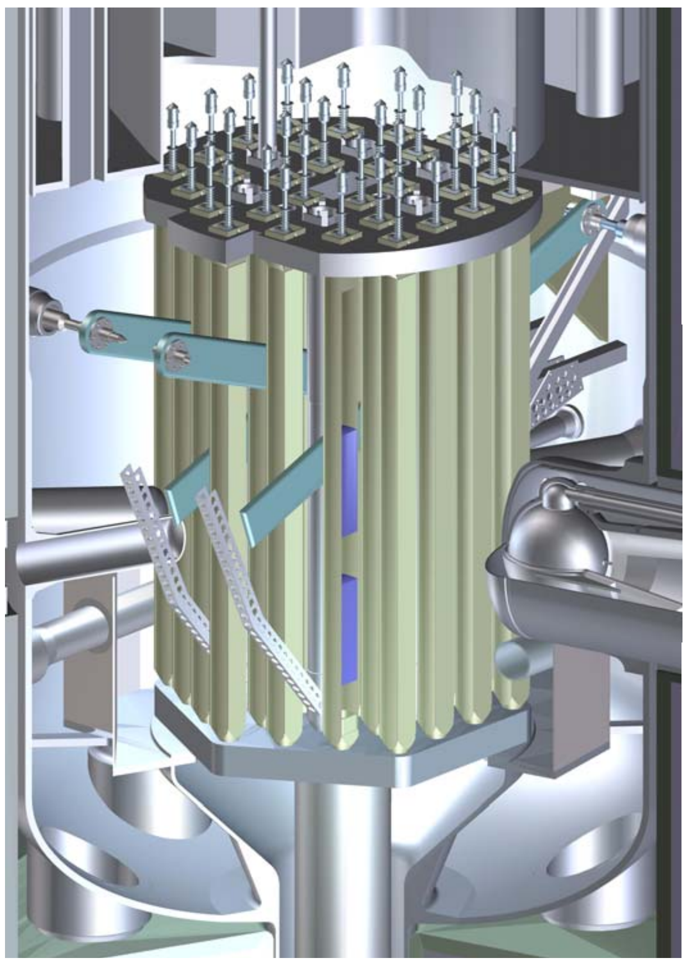
NISTIR 7105

Environmental Report for License Renewal for the National Institute of Standards and Technology Reactor – NBSR

NBSR 16



National Institute of Standards and Technology
Technology Administration, U.S. Department of Commerce

On the cover: A 3-D representation of the NBSR reactor core and internals.
Graphic Image by Paul Kopetka

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April 2004

U.S. DEPARTMENT OF COMMERCE
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TECHNOLOGY ADMINISTRATION
Phillip J. Bond, Under Secretary of Commerce for Technology
NATIONAL INSTITUTE OF STANDARDS AND TECHNOLOGY
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1 NIST CENTER FOR NEUTRON RESEARCH & NBSR

1.1 Introduction

The NIST Center for Neutron Research (NCNR) is a reactor-laboratory complex providing the National Institute of Standards and Technology (NIST) and the nation with a world-class facility for the performance of neutron-based research. The heart of this facility is the National Bureau of Standards Reactor (NBSR). The facility is located on the 575 acre NIST campus in upper Montgomery County, Maryland, approximately twenty miles northwest of the District of Columbia. NIST is a non-regulatory federal agency of the U.S. Commerce Department within the Technology Administration.

The NCNR is a national resource used by nearly 2000 engineers and scientists for some part of their research every year. In 2002, the researchers came from 30 other federal laboratories, 127 universities, 47 industrial laboratories, and 21 divisions and offices of NIST, and from all areas of the country. The major research areas include materials science, non-destructive evaluation, chemistry, biology, trace analysis, neutron standards and dosimetry, nuclear physics, and quantum metrology. A large cold neutron source and seven neutron guides provide the United States with world-class capabilities in cold-neutron research. Up to 25 cold and thermal neutron instruments provide the only internationally competitive neutron scattering capability in the country. As a result, the NCNR has served over 60% of the neutron users in the USA in the time period 2000-2003. The reactor is operated 24 hours a day, seven days a week with routine shutdowns every five-and-one-half weeks for partial refueling and as needed for maintenance. This operating schedule allows for the operation of a robust user program, which solicits proposals for experiments twice a year. Research done at the NCNR has formed the major justification for 8 major physics and chemistry prizes over the past decade. A recent study by an inter-agency working group of the Office of Science and Technology Policy (OSTP, 2002) stated "The NCNR is the highest performing and most used neutron facility in the United States at this time, and will remain in that position at least until the Spallation Neutron Source (SNS) is operational and robustly instrumented." The NBSR is the key to the success of the NCNR, which is critical to national goals, and is at the forefront internationally.

The NBSR is a heavy water moderated and cooled, enriched fuel, tank type reactor designed to operate at 20 MW of power. It is a custom designed variation of the Argonne CP-5 class reactor; it differs from the CP-5 in its power rating, core configuration and cold neutron source, but retains the proven technology. The three most notable modifications to this basic design are: a 7-inch (18-cm) gap between the upper and lower fuel regions in each fuel element to reduce the fast neutron background in the neutron beams; a double plenum at the bottom of the vessel to provide optimized cooling to the core; and the method for remote handling of fuel elements during refueling.

The design of the NBSR includes many inherent, passive safety features. The prompt neutron lifetime is relatively long as a result of heavy water moderation. The reactivity coefficients of void and temperature are negative. The reactor operates in a low temperature, unpressurized condition and has no large stored energy content. Two inner structures within the reactor vessel retain heavy water in the event of a loss of water from the vessel. In the event of a loss of cooling water, one of these structures immediately supplies emergency coolant flow to the elements without any operator intervention, while the other maintains water around the lower half of the core. An overhead reserve tank can supply heavy water for emergency cooling either to the top or to the bottom of the elements for extended periods of time.

1.2 General Description

The NCNR reactor-laboratory complex, located on the National Institute of Standards and Technology's campus approximately 20 miles (32 km) northwest of Washington, DC, provides NIST and the nation with an extensive facility for neutron-based research in biology, chemistry, engineering, materials science, and physics.

The NBSR is a highly enriched-uranium, heavy water cooled and moderated, and vessel type reactor. This type of reactor was chosen because of its well-degraded or thermalized neutron spectrum, its high flux, its flexibility for research, and its inherent safety. The high fluxes generated by the NBSR reactor are used in five principal ways:

a. To characterize the structure and dynamics of materials critical to the US economy
b. To image large structures, and to study nuclear and neutron physics
c. To develop material and radiation standards
d. To generate radioisotopes for activation analysis and tracer production
e. To study the effects of radiation on materials through in-pile irradiation

The NCNR reactor has a wide range of research capabilities. The liquid hydrogen cold source provides cold neutrons (neutrons slowed to speeds of 1000 m/s or less) directly to experiments in the Confinement Building, and through a network of seven neutron guides to experiments located in the Cold Neutron Guide Hall. Beam tubes provide thermal neutrons for experiments located within the confinement area immediately adjacent to the reactor. A pneumatic rabbit system provides researchers with the ability to automatically inject samples into the core region of the reactor, while vertical thimbles provide for their manual loading.

The fuel is U_3O_8 aluminum dispersion fuel enriched to 93%, which is clad in aluminum plate-type fuel element. The core is immersed in heavy water to thermalize fast moving neutrons to sustain the nuclear chain reaction, to remove heat created by the reaction, and finally to serve as the first stage of shielding.

The primary coolant system is closed, recirculating heavy water in an aluminum and stainless steel system. The heavy water is pumped through plate-type heat exchangers where it transfers its heat to light water (H_2O) before entering the core and then returning to the pumps. The secondary cooling system of light water transfers its heat to the atmosphere by means of evaporation from a cooling tower located outside of the Confinement Building.

The reactor operates at 20 MWt for 24 hours a day, 7 days a week with a routine shutdown every five-and-one-half weeks. This routine shutdown, which lasts approximately 10 days, is to refuel the reactor and perform maintenance.

1.3 Shared Facilities and Equipment

The Confinement Building, which is constructed of reinforced concrete and situated partially below grade, is attached to a laboratory complex dedicated primarily to nuclear-science-related research and other reactor support functions. Utilities such as municipal water and sewage, natural gas, and electricity are provided to the complex by the local utilities.

The Confinement Building has its own ventilation control system, capable of isolation mode of operation or dilution mode of operation to exhaust air to the atmosphere through an elevated stack located adjacent to the building.

1.4 Comparison with Similar Facilities

The NBSR has a large number of experimental beam lines. This type of reactor (using materials-testing-reactor (MTR) type plate fuel and heavy water cooled) is also being used at the Massachusetts Institute of Technology (MIT), and was used at Brookhaven National Laboratory, and at the Savannah River Plant before they ceased operation. Heavy water (D_2O) is used to obtain high flux values not otherwise achievable with that physical size of reactor. The design is a variation of the Argonne CP-5 class reactor.

1.5 Summary of Operations

Through 2001 NBSR has accumulated in excess of 2 million MW-hours of operation. The highly automated experimental facilities associated with the reactor allow it to be operated and utilized 24 hours a day, 7 days a week. Routine shutdowns are scheduled about every five-and-one-half weeks for partial refueling with an additional shutdown at the end of each calendar year. The reactor is normally on line approximately 250 days per year, and is fully utilized for experiments during that time.

1.6 Compliance with the Nuclear Waste Policy Act of 1982

The NBSR is a federally owned and operated facility that is part of the NIST. The U.S. Atomic Energy Commission (AEC) originally provided fuel for the operation of the NBSR. The U.S. Department of Energy (DoE) is the successor agency to the AEC. The DoE retains title to the uranium fuel used by NBSR. In a letter dated May 3, 1983, the DoE (R. L. Morgan) informed the NRC (H. Denton) of the title arrangement for the fuel. Specifically, the NBSR and the DoE have a contractual arrangement whereby DoE retains title to the fuel and is obligated to take the spent fuel and/or high-level waste for storage or reprocessing. All of the spent NBSR fuel has been returned to the DoE pursuant to this arrangement. A copy of the contract between NBSR and the DoE for fuel assistance is available.

1.7 References

Cappelletti, R.L., *et al*, "Materials Research With Neutrons at NIST," J. Res. Natl. Inst. Stand. Technol. **106** (2001) 127-230.

Office of Science and Technology Policy (OSTP) (June, 2002). *Report on the Status and Needs of Major neutron Scattering Facilities and Instruments in the United States*.

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 Appendix B. 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 Appendix C. 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° 7' 34" north and longitude 77° 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

Hurricane Events

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 (Appendix B). 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.

Water Levels and Groundwater Flow

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.

Permeability of Subsurface Geologic Material

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 (Appendix B)). 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 x 10^{-3} inch/sec (3.2 x 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).

Groundwater Velocity

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—(Appendix B)) 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 (Appendix B) 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 (Appendix B) 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 (Appendix B).

2.5.3 Seismicity

Table 2.5-1 of the URS report (Appendix B) 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 (Appendix B). 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 (Appendix B), 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 (Appendix B)]). 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 (Appendix B)]. 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 (Appendix B). 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 (Appendix B). 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.

2.5.8.1.1 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.

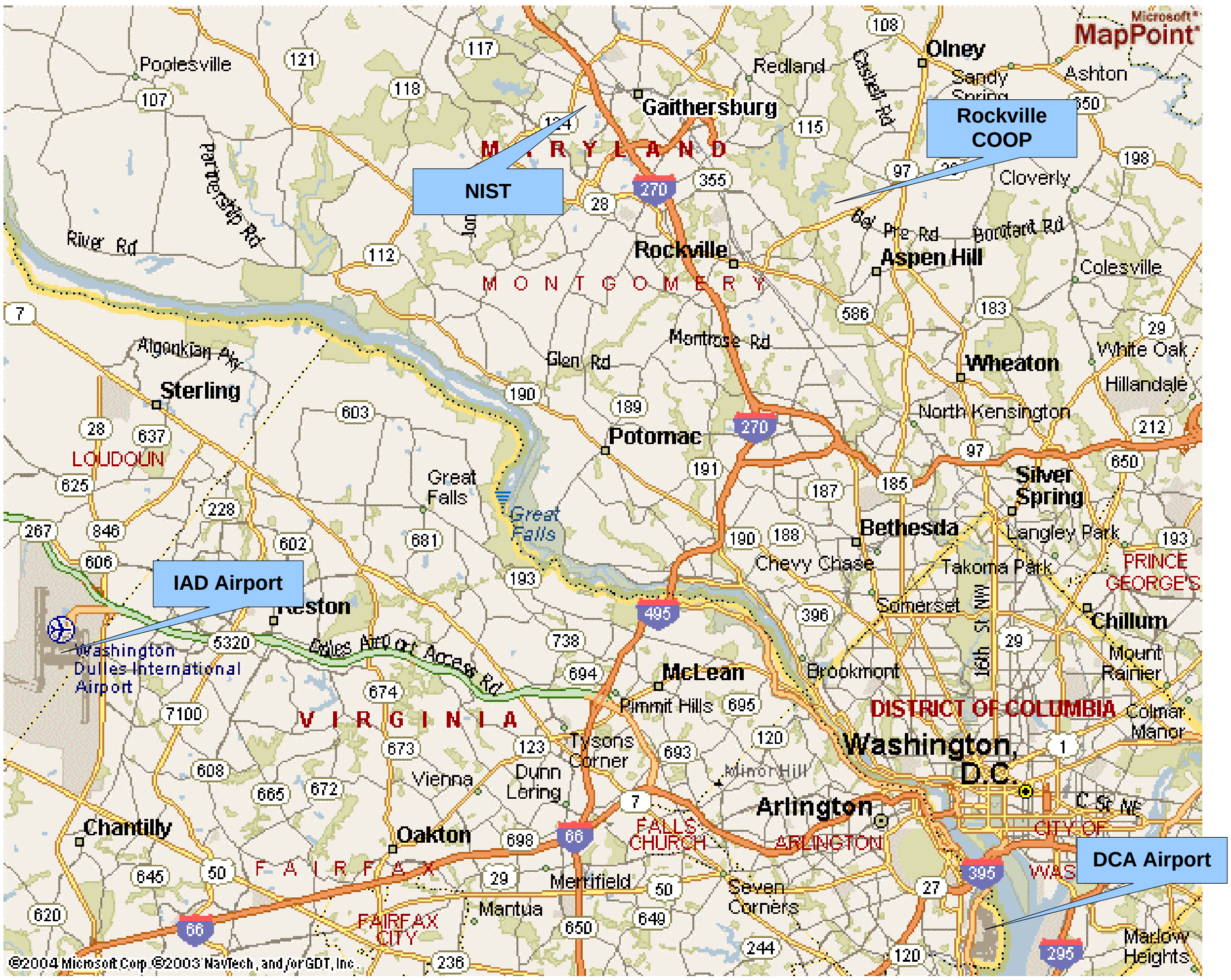


Figure 2.1: NIST Regional Map Showing Nearest Weather Stations

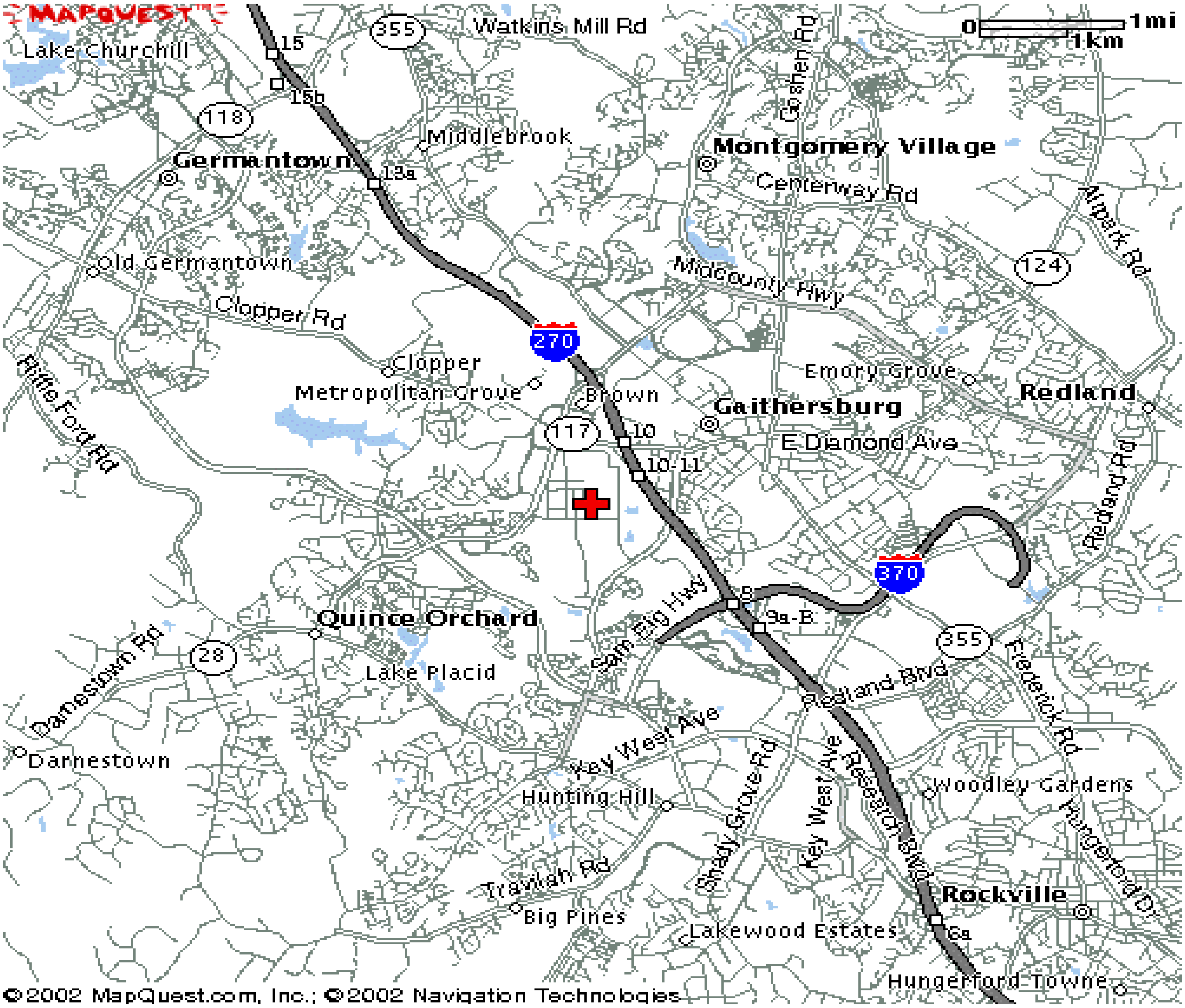
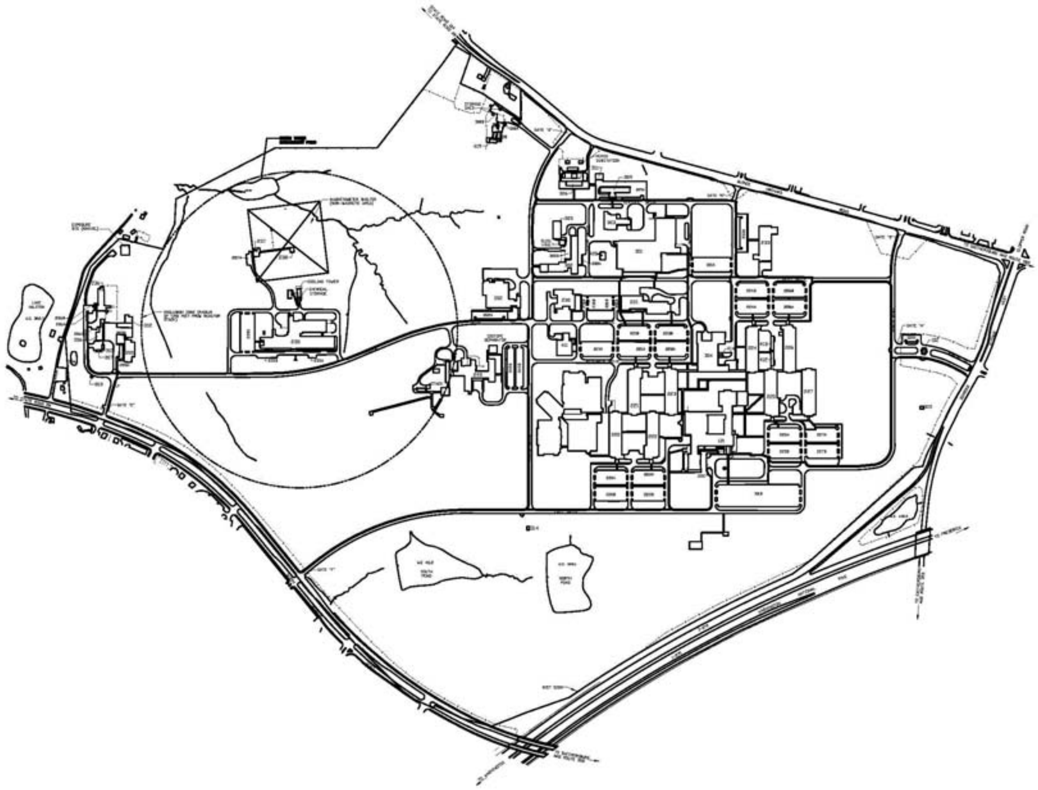
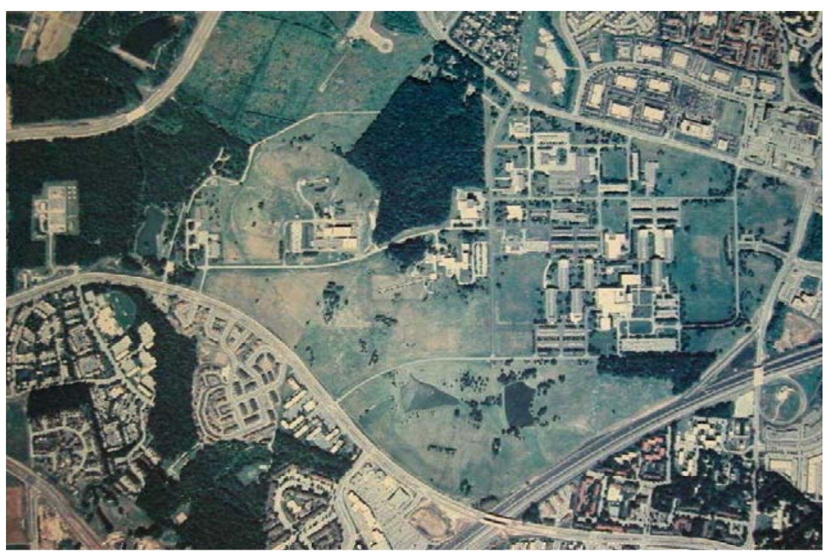


