and upgrade the design basis spectrum to "confirmed," the soil parameters available at the specific site or facility where it is being used must be reviewed and determined to be consistent with the data parameterized in the study.

Comparison of PC3 and PC4 design spectra to the SRS interim spectrum and the Blume envelope spectrum are shown in Figure 1.4-73 (Ref. 354, 357). There is broad general agreement between the PC3 and interim spectral shape. The SRS Interim Spectrum shape is significantly more conservative in the 0.5 to 2.0 Hz frequency range compared to the PC3 spectrum because the interim shape enveloped the 84th percentile Charleston deterministic spectrum rather than the 50th percentile as required by DOE-STD-1023-95 (Ref. 362). Comparisons of the Blume 0.20g anchored spectrum to the PC3 design spectrum indicate significant shape differences. The Blume spectrum was derived from deep soil recordings of western U.S. earthquakes and is not representative of eastern U.S. spectral shapes. The spectra show a generally more broadened shape as compared to the Blume spectra (see Figure 1.4-73). Low frequencies are enhanced with respect to Blume because the Blume spectra do not contain the fundamental site resonance (about 0.6 Hz). High frequencies are also enhanced with respect to Blume because of the difference in eastern and western U.S. attenuative properties. Both the PC3 spectrum and the Blume spectrum have a dynamic amplification of about 2.7 at 3 Hz. The significantly larger Blume PGA scaling factor causes the excess (as compared to the design basis spectrum) spectral values at the mid-range.

WSRC (PC1 And PC2 Site-Wide Design Spectra)

Design spectra guidelines for PC1 and PC2 facilities are reported by Lee (Ref. 358). The PC1 and PC2 design spectra were derived using DOE-STD-1023-95 guidelines and NEHRP-97

(Ref. 364) design criteria and account for the wide range in SRS material properties and geometries including soil shear-wave velocities, uncertainty or range in soil column thickness, and type of basement material. Additional design guidance is contained in the current revision of WSRC Engineering Standard 01060 (Ref. 373).

SRS-SPECIFIC PROBABILISTIC SEISMIC HAZARD ASSESSMENTS

An SRS-specific probabilistic seismic hazard assessment (PSHA) is critically dependent upon the local geological and geotechnical properties at the site or facility location. Past PSHAs, specifically those conducted by EPRI (NEI, 1994) and LLNL (Bernreuter, 1997; Savy, 1996) for the SRS, did not incorporate these detailed site properties and consequently, those soil hazard results were not appropriate for use at the SRS. An SRS-specific PSHA should account for soil properties derived from site geological, geophysical, geotechnical and seismic investigations (WSRC, 1997). An SRS-specific PSHA was developed using bedrock outcrop EPRI and LLNL hazard and SRS site properties including soil column thickness, soil and bedrock shear-wave velocity, and dynamic properties (WSRC, 1998).

The bedrock seismic hazard evaluations used for the SRS-specific soil surface hazard were the EPRI and LLNL results for bedrock for the SRS and vicinity (a later evaluation was completed using the U.S. National Map bedrock seismic hazard (WSRC, 1999, Frankel et al., 1996)). These evaluations did not revise or confirm in any way the experts' evaluations of activity rates, seismic source zonation, or the decay of ground motion with distance used in the LLNL or EPRI seismic hazard assessments. The analysis results in a SRS-specific hazard evaluation for a soil site by continuing the hazard from bedrock to the soil surface using detailed soil response functions. Earthquake magnitude and ground motion level dependence of the site response is accommodated by applying site response functions consistent with the distribution of earthquake magnitude and ground motion levels obtained from dissaggregating the bedrock uniform hazard spectrum.

Frequency and ground motion level dependent soil amplification functions (SAFs) developed in WSRC (1997) were used to account for the observed variations in properties throughout the SRS including: soil column thickness, stratigraphy, shear-wave velocity, and material dynamic properties, as well as basement properties. SAFs (frequency dependent ratio of soil response to bedrock input) were derived in WSRC (1997) by performing a statistical analysis of the response of bedrock spectra through realizable soil columns bounded by the observed variations in soil-column properties over the SRS. Ground motion level dependent distributions of SAFs were derived for each of 6 soil categories: three on crystalline basement and three on Triassic basement. Those SAF distributions were used to compute soil surface hazard.

The methodology to compute soil surface hazard was formalized by Cornell and Bazzurro (1997). The technique is to difference the bedrock hazard disaggregation for a suite of bedrock motions and sum the probability of exceedance (POE) of surface motions using the appropriate

magnitude and ground motion level-dependent soil/rock transfer functions. The approach yields soil surface hazard that would be obtained from correctly applying local site soil transfer functions to the ground motion attenuation model used in a PSHA. The analysis is repeated at the oscillator frequencies available in the bedrock hazard disaggregation and for each soil column thickness and bedrock type. The envelope of the hazard curves is taken from the soil and bedrock categories.

The curves represent hazard at the top of the soil column for oscillator frequencies of 1, 2.5, 5 and 10 Hz (Figure 1.4-7new). Open symbols on the dashed lines indicate extrapolation beyond either the LLNL or EPRI bedrock hazard values. Solid lines are computed soil surface hazard derived from the bedrock hazard disaggregations and distributions on soil transfer functions. Application of the hazard curves to PC3 and PC4 facilities require additional site-specific data to validate that the facilities properties are well represented by the SRS-specific properties.

High and low probability extrapolations of bedrock hazard curves were made to meet the ranges of probability required for engineering risk assessments (annual probabilities as low as 10^{-7} were considered). Soil surface hazard results computed in the range of bedrock hazard extrapolations are considered more uncertain. Consequently, computed ground surface hazard curves for annual probabilities greater than about 10^{-2} or less than about 10^{-6} should be used with caution. These results were computed using a 3-□ truncation on the ground motion probability of exceedance and a lower bound of 0.5 on the SAF.

PSHAs developed for the SRS prior to the LLNL and EPRI studies (i.e., Coats and Murray, 1984, URS/Blume, 1982) as well as the hazard derived from the combination of the original EPRI and LLNL soil surface hazard (Wingo, 1994), were derived for PGA only and did not use SRS-specific soils data. Historically, engineering applications and earthquake design used PSHAs that were PGA-based, a practice that has diminished for the last 20 years because of improved interpretations from broader-band seismic recording and the better understanding of the broad-band nature of seismic hazard. The engineering use of PGA PSHAs is neither recommended nor consistent with DOE-STD-1023.

1.4.4.4 Ground Motion Prediction Methodologies

This section briefly describes current ground motion prediction methodology and earthquake source, path, and site assumptions used for H Area, the most recent DBE work conducted for the SRS.

RANDOM VIBRATION THEORY (RVT) MODELING

To model ground motion, an RVT model (also called Band Limited White Noise) is used to estimate ground motion for the distant Charleston-type event (Ref. 374, 375). The RVT model is widely accepted and, with proper parameterization, is found to predict ground motion as successfully as empirically derived relationships (Ref. 376). Because of the model's simplicity, computational speed, ability to parameterize source, geometrical spreading, crustal attenuation, and site response, it is ideally suited to quantifying ground motion. The RVT methodology appears to be well suited in geologic environments where empirical strong motion data may not exist in the earthquake magnitude and distance ranges of interest. Nonlinear wave propagation within the soil column is accounted for by using a computer modeling program, such as SHAKE, or equivalent approach.

EARTHQUAKE SOURCE PARAMETERS

This section discusses the earthquake source parameter uncertainty affecting ground motion prediction for the SRS. Source parameters for the "distant event" or Charleston-type earthquake have been the most contentious in past design studies. Figure 1.4-61 shows a distance from the SRS site center to the 1886 Charleston MMI X isoseismal contour of approximately 120 km. The SRS center to the southern end of the Woodstock fault is approximately 130 km. The center of SRS to the center of the 1886 MMI X isoseismal, close to Middleton Place and central to Dutton's isoseismals, measures approximately 145 km. URS/Blume used 145 km as the distance from the SRS center to the 1886 Charleston earthquake epicenter (Ref. 354). Current ground motion studies analyze a recurrence of the 1886 event with a distance of 120 km. For estimates of median ground motions for a recurrence of the 1886 earthquake, a source distance of 120 km is conservative since the center of the isoseismal zone is at a distance of approximately 145 km.

For simplicity, the RVT models of ground motion assume a point source. The effects of focal depth and crustal structure on predicted ground motion are described in Lee (Ref. 356).

The distance and stress drop effects on rock motion predictions for a repeat of the Charleston Mw 7.5 event were described in Lee (Ref. 356). The 100-150 bar range in stress-drop is a probable range for the median value of an eastern U.S. earthquake. Somerville et al. (Ref. 377) found a value of 100 bars as the median stress-drop for eastern U.S. earthquakes; the EPRI guidelines (Ref. 376) report estimated a value of 120 bars as a median for stress drop, from data with reported stress-drops in the range of 20-600 bars.

Prior ground motion studies for SRS have used expected or median stress drops of 100-150 bars for a Charleston-type event. Peak ground motion is sensitive to the selection of stress drop (Ref. 356).

The 1886 isoseismal data are consistent with ground motion models with a slightly reduced earthquake moment magnitude of Mw 7.3, but with a corresponding higher stress-drop. The favored median model uses a Mw 7.3 at 120 km and stress drop of 150 bars (Ref. 357).

BEDROCK AND CRUSTAL PATH PROPERTIES

Ground motion estimates used a modified Herrmann crustal model developed from surface wave dispersion from Bowman, SC, to Atlanta, GA (Table 1.4-31) (Ref. 357, 378).

For geometrical attenuation, a plane-layered crustal model approximation by Ou and Herrmann is used that accounts for the post critical reflection (Ref. 379). The effect of this approximation is to decrease the attenuating loss between about 80-120 km. Using a point source and the local crustal structure for the Charleston event, the attenuation model predictions were found sensitive to source depth and source distance.

For development of the RVT rock spectra, anelastic attenuation is accounted for in two ways: (1) the crustal path operator Q that is frequency dependent; and (2) the site-dependent factor Kappa, related to Q by H/(Vs*Qs). Where Qs is the average quality factor over a several kilometer range of the near surface rock. The preferred Q model for these investigations is EPRI (Ref. 376).

The best mean EPRI model is given by (Ref. 376):

$$Qc = Qo*(f/f_o)^n = 670*f^{0.33} \quad \text{(Eq. 1.4-4)}$$

The ranges of the rock site attenuation operator Kappa are estimated to be 0.010-0.004 seconds with a median of 0.006 seconds (Ref. 376). RVT calculations for the SRS ground motion predictions use this median value of 0.006 seconds for Kappa.

For SRS ground motion predictions, bedrock properties underlying most of the SRS facilities are assumed uniform with a Vs of approximately 3.4 km/s(11,500 fps). For facilities situated above the Triassic rift basin (Dunbarton basin), filled with 3 km (1.8 miles) of sedimentary rock, a Vs estimated to be 2.4 km/s (8,000 fps) is used. This basin is surrounded by crystalline rock. For a first approximation to the ground motion effects of the basin, a one-dimensional plane-layer model is used to approximate the effect of contrasting velocities.

SOIL PROPERTIES

The SRS is located on soils (sedimentary strata) ranging in thickness from 180 to 460 meters (600 to 1,500 feet) overlying crystalline or Triassic basement. A sitewide design basis spectrum must account for the range and variability in SRS soil properties. Deep stiff soils, such as those present at the SRS, severely condition bedrock spectra by frequency-dependent amplification or deamplification. Depending upon the frequency and amplitude of bedrock motion, the key soil properties controlling the soil spectrum are the soil column thickness, the dynamic properties (strain dependent shear-modulus ratio and damping), low-strain soil shear-wave velocity structure and impedance contrast with the basement.

To accommodate the range of shear wave-velocity in the soil column, a database of velocity profiles was compiled for the SRS (Ref. 357). This database contains the range of soil and rock shear-wave velocities available from various borings and seismic surveys that have been conducted at the SRS using seismic cross-hole, down-hole, velocity logger, and refraction techniques. The shallow profiles database for the SRS is based primarily on site-specific seismic

piezocone penetration test soundings (SCPTU). An example of SCPTU shear-wave velocity profile is shown in Figure 1.4-74. Other velocity profiles consist of cross-hole and down-hole seismic surveys. The deeper soil profiles are based on measurements made in five deep boreholes drilled to basement at the SRS.

Other, more numerous, deep holes are used for stratigraphic purposes and to estimate the elevation of the top of bedrock. Nearly all of the velocity data are from the SRS F-, H-, A-, K-, and L-Areas, and the New Production Reactor site.

Basement shear-wave velocities are estimated from compressional-wave velocities measured at the SRS. These velocities were collected using seismic refraction techniques (Ref. 278). These data show that there is a significant shear-wave velocity contrast in the SRS basement between the Dunbarton Triassic basin rock and crystalline rock. The Pen Branch fault is the demarcation for basement contrasts in velocity.

Predicted peak soil strains for the SRS are sufficient to exceed the linear range of the constitutive relations (stress-strain). Consequently, laboratory testing of site-specific soil samples was required for reliable ground motion prediction of all critical facilities.

The normalized shear modulus and damping ratio versus shear strain relationships were developed for specific stratigraphic layers. Stratigraphic formation identification and their corresponding dynamic properties were developed specifically for the SRS by K.H. Stokoe of the University of Texas (Ref. 380, 381).

Stokoe et al. compiled a dynamic soil property database from available SRS reports on dynamic soil properties and new dynamic measurements made by the University of Texas. The SRS areas from which data were obtained are:

1 Area of the Pen Branch Fault Confirmatory Drilling Program;

2 H-Area ITPF;

3 H-Area RTF;

4 H-Area Building 221-H;

5 Proposed New Production Reactor site,

6 Par Pond Dam;

7 K-Reactor Area;

8 Burial Ground Expansion;

9 L-Reactor Area;

10 L-Area Cooling Pond Dam; and

11 F-Area, Sand Filter Structure.

These eleven areas represent eight general locations at the SRS.

Figure 1.4-756 illustrates the University of Texas recommended normalized mean shear modulus versus cyclic shear strain by formation. Figure 1.4-76 summarizes the hysteric damping versus cyclic shear strain by formation. These curves form the basis for the dynamic properties used in the site response analysis. Figures 1.4-75 and 1.4-76 summarize cyclic shear strain and damping for SRS.

Velocity Model Parameterization

An SRS generic shear-wave velocity profile was developed from the location-specific data and includes randomness in both stratigraphic layer thickness and velocity. Because the area-specific simulations were generally consistent with the generic simulations, the SRS generic (sitewide) simulation is applied to all areas of the SRS. There is no significant reduction in the site amplification variability by applying area-specific velocity model simulations for ground motion evaluations.

1.4.4.5 Current Design Response Spectra

This section describes the current recommended SRS design basis spectra.

The current PC-3 and PC-4 sitewide spectra are based on the WSRC analysis (Ref. 357) developed in 1997, and incorporates variability in soil properties and soil column thickness. Following the development of PC3 and PC4 design basis spectra (Ref. 357) and the PC1 and PC2 design basis spectra (Ref. 358), the Defense Nuclear Facilities Safety Board (DNFSB) had several interactions with the DOE and WSRC on seismic design spectra. As a result, additional conservatisms were applied to the PC3 spectral shape at high and intermediate frequencies (Ref. 382). The shape change was incorporated in the Site Engineering Standard (Ref. 373). The shape change, illustrated in Figure 1.4-77, increased the low-frequency (0.1-0.5 Hz) portion of the PC-3 spectrum and also increased intermediate frequencies (1.6-13 Hz) of the design basis spectrum. As a result of interactions with the DNFSB, SRS is committed to apply a load factor of 1.2 on seismic loads in the applicable load combinations for new PC3 and PC4 structures (Ref. 373). The factor provides additional conservatism in seismic designs.

The WSRC Civil/Structural Committee reviewed the PC1 and PC2 design spectra (Ref. 383) and recommended to the Engineering Standards Board (ESB) that the current Uniform Building Code (UBC) be used for the Site Engineering Standard (Ref. 373). The basis for the decision was that the UBC was more conservative than the WSRC (Ref. 358) spectra.

1.4.5 STABILITY OF SUBSURFACE MATERIALS

Soil properties vary across the SRS due to changes in depositional processes from area to area over time. Consequently, soil properties at SRS are highly site-specific and are detailed in the facility-specific SARs. However, geotechnical stability concerns at the SRS are categorized generically and listed below with the intent of defining the approaches and methods used to address stability of subsurface materials in site-specific studies. Geotechnical stability concerns at SRS fall into the following categories:

- Excavation and Backfill (Section 1.4.5.1),
- Foundation Settlement (Section 1.4.5.2),
- Liquefaction (Section 1.4.5.3), and
- Soft Zones (Section 1.4.5.4).

The following sections describe these categories on a SRS site-wide basis. For MFFF, a site-specific geotechnical program will be completed which will address these categories from a site and facility specific point of view.

1.4.5.1 Excavation and Backfill

Quality of backfill affects the stability of structures built on fill areas. The requirements and specifications for excavation and backfill have changed with time. Currently there are SRS guidelines for excavation and backfill (Ref. 384), however, project specifications take precedence over the general site guidelines. Geotechnical investigations should identify areas where fill has been placed and give some indication of the quality of the fill prior to building new structures. Following is a summary of excavation and backfill requirements that have been used at the SRS.

From 1950 to 1992, engineering requirements for the excavation and backfill were based on Du Pont Standard Engineering Specifications (Ref. 385), Civil Sections SC3E, SC3.1E, SC4E, and SC5E.

From 1992 to 1995, Requirement Document 02224-01-R (Ref. 386) provided engineering requirements of the excavation and backfill. This document allowed for the use of Controlled Low Strength Material (CLSM), a lean cement mixture having a 28-day compressive strength of 30 to 150 pounds per square inch.

Since 1995, excavation and backfill have been controlled by project specifications. Specifications are prepared to satisfy project-specific needs and may be more restrictive than the Requirement Document. The project specifications take precedence over the Requirement Documents.

In 1997, Engineering Guide 02224-G (Ref. 387) was issued to provide guidance for the excavation, backfill, and grading. Provisions provided in the Engineering Guide can be mandatory, if the Engineering Guide is invoked by the project or operation documents. Provisions in the Engineering Guide include:

- General requirements for excavation, drainage, fill materials, fill placement, CLSM, moisture control, compaction, test fill, grading, testing, erosion control, and inspection
- Requirements for structural fill including:
    a. Soil classified as well-graded sand or silty sand
    b. Range of gradation distribution
    c. Maximum plastic index of 15
    d. Compaction to a minimum density of 95% of the maximum dry density as determined by ASTM D1557 (Ref. 388).
- Requirements for common fill including:
    a. Soil classified as well-graded sand, poorly graded sand, silty sand, or clayey sand
    b. Range of gradation distribution
    c. Compaction to a minimum density of 90% of the maximum dry density as determined by ASTM D1557 (Ref. 388).
- Requirements for CLSM are also provided in the Engineering Guide 02224-G (Ref. 387).

1.4.5.2 Foundation Settlement

Settlement estimates are generally made prior to design of major facilities. Estimates require facility-specific structure information and site-specific geotechnical information for evaluation. Settlement issues are discussed in the facility-specific SARs. Major facilities are surveyed, analyzed, and evaluated routinely for settlement during construction and throughout service life. Allowable settlement is a function of the soil conditions, structure geometry, and loading and the magnitude of settlement that a facility may withstand without adversely affecting performance. Settlement may occur through (1) static settlement due to loading during operation and secondary consolidation, and (2) dynamic settlement due to dissipation of seismically induced pore water pressures. Estimation of static settlement has been performed for many years using various techniques proposed by many authors. There are currently many accepted analytical and empirical methods for estimating settlement published in the geotechnical literature. Two such references (by the ASTM and Department of the Navy) contain accepted methods for estimating settlement (Ref. 389, 390). Static settlements for larger SRS facilities generally fall in the range of 0.5 to 3 inches (1 to 8 cm) (Ref. 391, 392).

Seismically induced dynamic settlement is due to liquefaction or soft zone collapse discussed in the following sections.

1.4.5.3 Liquefaction Susceptibility

The liquefaction susceptibility of the subsurface materials at SRS has been evaluated using qualitative and quantitative approaches. Site-specific investigations have been conducted for F-Area (to include F-Separations, F-Tank Farm, and general F-Area), the CIF, the RTF, ITPF, H-Tank Farm, APSF, and CLWR-TEF (Ref. 383, 393-397). In each case, the potential for liquefaction has been determined to be either small or negligible. Approaches implemented include criteria for clayey soils, shear wave velocity evaluation, the stress method and the strain method. Field and laboratory testing programs have been conducted to characterize site conditions and to measure the cyclic shear strength and strain behavior of the native SRS soils. In this section, a summary of liquefaction evaluation methodologies used currently at SRS is presented. Each facility has its own particular soil profile and characteristics and requires site-specific characterization using one or more of the methodologies described below.

CRITERIA FOR CLAYEY SOILS

Laboratory tests and field performance data have shown that the majority of clayey soils will not liquefy during earthquakes. Criteria expressing these observations have been formulated by Wang (Ref. 398) and have been extended to laboratory testing conditions in the United States by Koester and Franklin (Ref. 399). The extended criteria state that clayey soils must satisfy all three of the following conditions to be considered potentially liquefiable:

- Laboratory-determined water content (increased by 2%) is greater than 90% of the laboratory-determined liquid limit (increased by 1%).
- Liquid limit (increased by 1%) is less than 35%.
- Clay content (decreased by 5%) is less than 15%.

In general, the SRS soils do not meet these criteria and are therefore considered non-liquefiable.

SHEAR WAVE VELOCITY EVALUATION

Several investigators have correlated liquefaction susceptibility to shear wave velocity using field performance data. For example, Seed et al. (Ref. 400) concluded, "Liquefaction will never occur in any earthquake if the shear wave velocity in the upper 50 feet (15 meters) of soil exceeds about 1200 fps (365 m/s)." This conclusion was based on the actual levels of cyclic shear stresses and corresponding shear moduli required to induce liquefaction and on the world-wide field observations of earthquakes.

In 1997, the National Center for Earthquake Engineering Research published proceedings of its workshop on evaluation of liquefaction resistance of soils (Ref. 401). The proceedings contain a chapter on Liquefaction Resistance Based on Shear Wave Velocity. In that chapter Andrus and

Stokoe have compiled field data from earthquakes that showed relationships between cyclic stress ratio and normalized shear wave velocity (Ref. 401). These relationships separate sands into liquefaction-susceptible or liquefaction-nonsusceptible groups (see Figure 1.4-78). In general, based on measured shear wave velocities and site-specific Cyclic Stress Ratios, SRS soils are not subject to liquefaction according to the work of Andrus and Stokoe (Ref. 401).

THE STRESS METHOD

The stress method compares the cyclic shear stress imposed by the earthquake with the cyclic shear strength of the soil. In cases where the earthquake-induced stress exceeds the cyclic shear strength of the soil, the soil is considered potentially liquefiable. To estimate the shear stress imposed by the earthquake, dynamic response analysis is used with SRS soil profiles. The cyclic shear strength is estimated from earthquake field performance data or from laboratory test data correlated with field results, such as Standard Penetration Test (SPT) N-value or Cone Penetrometer Test (CPT) tip resistance (see Figure 1.4-79).

The empirical chart proposed by Seed et al. (Ref. 400) is considered inappropriate for use at SRS because of the geologically older soils present at the site (Ref. 402). In its present form, this chart was developed from liquefaction case histories of recent (Holocene) sands and silty sands. In all cases, the liquefied sands were recent alluvial, beach, or deltaic deposits and are granular, clean sands with silty fines in some cases. However, older sand deposits exhibit greater liquefaction resistance than younger deposits (Ref. 403-410). From these studies, it appears that liquefaction is greatly restricted in deposits older than about 10,000 years.

Increased liquefaction resistance in older sand deposits may be a result of cementation, weathering (which chemically breaks down micas and feldspars into clays that inhibit liquefaction), increased exposure to low-level seismic shaking, cold bonding, and consolidation. All of these factors tend to increase the liquefaction resistance of sands. In addition to increasing liquefaction resistance, most of these factors probably increase, to some degree, the CPT tip resistance and the SPT blow count. Therefore, laboratory cyclic shear testing and the development of site-specific liquefaction curves are recommended when employing the stress method at the SRS (Ref. 394, 402).

Settlement due to liquefaction can be estimated from laboratory volumetric strain test results, which have been correlated to CPTU field data (Ref. 394). For example, the curves shown in Figure 1.4-79 have been used to determine Cyclic Stress Ratio (CSR) required to induce liquefaction. The CSR due to the design earthquake is divided by the CSR required to induce liquefaction to determine a factor of safety. Figure 1.4-80 relates CPTU field data to post-earthquake settlement once the factors of safety against liquefaction are known. Final estimates of post-earthquake settlement will depend on site-specific geotechnical information.

STRAIN METHOD

Cyclic shear straining and porewater pressure development of undrained sand is fundamental in the evaluation of seismic liquefaction potential (Ref. 411, 412). The strain method compares earthquake motion-induced cyclic shear strains to threshold cyclic strain. For this method,

site-specific laboratory testing and analysis is required. The cyclic shear strains are obtained from dynamic response analysis, and laboratory testing is used to model pore pressure buildup. For example, Figure 1.4-81 shows the relationship between induced porewater pressure ratio and repeated cyclic strains of various amplitudes for the Santee Formation at the ITPF (Ref. 394). For this case, the maximum induced shear strain for the EBE was about 0.03%, which results in an excess pore water pressure ratio of less than 15% (see Figure 1.4-81). Liquefaction is not expected to occur for this modest level of induced porewater pressure.

1.4.5.4 Evaluation of Soft Zones

Across SRS the soil zone between approximately 30 to 70 meters (100 to 250 feet) below the ground surface is a marine deposit labeled the Santee Formation. Within this interval are areas having locally high concentrations of calcium carbonate. Often found within these sediments, particularly in the upper third of this section, are weak zones interspersed in stronger matrix materials. These weak zones, which vary in thickness and lateral extent, are termed "soft zones". The existence of soft zones and the potential for settlement is a site-specific characteristic and requires subsurface characterization and engineering evaluation on a site-specific basis.

The soft zones are stable under static conditions. The Santee section, in which the carbonate and soft zones are found, is generally in the saturated zone well below the water table. Here the sediments are in a stable chemical environment, and carbonate dissolution is minimal. The further dissolution and removal of the Santee carbonate (in the engineering sense; i.e., the next 100 years) is a non-issue.

For the types of facilities constructed at the SRS, the increase in load on the soft zone soils is negligible. However, potential load increase due to a seismic event needs consideration even though the geologic record shows that soft zones encountered today have withstood the earthquakes that have occurred since their formation.

A complete summary of the origin, extent and stability of soft zones is presented by Aadland et al. in WSRC-TR-99-4083 (Ref. 235), "Significance of Soft Zone Sediments at the Savannah River Site." Details on the impact of soft zones for specific facilities can be found in the facility-specific SARs.

PREVIOUS STUDIES

Beginning with site exploration, a great many geological and geotechnical studies have been performed at SRS. As part of the original efforts to evaluate foundation conditions for various facilities, the United States Army Corps of Engineers (COE) conducted a geologic and engineering investigation, which comprised the first comprehensive evaluation of sitewide subsurface conditions (Ref. 255). Subsequent regional and area-wide studies include Colquhoun and Johnson and Siple (Ref. 218, 413).

As described in previous sections, the Santee Limestone consists of varying thicknesses of calcareous sediments that are intercalated with non-calcareous, fine-grain, quartz sand.

Calcareous horizons are rare in the northwestern part of SRS, more abundant but sporadic in the central part, and widespread and relatively thick in the southeastern part.

Siple hypothesized that calcareous materials have undergone post-depositional dissolution, which has caused subsidence of the overlying beds and resulted in ground surface depressions (Ref. 413). Siple mentions encounters with "voids" or loosely compacted sediments during drilling and notes that large amounts of cement grout were used to stabilize these subsurface "soft zones" before construction of heavy structures for the original plant facility. The COE performed foundation grouting in the early 1950s for each of the five reactors (C, K, L, P, and R) and both canyon facilities (221-H and 221-F). Since that time, foundation grouting has been performed at other SRS facilities, including K-Area cooling tower and cooling water line, Steel Creek Dam, portions of H- and F-Tank Farms, and DWPF.

Since 1980, several extensive subsurface investigations at scattered site locations within SRS have been completed, yielding more detailed information on the local extent and character of soft zones. In each case, the investigation demonstrated significant variations in subsurface stratigraphy such that the application of general design criteria for soft zone evaluation is not recommended. The investigations have revealed that soft zones within the calcareous materials are found at depths approximately 40 to 52 meters (130 to 170 feet) below natural ground surface and are probably the result of millions of years of carbonate and shell dissolution within the strata. This slow dissolution has resulted in zones of lower density and strength and, consequently, higher compressibility when compared with the surrounding, more intact and sometimes silicified, sandy material. The soft zones behave as local, underconsolidated pockets with overburden stresses arching around the underconsolidated zones. Because the soft zones have formed over a considerable period of time (late Eocene, or about 40 Ma), have survived for millions of years, and have apparently persisted through several historic earthquakes, it is reasonable to assume that the soft zones are of no engineering concern to the dynamic stability of surface or near-surface facilities. However, site-specific evaluations are required.

METHODOLOGIES

Analyses at several SRS facilities, such as K-Area (Ref. 414), assumed that the underconsolidated zones are "arched" by more competent material and that the arch is broken during an earthquake. In those analyses, very conservative subsurface conditions were assumed for the potential width, depth, and extent of the soft zones within the surrounding matrix material. Two basic methods were used to calculate the magnitude of potential surface settlement following a postulated collapse during an earthquake: (1) empirical, using analogies to both soft ground tunneling and coal mining, and (2) numerical modeling. Analyses of the K-Area soft zone suggest that the sandy soil matrix is incapable of arching soft zones larger than about 15 meters (50 feet) in diameter. Thus, zones of larger diameter could not occur (Ref. 414). For soft zone widths of about 15 meters (50 feet) and less, the numerical analyses predicted surface settlements of up to approximately 25% of the surface settlement predicted by the empirical approaches. Which analytical methods are used should depend on the facility under evaluation, the design criteria, and the site-specific subsurface conditions.

