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2 SITE CHARACTERISTICS

The siting requirements contained in 10 CFR 100 apply to applications for site approval for the purpose of operating stationary power as well as testing reactors. The site evaluation criteria for the National Bureau of Standards Reactor (NBSR) at the NIST Center for Neutron Research (NCNR) within the NIST campus are defined in 10 CFR 100, Subpart A, “Evaluation Factors for Stationary Power Reactor Site Applications Before January 10, 1997 and for Testing Reactors.”

In this chapter, Section 2.1, Geography and Demography, describes the geography and population distribution surrounding the NIST site; Section 2.2, Nearby Industrial, Transportation, and Military Facilities, describes all man-made facilities and activities that could pose a problem to the NBSR operation; and Section 2.3, Meteorology, provides the general climate of the region and its impact on the NBSR facility. Section 2.4, Hydrology, describes both the surface and groundwater conditions at the site and in the surrounding area. Section 2.5, Geology, Seismology, and Geotechnical Engineering discusses the seismicity and the properties of soils underlying the NCNR facility, including the NBSR, in Building 235 within the NIST site.

The discussions presented in this chapter are based on reviews of the most recent site-related information; several past reports; and published information since the last application for license renewal and power upgrade that will have an impact on site safety. The URS Group, Incorporated (URS), as a consultant to NIST, performed an extensive research on the geologic literature and near-site geotechnical reports. The URS study, covering Hydrology; and Geology, Seismology, and Geotechnical Engineering for the NBSR site, is documented in a report (URS, 2003). The key findings are discussed in Sections 2.4 and 2.5. Also, the EnviroTech Sensors Inc., as a consultant to NIST, performed the meteorological assessment for the NBSR site and the results of this effort are given in a report (ETSI, 2004). The key findings of this assessment are presented in Section 2.3.

2.1 Geography and Demography

2.1.1 Site Location and Description

Figure 2.1 is a regional map showing the location of the facility with respect to Maryland, Virginia, and the District of Columbia. Figure 2.2 shows the reactor’s location in relation to the surrounding communities of Gaithersburg, Rockville, and Germantown. Figure 2.3 presents a plan view and a photographic view of the NIST campus, and Figure 2.4 shows various Wings and buildings within the NCNR reactor-laboratory complex, the Building 235.

As shown in Figure 2.3, the NBSR is sited on the NIST campus to serve the Institute’s standards and measurements mission and to act as a regional and national resource to serve other U.S. government agencies, universities, and industries. The mission and needs of this multidisciplinary community encompass a wide range of interests in materials, chemical analysis, and radiological standards. The NCNR facility, which includes the NBSR, is a reactor-laboratory complex providing NIST with the means of performing research and establishing standards on materials and nuclear processes. The development of the Cold Neutron Source and the construction of the Cold Neutron Guide Hall provide the United States with world-class capabilities in cold-neutron research on materials.

The conclusion reached in this Safety Analysis Report (SAR) is that the site is well suited for the NBSR, given the reactor's characteristics. In particular, it operates at low power, at near-atmospheric pressure, and at low temperature. Consequently, there is neither a large inventory of radioactive fission products nor stored thermal energy to disperse that inventory to the surrounding area. The NBSR facility also has a full confinement to limit any radiological release to the environment in the unlikely event of an accident.

2.1.1.1 Specification and Location

The NBSR is located at latitude 39^{o} 7' 34" north and longitude 77^{o} 13' 6" west. The corresponding Universal Transverse Mercator (UTM) coordinates are Zone Number 18, Northing 4333105 m, and Easting 308252 m. The NCNR reactor-laboratory complex is located on Center Drive in the southern portion of the NIST campus in Gaithersburg, Montgomery County, Maryland (Figures 2.2 and 2.3). There are no prominent natural features in the immediate vicinity of the reactor, and the most prominent man-made feature is the Interstate I-270 adjacent to the eastern boundary of the NIST campus.

2.1.1.2 Boundary and Emergency Zone Area

The NCNR facility is located on the 575-acre NIST campus in upper Montgomery County, approximately twenty miles (32 km) northwest of Washington, D.C. (Figure 2.1). NIST is a non-regulatory federal agency of the U.S. Commerce Department within the Technology Administration.

The NCNR facility, shown in Figures 2.3 and 2.4, is located in Building 235 on the west side of Center Drive in the southern part of the NIST campus. The portion of the facility directly under the Nuclear Regulatory Commission's (NRC's) license consists of licensed operations within the Confinement Building in C-Wing, the Guide Hall and its auxiliary building in G-Wing, the Ventilation Stack east of the Pump House (not shown), the Emergency Control Station (ECS) and the Fuel Storage Area (FSA) located in the A-Wing basement area, the HVAC and electrical service equipment in the B-Wing basement, and also the high-bay area located on the main level of the B-wing immediately adjacent to the east side of the Confinement Building. There are several boundaries surrounding the NBSR with varying levels of access control. The reactor operations boundary consists of the building's perimeter. This area also includes the Cold Neutron Guide Hall (G-Wing) and its auxiliary support building (compressor building for cold neutron cryostat in F-Wing and the experiment support space in J-Wing), the office areas and support spaces (E-Wing), and the radioactive waste storage west of B-Wing. The perimeter fence that surrounds Building 235 including the Cooling Tower located immediately to the west, defines the NBSR site boundary. Also, this boundary includes the abandoned old cooling tower, the chemical building, and the Building 418 (i.e., radioactive waste storage and shipment building in H-Wing). Within this area, unescorted access is limited to those individuals on the access list; all others require an escort.

The Emergency Preparedness Zone (EPZ) is a 437-yard (400-meter) circle centered on the Ventilation Stack. This boundary is located entirely on the NIST campus and access is limited to those individuals having business there. Accordingly, the general public does not have access to the EPZ. Finally, the NIST boundary fence surrounds the entire campus. NIST Security controls access to the campus that is limited to employees, contractors, and individuals who have business on site. The campus employs approximately 3,500 employees and contractors. It also includes the NIST Child Care Center. This center lies within the 0.6-mile (1-km) circle around the reactor, but outside of the EPZ.

NIST is located within the I-270 Technology Corridor, as shown in Figure 2.2. This corridor is sited strategically in the Center of Montgomery County and constitutes the County's primary focus of economic and transportation activity. The corridor straddles Interstate I-270 from the I-495 Washington Beltway to the south, to Clarksburg in the north. By 2015, 62 percent of the County's job growth and 51 percent of its household growth will occur within this area.

The NIST campus, shown in Figure 2.3, is located between several major roads. The northeast boundary abuts Interstate I-270, a major commuter artery connecting communities in northern Montgomery County, Frederick County, and other points north to the employment areas in the Washington, DC metropolitan area. West Diamond Avenue forms the northern boundary of NIST, with Quince Orchard Road as the northwest boundary and Muddy Branch Road as the southeast boundary.

The closest railway parallels the northeast boundary of the NIST campus at a distance of approximately 1.25 miles (2 km) from the reactor at its closest point. This line carries goods and commuters through the region. The nearest Maryland Rail Commuter (MARC) station on this line is the Gaithersburg Stop 1.75 miles (3 km) away, and the nearest Metro Station for the Washington DC area is the Shady Grove Stop at 3.0 miles (5 km). While there are a few recreational lakes within the area, the nearest waterway is the Potomac River that forms the border between Maryland and Virginia. Its nearest point is 6.4 miles (10 km) from the reactor.

The closest commercial airport to the reactor is Dulles International, in northern Virginia. It is 18 miles (29 km) from the reactor. The other two nearby commercial airports, Reagan National in Washington, D.C., and Baltimore-Washington International (BWI) near Baltimore, Maryland are 25 miles (40 km) and 29 miles (47 km), respectively, from the reactor. One general aviation airport, Montgomery Air Park, lies within the 5-mile (8-km) circle around the reactor, at 4.5 miles (7 km) distance. There are no known air routes in the airspace over the NCNR facility.

The NIST campus and the general area within the 5-mile (8-km) circle about the NBSR have a gently rolling topography without any geographic features that could affect the diffusion and dispersion of airborne effluents. There are a few buildings within the area over three floors high. The closest is the NIST Administration Building (Building 101) located approximately 0.75 mile

(1.25 km) to the north of the NBSR. Other tall structures include several buildings in the Rio complex at the interchange of I-270 and I-370; they are approximately 1.5 mile (2.4 km) to the east of the reactor.

2.1.2 Population Distribution

The city of Gaithersburg surrounds the NIST campus (Figure 2.2). All of the area within the 1.25-mile (2-km) circle about the reactor and most of that within the 2.5-mile (4-km) circle are located in Gaithersburg. All of the town of Washington Grove and much of the city of Rockville also lie within the 5-mile (8-km) circle. Other unincorporated areas situated within the 5-mile (8-km) circle include Germantown, Montgomery Village, Darnestown, and North Potomac. According to the 2000 Census, the Germantown area was the seventh most populous place in Maryland with 55,419 residents, Gaithersburg was the tenth most populous with 52,613, Rockville the fourteenth at 47,388, and Montgomery Village the twenty-first at 38,051. In terms of percentage growth of their populations between 1990 and 2000, this represents an increase of 34.7%, 33.1%, 5.7%, and 17.8%, respectively. Table 2.1 presents the 1990 and 2000 Census Data for these places.

Montgomery County is the most populous county in the State of Maryland. Much of this growth occurred in the southern half of the county. Table 2.2 gives the 1950-2000 Census Population and Percentage Change figures for the county. Table 2.3 lists the population forecasts covering 2005-2025 for Montgomery County as provided by the National Capital Park and Planning Commission – Montgomery County Planning Board. Table 2.4 lists the Montgomery County Planning Area Forecasts for numbers of people during the years 2005 to 2025.

The populations within the 1 km, 2 km, 4 km, 6 km, and 8 km radii about the reactor were estimated from the 2000 Census Population Counts by Jurisdiction for the voting districts located within these encircled areas. For districts that are sited in more than one of the zones about the reactor, the percentage area located within each ring was estimated, and the population distribution within any one district was assumed linear with area. Table 2.5 gives the current population for each of the circles about the reactor for the year 2000 based upon the voting district data. This table also gives estimates for the population in 2010 and in 2025. These values were derived by applying the percentage changes, as determined from the Montgomery County Planning Area Forecasts, listed in Table 2.4 to the 2000 Census Data.

Most of the immediate area surrounding the NBSR lies on the campus of NIST. This area has laboratories and office buildings but no residential buildings. There is no part-time, transient, or seasonal occupation of any of the campus buildings. The closest permanent residences are more than one-quarter of a mile (400 m) directly to the east and directly to the west of the reactor.

2.2 Nearby Industrial, Transportation, And Military Facilities

2.2.1 Locations and Routes

Interstate I-270 forms the northeast boundary of the NIST campus and is a major commuter artery for workers in the Washington, DC metropolitan area living in Montgomery County, Frederick County, and other northern points. It is also a major truck route serving the area.

Three arterial and collector roads abut the NIST campus (Figure 2.3). West Diamond Avenue, Quince Orchard Road, and Muddy Branch Road all serve the Gaithersburg area surrounding the NIST campus, providing truck routes serving the local economy.

A CSX rail line (CSX Transportation Corp.) parallels the northeast boundary of the NIST campus. At its closest point to the reactor, it is approximately 1.25 mile (2 km) away. It carries goods through the region. This line also serves the MARC commuter train service that is used by people in northern Montgomery County, Frederick County and other points north traveling to Washington, DC. Shady Grove, the northern most station for the MetroRail system is located approximately 3.0 mile (5 km) away from the reactor.

The I-270 Technology Corridor is a major research and development center in the State of Maryland; while some manufacturing does occur here, there are no significant manufacturing plants near the reactor, including no chemical plants or refineries. Mining and quarrying operations are limited to those associated with constructing new office buildings. A pipeline carrying natural gas lies two miles (3.2 km) to the south of the reactor, and a liquid petroleum/gas pipeline is located one mile (1.6 km) to the north.

Andrews Air Force Base, the nearest military base, is approximately 32.5 miles (52 km) away. Just to the south of the NIST campus, there is a retired Nike missile site, with its abandoned silos.

2.2.2 Air Traffic

The three commercial airports within the region are Dulles International in northern Virginia, Reagan National in Virginia just across the Potomac River from Washington, DC, and Baltimore-Washington International (BWI) near Baltimore. No associated normal air routes, holding patterns, or approach patterns are known to exist above the NIST campus. Montgomery Airpark is approximately 4.5 miles (7 km) to the northeast of the reactor. Its runway is oriented $140^{o}/320^{o}$ relative to magnetic north, that is, it is nearly perpendicular to the line between the reactor and the airfield. While the airfield can handle an aircraft as large as the Gulf Stream 4, the largest one typically using it is the Falcon 900. There are approximately 140,000 annual take-offs and landings at this field. The airport has no known normal approach patterns. The typical air traffic in the general area is local air traffic, news aircraft, and an occasional military helicopter traversing the area.

Search of NTSB database (covering 1962 to the present) revealed 6 fatal accidents and 18 non-fatal accidents in Gaithersburg area. One involved a balloon while the remainder involved either airplanes or helicopters within 2 miles (3 km) of the Airpark. The following is a breakdown of the reported accidents:

Fatal:
- 3 occurred at Montgomery County Airpark.
- 1 occurred 0.6 miles to the east of Montogomery County Airpark.
- 1 occurred 2.0 miles to the northeast of Montgomery County Airpark.
- 1 involved a balloon.

Non-fatal:
- 18 occurred at Montgomery County Airpark.

The Airpark is 4.5 miles (7 km) to the northeast of NBSR and therefore, small planes flying at this Airpark poses no accident-related problems to the safe operation of the reactor.

2.2.3 Analysis of Potential Accidents at Facilities

To summarize the discussions in Sections 2.2.1 and 2.2.2 of this report, the NBSR facility is located in an urban setting with certain normal risks associated with transporting goods and materials on the highways and on the rail lines. These risks are regulated by several agencies, primarily by the U.S. Department of Transportation, to ensure safety. Also, the NIST campus serves as a buffer separating these transportation routes from the reactor. The fact that the NIST campus acts as a buffer between the NBSR and the surrounding community also provides operators with greater control over the immediate area should there be an accident at the reactor.

2.3 Meteorology

2.3.1 General and Local Climate

The NIST campus is located on the Maryland Piedmont Plateau about 30 miles (48 km) southeast of the Blue Ridge Mountains that cut a narrow path across Maryland with Catoctin Mountain near the Pennsylvania end and South Mountain near the Virginia end. The Blue Ridge rises to about 1,900 feet (580 m) above sea level. The NBSR site elevation is 420 feet (128 m) above mean sea level in a region of slightly rolling terrain. Easterly winds cause an upslope effect from the Atlantic Ocean, 125 miles (200 km) east, and from the Chesapeake Bay, about 45 miles (72 km) east. Westerly winds create a slight foehn effect (i.e., warm dry winds blowing down the side of a mountain).

The NBSR location in the middle latitudes, where the general atmospheric flow is from west to east, favors a continental climate with four well-defined seasons. The dominant weather feature of the Bermuda High influences the summers in Maryland. This area of high pressure is usually positioned in the Atlantic just south east of the Maryland region, and helps keep the area hazy, hot and humid. Winters tend to be mild. Generally pleasant weather prevails in spring and autumn. Climatic trends over the period show tendency towards warmer and wetter weather. For the period 1963 through 2003, the average annual air temperature has increased at the rate of 0.4 ^{o}F (0.2 ^{o}C) per decade and annual precipitation has increased at the rate of 1.17 inches (3 cm) per decade.

Figure 2.1 shows the location of NIST campus and the three (3) locations used as representative climatic data sources. They include official National Weather Service (NWS) observing stations at Dulles International Airport (IAD) and Washington Reagan National Airport (DCA), and the NWS cooperative observing station (COOP) in Rockville, Maryland. IAD is located 18 miles (29 km) SW of NIST, DCA is located 25 miles (40 km) SSE of NIST, and the Rockville COOP is 6 miles (10 km) ESE of the NBSR. At the time of the original license submittal in 1961, climatic data from DCA was used because it was the only official NWS site with sufficient data. For this assessment, data from Dulles and the Rockville COOP site are included to provide a more comprehensive and representative conditions of the NBSR climate. Reagan National Airport is located on the Potomac River and within the urban heat island of Metropolitan Washington. As a result, average high and low temperatures at DCA are the highest for the area.

In 2002, NIST has installed an AWS Convergence Technologies WeatherNet Weather Station on the roof of the Confinement Building. Due to the limited amount of data collected, it was not used in this assessment. Future climate study submittals will include data from this system. The climatic data presented in this section were obtained from the National Climatic Data Center (NCDC) and the Office of Maryland State Climatologist, Department of Meteorology at the University of Maryland, College Park in the following units.

- Temperature — Degrees Fahrenheit
- Humidity — Percent
- Wind Speed — Miles per Hour in Table 2.12
Meters per Second in Wind Roses in Figure 2.6
- Wind Direction — Degrees
- Precipitation — Inches
- Snowfall — Inches

2.3.1.1 Temperature and Humidity

The coldest period for Rockville, when the low daily temperatures average 23.8 ^{o}F (-4.5 ^{o}C), occurs in January. The warmest period for Rockville, when high daily temperatures average 85 ^{o}F (29 ^{o}C), occurs in July. Monthly averages of mean, minimum, and maximum temperatures over a 30-year period for IAD, DCA, and Rockville are presented in Table 2.6.

Monthly averages of morning and afternoon relative humidity for IAD and DCA are given in Table 2.7. The Rockville COOP station does not collect humidity data. The annual mean relative humidity for the two airport locations is 80% in the morning and 55% during afternoon.

2.3.1.2 Precipitation – Rain, Snow, Sleet

Monthly averages of precipitation totals for IAD, DCA, and Rockville are given in Table 2.8. Precipitation is rather evenly distributed throughout the year with an average annual precipitation of 43 inches (109 cm) in Rockville.

The maximum daily precipitation by month for Rockville is presented in Table 2.9. Rainfall of 7.9 inches (20 cm) in a 24-hour period was recorded on June 22, 1972.

Monthly averages of snowfall totals for IAD, DCA, and Rockville are given in Table 2.10. The seasonal snowfall occurs from November to March and averages 19 inches (48 cm) in Rockville, but varies greatly from season to season. Snowfalls of several inches are typical and remain on the ground for several days before melting. The Maryland Average Annual Snowfall Map in Figure 2.5 illustrates the uniformity of snowfall across the Maryland and Virginia Piedmont where NBSR and the local monitoring stations are located.

The maximum 2-day snowfall totals for Rockville are tabulated in Table 2.11. Accumulations of over 20 inches (50 cm) from a single storm are rare and are usually the result of a Nor'easter.

2.3.1.3 Wind Speed and Direction

The regional characteristics of wind speed and direction are detailed in Table 2.12. Wind data is only available from the official National Weather Service (NWS) stations at IAD and DCA. The average annual wind speed for Dulles and National Airports is 7.4 mph (12 km/h) and 9.4 mph (15 km/hr), respectively. The windiest period is late winter and early spring. Winds are generally less during the night and early morning hours and increase to a high in the afternoon. Winds may reach 50 to 60 mph (80 to 96 km/h) or even higher during severe summer thunderstorms, tropical storms, and winter storms.

Seasonal wind variability is best described graphically with the projection known as the "Wind Rose." The monthly Wind Rose data from the official National Weather Service (NWS) station at IAD is displayed in Figure 2.6. The Wind Rose shows the frequency of winds blowing from a particular direction. As observed in the monthly Wind Roses in Figure 2.6, the prevailing winds are from the south except during the winter months when they are from the northwest.

2.3.1.4 Historical Seasonal and Annual Frequency of Severe Weather Phenomena

<u>Hurricane Events</u>

Officially, Maryland has only experienced one hurricane (FRAN in 1996) but has been affected infrequently by their remnants and occasional tropical storms between January 1950 and December 2003. Typical damage includes downed trees and power lines, coastal flooding, and stream flooding. Therefore, the hurricane effect on the NBSR facility is considered to be minimal.

Tornado Events

For property damage from tornadoes, Maryland ranks 36th in the Nation. Between 1950 and 1994, Maryland has averaged only $2.33M per year in damages while the national average (all 50 states) averaged $1.103B annually. Maryland has experienced 275 tornados between 1952 and 2003. Montgomery County, where NBSR is located, has experienced only 11 tornadoes and 3 funnel clouds over the same period with an annual frequency of <0.22 events per year. The tornadoes in Montgomery County were rated as F0 (40-72 mph) or F1 (73-112 mph) and represent the lowest categories on the Fujita Tornado Scale. Therefore, the tornado effect on the NBSR facility is considered to be minimal. However, the Confinement Building was conservatively designed and built for a wind load of 100 mph (160 km/h).

Hail Events

Maryland has experienced 540 hail events between 1956 and 2003. Montgomery County, where NBSR is located, has experienced 80 hail events between 1965 through 2003 with an annual frequency of 2.1 events per year. The hail events have minimal effect on the safe operation of the NBSR.

Lightning Events

Maryland has experienced 216 lightning events between 1993 and 2003. Montgomery County, where NBSR is located, has experienced 20 lightning events that resulted in property damage during the same period with an annual frequency of 1.8 events per year. The lightning events have minimal effect on the safe operation of the NBSR.

Thunderstorm and High Wind Events

Maryland has experienced 1981 thunderstorm and high wind events between 1965 and 2003. Montgomery County, where NBSR is located, has experienced 42 thunderstorm and high wind events during the same period with an annual frequency of 1.1 events per year. These events have minimal effect on the safe operation of the NBSR.

Winter Weather Events

Maryland has experienced 336 winter weather events between 1993 and 2003. Montgomery County, where NBSR is located, has experienced 47 winter weather events during the same period. Winter weather events include some or all of snow, freezing rain, and ice. When pure snow events are subtracted from the database, Montgomery County experienced 25 events that included freezing rain and snow or ice and snow, with an annual frequency of 2.3 events per year. These events have minimal effect on the safe operation of the NBSR. The Confinement Building was designed and built for a snow load of 25 psf (1,200 N/m^2).

2.3.1.5 100-Year Return Wind Speed

Multi-return period wind speeds are generally calculated on a 50-year return period. The most recent American Society of Civil Engineers (ASCE) standard, ASCE 7-98, states that the maximum 50-year return period 3-second wind speed gust for Montgomery Count is 90 mph (144 km/h). This climate assessment requires a more complete estimation, namely the 100-year return wind speed so additional calculations and estimations are made. Figure 2.7 illustrates the ASCE peak gust 50-year return wind zones for the US.

Conversion of the 50-year peak return wind to the 100-year peak return wind as required by NRC is made using several published studies and is given in Table 2.13. Based on the results of these calculations, estimated 100-year return peak wind for Montgomery County is 102.5 mph. This estimated value is within the uncertainty limits for the 100 mph (160 km/h) wind load design for the Confinement Building.

2.3.1.6 100-Year Return Period Snowpack

Ground snow loads are generally calculated on a 50-year return period. The most recent American Society of Civil Engineers (ASCE) standard, ASCE 7-98, states that the ground snow load for Montgomery County is 25 psf. This assessment of climate requires a more complete estimation, namely the weight of the 100-year return period snowpack and the 48-hour probable maximum precipitation at the site. First, the weight of the 100-year snow pack is determined. Table 2.14 shows the 1-day, 2-day, and 3-day 100-year return estimate snowfalls for IAD, DCA, and Rockville sites.

It must be noted that snowfall and snow pack are not the same thing. Snowfall is the amount of snow that accumulates during an event and is measured in inches. Snowpack is the weight of the snow as it lies on the ground. As shown in Table 2.14(a), the 2-day total 100-year snowfall data for Rockville is 27 inches (68 cm). To convert this snow accumulation to snowpack, one must make an estimation of the snow water equivalent (SWE) and then convert SWE to snow load. SWE is the amount of water contained within the snow and is related to the snow depth and its density.

Snow density varies significantly depending on air temperature and wind velocity. According to the American Meteorological Society, snow density can range from 0.07 to 0.15 (Huschke, 1989).