Figure 2.2: Immediate Area Surrounding NIST



Plan View



Photographic View

Figure 2.3: NIST Site Plan

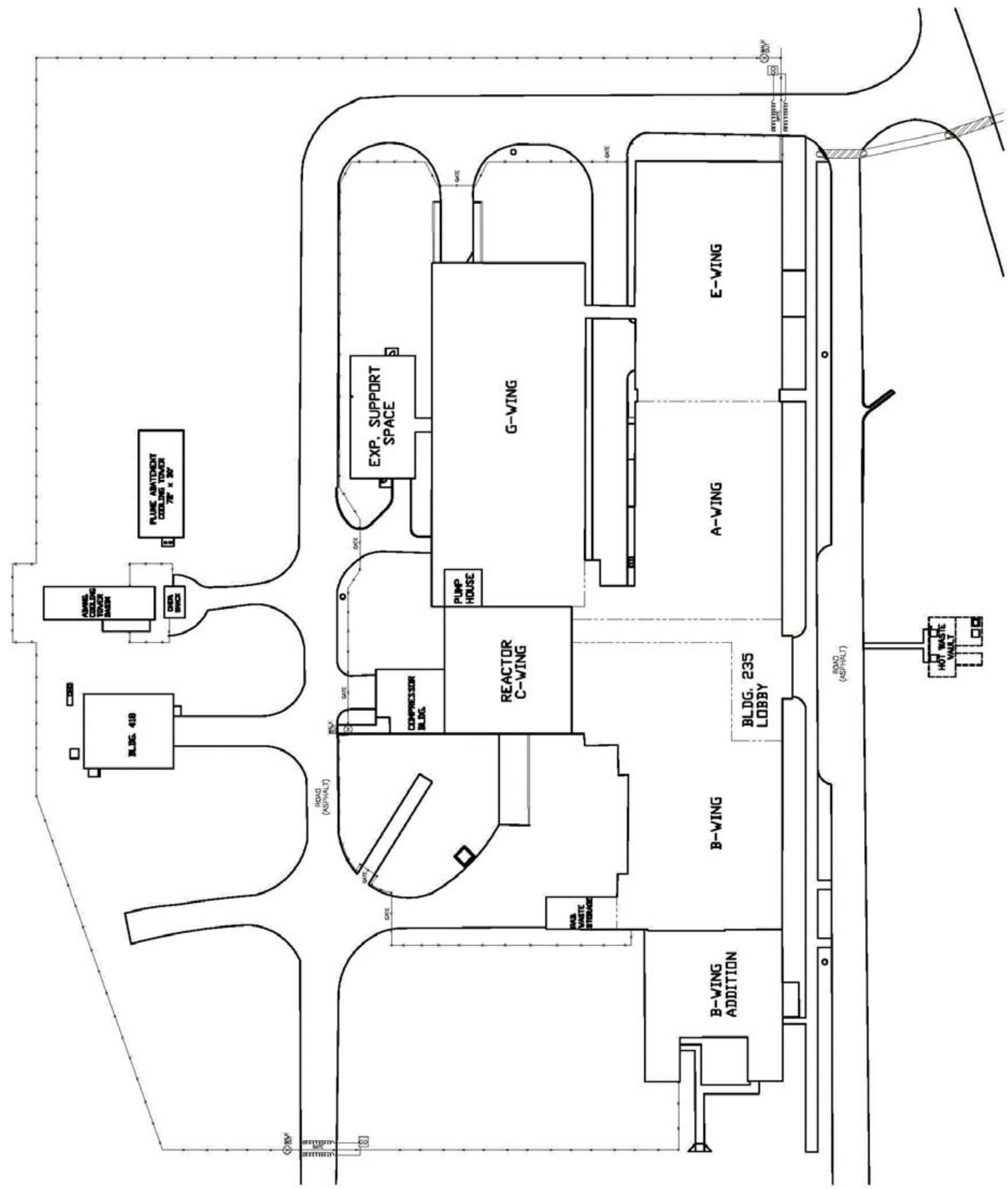


Figure 2.4: NCNR Facility at NIST Campus (Building 235)

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

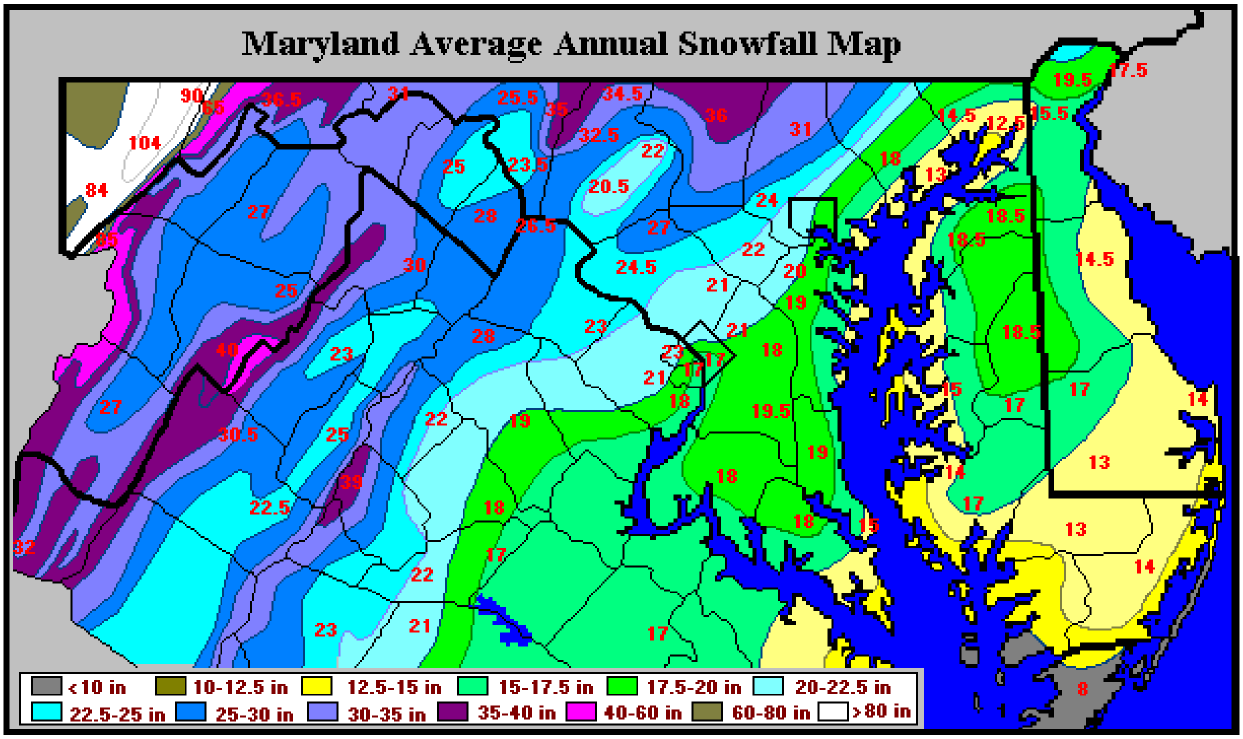


Figure 2.5: Washington Metropolitan Area Average Snowfall
[http://www.erh.noaa.gov/lwx/Historic_Events/snowmaps.htm]

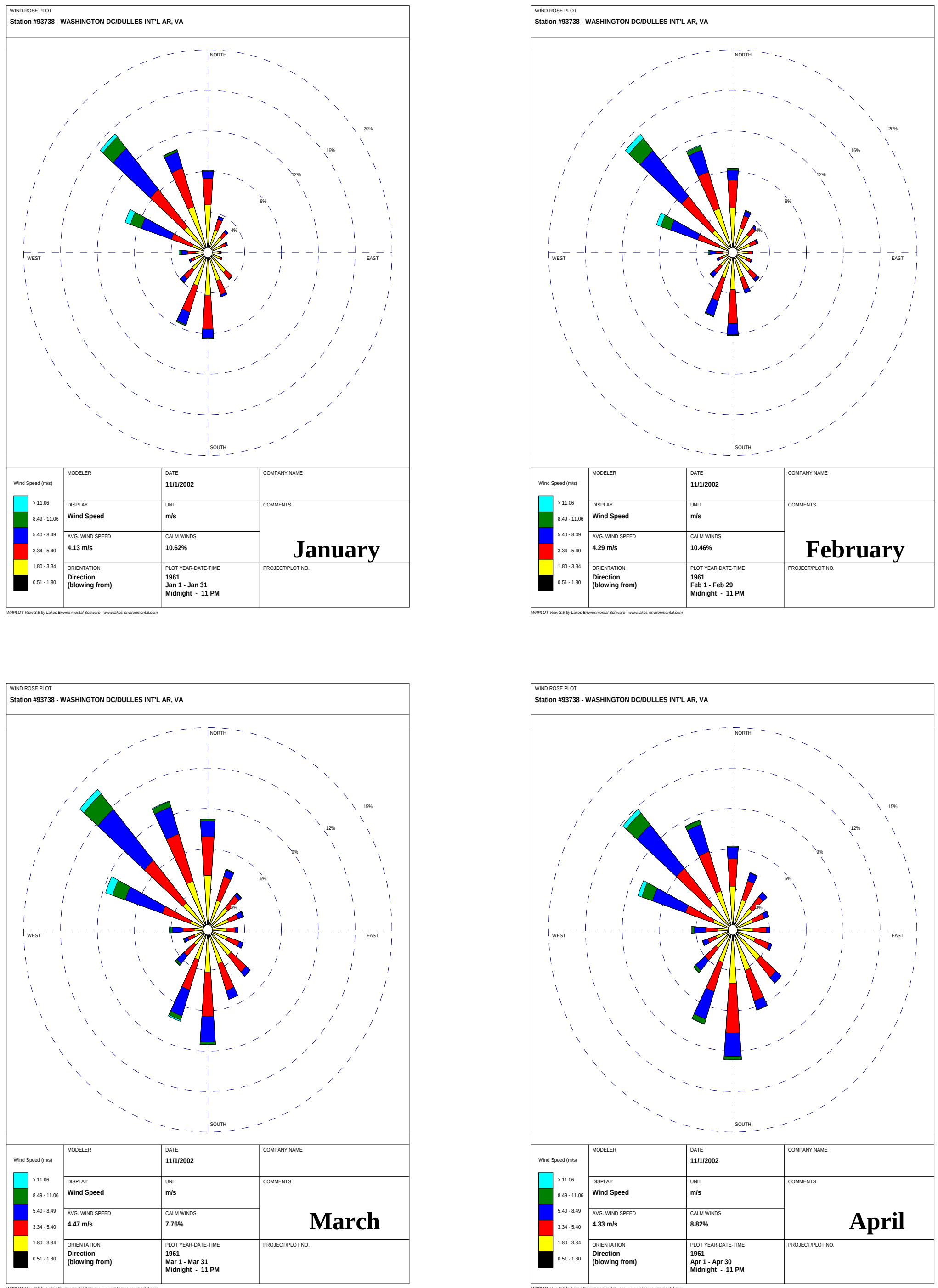
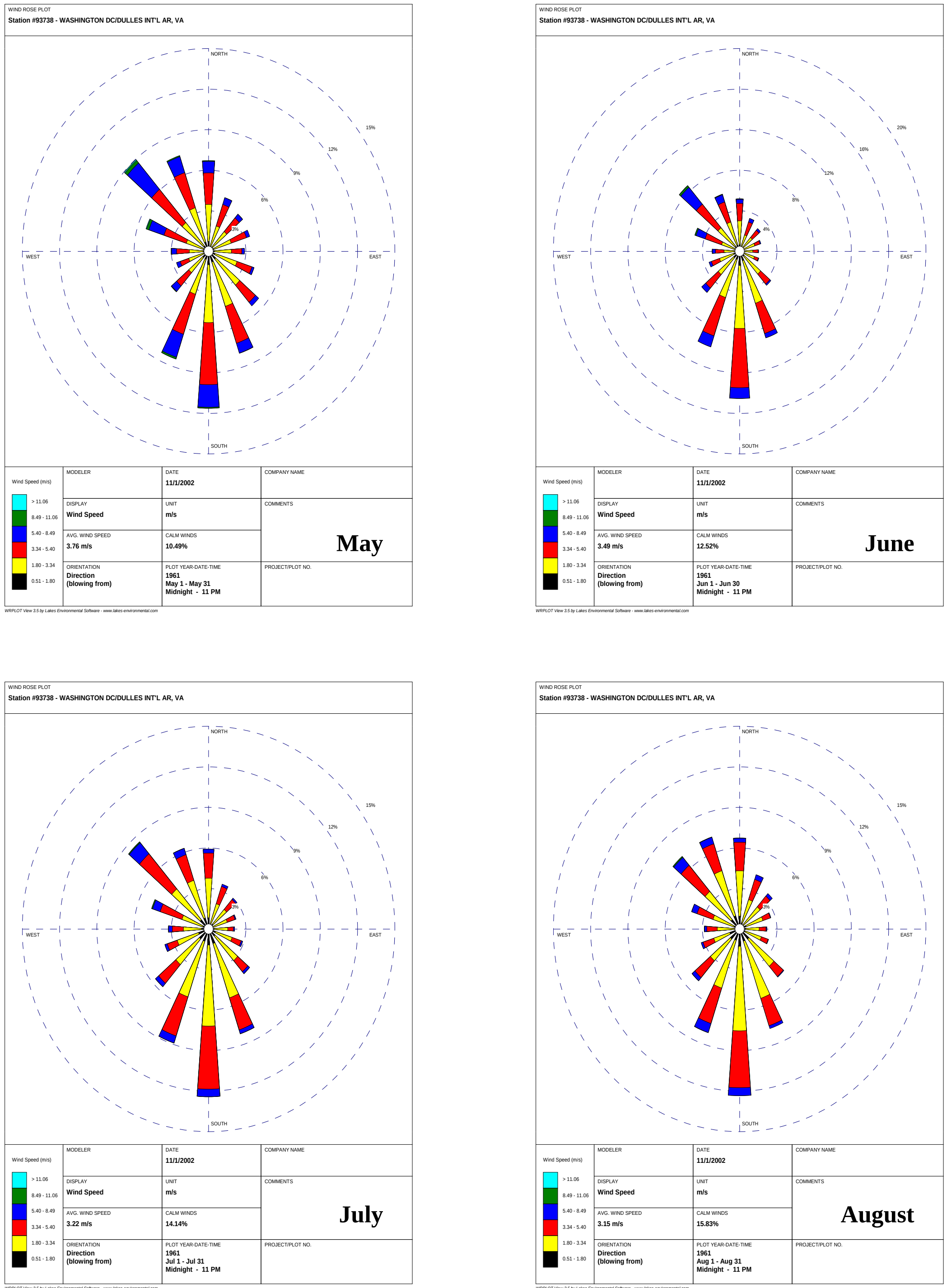
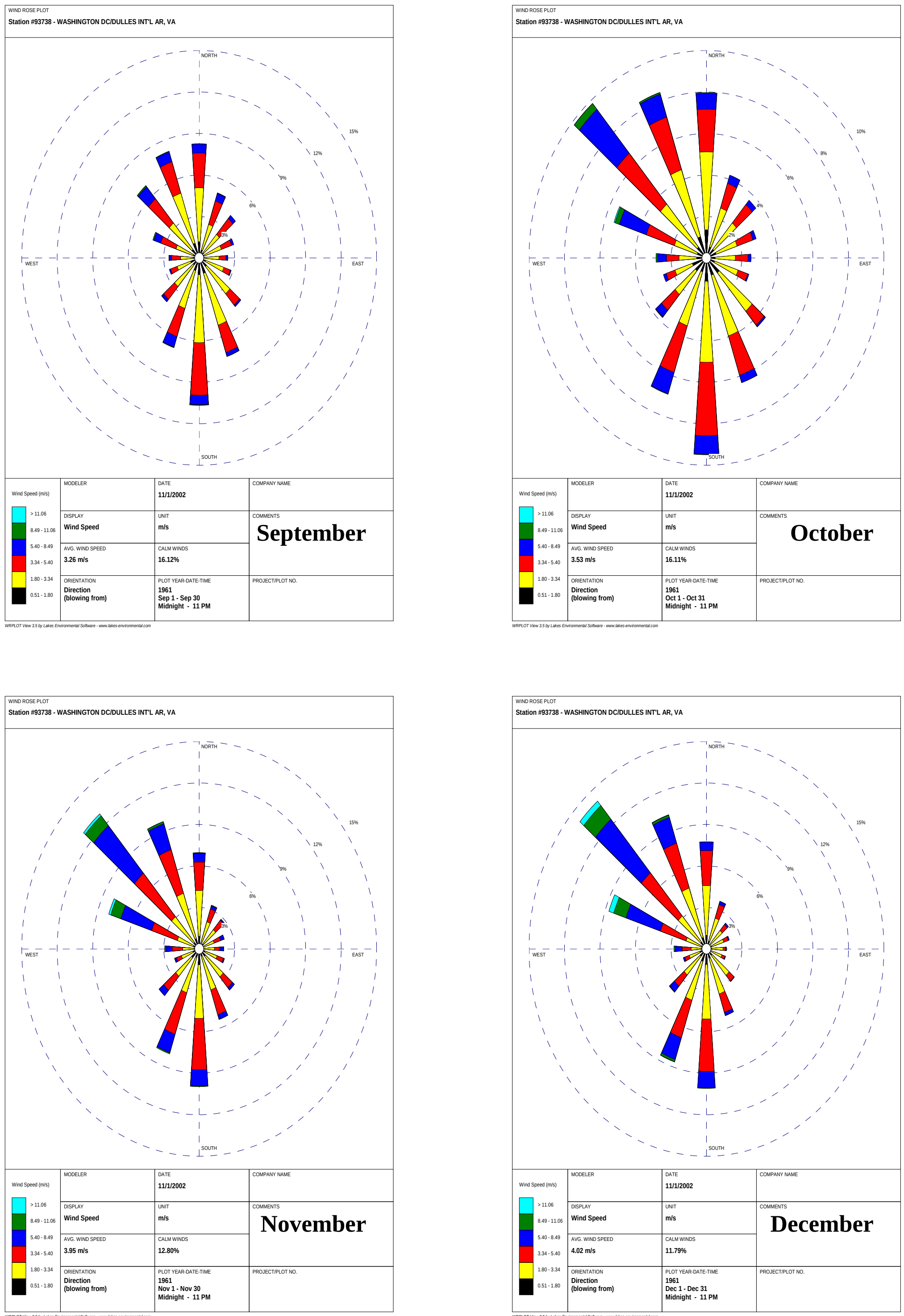


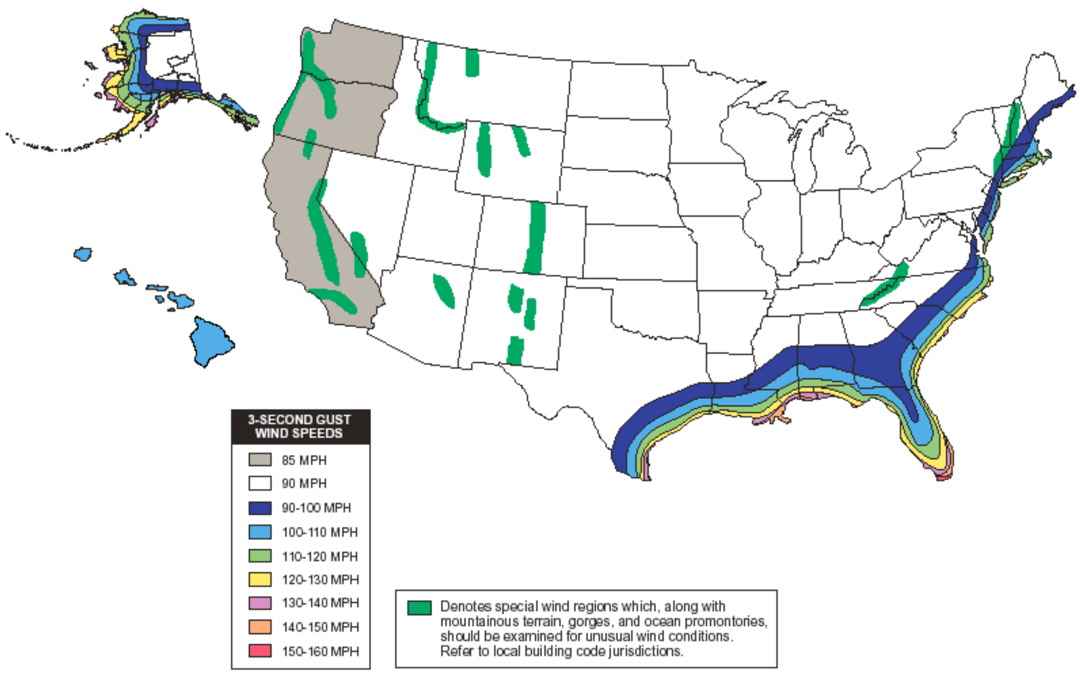
Figure 2.6: IAD Wind Rose Data – 1961 through 1991
http://www.wcc.nrcs.usda.gov/climate/windrose.html



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

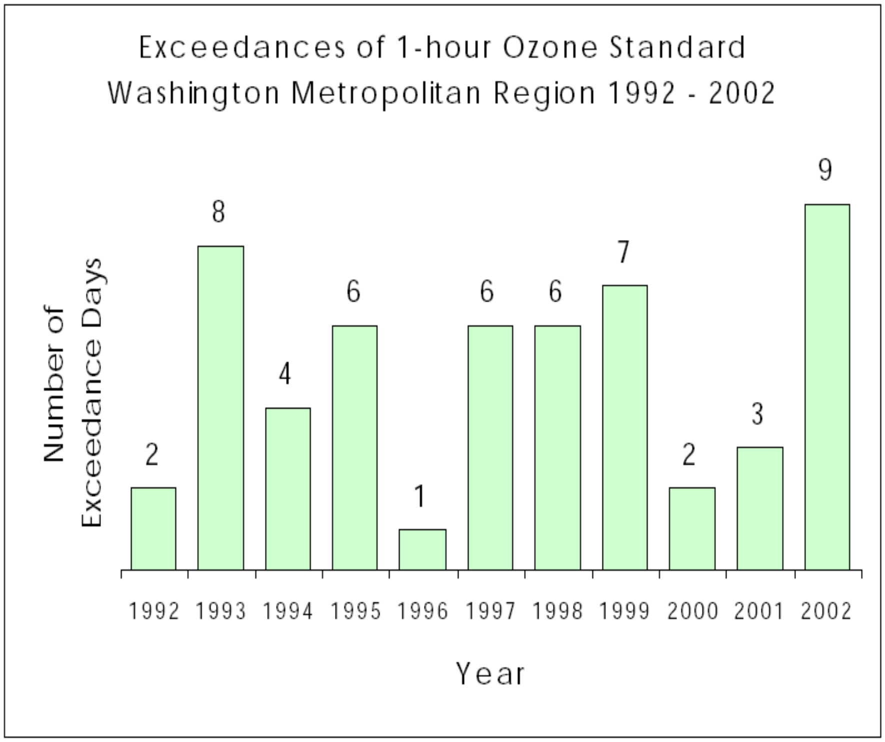


(Figure 2.6: IAD Wind Rose Data – 1961 through 1991 Cont'd.)