Numerical analyses of soft zone soils were conducted for the APSF site (Ref. 415). Computed ground settlements after all soft zones are compressed, varied up to approximately 7.6 cm (3 inches), depending on the configuration of soft zones used in the analysis. The results of the settlement analysis are considered in the design of the facility.

1.4.5.5 Current Design for Settlement

Static settlement due to loading during operation and secondary consolidation are considered in the structural design as self limiting loads in accordance with the Site Engineering Standard (Ref. 373).

Seismically induced dynamic settlement is also considered in the structural design as a self limiting load (Ref. 373). As a result of interactions with the DNFSB, SRS is committed to apply a load factor of 1.2 on the magnitude of seismically induced dynamic settlement for new PC3 and PC4 structures (Ref. 373). The 1.2 factor provides additional conservatism in seismic designs. Seismically induced differential settlement occurs after the inertial seismic loading, discussed in Section 1.4.4.5, and the effects of seismically induced differential settlement are not combined with the inertial load.

1.5 NATURAL PHENOMENA THREATS

This section identifies and describes natural phenomena events considered potential accident initiators at specific SRS facilities.

1.5.1 FLOODS

1.5.1.1 Flood History

All the floods represented by the data in this section were the result of excess precipitation runoff and the associated creek or stream flooding. There have been no floods caused by surge, seiche, dam failure, or ice jams.

FLOOD HISTORY OF THE SAVANNAH RIVER

Annual maximum daily flows for the Savannah River are presented in Table 1.5-1. Historical records span from 1796 to 1995. The earliest historical data were determined primarily from high-water marks; flow gauging by the USGS began in 1882. The record historical flood at Augusta, GA, occurred in 1796, with an estimated discharge of 360,000 cfs; the peak flow recorded by the USGS (350,000 cfs) occurred on October 3, 1929 (Ref. 79). Since Strom Thurmond Dam was constructed, no major flood has occurred at Augusta, GA. The United States Army Corps of Engineers (Ref. 507) simulated the October 3, 1929 storm event using current control requirements. The unregulated peak flow of 350,000 cfs resulted in a regulated peak flood flow of 252,000 cfs at Augusta, Georgia.

A statistical analysis of Savannah River annual maximum flows downstream at Augusta, GA, was conducted using the Log Pearson Type III distribution as described by Linsley et al. (Ref. 416). For the 30-year period from 1921 to 1950, before construction of Strom Thurmond Dam, the mean annual maximum flow was 92,600 cfs, the 10-year maximum flow was 211,000 cfs, and the estimated 50-year maximum flow was 362,000 cfs. After construction of the Strom Thurmond Dam, the Savannah River flows were controlled to meet various demands: hydroelectric power, water supply allocations, flood control, water qualities, habitat, recreation, and aquatic plant control. For the 44-year period from 1956 to 1999, after construction of Strom Thurmond Dam, the mean annual maximum flow, based on mean daily flow rates, was 36,300 cfs, the 10-year maximum flow was 55,400 cfs, and the estimated 50-year maximum flow was 74,600 cfs.

FLOOD HISTORY OF UPPER THREE RUNS CREEK

The annual instantaneous maximum flows for Upper Three Runs Creek gauging stations at Highway 278 near SRS Road C and at SRS Road A are listed in Table 1.5-2. The station at Highway 278 has the longest historical record.

For Upper Three Runs Creek at Highway 278, the maximum flood recorded was 820 cfs on October 23, 1990, and the corresponding flood stage elevation was 183.5 feet msl (Ref. 508). Similarly, the maximum flow at Road C was 2,040 cfs (129.4 feet msl) on October 12, 1990 and at Road A was more than 2,580 cfs (97.9 feet msl) on October 12, 1990. No dams are located in the Upper Three Runs Creek watershed.

FLOOD HISTORY OF TIMS BRANCH

The annual maximum daily flows for station 02197309 on Tims Branch at Road C are listed in Table 1.5-3. Data for water years 1974, 1975, and 1977 to 1984 were not available at the time this report was prepared.

The maximum flood discharge recorded for Tims Branch was 129 cfs on October 12, 1990, with a corresponding gage height of approximately 145.67 feet msl (Ref. 508). Highest flood stage level recorded was approximately 146.71 feet msl on May 29, 1976 (Ref. 508).

FLOOD HISTORY OF FOURMILE BRANCH

The annual instantaneous maximum flows for Fourmile Branch gauge stations at SRS Road C, SRS Road A-7, and SRS Road A-12.2 are listed in Table 1.5-3.1. The maximum floods occurred on August 2, 1991. The flood elevation at SRS Road C was 194.2 ft msl, at SRS Road A-7 was 161.9 ft msl, and at SRS Road A-12.2 was 116.7 ft msl (Ref. 508).

1.5.1.2 Flood Design Considerations

All safety-related structures are located on topographic high points and are well inland from the coast. The only significant impoundments, Par Pond and L Lake, are relatively small and sufficiently lower than any of the safety-related structures that there is no safety threat to safety-related structures from high water.

The calculated Probable Maximum Flood (PMF) water level for the Savannah River at the VEGP site is 118 feet above msl without wave run-up (Ref. 417). With wave run-up, the water may reach as high as 165 feet above msl. Because the minimum plant grade near a structure (L Reactor) is approximately 250 feet above msl, they are all well above the flood stage. If the valley storage effect between Strom Thurmond Dam and VEGP is taken into account, this results in a lower flood peak and lower flood stage.

Chen (Ref. 509) calculated the flood levels as a function of return period (annual probability of exceedance) for the Upper Three Runs, Tims Branch, Fourmile Branch, and Pen Branch basins due to precipitation. Reference 509 concluded that the probabilities of flooding at A-, C-, E-, F-, H-, K-, L-, S-, Y-, and Z-Areas are significantly less than 10E-5 per year. Chen used the basin hydrologic routing method to calculate the flood level as a function of the annual probability of exceedance, as described in Section 1.5.1.4.

D Area is located at an elevation slightly above the maximum flood. A flood could submerge pumphouse 5-G and make it inoperative, stopping cooling water flow to the powerhouse.

1.5.1.3 Effects of Local Intense Precipitation

Flood design considerations are described below in reference to specific local facilities. The descriptions are based on available information.

Unusually intense local rainfalls occurred on the SRS on July 25, 1990; August 22, 1990; October 10-12, 1990; and October 22-23, 1990. A report on these unusual rainfalls was prepared by the Environmental Transport Group of SRTC (Ref. 418). The report concluded that although over 6 inches of rain fell in a 10 square mile area during the August 22 storm, this amount is just 20% of the 6-hour probable maximum precipitation (PMP) of 31.0 inches (Ref. 418).

Rainfall amounts in SRS areas are identified below.

F AND E AREAS

The 6-hour, 10-square-mile PMP is 31 inches, as indicated in Schreiner and Reidel (Ref. 419), with a maximum intensity of 15.1 inches in 1 hour. This rainfall was adjusted to a point PMP of 19 inches in 1 hour, as shown by Hansen et al. (Ref. 420) and used to generate the PMF for the small watershed of the unnamed tributary near the SRS. Incremental rainfall for 1-hour periods adjacent to the PMP was also determined as shown in Table 1.5-4 (Ref. 421). A synthetic hydrograph was used to determine peak flow (Ref. 422). The peak stage corresponding to the PMF is 224.5 feet above msl or 75 feet below the F-Canyon site grade. Because F Area lies near a watershed divide, incident rainfall naturally drains away from the facilities.

Unusual short-duration heavy rainfall occurred in F Area and E Area in August 1990 and October 1990. Total rainfall measured in F Area was as follows:

- August 22, 1990, 6.10 inches rainwater collected in a trench used to dispose of radioactive waste. The water was sampled and later discharged to Fourmile Branch (Ref. 418).
- October 11 and 12, 1990, about 10 inches.

H, S, AND Z AREAS

The 6-hour cumulative PMP for a 10-square-mile area surrounding H, S, and Z Areas is 31 inches (Table 1.5-5) (Ref. 419). This rainfall was adjusted to a point PMP, as shown by Hansen and others and used to generate the PMF for the small watershed of Crouch Branch near the site (Ref. 420). A synthetic hydrograph was used to determine peak flow (Ref. 422). The peak stage corresponding to the PMF is 224.5 feet above msl or 83 feet below the area grades.

Unusual short duration heavy rainfall also occurred at H, S, and Z Areas in August 1990 and October 1990. Total rainfall measured at 200-H was:

- August 22, 1990, 6 inches
- October 11 and 12, 1990, about 10 inches

1.5.1.4 Flood Hazard Recurrence Frequencies

Reference 509 has calculated the flood levels due to precipitation as a function of annual probability of exceedance for the Upper Three Runs Creek, Tims Branch, Fourmile Branch, Pen Branch,and Steel Creek upstream from L-Lake basins. A basin hydrologic routing method was employed to calculate the flood level as a function of the annual probability of exceedance. The procedures used for the method are presented next.

Step 1. Hyetographs (rainfall depth or intensity as a function of time) for various return periods were synthesized based on rainfall intensity-duration-frequency data.

Step 2. The Hydrologic Modeling System computer code (Ref. 510) was used to calculate basin peak flow based on the hyetograph for a given return period and basin properties.

Step 3. The peak flow calculated by HEC-HMS (Step 2) was then used in the Computer Model for Water Surface Profile Computations (WSPRO), (Ref. 511) to calculate the flood water elevations. WSPRO was developed by the USGS for the Federal Highway Administration. WSPRO uses a step-backwater analysis method to calculate water surface elevations for one-dimensional, gradually-varied, steady flow through bridges and overtopping embankments.

Step 4. Steps 2 and 3 were repeated for each return period.

Steps 1 through 4 were applied to both the Upper Three Runs and Fourmile Branch basins.

DESIGN BASIS FLOOD

Flood flows and elevations for the Upper Three Runs Creek, Tim Branch, Fourmile Branch, and Pen Branch basins were calculated by the steps described above. Table 1.5-6 presents the synthesized 24-hour storm hyetographs for various annual probabilities of exceedance. Tables 1.5-7 to 1.5-8 show the calculated flood elevations at A-, C-, E-, F-, H-, K-, S-, and Y- and Z-Areas, and the proposed MFFF site as a function of performance category, respectively (Ref. 509).

L-Area sits at the north end of the L-Lake. Flooding of L-Area is determined by the L-lake water elevation. L-Lake was constructed in 1985 to function as a cooling water reservoir for L-Reactor at SRS to minimize the thermal damage to the Steel Creek flood plain. L-Lake occupies the middle reach of Steel Creek between SRS Road B at the north end of the lake and just upstream of Highway 125 at the south end of the lake. The L-Lake dam is at the south end of the lake. The top of the dam is at 200 feet above mean sea level and a natural spillway is at 195 feet above mean sea level. Factors that determine the L-Lake elevation during a severe storm include initial lake level, basin runoff to the lake, direct rainfall to the lake, discharge through the L-Lake dam gates, and the lake storage-elevation relationship. Operator action can affect discharge through the L-Lake gates. Ultimately, the lake level is limited by the spillway elevation at 195 feet above

mean sea level. Table 1.5-7 shows the calculated L-Area flood flows and flood elevations as a function of performance category. A conservative assumption, L-lake dam gates were closed, was used to calculate Table 1.5-7 (Ref. 509).

1.5.1.5 Potential Dam Failures (Seismically Induced)

RESERVOIR DESCRIPTION

The only significant dams or impoundment structures that could affect the safety of SRS are large dams on the Savannah River and its tributaries upstream of Augusta, GA (see Figure 1.4-12). Section 1.4.2.1 contains information on these structures. The Stephens Creek Dam is owned by SCE&G. All other dams on the Savannah River are owned by the U.S. Army Corps of Engineers. The dams on the Tugaloo and Tallulah rivers are owned by Georgia Power Company. The dams on the Keowee and Little Rivers are owned by Duke Power Company.

DAM FAILURE PERMUTATIONS

A domino failure of the dams on the Savannah River and its tributaries upstream of VEGP was analyzed in the VEGP Final SAR (Ref. 417). The worst possible case resulted from Jocassee Dam failing during a combined standard project flood and earthquake, with the resulting chain reaction.

Using conservative assumptions, this worst dam failure would yield a peak flow of 2,400,000 cfs at Strom Thurmond Dam. This rate, undiminished in magnitude, was transferred to below Augusta, GA. However, because of the great width of the flood plain, routing of the dam failure surge to the VEGP site (Savannah River Mile 151) resulted in a peak discharge of 980,000 cfs, with a corresponding stage of 141 feet above msl.

UNSTEADY FLOW ANALYSIS OF POTENTIAL DAM FAILURES

No dams are located near SRS Areas. Therefore, this section does not apply.

WATER LEVEL AT FACILITY SITE

The peak water surface elevation of the Savannah River that corresponds to wave run-up of a wind-induced wave, superimposed upon the passage of a flood wave resulting from a sequence of dam failures, is discussed in Section 1.5.1.2.

1.5.1.6 Probable Maximum Surge and Seiche Flooding

No large water bodies exist near the site; therefore, this section does not apply. Run-up of flood waters from the worst combination of wind and waves on the Savannah River is not a hazard at

the site because the peak flood elevation is well below minimum plant grade, and the maximum wave under the worst circumstances is less than 3 feet.

1.5.1.7 Ice Flooding

Because of regional climatic conditions, the formation of significant amounts of ice on streams and rivers rarely occurs. The Hartwell, Richard B. Russell, and Strom Thurmond dams moderate water temperature extremes, making ice formation on the Savannah River at SRS unlikely.

No historical ice flooding has been noted, although ice has, on several occasions, been observed in the Savannah River. Because the sites are so much higher than the nearest streams and rivers, it is not considered credible that they could be affected by ice flooding, even if the climatic conditions were conducive to ice formation.

1.5.1.8 Water Canals and Reservoirs

Each reactor has a 25-million-gallon intake basin, which is a concrete structure that is 225 feet wide, 800 feet long, and 20 feet deep with an open top. The basin is divided into three chambers that can be isolated from each other. These basins were used to store cooling water for the reactors and as reservoirs for cooling water to allow the operators to shut down the reactors if needed. These basins were designed as safety-related structures, including withstanding a DBE, and are located well above any PMF (Ref. 423).

1.5.1.9 Channel Diversions

There is no historical record of diversions of streams or rivers in the site area. Outside of precipitation, the only source of water to the site is groundwater. No waterway diversion could flood the sites because the sites are much higher than the surrounding streams and rivers.

1.5.1.10 Flooding Protection Requirements

Because the site is located on a local topographic high, there is no threat to the SRS from flooding, as described in previous sections. Special flooding protection requirements are not necessary to assure the safety of F, H, S, Z, and M Areas, and SRTC because they are located at elevations well above the maximum flood. D Area elevations are higher than the maximum flood; only the pump houses on the river could be flooded and inoperative.

1.5.1.11 Low Water Considerations

LOW FLOW IN RIVERS AND STREAMS

Low flow in the Savannah River adjacent to SRS is regulated by Strom Thurmond Dam and the New Savannah Bluff Lock and Dam. A minimum flow of 5,800 cfs is required for navigation in the river downstream from Strom Thurmond Dam. However, it should be noted that a discharge of 6,300 cfs is normal 80% of the time. A minimum required flow of 4,130 cfs is released from New Savannah Bluff Lock and Dam. The Strom Thurmond Dam project is designed for a maximum drawdown of 18 feet from the top of the power pool elevation of 330 feet msl to a minimum pool at 312 feet msl. However, it is not anticipated that the minimum pool will be reached more often than once in every 150 years.

During extreme drought conditions from July 1987 through April 1989, average discharge at Strom Thurmond Dam was cut to 3,600 cfs (Ref. 424). The reduced discharge lasted from April 1988 to April 1989 and was the minimum flow necessary to maintain water quality criteria for the Savannah River downstream of SRS. River flow at Augusta, GA, however, averaged 4,300 cfs weekly from April 1988 to December 1988 due to higher than normal influx downstream of Thurmond Lake. Discharges from Hartwell and Russell Reservoirs, upstream of Thurmond Lake, were also severely restricted. During this drought period, Thurmond Lake conservation pool elevations decreased substantially, reaching a low point of 1 foot above minimum pool level in February 1989.

A low flow stage at SRS corresponding to minimum river flow of 5,800 cfs is 80.4 feet msl at the SRS pumphouse.

Flow records for Augusta, GA, for the periods 1884 through 1906 and 1926 through 1970 were examined. A hypothetical extreme drought flow of 957 cfs was determined by statistical analysis of 1926 through 1950 flow records. During this period, no major dams were built on the river or its tributaries upstream of Augusta. It is concluded that the hypothetical extreme drought would have a stage elevation of 74 feet msl, which is 6 feet below the minimum required to operate any of the river pumping facilities.

From the flow records for the 62 years of examined data from the USGS, it is concluded that a sustained minimum release of 5,800 cfs (the planned operation of Hartwell and Thurmond reservoirs) could have been maintained for this period. A flow of 3,600 cfs at Ellenton Landing is required under present conditions to provide water to the pump intakes.

LOW WATER RESULTING FROM SURGES OR SEICHES

This situation does not apply because SRS does not withdraw water from a large body of water, nor is it located in a region of active seismicity or volcanism, which produce such surges.

HISTORICAL LOW WATER

The available flow records (62 years) for Augusta, GA, for the periods 1884 through 1906 and 1926 through 1970 were examined. The low flow of record for gauging station 02197000, on the Savannah River at New Savannah Bluff Lock and Dam (river mile 189.8) near Augusta, GA, before construction of Strom Thurmond Dam, occurred on September 24, 1939. This was caused by the operation of the gates at New Savannah River Lock and Dam. If the rating curve is extended below 1,400 cfs, an extreme minimum discharge of 648 cfs is reached. This is an extrapolated instantaneous minimum. Water stage recorder graphs and discharge measurements were furnished by the Corps of Engineers. On the day this low flow was recorded, the average daily flow was 2,940 cfs. Examination of the hydrograph for this day indicates that the lowest flow occurred for about 10 hours, the daily flow being over 2,000 cfs. The lowest mean daily flow shown in the Augusta record was 1,040 cfs, which occurred on October 2, 1927.

The minimum mean daily discharge for the period 1963 through 1970 (after the filling of both reservoirs) was 5,130 cfs in 1963. The storage for power and navigation releases (between normal and minimum pool levels) from Hartwell and Thurmond Reservoirs was 2,445,000 acre-feet, which would provide an average release of 3,350 cfs for 1 year assuming no inflow. The total storage (between top of gates and minimum pool level) from both reservoirs was 3,128,000 acre-feet, which would provide an average release of 4,300 cfs for 1 year assuming no inflow.

The Savannah River has been gauged at Augusta, GA, for more than a century. More recently (in 1971), a gauging station was established at Jackson, SC. Upper Three Runs Creek has been gauged since 1966 at Highway 278 near New Ellenton, SC, and near SRS Road A, below F Area. An additional gauging station on Upper Three Runs Creek was established near SRS Road C in 1974.

The minimum recorded flow for the Savannah River at Augusta, GA, was 1,040 cfs on October 2, 1927 (Ref. 100). This occurred during a period when the Savannah River was essentially unregulated. Since Strom Thurmond Dam was finished in the early 1950s, the river has been regulated by the Corps of Engineers. A minimum daily flow of 4,000 cfs was recorded October 22, 1991.

The minimum daily flow for Upper Three Runs Creek is 49 cfs at Highway 278; 111 cfs near SRS Road A; and 105 cfs near SRS Road C (Ref. 89). Although the period of data recording is short, Upper Three Runs Creek has a smaller range of flow variation than other streams in the area (Ref. 89).

Tims Branch has been gauged since March 1974 near its confluence with Upper Three Runs Creek. The minimum daily flow for Tims Branch was 1 cfs. Although the period of data recordings is short, Tims Branch has a smaller range in flow variation than other streams in the area (Ref. 81).

1.5.1.12 Future Control

Minimum flow conditions are controlled mainly by upstream dam releases, and no additional users of large amounts of water are anticipated.

1.5.2 EARTHQUAKES

Earthquakes are discussed in Section 1.4.4.

1.5.3 TORNADOES

Tornadoes are discussed in Section 1.4.1.1.

1.9 REFERENCES

1. Nuclear Safety Analysis Reports. DOE Order 5480.23, Change 1, U.S. Department of Energy, Washington, DC, April 1992.

2. Preparation Guide for U.S. Department of Energy, Nonreactor Nuclear Facility Safety Analysis Reports. DOE-STD-3009-94, Change Notice No. 1, U.S. Department of Energy, Washington, DC, January 2000.

3. Standards/Requirements Identification Document. WSRC-RP-94-1268, Westinghouse Savannah River Company, Aiken, SC.

4. Compliance Assurance Manual. WSRC Procedure Manual 8B, Westinghouse Savannah River Company, Aiken, SC.

5. WSRC Policy Manual. WSRC-1-01, Westinghouse Savannah River Company, Aiken, SC.

6. Management Requirements and Procedures. WSRC Procedure Manual 1B, Westinghouse Savannah River Company, Aiken, SC.

7. Environmental Compliance Manual. WSRC Procedure Manual 3Q, Westinghouse Savannah River Company, Aiken, SC.

8. Facility Safety Document Manual. WSRC Procedure Manual 11Q, Westinghouse Savannah River Company, Aiken, SC.

9. Conduct of Engineering and Technical Support. WSRC Procedure Manual E7, Westinghouse Savannah River Company, Savannah River Site, Aiken, SC.

10. Savannah River Site Environmental Report for 1996. WSRC-TR-97-0171, Westinghouse Savannah River Company, Aiken, SC, June 1997.

11. Site Development and Facility Utilization Plan, Savannah River Site. DPSP-87-271-2, Volume II. U.S. Department of Energy, Aiken, SC, 1986.

12. Dukes, E.K. The Savannah River Plant Environment. DP-1642, E.I. du Pont de Nemours & Co., Savannah River Laboratory, Aiken, SC, 1984.

13. Wike, L.O., et al. SRS Ecology Environmental Information Document. WSRC-TR-93-496, Westinghouse Savannah River Company, Aiken, SC, April 1994.

14. Bauer, L.R., et al. Reactor Operation Environmental Information Document. WSRC-RP-89-817, Vol. III. Westinghouse Savannah River Company, Aiken, SC, December 1989.

15. Alternative Cooling Water Systems. DOE/EIS-0121, U.S. Department of Energy, Savannah River Plant, Aiken, SC, October 1987.

16. Rogers, V.A. Soil Survey of Savannah River Plant Area, Parts of Aiken, Barnwell and Allendale Counties, South Carolina. U.S. Department of Agriculture, Soil Conservation Service, Washington, DC, June 1990.

17. Site Specific Cropland Erosion Inventory. U.S. Department of Agriculture, Soil Conservation Service, Aiken, SC, 1985.

18. Environmental Implementation Plan. Internal Report DPSP-87-121-2-2, Rev. 0, Westinghouse Savannah River Company, Aiken, SC, June 1989.

19. SRS Waste Acceptance Criteria Manual. WSRC Manual 1S, Westinghouse Savannah River Company, Aiken, SC, January 1999.

20. Savannah River Site Environmental Report for 1996. WSRC-TR-97-0171, Westinghouse Savannah River Company, Aiken, SC, June 1997.

21. M-AREA Justification for Continued Operation. DPSTSA-300-3A Addendum 1 Revision 1.a, January 1997.

22. Site Development and Facility Utilization Plan. Rev. 1, E. I. du Pont de Nemours & Co., Savannah River Plant, Aiken, SC, January 1987.

23. Occupational Radiation Protection. Code of Federal Regulations, 10 CFR, Part 835, U.S. Government Printing Office, Washington, DC.

24. Radiation Protection of the Public and the Environment. DOE Order 5400.5, Change 2, U.S. Department of Energy, Washington, DC, January 1993.

25. 1990 Census Data, Total Population Within a 50-Mile Radius of Savannah River Site. South Carolina Department of Research and Statistical Services, Columbia, SC, February 1994.

26. Savannah River Site Emergency Plan. WSRC Procedure Manual SCD-7, Westinghouse Savannah River Company, Aiken, SC.

27. Memorandum from J.C. Huang. New Onsite and Offsite Population Databases. NPSR Section, Westinghouse Savannah River Company, Aiken, SC, July 1993.

28. Development of Onsite and Offsite Population Distribution for Use in Dose Summary Codes. SRT-ETS-930635, Westinghouse Savannah River Company, Aiken, SC, June 1993.

29. Jannik, G.T., and Simpkins. Environmental Dose Assessment Manual. WSRC-IM-91-1, Rev. 1, Westinghouse Savannah River Company, Aiken, SC, October 1995.

30. 1998 Georgia Manufacturers Register. Manufacturers' News, Evanston, IL, 1997.

31. East, J.M. 1992 Onsite Worker Population for PRA Applications. WSRC-RP-93-197, Westinghouse Savannah River Company, Aiken, SC, January 1993.

32. South Carolina School Atlas (undated). South Carolina Department of Education, Columbia, SC.

33. South Carolina Education Profiles 1996. South Carolina Department of Education, Columbia, SC, October 1996.

34. Savannah River Plant Deer Hunts. U.S. Department of Energy, Savannah River Site, Aiken, SC, 1987.

35. South Carolina State Parks Attendance Fiscal Year 92/93. South Carolina Department of Parks, Recreation and Tourism, Division of State Parks, Columbia, SC, January 28, 1994.

36. Inpatient Care Facilities Licensed by South Carolina Department of Health and Environmental Control. Published by South Carolina Department of Health and Environmental Control, March 17, 1997.

37. Traffic Flow Maps and Printouts of Average Daily Traffic, Barnwell, Aiken, and Allendale Counties. South Carolina Department of Highways and Public Transportation, Columbia, SC, 1988.

38. Nuclear Weapons Complex Reconfiguration Site Proposal. Volume 7, "Transportation." U.S. Department of Energy, Savannah River Site, Aiken, SC.

39. Traffic Services Report, Savannah River Plant. Contract Report AX 86 7559, Wilbur Smith Associates, Prepared for Westinghouse Savannah River Company, Aiken, SC, 1989.

40. Site Development and Facility Utilization Plan, Savannah River Site. DPSP-87-271-3, Vol. III. U.S. Department of Energy, Savannah River Site, Aiken, SC, 1986.

41. "The South Carolina Railroad System 1984" (Map). South Carolina Public Service Commission, Transportation Division, Columbia, SC, 1984.

42. Agricultural Statistics for Allendale County. South Carolina Agricultural Statistics Service, Department of Agricultural Economics, Clemson University, 1993.

43. Agricultural Statistics for Aiken County. South Carolina Agricultural Statistics Service, Department of Agricultural Economics, Clemson University, 1993.

44. Agricultural Statistics for Barnwell County. South Carolina Agricultural Statistics Service, Department of Agricultural Economics, Clemson University, 1993.

45. Savannah District Long Range Drought Contingency Plan Draft. U.S. Army Corps of Engineers, Savannah District, January 1988.

46. Garrett, Alan. Correspondence to Carl Benhardt, Savannah River Laboratories, Aiken, SC, dated April 21, 1988, and Information Paper re: Maintenance on Savannah River Below Augusta. Navigation Section, U.S. Army Corps of Engineers, Savannah, GA, 1988.

47. Land and Water Use Characteristics in the Vicinity of the Savannah River Site. WSRC-RP-91-17, Westinghouse Savannah River Company, Aiken, SC, March 1991.

48. South Carolina County Agent's Irrigation Survey. 1980.

49. Hunter, C. H. A Climatological Description of the Savannah River Site. WSRC-RP-89-313, Westinghouse Savannah River Company, Aiken, SC, May 1990.

50. Hunter, C.H. to Talukdar, B. Updated Meteorological Data for Revision of the SRS Generic Safety Analysis Report. SRT-NTS-970265, WSRC Inter-Office Memorandum, Westinghouse Savannah River Company, Aiken, SC, August 14, 1997.

51. Hunter, C.H. to Howley, J. Meteorological Data for Revision 4 of the SRS Generic Safety Analysis Report. SRT-NTS-99-0043, Westinghouse Savannah River Company, Aiken, SC, March 1, 1999.

52. Local Climatological Data, Annual Summary with Comparative Data, 1991, Augusta, GA. U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Climate Data Center, Asheville, NC, 1992.

53. Tattelman, P., et al. Estimated Glaze Ice and Wind Loads at the Earth's Surface for the Contiguous United States. AFCRL-TR-73-0646, U.S. Air Force, October 1973.

54. Pautz, M.E. Severe Local Storm Occurrences, 1955-1967. Weather Bureau Technical Memorandum, No. 12, U.S. Department of Commerce, Washington, DC, 1969.

55. Marshall, J.L. Lightning Protection. John Wiley and Sons, New York, NY, 1973.

56. 1989-93 Measured Lightning Flash Density. Geomet Data Services Inc., 1994.

57. Weber, A.H., et al. Tornado, Maximum Wind Gust, and Extreme Rainfall Event Recurrence Frequencies at the Savannah River Site. WSRC-TR-98-00329, Westinghouse Savannah River Company, Aiken, SC, 1998.

58. Parker, M.J. Savannah River Site Tornado Damage of March 1991. WSRC-RP-91-439, Westinghouse Savannah River Company, Aiken, SC, 1991.

59. Natural Phenomena Hazards Design and Evaluation Criteria for Department of Energy Facilities. DOE-STD-1020-94, U.S. Department of Energy, Washington, DC, April 1994.

60. Addis, R.P. and Kurzeja, R.J. Heavy Rainfall at the SRS in July, August, and October of 1990. WSRC-TR-92-136, Westinghouse Savannah River Company, Aiken, SC.