Applying the known 2-day 100-year return snowfall and typical snow densities to the formulas below, we can calculate the snow load in pounds per square foot.

SWE = Snow Depth (in inches) x Snow Density Percentage

Snow Load in psf = SWE x 5.2

As shown in Table 2.15, the worst-case snow load occurs when the snow is very dense. Based on the results of these calculations, we estimate the 100-year return period snowpack for Montgomery County is 21.1 psf, less than the published ASCE 7-95 50-year return estimate of 25 psf.

NRC calculations of snow load must also account for the "rain-on-snow" surcharge that occurs when a significant rain event occurs on the existing snowpack. The maximum 24-hour precipitation that has occurred during the winter months in Rockville is shown in the Table 2.16.

For the months of December through March, the average maximum daily precipitation is 2.34 inches (6 cm) SWE. Note that the table of precipitation values includes the SWE of the accumulation of rain, snow, and sleet and is therefore overestimates what just fell as rain. To compensate for this, we have averaged the 4 monthly maximum precipitations and make the estimate that 50% of the precipitation is in the form of snow and 50% is in the form of rain. Because we have already calculated the 100-year snow load, we therefore consider the rain load to be 2.34 / 2 = 1.17 inches (3 cm) SWE. Converting the SWE to water load uses the same formula as used in the snow load calculations above.

$$\begin{aligned}\text{Water Load} &= \text{SWE} * 5.2\\ &= 1.17 \text{ inches} * 5.2\\ &= 6.1 \text{ psf}\end{aligned}$$

Based on the results of these calculations, it is estimated that the worst-case 100-year return period ground snow load with "rain-on-snow" surcharge for Montgomery County is 21.1 psf + 6.1 psf = 27.2 psf.

Calculation of roof load for a flat roofed building depends on several factors as described below. ASCE 7-1998 provides the following formula to convert ground snow load to roof snow load:

$$p_f = 0.7\, C_e\, C_t\, I\, p_g$$

where:
C_e = Exposure Factor
C_t = Thermal Factor
I = Importance Factor
p_g = Ground Snow Load

C_e = Exposure Factor = 1.0

Rational – based on "partially exposed terrain with urban and suburban areas".

C_t = Thermal Factor = 1.0

Rational - based on "All structures except structures kept just above freezing, unheated structures, and continuously heated greenhouses…"

I = Importance Factor = 1.2

Rationale - based on Category III, "Structures containing highly toxic materials… where the quantity of the material exceeds the exempt."

p_g = Ground Snow Load = 27.2 psf

Rationale - From calculations above.

$$p_f = 0.7*1.0*1.0*1.2*27.2 = 22.8 \text{ psf}$$

Based on the results of these calculations, it is estimated that the NIST Confinement Building roof snow load with 100-year return period rain-on-snow surcharge is 22.8 psf. This is based on a worst-case scenario. The snow load used in the original design was 25 psf, which is greater than this estimated value.

2.3.2 Site Meteorology

2.3.2.1 Regional Air Quality

The Baltimore / Washington region experiences some of the most severe ozone episodes in the northeastern United States [http://www.mwcog.org/environment/air/]. The worst episodes are usually the result of ozone build-up over several days. Though many factors contribute to ozone formation, several meteorological elements can indicate which days will be the highest. The ozone season occurs typically from May through September only. Some typical weather patterns and indicators include:

- Dominating high pressure off the coast or directly overhead.
- Clear or mostly clear skies.
- Wind speeds that are either calm or light.
- Wind direction that is either variable, or southwest (along the Baltimore / Washington corridor).
- Winds aloft are light.
- The best direction for winds aloft is from the northwest.
- This increases ozone through transport from the mid-west.
- Low chance of thunderstorms or thunderstorms occurring late in the day.
- A breeze off the Chesapeake Bay can form a barrier to ozone and cause it to "pool" when the winds are from the west or southwest.

On November 13, 2002, EPA proposed to find that the Washington serious ozone nonattainment area did not attain the 1-hour ozone national ambient air quality standard (NAAQS) by November 15, 1999. The proposed finding was based upon ambient air quality data from the years 1997, 1998, 1999. These data showed that the 1-hour ozone NAAQS of 0.12 parts per million (ppm) had been exceeded on an average of more than one day per year over this three-year period and that the area did not qualify for an attainment date extension. EPA also proposed that the appropriate reclassification of the area was to severe ozone nonattainment. For the purposes of this final rule, the Washington ozone nonattainment area (the Washington area) consists of: the District of Columbia; Calvert, Charles, Frederick, and Montgomery, Prince Georges counties in Maryland; and, the counties of Arlington, Fairfax, Loudoun, Prince William and Stafford and the cities of Alexandria, Fairfax, Falls Church, Manassas, and Manassas Park in Virginia.

The Washington Metropolitan Region exceedances of the 1-hour ozone standard and 8-hour ozone standard are shown in Figure 2.8.

2.3.2.2 Atmospheric Diffusion

Meteorological conditions govern the transport and dispersion of contaminants and can affect the amount of contaminant that becomes airborne. In dispersion modeling, wind speed is used in determining: (1) plume rise; (2) plume dilution; and (3) mass transfer rate into the atmosphere (used mostly in fugitive dust and evaporation rate models). Wind direction is used to approximate the direction of transport of the plume. Most wind data are collected near ground level (the standard height for wind measurement is 10 m), as collected at DCA and IAD.

Dispersion models currently use stability categories as indicators of atmospheric turbulence. Based on the work of Pasquill (1962), six stability categories have been defined: Category A representing extremely unstable conditions thru Category F representing very stable conditions. The amount of turbulence in the atmosphere has a major impact on the rise of stack gas plumes, and upon subsequent plume dispersion by diffusion. The more unstable the atmosphere becomes, the greater the turbulence, and therefore the greater the diffusion. Other factors used in dispersion modeling include:

- Ambient temperature to calculate the amount of rise of a buoyant plume and to calculate evaporation rates,
- Relative humidity to determine the amount of energy available in the atmosphere for plume mixing within the atmosphere, and
- Atmospheric pressure data to calculate gas and liquid release rates from storage and process vessels, and from pipes.

For the purpose of dispersion modeling, sites are classified as being in a predominantly "urban" or "rural" area. This determination is typically based on the land use in the area surrounding the site to be modeled. The general effect of an *urban* area is to create enough additional turbulence, due to the buildings and urban "heat island" effects, which enhance plume dispersion. Sources located in an area classified as urban should be modeled using urban dispersion coefficients, while sources located in an area classified as rural should be modeled using rural dispersion coefficients.

2.3.2.3 Onsite Meteorological Monitoring Program

NIST has installed an AWS Convergence Technologies WeatherNet Weather Station on the roof of the Confinement Building. Due to the limited amount of data collected, it was not used in this assessment. A photographic view of the new WeatherNet Weather Station installed on the southeast corner of the building is shown in Figure 2.9.

Data from sensors measuring the air temperature, relative humidity, barometric pressure, wind speed, wind direction, and rain amount are collected by the system as shown in Table 2.17. Locally, the data is archived and also sent via the WWW weather network to AWS. A sample of the formatted hourly data is shown below. As shown in Table 2.17, the data is clearly date and time tagged for easy reference. If necessary, this meteorological data could be used in the dispersion model during a radiological release from the NBSR to determine the direction of this release and the nearby affected area.

2.4 Hydrology

This section describes the hydrology and hydrogeology of the site and the region surrounding NBSR. The effects of surface water and groundwater on the site, and the site's effect on surface-water bodies and groundwater beneath the site are discussed.

Access to the site is through secured gates off West Diamond Avenue, Quince Orchard Road, or Muddy Branch Road. The topography in the vicinity of the reactor, as shown in Figure 2.10, is undulating and the relief is moderate (URS, 2003). The Confinement Building and cooling towers are at an elevation of approximately 420 feet (128 meters). Just north of the NBSR, on the NIST campus, the ground elevation exceeds 460 feet (140 meters). The nearest naturally occurring surface water that is mapped on a U.S. Geological Survey (USGS) topographic map is an unnamed tributary (called Tributary A in this SAR) to Muddy Branch, approximately 1,000 feet (305 meters) west-northwest of the site. Muddy Branch itself is a tributary of the Potomac River; the confluence is located approximately 6.25 miles (10 kilometers) southwest of the site. The elevation of this surface-water body at the nearest point to the Confinement Building is approximately 380 feet (116 meters) (USGS, 1979).

2.4.1 Hydrologic Description

2.4.1.1 Regional Hydrology

The NBSR site is located in the town of Gaithersburg, Montgomery County, Maryland. Montgomery County contains portions of four major watersheds: the Monocacy watershed in the northwestern portion of the county; the Middle Potomac-Catoctin watershed in the western half county; the Patuxent watershed in the northeastern portion; and, the Middle Potomac-Anacostia-Occoquan watershed in the eastern and southern portion of the county. The NBSR site is located within the Seneca Creek/Anacostia River sub-watershed of the Middle Potomac-Catoctin watershed of the Potomac River (EPA, 2003). The major rivers in the watersheds generally flow in a southerly direction, and eventually drain into the Chesapeake Bay.

Area utility companies withdraw surface water from rivers within the region and distribute it to municipalities. Three major Washington metropolitan agencies draw water from the Potomac

River: the Fairfax County Water Authority (FCWA) in northern Virginia; the Washington Suburban Sanitary Commission (WSSC) in Maryland; and, the Washington Aqueduct Division (WAD) of the U.S. Army Corps of Engineers (USACE) in Washington, D.C. (CO-OP, 2003).

Section 2.4.5 discusses groundwater withdrawal and use within the area.

2.4.1.2 Site Hydrology

Surface-water drainage at the site flows southwest to the Muddy Branch stream and its tributaries. Muddy Branch discharges to the Potomac River about 2 river miles (3 river kilometers) upstream from the WSSC water filtration plant, and approximately 5.5 river miles (8.9 river kilometers) upstream of the uppermost intake for the District of Columbia's water supply. The site is more than 10 river miles (16 river kilometers) along Muddy Branch from its confluence with the Potomac River.

The nearest naturally occurring surface water body to the site is Tributary A of Muddy Branch, approximately 1,000 feet (305 meters) to the west-northwest of the NBSR. Clebsch (1962) also identified this stream as the closest surface water to the site. This tributary flows through an on-site storm water retention pond on its way to Lake Varuna, an artificial surface water impoundment, approximately 2,000 feet (610 meters) from the site, before entering Muddy Branch, approximately 2,000 feet (610 meters) south of Lake Varuna. At its nearest point to the site, Muddy Branch is about 2,000 feet (610 meters) south of the NBSR. There is another unnamed tributary (called Tributary B in this SAR) to Muddy Branch some 1,900 feet (580 meters) southeast of the site. A topographic rise separates this tributary from the reactor site. Figure 2.10 depicts the features of the surface water drainage near the site.

Based on information from the well records of Montgomery County Health Department, there is no municipal or private use of Muddy Branch for drinking water. The closest downstream user of surface water for drinking purposes is the WSSC filtration plant on the Potomac River, at least 12 river miles (19 river kilometers) from the site. There is no known use of Muddy Branch or other surface waters within the county for irrigation.

While irrigation farming does occur in this region, well water is the primary source of its water. In Montgomery County, there are no irrigated farms. Subsection 2.4.5.1 discusses groundwater and the groundwater users near the site.

2.4.2 Floods

2.4.2.1 Flood History

The nearest mapped flood zone to the reactor, the Muddy Branch floodplain, is located approximately 2,000 feet (610 meters) south of the site (FEMA, 1982), as shown in Figure 2.11. The highest 100-year flood elevation for this floodplain is 376 feet (115 meters) at the confluence of the Tributary B, approximately 1,900 feet (580 meters) southeast of the site. A topographical rise separates the site from the 100-year flood zone for the Muddy Branch Tributary B. The 100-year flood elevation of the nearest downstream Muddy Branch flood zone is 342 to 344 feet (104 to 105 meters), located 2,000 feet (610 meters) south of the site.

The Federal Emergency Management Agency's (FEMA's) floodplain mapping and the topography of the site show that the site lies outside the 100-year and 500-year flood zones of the nearest surface-water bodies. There is no documented history of flooding occurring at the site either before or after the NBSR was constructed.

2.4.2.2 Flood Design Considerations

The 100-year flood event for Muddy Branch and its tributaries is considered the controlling event for determining appropriate measures for flood protection. All the existing safety-related structures for the site are protected against it. Since the Confinement Building and support structures are outside the 100-year and 500-year flood zones of these water bodies, there are no additional flood-design considerations.

2.4.2.3 Effects of Local Intense Precipitation

Since the location of the Confinement Building and support structures is outside the 100-year flood zone for nearby water bodies, no effects from local intense precipitation are anticipated. In addition, there are sufficient surface-water drainage systems at the site to convey away the precipitation from local, intense events.

2.4.2.4 Probable Maximum Flood on Streams and Rivers

The Probable Maximum Flood (PMF) was not determined, but no effects are anticipated based on topography and the existing maps of the floodplain.

2.4.2.5 Probable Maximum Surge and Seiche Flooding

Since there are no large bodies of water near the site where significant storm surges and seiche can form, there are no Probable Maximum Surge and Seiche Flooding considerations for this site.

2.4.2.6 Probable Maximum Tsunami Flooding

Since the site is not adjacent to a coastal area, it will not suffer the effects of tsunami flooding, and so, there are no Probable Maximum Tsunami Flooding considerations.

2.4.2.7 Potential Dam Failures, Seismically Induced

Since there are no existing or proposed dams on Muddy Branch Creek or its tributaries upstream of the site, there are no Seismically Induced Potential Dam Failures considerations for this site (Hancock, 2003).

2.4.2.8 Flooding Protection Requirements

The Confinement Building and support structures are located outside the 100-year flood zone and there are no water bodies within 1,000 feet (305 meters) distance, or 40 feet (12 meters) in elevation to the site; hence, there are no requirements for flooding protection.

2.4.3 Process Water

The NBSR core is cooled by heavy water circulating in the primary coolant system, a closed and sealed system. Light water in the secondary coolant system transfers heat from the water in the primary coolant system. Evaporation removes the heat from the secondary coolant system water as the water flows through the cooling towers. Blow down from the cooling towers is discharged into the sanitary sewer system. Process water is not discharged to surface water or groundwater. Water lost through evaporation from the secondary coolant system is replenished by the WSSC via municipal-water supply lines. Neither surface water nor groundwater is used as process water in either the primary or secondary coolant systems.

<u>Cooling Water Canals and Reservoirs</u>

Cooling water canals and reservoirs are not utilized at this site nor are they anticipated for future use.

<u>Channel Diversions</u>

Since the site does not rely on surface water for cooling or processing, channel diversions for surface water are not applicable.

<u>Low Water Considerations</u>

Since the site does not rely on surface water for cooling or processing, low water considerations for surface water are not applicable.

<u>Ice Effects</u>

The site is located outside the 100-year flood zone and so it does not rely on surface water for cooling or processing, no impacts are anticipated to the reactor or process water systems from ice effects.

2.4.4 Dispersion, Dilution, and Travel Times of Accidental Releases of Liquid Effluents in Surface Water

The effects of accidental releases of liquid effluents in surface waters are evaluated for components containing liquid radioactive materials. Liquid effluents from the Confinement Building are collected in the Liquid Waste System tanks located in underground vaults. The potential for discharges to surface water or groundwater is considered to be low. The nearest use of surface water is the WSSC's intake on the Potomac River. This intake structure is sited more than 12 river miles (19 river kilometers) downstream from the confluence of the Tributary A (closest to the reactor) with Muddy Branch Creek. According to (NBSR 9B):

> "…a liquid spilled or leaked at the site that entered the ground probably would move in a southwesterly direction toward the nearby stream at a velocity on the order of 1 foot per day [0.3 meters per day] or less. The risk to nearby groundwater supplies, as currently developed, is small to negligible. Under certain conditions, such as frozen ground, a liquid spill could flow overland to the tributaries to the Potomac River. Depending on stream conditions, total time of travel would range from a few hours to nearly a day."

The conditions of the surface soil at the site, the streams, and the usage of groundwater have not changed substantially since this last licensing review; therefore, the above statements still are valid.

There is minimal potential for discharges of contaminated groundwater to surface waters from accidental releases at the site. Section 2.4.5.1.2 has discussion on the potential impacts on groundwater.

From 1963 through 1983 water samples were collected monthly from five surface streams and one groundwater well near the NBSR. The samples were analyzed for gross gamma and tritium content. No significant changes in activity levels present in the soil, neither grass and neither water samples collected nor the external radiation background at the site have been observed since the start of the environmental monitoring program. From 1983 through 2002, in its operational reports to the NRC, NIST has continued the environmental sampling of water, vegetation and/or soil, as previously described and have continued to show no significant changes.

Routine environmental sampling of grass, soil, and water in streams and ponds continues. Samples are collected and analyzed at least quarterly from a minimum of four locations for each sample type. Soil samples are collected during the non-growing season (October through March) and grass samples are collected during the normal growing season (April through September). Water samples are collected all year dependent on availability. The collected samples are analyzed for possible neutron activation nuclides and fission product nuclides. Water samples are also assayed for tritium. Results are reported in the NBSR Annual Report to the NRC.

2.4.5 Groundwater

Montgomery County lies within the Piedmont physiographic province. Crystalline rocks of Precambrian to early Paleozoic age that are used extensively for groundwater supply underlie most of the County. The occurrence of groundwater in the Piedmont rocks largely depends on the character, aerial extent, and structure of these formations (Martin, 1954). The following subsections discuss the groundwater systems and properties of the rock formations near the site. Section 2.7 contains a glossary of geologic terms used in these sections.

2.4.5.1 Hydrogeologic Systems and Groundwater Use

2.4.5.1.1 Regional Hydrogeologic Systems

The site lies within the Lower Piedmont physiographic province that is composed of metamorphic and igneous rocks. A mantle of saprolite (residual soil formed by weathering of bedrock in place) covers most of these rocks, and rock outcrops constitute only a minor portion of the land surface. The exposed rocks consist predominantly of quartz-chlorite schist, quartz-muscovite schist, and quartz-feldspar-mica gneiss. The texture of the saprolite is silty or sandy, with locally significant amounts of clay and residual fragments of quartz, and weathered but more resistant rocks.

Groundwater in the Piedmont occurs almost exclusively in the crystalline rocks and saprolite under unconfined (groundwater table) conditions. Recharge to the groundwater table is derived from direct infiltration of precipitation and runoff. Average annual precipitation in the Maryland Piedmont is approximately 40 inches (101 cm), of which approximately 8 inches (20 cm) infiltrate to the groundwater table. In general, groundwater moves down gradient from topographic highs and eventually discharges to local streams, seeps, and lakes.

The saprolite, which typically mantles the crystalline rocks, is primarily silty or sandy; therefore, its porosity (defined as the percent of the total volume occupied by voids) is intergranular (or primary). The primary porosity of the unaltered, unfractured crystalline rock is usually very low, seldom exceeding 1%. Jointing or faulting of the unaltered rocks causes fractures in which the groundwater predominantly accumulates (secondary porosity). Typically, the size and frequency of fractures decreases with depth below the ground's surface. Therefore, the greatest amount of groundwater stored in the rocks of the Maryland Piedmont is in the saprolite and the upper hundred feet (few hundred meters) of the bedrock. The more porous saprolite serves as a storage reservoir, feeding water slowly to the fracture systems in the crystalline rock (NBS, 1981).

2.4.5.1.2 Site Hydrogeologic Systems

There are three sources of recent information on groundwater in the vicinity of the reactor. The first is from work carried out in summer 1994 at the Advanced Technology Laboratories (ATL) site (later changed to the Advanced Measurements Laboratory (AML)), located approximately

1,900 feet (580 meters) north-northeast of the Confinement Building. The second is from work undertaken in April 2000 before the new cooling towers were constructed. The third is from work done in December 1986 before building the Cold Neutron Guide Hall facility adjacent to the NBSR. The ground elevation at the AML site varies from 452.6 feet (138 meters) on the northeastern side, to 426.4 feet (130 meters) along the southwestern side of the site (Schnabel Engineering, 1996). The ground elevations at the new cooling towers and the Cold Neutron Guide Hall facility are about the same as the Confinement Building.

<u>Water Levels and Groundwater Flow</u>

Sixty-one soil test borings were drilled in July-August 1994 at the AML; previous borings were drilled there in 1993. Water-level readings taken in soil borings during this drilling and up to four days afterwards encountered groundwater between elevations 408.7 feet (124.6 meters) and 430.6 feet (131.3 meters), which was at depths of between 7.8 feet (2.4 meters) and 27.6 feet (8.4 meters) beneath the surface. Groundwater levels taken from five temporary wells at the AML recorded groundwater between elevations 409.8 feet to 427.2 feet (124.9 meters to 130.2 meters), which was 18.4 feet (5.6 meters) to 24.6 feet (7.5 meters) below ground surface. The groundwater contour map developed from these well readings indicates groundwater flow is generally in a southwest direction, the same as the slope of the ground surface (Figure 2.12). The water table aquifer is present within residual soils and the saprolite at the AML. The water table is maintained by infiltration from precipitation, and its elevation can vary seasonally (Schnabel Engineering, 1996).

In April 2000, two soil borings were drilled at the location of the present cooling towers. Groundwater was encountered at a depth of 22 feet (6.7 meters) three days after completing the borings. No additional tests were conducted or observations recorded for groundwater at this site.

Two soil borings were drilled at the location of the Cold Neutron Guide Hall facility in December 1986. Groundwater was reported at a depth of 14 to 26 feet (4.3 to 7.9 meters), or an elevation of 390 to 405 feet (119 to 123 meters) (Burns and Roe, 1987). There have been no additional tests or observations for groundwater at this site.

Water levels were measured at the Site on January 20, 1961 from foundation borings near the Confinement Building, as shown in Figure 2.13. The depth to water ranged from 1.67 feet (0.51 meters) in Hole 2-A, to 23.0 feet (7 meters) in Hole 3-A. The elevation of the water table ranged from 403.6 feet (123.0 meters) in Hole 2-A, to 411.4 feet (125.4 meters) in Hole 8-A. All the water levels were measured in sub-soil or decomposed rock. Groundwater contour maps developed from core holes drilled at the reactor site in January 1961 indicate a groundwater flow generally to the southwest, with northwest and south arms extending radially outward (Figure 2.13). The ground at the reactor site slopes generally toward the southwest (NBS, 1981).

The pronounced difference between the north westward gradient and the south westward gradient appears to be related to structural features of the rock because the schistosity has a northeasterly trend in rock outcrops west and southwest of the reactor site (NBS, 1981). The NBS stated that groundwater flow parallel to the schistosity would meet with less resistance than flow perpendicular to the schistosity, furthermore adding, “Thus it can be inferred with relative confidence that beneath the Confinement Building the groundwater flows in a generally southwestward direction.” Clebsch (1962) also suggests that groundwater flow across the schistosity of the bedrock would be unlikely.

Ultimately, groundwater flows to surface water bodies northwest, west, and southwest of the site because they are the principle drainage for the reactor site’s area. Although the tributary west and northwest of the reactor site is 500 to 600 feet (152 to 183 meters) nearer than the one to the southwest, it seems unlikely that the path of easiest movement of groundwater would be directly across the schistosity; therefore, groundwater probably moves preferentially south-westwardly from the site.

<u>Permeability of Subsurface Geologic Material</u>

The direction and rate of groundwater movement primarily depends on local topography and the porosity and permeability of the subsurface materials, as shown in Figure 2.10. Information on the permeability of the subsurface materials was obtained from the landfill site selection study made by Dames & Moore Montgomery County (Dames & Moore, 1978), and the AML site study (Schnabel Engineering, 1996).