Reproduced from ASCE 7-98, by the American Society of Civil Engineers, copyright 2000, with the permission of the publisher.

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



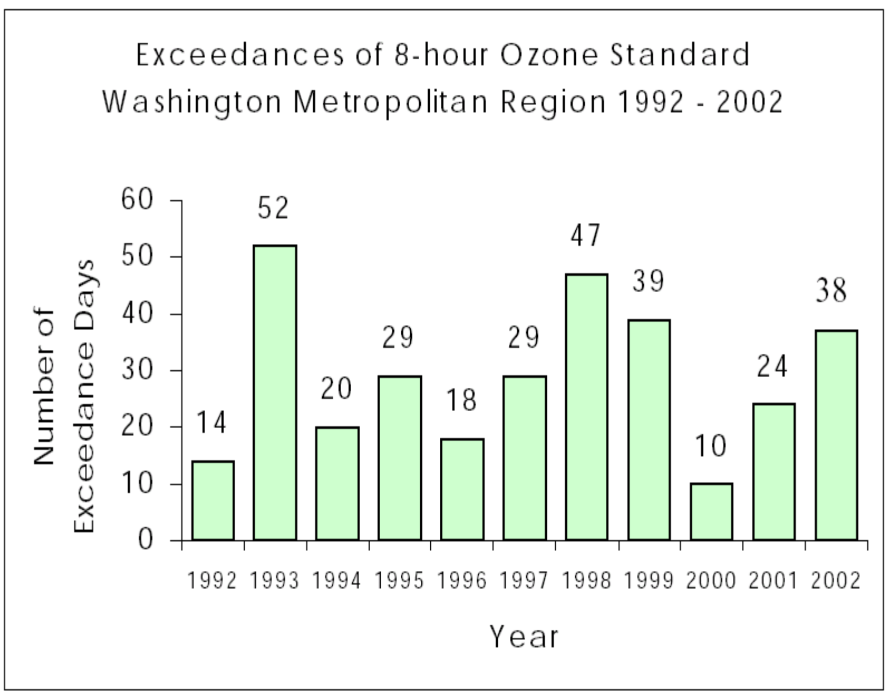


Figure 2.8: Local Ozone Exceedances

Figure 2.9: Location of WeatherNet Station on Confinement Building Roof

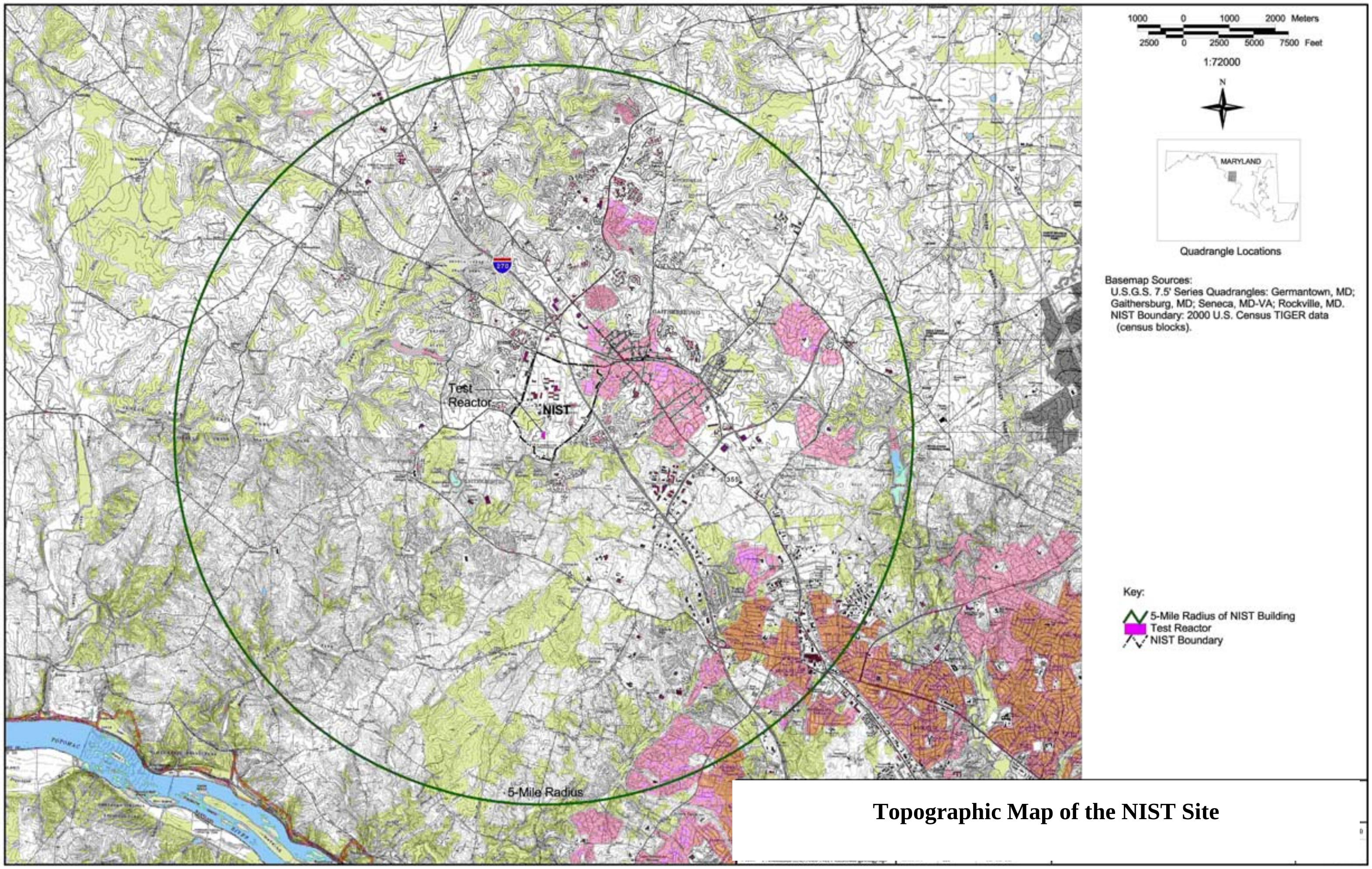


Figure 2.10: Topographic Map of NIST Site

15295020.00100-NIST\GISData\NIST 3.CDR (01-03) SS

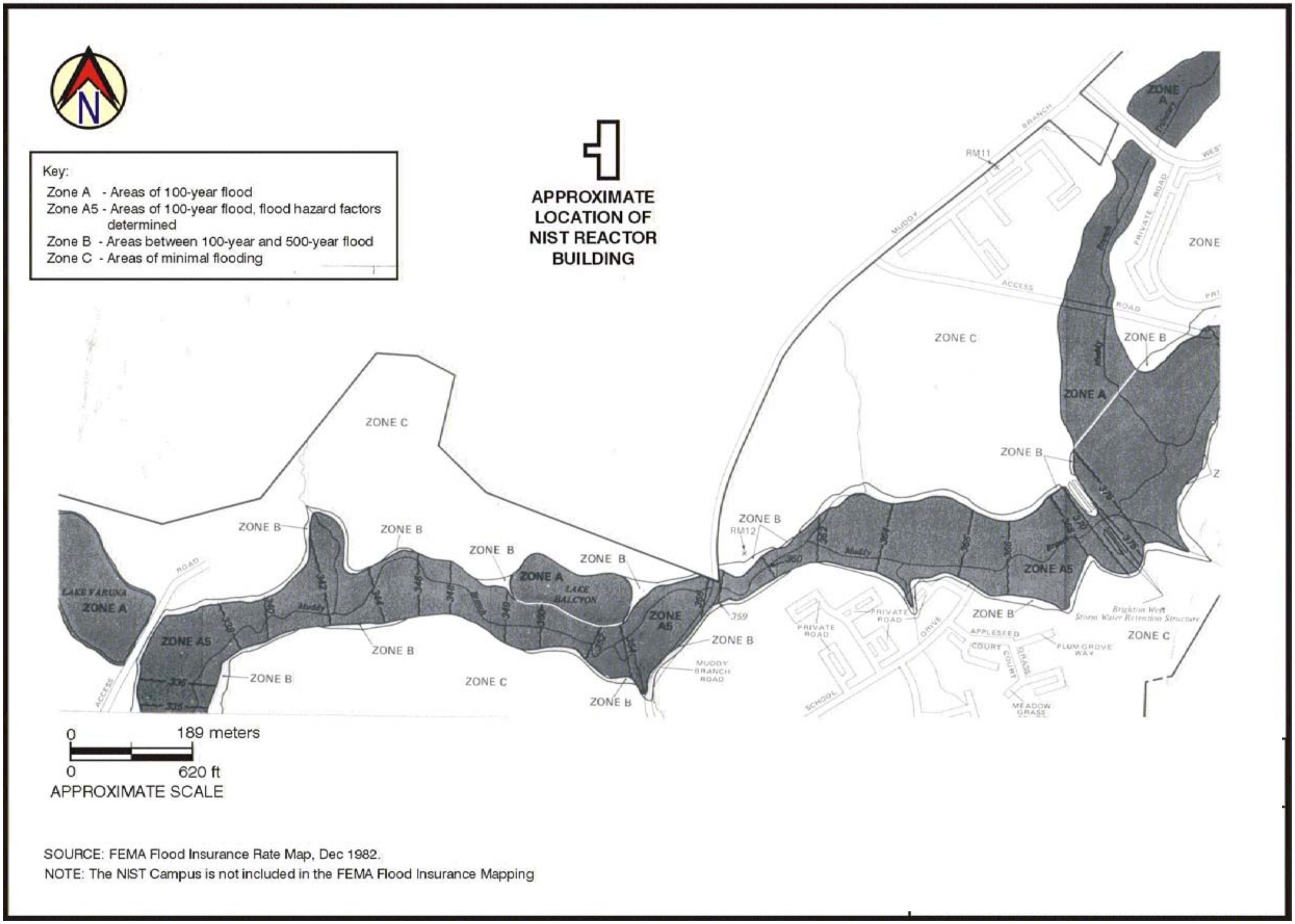


Figure 2.11: Flood Zone Map of Area Near NBSR Site

15295020.00100-NIST\GISData\NIST 2.CDR (01-03) SS

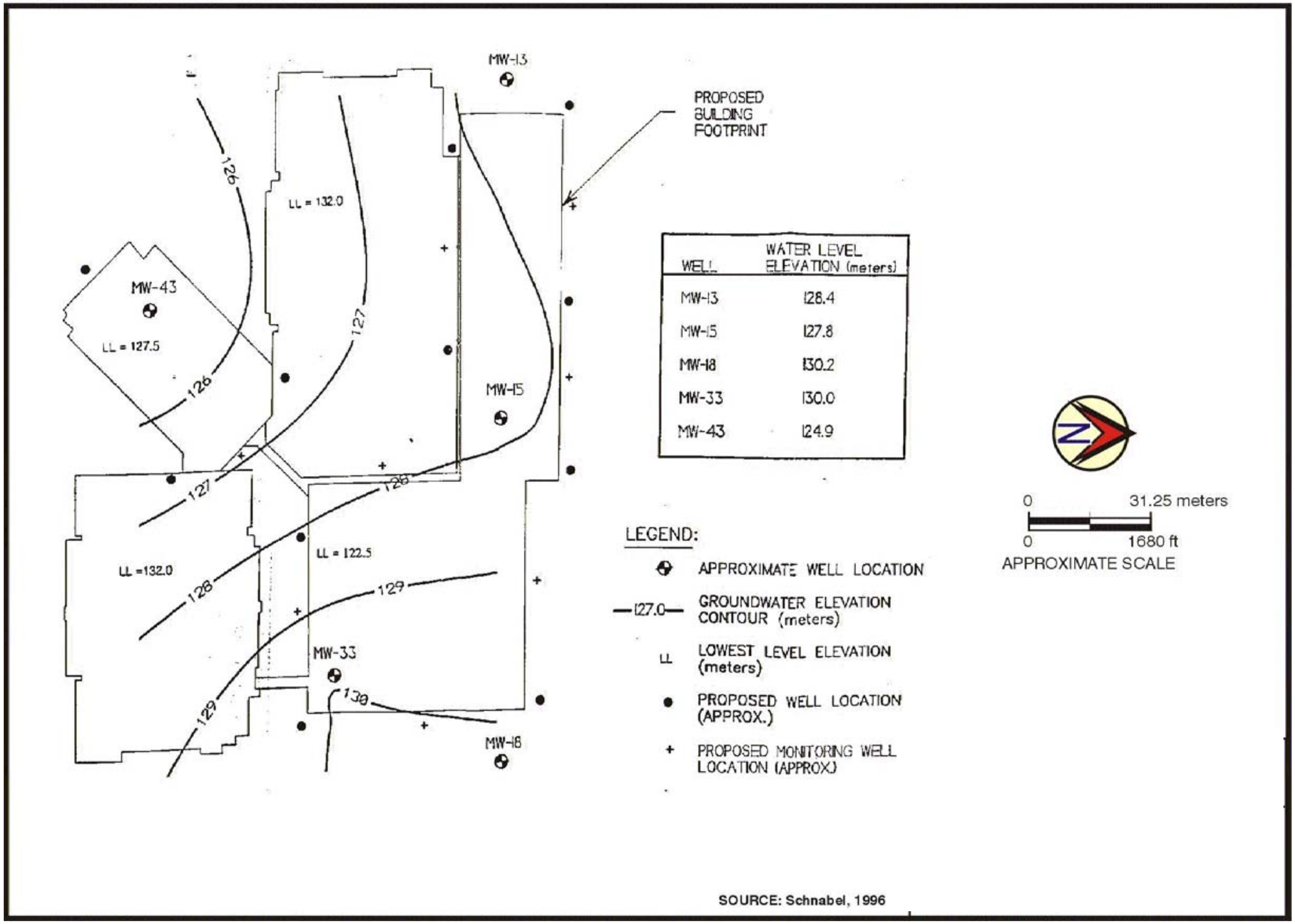


Figure 2.12: Groundwater Contours at AML Site

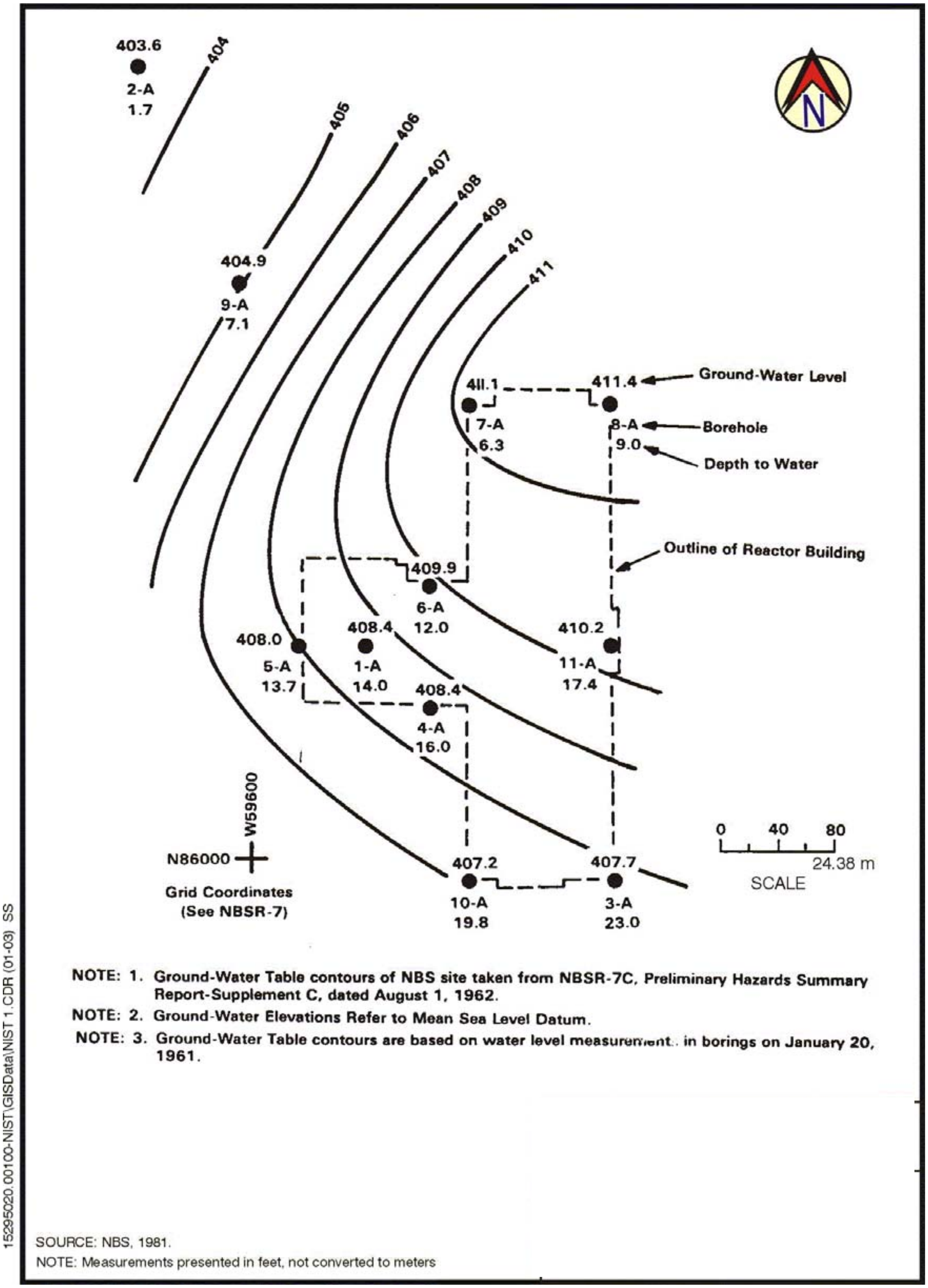
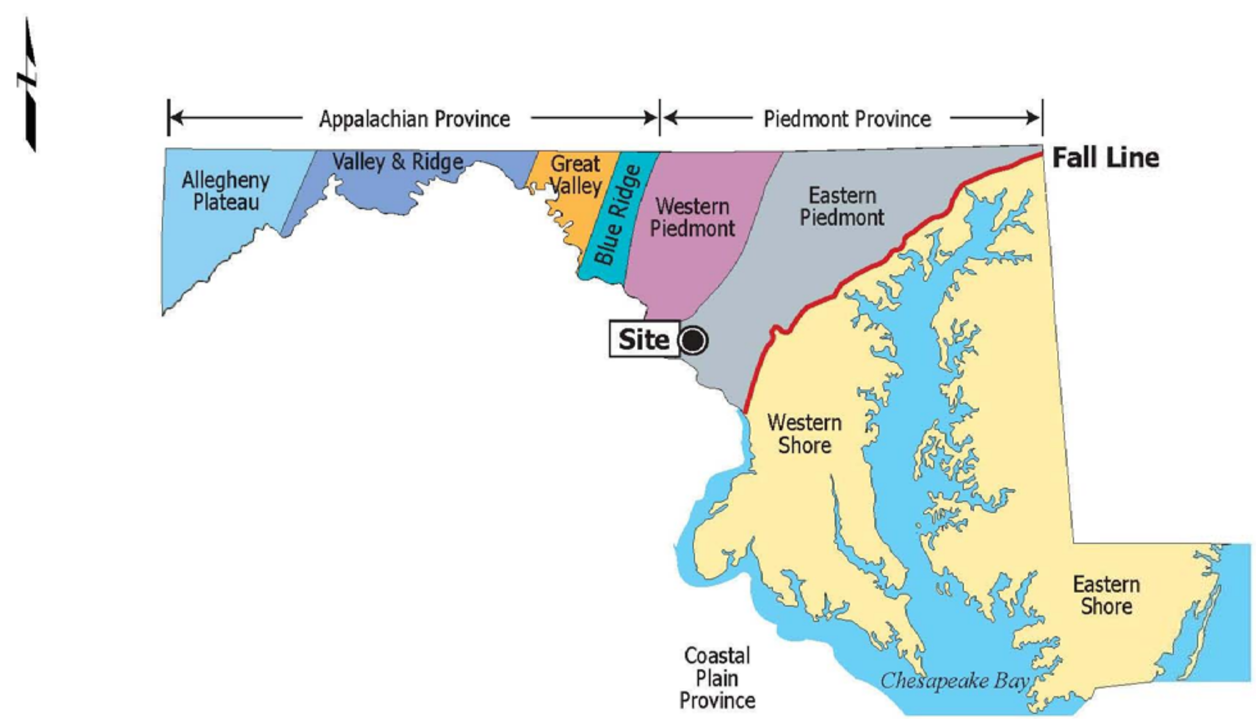