61. Miller, J.F. Two-to-Ten Day Precipitation for Return Periods of Two-to-One Hundred Years in the Contiguous United States. Technical Paper No. 49, U.S. Weather Bureau, U.S. Department of Commerce, Washington, DC, 1964.

62. Holzworth, G.C. Mixing Heights, Wind Speeds, and Potential for Urban Air Pollution Throughout the Contiguous United States. AP-101, U.S. Environmental Protection Agency, Washington, DC, January 1972.

63. Korshover, J. Climatology of Stagnating Anticyclones East of the Rocky Mountains, 1936-65. NOAA Technical Memorandum ERL-ARL-55, National Oceanic and Atmospheric Administration, U.S. Department of Commerce, Washington, DC, 1975.

64. Parker, M.J. and Addis, R. P. Meteorological Monitoring Program at the Savannah River Site. WSRC-TR-93-0106, Westinghouse Savannah River Company, Aiken, SC, 1993.

65. Hosler, C.R. "Low-Level Inversion Frequency in the Contiguous United States." Monthly Weather Review. Vol. 89, No. 9, 1961.

66. Pendergast, M.M. Turbulent Diffusion in the Planetary Boundary Layer Over the Savannah River Plant During Periods of Differing Thermal Structure. DP-1412, E.I. du Pont de Nemours and Company, Savannah River Plant, Aiken, SC, 1975.

67. Kurzeja, R.J., et al. The 1992-1996 SRS Meteorological Data Base. WSRC-RP-99-00076, Westinghouse Savannah River Company, Aiken, SC.

68. Savannah River Laboratory Environmental Dose Assessment. WSRC-IM-91-1, Rev. 1, Westinghouse Savannah River Company, Aiken, SC, October 1995.

69. Smith, L.L. "Solution Depressions in Sandy Sediments of the Coastal Plain in South Carolina." Journal of Geology. Vol. 39, 1931.

70. Prouty, W.F. "Carolina Bays and Their Origins." Geological Society of America Bulletin. Vol. 63, 1952.

71. Kuglar, B.E. State of South Carolina Water Resources Commission Water Use Report. Savannah River Site, 2nd Quarter, 1995.

72. Environmental Assessment for the Natural Fluctuation of Water Level in Par Pond and Reduced Water Flow in Steel Creek Below L-Lake at the Savannah River Site. DOE/EA-1070, U.S. Department of Energy, Savannah River Operations Office, Savannah River Site, Aiken, SC, August 1995.

73. Draft Environmental Impact Statement - Shutdown of the River Water System at the Savannah River Site. DOE/EIS-0268D, U.S. Department of Energy, Savannah River Operations Office, Savannah River Site, Aiken, SC, November 1996.

74. Water Resources Data for South Carolina, Water Year 1987. U.S. Geological Survey Data Report SC-8701, 1988.

75. Lower, M.W. "SRP Surface Water System." Hydrology, Quality and Use. DPST-85-611, E.I. du Pont de Nemours & Co., Savannah River Plant, Aiken, SC, 1985.

76. Alvin W. Vogtle Electric Generating Plant, Unit 1 and Unit 2, Final Safety Analysis Report. Georgia Power Company, Vol. 1-34, Georgia, 1987.

77. Mackey, H.E. Comprehensive Cooling Water Study Final Report. Volume IV, *Wetlands*. DP-1739-4, E.I. du Pont de Nemours & Co., Savannah River Plant, Aiken, SC, 1987.

78. Savannah River Plant Precipitation Summary. E.I. du Pont de Nemours & Co., Savannah River Plant, Aiken, SC, 1986.

79. Water Resources Data for South Carolina, Water Year 1986. U.S. Geological Survey Data Report SC-86-1, U.S. Geological Survey, 1987.

80. Water Resources Data for South Carolina, Water Year 1984. U.S. Geological Survey Data Report SC-84-1, U.S. Geological Survey, 1985.

81. Water Resources Data for South Carolina, Water Year 1988. U.S. Geological Survey Data Report SC-88-1, U.S. Geological Survey, 1989.

82. Root, R.W., Jr. Numerical Simulation of Ground H_2O Flow at Savannah River Plant, South Carolina. Department of Geosciences, Pennsylvania State University, Altoona, PA, 1987.

83. Ashley, et al. Environmental Monitoring at the Savannah River Plant for 1983. DPSPU-84-302, E.I. du Pont de Nemours & Co., Savannah River Plant, Aiken, SC, 1984.

84. Ziegler, et al. Environmental Monitoring at the Savannah River Plant for 1984. DPSPU-85-302, E.I. du Pont de Nemours & Co., Savannah River Plant, Aiken, SC, 1985.

85. Ziegler, et al. Savannah River Environmental Report for 1985. DPSPU-86-30-1, E.I. du Pont de Nemours & Co., Savannah River Plant, Aiken, SC, 1986.

86. Ziegler, et al. Savannah River Plant Environmental Report for 1986. DPSPU-87-30-1, E.I. du Pont de Nemours & Co., Savannah River Plant, Aiken, SC 1987.

87. Mikol, et al. U.S. Department of Energy Savannah River Plant Environmental Report for 1987. DPSPU-88-30-1, E.I. du Pont de Nemours & Co., Savannah River Plant, Aiken, SC, 1988.

88. Water Resources Data for South Carolina, Water Year 1983. U.S. Geological Survey Data Report SC-83-1, 1984.

89. Water Resources Data for South Carolina, Water Year 1985. U.S. Geological Survey Data Report SC-85-1, U.S. Geological Survey, 1986.

90. Specht, W.L. "Comprehensive Cooling Water Study Final Report." Volume V, Aquatic Ecology. DP-1739-5, E.I. du Pont de Nemours & Co., Savannah River Plant, Aiken, SC, 1987.

91. Continued Operation of K-, L-, and P-Reactors, SRS, Aiken, SC, Final Environmental Impact Statement. DOE/EIS-0147, U.S. Department of Energy, Washington, DC, 1990.

92. Langley, T.M. and Marter, W.L. The Savannah River Plant Site. DP-1323, E.I. du Pont de Nemours & Co., Savannah River Plant, Aiken, SC, 1973.

93. Paller, M. and Osteen, D.V. Annual Report on the Savannah River Aquatic Ecology Program -- November 1983-August 1984, Volume 1, *Adult Fish.* ECS-SR-17, Environmental and Chemical Science, Inc., Aiken, SC, 1985.

94. Giesy, J.P., Jr. and Briese, L.A. "Trace Metal Transport by Particulates and Organic Carbon in Two South Carolina Steams." Proceedings of the International Association of Theoretical and Applied Limnology. Vol. 20, 1978,

95. Lower, M.W. and Hayes, D.W. "Results of Gamma Spectroscopy Analyses." CCWS Sediment Cores. DPST-86-455, E.I. du Pont de Nemours & Co., Savannah River Plant, Aiken, SC, 1986.

96. "Comprehensive Cooling Water Study Final Report." Volume III. Radionuclide and Heavy Metal Transport. DP-1739-3, E.I. du Pont de Nemours & Co., Savannah River Plant, Aiken, SC, 1987.

97. Lower, M.W. Comprehensive Cooling Water Study Final Report. Volume II: Water Quality. DP-1739-2, E.I. de Pont de Nemours & Co., Savannah River Plant, Aiken, SC, October 1987.

98. Gibbons, J.W. and Sharitz, R.R. "Thermal Alterations of Aquatic Ecosystems." American Scientist. Vol. 62, 1974.

99. Lower, M.W. Compilation of Historic Water Quality Data Base. DPST-84-555, E.I. du Pont de Nemours & Co., Savannah River Plant, Aiken, SC, June 1984.

100. Aadland, R.K., et al. Hydrogeologic Framework of West Central South Carolina. Report 5, South Carolina Department of Natural Resources, Water Resources Division, 1995.

101. Aadland, R.K., and Bledsoe, H.W. Classification of Hydrostratigraphic Units at the Savannah River Site, South Carolina. WSRC-RP-90-987, Westinghouse Savannah River Company, Aiken, SC, 1990.

102. Aadland, R.K. and Bledsoe, H.W. "Hydrostratigraphy of the Coastal Plain Sequence, Savannah River Site (SRS), South Carolina." GSA Abstracts with Programs. Vol. 22, No. 7, 1990.

103. Bledsoe, H.W., et al. Baseline Hydrogeologic Investigation - Summary Report. WSRC-RP-90-1010, Westinghouse Savannah River Company, Aiken, SC, 1990.

104. Miller, J.A. and Renkien, R.A. "Nomenclature of Regional Hydrogeologic Units of the Southeastern Coastal Plain Aquifer System." U.S. Geological Survey, Water Resources Investigations Report 874202, 1988j.

105. Poland, J.F., et al. Glossary of Selected Terms Useful in Studies of the Mechanics of Aquifer Systems and Land Subsidence Due to Fluid Withdrawal. U.S. Geological Survey Water Supply Paper 2025, 1972.

106. Bates, R.L. and Jackson, J.A. Glossary of Geology. American Geological Institute, Falls Church, Virginia, 1980.

107. Lohman, S.W., et al. Definitions of Selected Groundwater Terms - Revisions and Conceptual Refinements. U.S. Geological Survey Water-Supply Paper No. 1988, 1972.

108. Miller, J.A. Hydrogeologic Framework of the Floridan Aquifer System in Florida and in Parts of Georgia, Alabama, and South Carolina. U.S. Geological Survey Professional Paper No. 1403-B, 1986.

109. Meisler, H. Plan of Study for the Northern Atlantic Coastal Plain Regional Aquifer System Analysis. U.S. Geological Survey Water-Resources Investigation Report 80-16, 1980.

110. Stringfield, V.T. Artesian Water in Tertiary Limestone in the Southeastern States. U.S. Geological Survey Professional Paper 517, 1966.

111. Krause, R.E. and Randolph, R.B. Hydrology of the Floridan Aquifer System in Southeast Georgia and Adjacent Parts of Florida and South Carolina. U.S. Geological Survey Professional Paper 1403-D, 1989.

112. Krause, R.E. Digital Model Evaluation of the Predevelopment Flow System of the Tertiary Limestone Aquifer, Southeast Georgia, Northeast Florida, and Southern South Carolina. U.S. Geological Survey Water-Resources Investigations Report 82-173, 1982.

113. Evans, E.K. and Parizek, R.R. Characterization of Hydraulic Conductivity Heterogeneity in Tertiary Sediments within the General Separations Area, Savannah River Site, South Carolina. Department of Geosciences, Pennsylvania State University, PA, 1991.

114. Beard, D.C. and Weyl, P.K. "Influence of Texture on Porosity and Permeability of Unconsolidated Sand." American Association of Petroleum Geologists Bulletin. No. 57, 1973.

115. Hydrogeologic Characterization of the MWMF (Mixed Waste Management Facility), SRS. WSRC-RP-92-837, Westinghouse Savannah River Company, Aiken, SC, 1992

116. Walton, C.W. Applied Hydrology. Merrell Publishing, Columbus, OH, 1988.

117. Fetter, W.C. Ground Water Resource Evaluation. McGraw-Hill Book Co., New York, NY, 1988.

118. Fallaw and Price. "Geological Investigations of the Central Savannah River Area, South Carolina, and Georgia." Carolina Geological Society Field Trip Guidebook for 1992. 1992.

119. Aadland, R.K., et al. Geology and Hydrostratigraphy of the A-M Area, Savannah River Site (SRS), South Carolina. WSRC-RP-92-440, Westinghouse Savannah River Company, Aiken, SC, 1992.

120. Aadland, R.K. Hydrogeologic Atlas of West-Central South Carolina. WSRC-RP-92-632, Westinghouse Savannah River Company, Aiken, SC, 1992.

121. Clarke, J.S., et al. Hydrogeology of the Dublin and Midville Aquifer Systems of East Central Georgia. Georgia Geological Survey Information Circular 74, 1985.

122. Aucott, W.R., et al. Geohydrologic Framework of the Coastal Plain Aquifers of South Carolina." U.S. Geological Survey Water-Resources Investigations Report 85-4271, 1988.

123. Siple, G.E. "Geology and Ground Water of the Savannah River Plant and Vicinity, South Carolina." Paper No. 1841, United States Geological Survey Water Supply. 1967.

124. Faye, R.E. and Prowell, D.C. Effects of Late Cretaceous and Cenozoic Faulting on the Geology and Hydrology of the Coastal Plain Near the Savannah River, Georgia and South Carolina. U.S. Geological Survey Open File Report 82-156, 1982.

125. GeoTrans, Inc. "Characterization of Ground Water Flow and Transport in General Separations Area, Savannah River Plant." Effects of Closure Options on Groundwater Flow at the F-Area Seepage Basins. 1988.

126. Stieve, A.L., et al. Pen Branch Fault Program: Consolidated Report on the Seismic Reflection Surveys and the Shallow Drilling. WSRC-TR-91-87, Westinghouse Savannah River Company, Aiken, SC, 1991.

127. Aucott, W.R. and Speiran, G.K. "Ground Water Flow in the Coastal Plain Aquifers of South Carolina." Journal of Ground Water. Vol. 23, No. 6, 1985a.

128. Benedict, M., et al. Permanent Storage of Radioactive Separations Process Wastes in Bedrock on the Savannah River Plant Site. E.I. du Pont de Nemours & Co., Savannah River Laboratory, Aiken, SC, 1969.

129. Wait, R.L. and Davis, M.E. Configuration and Hydrology of the Pre-Cretaceous Rocks Underlying the Southeastern Coastal Plain Aquifer System. U.S. Geological Survey Water-Resources Investigations Report 86-4010, 1986.

130. Marine, I.W. Hydraulic Correlation of Fracture Zones in Buried Crystalline Rock at the Savannah River Plant Near Aiken, South Carolina. Chapter D, Geological Survey Research 1966. U.S. Geological Survey Professional Paper 550-D, 1966.

131. Marine, I.W. "The Permeability of Fractured Crystalline Rock at the Savannah River Plant Near Aiken, South Carolina." Geological Survey Research 1967, Chapter B, U.S. Geological Survey Professional Paper 575-B, pp. B203-B211, 1967.

132. Marine, I.W. "The Use of Tracer Test to Verify an Estimate of Groundwater Velocity in Fractured Crystalline Rock at the Savannah River Plant Near Aiken, South Carolina." Isotope Techniques in the Hydrologic Cycle. Geophysical Monograph Series, Vol. 11, Washington, DC, American Geophysical Union, 1967.

133. Marine, I.W. "Geohydrology of Buried Triassic Basin at Savannah River Plant, South Carolina." American Association of Petroleum Geologists Bulletin. Vol. 58, 1974.

134. Webster, D.S., et al. Two-Well Tracer Test in Fractured Crystalline Rock. U.S. Geological Survey Water-Supply Paper 1 544-1, 1970.

135. Wyatt, D.E., et al. A/M Area Advanced Geological Study, Part 3, "Geologic Interpretation of the Structure and Stratigraphy of the A/M Area, Savannah River Site, South Carolina." WSRC-RP-97-0186, Rev. 0, 1997.

136. Aadland, R.K. Tertiary Geology of A/M Area Savannah River Site, South Carolina. WSRC-RP-97-0505, Rev. 1, Westinghouse Savannah River Company, Aiken, SC, 1997.

137. Strom, R.N. and Kaback, D.S. SRP Baseline Hydrogeologic Investigation: Aquifer Characterization, Groundwater Geochemistry of the Savannah River Site and Vicinity. WSRC-RP-92-450, Westinghouse Savannah River Company, Aiken, SC, 1992.

138. Chappelle, F.J. and Loveley, D.R. "Competitive Exclusion of Sulfate Reduction of Fe-III-Reducing Bacteria: A Mechanism for Producing Discrete Zones of High-Iron Ground Water." Ground Water. Vol. 30, No. 1, 1991.

139. Natural Phenomena Hazards Characterization Criteria. DOE-STD-1022-94, Change Notice No. 1, U.S. Department of Energy, Washington, DC, January 1996.

140. Hatcher, R.D., et al. Continent-Ocean Transect E5 Cumberland Plateau (North American Craton) to Blake Plateau Basin. The Decade of North American Geology Project, Geological Society of America, Boulder, CO, 1994.

141. Hatcher, R.D., Jr., et al. "Tectonic Map of the U.S. Appalachian, Plate 1, the Appalachian-Ouachita Orogen in the United States." The Geology of North America. Vol. F-2. Geological Society of America, Boulder, CO, 1990.

142. Dillon, W.P. and Popenoe, P. "The Blake Plateau Basin and Carolina Trough." The Geology of North America. V I-2, The Atlantic Continental Margin. DNAG Publication, Geological Society of America, Boulder, CO, 1988.

143. Klitgord, K.D., et al. "US Atlantic Continental Margin: Structural and Tectonic Framework." The Geology of North America. V I-2, The Atlantic Continental Margin. DNAG Publication, Geological Society of America, Boulder, CO, 1988.

144. Poag, C.W. and Valentine, P.C. "Mesozoic and Cenozoic Stratigraphy of the US Atlantic Continental Shelf and Slope." The Geology of North America. V I-3, The Atlantic Continental Margin. DNAG Publication, Geological Society of America, Boulder, CO, 1988.

145. Hatcher, R.D., Jr. and Goldberg, S.A. "The Blue Ridge Geologic Province." The Geology of the Carolinas. Carolina Geological Society 50th Anniversary Volume, 1991.

146. Hatcher, R.D., Jr. and Butler, J.R. Guidebook for Southern Appalachian Field Trip in the Carolinas, Tennessee, and Northeastern Georgia. International Geologic Correlation Program Project 27, University of North Carolina, Chapel Hill, NC, 1979.

147. King, P.B. "A Geologic Cross Section Across the Southern Appalachians, An Outline of the Geology in the Segment in Tennessee, North Carolina, and South Carolina." Guides to Southeastern Geology. Geological Society of America Annual Meeting, 1955.

148. Hopson, J.R. "Structure, Stratigraphy, and Petrogenesis of the Lake Burton Mafic-Ultramafic Complex." Georgia Geological Society Guidebook. Vol. 9, 1989.

149. Hatcher, R.D., Jr. "Tectonics of the Western Piedmont and Blue Ridge, Southern Appalachians: Review and Speculation." American Journal of Science. Vol. 278, 1978.

150. Hatcher, R.D., et al. "The Smokies Foothills Duplex and Possible Significance of the Guess Creek Fault, A Corollary to the Mapping of King and Neuman." Geological Society of America Abstracts with Programs. Vol. 18, 1986a.

151. Hatcher, R.D., Jr. "Developmental Model for the Southern Appalachians." Geological Society of America Bulletin. Vol. 83, 1972.

152. Nelson, K.D., et al. "New COCORP Profiling in the Southeastern United States: Part I: Late Paleozoic Suture and Mesozoic Rift Basin." Geology. Vol. 13, 1985.

153. Coruh, C., et al. "Results from Regional Vibroseis Profiling: Appalachian Ultradeep Core Hole Site Study." Geophysical Journal of the Royal Astronomical Society. Vol. 89, 1987.

154. Cook, F.A., et al. "Thin-skinned Tectonics in the Crystalline Southern Appalachians: COCORP Seismic Reflection Profiling of the Blue Ridge and Piedmont." Geology. Vol. 7, 1979.

155. Neuman, R.B. and Nelson, W.H. Geology of the Western Great Smoky Mountains, Tennessee. U.S. Geological Survey Professional Paper 349-D, 1965.

156. King, P.B., et al. Geology of the Great Smoky Mountains National Park, Tennessee and North Carolina. U.S. Geological Survey Professional Paper 587.

157. Fullagar, P.D., et al. "1200 m.y.-Old Gneisses in the Blue Ridge Province of North and South Carolina." Southeastern Geology. Vol. 20, 1979.

158. Fullagar, P.D. and Bartholomew, M.J. "Rubidium-Strontium Ages of the Watauga River Cranberry, and Crossing Knob Gneisses, Northwestern North Carolina." Geological Investigations in the Blue Ridge of Northwestern North Carolina: 1983 Guidebook for the Carolinas. Geological Society, North Carolina Division of Land Resources, Article 11, 1983.

159. Fullagar, P.D. and Odom, A.L. "Geochronology of Precambrian Gneisses in the Blue Ridge Province of Northwestern North Carolina and Adjacent Parts of Virginia and Tennessee." Geological Society of America Bulletin. Vol. 84, 1973.

160. Wehr, F. and Glover, L., III. "Stratigraphy and Tectonics of the Virginia-North Carolina Blue Ridge: Evolution of a Late Proterozoic-Early Paleozoic Hinge Zone." Geological Society of America Bulletin. Vol. 96, 1985.

161. Rast, N. and Kohles, K.M. "The Origin of the Ocoee Supergroup." American Journal of Science. V. 286, 1986.

162. Hopson, J.L., et al. "Geology of the Eastern Blue Ridge of Northeast Georgia and the Adjacent Carolinas." Georgia Geological Society Guidebook. Vol. 9, 1989.

163. Horton, J.W., Jr. and McConnell, K.I. "The Western Piedmont." The Geology of the Carolinas. Carolina Geological Society 50th Anniversary Volume, 1991.

164. Nelson, A.E., et al. "Generalized Tectonic Map of the Greenville 1x2 Quadrangle, Georgia, South Carolina, and North Carolina." U.S. Geological Survey Miscellaneous Field Studies Map MF-1898, Scale 1:250,000, 1987.

165. Goldsmith, R., et al. "Geologic Map of the Charlotte 1x2 Quadrangle, North Carolina and South Carolina." U.S. Geological Survey Miscellaneous Investigations Series Map I-1251-E, Scale 1:250,000, 1988.

166. Mitwede, S.K., et al. "Major Chemical Characteristics of the Hammett Grove Meta-Igneous Suite, Northeastern South Carolina." Southeastern Geology. Vol. 28, No. 1, 1987.

167. Hatcher, R.D., Jr., et al. "Detailed Geologic Map of the Appalachian Ultradeep Core Hole (ADCOH) Region." New Constraints on the Structure of the Southern Appalachian Internides. Geological Society of America Abstracts with Programs, Vol. 18, 1986b.

168. Secor, D.T., Jr., et al. "Confirmation of Carolina Slate Belt as an Exotic Terrane." Science. Vol. 221, 1983.

169. Samson, S., et al. "Biogeographical Significance of Cambrian Trilobites from the Carolina Slate Belt." Geological Society of America Bulletin. Vol. 102, 1990.

170. Vick, H.K., et al. "Ordovician Docking of the Carolina Slate Belt." Paleomagnetic Data: Tectonics. Vol. 6, 1987.

171. Noel, J.R., et al. "Paleomagnetism and 40 Ar/39 Ar Ages from the Carolina Slate Belt, North Carolina: Implications for Terrane Amalgamation." Geology. Vol. 16, 1988.

172. Hatcher, R.D., Jr., et al. "Geometric and Time Relations of Thrusts in the Crystalline Southern Appalachians." Geometry and Mechanisms of Appalachian Thrusting, with Special Reference to the Appalachians. Geological Society of America Special Paper 222, 1988.

173. Hooper, R.J. and Hatcher, R.D., Jr. "The Pine Mountain Terrane, a Complex Window in the Georgia and Alabama Piedmont-Evidence from the Eastern Termination." Geology. Vol. 16, 1988.

174. Steltenpohl, M.G. "Kinematics of the Towaliga, Bartletts Ferry, and Goat Rock Fault Zones, Alabama: The Late Paleozoic Dextral Shear System in the Southernmost Appalachians." Geology. Vol. 16, 1988.

175. Griffin, V.S., Jr. "Geology of the Abbeville East, Abbeville West, Latimer and Lowndesville Quadrangles, South Carolina." South Carolina Geological Survey MS-24. 1979.

176. Davis, G.J. The Southwestern extension of the Middleton-Lowndesville Cataclastic Zone in the Greensboro, Georgia, Area and its Regional Implications (M. S. Thesis). University of Georgia, Athens, Georgia, 1980.

177. Rozen, R.W. "The Middleton-Lowndesville Cataclastic Zone in the Elberton East Quadrangle, Georgia." Geological Investigations of the Kings Mountain Belt and Adjacent Areas in the Carolinas. Carolina Geological Society Guidebook, 1981.

178. Horton, J.W., Jr. "Shear Zone Between the Inner Piedmont and Kings Mountain Belts in the Carolinas." Geology. Vol. 9, 1981.

179. Heyn, T. "Geology of the Hinge Zone of the Sauratown Mountains Anticlinorium, North Carolina: Structure of the Sauratown Mountains Window, North Carolina." Carolina Geological Society Guidebook. 1988.

180. McConnell, K.I. "Geology of the Sauratown Mountains Anticlinorium; Vienna and Pinnacle 7.5 Minute Quadrangles: Structure of the Sauratown Mountains Window, North Carolina." Carolina Geological Society Guidebook. 1988.

181. Bobyarchick, A.R. "The Eastern Piedmont Fault System and Its Relationship to Alleghanian Tectonics in the Southern Appalachians." Journal of Geology. Vol. 89, 1981.

182. Secor, D.T., Jr. et al. "Character of the Alleghanian Orogeny in the Southern Appalachians, Part I: Alleghanian Deformation in the Eastern Piedmont of South Carolina." Geological Society of America Bulletin. Vol. 97, 1986a.

183. Secor, D.T., Jr., et al. "Character of the Alleghanian Orogeny in the Southern Appalachians: Part III, Regional Tectonic Relations." Geological Society of America Bulletin. Vol. 97, 1986b.

184. Hatcher, R.D., Jr. and Edelman, S.H. "Macro-Scale Partitioning in the Southern and Central Appalachians: Thrusting and Strike-Slip as Products of Alleghanian Collision." Geological Society of America Abstracts with Programs. Vol. 19, 1987.

185. Dennis, A.J. "Is the Central Piedmont Suture a Low-Angle Normal Fault?" Geology. Vol. 19, 1991.

186. Maher, H.D., et al. "40Ar/39Ar Constraints on Chronology of Augusta Fault Zone Movement and Late Alleghanian Extension, Southern Appalachian Piedmont, South Carolina and Georgia." American Journal of Science. Vol. 294, 1994.

187. Maher, H.D., et al. "The Eastern Piedmont of South Carolina." The Geology of the Carolinas. University of Tennessee Press, Knoxville, 1991.

188. Snoke, A.W., et al. "Deformed Hercynian Granitic Rocks from the Piedmont of South Carolina." American Journal of Science. Vol. 280, 1980.

189. Secor, D.T., Jr. "Regional Overview, Anatomy of the Alleghanian Orogeny as Seen from the Piedmont of South Carolina and Georgia." Carolina Geological Society Field Trip Guidebook. South Carolina Geological Survey, 1987.

190. Bramlett, K.W. Geology of the Johnston-Edgefield Area, South Carolina, and its Regional Implications. (M.S. Thesis). University of South Carolina, Columbia, SC, 1989.

191. Maher, H.D., Jr. Stratigraphy, Metamorphism, and Structure of the Kiokee and Belair Belts Near Augusta, Georgia (MS Thesis). University of South Carolina, Columbia, SC, 1979.

192. Snoke, A.W. and Frost, B.R. "Exhumation of High Pressure Pelitic Schist, Lake Murray Spillway, South Carolina: Evidence for Crustal Extension During Alleghanian Strike-Slip Faulting." American Journal of Science. Vol. 280, 1990.

193. Dallmeyer, R.D., et al. "Character of the Alleghanian Orogeny in the Southern Appalachians: Part II, Geochronological Constraints on the Tectonothermal Evolutions of the Eastern Piedmont in South Carolina." Geological Society of America Bulletin. Vol. 97, 1986.

194. Long, L.T. "The Carolina Slate Belt-Evidence of a Continental Rift Zone." Geology. Vol. 7, 1979.

195. Maher, H.D. "Stratigraphy and Structure of the Belair and Kiokee Belts near Augusta, Georgia, Geological Investigations of the Eastern Piedmont, Southern Appalachians." Carolina Geological Society Field Trip Guidebook. South Carolina Geological Survey, 1978.

196. Bramlett, K.W., et al. "The Belair Fault: A Cenozoic Reactivation Structure in the Eastern Piedmont." Geological Society of America Bulletin. Vol. 93, 1982.

197. Maher, H.D., Jr. "Kinematic History of Mylonitic Rocks from the Augusta Fault Zone, South Carolina and Georgia." American Journal of Science. Vol. 287, 1987.

198. Hatcher, R.D., Jr., et al. "Eastern Piedmont Fault System: Speculations on its Extent." Geology. Vol. 5, 1977.

199. Prowell, D.C. and O'Connor, B.J. "Belair Fault Zone: Evidence of Tertiary Fault Displacement in Eastern Georgia." Geology. Vol. 6, 1978.

200. Prowell, D.C. "Cretaceous and Cenozoic Tectonism on the Atlantic Coastal Margin, the Geology of North America, the Atlantic Continental Margin." Geological Society of America. Vol. I-2, 1988.

201. O'Connor, B.J. and Prowell, D.C. "The Geology of the Belair Fault Zone and Basement Rocks of the Augusta, Georgia Area." Georgia Geological Society Guidebook 16. 1976.

202. Daniels, D.L. "Geologic Interpretation of Geophysical Maps, Central Savannah River Area, South Carolina and Georgia." Geophysical Investigation Map GP-893, U.S. Geological Survey, 1974.

203. Manspeizer, W., et al. "Separation of Morrocco and Eastern North America: A Triassic-Liassic Stratigraphic Record." Geological Society of America Bulletin. Vol. 89, 1978.

204. Petersen, T.A., et al. "Structure of the Riddleville Basin from COCORP Seismic Data and Implications for Reactivation Tectonics." Journal of Geology. Vol. 92.

205. Ratcliffe, N.E. "The Ramapo Fault System in New York and Adjacent Northern New Jersey: A Case of Tectonic Heredity." Geological Society of America Bulletin. Vol. 82, 1971.

206. Lindholm, R.C. "Triassic-Jurassic Faulting in Eastern Northern America - A Model Based on Pre-Triassic Structures." Geology. Vol. 6, 1978.