Laboratory permeability tests performed by Dames & Moore on samples of soil from Zones A and B (zones of soil grading into bedrock, each exhibiting similar characteristics) indicate that the soil in Zone A may be slightly more permeable than that in Zone B (Table 2.4-1). NIST (NBS, 1981) has a detailed description of these zones. Similar soil zones at the site are described below in Section 2.5.8.3. Table 2.18 lists the results of laboratory tests documented in the Natural Resources Conservation Service report (USDA, 1995) and in (Otton, 1959). The Dames & Moore values from site E-57 (located 4 miles (6 kilometers) northeast of the Site) and site S-135/271 (located 9 miles (14 kilometers) south of the Site) seem to be the most representative of conditions at the NBS site for several reasons:

1. The results are based on a large number of tests at different depths and locations.
2. The two Dames & Moore sites are relatively near and geologically similar to the NBS site, while the permeability values given by Otton are for soil samples in Baltimore County (developed on rocks formerly mapped as the Wissahickon Formation (URS, 2003)). The value given by the Soil Conservation Service is a general one for the Glenelg silt loam, whenever it occurs in Montgomery County.
3. The Dames & Moore results are the most recent ones.

The Dames & Moore results are the only available data for Zones B, C, and D. The maximum average permeability value is 1.22×10^{-3} inch/sec (3.2×10^{-3} cm/sec) (Table 2.18). This value represents a conservative one (i.e., high permeability) for groundwater movement, and was used in computing the rate of groundwater movement at the Site. The permeability values for the soil, saprolite, and bedrock all fall within the low to medium permeability range as established by Terzaghi and Peck (1967).

Recent work at the AML site (Schnabel Engineering, 1996) complements Dames & Moore's study undertaken as part of the Montgomery County's landfill site selection and evaluation. Both studies suggest permeability values for surficial soils (Zone A) similar to those reported by Clebsch (1962).

Since the soil derives its structure from the in-place weathering of the rock, it might be expected to have a higher permeability parallel to the foliation and former bedding planes, and also that groundwater would flow preferentially along the planes of foliation. However, based on four different sites and approximately 2,200 acres mapped with groundwater table contours in Montgomery County, Dames and Moore (1978) concluded that the elevation of the groundwater table was controlled by topography rather than by geologic structure. This implies that the permeability of the soil and rock does not vary with direction.

A constant head test in MW-15 well at the AML site yielded a saturated hydraulic conductivity of 4.6×10^{-4} cm/sec. The hydraulic gradient (i) was calculated to be 0.02 to 0.4 from the groundwater contour map, and the permeability (k) was obtained by dividing hydraulic conductivity by porosity (assuming a porosity 0.2) (Schnabel Engineering, 1996). Therefore, permeability was determined to be 0.9×10^{-3} inch/sec (2.3×10^{-3} cm/sec).

<u>Groundwater Velocity</u>

The groundwater velocity can be computed from the hydraulic gradient and the permeability. The hydraulic gradient at the Site (measured from the groundwater table contours on Figure 2.13) varies from 6 feet/170 feet (1.8 meters/52 meters) or 0.035 to the northwest, to 4 feet/240 feet (1.2 meters/73 meters) or 0.017 to the south. All measurements on the contour maps obtained from other reports are in feet and were not converted to meters for this section.

Using the maximum average permeability value from Dames & Moore's field permeability tests on Sites E-57 and S-135/271 (3.2×10^{-3} cm/sec, see Table 2.18), the groundwater velocity (v) at the Site can be calculated from the equation below:

$$
\begin{aligned}
v &= (k) \times (i) \\
&= (3.2 \times 10^{-3} \text{ cm/sec}) (0.035 \text{ to } 0.017) \\
&= 1.1 \times 10^{-4} \text{ to } 5.3 \times 10^{-5} \text{ cm/sec } (0.3 \text{ to } 0.14 \text{ feet/day})
\end{aligned}
$$

This correlates well with Otton's (1959) estimate of 0.1 to 1.0 feet per day (3.6×10^{-5} to 3.6×10^{-4} cm/sec) and the study done at the AML site (Schnabel Engineering, 1996) (see Table 2.19 for a comparison of these different reports).

Based on the Dames & Moore work, topography rather than geologic structure appears to control groundwater movement. The estimated rate of movement is expected to be about 0.3 foot/day

(9.14 cm/day) using the maximum hydraulic gradient at the NBSR site measured from the groundwater table contours on Figure 2.13 and the maximum average permeability values from the Dames & Moore's field permeability tests. Groundwater movement is greater at the AML site due to a steeper groundwater gradient there.

Transport of Radionuclides

The cation-exchange capacity of the soil is a particularly important characteristic indicating the degree to which radionuclides will become adsorbed on, or fixed in, the solid phase of a soil-water system (Clebsch, 1962). Cation-exchange capacities have not been determined for samples from the NIST site, but determinations on samples are available from the same geologic unit (soil and weathered rock of the rock unit that was mapped as the Wissahickon Formation—(URS, 2003)) from two Dames & Moore sites (Dames & Moore, 1978) and from the site of the National Naval Medical Center Reactor (Clebsch, 1962); they should be reasonably representative of conditions at the NIST site. Table 2.20 lists their values. The Dames & Moore values differ from those obtained at the National Naval Medical Center site. The former are recommended for use because they were obtained from a larger number of tests, the results are more consistent with each other than those obtained for the Naval Medical Center, and they are more conservative, i.e., the cation-exchange values are lower.

Additional data on cation-exchange capacities from the Dames & Moore study indicate that the values at the NBSR site are lower than those referred to in Clebsch's (1962) report. Capacities of 2.4 meq/100 grams for Zone A, and 3.6 meq/100 grams for Zone B are considered reasonable based on Dames & Moore's study.

Because the movement of groundwater appears to be slow and groundwater flow through the site can be monitored for anomalous radioactivity then, should an accident occur releasing contaminants, corrective measures should be able to minimize any deleterious effects of the spill.

Groundwater Monitoring Program

A routine groundwater sampling and analysis program, described in NBS (1966), has been in effect since November 1963. Results are reported in the NBSR operational reports to the NRC.

2.4.5.2 Sources

Local precipitation, averaging about 40 inches (101 cm) per year, is the source of the groundwater in the vicinity of the reactor site, and elsewhere in the Maryland Piedmont, of which approximately 8 inches (20 cm) infiltrate to the groundwater table (NBS, 1981). This precipitation maintains a zone of saturation in the sub-soil that neither runs off directly, nor evaporates. Generally, the upper surface of the zone of saturation, or water table, is a subdued replica of the topography of the land surface. Hydraulic gradients exist in this zone, which result in the general, but variable, movement of groundwater to streams. Section 2.4.5.1.2, above, discussed this rate of movement.

2.4.5.2.1 Present and Future Groundwater Use

Regional Groundwater Use

Groundwater in the Maryland Piedmont is used for farm, domestic, commercial, institutional, industrial, and public supplies. Most rural homes and farms in Montgomery County rely on individual wells. The mean yield of the wells used for domestic supplies is about 10 gallons per minute (38 liters per minute). Most of them are less than 300 feet (91 meters) deep; however, several have been drilled to depths greater than 500 feet (152 meters) (NBS, 1981).

Local Groundwater Use

Based on a database search of wells currently permitted by Montgomery County, there is only one potable well within a one-mile radius of the Site, and hence, no major users of groundwater within that radius. As WSSC supplies more water for this area and development continues, there are no anticipated future uses of groundwater within a one-mile (1.6-km) radius of the Site.

Both domestic and farm supplies constituted the major use of groundwater within a 1-mile (1.6-km) radius of the reactor site at the time of the license renewal for the NBSR in 1983. Five wells, located southwest of the center of Gaithersburg, were public-supply wells owned by the WSSC; they formerly supplied water to the community but are no longer used (NRC, 1983). Potable water for the community currently comes from the Potomac River (CO-OP, 2003).

E.G. Otton (U.S. Geological Survey) surveyed existing wells in the vicinity of the site for the NBS in 1959 during his preparation of a report "Geohydrology of a Proposed Reactor Site near Gaithersburg, Maryland." To check and update the survey for the report, A. Schwebel, Health Physicist at the NBS, independently surveyed the wells adjacent to the site. His records showed thirty-one wells on the perimeter of the site within a one-mile radius, which substantiates and augments Otton's record of 1959. Currently, the Montgomery County Health Department has permits on record for one well within a one-mile (1.6-km) radius of the site.

Site Groundwater Use

The NBSR does not use groundwater during its operation. There are no permitted wells elsewhere on the NIST site.

2.4.5.3 Monitoring

Starting November 1963, NIST has employed a routine sampling and analysis program that assesses radioactivity levels in wells and groundwater. Following the recommendations of the U.S. Geological Survey, water from six stream locations has been sampled. Water from 35 wells was originally checked monthly to provide a comprehensive record of the background activity.

The early records taken showed relatively high natural radon concentrations in fresh well samples.

Concentrations in wells range between 400 and 3,300 pCi/L. The month-to-month variation of activity from any individual well is about ±20%. The stream water contains lower and more variable concentrations of radon, depending on the history of the stream's flow. Values for all six stream-sampling points average 100 pCi/L ±200%. After removing the radon, there was no evidence of natural activity from any other isotope.

Routine environmental sampling of grass, soil, and water in streams and ponds continues. Samples are collected and analyzed at least quarterly from a minimum of four locations for each sample type. Soil samples are collected during the non-growing season (October through March) and grass samples are collected during the normal growing season (April through September). Water samples are collected all year dependent on availability. The collected samples are analyzed for possible neutron activation nuclides and fission product nuclides. Water samples are also assayed for tritium. Results are reported in the NBSR Annual Report to the NRC.

2.4.6 Technical Specifications and Emergency Operation

2.4.6.1 Flooding

Since the Confinement Building and support structures are located outside the 100-year flood zone and there are no water bodies within 1,000 feet (305 meters) distance of the site, or 40 feet (12 meters) in elevation, there are no flood design considerations. Flooding is not expected to affect the reactor's safety.

2.4.6.2 Low Water Level

Since the site does not rely on surface water for cooling or processing, low water considerations for surface water are not applicable, and drought conditions will not affect the safety of the site.

2.5 Geology, Seismology, And Geotechnical Engineering

This section describes the geology of the NBSR site and the surrounding region and provides the framework for discussing regional and site geology, seismicity, seismic risks, and geotechnical characteristics. The discussions are based on reviews of recent publications, recent URS projects in Maryland, and discussions with the staff at the Maryland Geological Survey and the staff of U.S. Geological Survey. Section 2.7 has a glossary of the geologic terms used.

2.5.1 Regional Geology

2.5.1.1 Physiographic Setting and Geomorphic Processes

Maryland is comprised of three primary physiographic provinces: the Atlantic Coastal Plain Province, the Piedmont Province, and the Appalachian Province (Figure 2.14). The physiographic provinces are parallel to the Atlantic coast of the North American Continent and are mapped as belts of varying widths extending from Newfoundland, Canada to the Gulf of Mexico. In general, the land rises gently from the offshore continental slope and Atlantic Ocean shoreline across the Atlantic Coastal Plain Province, then more steeply across the Piedmont and Appalachian Provinces. Rock strata of different types, geologic origin, and, in general, different geologic ages underlie these three physiographic provinces. Unconsolidated sediments including gravel, sand, silt, and clay underlie the Atlantic Coastal Plain Province. Slight topographic relief and the absence of rapidly downcutting streams also are characteristic of this province. The Piedmont Province includes crystalline igneous and metamorphic rocks that have been weathered to varying degrees. It also encompasses younger Triassic-age red shale, siltstone and sandstone and Jurassic-age diabase intrusives. Gently rolling topography is a characteristic of this physiographic province, with broad divides between the relatively few major streams.

The Appalachian Province is subdivided into the Blue Ridge, Great Valley, Valley and Ridge, and Allegheny Plateau. The Blue Ridge sub-province is primarily underlain by relatively resistant metamorphic and igneous rock. These units form the Catoctin Mountain on the east, the Blue Ridge (Elk Ridge) on the west, and South Mountain between these other two ridges. Sedimentary rocks underlie the inter-mountain valleys that are incised by Catoctin Creek. The Valley and Ridge sub-province is underlain primarily by folded and faulted sedimentary rocks and comprised of a broad valley on the east and a series of long, northeast-trending ridges on the west. Under the broad "Great Valley" are less resistant limestones that are prone to dissolution. More resistant sedimentary rocks underlie the ridges, with valleys between them under which less resistant sedimentary rocks are found.

The NBSR is located in the southwestern portion of the city of Gaithersburg, Maryland within the Piedmont physiographic province (Figures 2.10 and 2.14). The Fall Line, which is the physiographic and tectonic boundary between the Coastal Plain and Piedmont provinces, is approximately 16.5 miles (26.5 kilometers) to the southeast of the NBSR site. The eastern margin of the Blue Ridge Province, the Catoctin Mountains, is approximately 20 miles (32 kilometers) west of the site.

The NBSR is located in the eastern Piedmont, which is characterized by gently sloping upland areas, and broad, relatively shallow valleys. Chemical weathering has altered the igneous and metamorphic (meta-sedimentary and meta-igneous) rocks under the eastern Piedmont to varying degrees. As a result, the residual soil (saprolite) derived from the underlying rocks blankets the Piedmont. This soil varies generally from less weathered, structured saprolite above sound bedrock, to highly weathered soils that contain almost no remnant minerals and geologic structure characteristic of the parent rock beneath. Bedrock outcrops occur in broadly scattered locations, mainly along the steep banks of stream valleys and in occasional excavations for roads, railroads and structures. In Montgomery County, natural outcrops are mainly found along the Potomac River and its major tributaries (Drake, Southworth, and Lee, 1999). The broad distribution of rock outcrops; intense weathering, and deep residual soils have complicated the mapping and interpretation of Piedmont geology.

Saprolitization is characteristic of warm, humid environments in the mid-Atlantic and southeastern United States. Saprolite is approximately 40 feet (12.2 meters) thick in the site's vicinity (Froelich, 1975b; 1975c). Borings there site indicate that, locally, the saprolite's thickness varies from 35 feet (10.5 meters) in Boring 9-A, to 73 feet (22.25 meters) in Boring 3-A (NBS, 1981; Burns and Roe, 1962). In general, its texture is predominantly silty or sandy in texture with locally significant amounts of clay and abundant residual fragments of quartz and other weathered, more resistant rocks.

The URS report (URS, 2003) discusses the stratigraphy and lithology of the regional geology based largely on recent results of detailed geological mapping and on discussions with Scott Southworth of the U.S. Geological Survey. To address the NRC requirements in 10 CFR 100, Appendix A, this discussion focuses on those geologic units and structures that occur within 5 miles (8 kilometers) of NIST (Figure 2.15). The bedrock and Surficial geologic units discussed in this report (URS, 2003) are shown on the area stratigraphic column and geologic time scale (Figure 2.16).

2.5.2 Site Geology

As discussed in Sections 2.5.1 and 2.5.8.3, saprolite (residual soil) varies from approximately 40 feet (13 meters) to 60 feet (20 meters) thick at the site. No large-scale geologic structures have been mapped there. First-generation Paleozoic rock cleavage and/or schistocity strikes north-northwest and dips 70° east-northeast at locations to the southwest and southeast of the test reactor. This fabric strikes northeast and dips 15° to 47° southwest at locations near a fold mapped south of the site (Drake, Southworth, and Lee, 1999). The deformation that produced this structure occurred more than 400 million years ago and is associated with the Taconic Orogeny. Retrograde metamorphism might be associated with either the younger Arcadian or Alleghenian Orogenies, both of which occurred during the Paleozoic. The site's safety is not affected by these structures.

The bedrock at the site is mapped as schist within the Mather Gorge Formation. Its geologic history is described in Regional Geology Section in the URS report (URS, 2003).

2.5.3 Seismicity

Table 2.5-1 of the URS report (URS, 2003) lists all the historically reported earthquakes (1701 through 2001) of Modified Mercalli Intensity (MMI) (as noted in Table 2.21) greater than III (Richter magnitude M_b greater than 3.0) that have occurred in all tectonic provinces, any part of which is within 120 miles (200 kilometers) of the site. The USGS website shows that no earthquakes with magnitudes greater than 3.0 occurred within 200 miles (322 kilometers) of the site during 2002. Figure 2.17 shows the locations of the earthquake epicenters listed on Table 2.5-1 of the URS report (URS, 2003). The only seismic source zones of concern are the Extended Continental Crust (ECC) and the Iapetan Rifted Margin (IRM). As stated in Regional Geology Section of the URS report (URS, 2003), the NIST site lies in the western portion of Zone ECC, approximately 20 miles (32 kilometers) from the eastern margin of Zone IRM.

2.5.4 Maximum Earthquake Potential

In general, outside the New Madrid fault zone, earthquakes in the Central and Eastern United States cannot be associated with mapped faults. The largest historical seismic events within Zone ECC are the earthquakes of 1884 (Rockaway Beach/New York City, mb 5.2), 1737 (New York City, M_b 5.2), and 1755 (Cape Ann, Massachusetts, M_b 6.2 [moment magnitude 5.8], Ebel, 2002; M_b 5.8 in the NCEER[1] catalog [Table 2.5-1 in (URS, 2003)]). The largest historical earthquake within Zone IRM is the 1897 Giles County, Virginia, earthquake (evaluated as having a maximum MMI VIII [Seeber and Armbruster, 1991, and NEIC[2] catalog], M_b 5.7), which occurred within the GCVSZ near the Virginia-West Virginia border (Bollinger and Hopper, 1971). The magnitude for the Giles County earthquake is estimated as M_b 5.8 in the current NCEER catalog [Table 2.5-1 in (URS, 2003)]. According to this catalog, four M_b 5.2 (MMI VII) earthquakes have occurred in the IRM seismic source zone. Therefore, the Cape Ann earthquake might be considered the maximum historical earthquake for Zone ECC[3]. The Giles County earthquake might be considered the maximum historical earthquake for Zone IRM.

The U. S. Geological Survey (USGS) updated its seismic hazard maps for the conterminous United States based on new seismological, geophysical, and geological information. They employed a probabilistic methodology that uses a combination of gridded, spatially smoothed seismicity, large background zones, and specific fault sources to calculate hazard curves for a grid of sites throughout the country (Frankel, et. al., 2002). The documentation for these hazard maps indicates that a maximum moment magnitude (Mmax) of 7.5 is applicable for an area that includes the Wabash Valley, New Madrid, Charleston, the aerial seismic source zones in New England, and the ECC in which the Site is located (Frankel, et. al., 2002); this maximum magnitude earthquake is incorporated as an upper bound for earthquake recurrence. As noted in Section 2.5.5, the USGS probabilistic analysis still results in relatively low ground-motion risk for a broad area surrounding the site.

2.5.5 Vibratory Ground Motion

No earthquakes with magnitudes greater than those considered for earlier licensing actions have occurred within the ECC and the IRM since the NRC Safety Evaluation Report in 1983. The site is located in an area that has experienced only minor earthquake activity (URS, 2003). The licensee concluded that the maximum potential earthquake for the area would generate a

[1] NCEER – National Center for Earthquake Engineering Research.
[2] NEIC – National Earthquake Information Center.
[3] ECC – Extended Continental Crust.

maximum peak horizontal ground-acceleration (PGA) at the site of 0.07 to 0.1g (NBS, 1966; NBS, 1981). The NBS discussion derives from the USGS's analysis of the frequency of earthquakes having Modified Mercalli intensities ranging from III to XII, and on expert judgment at that time (NBS, 1981; NBS, 1966).

Assuming that a Giles County MMI VIII earthquake could occur at the NIST site, a PGA of 0.10 was obtained (URS, 2003). In this deterministic analysis, the Piedmont and the Valley and Ridge provinces are considered as part of the Appalachian seismotectonic province. No distinction was drawn between ground motion in bedrock and ground motion in soils.

As stated in Section 2.5.4, the USGS seismic hazard maps use a probabilistic approach that is based a gridded, spatially smoothed seismicity and a large background zone (Frankel, et. al., 2002). These hazard maps are for a firm-rock site condition, where the shear-wave velocity averaged over the top 33 yards (30 meters) is 836 yards/second (760 meters/second). Note that the boundaries of National Earthquake Hazard Reduction Program site classes are B and C. (Frankel, et. al., 2000). Although the NRC does not require a probabilistic approach for this type of facility, the USGS regional seismic hazard maps for the Eastern and Central U.S. are included to show their current estimates of potential ground motion at the site. Figures 2.18a and 2.18b show PGA values with 10% and a 2% probability of exceedance in 50 years or corresponding return periods of 476 and 2,475-years, respectively. These maps indicate potential PGAs of 0.02-0.03g for the 476-year return period and approximately 0.07g for the 2,475-year return period. Figures 2.18c through 2.18f depict the results of spectral acceleration for 0.2 and 1.0 seconds.

2.5.6 Surface Faulting

No surface faulting has been documented for any earthquakes occurring in the ECC or the IRM. The only faults mapped within 5 miles (8 kilometers) of the site experienced deformation in the Paleozoic era (Section 2.5.2); they are not significant to site safety. The potential for surface faulting at the site is negligible.

2.5.7 Liquefaction Potential

Liquefaction potential is briefly discussed in Section 2.5.8. From the characteristics of the underlying soils and low level of seismicity, the potential for liquefaction is practically nonexistent.

2.5.8 Geotechnical Engineering

This section summarizes geotechnical and foundation information for the existing Confinement Building and the Cold Neutron Guide Hall Wing at the NCNR.

2.5.8.1 Objective

The objective of this section is to summarize the geotechnical data and information on the foundations of the existing Confinement Building and the Cold Neutron Guide Hall Wing. The section also discusses the condition and performance of the foundations based on their intended use.

2.5.8.2 Existing Building Foundations

The NCNR is comprised of a warm lab area, a cold lab area, and a reactor area. The facility, also referred to as Building 235, was constructed in 1963. The Cold Neutron Guide Hall in Wing G, located north of the existing Confinement Building, was added later in 1988. The facility locations are shown in Figure 2.4. Detailed descriptions of the reactor and buildings were given in previous relicensing documentation (NBS, 1966) and are discussed in detail in Chapter 3. Brief information on the foundations for the significant components of the facility is presented below.

2.5.8.2.1 Confinement Building

The Confinement Building is a 90 feet x 90 feet (27 m x 27 m) concrete structure, built to accommodate scientific programs. It has three main levels: basement, first floor, and second floor. Steel HP12 x 74 pile foundations were designed for a capacity of 95 tons (845 kN) each in order to support the building (NBS, 1962). For details, see Section 3.1.1.1.1.4.

2.5.8.2.2 Cold Neutron Guide Hall

The Cold Neutron Guide Hall (G-Wing) is 100 feet x 200 feet (30 m x 61 m) in plan dimensions. It contains one 20-ton (178-kN) crane and 7 neutron guide tubes. This wing is supported on spread footings. Since the neutron guide tubes and crane foundations reportedly are sensitive to settlement, pile foundations were provided for them.

Piles: Burns and Roe (May 1987) record that steel HP14 x 89 and HP12 x 74 piles initially were recommended for the crane and guide-tubes foundations. However, in a subsequent memorandum, it was stated that the HP14 x 89 piles should be replaced with 20-inch (50.8-cm) diameter auger cast piles with a minimum length of 40 feet (12.2 meters) or to refusal on rock. The HP12 X 74 piles and 20-inch (50.8-cm) diameter piles were designed for a capacity of 80 tons (712 kN) and 130 tons (1,068 kN), respectively, to support the neutron guide tubes and crane. These piles were also designed for 20-ton (178 kN) uplift capacity and 5-ton (44 kN) lateral load capacity. The intent was to be embedded the piles into rock or decomposed rock with standard penetration test N-values of more than 100 blows per foot (30 cm).

Footing: The designed allowable bearing pressure for spread footings on compacted soil with 4 in (10 cm) crushed stone cover was 4,000 psf (191 kPa) (Burns and Roe, 1987).

2.5.8.3 Available Geotechnical Information

The subsurface conditions at the Confinement Building and the Cold Neutron Guide Hall, as described in documents (Burns and Roe, 1962; Burns and Roe, 1987 and NBS, 1981), indicate four generalized geologic strata:

- **Layer A:** Topsoil and fill,
- **Layer B**: Residual soils,
- **Layer C:** Transition zone between Layer B and Layer D, and
- **Layer D:** Relatively sound bedrock.