Figure 2.13: Groundwater Contour at NBSR Site



SOURCE: Maryland Geological Survey
On-Line Maps:
mgs.dnr.md.gov/coastal/maps/h1.html
(updated 12/17/02)

Figure 2.14: Physiographic Provinces in Maryland

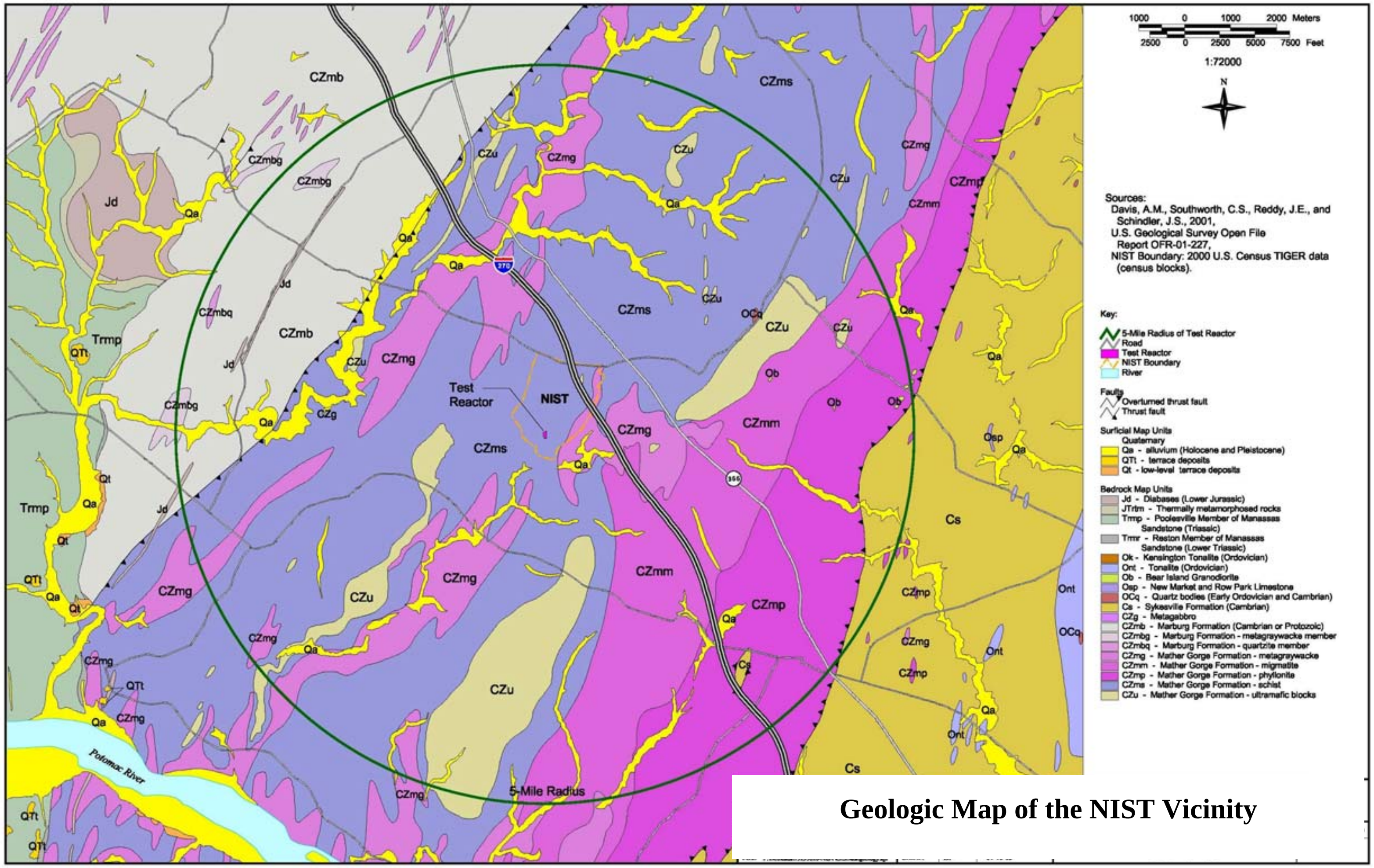


Figure 2.15: Geologic Map of NIST Vicinity

Era	Period	Epoch	Age Estimate (millions of years before present)	Geologic Formations in Project Area
Cenozoic	Quaternary	Holocene	0.010	Alluvium
		Pleistocene	1.8	Lower Terrace Deposits Upper Terrace Deposits
	Tertiary	Pliocene	5	
		Micocene	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
Precambria: Archean			3800	
Precambria: 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

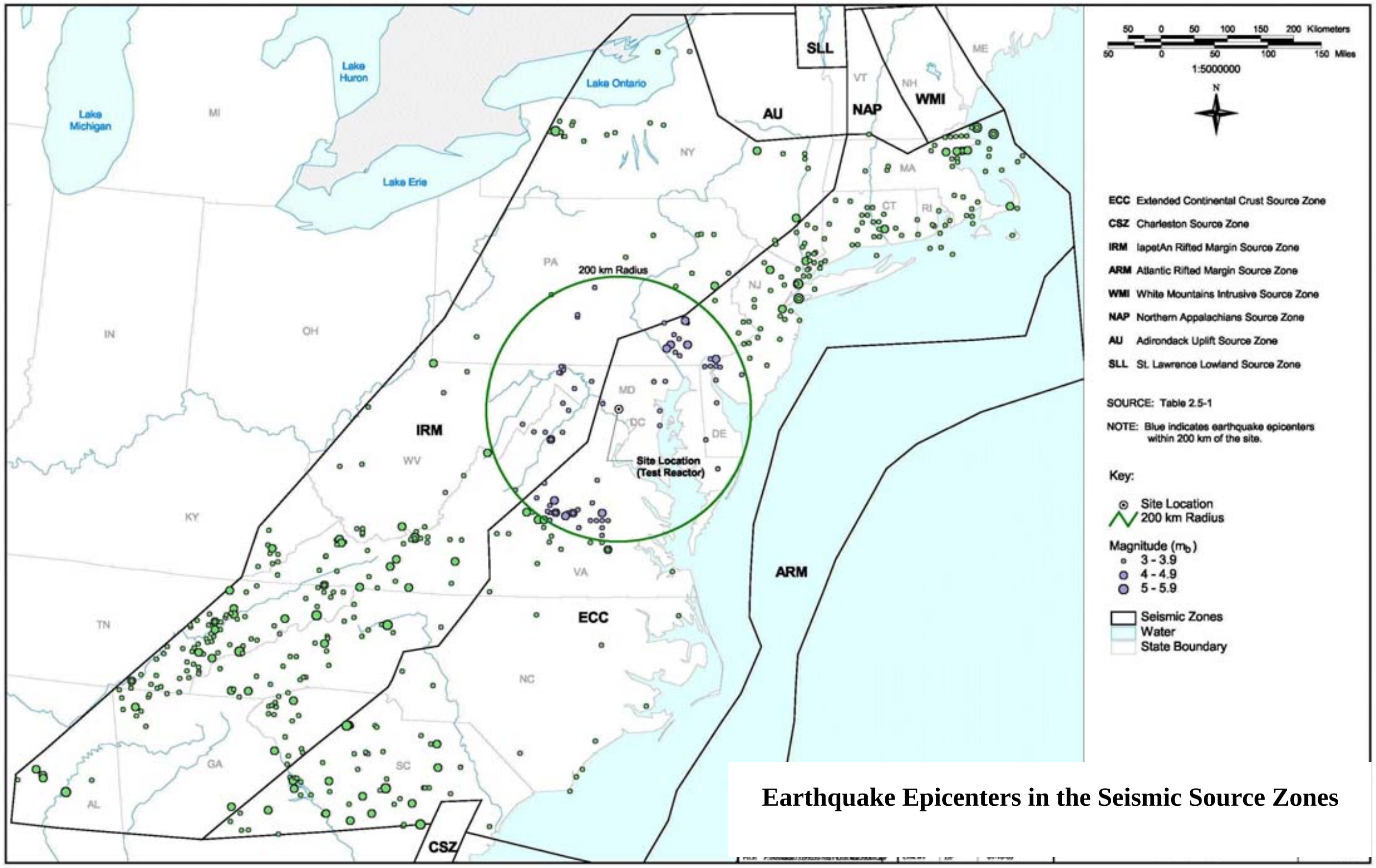
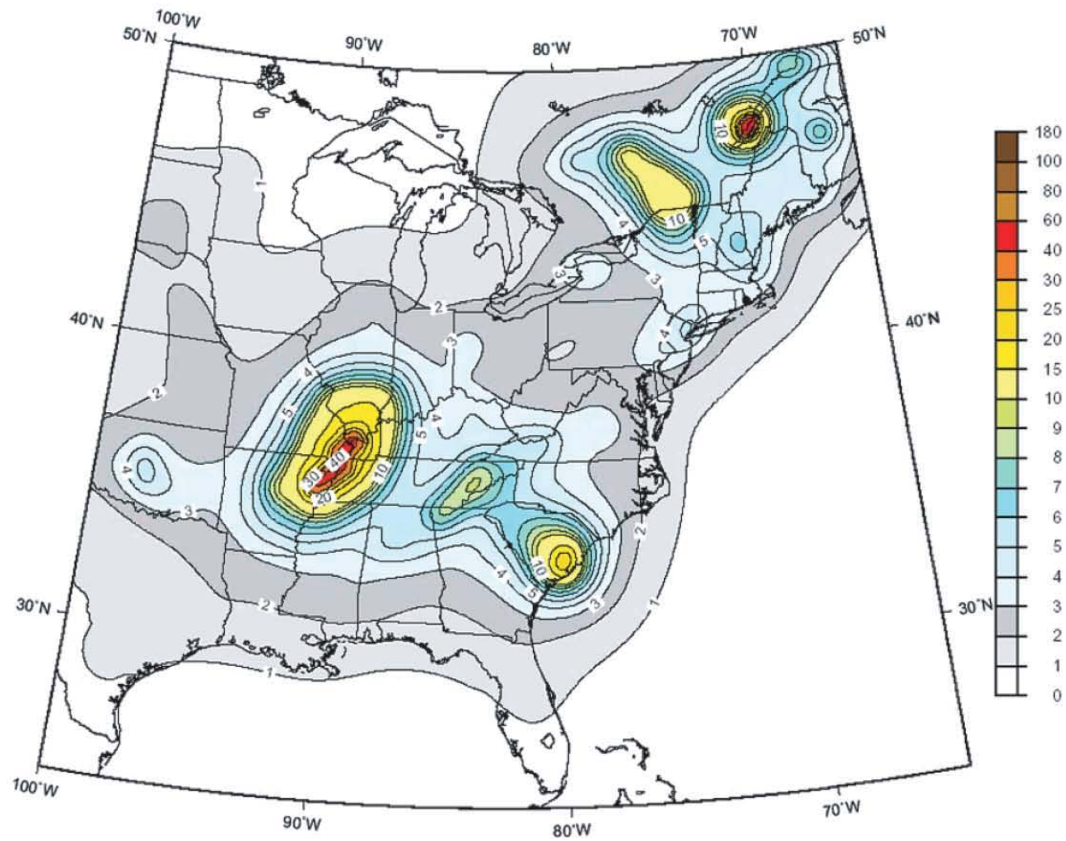


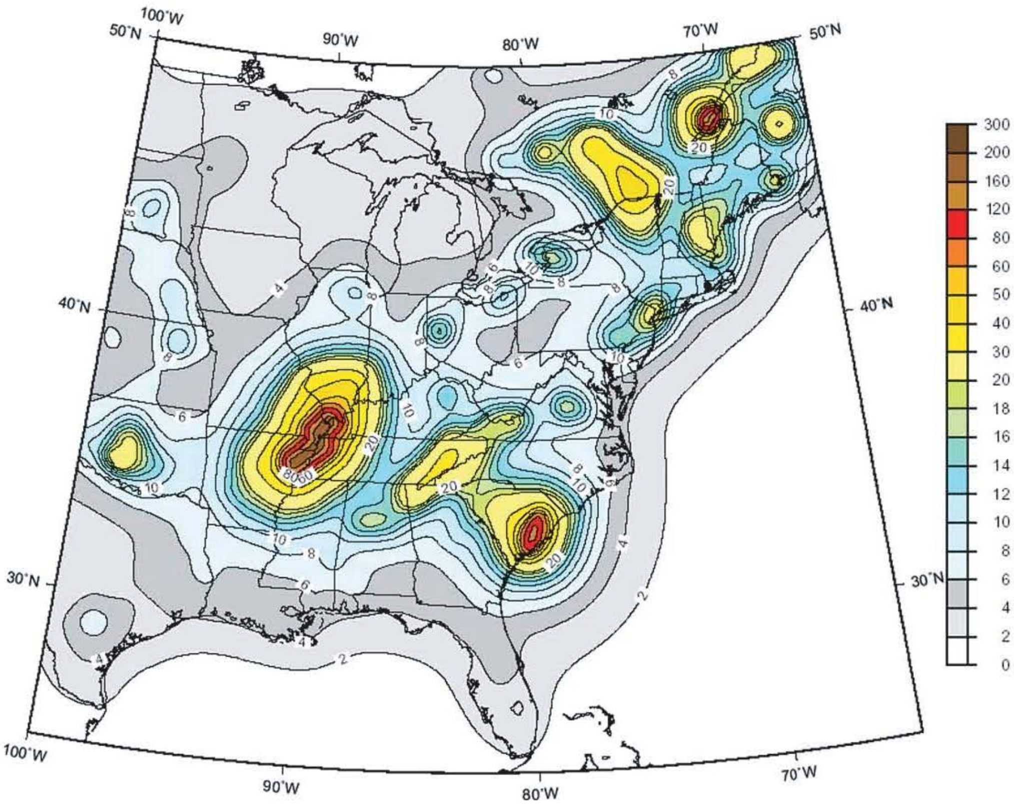
Figure 2.17: Earthquake Epicenters in the Seismic Source Zones



NOTE: 476-Year Return Period

SOURCE: http://geohazards.cr.usgs.gov
/eq/html/ceusmap.html
USGS Map, Oct. 2002

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



NOTE: 2,475-Year Return Period

SOURCE: http://geohazards.cr.usgs.gov
/eq/html/ceusmap.html
USGS Map, Oct. 2002

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

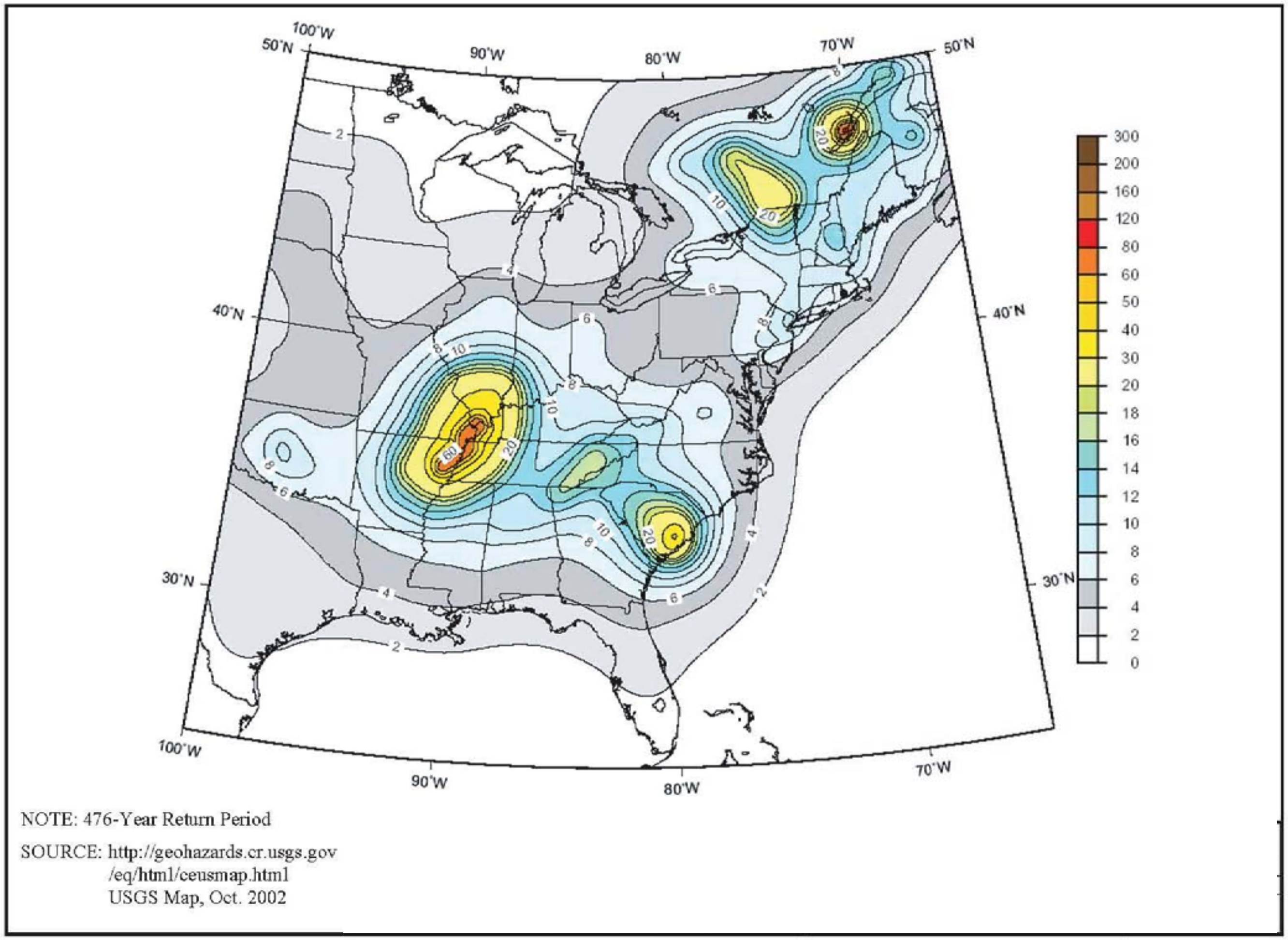


Figure 2.18c: USGS Map of 0.2 SEC Spectral Acceleration (%g) with 10% Probability of Exceedance in 50 Years

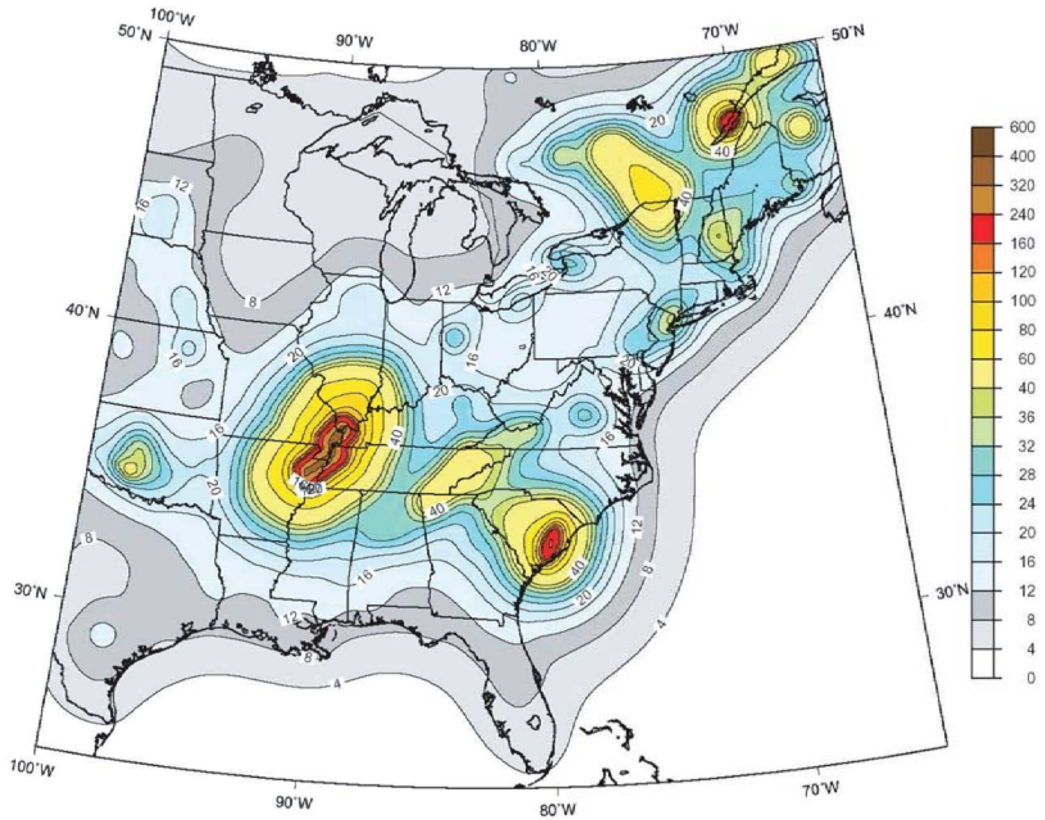


Figure 2.18d: USGS Map of 0.2 SEC Spectral Acceleration (%g) with 2% Probability of Exceedance in 50 Years