207. Glover, L., III, et al. "Diachronous Paleozoic Mylonites and Structural Heredity of Triassic-Jurassic Basins in Virginia." Geological Society of America Abstracts with Programs. Vol. 12, 1980.

208. Olsen, P.E., et al. "Rift Basins of Early Mesozoic Age." The Geology of the Carolinas. University of Tennessee Press, Knoxville, 1991.

209. King, P.B. Systematic Pattern of Triassic Dikes in the Appalachian Region, Second Report. U.S. Geological Survey Professional Paper 759-D, 1971.

210. Olsen, P.E. "On the Use of the Term Newark for Triassic and Early Jurassic Rocks of Eastern North America." Newsletters on Stratigraphy. Vol. 7, 1978.

211. Smoot, J.P. "The Closed-Basin Hypothesis and Its Use in Facies Analysis of the Newark Supergroup." Proceedings of the Second U.S. Geological Survey Workshop on the Early Mesozoic Basins of the Eastern United States. U.S. Geological Survey Circular 946, 1985.

212. Gore, P.J.W. "Depositional Framework of a Triassic Rift Basin: The Durham and Sanford Sub-basins of the Deep River Basin, North Carolina." Society of Economic Paleontologists and Mineralogists Field Guidebook. Third Annual Midyear Meeting, Raleigh, NC, 1986.

213. Olsen, P.E. and Schlische, R.W. "Unraveling the Rules of Rift Basins." Geological Society of America Abstracts with Programs. Vol. 20, 1988.

214. Schlische, R.W. and Olsen, P.E. "Quantitative Filling Model for Continental Extensional Basins with Application to the Early Mesozoic Rifts of Eastern North America." Journal of Geology. 1992.

215. Stieve, A.L. and Stephenson, D.E. "Geophysical Evidence for Post Late Cretaceous Reactivation of Basement Structures in the Central Savannah River Area." Southeastern Geology. Vol. 35, No. 1, 1995.

216. McBride, J.H. "Constraints on the Structure and Tectonic Development of the Early Mesozoic South Georgia Rift, Southeastern United States; Seismic Reflection Data Processing and Interpretation." Tectonics. Vol. 10, No. 5, 1991.

217. Klitgord, K.D. and Behrendt, J.C. Basin Structure of the U.S. Atlantic Margin, Geological and Geophysical Investigations of Continental Margins. American Association of Petroleum Geologists, Memoir 29, 1979.

218. Colquhoun, D.J. and Johnson, Jr., H.S. "Tertiary Sea-Level Fluctuation in South Carolina." Paleogeography, Paleoclimatology, Paleoecology. Vol. 5, 1968.

219. Cooke, C.W. "Geology of the Coastal Plain of South Carolina." U.S. Geological Survey Bulletin. No. 867, 1936.

220. Colquhoun, D.J., et al. "Surface and Subsurface Stratigraphy, Structure and Aquifers of the South Carolina Coastal Plain." SCDHEC Report ISBN 0-9613154-0-7, 1983.

221. Prowell, D.C., et al. "Geologic Section of the Updip Coastal Plain from Central Georgia to Western South Carolina." U.S. Geological Survey Miscellaneous Field Studies Map MF-1737, 1985a.

222. Logan, W.R. and Euler, G.M. Geology and Groundwater Resources of, Bamberg, and Barnwell Counties as Part of Aiken County, SC. South Carolina Water Resources Commission Report 155, 1989.

223. Swift, D. J. and Heron, S.D. "Stratigraphy of the Carolina Cretaceous." Southeastern Geology. Vol. 10, 1969.

224. Nystrom, P.G. and Willoughby, R.H. "Geological Investigations Related to the Stratigraphy in the Kaolin Mining District, Aiken County, South Carolina." 1982 Carolina Geological Society Field Trip Guidebook. South Carolina Geological Survey, 1982.

225. Prowell, D.C., et al. "Geologic Section of the Updip Coastal Plain from Central Georgia to Western South Carolina." Map MF-1737, USGS Miscellaneous Field Studies, 1985.

226. Christopher, R.A. "Quantitative Palynologic Correlation of Three Campanian and MaeStrichtian Sections Upper Cretaceous from the Atlantic Coastal Plain." Palynology. Vol. 2, 1978.

227. Sohl, N.F. and Christopher, R.A., the Black Creek-Peedee Formational Contact (Upper Cretaceous) in the Cape fear River Region of North Carolina. U.S. Geological Survey Professional Paper 1285, 1983.

228. Heron, S.D. "History of Terminology and Correlations of the Basal Cretaceous Formations of the Carolinas." South Carolina State Development Board, Division of Geology, Geologic Notes: Vol. 2, 1958.

229. Aadland, R.K. Geology of A/M Area, Savannah River Site South Carolina. WSRC-RP-96-0505, Rev. 0, Westinghouse Savannah River Company, Aiken, SC, 1996.

230. Gohn, F.S., et al. "The Fishburne Formation (Lower Eocene), a Newly Defined Subsurface Unit in the South Carolina Coastal Plain." U.S. Geological Survey Bulletin. No. 1537-C, 1983.

231. Fallaw, W.C. and Price, Van. "Stratigraphy of the Savannah River Site and Vicinity." Southeastern Geology. Vol. 35, No. 1, 1995.

232. Herrick, S.M. and Vorhis, R.C. Subsurface Geology of the Georgia Coastal Plain. Georgia Department of Natural Resources, Division of Mines, Mining, and Geology, Information Circular 25, 1963.

233. Fallaw, W.C., et al. "Effects of Varying Degrees of Marine Influence on Tertiary Sediments in Southwestern South Carolina." Geological Society of America Abstracts with Programs. Vol. 22, No 7, 1990.

234. Clarke, J.S., et al. "Geology and Ground-Water Resources of the Coastal Area of Georgia." Georgia Geological Survey Bulletin. No. 113, 1990.

235. Aadland, R.K., et al. Significance of Soft Zone Sediments at the Savannah River Site, Historical Review of Significant Investigations and Current Understanding of Soft Zone Origin, Extent, and Stability. WSRC-TR-99-4083, Rev. 0, Westinghouse Savannah River Company, Aiken, SC, September 1999.

236. Huddleston, P.F. and Hetrick, J.H. "Upper Eocene Stratigraphy of Central and Eastern Georgia." Georgia Geologic Survey Bulletin. No. 95, 1985.

237. Nystrom, P.G., Jr., et al. "Cretaceous-Tertiary Stratigraphy of the Upper Edge of the Coastal Plain between North Augusta and Lexington South Carolina." in Carolina Geological Society Field Trip Guidebook. South Carolina Geological Survey, 1986.

238. Colquhoun, D.J. et al. Sedimentology and Stratigraphy of the Upland Unit: Final Report under SCUREF Cooperation Agreement with DOE. Task 119 AA009OOT to DOE. Geological Sciences Department, Earth Sciences and Resources Institute, University of South Carolina, Columbia, SC, 1994.

239. Hanson, K.L., et al. "Applications of Quaternary Stratigraphic, Soil-Geomorphic, and Quantitative Geomorphic Analyses to the Evaluation of Tectonic Activity and Landscape Evolution in the Upper Coastal Plain, South Carolina." Proceedings, 4th DOE Natural Phenomena Hazards Mitigation Conference. Vol. 2, Atlanta, Georgia, 1993.

240. Preliminary Quaternary and Neotectonic Studies. Geomatrix, Savannah River Site, Aiken, SC, 1993.

241. Markewich, H.W. and Christopher, R.A. "Pleistocene and Holocene Fluvial History of Uphapee Creek, Macon County, Alabama," U.S. Geological Survey Bulletin. No. 1522, 1982.

242. Coleman, S.M. "Progressive Changes in the Morphology of Fluvial Terraces and Scarps Along the Rappahannock River, Virginia." Earth Surface Processes and Land Forms. Vol. 8, 1983.

243. Mixon, R.B., et al. "Geologic Map of the Coastal Plain and Adjacent Parts of the Piedmont, Virginia." U.S. Geological Survey Miscellaneous Investigations Map I-2033, 2 Pls., scale 1:250,000, 1989.

244. Markewich, H.W. "Geomorphic Evidence for Pliocene-Pleistocene Uplift in the Area of Cape Fear Arch, North Carolina, Tectonic Geomorphology." Proceedings of the 15th Annual Binghampton Geomorphology Symposium. Allen & Unwin, Boston, MA, 1985.

245. Soller, D.R. Geology and Tectonic History of the Lower Cape Fear River Valley, Southeastern North Carolina. U.S. Geological Survey Professional Paper 1466-A, 1988.

246. Brooks, M.J. and Sassaman, K.E. "Point Bar Geoarchaeology in the Upper Coastal Plain of the Savannah River Valley, South Carolina: A Case Study." Archaeological Geology of North America. Geological Society of America Centennial Special Publications No. 4, 1990.

247. Soller, D.R. and Mills, H.H. "Surficial Geology and Geomorphology." The Geology of the Carolinas. Carolina Geological Society Fiftieth Anniversary Volume, University of Tennessee Press, Knoxville, 1991.

248. Johnson, D.W. The Origins of Carolina Bays. Columbia University Press, New York, NY, 1942.

249. Gamble, E.E., et al. "The Goldsboro Ridge, an Enigma." Southeastern Geology, Vol. 12, 1977.

250. Cooke, C.W. Carolina Bays and the Shapes of Eddies. U.S. Geological Survey Professional Paper 254-I, 1953.

251. Melton, I.A. and Schriever, W. "The Carolina 'Bays' - Are They Meteorite Scars?" Journal of Geology. Vol. 41, 1933.

252. Thom, B.G. "Carolina Bays in Horry and Marion Counties, South Carolina." Geological Society of America Bulletin. Vol. 18, 1970.

253. Kaczorowksi, R.T. "Origin of the Carolina Bays." Terrigenous Clastic Depositional Environments. Technical Report No. 11-CRD, Coastal Research Division, Department of Geology, University of South Carolina, Columbia, 1976.

254. Savage, H., Jr. The Mysterious Carolina Bays. Columbia University Press 1982.

255. Foundation Grouting Operations. Savannah River Plant, Waterways Experiment Station. U.S. Army Corps of Engineers, Charleston District, Vicksburg, MS, 1952.

256. Rankin, D.W. Studies Related to the Charleston, South Carolina, Earthquake of 1886 -- Introduction and Discussion, Studies Related to the Charleston, South Carolina, Earthquake of 1886--A Preliminary Report. U.S. Geological Survey Professional Paper 1028, 1977.

257. Huddlestun, P.F. and Hetrick, J.H. "Stratigraphy of the Tobacco Road Sand - A New Formation." Georgia Geologic Survey. Bulletin 93, 1978.

258. Colquhoun, D.J. and Steele, K.B. Chronostratigraphy and Hydrostatigraphy of the Northwestern South Carolina Coastal Plain. Annual Cooperative Grant Agreement No. 13040 R-83-591, Project No. G868-05, Interim Technical Report to Water Resources Research Institute, Clemson University, Clemson, South Carolina, 1985.

259. Prowell, D.C., et al. "The Ellenton Formation in South Carolina: A Revised Age Designation from Cretaceous to Paleocene." U.S. Geological Survey Bulletin. No. 1605-A, 1985.

260. Dennehy, K.F., et al. "Geohydrology of the Defense Waste Processing Facility and Vicinity, Savannah River Plant, South Carolina." U.S. Geological Survey Water Resources Investigation, WRI 88-4221, 1988.

261. Nystrom, P.G., et al. "Clailbornian Stratigraphy of the Savannah River Site and Surrounding Area, 1990, Savannah River Region: Transition Between the Gulf and Atlantic Coastal Plains." Proceedings of the Second Bald Head Island Conference on Coastal Plains Geology. Hilton Head Island, November 6-11, 1990.

262. Marine, I.W. Geohydrology of the Buried Triassic Basin at the Savannah River Plant Groundwater. Vol. 2, 1974.

263. Marine, I.W. "Geohydrology of Buried Triassic Basin at the Savannah River Plant, South Carolina." American Association of Petroleum Geologists Bulletin, Vol. 58, 1974.

264. Marine, I.W. and Siple, G.E. "Buried Triassic Basin in the Central Savannah River Area, South Carolina and Georgia." Geological Society of America Bulletin. Vol. 85, 1974.

265. Snipes, D. S., et al. "The Pen Branch Fault: Documentation of Late Cretaceous-Tertiary Faulting in the Coastal Plain of South Carolina." Southeastern Geology. Vol. 33, No. 4, 1993.

266. Chowns, T.M., et al. Investigation of Triassic Basin Sediments – Savannah River Site. Task #52, Final Report prepared for Westinghouse Savannah River Company, Aiken, SC, 1996.

267. Geologic-Engineering Investigations, Savannah River Plant. DPWR-52, E.I. du Pont de Nemours and Company, Savannah River Plant, Aiken, SC, 1952.

268. Anderson, E.E. The Seismotectonics of the Savannah River Site: The Results of a Detailed Gravity Survey (M.S. Thesis). University of South Carolina, Columbia, SC, 1990.

269. Domoracki, W. A Geophysical Investigation of Geologic Structure and Regional Tectonic Setting at the Savannah River Site, South Carolina. Ph.D. Dissertation, Virginia Polytechnic Institute and State University, Blacksburg, Virginia, 1995.

270. Cumbest, R.J., et al. Basement Surface Faulting for Savannah River Site and Vicinity. WSRC TR-98-00346, Westinghouse Savannah River Company, Aiken, SC, 1998.

271. Stephenson, D.E. and Stieve, A. Structural Model of the Basement Based on Geophysical Data in the Central Savannah River Area, South Carolina and Georgia. WSRC-TR-92-120, Westinghouse Savannah River Company, Aiken, SC, 1992.

272. Cumbest, R.J., et al. "Gravity and Magnetic Modeling of the Dunbarton Triassic Basin, South Carolina." Southeastern Geology. Vol. 33, No. 1, 1992.

273. Latour, T.E., et al. Crystalline Basement Core – Savannah River Site. Final Report, ERDA Task 53, 1995.

274. Shervais, J.W., Mauldin, J., Dennis, A.J. Petrology and Geochemistry of Neo-Proterozoic Arc Plutons beneath the Atlantic Coastal Plain: Savannah River Site, South Carolina. Report submitted for SCURF, Task 170, 1996.

275. Mauldin, J., Shervais, J.W., Dennis, A.J. Petrology and Geochemistry of Metavolcanic Rocks from a Neoproterozoic Volcanic Arc, Savannah River Site, South Carolina. Report submitted for SCURF, Task 170, 1996.

276. Dennis, A.J., et al. Repeated Phanerozoic Reactivation of a Southern Appalachian Fault Zone Beneath the Up-Dip Coastal Plain of South Carolina. Report submitted for SCURF, Task 170, 1996.

277. Hall, M.H. Heavy Mineral Provinence of Triassic Dunbarton Basin Deposits, South Carolina. M.S. thesis, University of North Carolina, Wilmington, NC, 1997.

278. Chapman, W.L. and DiStefano, M.P. Savannah River Plant Seismic Survey, 1987-88. Research Report 1809-005-006-1-89, Conoco, Inc., Seismic Acquisition Section, 1989.

279. Leutgert et al. "Crystal Structure Beneath the Atlantic Coast Plain of South Carolina." Seismological Research Letters. Vol. 65, No. 2, 1994.

280. Parsons, et al. Bedrock Waste Storage Project, Triassic Basin Fault Probing Program Report. E. I. du Pont de Nemours and Co., Savannah River Plant, Aiken, SC, 1973.

281. Prowell, D.C. Preliminary Geologic Map of the Barnwell 30' x 60' Quadrangle, South Carolina and Georgia. Open File Report 94-673, U.S. Geological Survey, Atlanta, GA, 1994.

282. Reactor Site Criteria. 10 CFR 100, Washington, DC, November 15, 1983.

283. Stieve, A.L. et al. Confirmatory Drilling Project Final Report. WSRC-RP-94-0136, Westinghouse Savannah River Company, Aiken, SC, 1994.

284. Grow, J.A., et al. "Structure and Evolution of Baltimore Canyon Trough." The Geology of North America. Vol. I-1, *The Atlantic Continental Margin.* DNAG Publication, Geological Society of America, Boulder, CO, 1988.

285. Sheridan, R.E. and Grow, J.A. "The Geology of North America." The Atlantic Continental Margin. Vol. I-1 and I-2, DNAG Publication, Geological Society of America, Boulder, CO, 1988.

286. Maher, H.D., Jr., et al. "Magmatic Softening in the Orogenic Hinterlands Southern Appalachian Piedmont, Georgia." Geological Society of America Abstracts with Programs. Vol. 24, No. 2, 1992.

287. Farrar, S.S. "Tectonic Evolution of the Eastern-Most Piedmont, North Carolina." Geological Society of America Bulletin. Vol. 96, 1985.

288. Sacks, P.E. and Dennis, A.J. "The Modoc Zone-D_2 (Early Alleghanian) in the Eastern Appalachian Piedmont, South Carolina and Georgia, Anatomy of the Alleghanian Orogeny as Seen from the Piedmont of South Carolina and Georgia." Carolina Geological Society Field Trip Guidebook. South Carolina Geological Survey, 1987

289. Cook, F.A., et al. "COCORP Seismic Profiling of the Appalachian Orogen Beneath the Coastal Plain of Georgia." Geological Society of America Bulletin. Vol. 92, No. 10, 1981.

290. Sen, A.K. and Coruh, C. Removing Near-Surface Effects in Seismic Data: Application for Determination of Faults in the Coastal Plain Sediments. WSRC-TR-92-169, Westinghouse Savannah River Company, Aiken, SC, 1992.

291. Kanter, L.R. Tectonic Interpretation of Stable Continental Crust in: The Earthquakes of Stable Continental Regions. Electric Power Research Institute, Palo Alto, CA, 1994.

292. Keen, C.E. and Haworth, R.T. "DNAG Transect D-3: Rifted Continental Margin Off Nova Scotia: Offshore Eastern Canada." Geological Society of America, Centennial Continent/Ocean Transect #4. Boulder, CO, 1985.

294. Hutchinson, D.R. and Klitgord, K.D. "Evolution of Rift Basins on the Continental Margin Off Southern New England: Triassic-Jurassic Rifting: North America and Africa." American Association of Petroleum Geologists Memoir, 1986.

295. Price, V., et al. Pen Branch Fault Investigation Program Plan. ESS-SRL-89-395, 1989.

296. Klitgord, K.D. and Schouten, H. "Plate Kinematics of the Central Atlantic." The Geology of North America. Vol. M, The Western North Atlantic Region. DNAG Publication, Geological Society of America, Boulder, CO, 1986.

297. Zoback, M.D. and Zoback, M.L. Tectonic Stress Field of North America and Relative Plate Motions in Neotectonics of North America. Vol. I, Decade Map, Geological Society of America, Boulder, CO, 1991.

298. Gohn, G.S. "Late Mesozoic and Early Cretaceous Geology of the Atlantic Coastal Plain: North Carolina to Florida." The Geology of North America. Vol. I-2, The Atlantic Continental Margin, pp. 107-130, DNAG Publication, Geological Society of America, Boulder, CO.

299. Steckler, M.S., et al. "Subsidence and Basin Modeling at the U.S. Atlantic Passive Margin." The Geology of North America. Vol. I-2, The Atlantic Continental Margin. DNAG Publication, Geological Society of America, Boulder, CO, 1988.

300. Sawyer, D.S. "Thermal Evolution." The Geology of North America. Vol. I-2, The Atlantic Continental Margin. DNAG Publication, Geological Society of America, Boulder, CO, 1988.

301. Brown, P.M., et al. Structural and Stratigraphic Framework, and Spatial Distribution of Permeability of the Atlantic Coastal Plain, North Carolina to New York. U.S. Geological Survey Professional Paper 796, 1972.

302. Heller, P.L., et al. "Episodic Post-Rift Subsidence of the United States Atlantic Margin." Geological Society of America Bulletin. Vol. 93, No. 5, 1982.

303. Winkler, C.D. and Howard, J.D. "Correlation of Tectonically Deformed Shorelines on the Southern Atlantic Coastal Plain." Geology. Vol. 5, 1977.

304. Baum, G.R., et al. "Structural and Stratigraphic Framework for the Coastal Plain of North Carolina." Field Trip Guidebook for Carolina Geological Society and Atlantic Coastal Plain Geological Society. North Carolina Department of Natural Resources and Development, 1979.

305. Prowell, D.C. and Obermeier, S.F. "Evidence of Cenozoic Tectonism." The Geology of the Carolinas. University of Tennessee Press, Knoxville, TN, 1991.

306. Prowell, D.C. Index of Faults of Cretaceous and Cenozoic Age in the Eastern United States. U.S. Geological Survey Miscellaneous Field Studies Map MF-1269, 1983.

307. Moos, D. and Zoback, M.D. In Situ Stress Measurements in the NPR Hole, Savannah River Site, South Carolina: Final Report to Westinghouse Savannah River Co., Vol. 1, Results and Interpretations. Subcontract AA00925P, Science Applications International Corporation, Augusta, GA, 1992.

308. Moos, D. and Zoback, M.D. Near Surface "Thin Skin" Reverse Faulting Stresses in the Southeastern United States. Vol. 30, No. 7, 1993.

309. Talwani, P., et al. Induced Seismicity and Earthquake Prediction Studies in South Carolina. Tenth Technical Report to the USGS, Contract 14-08-001-17670.1980.

310. Stephenson, D.S. and Chapman, W.L. "Structure Associated with the Buried Dunbarton Basin, South Carolina from Recent Seismic Data." Geological Society of America, Southeastern Section Abstracts with Programs. Vol. 20, 1988.

311. Stephenson, D.E., et al. Savannah River Plant Earthquake of June 1985. DPST-85-583, E.I. du Pont de Nemours & Co., Savannah River Laboratory, Aiken, SC, 1985.

312. Seismograph Services Corporation. Gravity and Magnetic Survey, Savannah River Plant, South Carolina. Unpublished report prepared for E.I. du Pont de Nemours and Co., Inc., Engineering Department, Wilmington, DE, 1972.

313. Stieve, A.L. Pen Branch Fault Program: Interim Report on the High Resolution, Shallow Seismic Reflection Surveys. WSRC-TR-91-30, Westinghouse Savannah River Company, Aiken, SC, 1991.

314. Berkman, E. High Resolution Seismic Survey, Pen Branch Fault, Savannah River Site, South Carolina. WSRC-TR-91-38, Westinghouse Savannah River Company, Aiken, SC, 1991.

315. Pen Branch Fault Basement Drilling. Westinghouse Environmental and Geotechnical Services, 1991.

316. O'Connor, et al. "Recently Discovered Faults in the Central Savannah River Area." abstract, Georgia Academy of Science Bulletin. Vol. 32, 1974.

317. Prowell, D.C., et al. Preliminary Evidence for Holocene Movement Along the Belair Fault Zone Near Augusta, Georgia. Open File Report 75-680, U.S. Geological Survey, Atlanta, GA, 1976.

318. Wentworth, C.M. and Mergener, K.M. "Regenerate Faults of the Southeastern United States." Studies Related to the Charleston, South Carolina, Earthquake of 1886, Tectonics and Seismicity. U.S. Geological Survey Professional Paper 1313, 1983.

319. Gohn, G.S. Studies Related to the Charleston Earthquake of 1886: Tectonics and Seismicity. U.S. Geological Survey Professional Paper 1313, 1983.

320. Talwani, P. "Current Thoughts on the Cause of the Charleston, South Carolina Earthquakes." South Carolina Geology. Vol. 29, 1985.

321. Zoback, M.L. and Zoback, M.D. "State of Stress in the Conterminous United States." Journal of Geophysical Research. Vol. 85, 1980.

322. Long, L.T. and Chapman, J.W., Jr. "Bouguer Gravity Map of the Summerville-Charleston, South Carolina Epicentral Zone and Tectonic Implications." Studies Related to the Charleston, South Carolina Earthquake of 1886--A Preliminary Report. U.S. Geological Survey Professional Paper 1028, 1977.

323. Barstow, N.L., et al. An Approach to Seismic Zonation for Siting Nuclear Electric Power Generation Facilities in the Eastern United States. NUREG/CR-1577, U.S. Nuclear Regulatory Commission, Washington, DC, 1981.

324. Tarr, A.C., et al. "Results of Recent South Carolina Seismological Studies." Bulletin of the Seismological Society of America. Vol. 71, 1981.

325. Talwani, P. and Cox, S. "An Internally Consistent Pattern of Seismicity Near Charleston, South Carolina." Geology. Vol. 10, 1985.

326. Youd, T.L. "Liquefaction, Flow and Associated Ground Failure." U.S. Geological Survey Circular. No. 688, 1973.

327. Dutton, C.E. "The Charleston Earthquake of August 31, 1886." U.S. Geological Survey Annual Report 1887-1888. Government Printing Office, Washington, DC, 1889.

328. Cox, J. and Talwani, P. "Paleoseismic Studies in the 1886 Charleston Earthquake Meizoseismal Area." Geological Society of America, Abstracts with Programs. No. 16, 1983.

329. Talwani, P. and Cox, S. "Paleoseismic Evidence for Recurrence of Earthquakes near Charleston, South Carolina." American Association for the Advancement of Science. Vol. 229, July 1985.

330. Gohn, G.S., et al. "Field Studies of Earthquakes Induced Liquefaction-Flowage Features in the Charleston, South Carolina, Area Preliminary Report". U.S. Geological Survey Open-File Report 84-670, 1984.

331. Obermeier, S.F., et al. "Geologic Evidence for Recurrent Moderate to Large Earthquakes near Charleston, South Carolina." Science. Vol. 227, 1985.

332. Amick, D.R., et al. Paleoliquefaction Features Along the Atlantic Seaboard. NUREG/CR-5613, U.S. Nuclear Regulatory Commission, Washington, DC, 1990.

333. Obermeier, S.F., et al. Earthquake-Induced Liquefaction Features in the Coastal Setting of South Carolina and in the Fluvial Setting of the New Madrid Seismic Zone. U.S. Geological Survey Professional Paper No. 1504, 1990.

334. Amick, D. and Gelinas, R. "The Search for Evidence of Large Prehistoric Earthquakes along the Atlantic Seaboard." American Association for the Advancement of Science, February 1991. Vol. 251, 1991.

335. Sibol, M.S. and Bollinger, G.A. Earthquake Catalog for the Southeastern United States, 1698-1989. Virginia Polytechnic Institute and State University Seismological Observatory Computer File, Blacksburg, VA, 1990.

336. Bollinger, G.A., et al. "Seismicity of the Southeastern United States -- 1968–1986." Decade of Geology. 1987.

337. Visvanathan, T.R. "Earthquakes in South Carolina, 1698—1975," South Carolina Geological Survey Bulletin, Vol. 40, 1980.

338. Dewy, J.W., "Relocation of Instrumentally Recorded Pre-1974 Earthquakes in South Carolina Region," in Studies Related to the Charleston, South Carolina Earthquake of 1986 - Tectonics and Seismicity (ed. Gohn, G.S.), US Geological Survey Professional Paper 1313, 1983.

339. Talwani, P., "Crustal Structure of South Carolina," Second Technical Report to the U.S. Geological Survey, Contract #14-08-0001-14553; 1975.

340. Bollinger, G.A. "Specification of Source Zones, Recurrence Rates, Focal Depths, and Maximum Magnitudes for Earthquakes Affecting the Savannah River Site in South Carolina." U.S. Geological Survey Bulletin. No. 2017, 1992.

341. Lahr, J.C. "HYPOELLIPSE: A Computer Program for Determining Local Earthquake Hypocentral Parameters, Magnitude, and First Motion Pattern," U.S. Geological Survey Open File Report 84-519, 1984.

342. Bollinger, G.A. "Seismicity of the Southeastern United States." Bulletin of the Seismological Society of America. Vol. 63, No. 5, 1973.

343. Talwani, P.J., et al. "The Savannah River Plant, South Carolina, Earthquake of June 9, 1985 and its Tectonic Setting." Earthquake Notes. Vol. 56, No. 4, 1985.

344. Stephenson, D.E. Savannah River Plant Earthquake. DPST-88-841, E.I. du Pont de Nemours and Co., Savannah River Laboratory, Aiken, SC, August 1988.

345. Bollinger, G.A., et al. "Seismicity of the Southeastern United States: 1698-1986." Neotectonics of North America. Geological Society of America DNAG Map Vol. 1, 1991.

346. Domoracki, W.J., et al. "Seismotectonic Structures Along the Savannah River Corridor, South Carolina, USA." Journal of Geodynamics. 1997.

347. Phinney, R.A. and Roy-Chowdhury, K. Reflection Seismic Studies of Crustal Structure in the Eastern United States: Geophysical Framework of the Continental United States. Geological Society of America Mem. 172, 1989.

348. Coruh, C., et al. "Seismogenic Structures in the Central Virginia Seismic Zone." Geology. Vol. 16, 1988.

349 Bollinger, G.A., et al. "An Analysis of Earthquake Focal Depths in the Southeastern United States." Geophysical Research Letters. Vol. 12, 1985.

350. Sibson, R.H. "Frictional Constraints to Thrust, Wrench, and Normal Faults." Nature. Vol. 249, 1984.

351. Sibson, R.H. "Earthquakes and Rock Deformation in Crustal Fault Zones." Annual Review of Earth Planet Sciences. Vol. 14, 1986.

352. Scholz, C.H. The Mechanics of Earthquakes and Faulting. Cambridge University Press, 1990.

353. Housner, G.W. Earthquake Criteria for the Savannah River Plant. DPE-2383, E.I. du Pont de Nemours and Company, Savannah River Plant, Aiken, SC, 1968.

354. URS/John A. Blume and Associates, Engineers. Update of Seismic Criteria for the Savannah River Plant, Vol. 1 of 2, *Geotechnical.* USR/JAB8144, San Francisco, CA. Prepared for E.I. du Pont de Nemours and Company as DPE-3699, Savannah River Plant, Aiken, SC, 1982.