This information is primarily based on 10 borings that were drilled in 1961 for the original facility construction. Additional borings were drilled west of the Confinement Building for designing and constructing the new cooling towers. Figure 2.19 shows the boring locations. Generalized soil profiles for the area are presented in Figures 2.20 and 2.21. The various strata and groundwater conditions are briefly summarized below. Some soil characterization data, e.g., laboratory moisture content, plasticity, and fines content, is supplemented with information from a later geotechnical report from the Advanced Technology Laboratory (Schnabel Engineering, 1996).

Layer A: Topsoil/Fill – This layer contains sandy clayey silt and silty clay; however, it is mainly characterized as sandy SILT (ML) and was encountered in borings ranging from about 3.0 feet (1 meter) to 12 feet (4 meters) below ground surface. The natural moisture content of the soils ranged from about 6 to 29% (average about 19%). The percent fines (portions passing the No. 200 Sieve) varied from about 67 to 85% (average about 76%). The penetration resistance values (also known as "N" value) ranged from 5 to 12 blows per foot (30 cm).

Layer B: Residual Soils – Residual soils consisting of sandy silt, clayey silt, and silty sand with quartz and disintegrated rock, were encountered below the fill in all test borings (saprolite). They are mainly characterized as sandy SILT (ML) and silty SAND (SM), red brown and yellow brown, loose to very compact decomposed shaley schist with traces of quartz and disintegrated rocks. Their moisture contents vary from about 10 to 31% (average about 20%). The percent fines range from about 24 to 69% (average about 45%). Typically, the soils have a low plasticity index, varying from about 5 to 11 (average 8). The penetration resistance N-values ranged from 9 to 150 blows per foot (30 cm), but were typically more than 30 blows per foot (30 cm). The thickness of the residual soils was between about 30 feet (10 meters) to 60 feet (20 meters).

Layer C: Transition Materials – Transition materials, also known as disintegrated rock, are zones of materials that transition between the residual zone and the relatively sound bedrock (less weathered saprolite). This zone consists of gray, brown, and green shaley and seamy schist. The NIST report (NBS, 1981) defines transition materials as disintegrated rock with coring recovery of less than 70%. Schnabel Engineering (1996) identifies this layer as residual soils. Commonly, however, these materials are very compact weathered rock with N-values greater than 50 blows per foot (30 cm). The thickness of this transition zone is approximately 2 feet (0.5 meters) to 6 feet (2 meters).

Layer D: Bedrock – Underlying the transition materials, bedrock is encountered; it is a relatively sound, slightly weathered and moderately fractured, gray schist with shaley seams and zones of quartz. The rock was mapped as part of the Wissahickon Formation but now is recognized as schist within the Mather Gorge Formation (Sections 2.5.1.1.1 and 2.5.2). The depth to top of bedrock varies and in the borings was encountered from about 40 feet (13 meters) to 60 feet (20 meters) below the ground surface (NBS, 1981).

Groundwater - Groundwater level taken in 1961 at the Confinement Building and laboratory areas was approximately between elevation 407 feet (124.1 meters) and 411 feet (125.2 meters), which is at a depth from about 6.3 feet (2 meters) to 23.0 feet (7.0 meters) below the surface (NBS, 1966). Groundwater at the Cold Neutron Guide Hall and the office building area is similar at approximately elevation 400 feet (121.9 meters) and 405 feet (123.44 meters), respectively (Burns and Roe, 1987). The groundwater level measured in 2000 at the new Cooling Tower is at about 22 feet (6.7 meters) below the ground surface or at elevation 397 feet (121 meters) (Schnabel Engineering, 2000). This variation in groundwater level across the site probably is influenced by the varying topography and time of measurement, among other factors (see Section 2.4.5).

The soil descriptions are generally consistent with results of other soil investigations at other locations for projects near Building 235, e.g., the new Cooling Tower (Schnabel Engineering, 2000), and the new Advanced Measurement Laboratory (Schnabel Engineering, 1996).

2.5.8.4 Evaluations

As described in previous paragraphs, the buildings and facilities referred to are supported on shallow and deep foundations. The shallow foundations are believed to rest on competent residual soils and/or transition materials. Similarly, deep foundations are believed to be bearing into transition materials and/or bedrock. This conclusion is supported by the successful performance of the buildings and facilities' foundations since their original construction, and the lack of any reported signs of distress or movement in the foundations.

The foundations are expected to continue to perform satisfactorily as long as the geologic, hydrogeologic, and superimposed loads continue to remain consistent with those adopted in designing the facilities.

The NIST site is known for its absence of historically high-magnitude earthquakes. As discussed in Section 2.5.5, the maximum anticipated ground acceleration for the area is 0.10 g. Given the relatively low intensity/magnitude of seismic events, the presence of competent foundation soils at the site, and the performance of existing foundations to date, the site soils and foundations are expected to continue to perform satisfactorily for their design conditions. The potential for loss of bearing due to soil liquefaction is considered practically nonexistent.

2.6 Conclusions

In conclusion, there are no risks associated with the site conditions that render it unacceptable for the continued operation of the NBSR. Since hazards are minimal, it is anticipated that risks from these hazards also are minimal.

2.7 Glossary

diabase	An intrusive igneous rock whose main components are plagioclase feldspar (labradorite) and pyroxene and which is characterized by ophitic texture (lath-like plagioclase crystals partially or completely included in pyroxene).
intrusives	Igneous rocks that are forced while molten into cracks or between other layers of rock.
lithology	The area of geology that describes rocks, their mineral constitution and classification, and their mode of occurrence in nature.
muscovite	The most common form of mica, which ranges from colorless or pale yellow to gray and brown, and has a pearly luster.
orogeny	The process of mountain formation, especially by a folding and faulting of the earth's crust.
saprolite	Residual soil formed in place by the chemical decomposition (weathering) of igneous, metamorphic and sedimentary rock. Where less weathered it may be characterized by the preservation of structures that were present in the unweathered rock (structured saprolite). Where more completely weathered and clay-rich, it may be characterized as not having any structure.
saprolitization	The process of forming saprolite by chemical weathering of a parent rock.
schistosity	The texture (foliation) in a schist or other coarse-grained metamorphic rock formed by the parallel, planar arrangement of platy, prismatic or ellipsoidal minerals. It is considered to be a type of rock cleavage.
seismic source zones	A volume of the earth’s crust having similar geological, geophysical and seismological characteristics.
stratigraphy	The study of rock strata, especially the distribution, deposition, and age of sedimentary rocks.

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Table 2.1: NBSR Site Area Census Data

	1990 Population	2000 Population
Gaithersburg	39,542	52,613
Rockville	44,835	47,388
Washington Grove	-	515
Germantown	41,145	55,419
Montgomery Village	32,315	38,051
North Potomac	-	23,044
Darnestown	-	6,378

Table 2.2: Montgomery County Population

Year	Population	Percentage Change
1950	164,401	n/a
1960	340,928	107.4
1970	522,809	62.0
1980	579,053	10.8
1990	757,027	30.7
2000	873,341	15.4

Table 2.3: Montgomery County Population Forecasts

Year	Population	Percentage Change
2000	873,341	n/a
2005	925,000	6.0
2010	975,000	5.4
2015	1,020,000	4.6
2020	1,050,000	2.9
2025	1,070,000	1.9

Table 2.4: Montgomery County Planning Area Forecasts for Population

Planning Area	Year				
	2005	2010	2015	2020	2025
Darnestown	12,900	13,300	13,900	14,600	14,600
Gaithersburg	125,400	127,900	133,300	139,000	141,000
Germantown	81,000	82,300	85,600	86,800	86,800
Potomac	44,800	46,000	47,800	49,600	50,200
Rockville	48,900	52,500	51,000	50,100	50,000

Table 2.5: Population Estimates

Circle (km)	2000	2010	2025
1	3,462	3,677	4,054
2	19,178	20,367	22,457
4	73,121	77,654	85,624
6	155,402	168,163	180,247
8	218,752	237,848	253,100

Table 2.6: Normal Daily Temperatures in ^{o}F (1971 - 2000)

(a) Mean Temperatures

STATION	YRS	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANN
IAD	30	31.7	34.8	43.4	53.1	62.3	70.9	75.7	74.4	67.3	55.0	45.2	36.0	54.2
DCA	30	34.9	38.1	46.5	56.1	65.6	74.5	79.2	77.4	70.5	58.8	48.7	39.5	57.5
Rockville	30	31.8	34.6	43.2	53.3	62.3	70.7	75.3	73.3	66.5	55.1	45.2	36.3	54.0

(b) Minimum Temperatures

STATION	YRS	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANN
IAD	30	21.9	24.1	31.8	40.2	49.9	59.0	64.0	62.8	55.6	42.3	33.8	26.0	42.6
DCA	30	27.3	29.7	37.3	45.9	55.8	65.0	70.1	68.6	61.8	49.6	40.0	32.0	48.6
Rockville	30	23.8	25.8	33.6	42.4	51.7	60.3	65.1	63.2	56.3	44.4	35.7	28.1	44.2

(c) Maximum Temperatures

STATION	YRS	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANN
IAD	30	41.4	45.5	55.0	65.9	74.6	82.8	87.4	85.9	78.9	67.7	56.5	45.9	65.6
DCA	30	42.5	46.5	55.7	66.3	75.4	83.9	88.3	86.3	79.3	68.0	57.3	47.0	66.4
Rockville	30	39.7	43.3	52.8	64.1	72.8	81.0	85.4	83.4	76.6	65.8	54.7	44.4	63.7

Table 2.7: Average Relative Humidity Data in Percentage (%) (Through 2002)

STATION	YRS		JAN		FEB		MAR		APR		MAY		JUN	
	M	A	M	A	M	A	M	A	M	A	M	A	M	A
IAD	33	33	77	58	78	54	78	52	77	49	83	55	84	56
DCA	42	42	71	56	71	53	70	50	70	49	75	53	76	53
Rockville	N/A													

STATION	JUL		AUG		SEP		OCT		NOV		DEC		ANN	
	M	A	M	A	M	A	M	A	M	A	M	A	M	A
IAD	86	55	88	55	90	56	89	54	83	54	79	58	83	55
DCA	76	53	80	55	82	56	80	54	76	54	72	57	75	54
Rockville	N/A													

NOTES:
NWS = National Weather Service
IAD = NWS at Dulles International Airport
DCA = NWS at Reagan National Airport
Rockville = NWS Cooperative Observing Station (COOP)
ANN = Annual Mean
YRS = Number of Years Data
M = Morning
A = Afternoon
N/A = Not Available

Table 2.8: Average Monthly Precipitation in Inches (1971 - 2000)

STATION	YRS	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANN
IAD	30	3.05	2.77	3.55	3.22	4.22	4.07	3.57	3.78	3.82	3.37	3.31	3.0	41.80
DCA	30	3.21	2.63	3.60	2.77	3.82	3.13	3.66	3.44	3.79	3.22	3.03	3.05	39.35
Rockville	30	3.34	2.85	3.89	3.19	4.38	3.74	3.91	3.72	4.09	3.36	3.44	3.17	43.08

YRS = # Years of Data ANN = Annual Mean

Table 2.9: Maximum Daily Precipitation in Rockville (1948 – 1998)

Month	Maximum Daily Precipitation in Inches	Most Recent Date of Occurrence
January	2.42	1/1/76
February	1.92	2/12/85
March	2.75	3/23/91
April	2.20	4/14/70
May	3.15	5/5/89
June	7.90	6/22/72
July	4.32	7/9/58
August	4.50	8/1/78
September	4.46	9/26/75
October	4.36	10/23/90
November	3.50	11/27/93
December	2.28	12/24/86

Table 2.10: Average Snowfall in Inches
(Including Ice Pellets And Sleet - Data through 2002)

STATION	YRS	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANN
IAD	40	7.5	6.4	3.4	0.4	T	T	0.0	T	0.0	0.0	1.2	3.4	22.3
DCA	59	5.5	5.1	2.3	T	T	T	T	T	0.0	0.0	0.8	2.9	16.6
Rockville	30	6.7	4.8	3.4	0.1	0.0	0.0	0.0	0.0	0.0	T	1.0	3.0	19.0

YRS = # Years of data   ANN = Annual Mean   T = Trace

Table 2.11: Maximum 2-Day Snowfall in Rockville (1948 – 1998)

Month	Greatest 2-Day Snowfall Total in Inches	Most Recent Dates of Occurrence
January	25.7	1/7/96-1/8/96
February	23.0	2/16/03-2/17/03
March	19.0	3/6/62-3/7/62
April	2.0	4/6/90-4/7/90
May	0.0	N/A
June	0.0	N/A
July	0.0	N/A
August	0.0	N/A
September	0.0	N/A
October	0.0	N/A
November	8.9	11/6/53-11/7/53
December	15.0	12/11/60-12/12/60

Table 2.12: Wind Speed Data in mph Through 2002

(a) Average Wind Speed

STATION	YRS	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANN
IAD	40	8.1	8.6	9.0	8.8	7.4	6.8	6.2	5.8	6.2	6.6	7.6	7.7	7.4
DCA	54	10.0	10.3	10.9	10.5	9.3	8.9	8.3	8.1	8.3	8.7	9.4	9.6	9.4
Rockville	N/A													

(b) Maximum Wind Speed

STATION	YRS	JAN		FEB		MAR		APR		MAY		JUN	
		DR	SP	DR	SP	DR	SP	DR	SP	DR	SP	DR	SP
IAD	39	200	39	300	37	280	44	320	46	350	40	310	55
DCA	17	29	41	33	39	33	44	31	39	32	46	31	49
Rockville	N/A												

STATION	JUL		AUG		SEP		OCT		NOV		DEC		ANN	
	DR	SP	DR	SP	DR	SP	DR	SP	DR	SP	DR	SP	DR	SP
IAD	300	48	340	43	250	35	290	38	290	35	300	40	310	55
DCA	50	47	34	37	32	39	23	39	32	37	34	38	31	49
Rockville	N/A													

YRS = # Years of data ANN = Annual Monthly Max
DR = Wind Direction SP = Wind Speed

Table 2.13: Estimated 100-Yr Return Period Peak Wind

Published Source	50-Yr to 100-Yr Return Period Multiplier	x	ASCE 7-98 50-YR Return Period Wind	=	Estimated 100-YR Return Period Peak Wind
Hurricane Hazard Information for Coastal Construction [USAID-OAS, 1999]	1.134	x	90 mph	=	102 mph
Return Period of Hurricane Perils in the Caribbean [Johnson, USAID-OAS, 1998]	1.146	x	90 mph	=	103 mph
Average…					102.5 mph

Table 2.14: Snow Fall in Inches for Various Return Periods

(a) Rockville - Based on data from 1948-2000

Snowfall Amount (Inches)					
Time Frame	**Return Period**				**Observed Max**
	10-Yr	**25-Yr**	**50-Yr**	**100-Yr**	
1-day	11.3	15.3	18.5	22.0	19.3
2-day	13.1	18.0	22.3	27.0	25.7
3-day	13.6	18.5	22.5	26.9	28.3

(b) IAD (Dulles Airport) - Based on data from 1963-2000

Snowfall Amount (Inches)					
Time Frame	**Return Period**				**Observed Max**
	10-Yr	**25-Yr**	**50-Yr**	**100-Yr**	
1-day	13.0	17.0	20.3	23.7	22.5
2-day	15.0	19.3	22.6	26.1	23.2
3-day	15.3	19.4	22.6	25.9	24.6

(c) DCA (Reagan National Airport) - Based on data from 1949-2000

Snowfall Amount (Inches)					
Time Frame	**Return Period**				**Observed Max**
	10-Yr	**25-Yr**	**50-Yr**	**100-Yr**	
1-day	10.2	13.5	16.4	19.4	16.4
2-day	11.5	15.4	18.6	22.1	18.7
3-day	12.0	15.6	18.4	21.4	18.7

Table 2.15: Worst-Case Snow Load Calculation

2-Day 100-Yr Snow (inches)	x	Density	=	SWE (inches)	x	5.2 (Conversion Factor)	=	Snow Load (psf)
27	x	0.05	=	1.35	x	5.2	=	7.0
27	x	0.1	=	2.7	x	5.2	=	14.0
27	x	0.15	=	4.1	x	5.2	=	21.1

Table 2.16: Maximum Daily Precipitation in Rockville (1948 – 1998)

Month	**Maximum Daily Precipitation In Inches**	**Most Recent Date of Occurrence**
January	2.42	1/1/76
February	1.92	2/12/85
March	2.75	3/23/91
April	2.20	4/14/70
May	3.15	5/5/89
June	7.90	6/22/72
July	4.32	7/9/58
August	4.50	8/1/78
September	4.46	9/26/75
October	4.36	10/23/90
November	3.50	11/27/93
December	2.28	12/24/86
Water Average	**2.34**	**Calculated**

Table 2.17: Data Collected From the Confinement Building Weather Station

Observation Date	Outdoor Temp. (^oF)	Hum. (%)	Press. (in Hg)	Average Wind Speed (mph)	Average Wind Direction (degrees)	Hourly Gust (mph)	Daily Rainfall (inches)
12/7/03 0:00	27.224	75.248	29.96	6.357	318	16.003	0
12/7/03 1:00	26.499	69.972	29.953	7.234	313	20.826	0
12/7/03 2:00	25.825	71.884	29.956	8.33	304	19.291	0
12/7/03 3:00	24.417	74.44	29.947	8.769	298	20.168	0
12/7/03 4:00	24.585	75.053	29.94	9.426	308	20.168	0
12/7/03 5:00	24.754	76.883	29.936	9.426	307	24.772	0
12/7/03 6:00	24.864	78.601	29.952	7.453	298	20.168	0
12/7/03 7:00	24.923	72.528	29.969	9.207	301	19.511	0
12/7/03 8:00	25.091	63.133	29.989	7.234	320	22.58	0
12/7/03 9:00	26.381	62.98	30.001	4.165	308	21.922	0
12/7/03 10:00	26.777	64.094	30.013	10.961	298	27.183	0
12/7/03 11:00	27.224	65.811	30.01	14.688	321	28.937	0
12/7/03 12:00	28.75	65.198	29.989	11.619	321	25.868	0
12/7/03 13:00	31.28	64.891	29.978	7.453	313	26.087	0
12/7/03 14:00	31.845	61.487	29.952	8.769	307	28.718	0
12/7/03 15:00	32.519	62.939	29.968	10.742	310	26.306	0
12/7/03 16:00	32.907	64.36	29.98	7.015	306	25.649	0
12/7/03 17:00	31.845	66.231	29.994	2.85	336	20.387	0
12/7/03 18:00	31.389	65.995	30.012	3.727	314	14.469	0
12/7/03 19:00	30.656	63.941	30.026	4.165	321	16.441	0
12/7/03 20:00	29.644	66.65	30.041	3.727	307	11.399	0
12/7/03 21:00	29.535	67.682	30.055	3.946	304	15.345	0
12/7/03 22:00	29.307	68.633	30.055	6.796	300	17.538	0
12/7/03 23:00	29.307	69.819	30.067	5.7	301	16.222	0

Table 2.18: Comparison of Field and Laboratory Permeability Data From Different Sources

	Dames & Moore (1978) Landfill Study				Natural Resources Conservation Services (USDA, 1995)	Otton (1959)
	SITE E-57		SITE S-135/271			
	Lab	Field	Lab	Field		
Zone A	8×10^{-5} (3)		1.3×10^{-4} (5)		4.2×10^{-4} to 1.4×10^{-3}	6×10^{-4} to 4×10^{-3}
Zone B	1×10^{-5} to 7×10^{-5}	2.6×10^{-4} (10)	3.3×10^{-5} (22)	5×10^{-4}		
Zone C		3.2×10^{-3} (3)	1.5×10^{-5} (1)	1×10^{-5} to 5×10^{-4}		
Zone D		1.2×10^{-3} (3)		1×10^{-4}* 5×10^{-4}* to $<1 \times 10^{-6}$**		

All permeability values in cm/sec

(n) - indicates an average of n values

* - assumed zone of fractured bedrock

** - assumed zone of sound bedrock.

Table 2.19: Comparison of Groundwater Velocity and Related Values

Parameter	**AML site (Schnabel Engineering, 1996)**	**Dames & Moore Studies (1978)**	**Otton (1959)**
hydraulic conductivity	4.6×10^{-4} cm/sec (based on constant head tests)	Not Calculated	
permeability (k)	2.3×10^{-3} cm/sec (calculated by dividing hydraulic conductivity by porosity)	3.2×10^{-3} cm/sec (obtained from previous studies)	
Gradient (i) (calculated from groundwater contour map)	0.02 to 0.4	0.017 to 0.035	
Porosity	0.2 (assumed average value for this type of geologic material)	Not Calculated	
Velocity (calculated from equation $v = k \times I$)	4.6×10^{-5} to 9.2×10^{-4} cm/sec (0.13 to 2.6 ft/day)	5.3×10^{-5} to 1.1×10^{-4} cm/sec (0.14 to 0.3 feet/day)	3.6×10^{-5} to 3.6×10^{-4} cm/sec (0.1 to 1.0 feet per day)

Table 2.20: Cation Exchange Data (meq/100 grams)

Dames & Moore Study [1978]		
	Site E-37	**Site S-135/271**
Zone A	2.75 (1)	2.15 (1)
Zone B	3.60 (4)	3.65 (1)

National Naval Medical Center Reactor (Clebsch, 1962)	
Depth Below Surface	**Total Exchange Capacity**
2’-6 to 4’0”	7.6
19’-6” to 21’-0	15.1
33’-6 to 33’-9	5.7

Table 2.21: Abridged Modified Mercalli Intensity Scale

I	Not felt except by a few under especially favorable circumstances (RF* I)
II	Felt only by a few persons at rest, especially on upper floors of buildings. Delicately suspended objects may swing. (RF I to II)
III	Felt quite noticeably indoors, especially on upper floor of buildings, but many people do not recognize it as an earthquake. Standing motorcars may rock slightly. Vibration like passing of truck. Duration estimated. (RF III)
IV	Felt indoors by many, outdoors by few during the day. Some awakened at night. Dishes, windows, door disturbed; walls make creaking sound. Sensation like heavy truck striking building. Standing motorcars rocked noticeably. (RF IV to V).
V	Felt by nearly everyone, many awakened. Some dishes, windows, and other fragile objects broken; cracked plaster in a few places; unstable objects overturned. Disturbances of trees, poles, and other tall objects sometimes noticed. Pendulum clocks may stop. (RF V to VI)
VI	Felt by all, many frightened and run outdoors. Some heavy furniture moved; a few instances of fallen plaster and damaged chimneys. Damage slight. (RF VI to VII)
VII	Everybody runs outdoors. Damage negligible in buildings of good design and construction; slight to moderate in well built ordinary structures; considerable in poorly built or badly designed structures; some chimneys broken. Noticed by persons driving cars. (RF VIII)
VIII	Damage slight in specially designed structures; considerable in ordinary substantial buildings with partial collapse; great in poorly built structures. Panel wall thrown out of frame structures. Fall of chimneys, factory stacks, columns, monuments, walls. Heavy furniture overturned. Sand and mud ejected in small amounts. Changes in well water levels. Persons driving cars disturbed. (RF VIII + to IX)
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. (RF IX +)
X	Some well built structures destroyed; most masonry and frame structures destroyed with foundations; ground badly cracked. Rails bent. Landslides considerable from river banks and steep slopes. Shifted sand and mud. Water splashed, slopped over banks. (RF X)
XI	Few, if any, [masonry] structures remain standing. Bridges destroyed. Broad fissures in ground. Underground pipelines completely out of service. Earth slumps and land slips in soft ground. Rails bent greatly.
XII	Damage total. Waves seen on ground surface. Lines of sight and level distorted. Objects thrown into the air.

* Equivalent Rossi-Forel (RF) intensities.