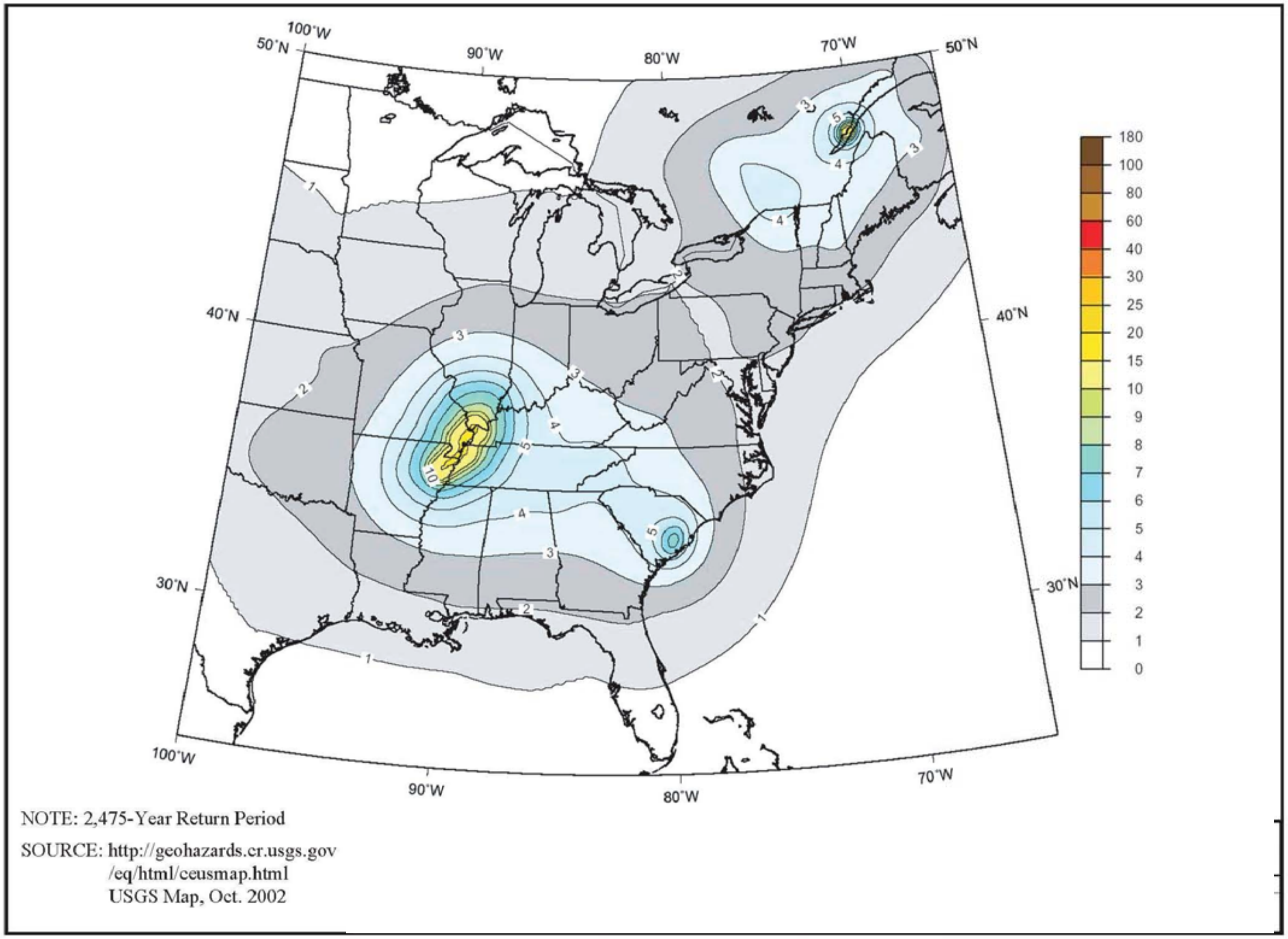


Figure 2.18e: USGS Map of 1.0 SEC Spectral Acceleration (%g) with 10% Probability of Exceedance in 50 Years

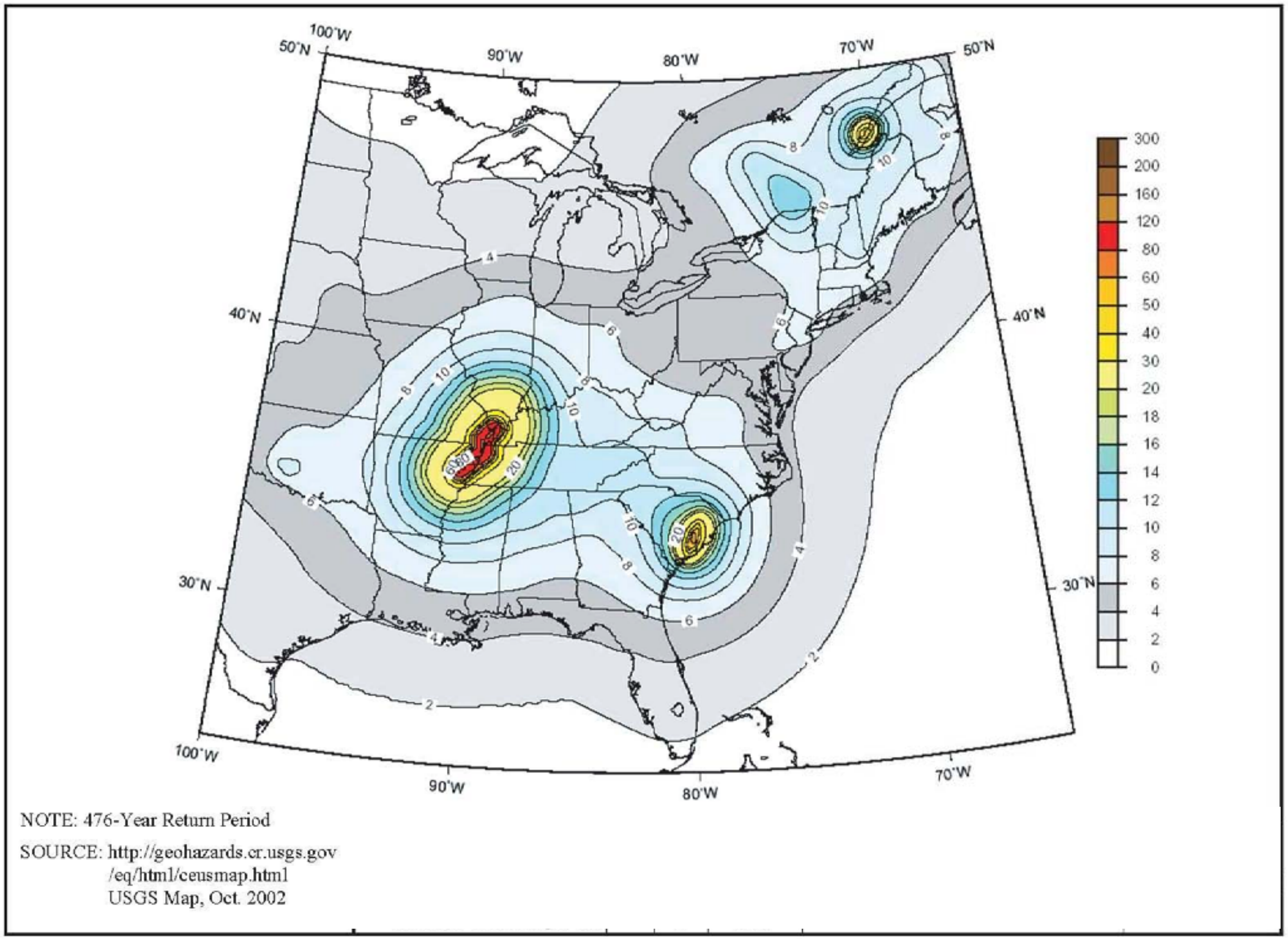


Figure 2.18f: USGS Map of 1.0 SEC Spectral Acceleration (%g) with 2% Probability of Exceedance in 50 Years

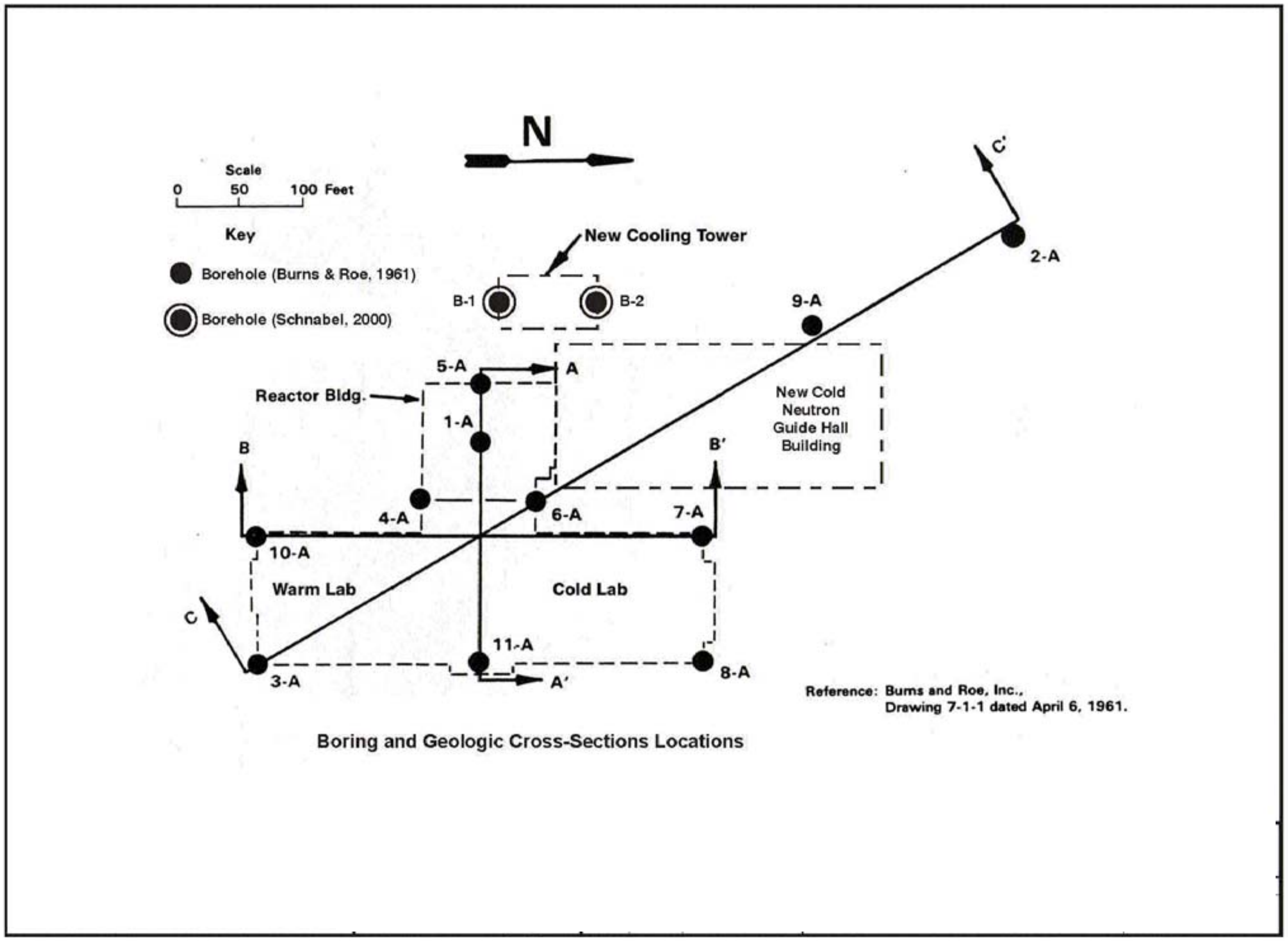


Figure 2.19: Boring and Geologic Cross-Section Locations at NBSR Site

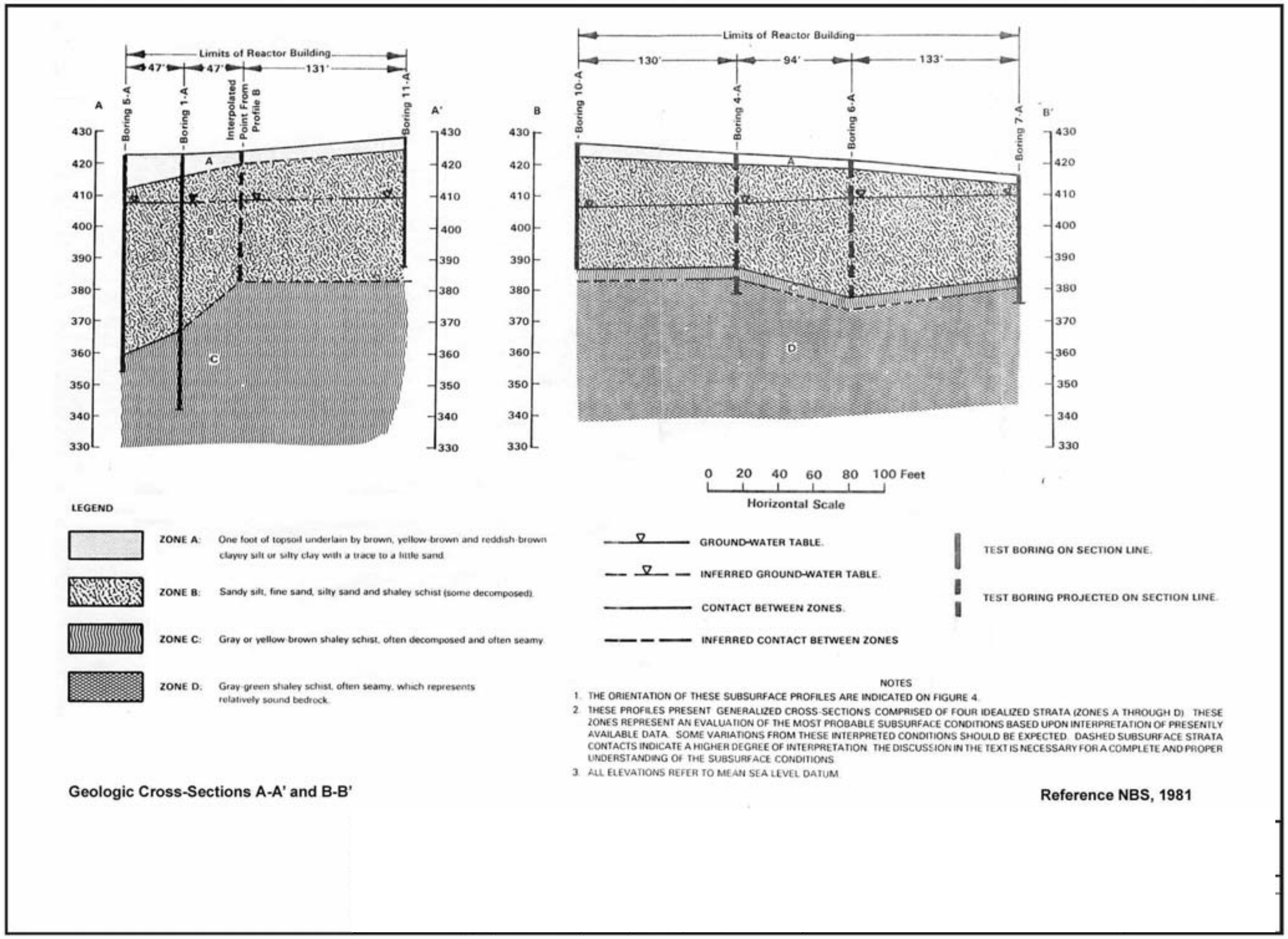


Figure 2.20: Geologic Cross-Sections A-A' and A-B' (see Figure 2.19)

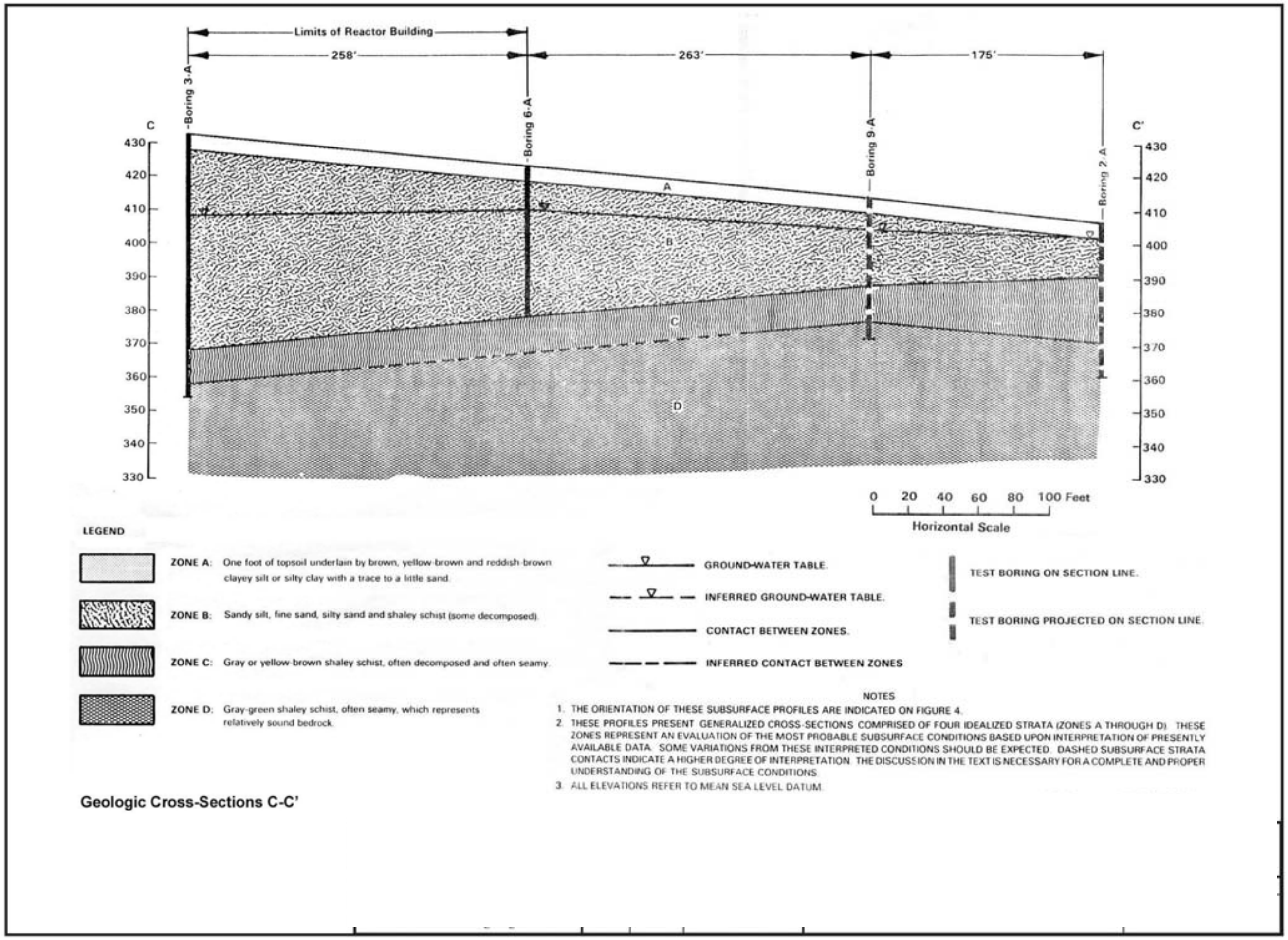


Figure 2.21: Geologic Cross-Sections C-C' (see Figure 2.19)

3 RADIATION PROTECTION AND WASTE MANAGEMENT

3.1 Radiation Protection

NIST has a structured radiation protection program that supports all aspects of NBSR operations. The health physics staff is equipped with sufficient radiation detection equipment to determine, control, and document all occupational radiation exposures. NIST also has established policies that employ the ALARA concept in all operations at NBSR. An environmental monitoring program is also in place to assure that potential radiation exposures in unrestricted areas surrounding the reactor facility are well within regulations and guidelines.

3.1.1 Radiation Sources

In this section, the sources of radiation that are monitored and controlled by the radiation protection and radioactive waste management programs are described. Radiation sources at NBSR can be classified into four general classes:

- Calibration & check sources
- Startup, and other sources used for instrumentation and nuclear support functions
- Airborne, liquid, and solid radiation sources from reactor operations
- Radiation sources produced within the experimental facilities.

The major radionuclide constituents of the radiation requiring monitoring and control by the radiation protection program are summarized below:

Major Sources of Radioactivity		
Airborne	Liquid	Solid
^{41}Ar, ^{3}H	^{3}H, ^{110m}Ag, ^{64}Cu, ^{66}Cu	^{60}Co, ^{55}Fe, ^{59}Fe, ^{65}Zn

Other sources of radioactivity that are found in various reactor and support systems, but are of negligible consequence to occupational or environmental doses are listed below.