355. Geomatrix Consultants, Inc. Ground Motion Following Selection of SRS Design Basis Earthquake and Associated Deterministic Approach. WSRC Subcontract AA2021S, Westinghouse Savannah River Company, Aiken, SC, 1991.

356. Lee, R.C. Update of H-Area Seismic Design Basis. WSRC-TR-94-0528, Rev. 1, Westinghouse Savannah River Company, Aiken, SC.

357. Lee, R.C., et al. Savannah River Site Seismic Response Analysis and Design Basis Guidelines. WSRC-TR-97-0085, Rev. 0, Westinghouse Savannah River Company, Aiken, SC, March 1997.

358. Lee, R.C. Soil Surface Seismic Hazard and Design Basis Guidelines for Performance Category 1 & 2 SRS Facilities. WSRC-TR-98-00263, Rev. 0, Westinghouse Savannah River Company, Aiken, SC, September 1998.

359. Facility Safety. DOE Order 420.1, U.S. Department of Energy, Washington, DC, 1995.

360. General Design Criteria. DOE Order 6430.1A, U.S. Department of Energy, Washington, DC, 1989.

361. Guidelines for Use of Probabilistic Seismic Hazard Curves at Department of Energy Sites. DOE-STD-1024-92, Change Notice No. 1, U.S. Department of Energy, Washington, DC, January 1996.

362. Natural Phenomena Hazards Assessment Criteria. DOE-STD-1023-95, Change Notice No. 1, U.S. Department of Energy, Washington DC, January 1996.

363. Natural Phenomena Hazards Performance Categorization Criteria for Structures, Systems, and Components. DOE-STD-1021-93, Change Notice No. 1, U.S. Department of Energy Washington, DC, January 1996.

364. National Earthquake Hazards Reduction Program (NEHRP) Recommended Provisions for Seismic Regulations for New Buildings and Other Structures. Building Seismic Safety Council, part 1 Provisions (FEMA 302).

365. Dutton, C. E. The Charleston Earthquake of August 31, 1886. U.S. Geological Survey, 1890.

366. Talwani, P. The Woodstock Fault is Alive and Ticking Near Charleston, South Carolina. Submitted to the Bulletin of the Seismological Society of America, 1982.

367. Talwani, P. "Seismotectonics of the Charleston Region." Proceedings, National Conference on Earthquake Engineering, 3rd. Earthquake Engineering Research Inst., Vol. 1, 1986.

368. Stephenson, D.E. Review of Seismicity and Ground Motion Studies Related to the Development of Seismic Design Criteria at SRS. WSRC-TR-90-0284, Westinghouse Savannah River Company, Aiken, SC, 1990.

369. Bollinger, G.A. "Reinterpretation of the Intensity Data for the 1886 Charleston, South Carolina Earthquake." Studies Related to the Charleston, South Carolina, Earthquake of 1886--A Preliminary Report. U.S. Geological Society Professional Paper 1028, 1977.

370. Kimball, J.K. "The Use of Site Dependent Spectra." Proceedings of the U.S. Geological Survey Workshop on Site Specific Effects of Soil and Rock on Ground Motions and the

Implications for Earthquake-Resistant Design. U.S. Geological Survey Open File Report 83-845, 1983.

371. Stephenson, D.E., et al. "Savannah River Site Disaggregated Seismic Spectra." Fourth DOE Natural Phenomena Hazards Mitigation Conference. U.S. Department of Energy, Washington, DC, 1993.

372. Quality Assurance. WSRC Procedure Manual 1Q, Westinghouse Savannah River Company, Aiken, SC.

373. Engineering Standards Manual, Structural Design Criteria Standard No 01060. Westinghouse Savannah River Company, Aiken, SC, 1999.

374. Hanks, T.C. and McGuire, R.K. "The Character of High-Frequency Strong Ground Motion." Bulletin of the Seismological Society of America. Vol. 71, No. 6, 1981.

375. Boore, D.M. "Stochastic Simulation of High-Frequency Ground Motions Based on Seismological Models of the Radiated Spectra." Bulletin of the Seismological Society of America. Vol. 73, 1983.

376. 1993 Guidelines for Determining Design Basis Ground Motions. EPRI TR-102293, Electric Power Research Institute, Palo Alto, CA, November 1993.

377. Somerville, P.G., et al. Comparison of Source Scaling Relation of Eastern and Western North American Earthquakes. BSSA, 77, #2, 322-346. 1987.

378. Herrmann, R.B. "Surface-Wave Studies of Some South Carolina Earthquakes." Bulletin of the Seismological Society of America. Vol. 76, No. 1, 1986.

379. Ou, G.B. and Herrmann, R.B. "A Statistical Model for Ground Motion Produced by Earthquakes at Local and Regional Distances." Bulletin of the Seismological Society of America. Vol. 80, No. 6, 1990.

380. Stokoe, K.H., et al. Correlation Study of Nonlinear Dynamic Soil Properties: Savannah River Site, Aiken, South Carolina. Rev. 0, File No. SRS-RF-CDP-95, University of Texas at Austin, Department Civil Engineering, September 13, 1995.

381. Lee, R.C. Investigations of Nonlinear Dynamic Soil Properties at the Savannah River Site. WSRC-TR-96-0062, Rev. 0, Westinghouse Savannah River Company, Aiken, SC, March 1996.

382. Gutierrez, B.J. "Revised Envelope of the Site-Specific PC3 Surface Ground Motion," letter from DOE to L.A. Salamone and F. Loceff, September 9, 1999.

383. APSF Liquefaction Settlement Analysis. K-CLC-F-00033, Rev. 0, Westinghouse Savannah River Company, Aiken, SC, June 1998.

384. SRS Engineering Practices Manual. WSRC-IM-95-58, Rev. 0, Guide No. 02224-G, "Excavation Backfill, and Grading," Westinghouse Savannah River Company, Aiken, SC, March 1997.

385. Standard Engineering Specifications, Civil Sections. E.I. du Pont de Nemours & Co., Savannah River Plant, Aiken, SC, November 1988.

386. Engineering Requirement Document 02224-01-R, Rev. 1. Westinghouse Savannah River Company, Aiken, SC, August 19, 1994.

387. SRS Engineering Practices Manual. Guide No. 02224-G, Rev. 0, "Excavation, Fill, and Grading," WSRC-IM-95-58, Westinghouse Savannah River Company, Aiken, SC, March 1997.

388. Laboratory Compaction Characteristics of Soil Using Modified Effort. ASTM D1557-91, American Society for Testing and Materials, Conshohocken, PA, 1999.

389. Technical Engineering and Design Guides Adapted from the US Army Corps of Engineers, No. 9, "Settlement Analysis," American Society of Civil Engineers Press, New York, NY, 1994.

390. Soil Analysis. NAVFAC DM-7.01, Department of the Navy, Washington, DC, September 1986.

391. Hasek, M.J. Settlement of H-Area Waste Storage Tanks and Structures. K-ESR-H-00011, Westinghouse Savannah River Company, Aiken, SC, October 1999.

392. Li, W.T. Settlement of Defense Waste Processing Facility. K-ESR-S-00003, Rev. 0, Westinghouse Savannah River Company, Aiken, SC, September 1999.

393. Geotechnical Summary Report for the Consolidated Incineration Facility. K-ESR-H-00004, Rev. 0, Westinghouse Savannah River Company, Aiken, SC, 1994.

394. In Tank Precipitation Facility (ITP) H-Tank Farm (HTF) Geotechnical Report. WSRC-TR-95-0057, Rev. 0, Westinghouse Savannah River Company, Aiken, SC, 1995.

395. Commercial Light Water Reactor Tritium Extraction Facility Geotechnical Summary Report. K-ESR-H-00010, Rev. 1, Westinghouse Savannah River Company, Aiken, SC, June 1999.

396. F-Area Geotechnical Characterization Report. WSRC-TR-96-0069, Rev. 0, Westinghouse Savannah River Company, Aiken, SC, September 1996.

397. Savannah River Site, Replacement Tritium Facility (233-H) Geotechnical Investigation. Volume 1, WSRC-RP-93-606, Bechtel Savannah River Incorporated, Savannah River Site, Aiken, SC, 1993.

398. Wang, W. Some Findings in Liquefaction. Water Conservancy and Hydroelectric Power Scientific Research Institute, Beijing, China, August 1979.

399. Koester, J.P. and Franklin, A.G. Current Methodologies for Assessing the Potential for Earthquake-Induced Liquefaction in Soils. NUREG/CR-430, U.S. Nuclear Regulatory Commission, Washington, DC, 1985.

400. Seed, R.B., et al. "Evaluation of Liquefaction Potential Using Field Performance Data." Journal of Geotechnical Engineering Division. Volume 97, No. 3, American Society of Civil Engineers, 1983.

401. Youd, T.L. and Idriss, I.M. Proceedings of the NCEER Workshop on Evaluation of Liquefaction Resistance of Soils. Technical Report NCEER-97-0022, Buffalo, NY, December 31, 1997.

402. Savannah River Site, Replacement Tritium Facility (233-H) Geotechnical Investigation. WSRC-RP-93-606, Vol. I, Bechtel Savannah River Incorporated, Savannah River Site, Aiken, SC, 1993.

403. Youd, T.L. and Hoose, S.N. "Liquefaction Susceptibility and Geologic Setting." Proceedings, 6th World Conference on Earthquake Engineering. New Delhi, India, Vol. 6, 1987.

404. Seed, H.B. "Soil Liquefaction and Cyclic Mobility Evaluation for Level Ground During Earthquakes." Journal of Geotechnical Engineering Division. Vol. 105, No. 2, American Society of Civil Engineers, February 1979.

405. Mitchell, J.K. and Solymar, Z.V. "Time Dependent Strength Gain in Freshly Deposited or Densified Sand," Journal of Geotechnical Engineering Division, Vol. 110, No. 11, American Society of Civil Engineers, November 1984.

406. Mitchell, J.K. "Practical Problems from Surprising Soil Behavior," The 20th Terzaghi Lecture, Journal of Geotechnical Engineering Division, Vol. 112, No. 3, American Society of Civil Engineers, March 1986.

407. Skempton, A.W. "Standard Penetration Test Procedures and the Effects in Sands of Overburden Pressure, Relative Density, Particle Size, Aging and Overconsolidation," Geotechnique, Vol. 36, No. 3, 1986.

408. Schmertmann, J.H. "The Mechanical Aging of Soils," The 25th Terzaghi Lecture, Journal of Geotechnical Engineering, Vol. 117, No. 9, American Society of Civil Engineers, September 1991.

409. Schmertmann, J.H. "Update on the Mechanical Aging of Soils," for the symposium *Sobre Envejecimiento de Suelos,* The Mexican Society of Soil Mechanics, Mexico City, Mexico, August 1993.

410. Lewis, M.R., et al. "Liquefaction Resistance of Old Sand Deposits," Proceedings of the XI Panamerican Conference on Soil Mechanics and Geotechnical Engineering. Foz do Iguassu, Brazil, August 1999.

411. Dobry, R., et al. Predication of Pore Water Pressure Buildup and Liquefaction of Sands During Earthquakes by the Cyclic Strain Method. National Bureau of Standards Building Science Series 138, 1982.

412. Martin, G.R., et al. "Fundamentals of Liquefaction Under Cyclic Loading." Journal of the Geotechnical Engineering Division. Proceedings Paper 11284, ASCE, Vol. 101, No. 5, May 1975.

413. Siple, G.E. Geology and Ground Water of the Savannah River Plant and Vicinity, South Carolina. U.S. Geological Survey Water-Supply Paper 1841, 1967.

414. K-Area Soil Stabilization Program Geotechnical Evaluation. WSRC-TR-92-299, Westinghouse Savannah River Company, Aiken, SC, July 1992.

415. APSF Soft Zone Settlement Analysis. K-CLC-00034, Rev. 0, Westinghouse Savannah River Company, Aiken, SC, June 1998,

416. Linsley, R. K., Jr., Kohler, M. A. and Poulhus, J. L. H. Hydrology for Engineers (3rd ed.). McGraw-Hill, Inc., New York, NY, 1982.

417. Alvin W. Vogtle Electric Generating Plant, Unit 1 and Unit 2, Final Safety Analysis Report. Vol. 1-34, Georgia Power Company, 1987.

418. Addis, R.P. and Kurzeja, R.J. Heavy Rainfall at the SRS in July, August and October of 1990. WSRC-TR-92-136, Westinghouse Savannah River Company, Aiken, SC.

419. Schreiner, L. C., and Riedel, J. T. Probable Maximum Precipitation Estimates, United States East of the 105th Meridian. National Oceanic and Atmospheric Administration (NOAA) Hydrometeorological Report No. 51, U.S. Department of Commerce, Washington, DC, 1978.

420. Hansen, E. M., Schreiner, L. C., and Miller, J. F. Application of Probable Maximum Precipitation Estimates -- United States East of the 105th Meridian. National Oceanic and Atmospheric Administration (NOAA) Hydrometeorological Report No. 52, U.S. Department of Commerce, Washington, DC, 1982.

421. Probable Maximum and TVA Precipitation for Tennessee River Basins up to 3,000 Square Miles in Area and Durations of 72 Hours. Hydrometeorological Report No. 45, National Weather Service, Silver Springs, MD, 1969.

422. Design Basis Floods for Nuclear Power Plants. NUREG 1.59, U.S. Nuclear Regulatory Commission, Washington, DC, 1977.

423. Savannah River Site Production Reactor Safety Analysis Report. WSRC-SA-10003, Westinghouse Savannah River Company, Aiken, SC, 1990.

424. Water Resources: Corps of Engineers' Drought Management of Savannah River Projects. GAO/RCED-89-169, United States General Accounting Office, Washington, DC, June 1989.

425. Evaluation of Accident Risks in the Transportation of Hazardous Materials by Truck and Rail at the Savannah River Plant. WSRC-RP-89-715, Rev. 1, Westinghouse Savannah River Company, Aiken, SC, September1992.

426. Map of the South Carolina Railroad System. South Carolina Public Service Commission, Transportation Division, Columbia, SC, 1986.

427. South Carolina Aeronautical Chart, 1988/89. South Carolina Aeronautics Commission, Columbia, SC, 1988.

428. Lower Savannah Region South Carolina Overall Economic Development Plan. Lower Savannah Council of Governments, Aiken, SC, 1993.

429. Safety Analysis - 200 Area Savannah River Plant H-Canyon Operations. DPSTSA-200-10, Sup. 5, E.I. du Pont de Nemours & Co., Savannah River Laboratory, Aiken, SC, 1986.

430. Safety Analysis - 200 Area Savannah River Plant Liquid Radioactive Waste Handling Facilities. DPSTSA-200-10, Sup. 18, E.I. du Pont de Nemours & Co., Savannah River Laboratory, Aiken, SC, 1986.

431. Site Development and Facility Utilization Plan, Savannah River Plant. Volume II, DPSP-87-271-2, U.S. Department of Energy, Savannah River Operations, Aiken, SC, 1987.

432. Savannah River Site Tier II Emergency and Hazardous Chemical Inventory Report (40 CFR 370) (Modified for the State of Georgia), for the reporting year 1997. Westinghouse Savannah River Company, Aiken, SC, March 1998

433. 1997 South Carolina Manufacturers Register. Manufacturers' News, Evanston, IL, 1997.

434. Atlas/Data Abstract for the United States and Selected Areas, Fiscal Year 1987. DTIC and NTIS No. DIOR.K93076, U.S. Department of Defense, Washington Headquarters Services, Directorate for Information, Washington, DC, 1987.

435. Haselow, J.S., Price V., Stephenson, D.E., Bledsoe, H.W., and Looney, B.B. Reactor Operation Environmental Information Document. "Volume I: Geology, Seismology and Subsurface Hydrology". WSRC-RP-89-815, Westinghouse Savannah River Company, Aiken, SC, December 1989.

436. Wike, L.D., et al. Reactor Operation Environmental Information Document. Volume II, Ecology. WSRC-RP-89-816, Westinghouse Savannah River Company, Aiken, SC, December 1989.

437. Wike, L.D., et al. SRS Ecology - Environmental Information Document. WSRC-TR-93-496, Westinghouse Savannah River Company, Aiken, SC, April 1994.

438. Bauer, L.R., Hayes, D.W., Hunter, C.H., Marter, W.L. and Moyer, R.A. Reactor Operation Environmental Information Document. Volume III: Meteorology, Surface Hydrology, Transport and Impacts. WSRC-RP-89-817, Westinghouse Savannah River Company, Aiken, SC, December 1989.

439. Final Environmental Impact Statement - Waste Management Activities for Groundwater Protection, Savannah River Plant, Aiken, SC. DOE/EIS-0120, U.S. Department of Energy, Washington, DC, December 1987.

440. Madabhushi, S. and Talwani, P. "Fault Plane Solution and Relocations of Recent Earthquakes in Middleton Place Summerville Seismic Zone Near Charleston South Carolina." Bulletin of the Seismological Society of America. Vol. 83, No. 5, 1993.

441. WSRC-(2000), Comparison of the Cenozoic ectonic Setting of Savannah River Site to the Atlantic Coast Fault Province with Implications Concerning Seismic Hazard, WSRC-TR-2000-00310, R.J., Cumbest, D. E Wyatt and D. E. Stephenson.

442. Bernreuter, D.L., 1997. Letter report from Don Bernreuter to Jeff Kimball. Lawrence Livermore National Laboratory, Fission Energy and Systems Safety Program, May 15, 1997, NTFS97-123.

443. Coats, D.W., and R.C. Murray, 1984. Natural Phenomena Hazards Modeling Project: Seismic Hazard Models for Department of Energy Sites, Lawrence Livermore National Laboratory, UCRL-53582, Rev. 1.

444. Cornell, C.A., and P. Bazzurro, 1997. Efficient Probabilistic Hazard Analysis for Non-Linear Soil Sites with Uncertain Properties.

445. Frankel, A., C. Mueller, T. Barnhard, D. Perkins, E.V. Leyendecker, N. Dickman, S. Hanson, and M. Hopper, 1996. National Seismic Hazard Maps, June 1996: Documentation, U.S. Geological Survey, Denver, CO, 73pp

446. NEI, 1994. Nuclear Energy Institute, Washington, D.C., Seismic Siting Decision Process, May 24, 1994.

447. Savy, J.B., 1996. Fission Energy and Systems Safety Program, April 24, 1996, SANT96-147JBS, letter from J.B. Savy, Deputy Associate Program Leader Natural Phenomena Hazards to Jeff Kimball, DOE.

448. URS/John A. Blume and Associates, Engineers, 1982. "Update of Seismic Criteria for the Savannah River Plant, Vol. 1 of 2", Geotechnical: URS/JAB 8144, San Francisco, CA, prepared for E.I. du Pont de Nemours and Company, DPE 3699, 293 pp.

449. Wingo, H.E., 1994. Development of Probabilistic Seismic Hazard Curve for DWPF at SRS, Rev. 1 (U), WSRC-TR-93-317.

450. WSRC, 1997. SRS Seismic Response Analysis and Design Basis Guidelines, WSRC-TR-97-0085, Rev. 0, by R.C. Lee, R.C., M.E. Maryak, and M.D. McHood.

451. WSRC, 1998. Soil Surface Seismic Hazard and Design Basis Guidelines for Performance Category 1 & 2 SRS Facilities, WSRC-TR-98-00263, Rev. 0, 9/30/98 by R.C. Lee.

452. WSRC, 1999. Computation of USGS Soil UHS and Comparison to NEHRP and PC1 Seismic Response Spectra for the SRS, WSRC-TR-99-00271, Rev. 0, 9/30/99, by R.C. Lee.

453 to 500 Intentionally Omitted

501. USDOE, 2000. Development of a Probalistic Tornado Wind Hazard Model for the Continental United States (Final Draft), Hazard Mitigation Center, Lawrence Livermore National Laboratory, Livermore, CA

502. Eliasson, J., 1997. A Statistical Model for Extreme Precipitation, Water Resources Research, Vol. 3, No. 3, pp 449-455.

503. WSRC, 2000, Savannah River Site, SRS Engineering Calculation # T-CLC-G-00146, Tornado Atmospheric Change (APC) Effects.

504. DOE, 1996, U. S. Department of Energy, Natural Phenomena Hazards Design and Evaluation Criteria for Department of Energy Facilities", DOE-STD-1020-94, Change Notice 1, January 1996.

505. McDonald-Mehta, 1997, Tornado Hazard Assessment, Memorandum of November 7, 1997 from McDonald-Mehta Engineers to B. J. Gutierrez of DOE/SR, related to the Accelerator Production of Tritium (APT) project.

506. McDonald, James R., 1999, Rationale for Wind-Borne Missile Criteria for DOE Facilities, UCRL-CR-135687, S/C B505188, September 1999.

507. Water Control Manual Savannah River Basin Multipurpose Projects: Hartwell Dam and Lake, Richard B. Russell Dam and Lake, J. Strom Thurmond Dam and Lake. USACE Savannah District, USACE 1996.

508. Water Resources Data for South Carolina, Water Year 1999. U.S. Geological Survey Data Report SC-99-1, U.S. Geological Survey, 1999.

509. Chen, Kuo-Fu, Flood Hazard Recurrence Frequencies for A-, K-, and L-Areas, and Revised Frequencies for C-, F-, E-, S-, H-, Y- and Z-Areas (U). Westinghouse Savannah River Company, Aiken South Carolina, WSRC-TR-2000-00206.

510.HEC-HMS Hydrologic Modeling System, User's Manual, Version 1.0, US Army Corps of Engineers, Hydrologic Engineering Center, Davis, California, 1998.

511.Shearman, J.O., User's Manual for WSPRO- A Computer Model for Water Surface Profile Computations, FHWA-IP-89--27, Research, Development, and Technology, Turner-Fairbank Highway Research Center, McLean, Virginia, 1990.

This page intentionally left blank.

1.10 - TABLES

Table 1.3-1 Approximate Driving Distances to Locations of Interest from SRS

Location of Interest from Center of Site	Distance by Road (Miles)
Atlanta, GA	180
Greenville, SC	115
Atlantic Ocean	100
Charleston, SC	100
Savannah, GA	100
Columbia, SC	60
Augusta, GA	25
Aiken, SC	20
Barnwell, SC	15
Williston, SC	15
Jackson, SC	12

Source: 1996 Road Atlas, United States, Canada, Mexico, Consumer Publications, American Automobile Association, Heathrow, FL, 1996.

Table 1.3-2 SRS Boundary and Area Coordinates

SRS Boundaries	Latitude	Longitude	SRS Coordinates
North	33.3485°	81.7551°	N 111,500 ; E 48,000
South	33.0958°	81.6145°	N 11,000 ; E 28,000
East	33.3859°	81.4832°	N 72,200 ; E 122,900
West	33.2336°	81.8310°	N 90,700 ; E 4,500
Area Centers			
F Area			N 77,687 ; E 51,345
SWDF			N 75,000 ; E 56,000
H Area			N 72,000 ; E 62,000
S Area			N 74,000 ; E 63,000
Z Area			N 75,600 ; E 74,800
M Area			N 105,000 ; E 52,000
SRTC			N 108,000 ; E 53,000
D Area			N 65,000 ; E 22,400

Source: "Savannah River Plant South Carolina Emergency Response Grid Map". Prepared for United States Department of Energy by EG&G Energy Measurements, Inc., Las Vegas, Nevada, Under the Direction of Savannah River Operations Office, August 1987.

Table 1.3-3 Vegetation Types and Acres Covered, 1989

Vegetation Types	Acres (est.)
Bottomland Hardwoods	28,492
Upland Hardwoods	6,459
Mixed Hardwood/Pine	10,425
Swamp Species	9,158
Undrained Flatwoods	551
Longleaf Pine	40,804
Loblolly Pine	63,952
Slash Pine	21,616
Other Pine	265
Permanent Grass Openings	4,419
Non-Forest	12,377
	198,518
	(Site Geographic Information Systems acres)

Source: Unofficial Communication, Rick Davalos, U.S. Forest Service, Savannah River Natural Resource Management and Research Institute, Aiken, SC, June 5, 1997.

Table 1.3-4 Fuel Loading Characteristics of SRS Vegetation (Total Fuel Accumulation for Three-Year Period)

Vegetation	Fuel Buildup, Tons/Acre	Average Range of Consumption by Prescribed Fire, Tons/Acre
Southern yellow pine	11 - 15	8 - 11
Hardwood	3 - 6	1 - 3
Pine-hardwood mixed	10 - 16	8 - 9
Pine clearcut	8 - 16	4 - 10

Source: Unofficial communication from Rick Davalos, U.S. Forest Service, Savannah River Natural Resource Management and Research Institute, Aiken, SC, June 25, 1997.

Table 1.3-5 Cities and Towns Within 50 Miles of the SRS Center

Population Center	County	State	Distance (miles)	Sector	Population [a]
Augusta	Richmond	GA	25.0	WNW	43,459
Aiken	Aiken	SC	19.5	NNW	24,929
North Augusta	Aiken/Edgefield	SC	23.4	NW	17,618
Orangeburg	Orangeburg	SC	47.5	ENE	13,762
Evans	Columbia	GA	33.0	NW	13,713
Belvedere	Aiken	SC			6,133
Red Bank	Lexington	SC			5,950
Waynesboro	Burke	GA	25.8	WSW	6,712
Barnwell	Barnwell	SC	16.4	ESE	5,600
Clearwater	Aiken	SC	19.3	NE	4,731
Allendale	Allendale	SC	27.3	SE	4,316
Batesburg	Lexington/Saluda	SC	43.3	N	4,380
Bamberg	Bamberg	SC	35.2	E	3,596
Millen	Jenkins	GA	31.6	SW	3,977
Denmark	Bamburg	SC	28.9	E	3,640
Grovetown	Columbia	GA	34.2	WNW	4,427
Williston	Barnwell	SC	15.0	ENE	3,445
Hampton	Hampton	SC	41.3	SE	3,146
Sylvania	Screven	GA	37.0	S	3,109
Saluda	Saluda	SC	49.7	N	2,957
Gloverville	Aiken	SC	24.5	NW	2,753
Blackville	Barnwell	SC	22.2	ENE	2,640
Johnston	Edgefield	SC	38.9	NNW	2,670
New Ellenton	Aiken	SC	9.4	NNW	2,494
Edgefield	Edgefield	SC	38.8	NNW	2,644
Hephzibah	Richmond	GA	26.6	W	2,925
Louisville	Jefferson	GA	48.6	WSW	2,542
Wrens	Jefferson	GA	43.8	W	2,577
South Congaree	Lexington	SC	49.3	NE	2,736
Estill	Hampton	SC	43.6	SSE	2,513
Fairfax	Allendale	SC	32.8	SE	2,397
Harlem	Columbia	GA	40.0	WNW	2,592
Leesville	Lexington	SC	44.8	N	2,235
Varnville	Hampton	SC	44.8	SE	2,140

Table 1.3-5 Cities and Towns Within 50 Miles of the SRS Center (Continued)

Population Center	County	State	Distance (miles)	Sector	Population[a]
Pineridge	Lexington	SC	49.5	NE	1,927
Jackson	Aiken	SC	9.4	WNW	1,876
McCormick	McCormick	SC	48.8	NW	1,701
Sardis	Burke	GA	22.7	SSW	1,217
Branchville	Orangeburg	SC	47.7	E	1,243
Gaston	Lexington	SC	48.4	NE	1,140
Ridge Spring	Saluda	SC	38.8	N	992
North	Orangeburg	SC	38.8	NE	827
Wagener	Aiken	SC	30.0	NNE	1,236
Midville	Burke	GA	47.2	SW	642
Brunson	Hampton	SC	36.4	SE	619
Dearing	McDuffie	GA	44.1	WNW	650
Swansea	Lexington	SC	44.5	NE	572
Springfield	Orangeburg	SC	25.8	NE	546
Burnettown	Aiken	SC	25.0	NNW	521
Salley	Aiken	SC	27.5	NE	515
Ehrhardt	Bamberg	SC	38.8	ESE	577
Neeses	Orangeburg	SC	34.5	ENE	474
Hilltonia	Screven	GA	27.7	S	414
Norway	Orangeburg	SC	31.7	ENE	411
Olar	Bamberg	SC	31.5	E	352
Hilda	Barnwell	SC	23.0	E	253
Pelion	Lexington	SC	40.3	NE	349
Stapleton	Jefferson	GA	48.3	W	330
Gilbert	Lexington	SC	46.4	NNE	356
Rowesville	Orangeburg	SC	47.2	E	350
Trenton	Edgefield	SC	33.6	NNW	315
Newington	Screven	GA	48.9	S	313
Gifford	Hampton	SC	37.8	SE	296
Blythe	Burke	GA	32.3	W	307
Monetta	Aiken/Saluda	SC	39.4	N	286
Kline	Barnwell	SC	20.6	ESE	293

Table 1.3-5 Cities and Towns Within 50 Miles of the SRS Center (Continued)

Population Center	County	State	Distance (miles)	Sector	Population[a]
Furman	Hampton	SC	49.5	SSE	267
Summit	Lexington	SC	45.9	NNE	273
Perry	Aiken	SC	30.3	NE	230
Elko	Barnwell	SC	16.4	ENE	207
Sycamore	Allendale	SC	32.3	SE	203
Woodford	Orangeburg	SC	40.6	NE	215
Rocky Ford	Screven	GA	43.9	SSW	223
Girard	Burke	GA	17.5	SSW	222
Parksville	McCormick	SC	48.1	NE	199
Williams	Colleton	SC	49.5	ESE	175
Scotia	Hampton	SC	48.0	SSE	189
Livingston	Orangeburg	SC	47.7	ENE	178
Lodge	Colleton	SC	42.7	ESE	198
Smoaks	Colleton	SC	50.0	ESE	147
Cordova	Orangeburg	SC	43.1	ENE	139
Ward	Saluda	SC	25.6	N	141
Snelling	Barnwell	SC	11.3	ESE	133
Cope	Orangeburg	SC	37.3	E	130
Windsor	Aiken	SC	15.3	NNE	130
Luray	Hampton	SC	40.3	SE	71
Plum Branch	McCormick	SC	50.0	NW	104
Govan	Bamberg	SC	27.3	E	80
Ulmer	Allendale	SC	35.5	SE	67

[a]As of July 1, 1994.

