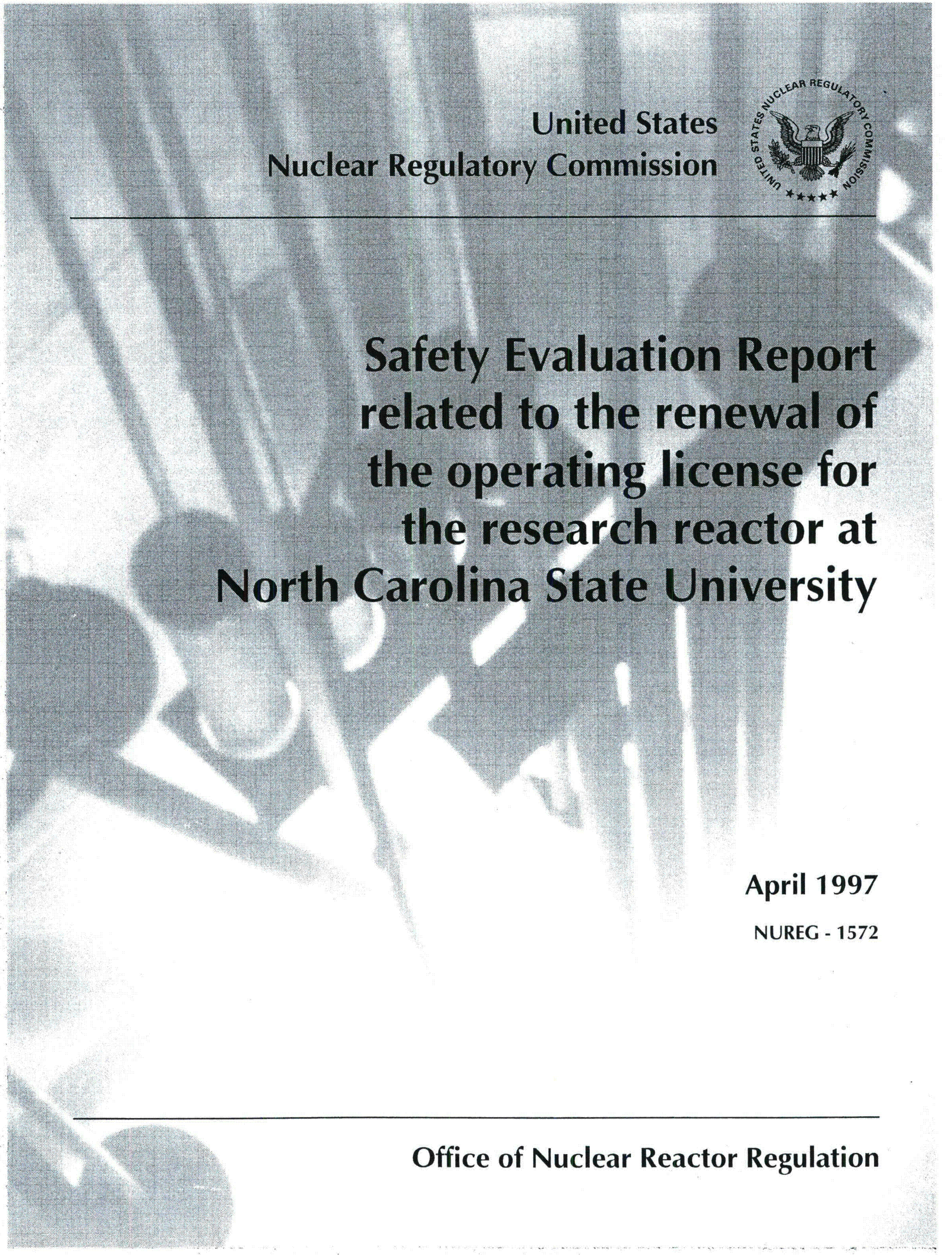

United States
Nuclear Regulatory Commission

Safety Evaluation Report related to the renewal of the operating license for the research reactor at North Carolina State University

April 1997

NUREG - 1572

Office of Nuclear Reactor Regulation

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ABSTRACT

This safety evaluation report (SER) summarizes the findings of a safety review conducted by the staff of the U.S. Nuclear Regulatory Commission (NRC), Office of Nuclear Reactor Regulation (NRR). The staff conducted this review in response to a timely application filed by North Carolina State University (the licensee or NCSU) for a 20-year renewal of Facility Operating License R-120 to continue to operate the NCSU PULSTAR research reactor. The facility is located in the Burlington Engineering Laboratory complex on the NCSU campus in Raleigh, North Carolina. In its safety review, the staff considered information submitted by the licensee (including past operating history recorded in the licensee's annual reports to the NRC), as well as inspection reports prepared by NRC Region II personnel and first-hand observations. On the basis of this review, the staff concludes that NCSU can continue to operate the PULSTAR research reactor, in accordance with its application, without endangering the health and safety of the public.

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1 INTRODUCTION

1.1 Overview

By letter (and supporting documentation) dated August 19, 1988, as supplemented on January 2, April 17, and December 18, 1989; April 17 and July 18, 1990; January 25, 1991; November 30, 1992; September 15, 1995; and October 4, November 25, and December 30, 1996, North Carolina State University (NCSU or the licensee) submitted to the U.S. Nuclear Regulatory Commission (NRC) a timely application for a 20-year renewal of the Class 104c Facility Operating License R-120 (NRC Docket No. 50-297). Such a renewal would authorize continued operation of the PULSTAR-type research reactor facility located in the Burlington Engineering Laboratories complex on the NCSU campus in Raleigh, North Carolina. Until the staff completes action on the renewal request, the licensee is permitted to operate the NCSU PULSTAR reactor under the conditions authorized in past amendments in accordance with Title 10, Section 2.109 of the *U.S. Code of Federal Regulations* (10 CFR 2.109).

The staff's review, with respect to renewing the NCSU operating license, was conducted on the basis of information contained in the renewal application, as well as supporting supplements and licensee responses to staff requests for additional information (RAIs). Specifically, the renewal application included financial statements, the safety analysis report, an environmental report, the Operator Requalification Program, and Technical Specifications (TSs). The licensee also requested that the staff consider as part of the application the PULSTAR Emergency Plan and Physical Security Plan previously filed with the NRC. The licensee has since updated these plans in response to RAIs issued by the staff as part of the license renewal process, and as part of the licensee's routine maintenance of the plans under 10 CFR 50.54(p) and (q). With the exception of the Physical Security Plan, this material is available for review in the Commission's Public Document Room located at 2120 L Street, NW, Washington, DC 20037. The approved Physical Security Plan is protected from public disclosure under 10 CFR 2.790.

In conducting its safety review, the staff evaluated the facility against the requirements of 10 CFR Parts 20, 30, 50, 51, 55, 70, and 73; applicable regulatory guides (RGs); and relevant accepted industry standards, such as the American National Standards Institute/American Nuclear Society (ANSI/ANS) 15 series. Because there are no specific accident-related regulations for research reactors, the staff compared calculated dose values for accidents with related standards in 10 CFR Part 20 (the standards for protecting employees and the public against radiation). Amendments to 10 CFR Part 20 (20.1001 through 20.2402 and Appendices) became effective January 1, 1994. Among other things, these amendments changed the dose limits for occupationally exposed persons and members of the public, as well as the concentrations of radioactive material that are allowed in effluents released from licensed facilities. The licensee must follow the requirements of 10 CFR Part 20, as amended, for all aspects of operation regarding the NCSU PULSTAR reactor. However, in conducting the accident evaluation, the staff used the dose limits in 10 CFR Part 20 that were in effect when the reactor was initially licensed in 1972 (10 CFR 20.1 through 20.602 and Appendices).

The purpose of this safety evaluation report (SER) is to summarize the findings of the staff's safety review of the NCSU PULSTAR research reactor facility and to delineate the technical details considered in evaluating the radiological safety aspects of continued operation. This SER will serve as the basis for renewing the license for operation of the NCSU PULSTAR reactor at thermal power levels up to and including 1000 kW. (The current license also authorizes pulsed operation, but the licensee has requested that the NRC eliminate pulsing from the renewed license.)

This SER contains 18 chapters which discuss the following topics:

- Chapter 1 contains a summary and conclusions regarding the principal safety considerations of the staff review, the history and a general description of the reactor facility, information on shared facilities and equipment, comparison with similar facilities, and how the licensee complies with the Nuclear Waste Policy Act of 1982.