NBSR Systems and Radiation Sources (Bolded nuclides are major components)

Primary coolant: **H-3**, **N-16**, Ar-41, Na-24, Mn-54, 56, Cr-51**, Co-60**, Sb-122, 124
Primary pipe (internal contamination): Cr-51, **Co-60**, Zn-65, **H-3**
Helium sweep: **Ar-41**, Kr-85m, 87, 88, Xe-131m, 133,135, 135m, 138, Cs-138
Thermal Shield Cooling System: **Cu-66**, **Cu-64**, **Ag-110m, Zn-65**, N-16
Reactor shield plug/refueling plug: Al and steel activation products, C-14
Air: **Ar-41**, **H-3**, Br-82, Cl-38, Cs-138
CO_2 sweep gas: **Ar-41**, Br-82, Cl-38, S-35
Storage pool: **H-3**, fuel piece cutting products from aluminum activation
Fuel pieces (6061 aluminum, stainless steel): **Fe-55**, **Co-60**, **Zn-65**, Ni-63, Mn-54
Resin beds: **Co-60**, **Zn-65**
Neutron guides: Co-58, **Zn-65**, Ni-59
Pneumatic system: **Co-60, Ag-110m, Zn-65**

3.1.1.1 Calibration, Check, Startup, and Other Radiation Sources

The primary reactor startup source is the combination of irradiated fuel and D_2O, which provide photoneutrons. The backup startup source is an AmBe neutron source that is contained in a solid sealed right-circular cylinder of approximately 1.02" by 1.57" in size (2.5 cm by 4 cm), and has an activity of approximately 2.0 Curies (Ci). It was manufactured by NUMEC of Apollo, Pa., and has a 4.5 MeV average fast neutron emission. It is stored in a shielded container in the reactor source storage room.

Instrumentation check and calibration sources used to support reactor and radiation protection activities are maintained under the Byproduct Materials license (SNM-362) that was issued by the NRC. These include ^{60}Co and ^{137}Cs sealed sources of various strengths (µCi to kCi activities) as well as sealed sources of other radionuclides, and a variety of unsealed sources used primarily for the calibration of laboratory instrumentation (*e.g.*, ^{137}Cs, ^{60}Co, ^{152}Eu, ^{14}C, ^{99}Tc, ^{3}H, and ^{90}Sr). These sources are mostly in the nCi to µCi activity range, in both solid and liquid form. They are stored in Restricted Areas and are subject to periodic surveillance.

The Safety Evaluation Committee reviews fissile and fissionable materials used in experiments that are inserted into the reactor for compliance with the Technical Specifications. These sources are acquired and maintained under NRC License SNM-362. They consist mainly of fission chambers and foils that are used to monitor or calibrate neutron beams and fields. These sources are strictly controlled and periodically inventoried.

Sources produced by the reactor that are related to experimental programs range in activity from aCi (1 attoCurie = 1.0×10^{-18} Ci) to kCi. These sources may consist of any chemical element in any physical form. Access to these sources is controlled and they are subject to the radioactive material accountability program.

3.1.1.2 Airborne Radiation Sources

The principal airborne sources of radioactivity associated with the operation of the NBSR are ^{41}Ar and tritium (^{3}H). The only release path for air from the various confinement building ventilation systems is via the building stack exhaust, which has a nominal flow rate of 30,000 cfm (850 m^3/sec). Annual emissions of ^{41}Ar typically ranges from 800 to1200 Ci and ^{3}H ranges from 400 to 800 Ci. This constitutes a dose of less than 2 mrem of exposure to the closest member of the public, which is less than 2% of the NRC dose limit to the public. This analysis was performed with the EPA COMPLY computer code using local wind rose data and computing the dose based on the closest resident in each wind sector, which constitutes conservative analytical boundary conditions.

Monitoring in both the stack and in the building ventilation systems utilizes both installed and periodic sampling. This provides redundant methods for assessing both occupational and public exposure. Occupational exposure is discussed below.

3.1.1.2.1 ^{41}Ar Sources

Argon (^{40}Ar) is about a 0.93% natural constituent of air. Any air volume that is exposed to neutrons will produce ^{41}Ar by the $^{40}Ar(n,\gamma)^{41}Ar$ reaction. ^{41}Ar is a strong beta and gamma emitter with a half-life of 110 minutes. At NBSR, extensive engineering and procedural measures have been taken to minimize ^{41}Ar production. These include:

- Maintaining all heavy water primary systems under positive helium pressure to minimize air in primary water
- Conducting all maintenance activities on primary systems in a way that minimizes air intrusion
- Using cover gases like CO_2 to exclude air wherever practicable in neutron irradiated volumes, such as the cavity around the reactor vessel, and using CO_2 as the driving gas for pneumatic samples being irradiated
- Sealing all penetrations and openings to the extent practicable to exclude air intrusion
- Designing the experiments to minimize neutron irradiated air volumes
- Regularly assessing ^{41}Ar production to verify the effectiveness of the existing reduction measures.

Production of ^{41}Ar at the NBSR is primarily due to the presence of air in the cavity around the reactor vessel. Production associated with experiments is less than 0.1 % of the total because of the smaller irradiated air volumes and because of lower neutron fluences associated with most experiments. The external exposure rate from ^{41}Ar is minimal because the concentrations of ^{41}Ar in the building are less than 1 DAC and the building volume represents a small fraction of a "semi-infinite" cloud. Actual dose rates to a person in the building from a uniform DAC cloud would be less than 0.2 mrem/hr. Personnel dose rates from typical ^{41}Ar levels observed within the NBSR confinement building have been less than 0.004 mrem/hr. This low level, when combined with typical occupancy times and reactor operating frequency results in an annual personnel exposure from this source that is less than 2 mrem. Direct measurements have demonstrated that the calculated values are conservative.

3.1.1.2.2 Tritium

Tritium is produced by the $^{2}H(n,\gamma)^{3}H$ reaction in the heavy water moderator/coolant of the reactor. This produces a primary coolant tritium concentration of 0.3 Ci/liter/yr. As an ALARA measure NIST replaces the heavy water at intervals chosen to limit tritium exposure. All used heavy water is stored onsite until transferred to authorized processors for recycling. With a maximum production concentration of 5 Ci/liter, the radioactivity concentration and exposures discussed below for NBSR would increase by no more than a factor of 5.

During normal operations, the primary release pathway for tritium results from helium leakage into the ventilation system. Since the helium is used to minimize air intrusion into the primary cooling system, it can become saturated with heavy water. Activation of the heavy water produces tritium. Secondary pathways can include various activities, such as refueling or any maintenance activity that exposes heavy water to the air. Abnormal loss conditions, such as a seal failure or a primary coolant boundary failure would be quickly identified by the various monitoring or leak detection systems. The airborne tritium monitoring system at NBSR is capable of detecting a few milliliters of leakage that can occur by water evaporation.

Confinement building tritium levels at a nominal primary concentration of 1 Ci/liter are typically less than 1.0% DAC. Since the operating staff is in the building less than 1500 hrs per year, this represents an annual dose commitment of less than 40 mrem. Bioassay data of the operating staff confirms that most exposures are well below this value. All other personnel are in the confinement building a much smaller fraction of time, and their annual tritium exposures are much less than 1 mrem. Local airborne exposure to heavy water sources by reactor operators during certain activities, such as refueling, can increase their annual exposure from tritium sources, but normally not in excess of 100 mrem.

Abnormal or transient conditions would increase these airborne tritium levels. Previously, when the ventilation system for NBSR was shut down for remediation over a five-day period, the tritium levels slowly approached DAC values. Also, when an auxiliary cooling loop had excessive heavy water leakage, the local airborne tritium levels increased to 1 $\mu Ci/m^3$, which corresponds to 5% DAC.

From a public dose perspective, tritium represents about one-tenth of the dose from ^{41}Ar, assuming equal release activities. Conducting operations in a way that minimizes ^{41}Ar production, even if that results in some increased heavy water loss and minor increases in tritium exposure, results in minimized collective dose because the increased occupational dose to the limited number of operational staff is more than offset by the reduced collective dose to the public. Therefore, ALARA efforts to reduce tritium losses, particularly through ventilation system modifications, must be tempered by possible related increases in ^{41}Ar emissions.

3.1.1.2.3 Fission Products

Noble gas fission products can be detected in the helium sweep system that is maintained over the primary coolant. Those detected radionuclides include gases of Xenon, Krypton, and ^{138}Cs (a daughter product of ^{138}Xe). Using the typical make up rate for the helium system, it is calculated that less than 0.1 Ci of these radionuclides are released annually. These release concentrations are so low (less than 10^{-10} μCi/ml) that they represent a negligible contribution to the total gaseous emissions.

3.1.1.3 Liquid Radiation Sources

The dominant liquid radionuclides of the NBSR are tritium and ^{16}N. Some other minor liquid sources are also discussed in subsequent sections.

3.1.1.3.1 Reactor Primary Coolant

The NBSR primary coolant consists of high purity heavy water. Its primary radionuclides come from the following reactions:

- ^{3}H, produced via $^{2}H(n,\gamma)^{3}H$, a low energy beta emitter
- ^{16}N, produced via ^{16}O (n,p) ^{16}N, a high energy beta and gamma emitter
- ^{24}Na, produced via $^{27}Al(n,\alpha)^{24}Na$, a high energy beta and gamma emitter
- ^{28}Al, produced via $^{27}Al(n,\gamma)^{28}Al$, a high energy beta and gamma emitter
- ^{60}Co, produced via $^{59}Co(n,\gamma)^{60}Co$, a low energy beta and high energy gamma emitter
- ^{51}Cr, produced via $^{50}Cr(n,\gamma)^{51}Cr$, a low energy gamma emitter

Other radionuclides present in the primary coolant include ^{65}Zn, ^{56}Mn, ^{99m}Tc, and ^{122}Sb. These are suspended corrosion products that are activated by neutrons, but are a minor portion of the total liquid radiation source.

During reactor operations, ^{16}N is the primary source of external radiation exposure from the primary piping system. Its short half-life of 7 seconds means that exposure from this source diminishes very rapidly after the reactor is shutdown. At the NBSR, there are two areas where an exposure potential from this source exists, the Process Room and the Monitoring Room. The Process Room contains all of the primary water pumping and processing systems. Dose rates in the process room during 20 MW operation range from a few mrem/hr in relatively shielded or distant zones, to 60 rem/hr in close proximity to the primary reactor piping. A detailed radiation survey of this area for 20 MW power operations is maintained in the event that an entry to the area during operation is required. Entries into the high radiation areas of this room are very rare.

If entry to those areas is necessary, the reactor power is reduced whenever possible. The ^{16}N source is present in the Monitoring Room only when the primary sampling system is in operation. General area dose rates when sampling is done at power are less than 5 mrem/hr. Additionally, the time primary water is flowing for sampling purposes is limited by an NBSR ALARA measure, which further limits personnel exposures.

Tritium is produced in the primary D_2O at a rate of 0.3 Ci/kg per year based on 5000 MWd per year. This is equivalent to about 3 Ci/MWd for the 12,000 gallons (45,500 liters) in the primary system. Excluding dilution by makeup, this would eventually result in an equilibrium concentration of about 5.3 Ci/liter. A 1 Ci/liter concentration is used for a number of reference calculations in this document. All used heavy water is stored onsite until transferred to authorized processors for recycle.

As discussed above, tritium is a significant source of exposure from airborne contamination due to evaporation of tritiated heavy water. Exposure by direct contact, thru skin absorption, could result in significant exposures. At a nominal primary coolant concentration of 1 Ci/liter, this represents an exposure of 62 mrem per milliliter of heavy water absorbed. Therefore, any work involving potential exposure by this mechanism requires control measures such as containment, eye protection, gloves, and protective clothing, to minimize and prevent such an occurrence. Individuals that perform this work are required to periodically provide tritium bioassays. The other radionuclides present are at such low concentrations that they represent a negligible residual contamination problem.

^{24}Na is present on the order of 0.1 mCi/liter. It represents a transient external exposure source term in the process room. Due to its short half-life (15 hrs), as an ALARA measure, work in the process room is limited for the first day following shutdown.

^{51}Cr represents the highest activity, longer-lived (half life of 27.7 days) primary system contaminant other than tritium. It is present in the primary at a concentration approaching 0.001 mCi/liter. Since ^{51}Cr emits a low energy gamma, it is almost totally self-shielded by the primary system components. As a contamination source, it is the dominant radionuclide, based on activity, by at least a factor of ten for freshly removed primary components. After several months, ^{65}Zn and ^{60}Co become the dominant residual sources of contamination due to decay of the ^{51}Cr. These radionuclides present an exposure primarily in terms of local external dose due to system contamination. Local "hot spot" radiation sources, at valves, heat exchangers, filters, and resin beds range from a few mrem/hr to 50 rem/hr. Components that have the higher dose rates, such as primary coolant filters and the resin beds, have local shielding to reduce the radiation levels to less than 5 mrem/hr. Exposures from other "hot spots" are controlled through local posting of the areas concerned. The general area dose rate in the process room due to the cumulative effect of these long-term internal contaminants ranges from a few mrem/hr. to about 20 mrem/hr. This room is routinely surveyed, and the survey data is made available for any work performed in this area. In 1995, the measured internal primary surface contamination, after predominately 15 MW power operations, was 0.4 $\mu Ci/cm^2$ for ^{51}Cr, and 0.001 $\mu Ci/cm^2$ for ^{60}Co.

3.1.1.3.2 Reactor Secondary Coolant

The NBSR secondary system consists of plate type heat exchangers and a plume suppression cooling tower that holds about 132,000 gallons (500,000 liters) of light water. Inherent primary to secondary integrity of a plate interface with no seals or welds provides a high degree of confidence that a primary to secondary leak path would not develop. Water sampling of the secondary system has demonstrated the absence of a primary to secondary leakage at a greater than 1 ml of primary water sensitivity in the primary heat exchanges. This is based on liquid scintillation analysis of 10 ml samples of secondary water and the primary system tritium concentration averaging approximately 1.5 Ci/liter. Based upon sampling and the demonstrated level of integrity, there are no likely operational radiological issues associated with the secondary coolant. Nevertheless, this system is subject to regular surveillance.

3.1.1.3.3 Thermal Column D_2O Tank Coolant

The Thermal Column D_2O Tank Coolant is an independent heavy water system. The measured tritium production rate in this system is 25 to 30 mCi/liter per reactor cycle. Equilibrium tritium concentrations in this system typically would not exceed 4 Ci/liter. This is determined by multiplying 30 mCi /liter per cycle times 7 cycles per year times the tritium mean life. Planned periodic replacement of the Thermal Column D_2O will limit the tritium concentration to levels similar to those of the primary coolant water. Losses from this system go to a collection system and the D_2O is recycled. Personnel exposure is minimal from this collection system. Concentrations of other contaminant radionuclides, such as ^{60}Co, ^{51}Cr, and ^{65}Zn, are slightly higher than the primary D_2O. This is due to accumulated contamination in the system prior to its conversion to an independent cooling loop. Since this is prior contamination, the existing levels of 0.5 to 5 nCi/gm should not increase. Additionally, because of the limited volume of this system, these activities are a minor radiological issue for normal maintenance activities, such as resin and filter handling.

3.1.1.3.4 Thermal Shield Cooling System

Cooling of the thermal shield uses purified, light water. The primary radionuclides present in the cooling system include the following:

- ^{16}N, which presents a local dose rate at the ring header ranging from 5 to 30 mrem/hr at one foot, during power operations at various tube locations around the header.
- ^{66}Cu and ^{64}Cu, which are the primary short-term sources of external exposure following reactor shutdown. The ALARA measure for routine maintenance on this system is to delay the start of that work for 36 to 48 hours. ^{64}Cu concentrations up to 1 mCi/liter have been observed.
- ^{65}Zn and ^{110m}Ag, which are the long-term radionuclides in the system. Maintenance procedures are formulated to maximize containment of all fluid transfers to control this potential source of contamination. Concentrations are typically less than 0.01 mCi/liter for ^{65}Zn and 0.001 mCi/liter for ^{110m}Ag.

In the main experimental room, C100, aside from beam experiments, the Thermal Shielding System is the main source of external radiation exposure. General area dose rates are about 0.2 mrem/hr at 6 meters. Local shadow shielding is employed, where practical, to reduce exposures to experimenters working in the room. Control of the cooling water chemistry is also used to minimize the concentration of these radionuclides when practicable.

3.1.1.3.5 Fuel Storage Pool

Water in the spent fuel storage pool is contaminated due to the transfer of spent fuel elements to the pool and from cutting operations performed on them. The major radionuclide present is tritium, at concentrations ranging from 0.01 to 0.2 μCi/ml. Since the volume of the spent fuel pool is 33,000 gallons (124,900 liters), the total pool tritium inventory ranges from 1 to 25 Ci.

Extensive drying of each transferred element is performed as an ALARA measure to limit the amount of transferred tritium. Documentation indicates that about 40 ml of trapped or absorbed D_2O evolves from each element over several months. Since the primary coolant system tritium concentration is approximately 1 Ci/liter, this translates into a tritium release to the pool water of 0.28 Ci per each four-element transfer, or about 2 Ci per year, based on 7 refueling cycles. These small quantities are manageable through simple evaporation or liquid releases.

Cutting of spent fuel elements releases various chips and small particles of aluminum to the pool water. These particles contain the normal activation constituents of aluminum, which are ^{51}Cr, ^{60}Co, and ^{65}Zn. An aggressive spent fuel pool vacuuming program and spent fuel pool filtration maintain these radionuclides to less than nCi/liter levels.

3.1.1.3.6 Miscellaneous Systems

At NBSR, the cold neutron source consists of a liquid/gaseous hydrogen loop cooled by helium. The liquid hydrogen is subjected to a high neutron flux. Consequently tritium is produced in this fluid resulting from the natural occurrence of deuterium in hydrogen. However, this is a closed system designed not to require opening for any kind of maintenance, except for removal of the cold source. Therefore, no operational radiological consequences associated with this system fluid exist.

The Helium Cooling System for the cold source has no exposure to neutrons or to any contaminated system. Therefore, this system has no radiological consequences.

The Liquid Waste System is comprised of selected drains in the laboratory wing and all light water drains from the confinement building. These drains are routed to the liquid waste collection facility. The dominant radionuclide in the collection system is tritium, and is discussed further in Section 3.2.6.

There are no radiological consequences associated with the experiment light water cooling system. Since it is located in the confinement building and contains water, there is the potential for absorption of trace amounts of tritium. However, experience has shown that resultant contamination is negligible.

3.1.1.4 Solid Radiation Sources

Solid sources of radiation at NBSR result from reactor operations. The sources range from very low specific activity, such as used rubber gloves from handling potentially contaminated materials, to intermediate activity items such as activated foils from experiments, and to the high activity spent fuel from the reactor. These sources are described in the following subsections.

3.1.1.4.1 Fuel Elements

All operations involving movement of irradiated reactor fuel elements are performed underwater, which provides the needed shielding. The non-fuel element portions of the spent fuel are removed by underwater cutting and are disposed of separately from the fueled portions of the fuel elements. The radioactivity at the time of shutdown in the pieces from a single fuel element that was used for eight operating cycles is shown in Table 3.1. Only the longer-lived radionuclides are tabulated because of the time delay to shipment. This delay is a minimum of approximately 280 days, but is more typically greater than a year. Table 3.1 shows that when shipments are normally made, the shipment total activity is dominated by ^{55}Fe, ^{60}Co, and ^{65}Zn. For elements used for fewer operating cycles, these values would be reduced, because the neutron exposure time (production time) would be less. Personnel exposure when performing spent fuel handling operations is minimal and is controlled through the use of shielding.

The fission product inventory for one NBSR fuel element is depicted in Table 3-2. Radiation dose rates from these elements are the primary issue for personnel protection. All fuel transfers are performed within a shielded pathway. The room through which the elements are transferred is controlled as a Very High Radiation Area during these transfers per 10CFR20.1602 requirements. All handling of the fuel in the storage pool is monitored with area monitors or survey instruments as a precaution to ensure the fuel element being handled remains adequately shielded.

New NBSR fuel elements nominally contain 350 grams of ^{235}U. Upon receipt they are surveyed for both radiation level and contamination. Prior to insertion into the reactor, each element undergoes a thorough quality assurance evaluation. Dose to operators when handling the new fuel is negligible, since there are no fission or activation products present.

3.1.1.4.2 Reactor Shims

Control shims are the only other high activity component routinely removed from the reactor. This occurs usually every 4 to 5 full-power years. After a minimum decay period of 3 months, the stainless steel hubs are separated from the Cd-Al body and shipped with the other radioactive non-fuel element metal pieces. The Cd-Al shim body is stored in the storage pool or in shielded dry storage wall cavities. Radioactivity for the hub is typically about 20-25 Ci, and the shim body is typically less than 1 Ci. Personnel exposure when performing preparatory operations for shipping is controlled through the use of shielding and the delay between when the shims are removed from the reactor and the preparation of the offsite shipment begins.

3.1.1.4.3 Other Radioactive Solids

Other radioactive solids that contribute to personnel dose and waste volume include:

- Reactor primary resins, which are replaced very infrequently on the order of once every 10 to 20 years
- Reactor primary filters, replaced as needed, usually once or twice a year
- Filters and resins from other systems
- Shielding plugs and related neutron beam shields
- Experiments, or experimental components removed from high neutron flux locations
- Activated experiment samples
- Miscellaneous contaminated materials, such as laboratory waste
- Emergency response.