Source: Population Distribution and Population Estimates Brochures, U.S. Bureau of the Census, (October, 1995).

Table 1.3-6 Peak Daytime Onsite Population Within a 5-Mile Radius of F Area

Location	November 1992 Population[a]
A and M Areas (including G Area)	7736
B Area	612
C Area	831
N Area (Central Shops)	1456
E Area	66
F Area	2027
H Area	3044
K Area	1111
S Area	1192
Z Area	245

[a]Latest data available

Source: 1992 Onsite Worker Population for PRA Applications, J. M. East, WSRC-RP-93-197, January 1993.

Table 1.3-7 Peak Daytime Onsite Population Within a 5-Mile Radius of H Area

Location	November 1992 Population[a]
B Area	612
C Area	831
N Area (Central Shops)	1456
E Area	66
F Area	2027
H Area	3044
R Area	0
S Area	1192
Z Area	245

[a]Latest data available

Source: 1992 Onsite Worker Population for PRA Applications, J. M. East, WSRC-RP-93-197, January 1993.

Table 1.3-8 Peak Daytime Onsite Population Within a 5-Mile Radius of A and M Areas

Location	November 1992 Population[a]
A and M Areas (including G Area, SREL, and SRFS)	7736
B Area	612

[a]Latest data available

Source: 1992 Onsite Worker Population for PRA Applications, J. M. East, WSRC-RP-93-197, January 1993.

Table 1.3-9 Public School Population Within Approximately 5 Miles of SRS, 1995-1996

District School	Address	Grade Level	Enrollment 1995-1996
Aiken, Area 5			
Greendale Elementary	505 S. Boundary New Ellenton, SC	Pre-K-5	439
Jackson Middle	SCR 125 Jackson, SC	6-8	546
New Ellenton Middle	814 Main St. New Ellenton, SC	6-8	276
Redcliff Elementary	SC 125 N. Jackson, SC	Pre-K-5	1033
Silver Bluff High	280 Desoto Dr. Aiken, SC	9-12	876
Barnwell 29			
Kelly Edwards Elementary	808 Elko St. Williston, SC	K-4	354
Williston-Elko High	408 Main St. Williston, SC	9-12	307
Williston-Elko Middle	404 Main St. Williston, SC	5-8	249
Barnwell 45			
Barnwell Elementary	Marlboro Avenue Barnwell, SC	Pre-K-5	1316
Barnwell High	Jackson St. Barnwell, SC	9-12	794
Guinyard-Butler Middle	Allen St. Barnwell, SC	6-8	643

Sources: "South Carolina Education Profiles 1996," South Carolina Department of Education, Columbia, SC, October 1996.

Table 1.3-10 Attendance at State Parks Near SRS, Fiscal Year 1994/1995a

State Park	Cabin Users and Campers	Picnickers	Total Park Visitors
Aiken	4,488	15,908	35,698
Barnwell	3,112	18,241	64,366
Redcliffe Plantation	NA	10,930	15,539

[a]Latest data available

Source: South Carolina State Parks Attendance, FY 94/95 , South Carolina Statistical Abstract, South Carolina Office of Research and Statistics, Columbia, South Carolina, February, 1996.

Table 1.3-11 Health Care Population Within a 5-Mile Vicinity of SRS, 1998

Name of Facility	Location	Facility Type	Licensed Beds
Barnwell County Hospital	Barnwell	Acute care hospital	53
Barnwell County Nursing Home	Barnwell	Skilled care and intermediate nursing home	40
Southern Manor	Barnwell	Community Residential Care	5
Triple E Residential Care	Barnwell	Community Residential Care	10
Academy Street Community Residence	Williston	Intermediate Care for Mentally Retarded	8
Black's Drive Community Residence	Williston	Intermediate Care for Mentally Retarded	8
Harley Road Community Residence	Williston	Intermediate Care for Mentally Retarded	8
Lemon Park Community Residence	Williston	Intermediate Care for Mentally Retarded	8
Silver Springs Long Term Care	Williston	Skilled and intermediate care facility	44
New Ellenton Nursing Center	New Ellenton	Skilled and intermediate care	26

Sources: Aiken County Health Care Facilities, Health Care Facility Information, published by South Carolina Department of Health and Environmental Control, April, 10 1998.

Barnwell County Health Care Facilities, Health Care Facility Information, published by South Carolina Department of Health and Environmental Control, April 10, 1998.

Table 1.3-12 Selected SRS Road Traffic Counts 1996-1997 (Average Daily Traffic Tuesday through Thursday)

Road Segment	Traffic Direction	Count
Road 2, between B Area and Road C	Combined	3,500
Road 2, between C Road and D Road	Combined	6,500
Road 2, between D Road and F Road	Combined	3,000
Road 3 West of Road 5	East	650
Road 3 West of Road 5	West	400
Road 4, between Road E and H Area	East	4,500
Road 4, between Road E and H Area	West	4,200
Road 4, between S Area and H Area (North Entr.)	East	3,000
Road 4, between S Area and H Area (North Entr.)	West	2,800
Road 7, west of Road C	East	300
Road 7, west of Road C	West	300
Road C, between landfill and Road 2	North	7,000
Road C, between landfill and Road 2	South	7,000
Road D, at Old Gunsite	North	2,000
Road D, at Old Gunsite	South	1,800
Road E, at Burial Ground	North	4,550
Road E, at Burial Ground	South	3,650
Road F, near 603-3G	North	3,300
Road F, near 603-3G	South	3,100

Source: Unofficial data from R. Swygert, Engineering Services, WSRC, June 1997.

Table 1.3-13 Land Use at SRS (Acres)

Use	Acres	
Vegetation Types		
Bottomland Hardwoods	28,492	
Upland Hardwoods	6,459	
Mixed Hardwood/Pine	10,425	
Swamp Species	9,158	
Undrained Flatwoods	551	
Longleaf Pine	40,804	
Loblolly Pine	63,952	
Slash Pine	21,616	
Other Pine	265	
Permanent Grass Openings	4,419	
Non-Forest	12,377	
	198,518	(site GIS acres)
Water/Wetlands		
Savannah River Swamp	9,894	
Par Pond	2,640	
L Lake	1,184	
	13,718	
Production and Support Areas		
100-C	182	
100-K	247	
100-L	183	
100-P	185	
100-R	137	
200-E & F	1,058	
200-S & H	580	
200-Z	182	
300-M & 700-A	330	
400-D	422	
600-B	114	
N-Area (Central Shops)	375	
	3,995	
Total	216,231[a]	

[a]Exceeds site total due to overlap in wetlands and bottomland hardwood acres and the addition of new areas (S, Y, and Z) and L Lake without recalculating acreage.

Source: Unofficial communication with Rick Davalos, Savannah River Natural Resource Management and Research Institute, SRS, Aiken, SC June 5, 1997.

Table 1.3-14 Number and Size of Farms in Aiken County, South Carolina

Year	Number of Farms	Total Acreage of Farms	Average Acreage of Farms
1981	900	171,300	190
1982	850	163,100	192
1983	790	157,700	200
1984	760	152,300	200
1985	750	149,500	199
1986	740	146,800	198
1987	710	141,400	199
1988	760	152,700	201
1989	750	152,700	204
1990	740	149,900	203
1991	710	149,900	208
1992	720	149,900	208
1993	710	148,400	209
1994	760	155,700	205
1995	730	154,200	211
1996	710	152,700	215
1997	710	152,700	215

Source: Agricultural Statistics for Aiken County, South Carolina Agricultural Statistics Service, Department of Agricultural and Applied Economics, Clemson University, 1998.

Table 1.3-15 Number and Size of Farms in Allendale County, South Carolina

Year	Number of Farms	Total Acreage of Farms	Average Acreage of Farms
1981	210	153,800	732
1982	200	146,400	732
1983	190	141,500	745
1984	180	136,700	759
1985	180	134,200	746
1986	180	131,800	732
1987	170	126,900	746
1988	140	132,400	946
1989	130	132,400	1018
1990	130	129,900	999
1991	130	129,900	999
1992	130	129,900	999
1993	130	128,600	989
1994	130	92,700	989
1995	120	91,800	713
1996	120	91,800	765
1997	120	91,800	765

Source: Agricultural Statistics for Allendale County, South Carolina Agricultural Statistics Service, Department of Agricultural and Applied Economics, Clemson University, 1998.

Table 1.3-16 Number and Size of Farms in Barnwell County, South Carolina

Year	Number of Farms	Total Acreage of Farms	Average Acreage of Farms
1981	360	120,800	336
1982	340	115,000	338
1983	320	111,200	348
1984	310	107,400	346
1985	300	105,400	351
1986	300	103,500	345
1987	290	99,700	344
1988	310	95,700	309
1989	300	95,700	319
1990	290	93,900	324
1991	290	93,900	324
1992	290	93,900	324
1993	290	93,000	321
1994	320	85,200	266
1995	300	84,400	281
1996	300	83,000	277 1997
300	83,000	277	

Source: Agricultural Statistics for Barnwell County, South Carolina Agricultural Statistics Service, Department of Agricultural and Applied Economics, Clemson University, 1998.

Table 1.3-17 Agricultural and Forest Land Use in Richmond and Burke Counties, Georgia

County	No. of Farms	Total Acreage Farm Size	Average Acreage in Forest	Total Acreage
Burke	315	82,517	262	293,529
Richmond	113	6,201	54.9	120,769

Source: The Georgia County Guide Fifteenth Edition, College of Agricultural and Environmental Sciences, The University of Georgia, Athens, GA, August 1996.

Table 1.3-18 Major Reservoirs (Area Greater than 1,000 Acres) in South Carolina

Lake Name and/or Owner or Governing Body	Use[a]	Surface Area, acres	Capacity, Acre-feet
Lake Jocassee (O)	P, R	7,565	1,185,000
Lake Keowee (O)	P, R, Ws	18,372	1,000,000
Hartwell Reservoir (O)	P, R, Ws	56,000	2,549,000
Thurmond Lake (O)	P, R, Ws, Fc	70,000	2,510,000
Greenville Water Works, North Saluda Reservoir	Ws	1,080	76,108
Lake Greenwood (O)	P, R, Ws	11,400	270,000
Lake Murray (O)	P, R, Ws	51,000	2,114,000
Spartanburg Water Works, also called Lake Bowen	Ws, R	1,600	24,550
Monticello Reservoir	Ws	6,800	431,050
Parr Reservoir (O)	P, R	4,400	32,533
Lake Wylie, also called Lake Catawba (O)	P, R	12,455	281,900
Fishing Creek Reservoir (O)	P, R, Ws	3,370	80,000
Lake Wateree (O)	P, R, Ws	13,710	310,000
Lake Marion (O)	P, R	110,600	1,400,000
Lake Moultrie (O)	P, R, Ws	60,400	1,211,000
Lake Robinson (O)	I, P, R	2,250	31,000
Lake Russell	P, R, Ws, Fc	26,650	1,026,000
Savannah River Site L Lake	I	1,050	21,208
Savannah River Site Par Pond	I	2,700	54,000
TOTALS		461,402	14,607,349

[a]P = Power
I = Industrial
R = Recreation
O = Open to public, free
Ws = Water supply
Ir = Irrigation
Fc = Flood control

Sources: Inventory of Lakes in South Carolina Ten Acres or More in Surface Area, State of South Carolina Water Resources Commission, Report Number 171, 1991.

Unofficial data from B. Badr, South Carolina Department of Natural Resources Water Resources Division, July 10, 1997.

Table 1.3-19 Lakes of 10 Acres or More in Aiken, Allendale, and Barnwell Counties, South Carolina

County	Number of Lakes	Surface Area, acres	Capacity Acre-feet
Aiken	124	3,357	18,559
Allendale	29	690	2,208
Barnwell[a]	28	4,695	81,495

[a]Includes Par Pond and L-Lake at SRS.

Sources: List of Major Reservoirs in South Carolina (larger than 1000 acres surface area), provided by Steve de Kozlowski, South Carolina Water Resources Commission, Columbia, SC, February 8, 1994.

Unofficial data provided by B. Badr, South Carolina Department of Natural Resources Water Resources Division, July 10, 1997.

Table 1.3-20 Lakes of 10 Acres or More in Burke, Richmond, and Screven Counties, Georgia

County	Number of Lakes	Surface Area, acres
Richmond	9	980
Burke	8	256
Screven	2	115

Source: Preliminary Safety Analysis Report: Defense Waste Processing Facility, E.I. du Pont de Nemours & Co., Aiken, SC, 1983.

Table 1.3-21 Public Boat Landings on the Savannah River Downstream from Augusta

State	County	Identification of Landing
South Carolina	Aiken	North Augusta
		Silver Bluff
		Jackson Boat Club (private)
	Allendale	Highway 368
		Johnson's Landing
		Cohen's Bluff
	Hampton	Stoke's Bluff
	Jasper	B & C Landing
		Millstone
		Union
Georgia	Richmond	Fifth Street Landing (Augusta)
		Below Lock & Dam Savannah Bluff
	Burke	Brighams Landing Rd E of Girard
	Screven	Dick's Lookout/Tuckahoe WMA NE of GA 24
		Poor Robins Landing
		U.S. Hwy 301 Crossing
		Blue Springs E. of GA Hwy 24
	Effingham	Tuckassee King Landing/off GA Hwy 119
		Abercom Creek/County Rd S983
	Chatham	Pt. Wentworth/U.S. Hwy 17/old ramp
		Pt. Wentworth/U.S. Hwy 17
		Savannah NWR/U.S. 17
	Columbia	GA ramp/below Clarks Hill Dam

Sources: Unofficial data provided by J. Duke, South Carolina Department of Natural Resources, August 4, 1997.

Unofficial data provided by L. Ager, Georgia Department of Natural Resources, August 4, 1997.

Table 1.3-22 Capabilities of Sprinkler Irrigation Systems in the Lower Savannah Region, 1983

Type of System Used (Acres)							
County	Center Pivot	Traveler	Hand Moved	Drip	Solid Set	Other	Total Capacity
Aiken	840	960	200	110	450	150	2,710
Allendale	10,000	2,000	25	25	-	-	12,050
Barnwell	2,400	1,700	100	-	-	-	4,200

Source: South Carolina County Agent's Irrigation Survey, 1983.

Table 1.3-23 Surface Water Supplies for Aiken County, South Carolina

Water System	Estimated Population Water Serves	Water Source	[a]Treatment	Capacity of System (mgd)	Storage Capacity (mgd)	Average Water Use Total (mgd)
Aiken	31,500	Shaw Creek, Shilo Springs 4 wells	Fil, Cl, pH, F, p	15.90	4.60	7.10
Graniteville	2,050	Bridge Creek, 1 well	Fil, Cl, pH, p	2.70	1.25	1.85
North Augusta	25,900	Savannah River	Fil, Cl, pH, p	8.00	2.95	2.87

[a]Fil = Filtration; pH= pH adjustment; F = Fluorination; Cl = Chlorination; p = Phosphorous

Source: Unofficial data provided by Jim Brownlow, South Carolina Department of Health and Environmental Control, Aiken SC, February 22, 1994.

Table 1.3-24. Surface Water Supplies for Augusta-Richmond County and Burke County, Georgia

County	Plant Source	Average Capacity, mgd	Consumption, mgd
Augusta-Richmond County System	Savannah River and 28 wells	85	37
Waynesboro City System	Briar Creek and 2 wells	2	1.5

Sources: Unofficial data provided by April Myers, Augusta-Richmond County Utilities Department, August 7, 1997; and Jody Ellison, Waynesboro Water System, August 8, 1997.

Table 1.3-25 Average Daily Finished Water Production at the Beaufort/Jasper and City of Savannah Water Treatment Plants

Year	Beaufort/Jasper, SC (mgd)	City of Savannah, GA (mgd)
1983	5.8	31.6
1984	6.1	36.1
1985	5.4	31.4
1986	6.6	33.0
1987	6.5	NA
1988	6.9	NA
1989	7.0	37.6
1990	5.9	38.5
1991	5.9	42.3
1992	6.0	43.5
1993	6.6	46.7

Sources: Unofficial data provided by Mr. Billy Smith, Beaufort/Jasper Water/Sewer Authority, February 10, 1994; and Mr. Willy Weil, Savannah Industrial and Domestic Water Supply, February 10, 1994.

Table 1.4-1 Maximum Snow, Ice Pellets - Augusta, Georgia, in Inches

Month	Average	Maximum (Year)		24-Hr Maximum (Year)
January	0.3	2.6 (1992)		2.6 (1992)
February	0.7	14.0 (1973)		13.7 (1973)
March	<0.1	1.1 (1980)		1.1 (1980)
April	0.0	0.0	--	0.0
May	0.0	0.0	--	0.0
June	0.0	0.0	--	0.0
July	0.0	0.0	--	0.0
August	0.0	0.0	--	0.0
September	0.0	0.0	--	0.0
October	0.0	0.0	--	0.0
November	<0.1	Trace (1968)		Trace (1968)
December	0.1	1.0 (1993)		1.0 (1993)
Year	1.1	14.0 (1973)		13.7 (1973)

Period of record, 1951-1995.

Source: Local Climatological Data, Annual Summary with Comparative Data, 1995, Augusta, Georgia. National Oceanic and Atmospheric Administration, National Climate Data Center, Asheville, NC (1996).

Table 1.4-2 Estimated Ice Accumulation for Various Recurrence Intervals for the Gulf Coast States

Recurrence Interval (yr)	Accumulation (in.)
2	0
5	0.24
10	0.39
25	0.51
50	0.59
100	0.66

Source: Tattelman, P., et al. Estimated Glaze Ice and Wind Loads at the Earth's Surface for the Contiguous United States. AFCRL-TR-73-0640, U.S. Air Force (1973).

Table 1.4-3 Percent Occurrence of Atmospheric Stability Class for SRS Meteorological Towers

Stability Class	Percent Occurrence Per Year							
	A-Area	C-Area	D-Area	F-Area	H-Area	K-Area	L-Area	P-Area
A	17.5	15.6	20.5	13.3	25.9	15.4	16.8	14.9
B	10.6	8.8	11.9	8.3	13.2	9.8	10.2	9.4
C	17.6	15.7	19.4	15.2	20.1	17.0	18.0	16.4
D	26.6	27.1	24.9	28.6	22.1	25.4	25.1	26.5
E	19.6	20.6	17.4	24.9	15.5	21.2	18.7	21.1
F/G	8.0	12.1	6.0	10.6	3.2	11.1	11.1	11.8

Period of record: 1992-1996.

Source: Hunter, C. H. to J. Howley, Updated Meteorological Data for Revision 4 of the SRS Generic Safety Analysis Report, SRT-NTS-990043.

Table 1.4-4 Average Number of Thunderstorm Days, Augusta, Georgia, 1951-1995

Month	Thunderstorm Days
January	0.8
February	1.7
March	2.6
April	3.9
May	6.3
June	9.7
July	13.1
August	10.0
September	3.5
October	1.3
November	0.8
December	0.7
Annual	54.4

Period of record, 1951-1995.

Source: Local Climatological Data, Annual Summary with Comparative Data, 1995, Augusta, Georgia. National Oceanic and Atmospheric Administration, National Climate Data Center, Asheville, NC (1996).

Table 1.4-5 Number of Tornadoes Reported Between 1951 and 1996 by Month and F-Scale in a Two-Degree Square Centered at SRS

Month	F-0	F-1	F-2	F-3	F-4	F-5	Total	Percent
January	3	8	2	1	0	0	14	7.0
February	4	12	1	0	0	0	17	8.5
March	1	10	9	0	1	0	21	10.5
April	4	17	4	1	0	0	26	13.0
May	3	18	6	0	0	0	27	13.5
June	4	10	0	0	0	0	14	7.0
July	2	8	3	0	0	0	13	6.5
August	4	7	5	2	0	0	18	9.0
September	0	5	3	0	0	0	8	4.0
October	1	2	4	0	0	0	7	3.5
November	10	8	7	2	0	0	27	13.5
December	1	2	2	2	1	0	8	4.0
Total	37	107	46	8	2	0	200	100.0

Source: C.H. Hunter to J. Howley, Meteorological Data for Revision 4 to SRS Generic Safety Analysis Report, SRT-NTS-99043, March 1, 1999.

Table 1.4-6 Fujita Scale for Damaging Tornado Winds

Scale	Rotational Wind Speed	Expected Damage
F-0	40 - 72	Light damage
F-1	73 - 112	Moderate damage
F-2	113 - 157	Considerable damage
F-3	158 - 206	Severe damage
F-4	207 - 260	Devastating damage
F-5	261 - 318	Incredible damage

Source: Hunter, C. H., A Climatological Description of the Savannah River Site, WSRC-RP-89-313, Westinghouse Savannah River Company, Savannah River Site, Aiken, SC, May 1990.

Table 1.4-7 Estimated Maximum Three-Second Wind Speeds for Tornadoes and "Straight-Line" Winds

Recurrence Interval, years	Probability events/year	Estimated Maximum 3-Sec Wind Speed, mph	
		Tornadoes	"Straight-Line" Winds
100	1×10^{-2}	---	88
200	5×10^{-3}	---	94
500	2×10^{-3}	---	102
1,000	1×10^{-3}	70	107
5,000	2×10^{-4}	120	120
10,000	1×10^{-4}	135	126
50,000	2×10^{-5}	180	140
100,000	1×10^{-5}	200	145
500,000	2×10^{-6}	240	---
1,000,000	1×10^{-6}	251	---

Sources: U. S. Department of Energy, Development of a Probabilistic Tornado Wind Hazard Model for the Continental United States (DRAFT), Hazard Mitigation Center, Lawrence Livermore National Laboratory, Livermore CA (2000). (Tornadoes)

A. H. Weber, et al., "Tornado, Maximum Wind Gust, and Extreme Rainfall Event Recurrence Frequencies at the Savannah River Site", WSRC-TR-98-00329, Westinghouse Savannah River Comapany, Aiken, SC (1998). (Straight-line Winds)

Table 1.4-7.1 Wind and Tornado Design Criteria for MFFF Site

	Item	PC-3	PC-4
WIND	Annual Hazard Exceedance Probability	$1x10^{-3}$	$1x10^{-4}$
	Three Second Wind Speed, mph	110 rounded up value	130 rounded up value
	Missile Criteria	2x4 timber plank 15 lb. @50 mph (horizontal); max height 30 ft.	2x4 timber plank 15 lb. @50 mph (horizontal); max height 50 ft.
	ASCE 7-98, See Note		
TORNADO	Annual Hazard Exceedance Probability	$2x10^{-5}$	$2x10^{-6}$
	Three Second Tornado Speed, mph	180	240
	Atmospheric Pressure Change (APC), psf, at the rate of psf/sec	70 psf at 31 psf/sec	150 psf at 55 psf/sec
	Missile Criteria	2x4 timber plank 15 lb. @100 mph (horizontal); max height 150 ft; 70 mph (vertical) 3 in. diameter standard steel pipe, 75 lb. @50 mph (horizontal); max height 75 ft; 35 mph (vertical) 3000 lb. automobile @19 mph rolls and tumbles	2x4 timber plank 15 lb. @150 mph (horizontal); max height 200 ft; 100 mph (vertical) 3 in. diameter standard steel pipe, 75 lb. @75 mph (horizontal); max height 100 ft; 50 mph (vertical) 3000 lb. automobile @25 mph rolls and tumbles
	ASCE 7-98, See Note		

Note:
For determining wind and tornado loads using the ASCE 7-98 procedure following definitions shall apply:
I = 1.0,
Exposure Category = C,
K_{zt} = 1.0, and K_d = 1.0

Table 1.4-8 Observed Annual Fastest 1-Minute Wind Speeds for SRS [a,b]

Year	Wind Speed (mph)[c]	Direction	Date
1967	52	W	5/8
1968	43	NW	7/16
1969	43	NE	7/8
1970	52	NW	7/16
1971	34	SW	7/11
1972	56	SW	3/2
1973	37	NW	11/21
1974	49	W	3/21
1975	37	W	7/6*
1976	32	NW	3/9
1977	43	S	10/2
1978	39	SW	1/26
1979	30	W	5/12
1980	32	S	7/9
1981	33	NW	3/16
1982	40	NW	2/16
1983	32	NW	12/31
1984	32	SW	3/28
1985	35	W	2/11
1986	32	NW	7/2
1987	35	NNW	7/24
1988	32	WNW	5/24
1989	39	NW	6/22
1990	28	WSW	1/29
1991	29	NW	2/15
1992	29	SW	7/1
1993	33	W	3/13
1994	34	SE	7/10
1995	38	W	11/11
1996	35	W	2/12

Maximum 1-minute wind since 1950: 83 mph on 5/28/50

[a] Data for 1967-1994 from National Weather Service Office, Bush Field, Augusta, Georgia.
Source: Local Climatological Data, Annual Summary with Comparative Data, 1995, Augusta, Georgia. National Oceanic and Atmospheric Administration, National Climate Data Center, Asheville, NC (1996).

[b] Data for 1995-1996 from SRS Central Climatology Facility.
Source: Hunter, C. H., Updated Meteorological Data for Revision 2 of the SRS Generic Safety Analysis Report, SRT-NTS-970265.

[c] Values interpolated to a 10 m anemometer height.

Table 1.4-9 Total Occurrences of Hurricanes in South Carolina by Month, 1700-1992

Month	Number	Percent of Total
June	1	2.8
July	2	5.6
August	11	30.5
September	18	50.0
October	4	11.1

Source: Memo from Chuck Hunter to Baren Talukdar, SRT-NTS-970285 dated August 14, 1997, Westinghouse Savannah River Co., Aiken, SC.

Table 1.4-10 Extreme Total Rainfall for SRS Region (August 1948-December 1995)

Period Hours	Period Days	Inches/ Period	Begin Time	Begin Date
Augusta Bush Field				
1		3.14	1300	7/24/86
3		4.25	1900	9/20/75
6		4.50	1900	9/20/75
12		7.62	2100	10/11/90
24		8.57	1300	10/11/90
	3	12.24		10/10/90
	7	12.24		10/10/90
	10	12.24		10/10/90
	14	14.56		10/10/90
	30	15.47		9/30/90
	60	19.84		7/15/64
	90	25.88		7/18/64
Columbia Airport				
1		3.80	2000	8/18/65
3		5.03	1900	8/18/65
6		5.29	1700	6/15/73
12		7.03	2200	8/16/49
24		7.66	1600	8/16/49
	3	8.41		8/14/90
	7	10.22		6/15/73
	10	10.29		6/13/73
	14	14.71		8/14/49
	30	19.30		7/29/49
	60	25.64		6/18/71
	90	33.69		7/18/64

Source: C. H. Hunter to J. Howley, Updated Metereology for Revision 4 of the SRS Generic Safety Analysis Report, SRT-NTS-99-0043.

Table 1.4-11 Extreme Precipitation Recurrence Estimates by Accumulation Period.

Recurrence Interval (years)	15 min	1 hr	3 hr	6 hr	24 hr	48 hr
10	1.5	2.7	3.3	3.6	5.0	6.5 7.39[b]
25	1.8	3.2	4.0	4.4	6.1	7.9
50	2.0	3.5	4.6	5.0	6.9 (7.39)[b]	8.6
100	2.1	3.9	5.1 (5.2)[a]	5.7 (5.8)[b]	7.8	9.4 (10.2)[c] (11.15)[d]
1000	2.7	5.0	7.4	8.3	11.5	N/A
10,000	3.3	6.2	10.3	11.8	16.3	N/A
100,000	3.9	7.4	14.1	16.7	22.7	N/A

[a]July 25 rainfall at the 700 Area

[b]August 22 rainfall at the Climatology Site

[c]October 11-12 rainfall at the 773-A Area

[d]October 11-12 rainfall at Bush Field

Sources: A.H. Weber, et al., "Tornado, Maximum Wind Gust, and Extreme Rainfall Event Recurrence Frequencies at the Savannah River Site", WSRC-TR-98-00329, Westinghouse Savannah River Company, Aiken, SC (1998). (15-minute through 24 hour rainfall estimates)

J. F. Miller, "Two-To-Ten Day Precipitation for Return Periods of Two-to-One Hundred Years in the Contiguous United States," Technical Paper No. 49, U.S. Weather Bureau, USDOC (1964). (48-hour rainfall estimate)

Addis, R. P. and Kurzeja, R. J. Heavy Rainfall at the SRS in July, August, and October of 1990. WSRC-TR-92-136, Westinghouse Savannah River Co., Aiken, SC, (1992). (observed rainfall events)

Table 1.4-12 Monthly Average and Extreme Temperatures for SRS

	Average Daily Temperature, °F [a]			Extreme Temperature, °F [b]	
Month	Maximum	Minimum	Month	Maximum (Yr)	Minimum (Yr)
January	55.9	36.0	45.8	86 (1975)	-3 (1985)
February	60.0	38.3	49.1	86 (1989)	10 (1996)
March	68.6	45.4	57.0	91 (1974)	11 (1980)
April	77.1	52.5	64.8	99 (1986)	29 (1983)
May	83.5	60.7	72.1	102 (1963)	38 (1989)
June	89.6	68.0	78.8	105 (1985)	48 (1984)
July	92.1	71.5	81.7	107 (1986)	56 (1963)
August	90.1	69.6	80.3	107 (1983)	56 (1986)
September	85.4	65.6	75.4	104 (1990)	41 (1967)
October	76.6	54.6	65.6	96 (1986)	28 (1976)
November	67.0	45.2	56.2	89 (1974)	18 (1970)
December	59.3	39.1	49.1	82 (1984)	5 (1962)
Annual	75.5	54.0	64.7	107 (1986)	-3 (1985)

[a] Period of record: 1967-1996.
[b] Period of record: 1961-1996.

Source: Hunter, C. H., Updated Meteorological and Hydrological Data for Revision 2 of the SRS Generic Safety Analysis Report, SRT-NTS-970265.