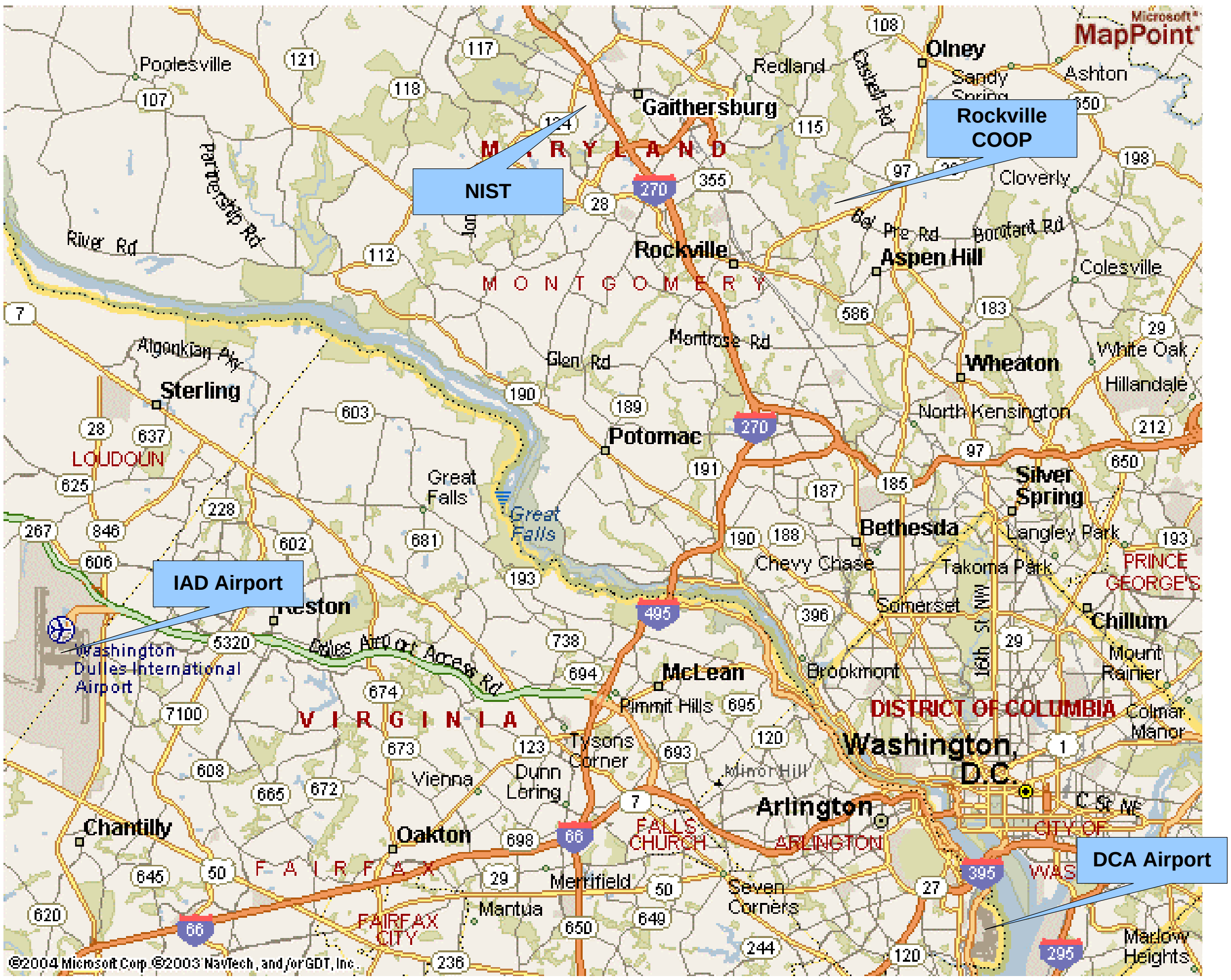


Figure 2.1: NIST Regional Map Showing Nearest Weather Stations

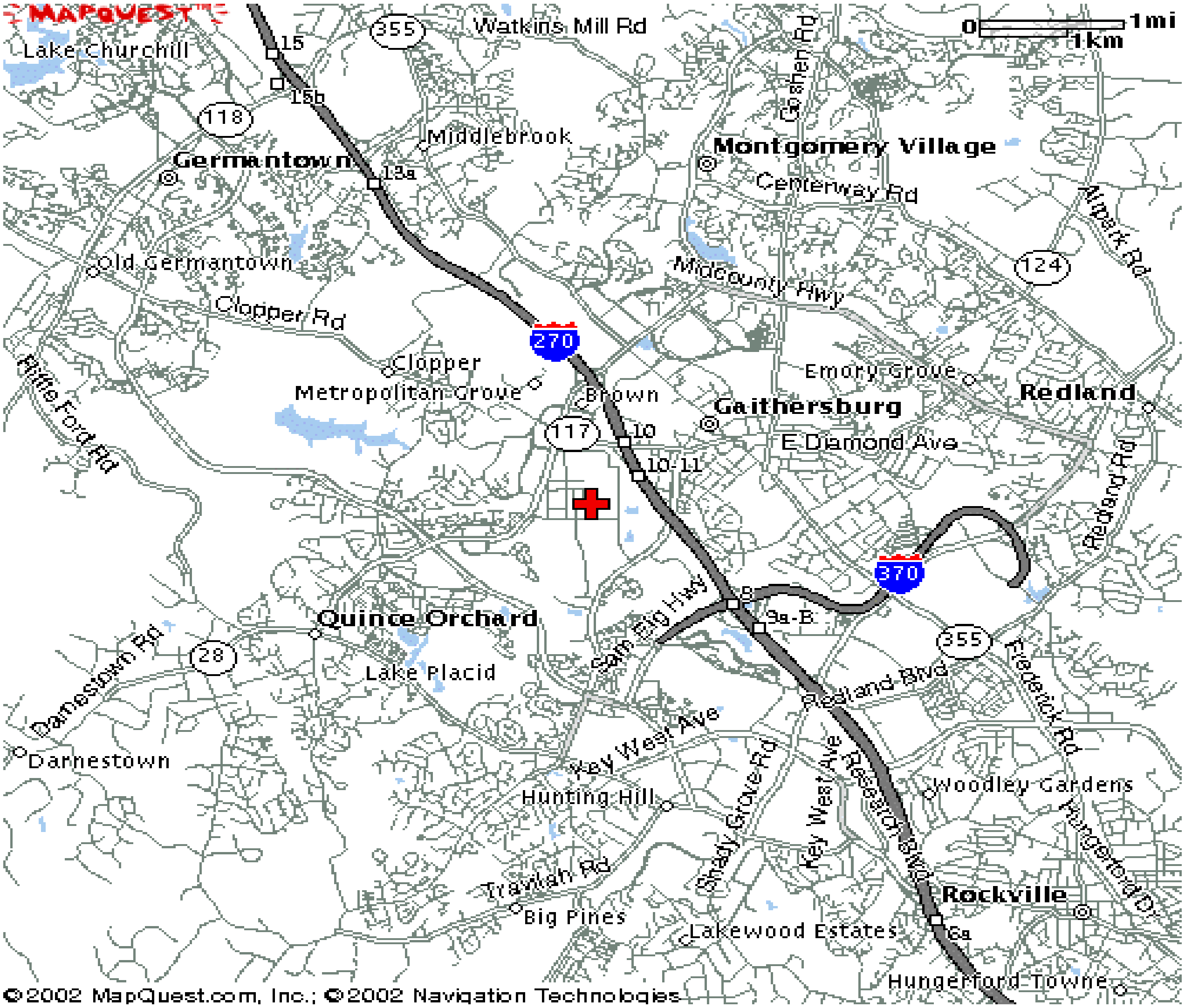
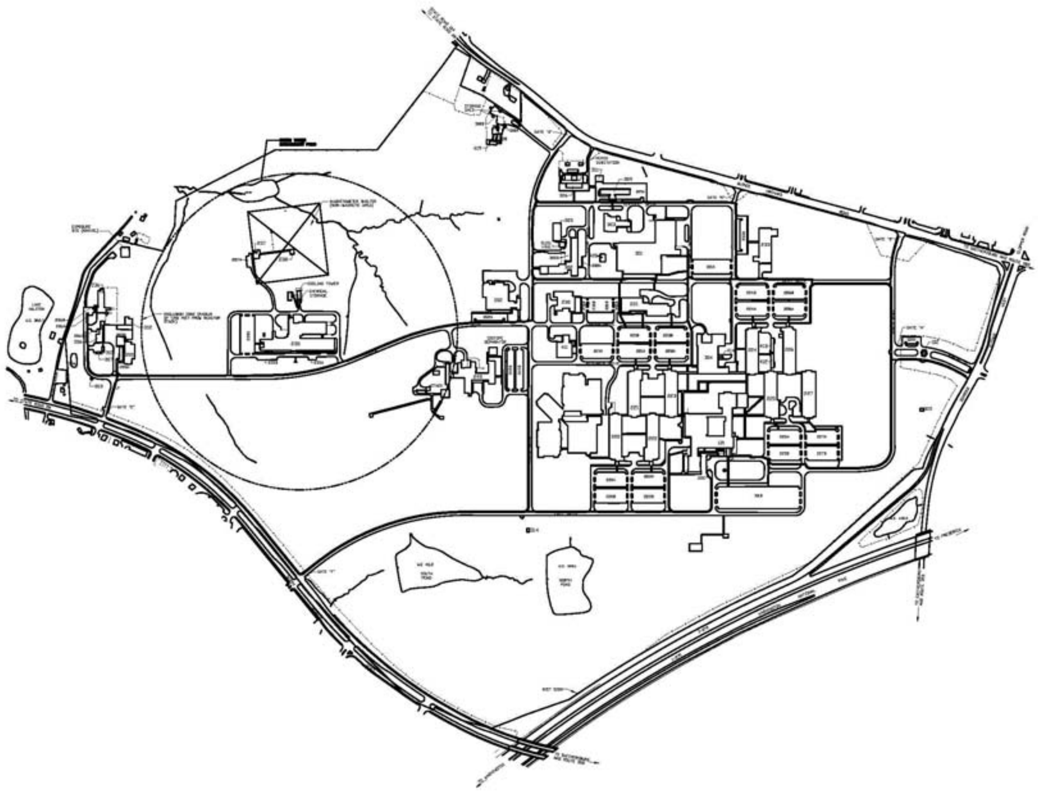


Figure 2.2: Immediate Area Surrounding NIST



Plan View

Photographic View

Figure 2.3: NIST Site Plan

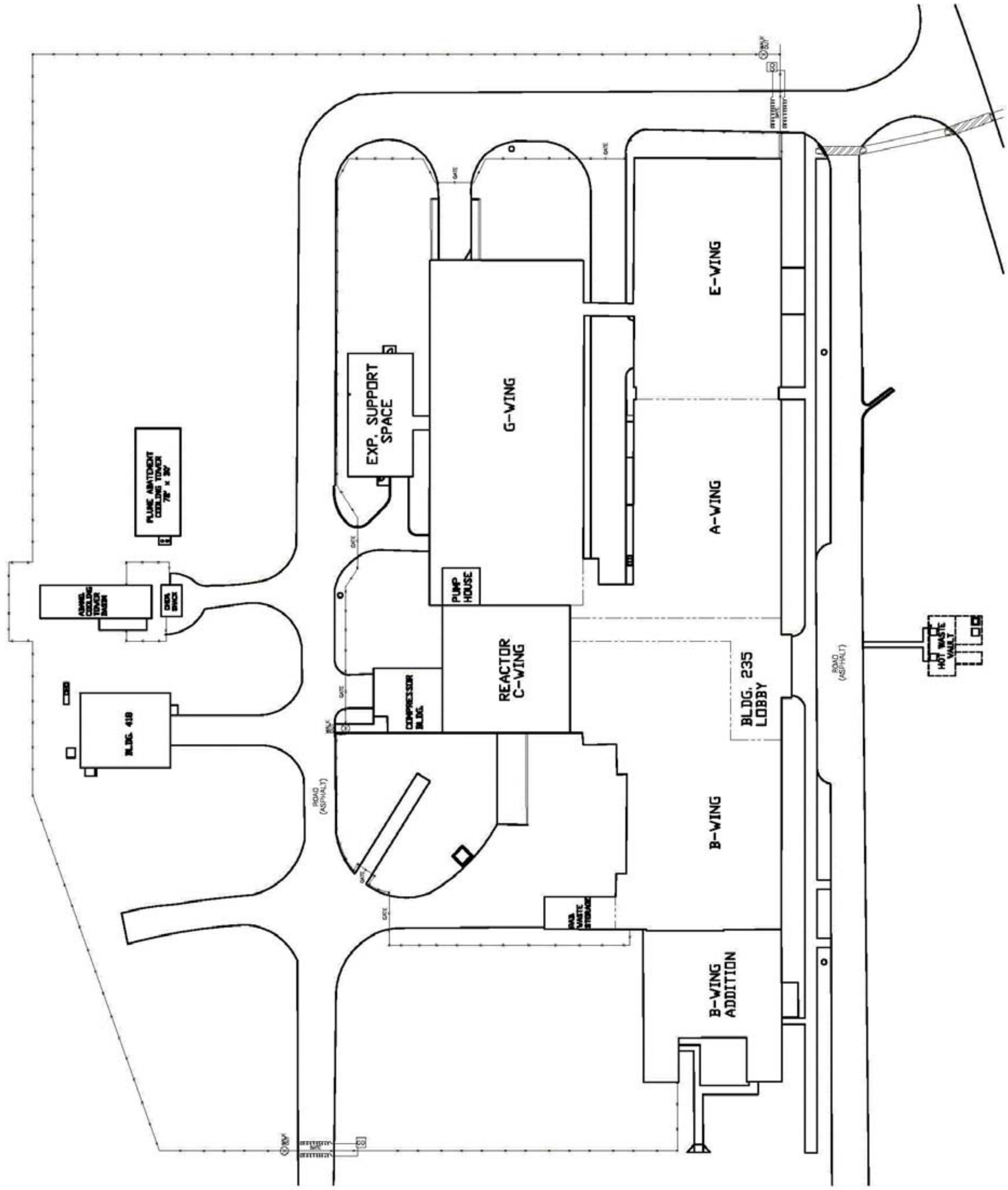


Figure 2.4: NCNR Facility at NIST Campus (Building 235)

Figure 2.4: NCNR Facility at NIST Campus (Building 235)

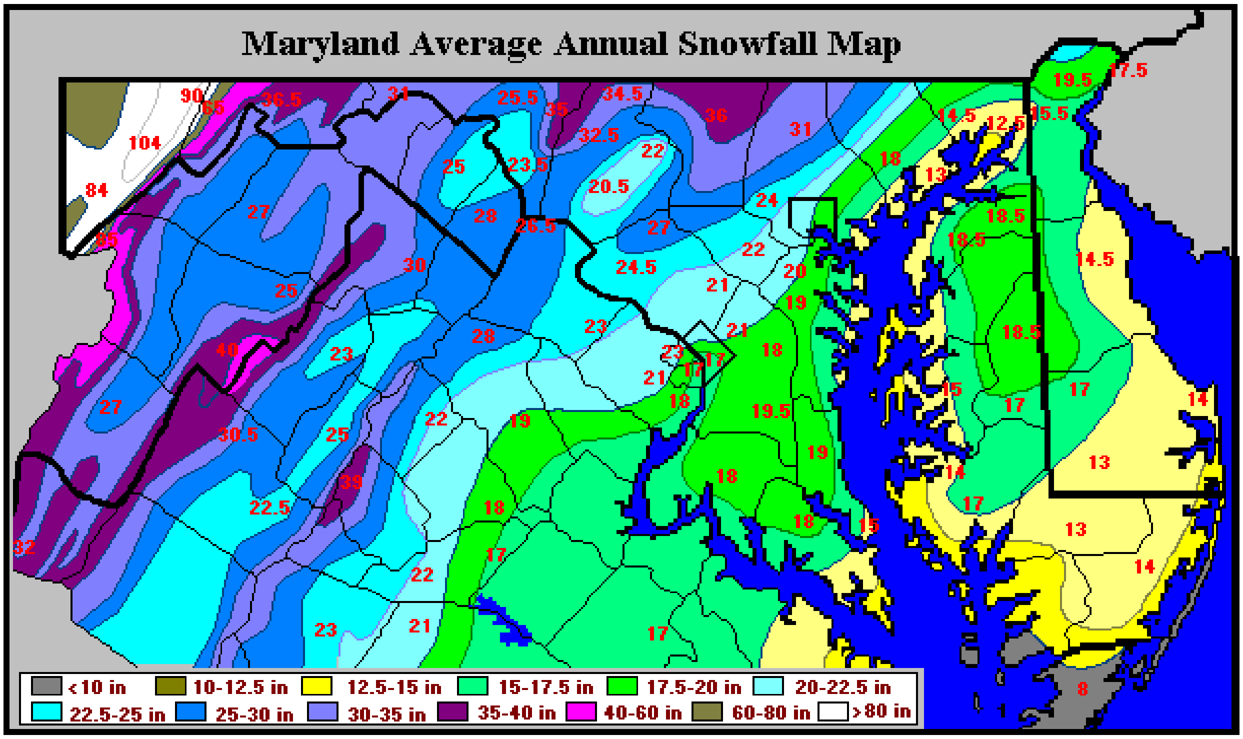


Figure 2.5: Washington Metropolitan Area Average Snowfall
[http://www.erh.noaa.gov/lwx/Historic_Events/snowmaps.htm]

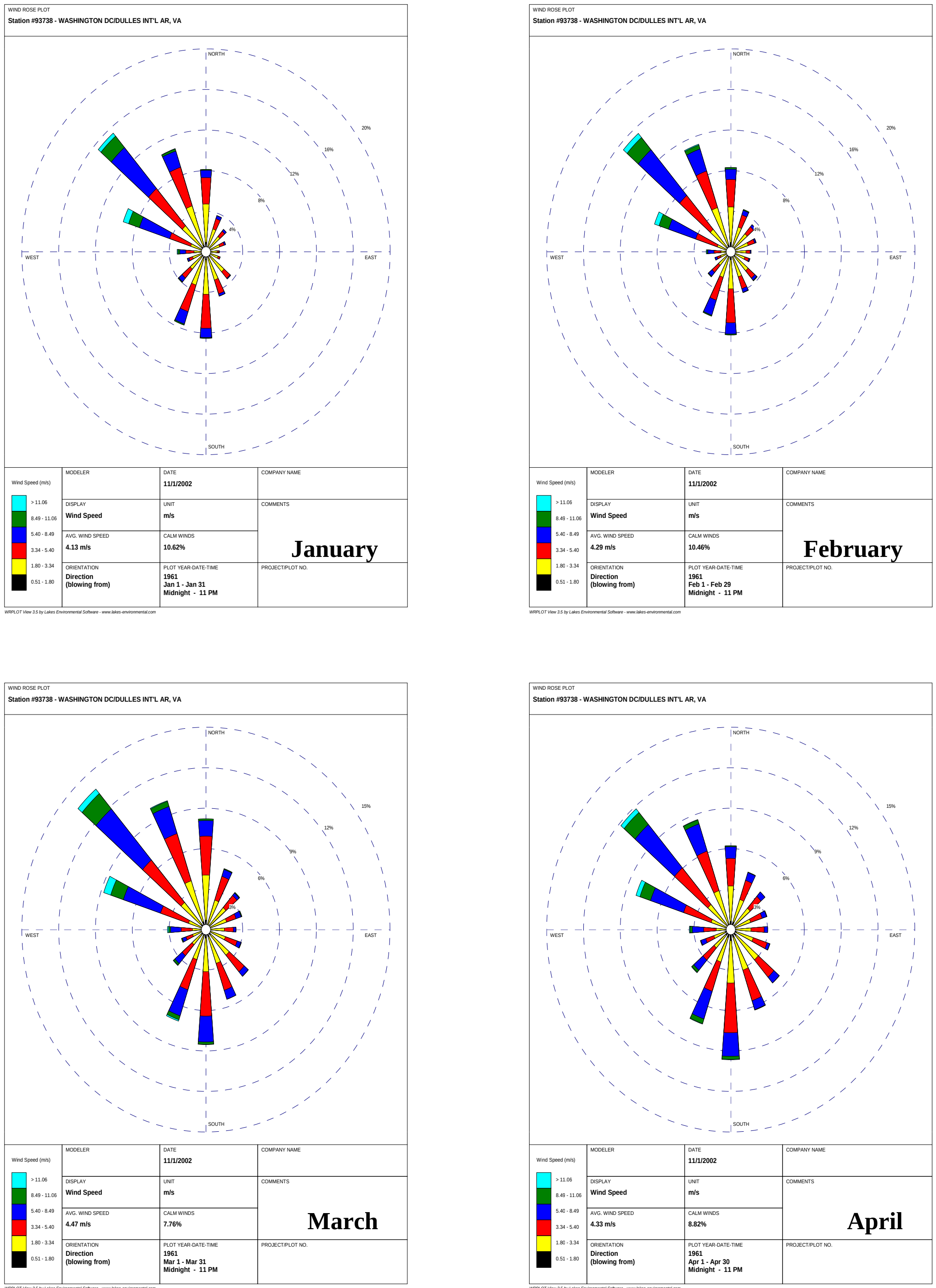
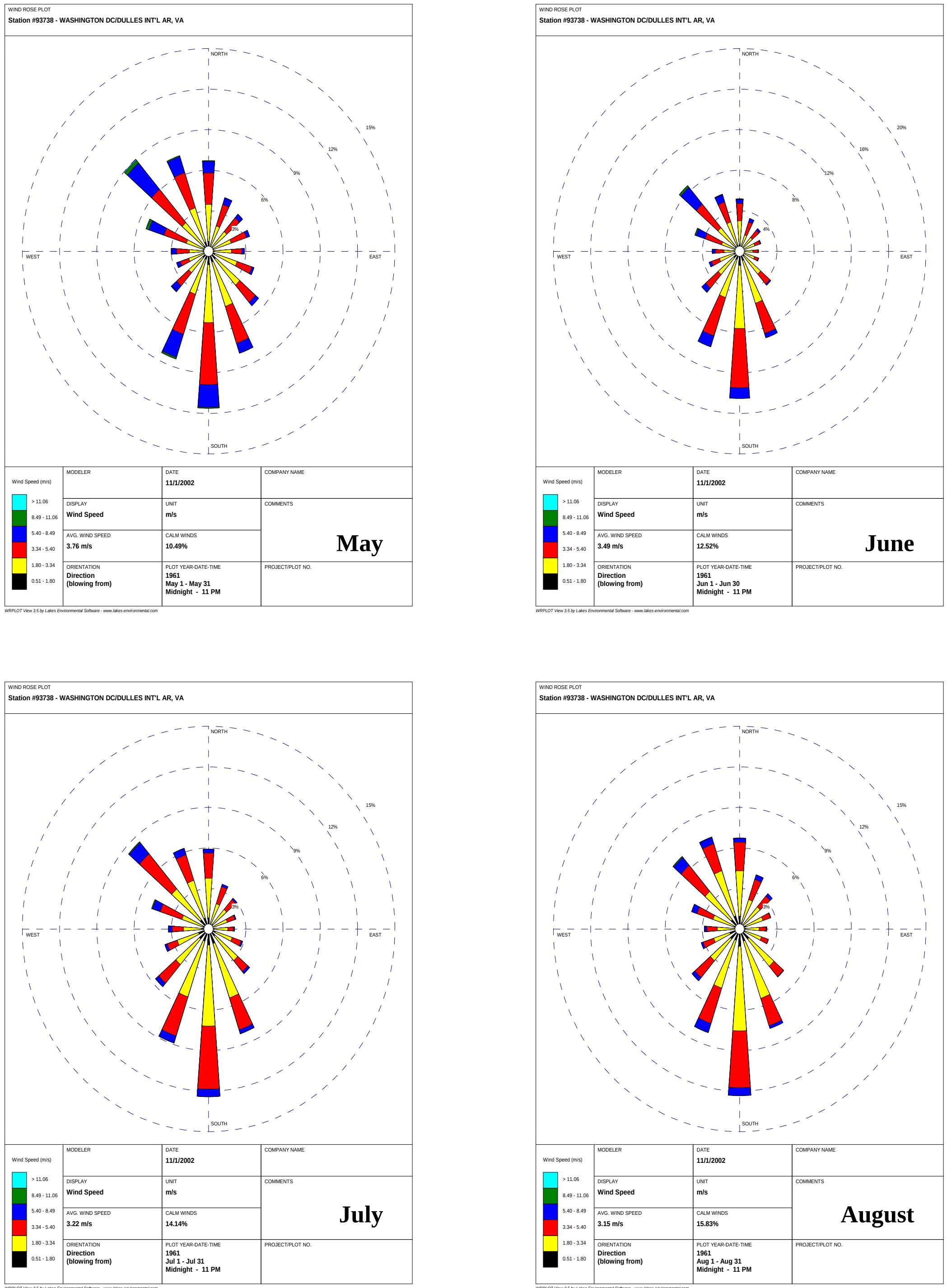
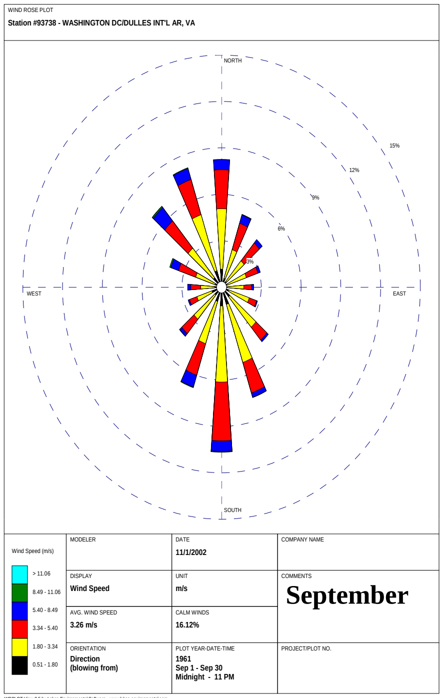
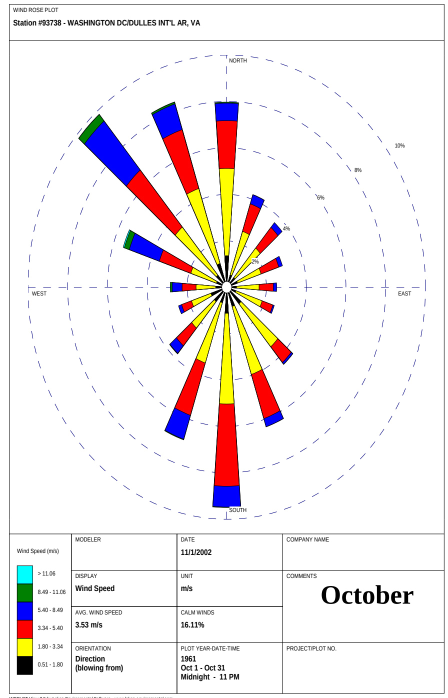