The radioactivity in these items range from curie quantity material for items such as resins, to barely detectable levels in other items, which constitute the bulk of the waste volume. ^{60}Co in the activated metals, resins, and much of the waste is the primary contributor to personnel external dose rate. This material is stored in restricted areas where access and area dose rates are controlled to limit personnel exposure. Local shielding is used as necessary to limit areas to less than Radiation Area conditions. Sometimes this material is stored in shielded casks or the concrete shield cave facility located in the G-Wing of Building 235. Bulky items with low-level activation, typically experiment shields and components, may be stored in Building 418, which is adjacent to the reactor building. Both of these storage areas are maintained as restricted areas.

3.1.1.4.4 Solid Radioactive Waste Disposition

All radioactive waste is disposed of in accordance with 10CFR20, Subpart K. Solid waste is transferred to organizations specifically authorized or licensed to receive the material, such as the Department of Energy. Materials designated as radioactive waste are transferred to the H wing of the facility for characterization, packaging, and preparation for transfer to authorized recipients. Annual radioactive waste volumes and activities are typically in the range of 126 to 423 ft^3 (11 to 36 m^3) and are less than 1 Ci. In years when unfueled element shipments occur, or major facility modifications performed, larger quantities of radioactive material will be involved. Based on past experience, these are infrequent occurrences on the order of once every 5 or more years.

3.1.1.5 Radiation Sources from Experimental Facilities

NBSR is primarily used for research purposes. The majority of this research involves the use of neutrons to study material constituents, processes, and structure. Therefore, radiation sources will be present in the experimental facilities supporting these activities. These sources are described in the subsections below.

3.1.1.5.1 Neutron Beams

Neutron beams at the NBSR typically range from a few mm^2 to 200 cm^2. Beams with an in-beam dose rate in excess of 100 mrem/hr and accessible (have an open path in excess of 30 cm) are designated as High Radiation Areas. Section 3.1.5.1 has a discussion of beam controls. A characteristic of neutron beams is that the radiation field outside of the beam is typically less than 5 mrem/hr. Sometimes experimental samples or equipment, such as collimators or filters, can result in Radiation Area or possibly High Radiation Area conditions in areas near the beams. These areas are controlled as required by 10CFR20 Sections1601 and 1902. Non-beam related and short-term experiments are shielded and controlled to keep personnel exposures ALARA.

3.1.1.5.2 Thermal Column Facility

This facility is used to provide highly thermalized neutron beams. Although rare, experiments requiring almost the full area of the column, such as for large cross-section exposures involving irregular exposure geometries or full-field exposure geometries, are performed using this facility. Thermal neutron fluxes in the external beams are on the order of 8×10^7 n/cm^2-sec. This facility is typically controlled as a High Radiation Area, per 10CFR20.1601.

3.1.1.5.3 Pneumatic System and In-core Exposure Facilities

Experiments utilizing these facilities are highly variable, frequently producing multi-curie activity sources. All elements of the activity, facility usage, disposal, and potential personnel exposures are addressed by technical review and administrative authorization processes. Holding the source in a shielded configuration to allow sufficient decay prior to direct manipulation, processing, or analysis is the primary ALARA technique used in these situations.

3.1.1.5.4 Cold Neutron Experiments

The cold neutron guides are fully shielded to the point of neutron beam extraction, wherever possible. At the entry wall to the Guide Hall, the unshielded dose rate from a typical guide is 300 mrem/hr (neutron) and 100 mrem/hr (gamma) at one meter from the guide. The guides vary in size up to 14 in^2 (90 cm^2), and have a cold neutron flux of approximately 5×10^9 n/cm^2-sec. The in-guide gamma and fast neutron flux rates decrease by the square of the guide length for straight guides. For filtered guides with either bulk or optical filters, the fast neutron and core gamma components of the flux are largely removed. All seven guides in the Guide Hall have primary shutters. These shutters are key controlled, and have status indication (opened or closed). When closed, the design allows unrestricted disassembly and work on experiments for a particular guide.

3.1.2 Radiation Protection Program

In this section, the structure of the organization administering the radiation protection program at NBSR as required by 10CFR 20.1101 is described. The working relationship with other safety and operational organizations is also discussed as well as the authorization basis for the radiation protection program.

3.1.2.1 Radiation Protection Program Staff

Administration of the radiation protection program is performed by the reactor health physics section. This group is administratively separate from the group that manages the operation of the reactor facility. This structure is shown in Figure 3.1.

A Reactor Senior Health Physicist (RSHP) oversees the activities of the Reactor Health Physics Section and is responsible for the implementation of the Radiation Protection Program for the NBSR facility. The RSHP has a separate administrative reporting chain for normal organizational administrative functions, and also for radiation protection program elements related to the NIST materials licenses. Since maintaining the reactor operating license is the responsibility of the Director of the NIST Center for Neutron Research (NCNR), the RSHP has an additional functional reporting relationship to the Director, NCNR. The activities of the Reactor Health Physics Section include:

- Calibration of survey instrumentation
- Effluent and environmental monitoring
- Radiation and contamination surveys
- Personnel monitoring
- Review of proposed experiments and compliance reviews of operating experiments
- Radiological sample analysis
- Training of reactor staff, visiting researchers, and NIST support staff
- Safety Evaluation Committee membership

In addition to the RSHP, the Reactor Health Physics Section is typically staffed with 2 to 4 Health Physicists and 2 to 4 Radiation Protection Technicians. All of the Health Physicists meet the qualification requirements of the Office of Personnel Management for Health Physicists, GS-7 or higher and typically have sufficient training and experience to meet the American Board of Health Physics requirements for comprehensive certification.

Radiation Protection Technicians meet the qualification requirements of the Office of Personnel Management for Physical Science Technicians, GS-5 or higher. They receive additional on-the-job training specific to the NBSR prior to becoming fully qualified as a Reactor Radiation Protection Technician.

3.1.2.2 Plans and Procedures

Plans and procedures for the implementation of the Radiation Protection Program relating to reactor activities may be written by either the operations or the health physics staff. Such plans and procedures, regardless of authorship would be reviewed by appropriate members of both staffs as a minimum, and usually by the Safety Evaluation Committee (SEC) as well. Obtaining final approval from the SEC and document control is assigned to an individual on the operating staff. That person retains the original, signed document as the master and ensures the appropriate distribution to the staff is made. Plans and procedures not directly related to reactor operations, such as instrument calibration, routine shipping and receiving of radioactive materials, are maintained under the NIST materials license and controlled through an analogous structure involving the NIST Radiation Protection Officer and the NIST Ionizing Radiation Review Committee. Plans and procedures that are needed under both programs are either dual approved or are maintained as separate but consistent procedures.

3.1.2.3 Safety Evaluation Committee and Safety Audit Committee

The SEC provides the NCNR with a method for the independent review of the safety aspects of reactor facility operations and health physics, in accordance with Technical Specification 6.2.1 The committee assists the Director of NCNR in examining reactor safety activities, improving the quality of programs, and correcting problems. The SEC is composed of at least four senior technical personnel who collectively provide a broad spectrum of expertise in reactor technology (e.g., nuclear engineering, electrical engineering, mechanical engineering, and radiation protection). If necessary, for particular areas of expertise or review of particular issues, the committee may establish subcommittees using members or outside experts. At least two members are from NCNR and one is from Health Physics.

The Safety Audit Committee (SAC) provides the NCNR with a method for performing independent audits of various aspects of the reactor facility, in accordance with Technical Specification 6.2.2. This committee assists the Director of NCNR in auditing reactor safety activities, improving the quality of programs, and correcting problems. The Director of NCNR appoints the SAC members. The SAC is composed of at least three senior technical personnel who collectively provide a broad spectrum of expertise in reactor technology appropriate to the areas scheduled for audit (e.g., nuclear engineering, electrical engineering, mechanical engineering, and radiation protection) and who are not regular employees of NIST. These two committees are described in further detail in Chapter 12 of this SAR.

3.1.2.4 Interdiction Authority

Any licensed reactor operator, any member of the NCNR management, and any NBSR staff Health Physicist have the authority to interdict and terminate any activity related to the use of the reactor or the use of radioactive materials within the reactor facility that is judged unsafe or that could reasonably lead to an unsafe condition or violation of NRC regulations. Only the licensed operators have jurisdiction over the operation of the reactor itself.

3.1.2.5 Radiation Safety Training Program

To obtain unescorted access to Building 235, individuals must be trained in the following subject areas:

- Basic radiation science
- Meaning and proper response to radiation signs
- Proper use of assigned radiation dosimetry
- Proper response to emergency alarms
- NBSR procedures related to their duties

Individuals who have duties relating to the direct use of radioactive materials or reactor experiments are given additional training, which includes:

- Radiation science specific to their radioactive material usage
- Radiation protection techniques for their specific duties
- Proper use of the appropriate radiation survey instruments
- NBSR procedures and NRC regulations specific to the materials' usage pertaining to usage limitations, ALARA requirements, and material control

Individuals requiring training include the NCNR staff who reside in Building 235, visiting researchers using NBSR experiment facilities, selected plant personnel, and security and fire protection personnel who have unescorted access within Building 235. All trained personnel receive refresher training every 24 months, not to exceed a 30-month interval. Reactor operating staff and the reactor Health Physics staff maintain their radiation safety skills through ongoing training (i.e., on the job training).

3.1.2.6 Records

The following records are retained for the life of the facility, as prescribed in 10CFR20 Sections 2101 through 2110.

- Personnel exposure records
- Radioactive emission determinations and related calculations
- Survey data in areas where radioactive materials are used and any contamination events related to personnel exposure in those areas
- Results of air sampling, surveys, and bioassays required by 10CFR20.1703(a)(3)

All other radiation protection documents (survey records, calibration records, work logs) are retained for at least 10 years. Records relating to 10CFR Part 21 issues are retained for at least 5 years.

3.1.2.7 Part 21 Program

At NBSR, a senior staff member has been designated the responsible individual for receiving, reviewing, and reporting to the NRC any matter relating to requirements under 10CFR21. All staff and facility users required to have radiation protection training also receive training on 10CFR21 reporting requirements. NBSR has promulgated procedures reflecting the 10CFR21.21 requirements. A notice is also posted in a prominent location outlining the reporting requirements and the staff responsibilities required under 10CFR21.6.

3.1.3 ALARA Program

The NBSR ALARA program, as required by 10CFR20.1101, addresses all aspects of NBSR operations. These activities include specific emphasis on proposed new experiments, planned activities involving significant potential personnel exposures, ambient radiation environments within NBSR, and retrospective reviews of occupational and public doses. The Reactor Senior Health Physicist and the SEC have primary responsibility for the prospective analyses, while the SEC and SAC have primary responsibility for retrospective ALARA reviews and audits.

Activities involving the potential for exposures greater than 0.5 person-rem usually require a formal operating plan, a meeting of the involved personnel to discuss the plan, identification of methods for reducing exposures, and specific oversight by the Health Physics staff to ensure that recommended ALARA measures are implemented. Activities involving less potential for personnel exposure have less formal planning and a pre-operational review.

Examples of various ALARA activities implemented at NBSR are identified in Section 3.1.1 above. Engineering controls, such as shielding are utilized to the maximum extent practicable to minimize radiation levels in work areas. Through review of regular surveillance surveys, the Reactor Senior Health Physicist will identify unusual radiation conditions or work practices and recommend improved methods, as well as “lessons learned” feedback to the staff involved.

Minimum ALARA goals are to improve on past performance for ongoing activities and to achieve the lowest exposures by thorough planning. Explicit numerical ALARA goals are rarely established due to the non-routine nature of much of the NBSR research environment. The typical monetary equivalent expended per person-rem avoided is greater than $100,000. The NBSR ALARA goal is to limit radiation doses in unrestricted areas to 10% of 10CFR20.1301(a)(1) using shielding and procedures. An explicit limit for public dose from gaseous effluents has been established at 10 mrem per year, pursuant to 10CFR20.1101(d).

3.1.4 Radiation Monitoring and Surveying

Health Physics supports the NCNR by maintaining portable and fixed monitoring instrumentation as well as laboratory radiological analysis instrumentation. Similar instrumentation located in the Radiation Physics Building provides on-site back up for most of the NBSR instrumentation requirements. Laboratory instrumentation available includes low background proportional counters for alpha-beta counting, liquid scintillation systems for tritium and other low energy beta counting, gross beta counting, and beta spectroscopy, and InGe gamma spectroscopy systems.

Health Physics instruments used for quantitative radiation measurements are calibrated and performance checked at specific frequencies for the radiation measured. Health Physics conducts internal quality control programs to assess the reliability and stability of the laboratory radiological analysis instrumentation. All calibration sources are traceable to either manufacturer supplied reference standards or to national reference standards, such as NIST Standard Reference Materials or NIST primary standards. Radiation instrumentation that provides engineered safety functions related to the operation of the reactor are described elsewhere.

3.1.4.1 Area Radiation and Contamination Monitoring

Contamination and radiation surveys are conducted weekly during operation. During extended shutdowns, alternative schedules are established, which are usually more frequent. Areas that are surveyed include the accessible areas of the Confinement Building and other radioactive material work areas, with emphasis on those areas that pose the greatest potential for changing conditions. These would include the reactor systems and experiments. Additional surveys are performed on an as-needed basis. Typically radiation surveys of active work locations are performed daily.

Spot contamination measurements are routinely performed with paper smears over a 100 cm^2 area. The sensitivity of the instrumentation is typically better than 10 pCi of beta activity and 2 pCi of alpha activity. Large area coverage contamination surveys are performed with floor contamination beta monitors on an as-needed basis.

A full range of portable beta, gamma, and neutron survey instruments are available at NBSR. These include G-M detectors, ion chambers, proportional detectors, plastic scintillation gamma detectors, NaI detectors, and BF_3 and ^{6}LiI moderated neutron instruments. These detectors cover dose rate ranges from 20 μrem/hr to 1,000 rem/hr. Selected portable survey instruments are positioned at various locations around the facility and near experiments for ready use.

Fixed gamma area radiation monitors are positioned at ten selected locations in the confinement building. These ten locations are: three on the C200 level, which includes the control room, top of the reactor, and west wall of C200; four on the C100 level, which includes the experiment and neutron beam room; two in the process room, which contains primary cooling water systems; and one in the spent fuel storage pool area. Alarm set points are specified in NBSR procedures. Typical alarm settings are 5 mrem/hr and adjusted as needed for non-routine activities, generally with the objective of identifying unusual changes in radiation conditions.

Monitors in the spent fuel storage pool area are positioned to detect: increased radiation levels associated with handling of irradiated fuel elements; a loss of shielding from a loss of pool water; or criticality in the pool. The monitor installed in the new fuel storage area serves as a criticality detector.

Fixed personnel contamination monitors are located at the entrances to the reactor confinement building, and elsewhere on an as-needed basis. Three types of monitors are available for this use. They are:

- Hand and foot monitors using G-M or proportional detectors
- Portal monitors using G-M or plastic scintillation detectors
- Half-body contamination monitors using sealed tube or gas-flow proportional detectors

3.1.4.2 Air Monitoring

Conditions requiring airborne radioactivity monitoring under 10CFR20.1502(b) are rarely present at the NBSR. The two primary airborne radionuclides present at the NBSR are ^{41}Ar and ^{3}H. For ^{41}Ar, area radiation monitors are used to control personnel radiation exposures. Cary ion chambers or gas Marenelli chambers are used to determine airborne activity concentrations, with a sensitivity of better than 0.1 of DAC. An installed gas-flow ion chamber system takes samples from representative areas of the building and from the ventilation system for tritium detection. This system can detect 10% of DAC for tritium levels and is also sensitive to ^{41}Ar. "Cold trap" sampling is also used to sample for tritium. These cold trap samples are analyzed using liquid scintillation, with a sensitivity of better than 10^{-6} DAC.

Continuous air monitors are available for airborne particulate and iodine monitoring on an as-needed basis. One continuous air monitor is typically positioned in the spent fuel storage pool area. Filter and charcoal cartridge samplers are also available for iodine and particulate sampling. These filter and cartridge samples are analyzed in the radioanalysis laboratory.

3.1.4.3 Effluent Monitors

^{41}Ar effluent at NBSR is monitored with a G-M detector located in the stack. This system is calibrated by comparison to a grab sample that is analyzed in the radioanalysis laboratory. The nominal monitor sensitivity is 1.4×10^{8} cpm/(μCi/ml).

The NBSR tritium effluent out the stack is continuously monitored by the building tritium monitoring system. Monthly grab samples from the stack are also collected and analyzed for verification purposes. More frequent sampling or additional continuous monitoring is implemented when unusual or non-routine activities involving the potential for added tritium release are performed. Effluent sampling can also be performed with a particulate filter and charcoal cartridge, and analyzed on an as-required basis.

3.1.4.4 Environmental Monitors

Thermoluminescent dosimeters (TLDs) are used for environmental ambient gamma monitoring. Also used for selected monitoring situations are:

- A pressurized tissue-equivalent ion chamber system with sensitivity of 0.1μrad/hr.
- Environmental G-M monitors with data logging
- A gain stabilized NaI system for monitoring ^{41}Ar or other specific gamma emitters, with a sensitivity of 0.01 μrad/hr for ^{41}Ar

3.1.4.5 Personnel Dosimeters

Personal radiation dosimeters, for both gamma and neutron dose measurement capabilities are provided by a NVLAP certified supplier. Occupational doses can also be determined by pocket ion chambers (PICs) or electronic dosimeters, or by area radiation surveys combined with stay-times. Extremity dosimeters, such as finger TLDs, wrist TLD badges, and wrist PICs are also used when needed.

3.1.5 Radiation Exposure Control and Dosimetry

This section describes how radiation exposure is controlled within the facility and how uncontrolled radioactivity is prevented from entering work areas or the environment. Facility conditions that require protective measures for personnel and the bases for expected dose to workers are also discussed.

3.1.5.1 Exposure Control

The NIST Gaithersburg site on which NBSR is located is a Controlled Area. Shielding, fencing, and controls on radiation sources are applied to limit dose rates in unrestricted areas and doses to the public from direct radiation to values in compliance with 10CFR20.1301. The NBSR ALARA goal is to limit radiation levels in unrestricted areas to 10% of 10CFR20.1301(a)(1) using shielding and procedures.

Building 235, the NCNR building, is under security access control that requires a key or appropriately coded ID card for entry, and is controlled as a Restricted Area. Other areas, such as the south yard and Building 418, may be established as restricted areas on an as-needed basis. Aside from engineered controls, the primary exposure controls are appropriate training and aggressive surveillance oversight. Unescorted access to the facility requires appropriate training (see Section 3.1.2.5). Dose rates in office and generally accessible work areas are limited to 10CFR20.1301 levels. Radioactive material usage is limited to designated areas within the facility.

Many of the areas around beam experiments and around the local shielding for beam experiments are posted as Radiation Areas. Radiation levels around experiments are minimized by careful attention to:

- The materials placed in neutron beams to minimize prompt gamma radiation, such as the use of cadmium and gadolinium as mask materials.
- Designing the experiment for minimum exposure to surroundings and personnel.
- Performing an ALARA review and use of shielding where appropriate.

The design requirement for long-term experiment shielding is less than 5 mrem/hr at one foot from the shielding for routinely accessed areas, with an ALARA goal of less than 0.5 mrem/hr at that distance. Dose rates of up to 100 mrem/hr at local "hot spots" may be permitted where added shielding is not practical, but only if the impact on personnel exposures is minimal. Dose rates of up to 100 mrem/hr may also be permitted in areas not routinely accessed, such as areas between guide shields. In all cases 10CFR20.1902 controls are applied.

Neutron beams with an in-beam dose rate in excess of 100 mrem/hr., (the High Radiation criterion), that are accessible (have an open path in excess of 30 cm) are controlled as follows:

- Rooms containing such beams are posted with a message indicating that the neutron beams are High Radiation Areas
- The point at the shield from which the beam projects is posted with the sign "Caution - Neutron Beam"
- A barrier or structure, sometimes the experiment itself, will be present to prevent inadvertent entry to the beam area
- A beam stop will be added to limit the path length to the minimum needed for the experiment.
- The experiment will be equipped with a local shutter and a local shutter control to stop the neutron beam when not needed.
- A prominent visual indicator will be present to alert persons in the vicinity of the neutron beam when the shutter is open.
- A detector capable of sensing entry to the beam area will be present to provide both an audible and visual local warning signal, whenever the beam is on.

Large area neutron fields in excess of 100 mrem/hr are controlled in accordance with 10CFR20.1601. Neutron beams with absorbed dose rates in excess of 500 rad/hr will be controlled in accordance with 10CFR20.1602. At present, there are no neutron beams in excess of 500 rad/hr operational at the NBSR. Long-term High Radiation Areas within the facility, such as the process room, are controlled by permanent internal procedures and comply with 10CFR20.1601.

Total annual exposure for the staff at NBSR over the last 10 years has ranged from 7.4 to 8.7 person-rem for 500 to 800 workers. This excludes the few years that involved high-exposure maintenance and major upgrade activities, where the yearly exposure ranged from 18 to 22 person-rem.

3.1.5.2 Personnel Dosimetry

Only a few persons at the NBSR facility, typically less than 20, meet the 10CFR20 Subpart F requirement for personal monitoring. In all cases, workers are monitored in the manner required by 10CFR20.1502. The NBSR policy for issuance of personal radiation exposure monitors is much more conservative. Typically all the persons assigned to the NBSR have a personal dosimeter. Temporary personnel requiring monitoring under the 10CFR20.1502 requirements, such as visitors, will normally be issued pocket ion chambers (PICs) or a NVLAP badge.

Individuals that could exceed 500 mrem in a year are also issued a pocket ion chamber for administrative trending of their exposure, which can be read on a daily basis. These individuals also have their radiation badges processed at least quarterly and their pocket dosimeters read at least monthly. Minors are usually not permitted to work in areas where their duties could result in an annual exposure in excess of 100 mrem. In the event that such work is permitted, those individuals will be monitored as required by 10CFR20.1502.