- Chapter 2 describes the site and applicable site characteristics, including geography, demography, meteorology, hydrology, geology, seismology, and interaction with nearby installations and facilities.

- Chapter 3 describes the design bases of facility structures, systems, and components and the responses to environmental factors on the reactor site.

- Chapter 4 describes the design bases and the functional characteristics of the reactor core and its components. In this chapter, the safety considerations and features of the reactor are discussed.

- Chapter 5 lists the design bases and describes the function of the reactor coolant and associated systems, including the primary and secondary coolant systems, and coolant makeup and purification systems.

- Chapter 6 lists the design bases and describes the function of engineered safety features (ESFs) that may be required to mitigate consequences of postulated accidents at the facility.

- Chapter 7 lists the design bases and describes the function of the instrumentation and control (I&C) systems and subsystems at the facility, placing emphasis on safety-related systems and safe reactor shutdown.

- Chapter 8 lists the design bases and describes the functions of the normal and emergency electrical power systems at the facility.

- Chapter 9 lists the design bases and describes the functions of auxiliary systems, such as fuel handling and storage, compressed air, warning and communication, and fire protection.

- Chapter 10 lists the design bases and describes the functions of the experimental facilities. Non-power reactors are designed with irradiation capabilities for research, education, and technological development. This chapter discusses the characteristics of experiment and irradiation facilities on the basis of the proposed experimental programs.

- Chapter 11 lists the design bases and describes the functions of the radiation protection and the radioactive waste management programs at the facility. The description of the radiation protection program includes health physics staffing and procedures, monitoring programs for personnel exposures and effluent releases, and assessment and control of radiation doses, both to workers and the public. The facility program to maintain radiation exposures and releases as low as reasonably achievable (ALARA) is described in this chapter. The program for radioactive waste management is described including the control and disposal of radiological waste from both reactor operations and experimental programs.

- Chapter 12 lists the bases and describes the functions of plans and procedures for the conduct of facility operations. These include discussions of the management structure, personnel training and evaluation, provisions for safety review and auditing of operations by the safety committees, and other required functions, such as reporting, and security and emergency planning.
- Chapter 13 lists the bases, scenarios, and analyses of accidents at the reactor facility, and describes the maximum hypothetical accident, which is a fission product release from three fuel pins. The radiological consequences from analyzed accidents to the facility staff and members of the public are discussed.
- Chapter 14 discusses the TSs, which state the operating limits and conditions and other requirements for the facility to acceptably ensure protection of the health and safety of the public.
- Chapter 15 concerns financial qualifications of the licensee for continuing operations and decommissioning.
- Chapter 16 discusses prior reactor utilization focusing on the fuel cladding.
- Chapter 17 contains the major conclusions of the staff review of the NCSU renewal application.
- Chapter 18 contains references used for the staff review.

This SER was prepared by Mr. Alexander Adams Jr., Senior Project Manager, from the NRC's Office of Nuclear Reactor Regulation (NRR), Division of Reactor Program Management, Non-Power Reactors and Decommissioning Project Directorate. Other major contributors to the technical review included R.E. Carter, C. Cooper, and R. Carpenter of the Idaho National Engineering Laboratory (INEL) under contract to the NRC.

1.2 Summary and Conclusions Regarding the Principal Safety Considerations

In its evaluation, the staff considered the information submitted by the licensee (including past operating history recorded in the licensee's annual reports to the NRC), as well as inspection reports prepared by NRC Region II personnel and first-hand onsite observations. On the basis of this evaluation and resolution of the principal issues reviewed for the NCSU PULSTAR, the staff reached the following findings:

(1) The design, testing, and performance of the NCSU PULSTAR reactor structure and the systems and components important to safety during normal operation were adequately planned, and safe operation of the facility can reasonably be expected to continue.

(2) The licensee's management organization is adequate to maintain and operate the reactor so that there is no significant radiological risk to the facility's employees or the public.

(3) The licensee's management organization, training and research activities, and security measures are adequate to ensure safe operation of the facility and protection of its special nuclear material.

(4) The licensee and staff have considered the expected consequences of several postulated accidents, emphasizing those likely to cause a loss of integrity of fuel-element cladding. The staff performed conservative analyses of the most serious, hypothetically credible accidents. As a result, the staff determined that the calculated potential radiation doses outside the reactor site are not likely to exceed the guidelines for doses in unrestricted areas, as specified by 10 CFR 20.1 through 20.602 and Appendices for research reactors initially licensed before January 1, 1994.

(5) Releases of radioactive materials and wastes from the facility are not expected to result in concentrations beyond the limits specified by the Commission's regulations and are as low as is reasonably achievable (ALARA).

(6) The licensee's TSs which state limits controlling operation of the facility, give a high degree of assurance that the facility will be operated in accordance with the assumptions and analyses in the safety analysis report. There has been no significant degradation of equipment, and the TSs will continue to ensure that there will be no significant degradation of equipment.

(7) The financial data submitted with the application demonstrate that the licensee has reasonable access to sufficient revenues to cover operating costs and eventually to decommission the reactor facility.

(8) The licensee's program for physically protecting the facility and its special nuclear materials complies with the requirements of 10 CFR Part 73.

(9) The licensee's procedures for training its reactor operators and the plans for operator requalification are adequate; they give reasonable assurance that the reactor will be operated in a competent manner.

(10) The licensee's emergency plan provides reasonable assurance that the licensee is prepared to assess and respond to emergency events.

On the basis of these findings, the staff concludes that NCSU can continue to operate the PULSTAR reactor, in accordance with its application, without endangering the health and safety of the public.

1.3 History

On October 1, 1968, the U.S. Atomic Energy Commission (AEC) issued to NCSU a Construction Permit (CPRR-106). This permit authorized NCSU to construct an American Machine and Foundry PULSTAR-type research reactor on its campus in Raleigh, North Carolina. On August 25, 1972, the AEC issued Facility License R-120, authorizing NCSU to operate the PULSTAR reactor at steady-state power levels up to 1000 kW(t) and with pulse energy releases up to 38 MW-sec. The reactor first reached criticality in September 1972.

1.4 Reactor Description

The NCSU PULSTAR is a heterogeneous, pool-type reactor. The core is immersed in a 15,600-gallon (59,000-L), above-ground, aluminum-lined, reinforced-concrete pool. The core is normally cooled by forced convection, but it may also be cooled by natural convection at lower power levels. The coolant and moderator is light water, and the reactor core may be reflected by light water or graphite. The reactor coolant is circulated through an external heat removal and purification system. The reactor's experimental facilities include space adjacent to the reactor core, a pneumatic transfer system, beam tubes, and a thermal column.

The PULSTAR fuel design is similar to that of nuclear power reactors. Specifically, it consists of pellets of sintered uranium dioxide stacked in long, thin-walled zircaloy-2 tubes. The uranium is enriched to 4 percent in the uranium-235 isotope. The reactor exhibits a large negative temperature coefficient of reactivity, including a Doppler effect of broadening uranium-238 absorption resonances. Reactivity is controlled by three control rods. A fourth control rod, the former pulse rod, will be converted to a non-scramming shim-control rod that will be available to control the reactor. The control rods are comprised of a mixture of silver, indium, and cadmium.

1.5 Shared Facilities and Equipment

The NCSU PULSTAR reactor building contains the reactor bay, a mechanical equipment room, the reactor control room, and the primary piping vault. Offices for reactor program personnel and laboratories associated with the reactor program are located in the adjoining Burlington Engineering Laboratory. The Burlington Engineering Laboratory also provides the reactor building with electricity, water, and heating, as well as cooling for the control room. Air from the reactor building is exhausted by a stack that is concentrically located inside the stack used to exhaust the south wing of the Burlington Engineering Laboratory.

1.6 Comparison With Similar Facilities

The NCSU PULSTAR reactor is similar to the NRC-licensed research reactor at the State University of New York at Buffalo (SUNYAB) and relies on nuclear power reactor technology. The instruments and controls are similar in principle to most non-power reactors licensed by the NRC.