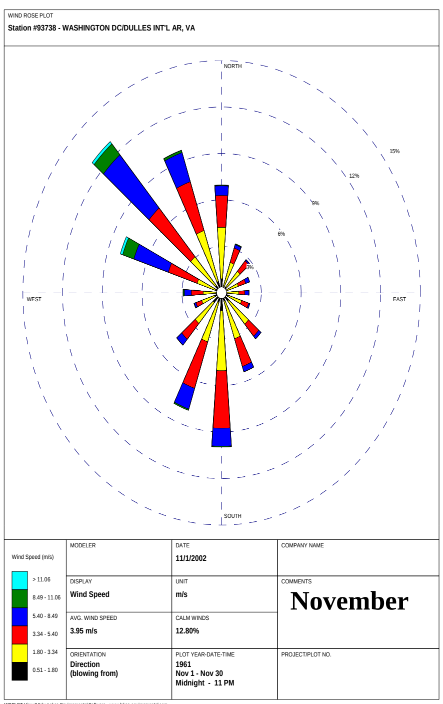
Figure 2.6: IAD Wind Rose Data – 1961 through 1991
http://www.wcc.nrcs.usda.gov/climate/windrose.html

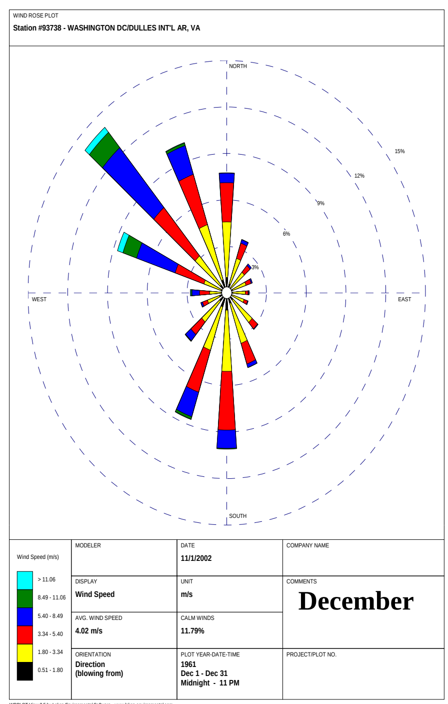


(Figure 2.6: IAD Wind Rose Data – 1961 through 1991 Cont'd.)









(Figure 2.6: IAD Wind Rose Data – 1961 through 1991 Cont'd.)

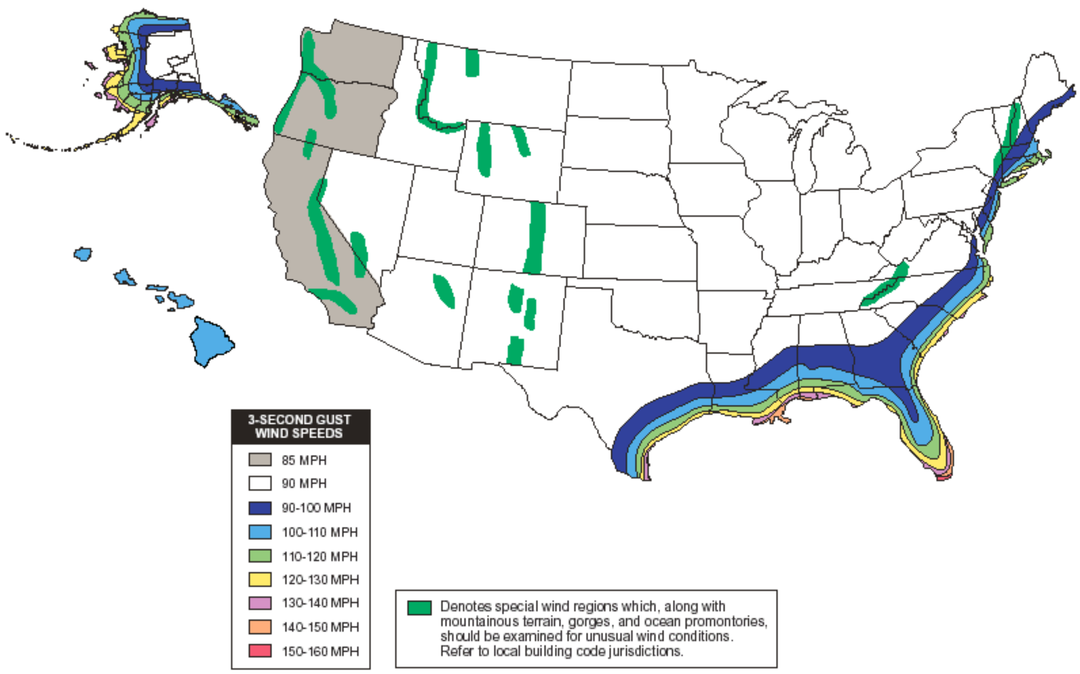
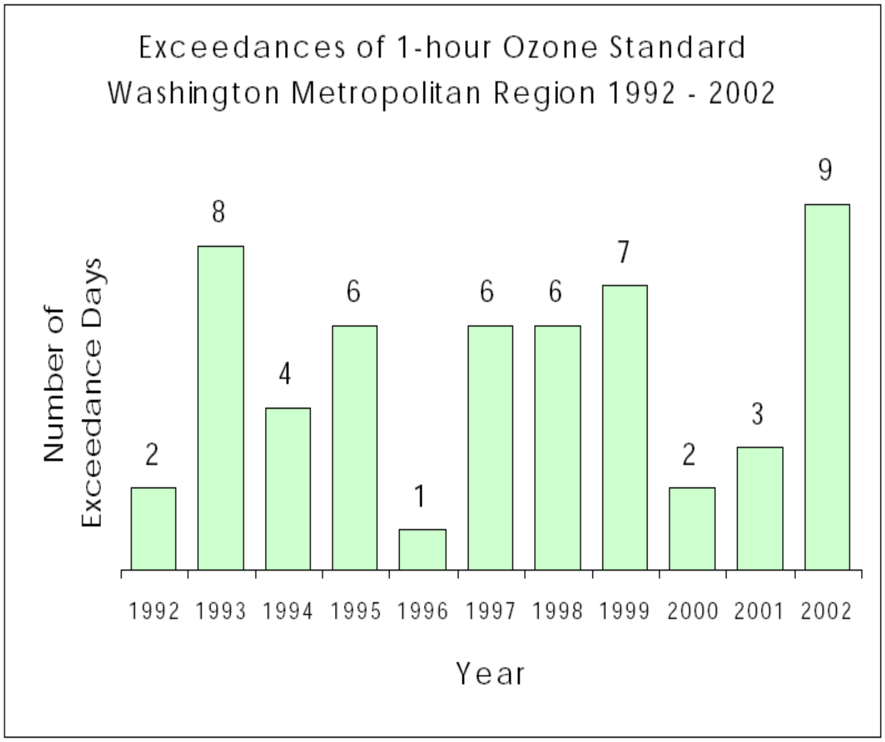


Figure 2.7: ASCE 50-Year Wind Zones (ASCE 7-98, 2000)



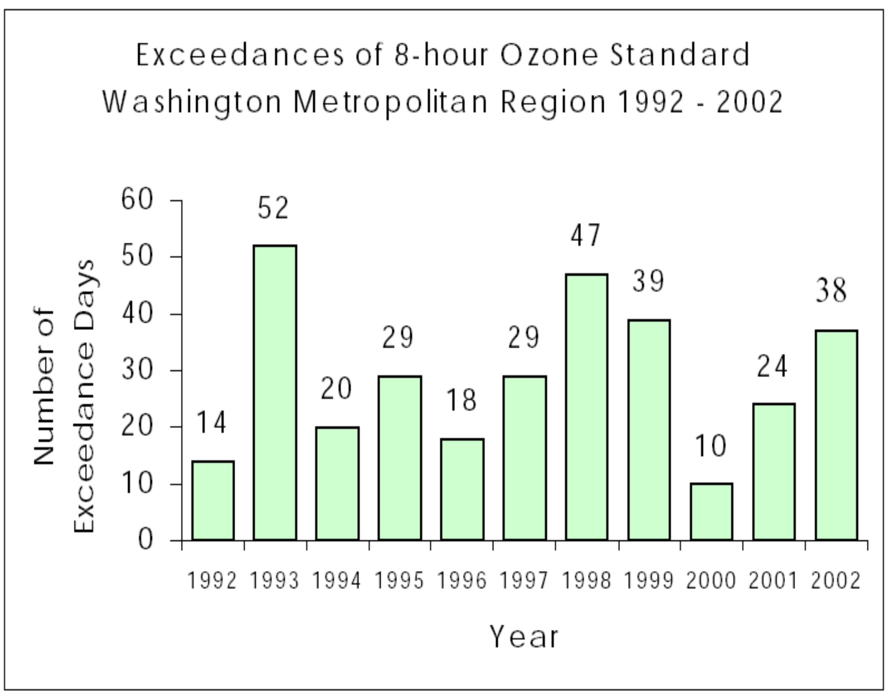


Figure 2.8: Local Ozone Exceedances

Figure 2.9: Location of WeatherNet Station on Confinement Building Roof

Figure 2.10: Topographic Map of NIST Site

Figure 2.10: Topographic Map of NIST Site

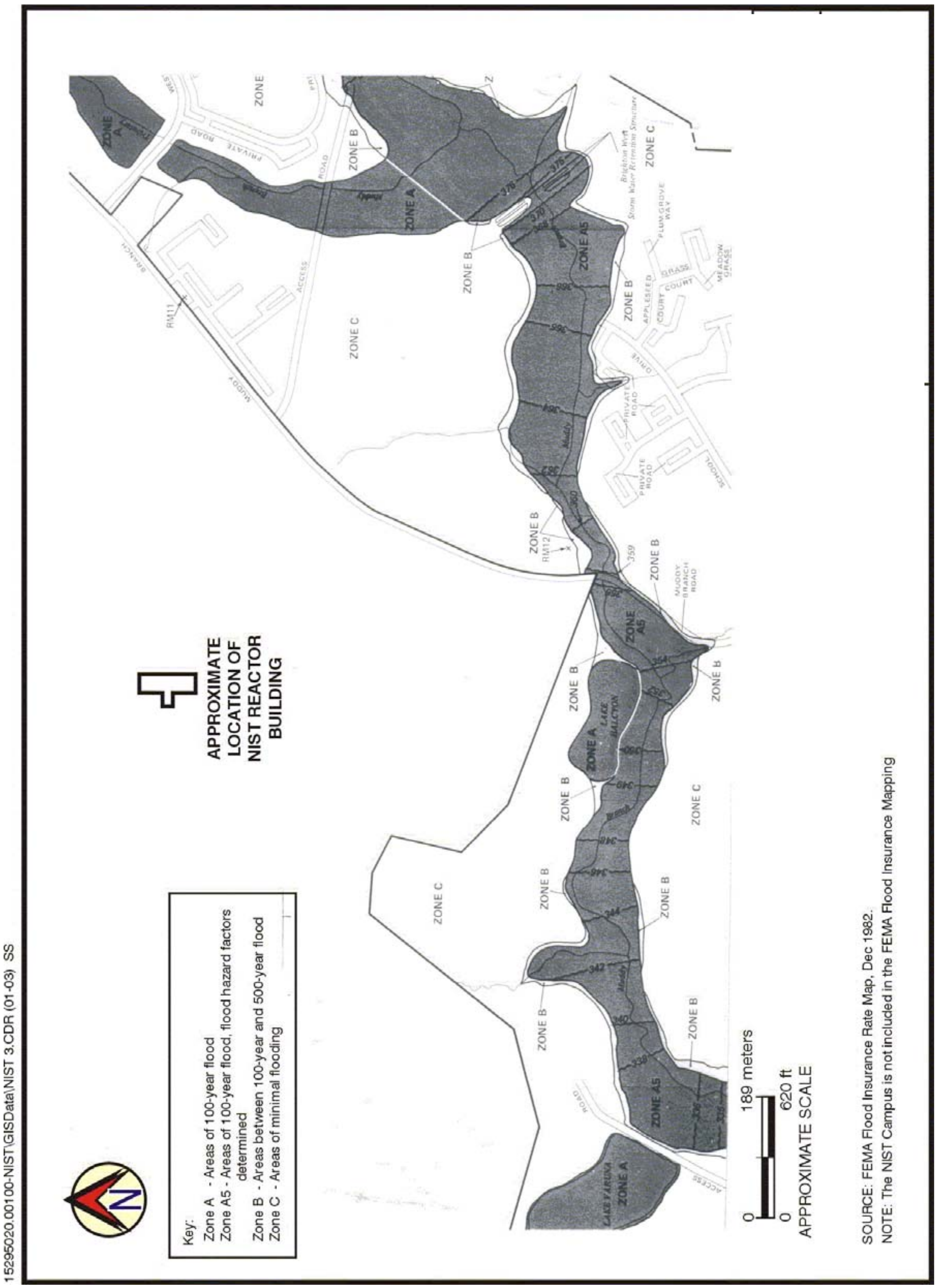


Figure 2.11: Flood Zone Map of Area Near NBSR Site

Figure 2.11: Flood Zone Map of Area Near NBSR Site

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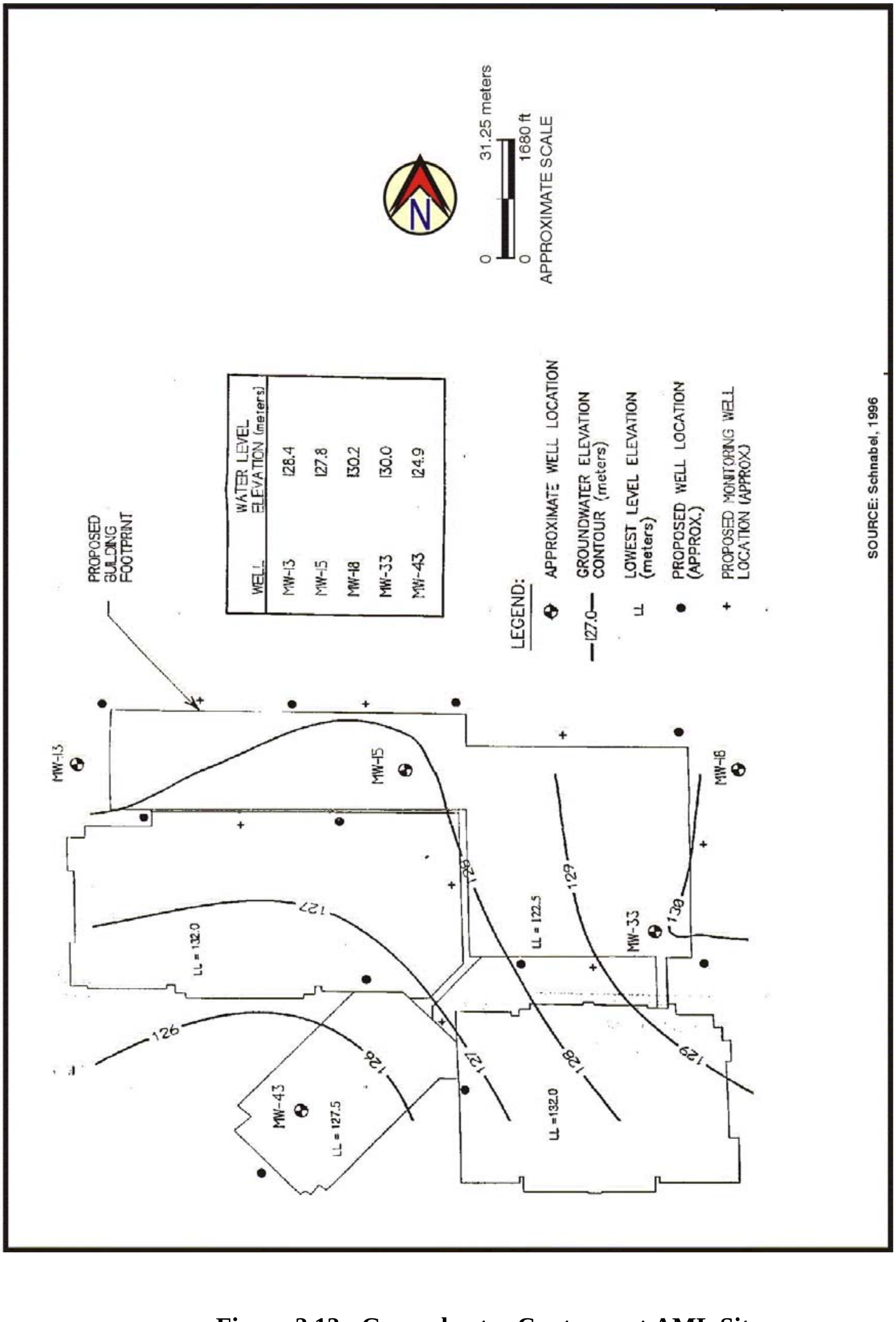
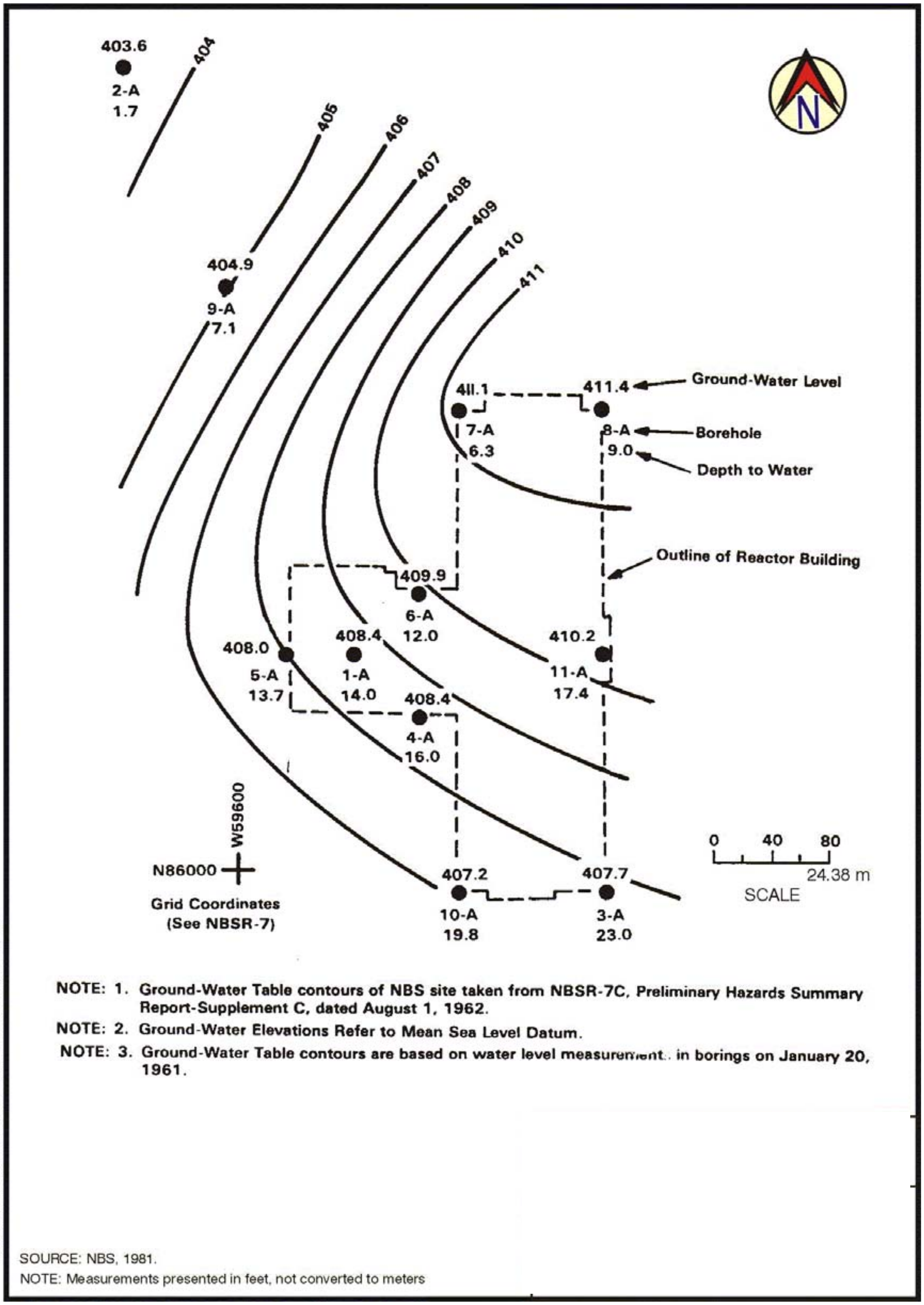