Table 1.4-13 Average and Extreme Precipitation at SRS (Water Equivalent), in Inches

Month	Average[a]	Maximum (Year)[b]	Minimum (Year)[b]
January	4.44	10.02 (1978)	0.89 (1981)
February	4.25	7.97 (1995)	0.94 (1968)
March	4.83	10.96 (1980)	0.91 (1995)
April	3.02	8.20 (1961)	0.57 (1972)
May	3.86	10.90 (1976)	1.33 (1965)
June	4.53	10.98 (1973)	0.89 (1990)
July	5.57	11.48 (1982)	0.90 (1980)
August	5.44	12.34 (1964)	1.04 (1963)
September	3.63	8.71 (1959)	0.49 (1985)
October	3.40	19.62 (1990)	0.00 (1963)
November	2.89	7.78 (1992)	0.21 (1958)
December	3.59	9.55 (1981)	0.46 (1955)
Year	49.46	73.47 (1964)	28.82 (1954)

[a] Period of record: 1967-1996.
[b] Period of record: 1952-1996.

Source: Hunter, C. H., Updated Meteorological, and Hydrological Data for Revision 2 of the SRS Generic Safety Analysis Report, SRT-NTS-970265.

Table 1.4-14 Average Relative and Absolute Humidity at SRS.

Month	Relative Humidity (%)a			Absolute Humidity (g/m^3)b		
	Min	Max	Avg	Min	Max	Avg
January	51	86	70	2.3	13.2	6.0
February	44	84	65	2.9	11.3	6.6
March	40	86	61	3.4	11.8	7.0
April	36	88	56	3.7	13.3	8.4
May	40	93	63	6.2	17.6	12.7
June	44	95	75	10.2	19.2	15.6
July	47	96	75	13.0	20.6	18.4
August	50	97	78	11.1	21.3	18.3
September	48	96	78	9.8	19.1	15.4
October	45	93	74	5.8	17.6	11.3
November	46	90	70	3.4	15.8	7.3
December	48	87	70	2.3	12.4	6.0
Average	45	91	70			11.1

a Period of record: 1967-1996.
b Period of record: 1995-1996.

Source: Hunter, C. H. to B. Talukdar, Updated Meteorological, and Hydrological Data for Revision 2 of the SRS Generic Safety Analysis Report, SRT-NTS-970265.

Table 1.4-15 Flow Summary for the Savannah River and Savannah River Site Streams (values in ft^3/second)

	Mean	STD Dev.	7Q10	7-Day Low Flow
Savannah River				
at Augusta, GA	9493	2611	4332	3746
at SRS Boat Dock	----	----	4293	3773
at Hwy 301 [a]	10397	2830	4411	3991
at Clyo	12019	3687	5211	4513
Upper Three Runs				
at Hwy 278	105	8	56	55
at SRS Road C	211	30	100	86
at SRS Road A	245	41	100	84
Beaver Dam Creek				
at 400D	81.5	8.7	0.01	18
Fourmile Branch				
at SRS Site 7	17.8	5.4	0.58	3.2
Pen Branch				
at SRS Road B	7.5	8.2	0.27	0.22
at SRS Road A-13	210	45	5.5	8.8
Steel Creek				
at Hattiesville Bridge	160	12.3	12.9	12.0
Lower Three Runs				
below Par Pond	38.4	10.4	1.2	0.9
near Snelling, SC	85.8	27.9	16	15

[a] Eleven years are missing between 1971 and 1982.

Source: Hunter, C. H., Updated Meteorological, and Hydrological Data for Revision 2 of the SRS Generic Safety Analysis Report, SRT-NTS-970265.
Chen, Kou-fu, 7Q10 Flows for SRS Streams, WSRC-RP-96-340, Westinghouse Savannah River Co., Aiken, SC, 1996.

NOTE: The flow data used for computing statistics for the Savannah River and Savannah River Site Streams were based on U. S. Geological Survey stream gage measurements after construction of Thurmond Dam. Values listed for 7-day low flow, ten year recurrence (7Q10) are based on adjusted "natural" flows, i.e. without the effects of cooling water discharges from Savannah River Site reactors.

Table 1.4-16 Water Quality of the Savannah River Above SRS for 1983-1987

Analyte	Units	No. of Analyses	Min	Max	Mean
Alkalinity	mg/L	36	13	23	18.28
Aluminum	mg/L	36	0.08	0.95	0.38
Ammonia	mg/L	36	0.04	0.27	0.11
Cadmium	mg/L	36	0	0	0
Calcium	mg/L	36	3.1	4.24	3.62
Chloride	mg/L	36	4	13	7.73
Chromium	mg/L	36	0	0.01	0.01
Conductivity	μS/cm[a]	36	54	107	80.42
Copper	mg/L	36	0	0	0
DO	mg/L	72	6.4	24	9.42
Fixed residue	mg/L	36	1	17	7.69
Iron	mg/L	36	0.27	1.39	0.62
Lead	mg/L	36	0	0	0
Magnesium	mg/L	36	0.98	1.55	1.31
Manganese	mg/L	36	0.06	0.1	0.08
Mercury	mg/L	36	0	0	0
Nickel	mg/L	36	0	0.03	0.02
Nitrate + Nitrite	mg/L	36	0.02	0.63	0.27
Phosphate	mg/L	36	0.03	0.09	0.06
Sodium	mg/L	36	4.67	11.6	8.93
Sulfate	mg/L	36	4	9	6.82
Suspended solids	mg/L	36	3	18	9.69
Temperature	C	36	8.9	24.8	17.48
Total Dissolved Solids	mg/L	36	48	85	63.89
Total Solids	mg/L	36	54	96	73.58
Turbidity	NTU	36	2.22	3.3	9.66
Volatile Solids	mg/L	36	1	7	2.34
Water Volume	L	36	1.08E+11	2.31E+12	8.4E+11
Zinc	mg/L	36	0	0.02	0.01
pH	pH	36	5.7	7.8	6.44

[a]Micro [a]microsiemens per centimeter

Source: SRS Environmental Monitoring Reports for 1992, 1993, and 1994. Report numbers WSRC-TR-92-0075, WSRC-TR-93-0075, and WSRC-TR-94-0075. Data summary provided by J. Gladden, WSRC Environmental Analysis.

Table 1.4-17 Water Quality of the Savannah River Below SRS (River Mile 120) for 1992-1994

Analyte	Units	No. of Analyses	Min	Max	Mean
Alkalinity	mg/L	48	13	26	19.24
Aluminum	mg/L	36	0.08	0.64	0.4
Ammonia	mg/L	48	00.02	0.44	0.13
BOD 5 Day	mg/L	12	0.7	1.8	1.29
Cadmium	mg/L	36	0	0	0
Calcium	mg/L	38	3.26	5.02	4.18
Chloride	mg/L	36	4	12	6.27
Chromium	mg/L	36	0	0.01	0.01
Conductivity	µS/cm[a]	48	51	114	83.93
Copper	mg/L	36	0	0	0
DO	mg/L	84	5.8	21	8.77
Fecal Colloms	MPNECMED[b]	12	430	9300	3749.17
Fixed residue	mg/L	36	1	42	8.81
Iron	mg/L	36	0.40	1.32	0.79
Lead	mg/L	36	0	0	0
Magnesium	mg/L	36	0.92	1.52	1.3
Manganese	mg/L	36	0.03	0.1	0.07
Mercury	mg/L	36	0	0.92	0.23
Nickel	mg/L	36	0	0.03	0.02
Nitrate + Nitrite	mg/L	48	0.11	0.47	0.29
PH	pH	1	6.7	6.7	6.7
Phosphate	mg/L	36	0.03	0.01	0.06
Sodium	mg/L	36	5.28	13	9.29
Sulfate	mg/L	36	4	11	7.64
Suspended solids	mg/L	36	3	48	11.31
TOC	mg/L	12	1.5	14	5.08
Temperature	C	60	1	30	17.83
Total Dissolved Solids	mg/L	36	49	105	65.94
Total Phosphate	mg/L	12	0.07	0.13	0.1
Total Solids	mg/L	36	54	120	77.26
Turbidity	JTU[c]	48	2.66	32.4	10.77
Volatile Solids	mg/L	36	1	9	2.72
Water Volume	L	36	4E+11	2.68E+12	9.58E+11
Zinc	mg/L	36	0	0.01	0.01
PH	pH	36	5.9	7.2	6.34
pH (lab)	pH	12	6.7	7	6.86

[a] microsiemens per centimeter
[b] Maximum probable number per 100 mL
[c] Jackson turbidity units

Source: SRS Environmental Monitoring Reports for 1992, 1993, and 1994. Report numbers WSRC-TR-92-0075, WSRC-TR-93-0075, and WSRC-TR-94-0075. Data summary provided by J. Gladden, WSRC Environmental Analysis.

Table 1.4-18 Hydraulic Parameters of the Carbonate Phase of the Floridian Aquifer

Parameter	Value [Mean] (Average)	Maximum	Minimum	Comments	Source	
Transmissivity	[1,486 m^2/day]	9,290 m^2/day	30 m^2/day	Floridan undifferentiated, South Carolina	Newcome, 1993	(Ref. a)
		46,450	929	Upper Floridan, various areas, Georgia	Krause and Randolph, 1989	(Ref. b)
		3,066	2,601	Upper Floridan, Savannah, Georgia	Krause and Randolph, 1989	(Ref. b)
	(929 to 4,645)			Upper Floridan, Coastal South Carolina	Hayes, 1979	(Ref. c)
		20,066	186	Lower Floridan	Krause and Randolph, 1989	(Ref. b)
		465	46	Lower Floridan	Hayes, 1979	(Ref. c)
		929	65	Updip clastic phase	Aucott, 1988	(Ref. d)
Hydraulic Conductivity	(53 to 122 m/day)			Upper Floridan, Beaufort county	Hayes, 1979	(Ref. c)
		31 m/day	23 m/day	Lower Floridan, Coastal South Carolina	Hayes, 1979	(Ref. c)

Sources: Ref. a: Newcome, Roy, Jr. 1993, the 100 largest public water supplies in south Carolina: South Carolina Water Resources Commission Report 169, 57 p.

Ref. b: Krause, R. E., and Randolph, R. B. Hydrology of the Floridan Aquifer System in Southeast Georgia and Adjacent Parts of Florida and South Carolina. U.S. Geological survey Professional Paper 1403-D, 1989

Ref. c: Hayes, L. R., 1979 The groundwater resources of Beaufort, Colleton, Hampton, and Jasper Counties, South Carolina: South Carolina Water Resources Commission report 9, 91 p.

Ref. d: Aucott, W. R., et al. Geohydrologic Framework of the Coastal Plain Aquifers of South Carolina. U.S. Geological survey Water Resources Investigations Report 85-4271, 1988

Table 1.4-19 Parameters Determined for the Upper Three Runs Aquifer Unit

Parameter	Value [Mean] (Average)	Maximum	Range Minimum	Comments	Source	
Hydraulic Conductivity (vertical)	[2.71 x 10^{-3} m/d]	1.55 x 10^{-1} m/d	8.2 x 10^{-3} m/d	Clayey sand samples	Bledsoe et al., 1990	(Ref. a)
Hydraulic Conductivity (horizontal)	[3.38 x 10^{-3} m/d]	7.3 x 10^{-1}	9.66 x 10^{-4}	Clayey sand samples	Bledsoe et al., 1990	(Ref. a)
Porosity	[40%]	55%	10%	Clayey sand samples	Bledsoe et al., 1990	(Ref. a)
Effective porosity	12%			Clayey sand samples	Fetter, 1988	(Ref. b)
Hydraulic Conductivity (vertical)	5.09 x 10^{-3} m/d	6.4 x 10^{-3} m/d	1.04 x 10^{-3} m/d	Sandy clay samples	Bledsoe et al., 1990	(Ref. a)
Hydraulic Conductivity (horizontal)	1.24 x 10^{-4} m/d	9.85 x 10^{-2}	7.77 x 10^{-4}	Sandy clay samples	Bledsoe et al., 1990	(Ref. a)
Porosity	41%	71%	23%	Sandy clay samples	Bledsoe et al., 1990	(Ref. a)
Effective porosity	5%			Sandy clay samples	Fetter, 1988 .	(Ref. b)
Leakance coefficient		2.58 x 10^{-4} m/d	4.11 x 10^{-4} m/d		Walton, 1970	(Ref. c)

Sources:

Ref. a: Bledsoe et al., 1990 — Baseline Hydrogeologic Investigation - summary Report. WSRC-RP-90-1010, Westinghouse Savannah River Company, Savannah River Site, Aiken SC, 1990

Ref. b: Fetter, 1988 — Ground Water Resource Evaluation. McGraw-Hill Book Co., New York, NY, 1988

Ref. c: Walton, 1970 — Applied Hydrology. Merrell Publishing, Columbus OH, 1988.

Table 1.4-20 Parameters Determined for the Gordon Confining Unit

Parameter	Value [Mean] (Average)	Maximum	Range Minimum	Comments	Source	
Hydraulic Conductivity (vertical)		9.1 x 10^{-3} m/d	9.1 x 10^{-4} m/d	"green clay" confining zone	Eddy et al., 1991	(Ref. a)
Hydraulic Conductivity (horizontal)	[1.24 x 10^{-3} m/d]	4.85 x 10^{-2}	1.74 x 10^{-4}	Clayey sand samples	Bledsoe et al., 1990	(Ref. b)
Hydraulic Conductivity (vertical)	[8.75 x 10^{-3}]	1.12 x 10^{-4}	6.83 x 10^{-3}	Sandy clay samples	Bledsoe et al., 1990	(Ref. b)
Hydraulic Conductivity (horizontal)	(1.1 Darcies)			Minipermeameter data from sandy muds in General Separations Area	Kegley, 1993	(Ref. c)
Porosity		90%	35%	"green clay" confining zone	Eddy et al., 1991	(Ref. a)
Porosity	(34.6%)			From sleeve analyses of sand samples (<25% clay)	Aaland, 1995	(Ref. d)
Permeability	(16.3 Darcies)			From sleeve analyses of sand samples (<25% clay)	Aaland, 1995	(Ref. d)

Sources:

Ref. a:	Eddy et al., 1991	Characterization of the geology, geochemistry, hydrology, and microbiology of the bi-situ air stripping demonstration site at the Savannah River Site: USDOE Report WSRC-RD-91-21. Westinghouse Savannah River Laboratory, Aiken SC 29808, 118 pages
Ref. b:	Bledsoe et al., 1990	Baseline Hydrogeologic Investigation - Summary Report. WSRC-RP-90-1010, Westinghouse Savannah River Company, Savannah River Site, Aiken SC, 1990
Ref. c:	Kegley, 1993	Distribution of permeability at the MWD Well Field, Savannah River Site, Aiken SC: M.S. Thesis, Clemson University, Clemson SC, 186 pages
Ref. d:	Aaland, 1995	Hydrogeologic framework of West Central South Carolina

Table 1.4-21 Hydraulic Parameters for the Gordon Aquifer Unit

Parameter	Value [Mean] (Average)	Maximum	Range Minimum	Comments	Source	
Hydraulic Conductivity	(11 m/d)	12 m/d	7 m/d	Derived from long-term pumping test of Gordon Aquifer Unit.	Aaland, 1995	(Ref. a)
Hydraulic Conductivity	(13.1	19	9.6	Derived from long-term pumping test of Steed Pond Aquifer Unit (updip equivalent of Gordon Aquifer Unit)	Aaland, 1995	(Ref. a)

Source: Aaland, R. K., et al. Hydrogeologic framework of West Central South Carolina, 1995

Table 1.4-22 Hydraulic Conductivity Values from Single- and Multiple-Well Aquifer Tests and Slug Tests for Upper Three Runs, Gordon, and Steed Pond Aquifers

Hydrologic unit	Type of test	Number of tests	Mean Hydraulic Conductivity (ft/d)	Median Conductivity (ft/d)	Hydraulic Source
"Upper" aquifer zone of Upper Three Runs aquifer	Slug tests	190	5.62	1.38	GeoTrans (1992b) (Ref. a)
do.	Short-duration single-well pumping tests	38	0.67	0.61	Parizek and Root (1986) (Ref. b)
do.	Short-duration single-well pumping tests	14	5.09	1.22	Evans and Parizek (1991) (Ref. c)
do.	Long-duration multiple-well pumping tests	1	13	-	D'Appoinia (1981) (Ref. d)
do.	Minipermeameter tests	317	12.6	-	Kegley, (1993) (Ref. e)
"Lower" aquifer zone of Upper Three Runs aquifer	Slug tests	173	5.62	1.00	GeoTrans (1992b) (Ref. a)
do.	Short-duration single-well pumping tests	51	0.91	0.61	Parizek and Root (1986) (Ref. b)
do.	Short-duration single-well pumping tests	7	33.3	1.22	Evans and Parizek (1991) (Ref. c)
do.	Long-duration single-well pumping tests	4	1.06	-	D'Appoinia (1981) (Ref. d)
do.	Long-duration multiple-well pumping tests	1	10	-	Chas. T. Main, Inc. (1990) (Ref. f)
do.	Pumping test	1	19	-	Christensen and Gordon (1983) (Ref. g)
do.	Minipermeameter tests	199	23.8	-	Kegley, (1993) (Ref. e)
Steed Pond aquifer	Long-duration multiple-well pumping tests	4	43	N/A	Geraghty and Miller (1986) (Ref. h)
"M-Area" aquifer zone of the Steed Pond aquifer	Slug tests	6	2.19	N/A	Sirrine (1991c) (Ref. i)
"Lost Lake" aquifer zone of the Steed Pond aquifer	Slug tests	14	18.9	N/A	Sirrine (1991c) (Ref. i)
do.	Long-duration multiple-well pumping tests	8	58	N/A	Geraghty and Miller (1986) (Ref. h)
do.	Long-duration multiple-well pumping tests	1	31.2	-	Hiergesell (1993) (Ref. k)
Gordon aquifer	Slug tests	41	4.9	2.82	GeoTrans (1992b) (Ref. a)
do.	Short-duration single-well pumping tests	10	13.8	1.91	do.
do.	Long-duration single- and multiple-well pumping tests	8	35	N/A	(see text)

Table 1.4-22 Hydraulic Conductivity Values from Single- and Multiple-Well Aquifer Tests and Slug Tests for Upper Three Runs, Gordon, and Steed Pond Aquifers (Continued)

Source:	Ref. a:	GeoTrans, Inc., 1992b, Groundwater flow and solute transport modeling of the F- and H-Area seepage basins: prepared for Westinghouse Savannah River Company, Environmental Group, Sept. 1992, Corporate Parkway, CCC4, Aiken, SC, 29803, 77 pages.
	Ref. b:	Parizek, R. R., and Root, R. W., 1986, Development of a ground water velocity model for the radioactive waste management facility, Savannah River Plant, Aiken, SC: USDOE Report DPST-86-658, E. I. duPont de Nemours & Co., Savannah River Laboratory, Aiken, SC, 29808.
	Ref. c:	Evans, E.K. and Parizek, R.R., Characterization of Hydraulic Conductivity Heterogeneity in Tertiary Sediments within the General Separations Area, Savannah River Site, South Carolina. Department of Geosciences, Pennsylvania State University, PA, 1991.
	Ref. d:	D'Appolonia, Inc., 1981, Report, DWPF - stage 1 investigation aquifer performance tests, 200-S Area: Savannah River Plant, SC, Project No. 76-372, Pittsburgh, PA.
	Ref. e:	Kegley, W.P., 1993, Distribution of permeability at the MWD Well Field, Savannah River Site, Aiken, SC: M.S. Thesis, Clemson University, Clemson, SC, 186 pages.
	Ref. f:	Chas. T. Main, Inc., 1990, F-Area aquifer pump test report: Report prepared for Westinghouse Savannah River Company, Aiken, SC, 29808, 13 pages.
	Ref. g:	Christensen, E. J., and Gordon, D. E., 1983, Technical summary of groundwater quality protection program at Savannah River Plant, Vol. 1, site geohydrology and solid and hazardous wastes: Savannah River Laboratory Report DPST-83-929, E. I. duPont de Nemours & Co., Aiken, SC, 29808
	Ref. h:	Geraghty and Miller, Inc., 1986, Hydraulic properties of the Tertiary aquifer system underlying the A/M: E. I. duPont de Nemours & Co., Atomic Energy Division, Aiken, SC, 29808, 56 pages.
	Ref. i:	Sirrine Environmental Consultants, 1991c, 1992 RCRA Part B permit renewal application M-Area Hazardous Waste Management Facility: (Draft), 300 pages.
	Ref. j:	Hiergesell, R.A., 1993, Hydrologic analysis of data for the Lost Lake aquifer zone of the Steed Pond aquifer at recovery well RWM-16: WSRC-TR-92-529, Rev. 1, Westinghouse Savannah River Company, Savannah River Site, Aiken, SC, 29808, 36 pages.

Table 1.4-23 pH and Composition of Water from Cretaceous to Eocene Sources in the Vicinity of SRS

				Chemical Content (ppm)										
Aquifer / Confining System or Unit	No. of Analyses	Range and Median	pH	Fe	Ca	Na	Na+K	HCO_3	SO_4	Cl	F	NO_3	TDS[a]	Hardness ($CaCO_3$)
Dublin-Midville Aquifer System	13	Maximum	6.9	0.77	1.4	0.9	6.7	17	4.8	4.0	0.1	8.8	28	7
		Minimum	4.4	0	0.3	0	0.9	0	0.5	0.8	0	0	14	2
		Median	5.4	0.16	0.9	0.5	2.1	3	1.4	2.2	0	0.6	19	5
Dublin-Midville Aquifer System/ Meyers Branch Confining System	16	Maximum	6.8	4.1	8.7	1.3	4.2	23	27	6.0	0.2	0.9	54	30
		Minimum	4.4	0.10	3.9	0.4	1.5	4	7.4	1.5	0	0	36	10
		Median	5.9	1.1	6.4	1.0	2.7	12	11	2.1	0.1	0	41	19
Calcareous Facies of Floridan Aquifer System	15	Maximum	7.6	1.0	47	9.4	19	171	14	4.5	0.5	6.2	192	132
		Minimum	6.8	0	17	0.3	0.4	55	0.8	0.4	0	0	75	50
		Median	7.1	0.25	27	2.0	1.7	94	4.3	2.8	0.1	0.2	95	72
Arenaceous Facies of Floridan Aquifer System	9	Maximum	6.1	1.84	8.7	4.2	2.4	17	9.3	4.0	0.3	2.3	29	15
		Minimum	4.2	0.04	0.5	0.3	0.4	1	0.8	1.5	0	0	20	4
		Median	5.5	0.16	1.5	0.7	2.1	5.5	1.9	2.7	0.1	1.3	21	8

Source : Siple, "Geology and Ground Water of the Savannah River Plant and Vicinity, South Carolina." U.S. Geological Survey Water Supply Paper 1841 (1967).

[a] TDS = total dissolved solids.

Table 1.4-24 Pumpage for Municipal Supplies

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

[a] See Figure 1.4-50.

[b] 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.

[c] "Tuscaloosa" refers to undifferentiated Cretaceous formations of the Lumbee Group.

Table 1.4-25 Radioactivity and Chemical Concentrations in F-Canyon Monitoring Wells

Well		FCA 16B	FCA 16D
Plant Coor.	North	78898	78899
	East	53571	53720
Screen Interval (ft)	Top	11.0	69.0
	Bottom	15.0	89.0
Date		3/24/88	3/19/88
Water Temperature		27.4C	20.9C
pH		6.3	6.3
Alkalinity			14 Mg/L
Spec. Conductance		158uMh/Cm	116uMh/Cm
Contaminants (1-in. uG/L, 2-in. pCi/L)			
Silver(1)			2
Arsenic(1)			2
Barium(1)			32
Calcium(1)			8950
Carbon Tetrachloride(1)			1
Cadmium(1)			2
Chloroform(1)			1
Chloride			5200
Fluoride			100
Iron(1)			22
Potassium(1)			1500
Magnesium(1)			790
Manganese(1)			21
Sodium(1)			12000
Nitrate as Nitrogen(1)			11900
Lead			6
Phenols(1)			5
Sulfate(1)			5000
Tetrachloroethylene(1)			1
Total Organic Carbon(1)			1300
Total Organic Halogens(1)			234
Total Phosphates(1)			120
Trichloroethylene(1)			284
1,1,1-Trichloroethane (1)			1
Gross Alpha (2)		0.21+/-0.41	9.00+/-2.50
Nonvolatile Beta (2)		7.22+/-1.71	21.50+/-2.70
Cerium-144 (2)		0.00+/-0.26	
Cobalt-60 (2)		0.00+/-0.04	
Chromium-51 (2)		0.00+/-0.45	
Cesium-134 (2)		0.00+/-0.03	
Cesium-137 (2)		0.00+/-0.03	
Iodine-131 (2)		0.00+/-0.22	
Ruthenium-103 (2)		0.00+/-0.05	
Ruthenium-107 (2)		0.00+/-0.37	
Antimony-125 (2)		0.00+/-0.11	
Strontium-90 (2)		1.38+/-3.08	less than 0.00
Total Radium (2)			3.00+/-1.00
Tritium (2)		13.22+/-1.41	228+/-1.00
Zirconium/Niobium-95 (2)		0.00+/-0.11	

Table 1.4-26 Significant Earthquakes Within 200 Miles of SRS (Intensity > 4 or Magnitude > 3)

DATE yr/mm/dd	Latitude Deg. N	Longitude Deg. W	Depth mi.	Magnitude(s)*Intensity		Distance mi.
1776/11/05	35.2	83			IV	154
1799/04/04	32.9	80			V	96
1799/04/11	32.9	80			V	96
1799/04/11	32.9	80			V	96
1817/01/08	32.9	80			V	96
1820/09/03	33.4	79.3			IV	133
1827/05/11	36.1	81.2			IV	195
1851/08/11	35.6	82.6			V	170
1853/05/20	34	81.2			VI	56
1857/12/19	32.9	80			V	96
1860/01/19	32.9	80			V	96
1861/08/31	36.1	81.1			VI	195
1869	32.9	80			IV	96
1872/06/17	33.1	83.3			V	98
1874/02/10	35.7	82.1			V	170
1874/02/22	35.7	82.1			IV	170
1874/03/17	35.7	82.1			IV	170
1874/03/26	35.7	82.1			IV	170
1874/04/14	35.7	82.1			IV	170
1874/04/17	35.7	82.1			IV	170
1875/11/02	33.8	82.5			VI	62
1876/12/12	32.9	80			IV	96
1879/12/13	35.2	80.8			IV	141
1885/08/06	36.2	81.6			V	200
1885/10/17	33	83			IV	82
1886/08/27	32.9	80			V	96
1886/08/28	32.9	80			VI	96
1886/08/28	32.9	80			IV	96
1886/08/28	32.9	80			IV	96
1886/09/01	30.4	81.7			IV	197
1886/09/01	32.9	80		6.9F	X	96
1886/09/01	32.9	80			V	96
1886/09/02	32.9	80			V	96
1886/09/03	30.4	81.7			IV	197
1886/09/04	32.9	80			V	96
1886/09/04	30.4	81.7			IV	197
1886/09/05	30.4	81.7			IV	197
1886/09/06	32.9	80			V	96
1886/09/06	32.9	80			IV	96
1886/09/08	30.4	81.7			IV	197
1886/09/09	30.4	81.7			IV	197
1886/09/17	32.9	80			VI	96
1886/09/21	32.9	80			VI	96
1886/09/21	32.9	80			V	96
1886/09/27	32.9	80			VI	96
1886/09/27	32.9	80			V	96
1886/10/09	32.9	80			IV	96

Table 1.4-26 Significant Earthquakes Within 200 Miles of SRS (Intensity > 4 or Magnitude > 3) (Continued)

DATE yr/mm/dd	Latitude Deg. N	Longitude Deg. W	Depth mi.	Magnitude(s)*	Intensity	Distance mi.
1886/10/09	32.9	80			IV	96
1886/10/09	32.9	80			V	96
1886/10/22	32.9	80			VI	96
1886/10/22	32.9	80			VII	96
1886/10/23	32.9	80			IV	96
1886/11/05	32.9	80			VI	96
1886/11/28	32.9	80			IV	96
1887/01/04	32.9	80			V	96
1887/03/04	32.9	80			IV	96
1887/03/17	32.9	80			V	96
1887/03/18	32.9	80			IV	96
1887/03/19	32.9	80			IV	96
1887/03/24	32.9	80			IV	96
1887/03/24	32.9	80			IV	96
1887/03/28	32.9	80			IV	96
1887/04/07	32.9	80			IV	96
1887/04/08	32.9	80			IV	96
1887/04/10	32.9	80			IV	96
1887/04/14	32.9	80			IV	96
1887/04/26	32.9	80			IV	96
1887/04/28	32.9	80			V	96
1887/05/06	32.9	80			IV	96
1887/06/03	32.9	80			IV	96
1887/07/10	32.9	80			IV	96
1887/08/27	32.9	80			V	96
1887/08/27	32.9	80			IV	96
1888/01/12	32.9	80			VI	96
1888/01/16	32.9	80			IV	96
1888/02/29	32.9	80			V	96
1888/03/03	32.9	80			IV	96
1888/03/03	32.9	80			IV	96
1888/03/04	32.9	80			IV	96
1888/03/14	32.9	80			V	96
1888/03/20	32.9	80			IV	96
1888/03/25	32.9	80			IV	96
1888/04/16	32.9	80			IV	96
1888/04/16	32.9	80			IV	96
1888/05/02	32.9	80			IV	96
1889/02/10	32.9	80			IV	96
1889/07/12	32.9	80			IV	96
1891/10/13	32.9	80			IV	96
1893/06/21	32.9	80			V	96
1893/06/21	30.4	81.7			IV	197
1893/07/05	32.9	80			IV	96

Table 1.4-26 Significant Earthquakes Within 200 Miles of SRS (Intensity > 4 or Magnitude > 3) (Continued)