1.7 Nuclear Waste Policy Act of 1982

Section 302(b)(1)(B) of the Nuclear Waste Policy Act of 1982 specifies that the NRC may require, as a precondition to issuing or renewing an operating license for a research or test reactor, that the applicant shall have entered into an agreement with the U.S. Department of Energy (DOE) for the disposal of high-level radioactive wastes and spent nuclear fuel. In a letter dated May 3, 1983, R.L. Morgan of the DOE informed H. Denton of NRC that DOE has determined that universities and other government agencies operating non-power reactors have entered into contracts with the DOE providing that the DOE retains title to the fuel and is obligated to take the spent fuel and/or high-level waste for storage or reprocessing. By entering into such a contract with the DOE, NCSU has satisfied the requirements of the Waste Policy Act of 1982, as they apply to the NCSU PULSTAR reactor.

2 SITE CHARACTERISTICS

2.1 Reactor Site

The NCSU PULSTAR reactor is located in a separate reactor building within the Burlington Engineering Laboratories complex (Figure 2.1) near the center of the NCSU campus (Figure 2.2). The campus is located in the western part of Raleigh, in Wake County, North Carolina (Figure 2.3), in an area consisting primarily of residential communities with some small businesses.

The area within 15 mi (24 km) of the reactor site is characterized by gently rolling land ranging in altitude from 350 ft (110 m) to 450 ft (140 m) above mean sea level. The reactor is located at an elevation of 396 ft (121 m) above mean sea level. The campus slopes to the east, south, and west of the reactor site affording good natural drainage. The area is also well drained by creeks that carry surface water to the southeast. The nearest mountains are 75 mi (120 km) to the northwest.

2.2 Demography

The area within 5 mi (8 km) of the reactor site supports a population of approximately 185,000; the total population of the Raleigh metropolitan area is approximately 267,000. Because the university has a large commuter population, the campus population varies from approximately 34,000 during the day to less than 3,100 at night during the academic year. The campus population further decreases during the summer. The nearest student dormitory (Carroll Hall) is located 850 ft (260 m) west-southwest of the Burlington Engineering Laboratory. The residence closest to the reactor is located 790 ft (240 m) northwest of the Burlington Engineering Laboratory.

2.3 Nearby Industrial, Transportation, and Military Facilities

There is limited industry within a 5-mi (8-km) radius of the reactor site, with the greatest predominance to the east. The area surrounding the campus is primarily residential, with small businesses and shops that cater to the student population.

Several main commuter routes border the campus, and Interstate 440, the nearest major highway that carries heavy truck traffic, is 2 mi (3 km) to the west. The nearest major airport (Raleigh-Durham International Airport) is approximately 10 mi (16 km) northwest from the reactor site. No airways cross the campus. Because of the distance of these routes and the airport from the reactor site, the staff concludes that there is no significant risk to the continued safe operation of the NCSU PULSTAR reactor.

The nearest railroad line is 377 ft (115 m) south of the site. A row of large multi-story buildings stands between the reactor site and the rail line, making the possibility remote that a derailment would directly affect the reactor. Wake County and NCSU have emergency plans to deal with rail accidents on campus. If a rail accident were to occur, NCSU Public Safety would contact the reactor staff and the PULSTAR Emergency Plan would be put into action if the reactor facility was directly affected. The staff concludes that the licensee has sufficient emergency planning in place to manage rail accidents near the reactor site.

There are no major military installations near the campus.

With the exception of the rail line, which has been satisfactorily considered by NCSU, there are no major transportation routes and no significant military or industrial facilities in the vicinity of the reactor site. Consequently, the staff concludes that these facilities pose no significant risk to the continued safe operation of the NCSU PULSTAR reactor.

2.4 Climatology and Meteorology

The climatology of the NCSU PULSTAR reactor site is described in the following sections. This includes information on precipitation, winds, and temperature. The sources of meteorological data to be used in case of an emergency is also discussed.

2.4.1 Climatology

The climate in the vicinity of NCSU is classified as transitional between the Coastal Plain and Piedmont Plateau in the eastern portion of North Carolina. The PULSTAR site is subject to translation of large-scale weather systems moving from all directions across the area. The movement of the weather systems accounts for the variability observed in temperature, as well as the types and amount of precipitation measured over an annual period. Precipitation, in the form of rain, ice, and snow averages about 38 in (95 cm) per year. Long-term conditions are well defined by meteorological records collected at the Raleigh-Durham National Weather Service station, as well as other locations in the area dating back to the late 1800s.

2.4.2 Temperature and Wind Variability

Temperature extremes have ranged from -9 °F (-23 °C) to 105 °F (41 °C) during the time records have been kept. Similarly, winds show a variation in both direction and speed, with the maximum speed being over 70 mph (112 kph).

2.4.3 High Winds

High winds result from thunderstorms and intense low-pressure systems including hurricanes, that traverse the region. An average of 12 tornadoes are observed in North Carolina each year, and the state observed a total of 437 tornadoes during the period from 1953 through 1988. The random occurrence of tornadoes is illustrated by the passage of a tornado about 5.5 mi (9 km) from the NCSU reactor facility in November 1988. This tornado was sufficiently far from the reactor, and did not pose any threat to the Burlington Engineering Laboratory or the reactor building. Tornadoes that are observed in the Raleigh area are reported in the National Weather Service Storm Data Reports. In general, tornadoes of any wind intensity have an average probability of being observed at the reactor site of 1.3×10^{-4} per year, as indicated by data from 1954 through 1983 shown in NUREG/CR-4461, "Tornado Climatology of the Contiguous United States."

2.4.4 Sources of Meteorological Data for Emergencies

Local meteorological measurements for use in evaluating accidental gaseous releases from the reactor building are not available; however, regional meteorological data can be obtained from the National Weather Service at Raleigh-Durham International Airport or from the North Carolina Division of Emergency Management. The meteorological data available from these sources enable the licensee to work closely with the North Carolina Division of Emergency Management to predict the dispersion of an accident-related gaseous release to the environment.

2.4.5 Conclusion

The meteorological characteristics of the NCSU PULSTAR reactor site and vicinity are quite variable, in terms of both temperature extremes and wind direction and speed. While tornadoes are not uncommon in North Carolina, the staff concludes, on the basis of the above discussion, that the strike probability is acceptable low for any given location (such as the NCSU reactor). The procedure established by the licensee for collecting meteorological information to be used during a facility emergency is acceptable to the staff. Therefore, the staff concludes that there are no unique meteorological conditions that could produce or cause a significant risk to the continued safe operation of the NCSU PULSTAR reactor.

2.5 Geology and Seismology

The NCSU PULSTAR reactor is located in the southern (Piedmont) part of the New England-Piedmont tectonic province. The Piedmont province tends northeasterly and is bordered on the east by the Coastal Plain province and on the west by the Blue Ridge province. The last tectonic activity in the Piedmont province occurred about 200 million years ago and formed a series of northeast trending basins.

North Carolina is characterized by a low level of seismicity, except in the Blue Ridge in the western part of the state (Figure 2.4). The closest earthquakes to Raleigh were two intensity III events (modified Mercalli scale) near Raleigh in 1808 and 1898. Seismic instruments in the southeastern United States have recorded no earthquakes with epicenters in the site area. Thus, recent seismic monitoring supports the observation that the site is located in an area of historically low seismicity.

The largest historical event in the southeastern United States was the 1886 earthquake in Charleston, South Carolina, which had a maximum intensity of X. This earthquake, which occurred about 200 mi (320 km) south of Raleigh, was felt with an intensity of V to VI in the Raleigh area.

2.6 Hydrology

The campus grounds at the reactor site slope to the east, south, and west, and afford good natural drainage (Figure 2.5). The Rocky Branch Creek, about 1700 ft (520 m) south of the reactor, carries the surface water to rivers that flow to the southeastern part of the state.

Drinking water for the city of Raleigh is supplied from Falls Lake, which is located 12 mi (20 km) north of the reactor site. There is no direct natural drainage from the reactor site to Falls Lake.

Ground water at the site moves slowly (from a few feet per year to a few feet per day) through the soil and would be shunted laterally by the bedrock and discharged into Rocky Branch Creek. No major wells are located between the reactor site and the portion of Rocky Branch Creek where ground water would be expected to be discharged.

2.7 Conclusion

On the basis of the above considerations regarding both natural and man-made hazards, the staff concludes that there is no significant risk associated with the site that would make it unacceptable for continued operation of the reactor.