Figure 2.12: Groundwater Contours at AML Site

Figure 2.12: Groundwater Contours at AML Site



15295020.00100-NIST\GISData\NIST 1.CDR (01-03) SS

Figure 2.13: Groundwater Contour at NBSR Site

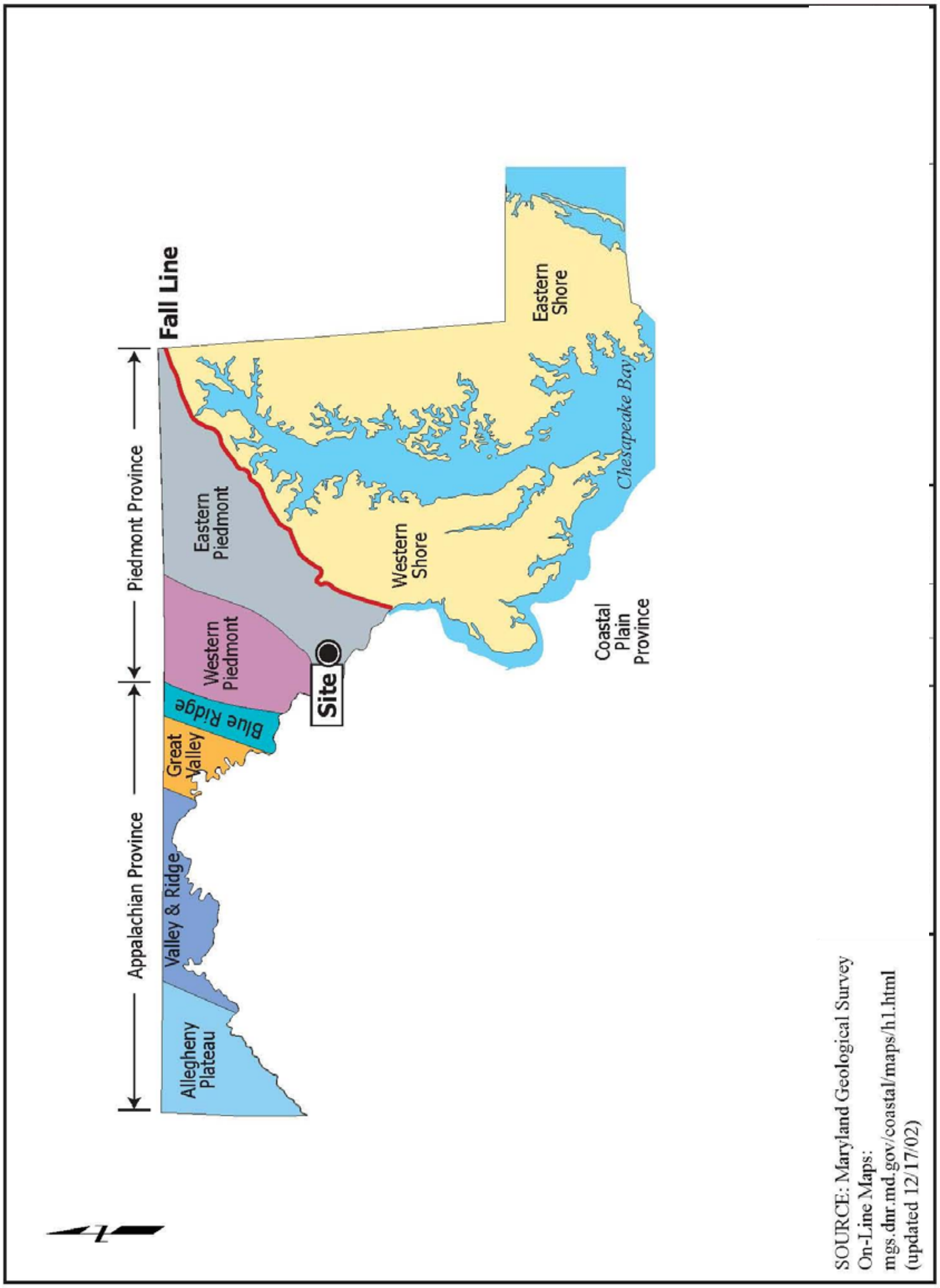


Figure 2.14: Physiographic Provinces in Maryland

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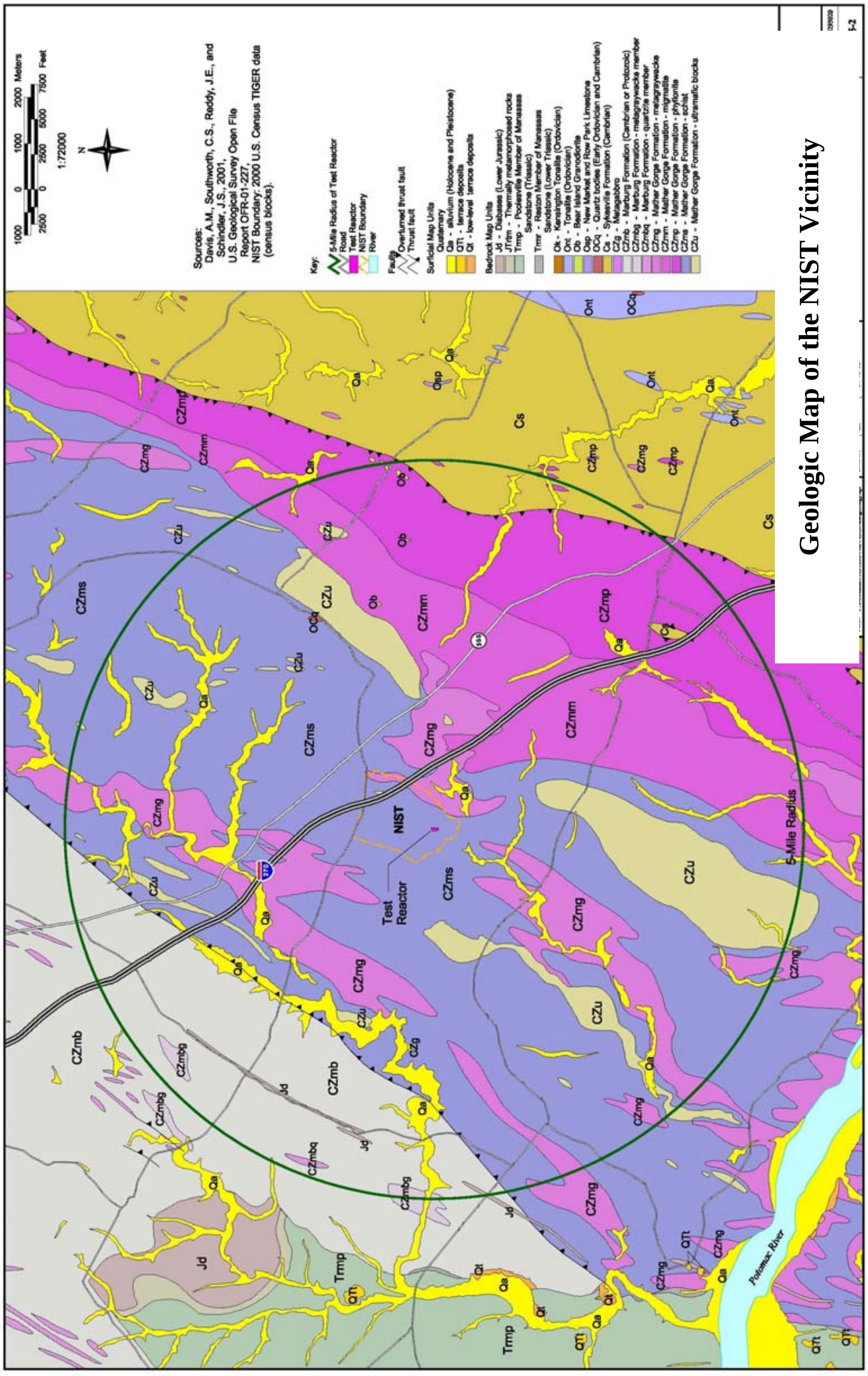

Figure 2.15: Geologic Map of NIST Vicinity

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Era	Period	Epoch	Age Estimate (millions of years before present)	Geologic Formations in Project Area
Cenozoic	Quaternary	Holocene	0.010	Alluvium Lower Terrace Deposits Upper Terrace Deposits
		Pleistocene	1.8	
	Tertiary	Pliocene	5	
		Miocene	24	
		Oligocene	34	
		Eocene	55	
		Paleocene	65	
Mesozoic	Cretaceous	Late Cretaceous	96	
		Early Cretaceous	145	
	Jurassic		213	Diabase intrusives
	Triassic		248	Manassas Sandstone, Poolesville Member Manassas Sandstone, Reston Member
Paleozoic	Permian		286	
	Pennsylvanian		325	
	Mississippian		360	
	Devonian		410	
	Silurian		490	
	Ordovician		505	
	Cambrian		544	Sykesville Formation
Precambria	Proterozoic		2500	Marburg Formation Mather Gorge Formation
	Archean		3800	
	Hadean		4500	

Sources: http://geology.er.usgs.gov/paleo/geotime.shtml; Drake, Southworth and Lee (1999)

Figure 2.16: Strategraphic Column and Geologic Time Scale

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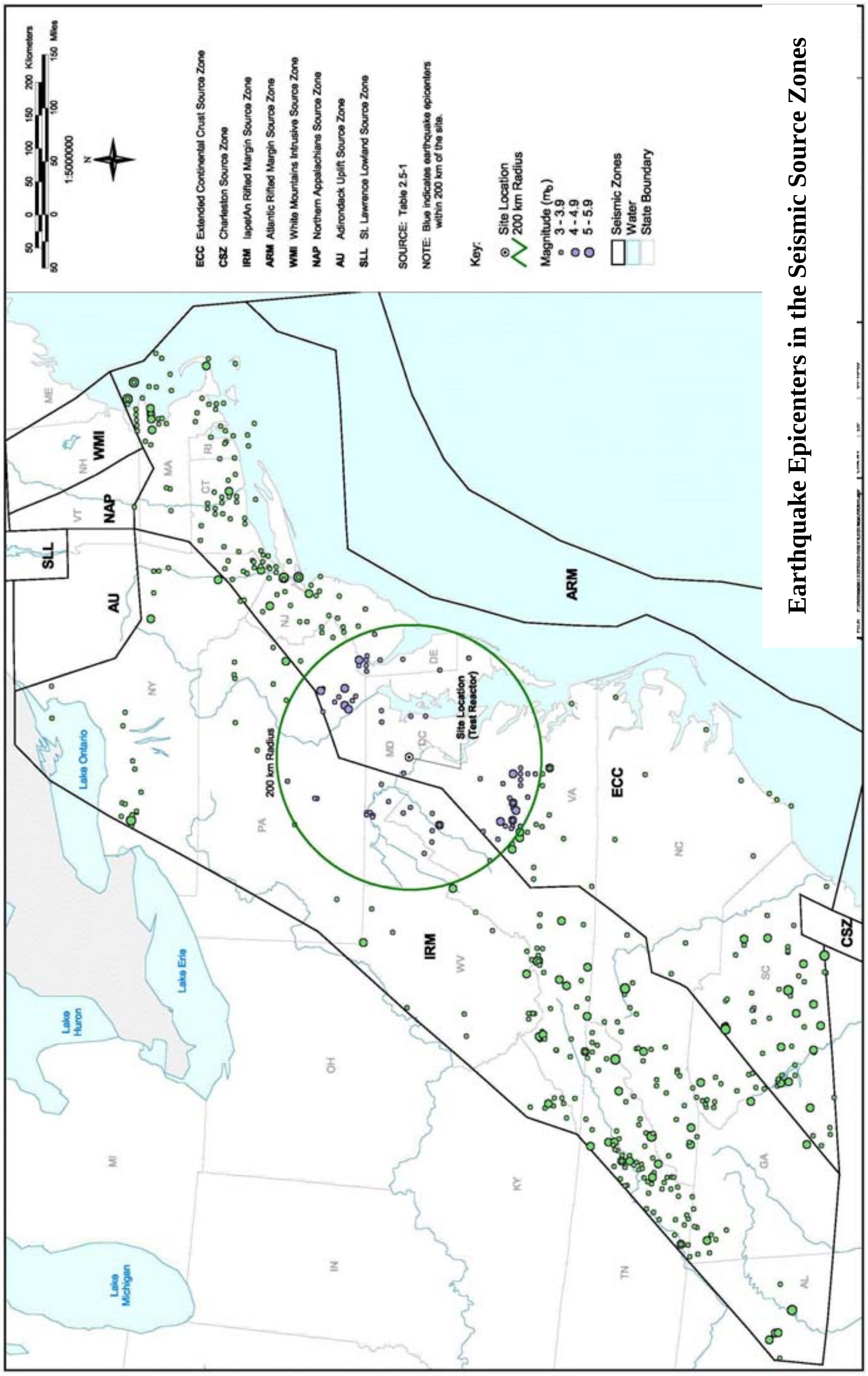

Figure 2.17: Earthquake Epicenters in the Seismic Source Zones

Figure 2.17: Earthquake Epicenters in the Seismic Source Zones

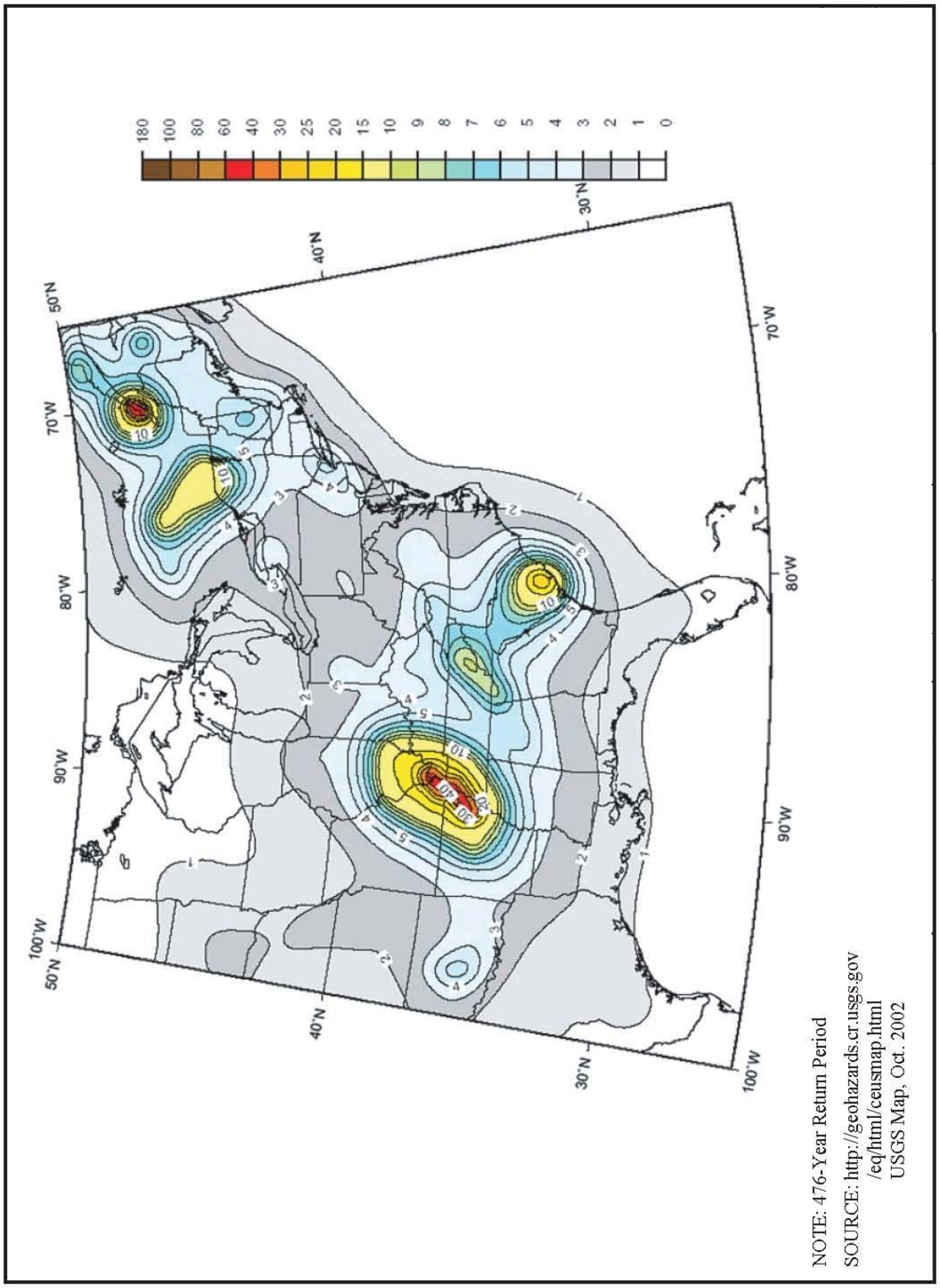

Figure 2.18a: USGS Map of Peak Acceleration (%g) with 10% Probability of Exceedance in 50 Years

Figure 2.18a: USGS Map of Peak Acceleration (%g) with 10% Probability of Exceedance in 50 Years

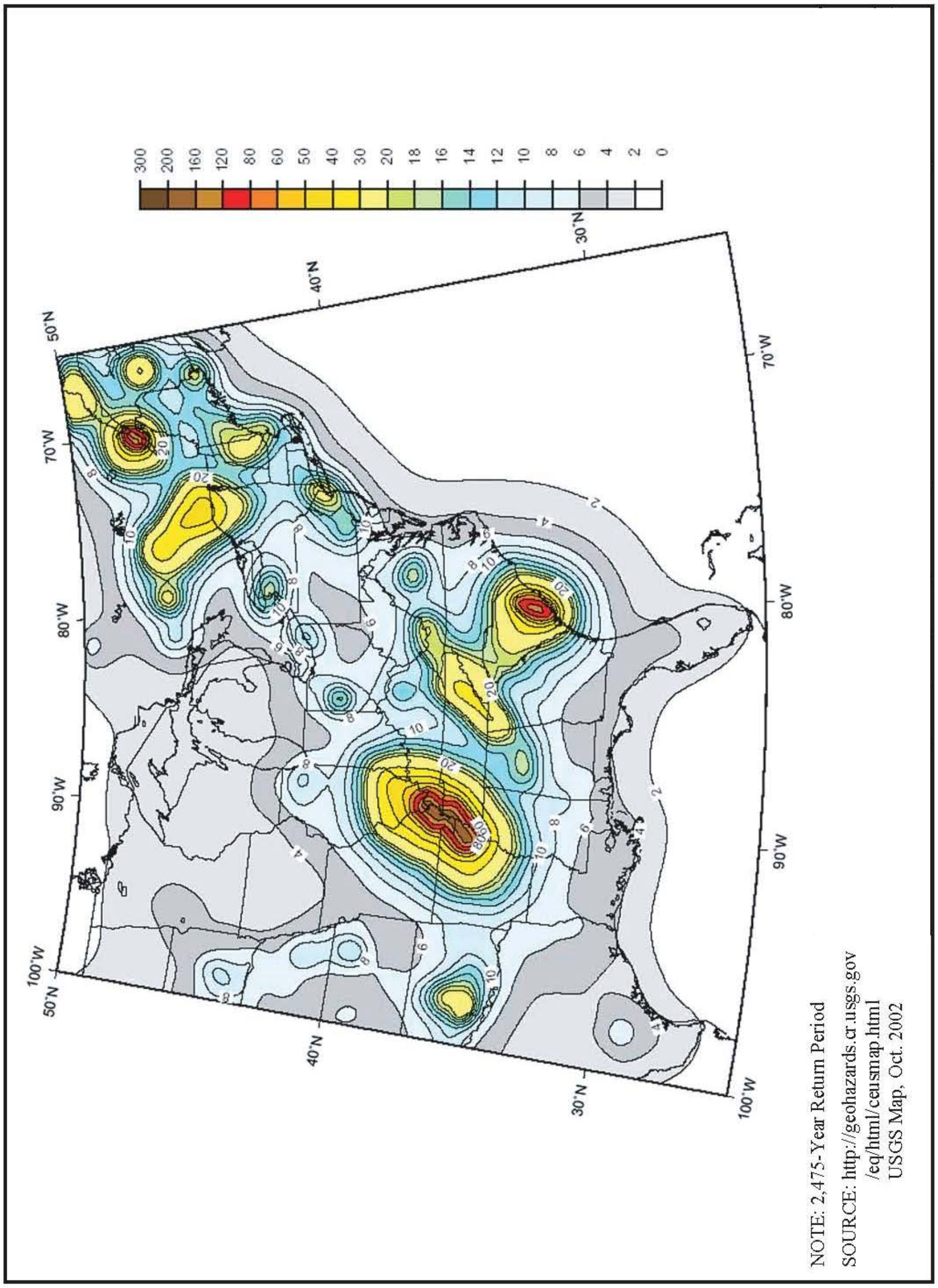

Figure 2.18b: USGS Map of Peak Acceleration (%g) with 2% Probability of Exceedance in 50 Years

Figure 2.18b: USGS Map of Peak Acceleration (%g) with 2% Probability of Exceedance in 50 Years

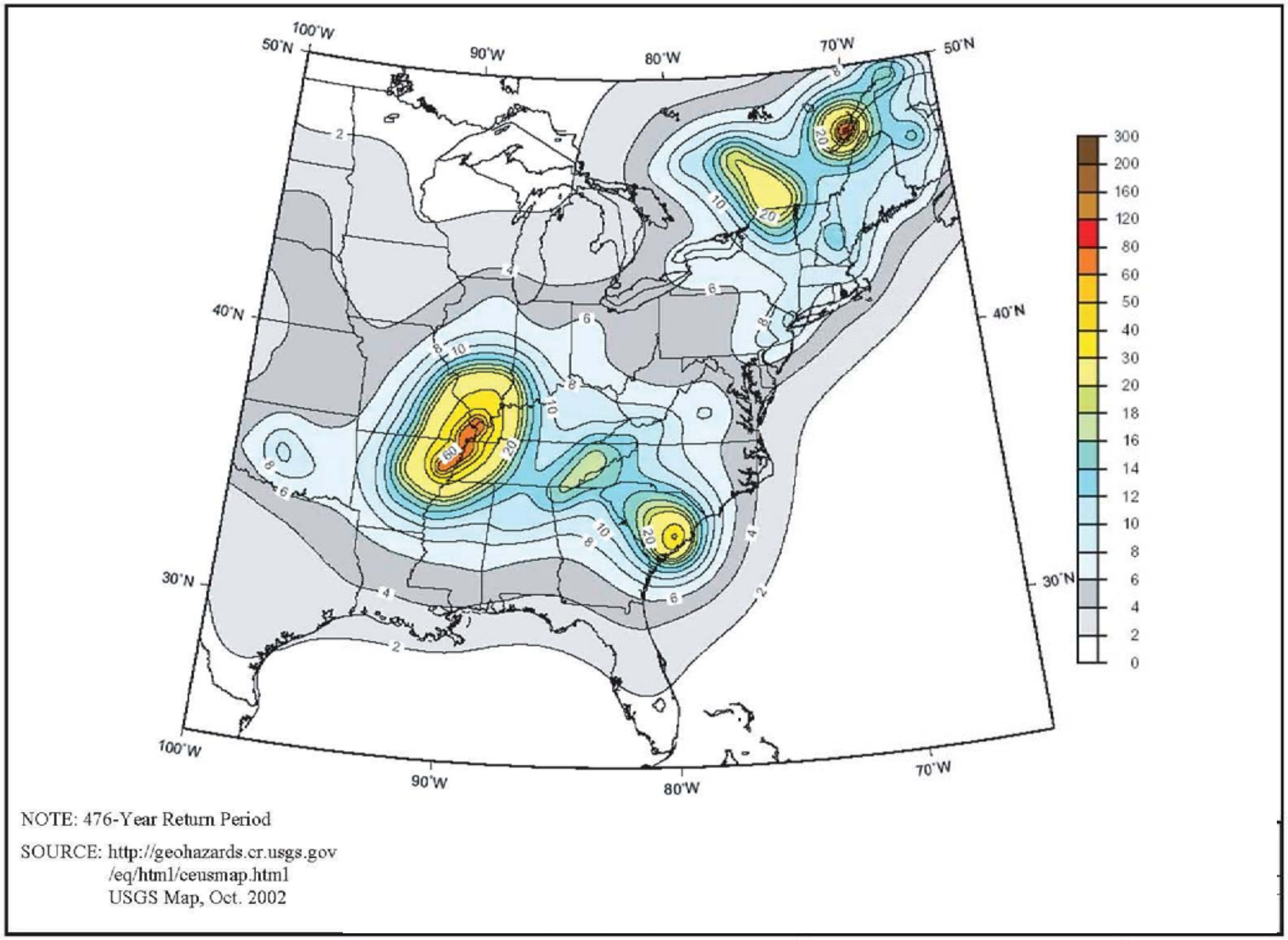

Figure 2.18c: USGS Map of 0.2 SEC Spectral Acceleration (%g) with 10% Probability of Exceedance in 50 Years