The average researcher annual exposure is less than 20 mrem, and the maximum staff annual exposures rarely exceed 500 mrem during routine operations. Potential exposures that exceed regulatory limits to special populations, such as embryos or declared pregnant women, are very limited. In these rare cases, added surveillance is provided and work is adjusted to further limit exposure to radiation and to radioactive materials.

Monitoring for internal exposures from airborne radioactivity as per 10CFR20.1502(b) is rarely required at the NBSR. Nevertheless, selected personnel are monitored for tritium exposure as an ALARA and quality assurance measure. Additionally, a whole body counting facility is available for assessing potential internal exposures from gamma emitting radionuclides. Annual reports are made to the NRC as required by 10CFR20.2206(a)(1). The use of Planned Special Exposures is not envisioned at the NBSR. In the event that such are needed in the future, a program will be established as required by 10CFR20.1206.

3.1.5.3 Respiratory Protection Program

NIST does not use a respiratory protection program to limit exposure to radioactive material as described in 10CFR20.1703. NIST does use an OSHA related respiratory protection program and respiratory protective devices at the NBSR for non-radiological protection purposes, such as pipe welding and cutting. Sometimes this work is performed in areas with a radiological involvement. However, in these cases, engineering controls are instituted in a manner that protection from airborne radioactive material under 10CFR20.1703 is not required or needed.

3.1.5.4 Radioactive Material Control

Sources produced by the reactor related to experimental programs range from aCi to kCi in activity. They can be in all physical forms and can involve virtually any chemical element. For beam experiments, the activity levels are typically less than 1 μCi. All experiments are reviewed with regard to the production, use, manipulation, control, and disposal of radioactive material. Appropriate controls related to exposure minimization, such as shielding and security, are established for the anticipated activities and radionuclides during the experiment approval process. This approval process might include special administrative controls, a walk-through of planned activities, or even a test irradiation at reduced conditions with less materials involved and a reduced neutron flux. Sources possessed under NRC License SNM-362, but used during the conduct of any reactor experiment, will be similarly reviewed and controlled.

Radioactive material is transferred from the reactor experiment areas only to approved usage areas. All materials removed from the reactor experiment areas are surveyed prior to removal, particularly for contamination. This is to prevent inadvertent transfer of radioactive materials. Any radioactive material to be transferred from the NCNR facility is required to have prior Health Physics clearance.

3.1.6 Contamination Control

The primary contamination control measure is to control sources of potential contamination such that the spread of contamination is avoided, preferably with engineered controls, such as negative pressure ventilation and enclosed handling in hoods or glove boxes. At NBSR any removable activity found is cleaned to non-detectable levels (less than 0.2 dpm/cm^2 of removable beta activity over 100 cm^2). Reasonable decontamination efforts are made to achieve the NBSR goal of no detectable removable activity being present in any area. In areas where external exposure is high and benefits of decontamination efforts minor, minimal efforts are performed for ALARA reasons. An example of this would be the process room, because the related external exposure for decontamination efforts is greatly in excess of the potential internal exposure.

The NBSR criteria for establishing contamination controls for an area and for equipment and items to be released for unrestricted use are based on the NRC Guidelines for Decontamination of Facilities and Equipment Prior to Release for Unrestricted Use or Termination of Licenses for Byproduct, Source, or Special Nuclear Material, July 1982, (re-issued April 1993). Reasonable decontamination efforts shall be made to achieve the goal of no detectable removable activity being present on any items or equipment released to an Unrestricted Area. Items with detectable radioactivity, either removable or fixed, for which decontamination is not possible or practical, will be retained for radioactive material disposal when identified as unneeded.

3.1.7 Environmental Monitoring

The NBSR Environmental Monitoring Program is designed to verify that the radiation doses to the public are less than 10CFR20.1301 requirements. The methods used involve active effluent sampling and monitoring, performing environmental surveys, and monitoring of liquid waste releases. These methods are described in paragraph 3.1.4.3. Real-time monitoring instruments displayed in the reactor control room are capable of recognizing a potential elevated release from the NBSR, since normal operational releases represent a negligible fraction of the regulatory limits. Reviews of the recorded release data are also performed quarterly. Public dose is based on measured emissions and is determined by computational models. At NBSR, the EPA COMPLY code is an example of several that are used for these computations. Continuous, passive radiation monitoring at the NIST site boundary using TLDs or similar monitoring devices is also performed. The individual device dose sensitivity is less than 1 mrem, but the sensitivity for detecting an annual dose above background is a factor of ten higher.

Environmental surveys include radiation surveys, sampling of grass and soil, and water sampling of local streams and ponds. The collected samples are analyzed for possible activation radionuclides and fission products. Water samples are also assayed for tritium. Environmental samples of water, soil, and grass 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). This analysis typically has a sensitivity of better than 1 pCi per sample. Liquid scintillation analysis of water samples is also done and typically has sensitivity better than 10 pCi/ml.

3.2 Radioactive Waste Management

In this section the overall radioactive waste management program for NBSR is described. At NBSR, the radioactive waste management program is assigned to the health physics group. One health physicist within the group, under the supervision of the Reactor Senior Health Physicist, is assigned primary oversight for this program. Waste management is an integral part of the Radiation Protection Program and is subject to all the management and oversight measures of that program. The operation of the NBSR and the experimental facilities is conducted to minimize radioactive waste production consistent with ALARA objectives. Disposition of gaseous effluent is discussed in sections 3.1.1.2 and 3.1.4.3.

3.2.1 Solid Radioactive Waste Controls

Solid radioactive waste is defined at the NBSR as any item that has been identified as having no further usefulness, and is contaminated with detectable radioactivity, either removable or fixed, or can reasonably be presumed to be contaminated based on its usage history and knowledge of the related processes, and further decontamination is not practicable.

Radioactive waste is segregated from non-radioactive waste. This segregation is primarily based on process knowledge, e.g. knowing where the material was used or from what system the material originated. Items that are exposed to neutrons or to sources of contamination are considered potentially radioactive. These items would include irradiated portions of experiments or items that came in contact with primary reactor coolant. Sometimes the usage knowledge provides a reasonable presumption that the item can be decontaminated. If decontamination of an item is successful, as determined by a radiation survey and contamination check, only then will that material be released for unrestricted use or disposal.

Characterization of solid radioactive waste is done by direct assay, involving sampling and direct gamma spectroscopy, as well as by process knowledge. The following are examples of process knowledge application:

- For neutron-activated materials, activation calculations are performed using the full knowledge of the constituents of the material irradiated. This technique is applied to identify radioactive constituents that are undetectable by routine survey techniques.
- For materials in liquid systems, the knowledge of the radionuclides present in those systems is applied. In particular, if the material were exposed to primary water, the tritium analysis would be based on the maximum moisture content possible in the material and the concentration of tritium in the primary at the time the material was exposed.

Determination of whether a material is radioactive or not is usually made through the survey process. Instrumentation in combination with process knowledge is used to determine both the activity level and constituents of any radioisotopes present in the material. These surveys are conducted in low background radioactivity conditions and explicit criteria for a positive indication above background is established. An example of this criterion is 5 µR/hr for a 1" x 1" (2.5cm x 2.5cm) NaI, 'µR' survey instrument. The instrumentation used at NBSR includes:

- NaI detectors using rate or scalar mode counting for gamma emitters
- Shielded plastic scintillation detectors, mainly for determining contamination on tools
- G-M or windowed proportional detectors for beta emitters

Solid radioactive waste is accumulated at the point of production and collected consistent with keeping exposures ALARA. All accumulation containers are appropriately labeled. Collected low-level waste is typically transferred to the H wing of Building 235. Records of the origin of the waste and its radiological contents are kept in preparation for packaging and shipment. Other waste requiring special handling or containing high levels of radioactivity, such as primary filters and large neutron beam shields, are stored at other locations.

Systems, components, and experiments are designed so as to prevent the production of mixed waste (toxic and radioactive) to the maximum extent practicable. Any such waste (i.e. lead or cadmium) exposed to neutrons, is segregated and stored until disposal at an authorized facility is arranged.

All solid radioactive waste is disposed of by either transfer to licensed disposal sites or processing facilities. It is transported as required by 10CFR Parts 61, and 71, and by the applicable state licenses of the recipient. Detailed radioactive waste characterization documents and manifests are prepared and retained in accordance with 10CFR20.2006.

3.2.2 Solid Waste Minimization

Since the costs of solid radioactive waste disposal are high, materials with low activation potential are used wherever practical to minimize the production of radioactive waste. At NBSR, experiments are designed to be reusable and to minimize the amount of neutron activated material, and the amount of materials used in processes that become contaminated are minimized to the greatest extent practicable.

Disassembling and segregating also minimizes radioactive waste. In this way only the contaminated or activated portions of objects are disposed as radioactive waste. To the extent practicable, a commercial, HEPA-filtered compactor is used to minimize the volume of radwaste. It is typically used for laboratory paper waste and contaminated gloves.

3.2.3 Gaseous Waste

The three gaseous waste streams of the reactor facility are the Normal Air, Irradiated Air, and Process Room ventilation systems. The radionuclides present in these systems are discussed in Section 3.1.1.2. Processes that might generate airborne or gaseous contamination are vented through one of these systems. Gases in these systems are passed through HEPA filters prior to release up the stack. For an upset or abnormal operating condition, these ventilation systems go into a recirculation mode of operation, and a standby charcoal filter is made operational.

3.2.4 Liquid Waste

Selected drains in the laboratory wing and all light water drains from the confinement building are routed to the liquid waste collection facility. This facility consists of a 1,000 gallon (3,785 liter) tank, two 5,000 gallon (18,900 liter) tanks, various filters, and related pumps and valves. Water collected is sampled and analyzed for its radioactive constituents and then filtered to meet 10CFR20.2003 solubility requirements prior to release to the sanitary sewer. Credit is taken for the daily NIST site release volume of approximately 260,000 gallons (984,100 liters) to meet the 10CFR20.2003 concentration limits.

If unanticipated quantities of radioactive material are accumulated in the system, the capability is present to either circulate the water through filters or resin beds to reduce the radionuclide concentration, to transfer the water to containers for off-site processing at a NRC licensed facility, or to store it and allow radioactive decay to reduce the level of activity. As an ALARA measure, the general operating practice, when practicable at the NBSR, is to collect any high activity liquid waste at the source and separately process and dispose of that waste.

The dominant radionuclide at NBSR is tritium, with annual releases on the order of 2 to 5 Ci. Tritium releases will comply with the limits contained in 10CFR20.2003(a)(2) and (3). Annual releases of other prominent beta-gamma (^{60}Co, ^{65}Zn, ^{110m}Ag) emitters are typically in the range of 0.1 to 1 mCi, with an average concentration of less than 3×10^{-9} µCi/ml. Releases to the sanitary sewer under NIST materials license SNM-362 are a small fraction of the total NBSR liquid radioeffluent produced. These releases are included in the totals for compliance with 10CFR20.2003(a)(2) and (3). Confinement Building air conditioning condensate is the major contributor to the liquid waste volume. This is due to low-level tritium contamination in the building air. The annual volume of radioeffluent waste released is typically 300,000 gallons (1,135,500 liters), which is diluted by the NIST site sanitary sewer volume of approximately 100 million gallons (378.5 million liters).

3.2.5 Long Term Storage

The policy at the NBSR is to dispose of items identified as waste. When that cannot be done expeditiously, there is a long-term storage area for radioactive waste material located in the G wing of Building 235. At this location there are 33 shielded concrete cavities, each about 10 feet (3 meters) deep and varying diameter. This is the primary location for storing items that present a significant exposure potential, but have potential future use. It is also used to store some items to allow radioactive decay to reduce the activity level prior to disposal.

Table 3.1: Long-Lived Isotopes in the Unfueled Portion of a Spent Fuel Element

Radionuclide	Half life	Activity (Ci)
Fe-55	**2.7 y**	**3.3**
Fe-59	44.5 d	0.45
Co-60	**5.27 y**	**0.7**
Zn-65	**244 d**	**2.6**
Mn-54	312 d	0.3
Cr-51	27.7 d	0.0033
Ni-63	100 y	0.016
Ni-59	76000 y	0.00013
Co-58	70.9 d	0.37
Hf-181	42.4 d	0.063
Sc-46	83.8 d	0.0068
Sb-124	60.2 d	0.0012

Table 3.2: Fission Product Inventory for one Fuel Element

Nuclide	Activity (Ci.)	Nuclide	Activity (Ci.)	Nuclide	Activity (Ci.)
KR 85	7.91E+01	SN123	2.10E+01	BA137m	6.16E+02
SR 89	2.47E+04	SN125	5.50E+01	BA140	2.65E+04
SR 90	6.29E+02	SB125	3.42E+01	LA140	3.01E+04
Y 90	6.76E+02	SB127	3.27E+02	CE141	2.90E+04
Y 91	3.05E+04	TE127	4.04E+02	CE143	2.68E+03
ZR 95	3.26E+04	TE127m	9.20E+01	PR143	2.75E+04
NB 95	3.29E+04	TE129	3.19E+02	CE144	1.57E+04
NB 95m	2.37E+02	TE129m	4.91E+02	PR144	1.57E+04
ZR 97	2.37E+02	TE131m	1.27E+02	PR144m	1.88E+02
NB 97	2.38E+02	I131	1.06E+04	ND147	9.21E+03
NB 97m	2.25E+02	XE131m	1.69E+02	PM147	1.25E+03
MO 99	9.54E+03	TE132	8.19E+03	PM148	3.13E+03
TC 99m	9.19E+03	I132	8.44E+03	PM148m	2.03E+02
RU103	1.60E+04	I133	7.01E+02	PM149	2.65E+03
RH103m	1.44E+04	XE133	2.29E+04	PM151	1.24E+02
RH105	3.75E+02	XE133m	3.61E+02	SM153	1.25E+03
RU106	9.73E+02	CS134	6.82E+02	EU154	3.08E+01
RH106	9.73E+02	CS136	1.53E+02	EU155	1.73E+01
AG111	7.94E+01	CS137	6.51E+02	EU156	2.23E+03
Total Activity (Ci) = 3.97E+05					

Data Source: ORIGEN Code Output performed by BNL on May 7, 2003.

Note: The Fission Product Activity listed here is for one NBSR fuel element that has been irradiated for 304 days (8 cycles) at an average power of 667 kW and “cooled” for 5 days in the core prior to removal (NBSR administrative policy).

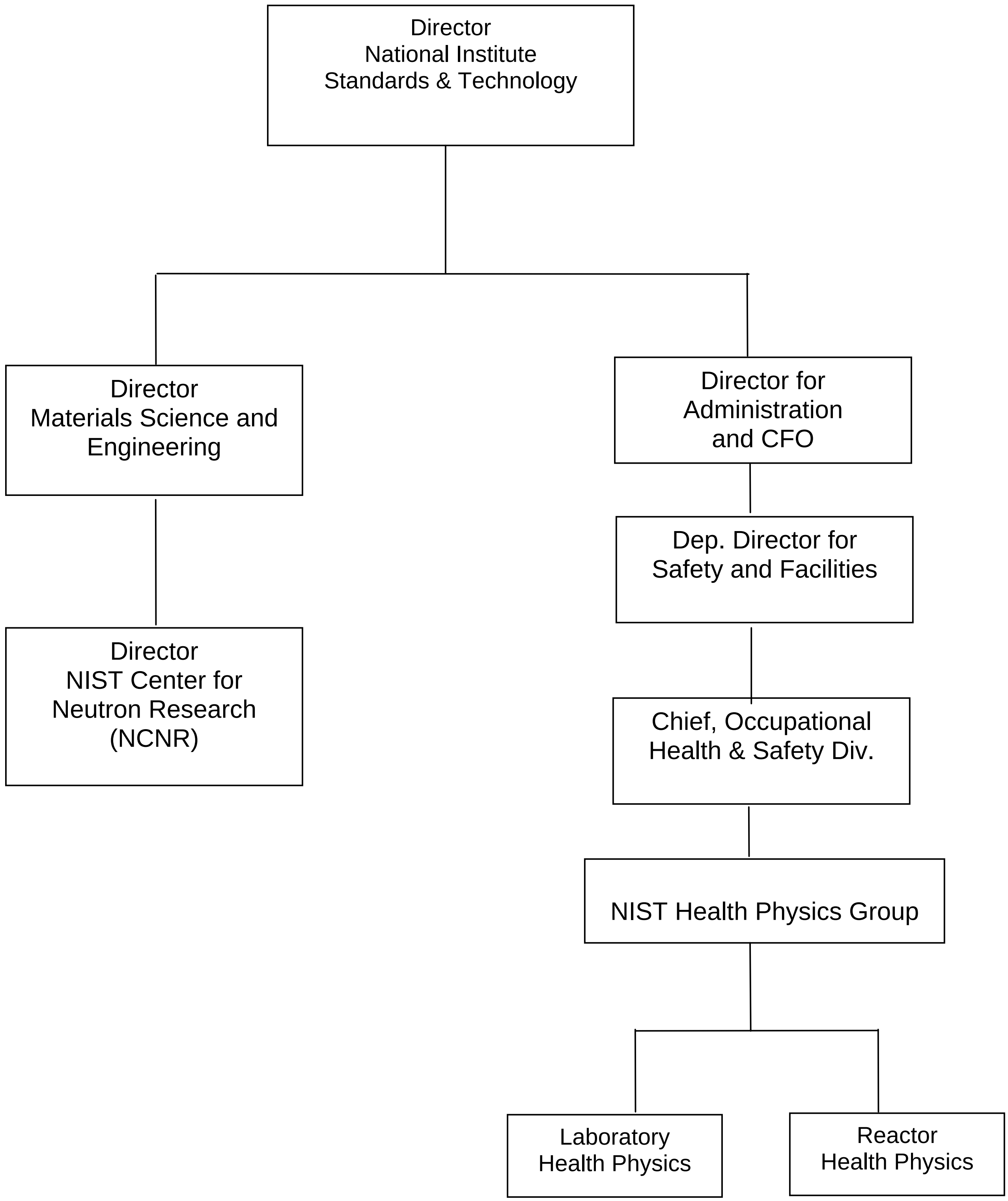


Figure 3.1: NIST Organizational Chart

4 BENEFITS OF FACILITY OPERATION

The NBSR is at the heart of the NIST Center for Neutron Research (NCNR), the nation's premier neutron source. In the words of a recent report issued by the White House Office of Science and Technology Policy, "The NCNR is the highest performing and most used neutron facility in the United States at this time, and will remain in that position until the Spallation Neutron Source is operational and robustly instrumented" (OSTP, 2002). The NCNR is the only source in the U.S. offering all neutron scattering methods coupled with modern instrumentation that is competitive with the worlds best. The NCNR has developed strong working relations with other Federal agencies, including the National Science Foundation and the National Institutes of Health, as well as with federally funded national laboratories (e.g. Brookhaven National Laboratory). Major universities across the nation, such as the University of California, Penn, Johns Hopkins, SUNY at Stony Brook and international organizations such as ANSTO in Australia, Tsinghua University in Taiwan, and the Institut Laue Langevin in France perform work at the NBSR. The current replacement cost of this facility, including the instrumentation, is estimated to exceed $800M.

More than 2000 participants used the NCNR during 2003, in various scientific fields, including biology, materials science, and theoretical physics. Since these participants come from every regional area within the nation, the NCNR is a truly national resource. The impact this facility has on science is exceptional – more than 8 major awards from national science organizations in the past decade have been based on work done at the NCNR. Additionally, more than 200 graduate students yearly, use the NCNR in their thesis research. Unique and innovative instrumentation, such as the High Flux Back Scattering Spectrometer for high-resolution inelastic scattering, which was developed at NCNR, has been reproduced for use in major facilities worldwide. Although reactors of higher neutron flux than the NBSR are in service, several specialized instruments at the NCNR are clearly the best in the world.

The NCNR is used for various research activities, including:

- Studies involving novel catalyst structures that have led to major chemical processing advances,
- Studies of how both giant (current data storage technology) and colossal (future data storage technology) magnetrostriction works, which is the key phenomenon that enables the increase in computer disk drive capacity, while cost has decreased,
- Studies of the dynamic motion of proteins in solution that provides fundamental knowledge on how biological processes function,
- Studies of the stresses produced during the welding of railway tracks that can lead to premature failure of the weld,
- Studies that provide fundamental property data on quantum, one dimensional magnetic chains, which have very special and unique physical characteristics,
- Studies on neutron lifetime by trapping ultra cold neutrons of energies corresponding to less than 10^{-3} K in temperature, using a magnetic trap,

- Studies of jet engine turbine failures from hydrogen embrittlement,
- Studies of polymer structures used to develop additives that prevent diesel fuel from freezing and clogging in fuel lines,
- Studies of complex fluid motions critical to mixing in chemical processes.

A key aspect of the NCNR has been, and will continue to be improvement-based change. New thermal neutron spectrometers will provide the most intense triple axis crystal spectrometers ever constructed, allowing a new class of measurements to be performed involving problems of major national importance. A new cold neutron triple axis crystal spectrometer will become the world's most intense cold neutron instrument, once again setting a new standard for the field. Even though 37 years have passed since first criticality of the NBSR, this facility is still a critical component in the nation's research and development infrastructure, and remains at the forefront of neutron research in the United States and the world.

5 CONCLUSIONS

5.1 Non-radiological

There is no non-radiological impact from the continued operation of the NBSR

5.2 Radiological

During routine operation, radiation exposures to reactor personnel are administratively controlled to meet the ALARA criteria. Routine exposures to the general public is estimated to be less than one (1) mrem per year. These figures are well below the 10 CFR, Part 20 limits of 500 mrem per year for the general public. Accidents other than the MHA will not result in fuel damage. The MHA is an unlikely event. If it were to occur, radioactive exposures to the general public will be well below the 10 CFR, Part 100 limits.