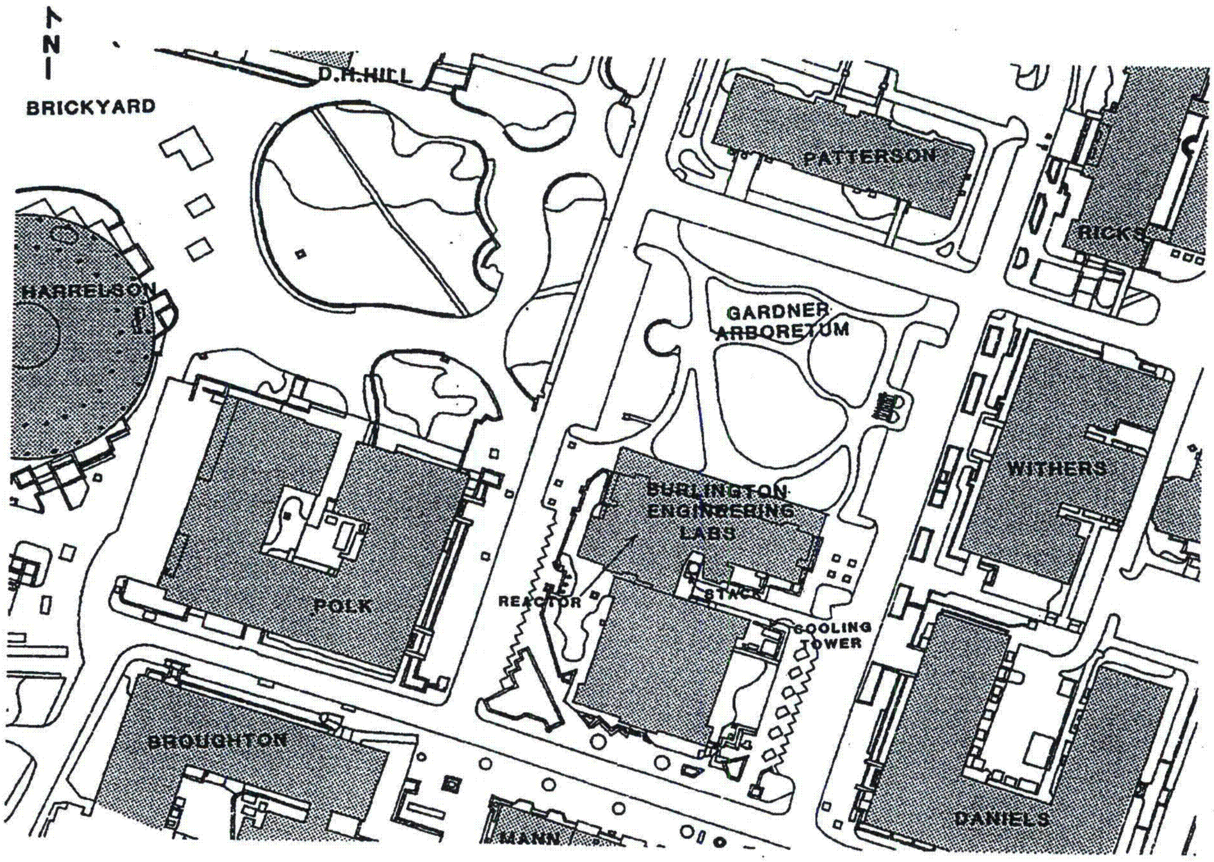


Figure 2.1 NCSU campus surrounding the Burlington Engineering Laboratories complex

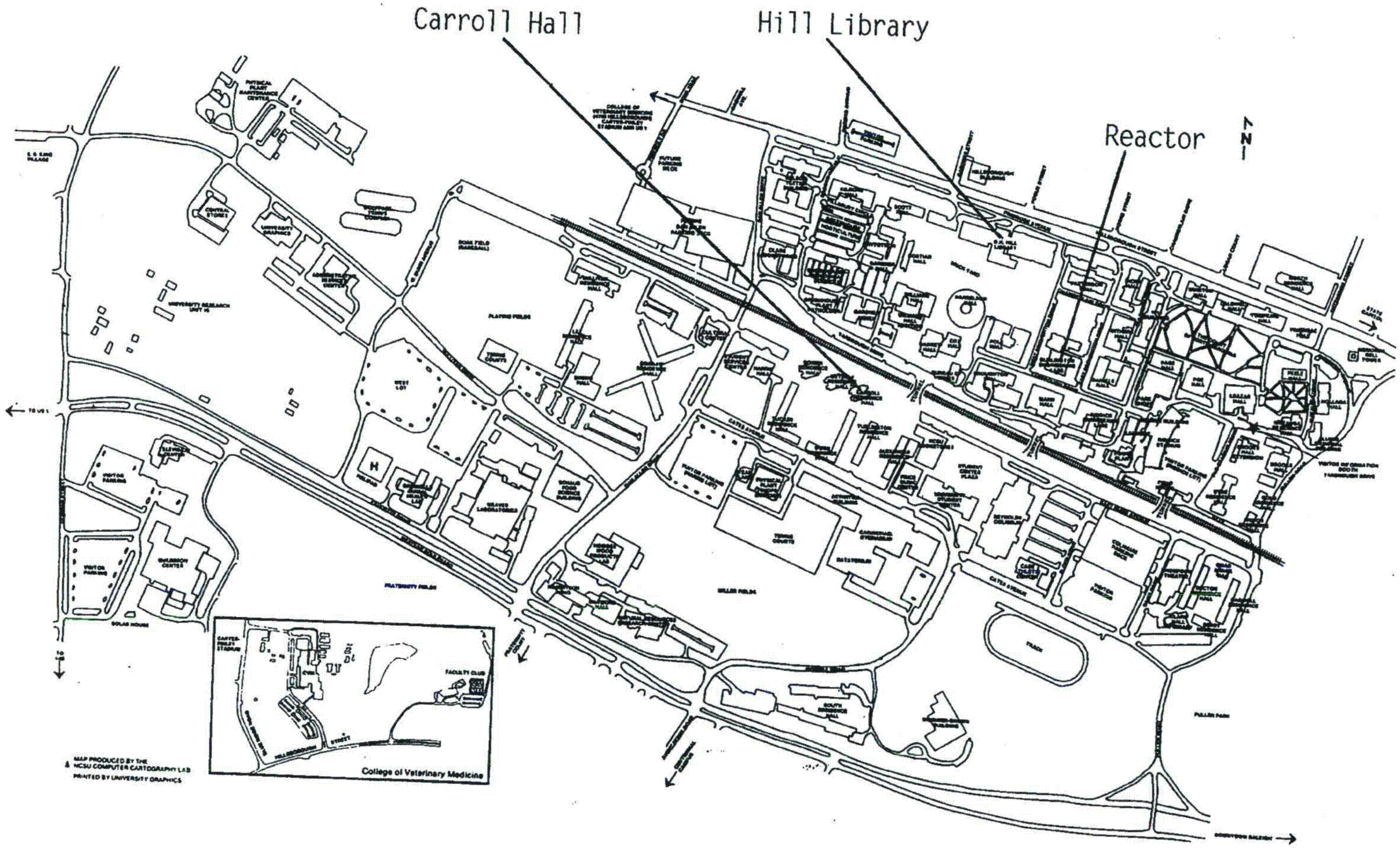
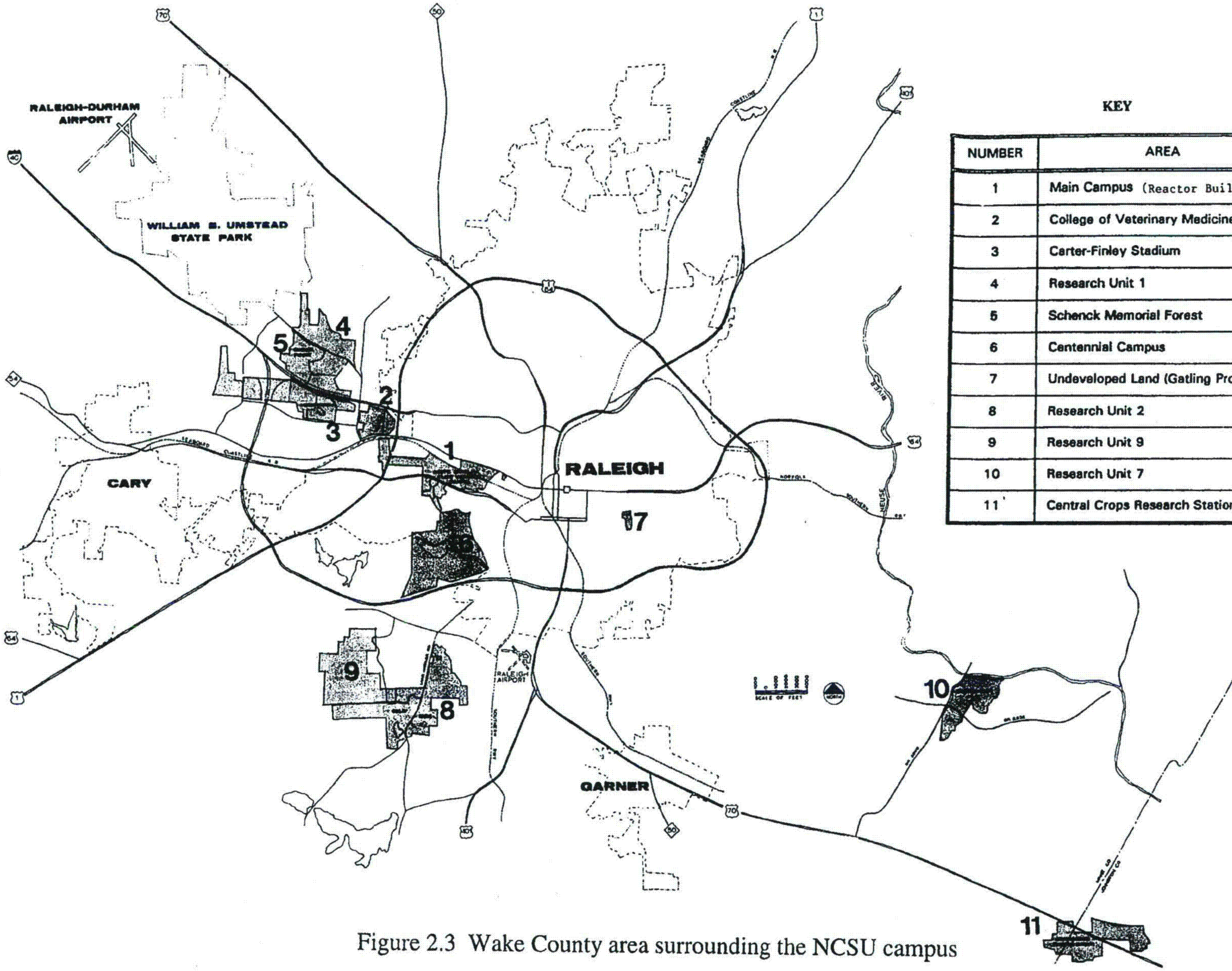