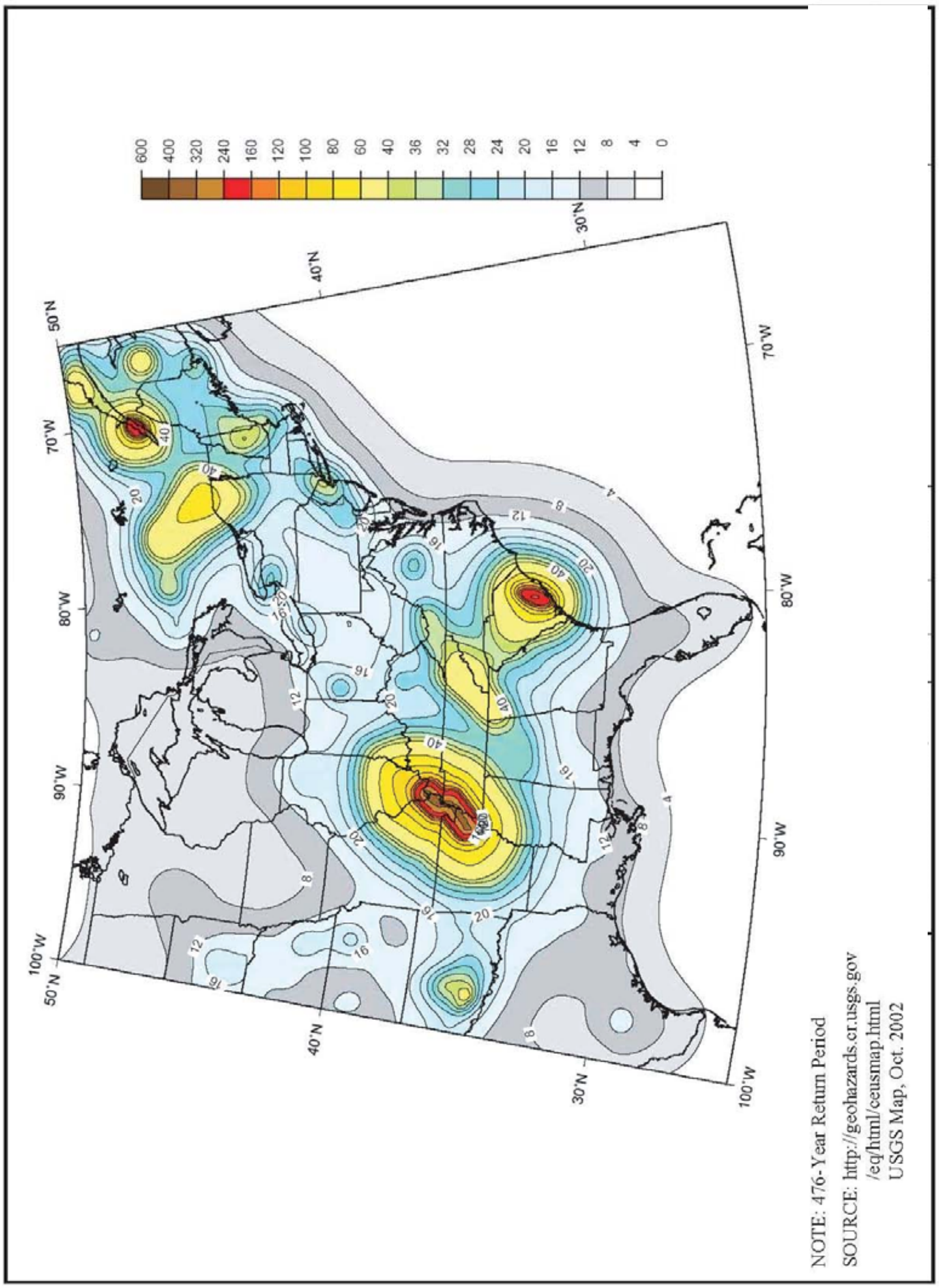

Figure 2.18d: USGS Map of 0.2 SEC Spectral Acceleration (%g) with 2% Probability of Exceedance in 50 Years

Figure 2.18d: USGS Map of 0.2 SEC Spectral Acceleration (%g) with 2% Probability of Exceedance in 50 Years

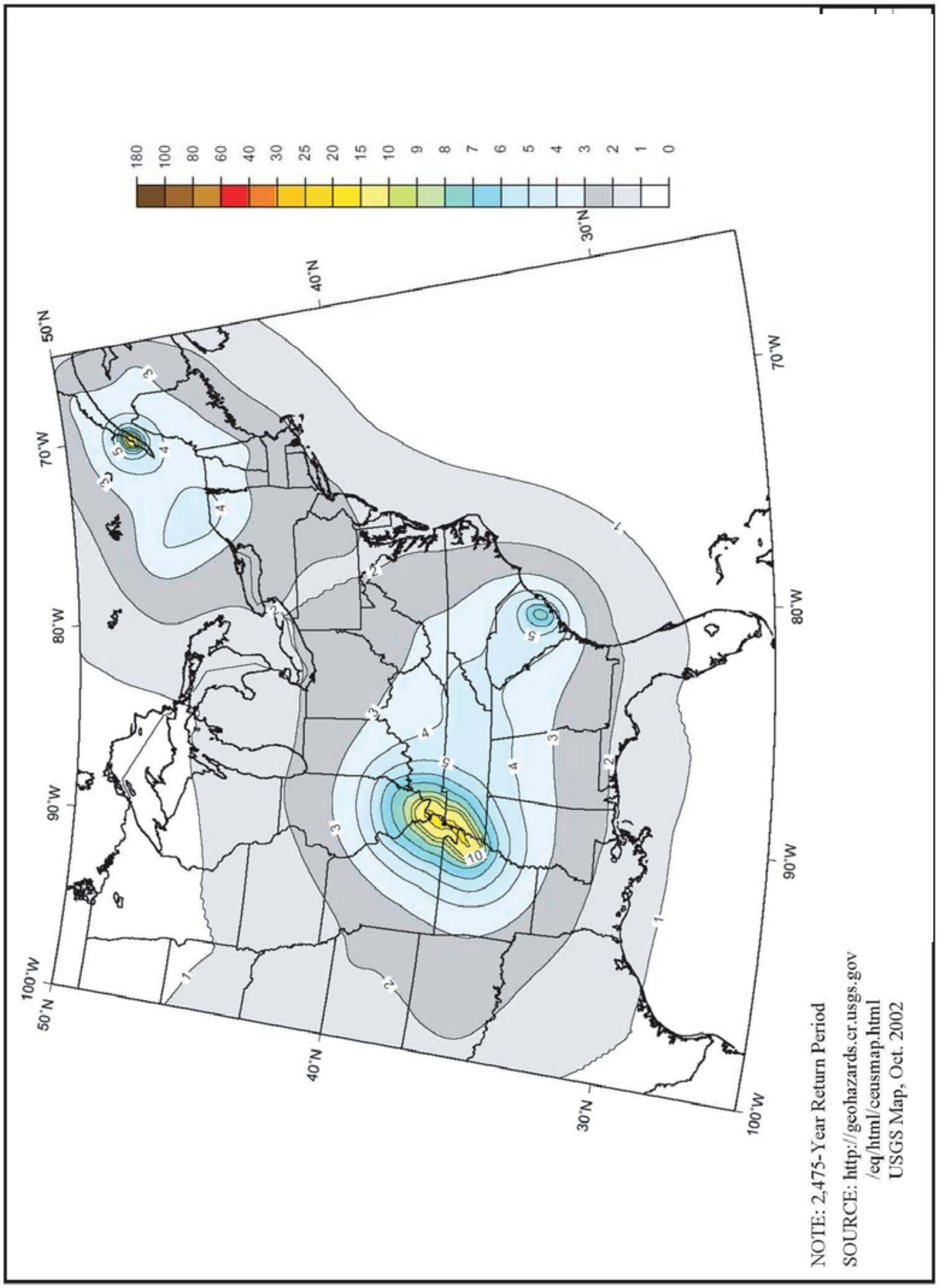

Figure 2.18e: USGS Map of 1.0 SEC Spectral Acceleration (%g) with 10% Probability of Exceedance in 50 Years

Figure 2.18e: USGS Map of 1.0 SEC Spectral Acceleration (%g) with 10% Probability of Exceedance in 50 Years

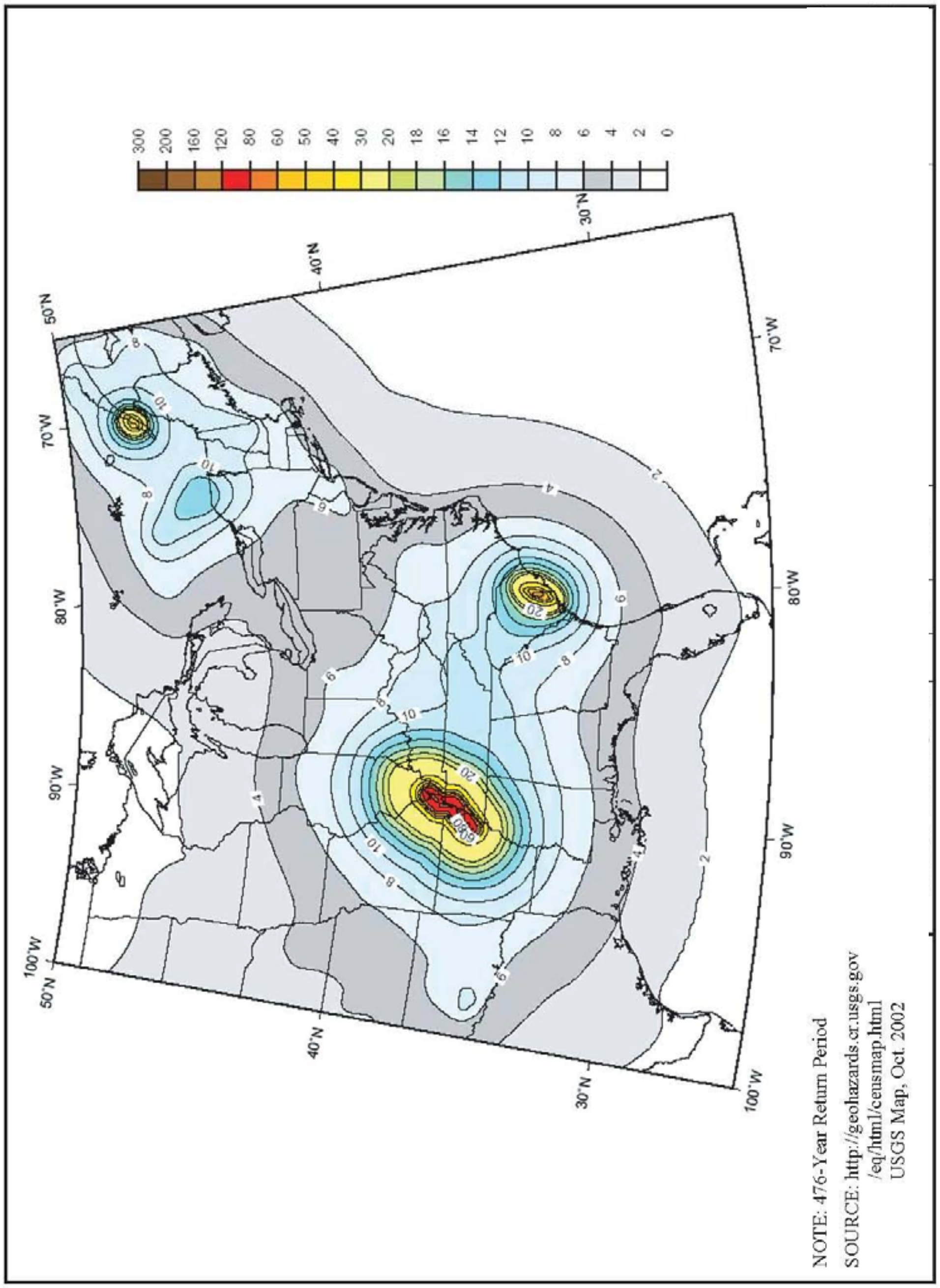

Figure 2.18f: USGS Map of 1.0 SEC Spectral Acceleration (%g) with 2% Probability of Exceedance in 50 Years

Figure 2.18f: USGS Map of 1.0 SEC Spectral Acceleration (%g) with 2% Probability of Exceedance in 50 Years

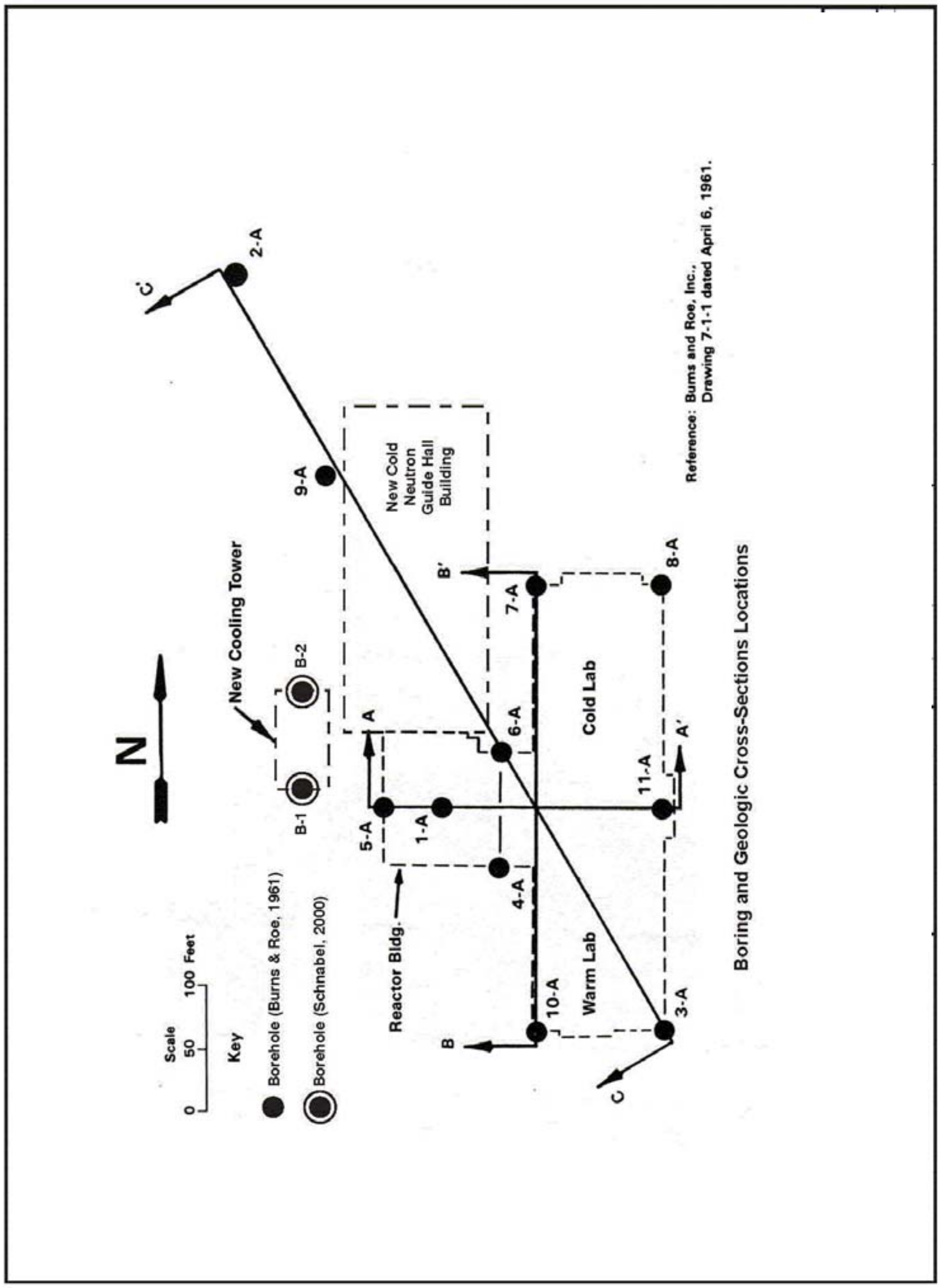

Figure 2.19: Boring and Geologic Cross-Section Locations at NBSR Site

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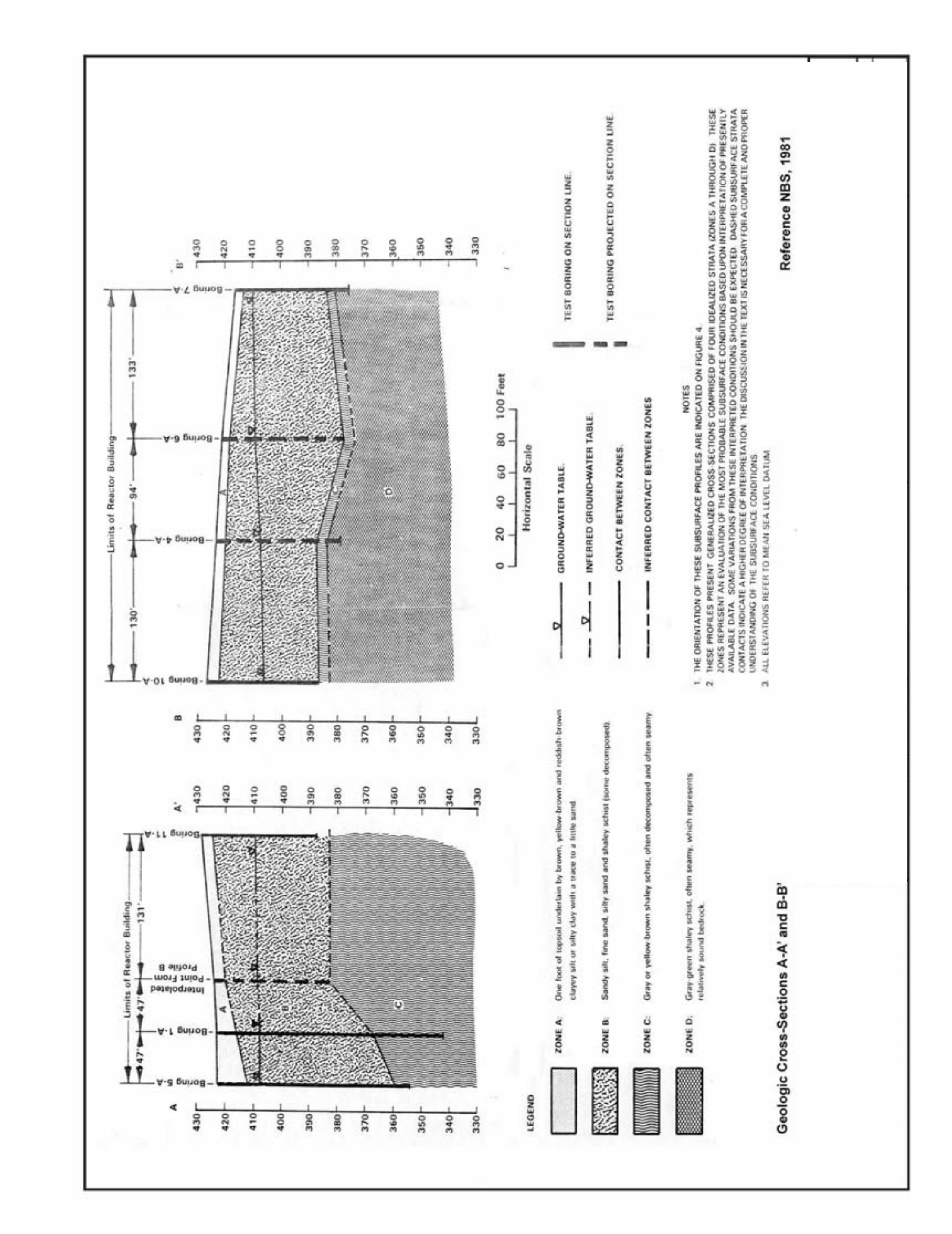

Figure 2.20: Geologic Cross-Sections A-A' and A-B' (see Figure 2.19)

Figure 2.20: Geologic Cross-Sections A-A' and A-B' (see Figure 2.19)

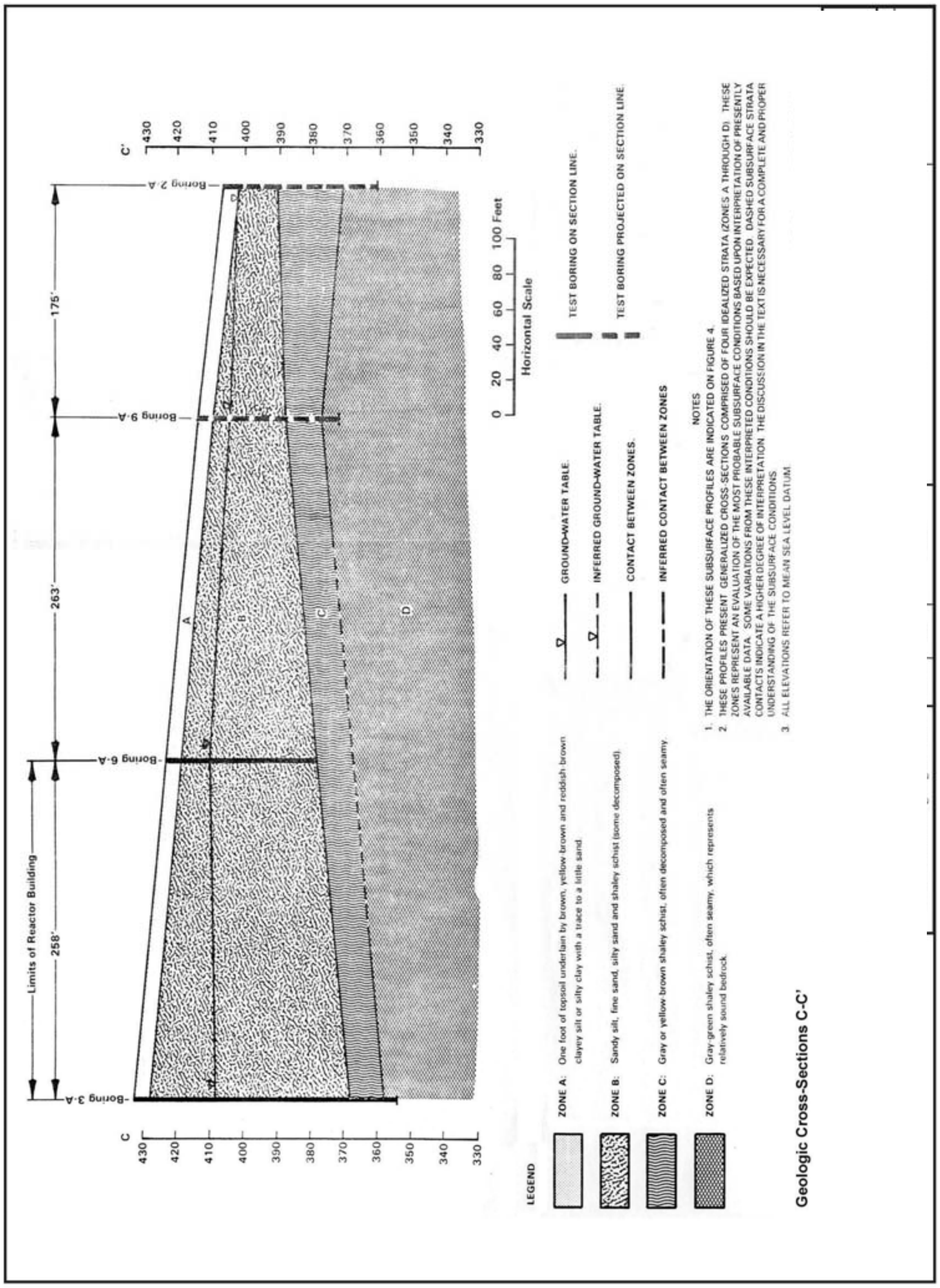

Figure 2.21: Geologic Cross-Sections C-C' (see Figure 2.19)

Figure 2.21: Geologic Cross-Sections C-C' (see Figure 2.19)