DATE yr/mm/dd	Latitude Deg. N	Longitude Deg. W	Depth mi.	Magnitude(s)*	Intensity	Distance mi.
1893/07/06	32.9	80			IV	96
1893/07/08	32.9	80			IV	96
1893/07/08	32.9	80			IV	96
1893/09/19	32.9	80			IV	96
1893/09/19	32.9	80			IV	96
1893/09/19	32.9	80			IV	96
1893/11/08	32.9	80			IV	96
1893/11/08	32.9	80			IV	96
1893/12/27	32.9	80			IV	96
1893/12/27	32.9	80			IV	96
1893/12/27	32.9	80			IV	96
1893/12/27	32.9	80			IV	96
1893/12/28	32.9	80			IV	96
1894/01/10	32.9	80			IV	96
1894/01/10	32.9	80			IV	96
1894/01/10	32.9	80			IV	96
1894/01/30	32.9	80			IV	96
1894/02/01	32.9	80			IV	96
1894/06/16	32.9	80			IV	96
1894/12/11	32.9	80			IV	96
1895/01/08	32.9	80			IV	96
1895/01/08	32.9	80			IV	96
1895/01/08	32.9	80			IV	96
1895/04/27	32.9	80			IV	96
1895/07/25	32.9	80			IV	96
1895/10/06	32.9	80			IV	96
1895/10/20	32.9	80			IV	96
1895/11/12	32.9	80			IV	96
1896/03/19	32.9	80			IV	96
1896/08/11	32.9	80			IV	96
1896/08/11	32.9	80			IV	96
1896/08/11	32.9	80			IV	96
1896/08/11	32.9	80			IV	96
1896/08/12	32.9	80			IV	96
1896/08/14	32.9	80			IV	96
1896/08/30	32.9	80			IV	96
1896/09/08	32.9	80			IV	96
1896/11/14	32.9	80			IV	96
1899/03/10	32.9	80			IV	96
1899/12/04	32.9	80			IV	96
1900/10/31	30.4	81.7			V	197
1901/12/02	32.9	80			IV	96
1903/01/24	32.9	80			IV	96
1903/01/24	32.1	81.1			VI	85
1903/01/31	32.9	80			IV	96
1907/04/19	32.9	80			V	96
1911/04/20	35.1	82.7			V	141

Table 1.4-26 Significant Earthquakes Within 200 Miles of SRS (Intensity > 4 or Magnitude > 3) (Continued)

DATE yr/mm/dd	Latitude Deg. N	Longitude Deg. W	Depth mi.	Magnitude(s)*	Intensity	Distance mi.
1903/02/03	32.9	80			IV	96
1904/03/05	35.7	83.5		4.0F	V	198
1912/06/12	32.9	80			VII	96
1912/06/20	32	81			V	94
1912/09/29	32.9	80			IV	96
1912/10/23	32.7	83.5			IV	115
1912/11/17	32.9	80			IV	96
1912/12/07	34.7	81.7			IV	98
1913/01/01	34.7	81.7			VII	98
1913/04/17	35.3	84.2		3.9F	V	203
1914/03/05	33.5	83.5			VI	109
1914/03/07	34.2	79.8			IV	122
1914/07/14	32.9	80			IV	96
1914/09/22	32.9	80			V	96
1915/10/29	35.8	82.7			IV	184
1915/10/29	35.8	82.7			V	184
1916/02/21	35.5	82.5			VII	162
1916/03/02	34.5	82.7			IV	104
1916/08/26	36	81			V	190
1924/01/01	34.8	82.5			IV	117
1924/10/20	35	82.6			V	131
1926/07/08	35.9	82.1			VII	182
1928/11/03	36.112	82.828	3.1	4.5N	VI	206
1928/11/20	35.8	82.3			IV	178
1928/12/23	35.3	80.3			IV	158
1929/01/03	33.9	80.3			IV	88
1929/10/28	34.3	82.4			IV	83
1930/12/10	34.3	82.4			IV	83
1930/12/26	34.5	80.3			IV	114
1931/05/06	34.3	82.4			IV	83
1933/12/19	32.9	80			IV	96
1933/12/23	32.9	80			V	96
1933/12/23	32.9	80			IV	96
1934/12/09	32.9	80			IV	96
1935/01/01	35.1	83.6			V	170
1938/03/31	35.6	83.6			IV	195
1940/12/25	35.9	82.9			IV	195
1941/05/10	35.6	82.6			IV	170
1943/12/28	32.9	80			IV	96
1944/01/28	32.9	80			IV	96
1945/01/30	32.9	80			IV	96
1945/07/26	33.75	81.376	3.1	4.4F	VI	35
1947/11/02	32.9	80			IV	96
1949/02/02	32.9	80			IV	96
1952/11/19	32.9	80			V	96
1956/01/05	34.3	82.4			IV	83
1956/01/05	34.3	82.4			IV	83

Table 1.4-26 Significant Earthquakes Within 200 Miles of SRS (Intensity > 4 or Magnitude > 3) (Continued)

DATE yr/mm/dd	Latitude Deg. N	Longitude Deg. W	Depth	Magnitude(s)* mi.		Intensity	Distance	mi.
1949/06/27	32.9	80					IV	96
1951/03/04	32.9	80					IV	96
1951/12/30	32.9	80					IV	96
1956/05/19	34.3	82.4					IV	83
1956/05/27	34.3	82.4					IV	83
1956/09/07	35.5	84				4.1F	V	203
1957/05/13	35.799	82.142		3.1		4.1F	VI	176
1957/07/02	35.6	82.7		4.4			VI	171
1957/11/24	35	83.5				4.0F	VI	160
1958/05/16	35.6	82.6					IV	170
1958/10/20	34.5	82.7					V	104
1959/08/03	33.054	80.126		0.6		4.4F	VI	88
1959/10/27	34.5	80.2					VI	117
1960/01/03	35.9	82.1					IV	182
1960/03/12	33.072	80.121		5.6		4.0F	V	88
1960/07/24	32.9	80					V	96
1963/04/11	34.9	82.4					IV	120
1963/05/04	32.972	80.193		3.1		3.3M	IV	85
1963/10/08	33.9	82.5				3.2M		67
1964/01/20	35.9	82.3					IV	184
1964/03/07	33.724	82.391		3.1		3.3M		54
1964/03/13	33.193	83.309		0.6	4.4P	3.9M	V	98
1964/04/20	33.842	81.096		1.9		3.5M	V	50
1965/09/09	34.7	81.2				3.9M		101
1965/09/10	34.7	81.2				3.0M		101
1965/11/08	33.2	83.2				3.3M		91
1967/10/23	32.802	80.221		11.8	3.8P	3.4N	V	86
1968/07/12	32.8	79.7					IV	115
1968/09/22	34.111	81.484		0.6	3.7P	3.5M	IV	58
1969/05/09	33.95	82.58				3.3N		72
1969/05/18	33.95	82.58			3.5N			72
1969/12/13	35.036	82.84	6	3.7		3.7M	IV	141
1970/09/10	36.02	81.421		0.6		3.1N	V	189
1971/05/19	33.359	80.655		0.6	3.4P	3.7N	V	56
1971/07/13	34.76	82.98			3.8N		VI	128
1971/07/13	34.7	82.9			3.0M			122
1971/07/31	33.341	80.631		2.5	3.8N		III	56
1971/08/11	33.4	80.7			3.5N			54
1971/10/09	35.795	83.371	5	3.4P	3.7N		V	200
1971/10/22	36	83			3.3M			203
1972/02/03	33.306	80.582		1.2	4.5P	4.5N	V	59
1972/02/07	33.46	80.58			3.2M		III	61
1972/02/07	33.46	80.58			3.2M		III	61
1972/08/14	33.2	81.4				3.0L	III	14
1973/12/19	32.974	80.274		3.7		3.0M	III	80
1974/10/28	33.79	81.92				3.0L	IV	40
1974/11/05	33.73	82.22				3.7L	II	46

Table 1.4-26 Significant Earthquakes Within 200 Miles of SRS (Intensity > 4 or Magnitude > 3) (Continued)

DATE yr/mm/dd	Latitude Deg. N	Longitude Deg. W	Depth mi.	Magnitude(s)*		Intensity	Distance mi.
1974/08/02	33.908	82.534	2.5	4.3P	4.1N	V	69
1974/10/08	33.9	82.4	3.1P			III	62
1974/11/22	32.926	80.159	3.7	4.7P	4.3N	VI	88
1974/12/03	33.95	82.5			3.6L	IV	69
1975/04/01	33.2	83.2			3.9M		91
1975/04/28	33	80.22	6.2		3.0N	IV	83
1975/10/18	34.9	83				IV	136
1975/11/25	34.943	82.896	6.2		3.2N	IV	136
1976/12/27	32.06	82.504	8.7		3.7N	V	98
1977/01/18	33.058	80.173	0.6		3.0N	VI	85
1977/03/30	32.95	80.18	5		2.9D	V	85
1977/08/04	33.369	80.699	5.6		3.1N		54
1977/08/25	33.369	80.698	2.1	3.1N	2.8D	IV	54
1977/12/15	32.944	80.167	4.7	3.0N	2.6D	V	86
1978/09/07	33.063	80.21	6.2	2.7N	2.6D	IV	83
1979/08/13	35.2	84.353	13.8	3.7N	3.7D	V	203
1979/08/13	33.9	82.54	14.3		4.1D		69
1979/09/06	35.298	83.241	6.2		3.2D		166
1979/09/12	35.579	83.941	16.8	3.2N	3.1D	V	206
1979/12/07	33.008	80.163	3.1	2.8N	2.8D	IV	85
1980/06/10	35.458	82.815	0.4	3.0N	2.5D		165
1980/09/01	32.978	80.186	4.4	2.7N	2.9D	IV	85
1981/03/04	35.81	79.737	0.6	2.8N	2.2D	IV	203
1981/04/09	35.514	82.051	0.1	3.0N	3.3D	V	157
1981/05/05	35.327	82.422	6.3	3.5N	3.1D	V	149
1982/01/28	32.982	81.393	4.4	3.4N	2.4D		24
1982/03/01	32.936	80.138	4.2	3.0N	2.8D	IV	88
1982/07/16	34.32	81.55	1.2		3.1D	III	72
1982/10/31	32.671	84.873		2.9N	3.0D	V	192
1982/10/31	32.644	84.894		3.1N	3.1D		194
1982/12/11	32.853	83.532			3.0D		114
1983/01/26	32.853	83.558		3.5N	3.5D		115
1983/03/25	35.333	82.46	7.1	3.2N	3.3D	V	149
1983/11/06	32.937	80.159	6		3.3D	V	88
1985/12/22	35.701	83.72	8.3		3.3D		205
1986/03/13	33.229	83.226	3.1		2.4D	IV	93
1986/09/17	32.931	80.159	4.2		2.6D	IV	88
1987/03/16	34.56	80.948	1.9		3.1D		96
1988/01/09	35.279	84.199	7.6		3.2D	IV	200
1988/01/23	32.935	80.157	4.6		3.3D	V	88
1988/02/18	35.346	83.837	1.5	3.5N	3.3D	IV	190
1989/06/02	32.934	80.166	3.6		2.0D	IV	86
1990/11/13	32.947	80.136	2.1	3.5N	3.2D	V	88
1991/06/02	32.98	80.214	3.1		1.7D	V	83

Table 1.4-26 Significant Earthquakes Within 200 Miles of SRS (Intensity > 4 or Magnitude > 3) (Continued)

DATE yr/mm/dd	Latitude Deg. N	Longitude Deg. W	Depth mi.	Magnitude(s)*		Intensity	Distance mi.
1992/01/03	33.981	82.421	2.1		3.4D	V	67
1992/08/21	32.985	80.163	4	4.1N	4.1D	VI	86
1993/01/01	35.878	82.086	1.4		3.0D		181
1993/08/08	33.597	81.591	5.3	3.2N	2.9D	V	22

Source: SEUSSN Bulletins, Va. Tech Publications, Complete through 1/95)
* MAGNITUDE TYPE CODES (FOLLOWS MAGNITUDE VALUE)
" D - Md from duration or coda length"
" F - mb from felt area or attenuation data"
" L - ML (Richter, 1958)"
" M - mb determined from modified instruments/formuli"
" N - mb from Lg wave data (Nuttli, 1973)"
" P - mb from P wave data (Gutenberg and Richter (1956)"

Table 1.4-27 Modified Mercalli Intensity Scale of 1931

Level	Definition
I.	Not felt except by a very few under especially favorable circumstances (I Rossi-Forel Scale).
II.	Felt by only a few persons at rest, especially on upper floors of buildings. Delicately suspended objects may swing (I and II, Rossi-Forel Scale).
III.	Felt quite noticeably indoors, especially on upper floors of buildings, but many people do not recognize it as an earthquake. Standing motor cars may rock slightly. Vibration like passing truck. Duration estimated (III Rossi-Forel Scale).
IV.	During the day felt indoors by many; outdoors by few. At night some awakened. Dishes, windows, doors disturbed; walls made creaking sound. Sensation like heavy truck striking building. Standing motor cars rocked noticeably (IV to V Rossi-Forel Scale).
V.	Felt by nearly everyone; many awakened. Some dishes, windows, etc., broken, a few instances of cracked plaster, unstable objects overturned. Disturbance of trees, poles, and other tall objects sometimes noticed. Pendulum clocks may stop (V to VI Rossi-Forel Scale).
VI.	Felt by all; many are frightened and run outdoors. Some heavy furniture moved; a few instances of fallen plaster or damaged chimneys. Damage slight (VI to VII Rossi-Forel Scale).
VII.	Everybody runs outdoors. Damage negligible in buildings of good structures; considerable in poorly built or badly designed structures; some chimneys are broken. Noticed by persons driving motor cars (VIII Rossi-Forel Scale).
VIII.	Damage slight in specially designed structures; considerable in ordinary substantial buildings with partial collapse; great in poorly built structures. Panel walls thrown out of frame structures. Fall of chimneys, factory stacks, columns, monuments, and walls. Heavy furniture overturned. Sand and mud ejected in small amounts. Changes in well water. Disturbs persons driving motor cars (VIII+ to IX Rossi-Forel Scale).
IX.	Damage considerable in specially designed structures; well designed frame structures thrown out of plumb; great in substantial buildings with partial collapse. Buildings shifted off foundations. Ground cracked conspicuously. Underground pipes broken (IX+ Rossi-Forel Scale).
X	Some well built wooden structures destroyed; most masonry and frame structures destroyed with foundations, ground badly cracked. Rails bent. Landslides considerable from riverbanks and steep slopes. Shifted sand and mud. Water splashed (slopped) over banks (X Rossi-Forel Scale).
XI.	Few, if any, masonry structures remain standing. Bridges destroyed. Broad fissures in ground. Underground pipe lines completely out of service. Earth slumps and land slips in soft ground. Rails bent greatly.
XII.	Damage total. Waves seen on ground surfaces. Lines of sight and level distorted. Objects thrown upward into the air.

Source: Earthquake Intensity and Ground Motion, pp 7-8, by Frank Neumann, University of Washington Press, Seattle, WA (1954).

Table 1.4-28 Historic Earthquakes Recorded Within 50 Miles of SRS (through December 1999)

Date	Latitude	Longitude	Depth (km)	Magnitude
05/06/1897	33.3000	-81.2000		elt
05/09/1897	33.9000	-81.6000		elt
05/24/1897	33.3000	-81.2000		elt
05/27/1897	33.3000	-81.2000		elt
8/14/1972	33.2000	-81.4000		20
10/28/1974	33.7900	-81.9200		00
11/5/1974	33.7300	-82.2200		70
9/15/1976	33.1440	-81.4130	50	40
6/5/977	33.0520	-81.4120	50	70
2/21/1981	33.5933	-81.1476	61	00
1/28/1982	32.9800	-81.3900	00	40
6/9/1985	33.2225	-81.6842	81	70
2/17/1988	33.5113	-81.6966	1.73	50
8/5/1988	33.1873	-81.6290	26	20
7/13/1992	33.4798	-81.1920	60	90
10/2/1992	33.4990	-81.2020	00	40
12/12/1992	33.2798	-81.8328	1.80	20
6/29/1993	33.4652	-81.2210	90	20
8/8/1993	33.5893	-81.5852	).18	20
8/8/1993	33.5885	-81.5812	22	60
9/18/1996	33.6915	-82.1248	38	80
5/17/1997	33.2118	-81.6765	44	50

Source: SEUSSN Bulletins, Virginia Tech Publication; complete through 12/99)

Table 1.4-29 Blume (1982) Estimated Site Motions for Postulated Maximum Events

Location	Epicentral Intensity (MMI)	R (km)	Site Intensity (MMI)	Site PGA (%g)
Local	VII	0-10	VII	0.10
Fall Line	VIII	45	VI	0.06
Bowman	X	95	VII	0.10
Middleton	X	145	VI-VII	0.075

Source: URS/John A. Blume and Associates, Engineers. Update of Seismic Criteria for the Savannah River Plant, Vol. 1 of 2, *Geotechnical*. USR/JAB 8144, San Francisco, CA. Prepared for E.I. du Pont de Nemours and Company, as DPE-3699, Savannah River Plant, Aiken, SC, 1982.

Table 1.4-30 Geomatrix Estimated Site Motions for Postulated Maximum Events

Location	Magnitude (Mw)	R (km)	Site PGA[a] (%g median, horizontal)
Local	5.0	<25	0.18
Bowman	6.0	80	0.06
Charleston	7.5	110	0.11

[a] 25 Hz

Source: Geomatrix Consultants, Inc., Ground Motion Following Selection of SRS Design Basis Earthquake and Associated Deterministic Approach, WSRC Subcontract AA2021S, Westinghouse Savannah River Company, Savannah River Site, Aiken, SC, 1991.

Table 1.4-31 Modified Herrmann (1986) Crustal Model

H (km)	Vs (km/s)	density (g/cc)
5.0	3.75	2.7
9.5	3.76	2.7
14	4.01	2.8
inf	4.56	3.3

Source: Herrmann, R.B., "Surface-Wave Studies of Some South Carolina Earthquakes," Bulletin of Seismological Society of America, Vol. 76, No. 1, 1986.

Table 1.5-1 Annual Maximum Instantaneous Discharges of the Savannah River at Augusta, Georgia, for Water Years 1921 Through 1999 (USGS Flow Data, 1922-1999)

Year	Discharge (cfs)	Year	Discharge (cfs)
		1961	34,800
1921	129,000		
1922	92,000	1962	32,500
1923	59,700	1963	31,300
1924	56,400		
		1964	87,100
1925	150,000	1965	34,600
		1966	39,300
1926	55,300		
1927	39,000	1967	35,900
1928	226,000	1968	35,900
1929	191,000		
		1969	45,600
1930	350,000	1970	25,200
		1971	63,900
1931	26,100		
1932	93,800	1972	33,700
1933	48,200	1973	40,200
1934	73,200		
		1974	32,900
1935	63,700	1975	45,600
		1976	33,300
1936	258,000		
1937	90,200	1977	34,200
1938	65,300	1978	43,100
1939	82,400		
		1979	37,300
1940	252,000	1980	47,200
		1981	17,300
1941	52,200		
1942	115,000	1982	30,700
1943	132,000	1983	66,100
1944	141,000		
		1984	34,000
1945	62,100	1985	25,700
		1986	21,000
1946	109,000		
1947	90,200	1987	29,200
1948	76,100	1988	13,600
1949	172,000		
		1989	20,200
1950	32,500	1990	35,300
		1991	59,200
1951	41,400		
1952	39,300	1992	22,100
1953	35,200	1993	45,100
1954	25,500	1994	40,700
1955	23,900	1995	33,600
1956	18,600	1996	34,400
1957	18,000	1997	26,300
1958	66,300	1998	43,000
		1999	19,000
1959	28,500		
1960	34,900		

Source: Water Resources Data for South Carolina, USGS Annual Data Reports for Water Years 1967-1999.

Note: Station 02197000; drainage area 7,508 square miles (including Butler Creek drainage area). The maximum instantaneous discharge since gaging by the USGS began in 1882 is 350,000 cfs on October 3, 1929. The maximum historical flow is 360,000 cfs in 1796.

Table 1.5-2 Annual Maximum Instantaneous Discharges of Upper Three Runs Creek for Water Years 1967 Through 1999

Water Year	Discharge at High-way 278[a] (cfs)	Discharge at SRS Road C[b] (cfs)	Discharge at SRS Road A[c] (cfs)
1967	320	-[d]	
1968	237	-	-
1969	301	-	-
1970	303	-	-
1971	420	-	-
1972	382	-	-
1973	472	-	-
1974	260	-	-
1975	341	586	-
1976	429	732	1230
1977	304	540	717
1978	344	646	Not gauged
1979	341	680	996
1980	420	880	951
1981	308	582	620
1982	364	696	793
1983	472	880	1010
1984	466	840	861
1985	400	962	893
1986	360	802	780
1987	370	819	869
1988	278	460	428
1989	304	613	592
1990	202	869	572
1991	820	2040	2580
1992	742	1010	926
1993	421	1280	1100
1994	302	826	667
1995	412	1240	1010
1996	240	691	638
1997	242	840	709
1998	596	-	1200
1999	252	-	717

Source: Water Resources Data for South Carolina, USGS Annual Data Reports for Water Years 1967-1999.

[a]Station 02197300; drainage area 87 square miles.

[b]Station 02197310; drainage area 176 square miles.

[c]Station 02197315; drainage area 203 square miles.

[d]Indicates discharge point that was not monitored.

Table 1.5-3 Annual Maximum Instantaneous Discharges of Tims Branch for Water Years 1974 Through 1995, Station 02197309.

Water Year	Discharge at Road C (ft^3/s)[a]	Gage Height (feet msl)
1974	N/A	N/A
1975	N/A	N/A
1976	61	6.17
1977	N/A	N/A
1978	N/A	N/A
1979	N/A	N/A
1980	N/A	N/A
1981	N/A	N/A
1982	N/A	N/A
1983	NM	NM
1984	N/A	N/A
1985	41	144.76
1986	42	144.88
1987	63	145.16
1988	38	144.28
1989	38	144.26
1990	91	145.27
1991	129	145.69
1992	61	144.77
1993	107	145.47
1994	77	145.07
1995	107	145.47

Source: Water Resources Data for South Carolina, U.S. Geological Survey Annual Data Reports for Water Years 1974-1995.

[a] Drainage area 17.5 square miles.

N/A = data not available at time of publication.

NM = discharge point not monitored.

Table 1.5-3.1 Annual Maximum Daily Discharges of Fourmile Branch for Water Years 1980 Through 1999

Water Year	Discgarge at SRS Road C[a] (cfs)	Discharge at SRS Road A-7[b] (cfs)	Discharge at SRS Road A-12.2[c] (cfs)
1980	288	204	903
1981	123	-[d]	585
1982	262	177	745
1983	136	163	678
1984	267	189	692
1985	149	121	621
1986	211	181	415
1987	161	163	436
1988	89	74	102
1989	-	157	392
1990	-	1230	1060
1991	-	-	-
1992	135	465	493
1993	126	500	477
1994	90	176	-
1995	179	610	595
1996	89	156	200
1997	-	254	299
1998	-	773	837
1999	-	194	264

Sources: USGS Flow Data, 1980-1999.

[a] Station 02197340; drainage area 7.53 square miles.
[b] Station 02197342; drainage area 12.5 square miles.
[c] Station 02197344; drainage area 22.0 square miles.
[d] Indicates discharge unknown.

Table 1.5-4 Probable Maximum Precipitation for F Area

Time (hr)	Incremental Rainfall (in.)	Total Rainfall (in.)
0	–	0
1	2.2	2.2
2	2.8	5
3	3.1	8.1
4	15.1	23.2
5	4.9	28.1
6	2.7	30.8

Source: U. S. Dept. of Commerce, Probable Maximum Precipitation Estimates, United States East of the 105th Meridian, Hydrometeorological Report No. 51, Washington, DC, (1978).

Table 1.5-5 Cumulative Probable Maximum Precipitation for a 10-Square-Mile Area Surrounding the H, S, Z, and M Areas

Time (hr)	Incremental Rainfall (in.)	Total Rainfall (in.)
0	–	0
1	2.2	2.2
2	2.8	5
3	3.1	8.1
4	15.1	23.2
5	4.9	28.1
6	2.7	30.8

Source: U. S. Dept. of Commerce, Probable Maximum Precipitation Estimates, United States East of the 105th Meridian, Hydrometeorological Report No. 51, Washington, DC, (1978).

Table 1.5-6 Hour Storm Rainfall Distributions as a Function of Annual Probability of Exceedance

Annual Probability of Exceedance	2E-02	1E-02	2E-03	1E-03	2E-04	1E-04	2E-05	1E-05
				Rainfall	(inches)			
Hour 1	0.035	0.039	0.052	0.058	0.074	0.082	0.103	0.114
Hour 2	0.062	0.070	0.093	0.104	0.132	0.147	0.185	0.204
Hour 3	0.083	0.094	0.124	0.138	0.176	0.196	0.247	0.272
Hour 4	0.242	0.273	0.361	0.403	0.515	0.571	0.721	0.795
Hour 5	0.393	0.445	0.587	0.656	0.838	0.929	1.174	1.294
Hour 6	0.524	0.593	0.783	0.874	1.117	1.239	1.566	1.725
Hour 7	0.725	0.819	1.082	1.208	1.544	1.712	2.163	2.384
Hour 8	1.863	2.106	2.781	3.105	3.969	4.401	5.562	6.129
Hour 9	1.139	1.287	1.700	1.898	2.426	2.690	3.399	3.746
Hour 10	0.628	0.710	0.937	1.047	1.338	1.483	1.875	2.066
Hour 11	0.414	0.468	0.618	0.690	0.882	0.978	1.236	1.362
Hour 12	0.338	0.382	0.505	0.564	0.720	0.799	1.009	1.112
Hour 13	0.117	0.133	0.175	0.196	0.250	0.277	0.350	0.386
Hour 14	0.076	0.086	0.113	0.127	0.162	0.179	0.227	0.250
Hour 15	0.048	0.055	0.072	0.081	0.103	0.114	0.144	0.159
Hour 16	0.035	0.039	0.052	0.058	0.074	0.082	0.103	0.114
Hour 17	0.035	0.039	0.052	0.058	0.074	0.082	0.103	0.114
Hour 18	0.028	0.031	0.041	0.046	0.059	0.065	0.082	0.091
Hour 19	0.028	0.031	0.041	0.046	0.059	0.065	0.082	0.091
Hour 20	0.021	0.023	0.031	0.035	0.044	0.049	0.062	0.068
Hour 21	0.021	0.023	0.031	0.035	0.044	0.049	0.062	0.068
Hour 22	0.021	0.023	0.031	0.035	0.044	0.049	0.062	0.068
Hour 23	0.014	0.016	0.021	0.023	0.029	0.033	0.041	0.045
Hour 24	0.014	0.016	0.021	0.023	0.029	0.033	0.041	0.045
Accumulation	6.900	7.800	10.300	11.500	14.700	16.300	20.600	22.700

TABLE 1.5-7 DESIGN BASIS FLOOD

PERFORMANCE CATEGORY	1	2	3	4
ANNUAL EXCEEDANCE PROBABILITY	**2E-03**	**5E-04**	**1E-04**	**1E-05**
TIMS BRANCH BASIN (A-AREA)				
Flood (cfs)	2399	3568	5154	8233
Flood Elevation (feet msl)	247.1	247.4	247.6	248.2
FOURMILE BRANCH BASIN (C-AREA)				
Flood (cfs)	2072	3040	4413	7102
Flood Elevation (feet msl)	189.3	190.3	191.5	193.6
FOURMILE BRANCH BASIN (E-AREA)				
Flood (cfs)	1440	2155	3189	5246
Flood Elevation (feet msl)	202.0	203.0	204.4	207.9
UPPER THREE RUNS CREEK BASIN (F-AREA)				
Flood (cfs)	11966	17396	25022	39576
Flood Elevation (feet msl)	144.4	146.6	148.6	150.9
FOURMILE BRANCH BASIN (F-AREA)				
Flood (cfs)	1683	2507	3700	6058
Flood Elevation (feet msl)	193.2	194.2	195.5	197.7
FOURMILE BRANCH BASIN (H-AREA)				
Flood (cfs)	1404	2103	3113	5126
Flood Elevation (feet msl)	236.1	236.8	237.1	239.2
PEN BRANCH BASIN (K-AREA)				
Flood (cfs)	4430	6224	8638	13185
Flood Elevation (feet msl)	176.3	177.7	179.7	182.5
INDIAN GRAVE BRANCH BASIN (K-AREA)				
Flood (cfs)	781	1087	1524	2326
Flood Elevation (feet msl)	180.5	181.1	181.8	182.9

TABLE 1.5-7 DESIGN BASIS FLOOD (CON'T)

PERFORMANCE CATEGORY	**1**	**2**	**3**	**4**
ANNUAL EXCEEDANCE PROBABILITY	**2E-03**	**5E-04**	**1E-04**	**1E-05**
UPPER THREE RUNS CREEK BASIN (S-AREA)				
Flood (cfs)	11966	17396	25022	39576
Flood Elevation (feet msl)	151.8	153.4	155.3	158.2
UPPER THREE RUNS CREEK BASIN (Z- AND Y-AREAS)				
Flood (cfs)	11966	17396	25022	39576
Flood Elevation (feet msl)	158.5	160.4	161.7	163.8

TABLE 1.5-8 DESIGN BASIS FLOOD FOR PROPOSED MFFF FACILITY

PERFORMANCE CATEGORY	1	2	3	4
ANNUAL EXCEEDANCE PROBABILITY	**2E-03**	**5E-04**	**1E-04**	**1E-05**
UPPER THREE RUNS CREEK BASIN				
Flood (cfs)	11966	17532	25022	39576
Flood Elevation (feet msl)	146.4	148.4	150.5	153.1
FOURMILE BRANCH BASIN				
Flood (cfs)	1440	2155	3189	5246
Flood Elevation (feet msl)	202.0	203.0	204.4	207.9