Figure 2.2 NCSU campus



KEY

NUMBER	AREA
1	Main Campus (Reactor Building)
2	College of Veterinary Medicine
3	Carter-Finley Stadium
4	Research Unit 1
5	Schenck Memorial Forest
6	Centennial Campus
7	Undeveloped Land (Gatling Property)
8	Research Unit 2
9	Research Unit 9
10	Research Unit 7
11	Central Crops Research Station

Figure 2.3 Wake County area surrounding the NCSU campus

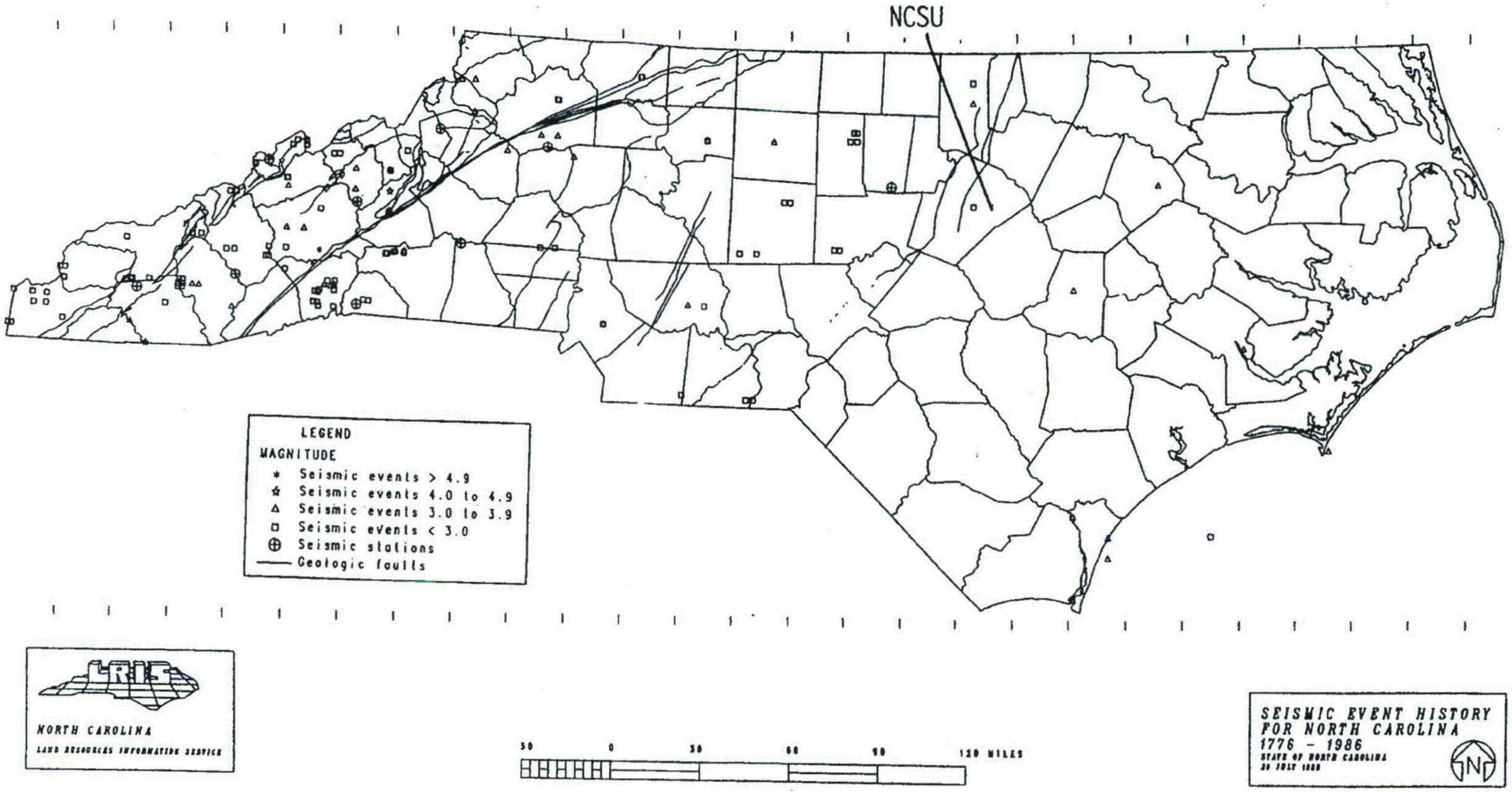


Figure 2.4 North Carolina seismicity

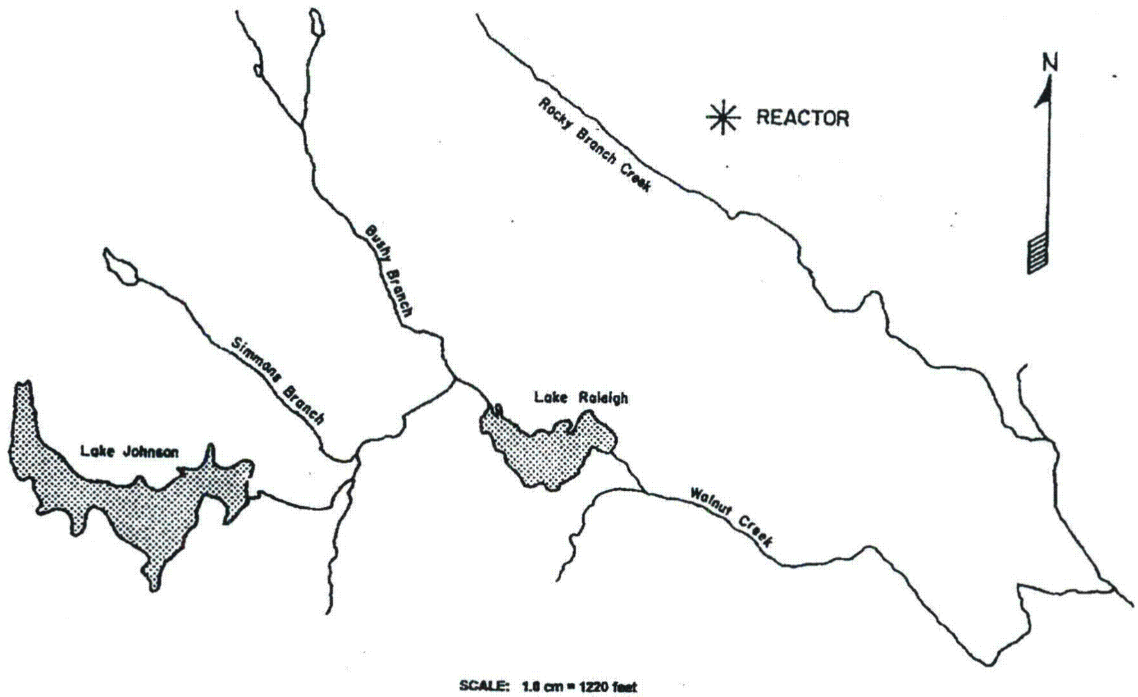


Figure 2.5 Surface water near the NCSU reactor site

3 DESIGN OF STRUCTURES, SYSTEMS, AND COMPONENTS

3.1 Reactor Facility Description

The NCSU PULSTAR reactor is located in a separate bay of the Burlington Engineering Laboratory, which is sometimes referred to as the reactor building. The reactor building was designed and built to meet or exceed building code requirements in place at the time the facility was designed. The reactor building is a reinforced, monolithic concrete structure faced with a brick veneer and painted on the inside surface with minimum penetrations. The walls of the reactor bay are 16 in (41 cm) thick. The reactor bay roof is a 3-in (8-cm) thick steel-reinforced concrete layer, with 6-in (15-cm) by 18-in (46-cm) steel-reinforced monolithic concrete webs on 30-in (76-cm) centers. Three 16-in (41-cm) by 33-in (84-cm) steel-reinforced concrete joists span the reactor bay, centered over the biological shield.

The reactor building is designed to function as a confinement-type structure, providing for controlled release of any airborne radioactivity through a 100-foot (30-m) high exhaust stack. The internal dimensions of the reactor bay are 55 ft (16.8 m) high by 37 ft (11.3 m) wide by 94 ft (28.7 m) long, encompassing a free air volume of about 86,500 ft^3 (2450 m^3). During normal operation, the ventilation exhaust rate is 10050 cfm (285 m^3/min), and this can be switched in emergencies to 600 cfm (17 m^3/min) through an absolute high-efficiency particulate air (HEPA) filter and a charcoal absorber. Figure 3.1 shows a plan view of the reactor building and Figure 3.2 shows a sectional view of the reactor building.

The reactor core is contained in a water-filled tank that is approximately 28 ft (8.6 m) deep. The tank is above ground, serves as a biological shield, and is constructed of reinforced high-density and regular concrete ranging in thickness from 5.83 ft (1.77 m) at core level to 1.25 ft (0.4 m) at the pool top. This design is typical of many research reactors. (Section 4.2 provides further details on the reactor tank.)

3.2 Wind and Water Damage

As summarized in Section 2.4.3, the Raleigh area experiences relatively few extreme wind conditions such as tornadoes or tropical storms. Furthermore, as described above, the reactor building is a reinforced, monolithic concrete structure, with the reactor itself contained in a reinforced concrete pool. In addition, the reactor building is situated well above the flood plain. Therefore, the staff concludes that wind or water damage to the NCSU PULSTAR facility is very unlikely.

3.3 Seismically Induced Reactor Damage

Available information on past seismic activity and the likelihood of future earthquakes in the Raleigh area indicates that the NCSU PULSTAR facility is located in a region with a low probability of severe seismic activity. In the event of an earthquake causing catastrophic damage to the pool, reactor coolant might be released. However, as discussed in Section 14 of this SER even catastrophic damage resulting in a total loss of coolant would not lead to core damage.

3.4 Mechanical Systems and Components

The mechanical systems important to safety are the neutron-absorbing control rods suspended from the superstructure. The motors, electromagnets, gear boxes, switches, and wiring are all above the level of the tank water where they are readily accessible for visual inspection, testing, and maintenance. The licensee has a preventive maintenance program in place to ensure that these systems and components meet the performance requirements of the TSs. Section 17 of this SER discusses the staff's findings regarding the effects of aging on the continued performance of these components.

3.5 Conclusion

On the basis of the above considerations, the staff concludes that the NCSU PULSTAR reactor was adequately designed and built to withstand all credible and likely wind, water, and seismic damage associated with the site. The design and performance of the safety systems have been verified through 24 years of operation. Accordingly, the staff concludes that the reactor systems and components are adequate to provide reasonable assurance that continued operation will not cause significant radiological risk to the health and safety of the public.

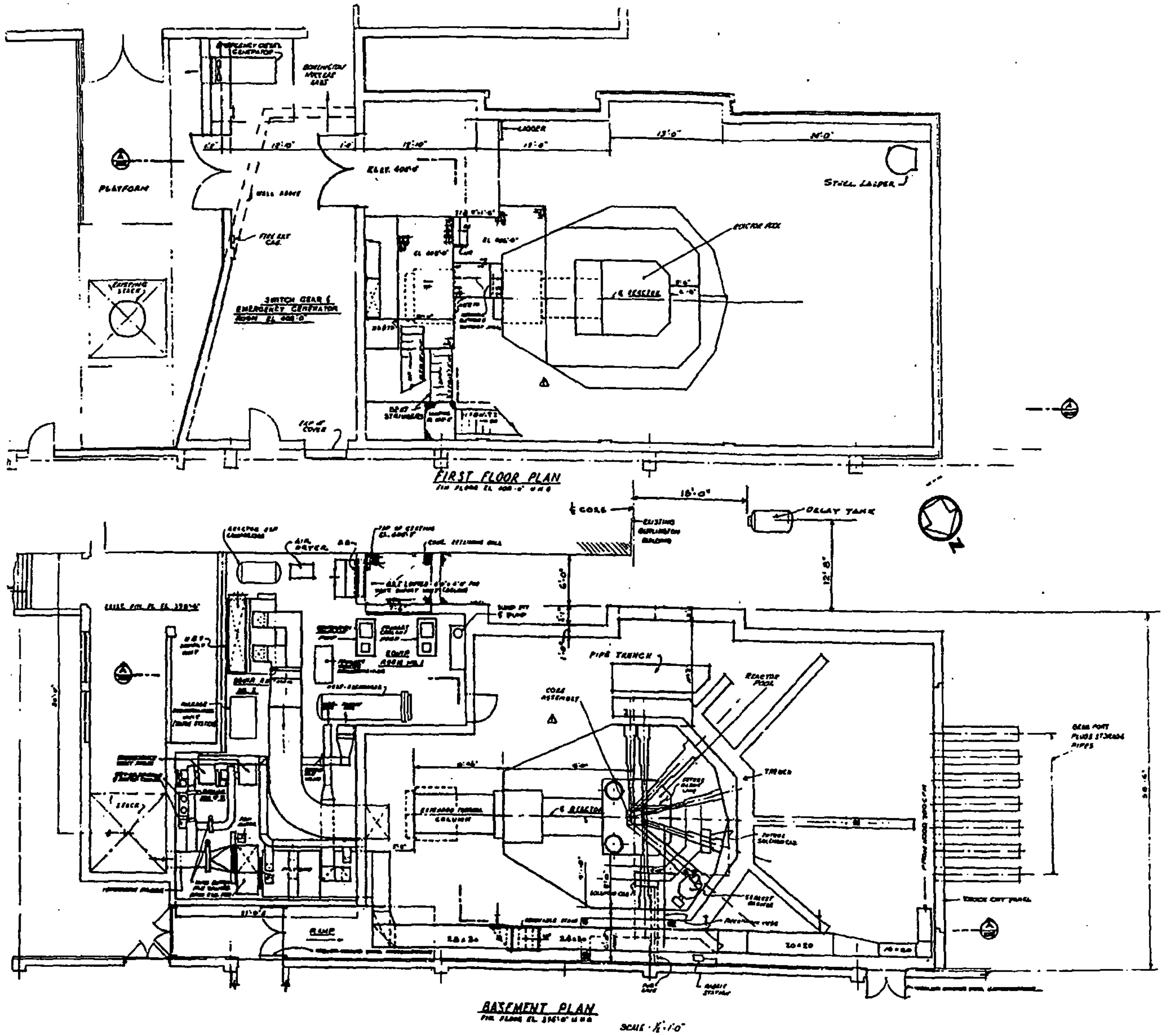


Figure 3.1 Plan view of the NCSU PULSTAR reactor building

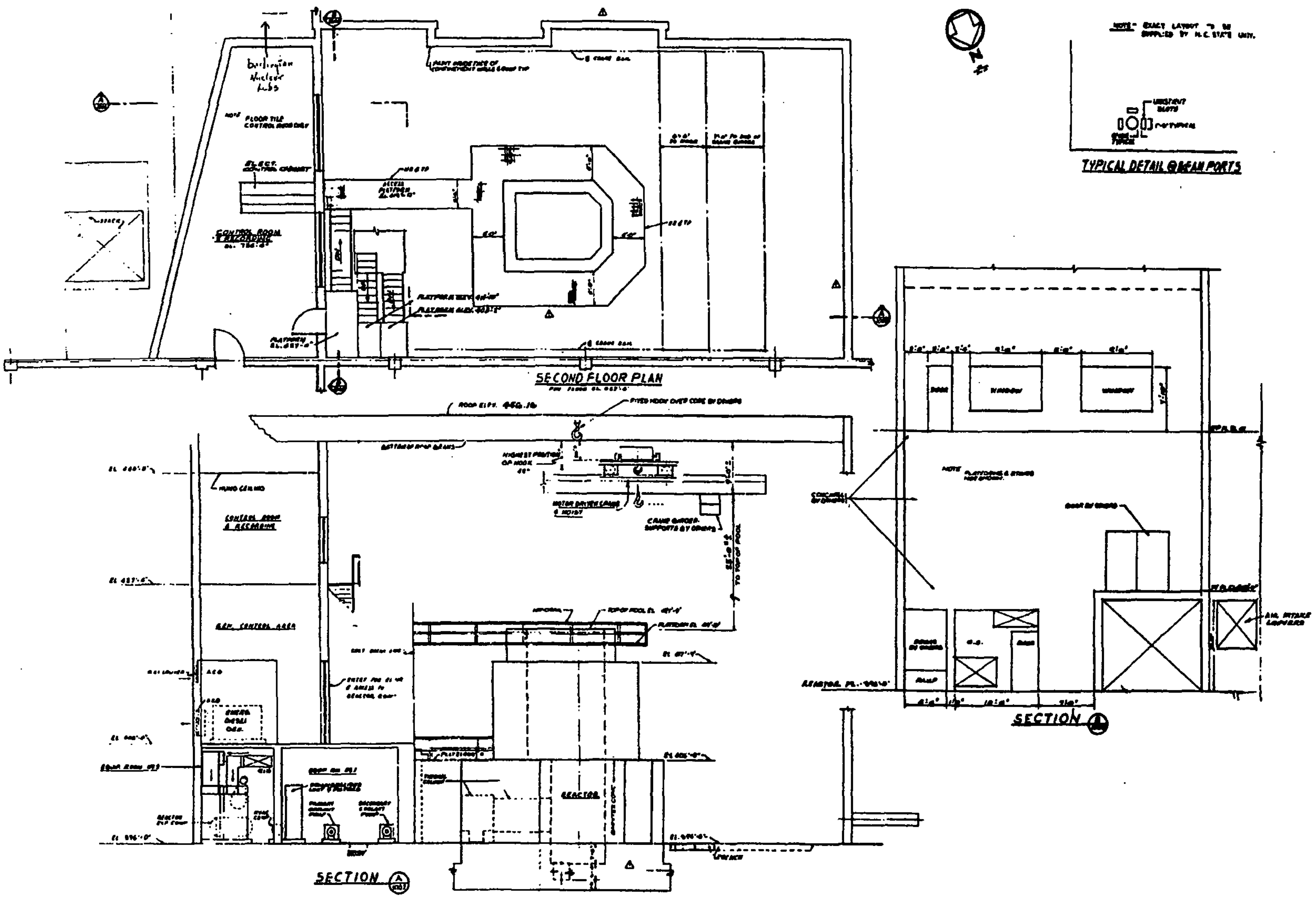


Figure 3.2 Sectional view of the NCSU PULSTAR reactor building

4 REACTOR

The NCSU PULSTAR reactor is a fixed-core, pool-type research reactor that uses light water as the moderator, coolant, and partial shield, along with solid pin-type fuel assemblies. The reactor was authorized to operate in the steady-state mode at power levels up to and including 1 MW, as well as in the pulsing mode with maximum energy generation up to 38 MW-sec per pulse. However, the licensee has requested that the NRC eliminate the pulse-mode authorization from the renewed license.

The reactor core is immersed in a reinforced concrete, water-filled, open-topped pool. The pool is spanned by a fixed structure that supports the control rod systems, reactor instrumentation, and some experimental facilities. The core itself is located near the bottom of the pool, where it is supported on a plenum structure that rests on the pool floor (Figure 4.1).

Reactor control is achieved by inserting or withdrawing neutron-absorbing control rods suspended from the drive mechanisms by electromagnets. Heat generated by fission is transferred from the fuel to pool water. The water is normally pumped downward through the fuel to an external heat exchanger. At lower power levels, cooling may be provided by natural convection of the water within the pool. The PULSTAR reactor at SUNYAB, which was the prototype for the NCSU PULSTAR reactor, was used extensively in the development of PULSTAR-type fuel. Consequently, the staff reviewed original reports providing the discussions and results of those studies, as applicable to the NCSU reactor. Table 4.1 compares the SUNYAB and NCSU reactors.

4.1 Reactor Core

The NCSU PULSTAR reactor core is composed of low-enriched uranium-dioxide (UO_2) fuel assemblies inserted in the grid plate together with control blades and control blade guides, graphite reflector elements, sample irradiation stringers, and incore experiments. The fuel assembly end fittings are similar to those of materials testing reactor (MTR)-type fuel elements and to the SUNYAB reactor fuel (Figure 4.2).

The reactor is critical with approximately 20 fresh fuel assemblies. Typical core loadings contain 25 fuel assemblies depending on burnup and experimental needs. The assemblies may be arranged in a variety of lattice patterns depending on experimental requirements. Special handling tools are used for underwater insertion or removal of assemblies attached to the grid plate.

4.1.1 Fuel Assemblies

The NCSU reactor uses a type of fuel commonly referred to as PULSTAR (Figure 4.3). The fuel consists of sintered uranium-dioxide pellets in a pin geometry, similar to current light-water power reactor fuels.

Each fuel assembly consists of 25 fuel-bearing pins. The pins are thin-walled (0.0205-in or 0.52-mm) zircaloy-2 tubes filled with sintered uranium-dioxide pellets with welded zircaloy-2 end plugs. The fuel is enriched to 4 percent with the uranium-235 isotope. The uranium-dioxide pellets are about 0.42 in (1.1 cm) in diameter and about 0.6 in (1.5 cm) long. A finished pin is 0.4725 in (1.2 cm) in diameter and 26 in (66.0 cm) long, with spacers brazed around the circumference (90° apart) of the pin near the ends and at the center.

In fresh, unirradiated fuel, approximately 20.5 g of uranium-235 (513 g U) is contained in each pin, yielding 513 g of uranium-235 (12.8 kg U) per assembly. The pins are mechanically fastened in groups of 25 with aluminum end fittings and are constrained in a zircaloy-2 box. A guide tube (nosepiece) machined to fit the grid plate is attached to the lower end of the fuel pin assembly. A bail is inserted between two sides of the box near the upper end of the fuel assembly and serves as a handle for inserting or removing the assembly from the grid plate. The finished assembly is about 38 in (97 cm) long with a cross-section of about 2.74 in (7 cm) by 3.15 in (8 cm). The nosepiece is inserted in a large hole in the grid plate that supports the entire fuel array. Two small pins set in the grid plate mate with holes in the nosepiece shoulder to position the assembly axially. Both ends of the assembly are open so that cooling water can flow up or down around the fuel pins.

4.1.2 Control Rods

The reactor control system operates by inserting control rods between fuel assemblies (Figure 4.4). The reactor is controlled by three thermal neutron-absorbing control rods and one pulse (shim) rod. The four rods are made of a nickel and tin-plated alloy comprised of silver, indium, and cadmium. One of the control rods may be used for automatic servo-control of reactor power, thus serving the function of a regulating rod. Two control rods are used as safety rods. The control rods provide coarse adjustment of the neutron flux density, and the regulating rod attached to the servo-control system provides fine adjustment. As discussed in Section 4.6.2, the licensee has proposed that the fourth rod (pulse rod) previously used for pulse-mode operation be converted to a non-scramming shim-control rod.

Drive mechanisms are actuated from the control console for remote positioning of the control rods. The drives and control rods could be relocated to cover any of the spaces in the grid plate, provided that TS limits on reactivity conditions are followed.

The three control rods have extension rods reaching above the surface of the pool water and terminating in iron armatures. These provide a scram capability by mating with electromagnets on the bottom of the drive mechanism. When the electromagnet current is interrupted, the armature is released and gravity causes the control rods to fall in their slots into the core. The elapsed time from scram initiation to full insertion of the rods is normally less than 0.6 sec (the TS limit is 1 sec). Means are provided for automatic or manual scrams, drive reversal, and drive inhibits, to maintain the reactor in a safe operating range or for safe shutdown.

For usual core loadings of 25 fuel assemblies, the typical reactivity worth of the set of three control rods is approximately 9000 pcm (9% $\Delta k/k$). The shim (pulse) rod is normally kept fully withdrawn from the core and has a worth of about 2800 pcm (2.8% $\Delta k/k$). The maximum worth of a single rod is about 4000 pcm (4% $\Delta k/k$). All of these values will vary with the nuclear characteristics of any specific core loading, including the burnup parameters of the fuel.

4.1.3 Reflector

Like many other non-power reactors, the NCSU PULSTAR reactor was designed to operate with more than one type of neutron reflector material surrounding the fuel (Figure 4.5). One side of the NCSU core is adjacent to the thermal column graphite nosepiece, and the other three sides can be reflected by combinations of water, and graphite elements similar in size and shape to fuel assemblies. The safety analysis report compares reactivity conditions with various combinations, showing how the licensee plans to compensate for reactivity changes associated with fuel burnup by replacing water with the more effective graphite elements. Changes in reactor core geometry to accommodate experimental programs may also include changes in the combinations of graphite and water.

4.1.4 Neutron Source

Non-power reactors are required to ensure that the reactivity status of the reactor can be determined at all times, including at reactor shutdown. This is generally achieved using a neutron detector and a radioactive neutron source located in or near the core. The locations of the detector and source, the sensitivity of the detector, and the emission rate of the source are all chosen to provide a significant indication of the presence of neutrons for reactor startup. Characteristics of the neutron source are noted in the safety analysis report, and several types of sources are acceptable for use. The NCSU PULSTAR reactor uses a standard commercial neutron source consisting of 5 curies of plutonium mixed with beryllium, sealed in a stainless steel capsule. The licensee has established in the TSs a minimum rate of two counts per second in the startup channel before reactor startup.

4.1.5 Conclusion

The staff has reviewed the information pertaining to the design, construction, and function of the NCSU PULSTAR fuel, reflector, neutron source, control-safety rods, pulse rod, and control rod drives. On the basis of this review, the staff has concluded that the design of these core-related components are acceptable and will continue to permit safe operation and shutdown of the reactor.

4.2 Reactor Pool

The reactor core is located in a 26.5-ft (8-m) deep water-filled pool, open at the top, formed by a reinforced-concrete biological shield. The inside dimensions of the pool at the core elevation approximately form an 8-ft (2.4-m) square, consisting of high-density concrete at least 5.83 ft (1.78 m) thick. The high-density concrete extends upward from the floor to about 7 ft (2.1 m) above the core centerline, where the shield thickness decreases to 3.5 ft (1.1 m); ordinary concrete is used from there up to the top. At about 18.8 ft (5.7 m) above the core centerline, the shield thickness is again stepped down to about 1.25 ft (0.4 m). The concrete surrounds an aluminum pool liner that is 0.25 in (0.64 cm) thick. A sealant protects this liner from direct contact with the concrete. The concrete and pool liner are penetrated by five horizontal beam tubes and one through tube at or near the core centerline, a graphite thermal column at one face of the core, and the coolant inlet and outlet pipes embedded in the pool floor. The basic horizontal beam tube consists of an aluminum sleeve embedded in and penetrating the concrete, with a coaxial reentrant tube extending through the sleeve to the face of the core.

There are four fuel storage facilities located in the reactor pool, including two 13-element pits in the bottom of the pool liner and two storage racks at the pool sides. One rack has a capacity of 7 fuel elements, while the other accommodates 13 elements. All of these storage facilities would be well below critical when fully loaded (the TS limit is k_{eff} no greater than 0.9) because minimum criticality of the core is achieved with 20 fuel elements in an optimum geometry.

4.3 Core Support Structure

The grid plate is a 5-in (12.7-cm) thick aluminum plate mounted on a plenum chamber. Thirty-six holes capable of accommodating the nosepieces of the fuel assemblies are arranged in a 6-by-6 pattern in the plate. Grid plate holes not required for fuel assemblies or incore experiments are plugged to confine coolant flow to core assemblies and experiment positions.

Small pins set in the grid plate mate with holes in the nosepiece shoulder to prevent misalignment of the assemblies in the core.

The plenum chamber, which channels the coolant flow to the discharge pipe during forced convection cooling, is supported by the discharge pipe. The aluminum superstructure, also supported by the discharge pipe, provides a guide rack for the neutron detection chambers.

4.4 Reactor Instrumentation

The reactor instrumentation is similar to that found in research reactor installations at other laboratories. The initial control console and associated instruments were typical of those for approximately 17 research reactors supplied by the same instrumentation vendor. During the past several years, however, a number of instruments have been improved or replaced to maintain a state-of-the-art facility.

The nuclear instrumentation gives the operator the necessary information for proper manipulation of the controls. The following instrument channels are provided, as discussed in more detail in Section 4.7 and Chapter 7, "Instrumentation and Control Systems."

- source range channel (fission chamber)
- linear channel
- log and linear channel
- safety channel
- nitrogen-16 monitor
- cooling system temperatures

4.5 Biological Shield

The reactor core is shielded in the lateral directions by pool water and the concrete walls of the pool. Vertical shielding is provided by about 20 ft (6.1 m) of water above the core, and about 2 ft (0.6 m) between the core and the pool floor. The concrete walls vary in thickness from top to bottom, as described in Section 4.2.

After reviewing the biological shield design and operational experience at NCSU, the staff concludes that the shielding was adequately designed to reduce external radiation exposure rates to acceptable levels.

4.6 Dynamic Design Evaluation

To ensure safe and responsive operation, the reactor is provided with multiple control rods and nuclear instrumentation. The inherent negative moderator temperature coefficient and strong, prompt Doppler fuel temperature coefficients of the PULSTAR design provide negative reactivity feedback during steady-state operation, as well as provide a self-limiting mechanism for transients initiated by rapid additions of excess reactivity (Spano, 1963). As discussed in the safety analysis report by the licensee, most of the negative temperature coefficient of reactivity is caused by the Doppler broadening of uranium-238 neutron absorption resonances in the low-enriched (4% uranium-235) fuel of the PULSTAR reactor. Values for reactivity coefficients are given in Table 4.1.

During reactor operation, plutonium-239 is produced by neutron capture in uranium-238. In low-enriched fueled reactors the buildup of plutonium must be explicitly considered. The licensee has estimated that on average, approximately one plutonium atom is formed for every two uranium-235 nuclei fissioned. The plutonium-239 is also fissile, so its buildup tends to retard the loss of reactivity resulting from uranium burn-up. Because the delayed neutron fraction from plutonium fission is smaller than that of uranium, some effects on the kinetic behavior of the reactor could occur. However, such effects have been found to be small at the SUNYAB reactor, and have not been detected at the NCSU reactor.

4.6.1 Core Thermal and Hydraulic Characteristics

The initial thermal-hydraulic analysis of a PULSTAR core was performed at SUNYAB in 1963 [Western New York Nuclear Research Center, Inc. (hereafter, WNY) safety analysis report 1963]. Subsequent pulse test programs carried out since 1963, as well as extensive steady-state operation, provided considerable information on the thermal-hydraulic behavior of the core. In particular, the work demonstrated that boiling at the outlet of a coolant channel does not cause significant risk of damage to fuel or cladding (WNY-017, 1964,; WNY PULSTAR Summary Report, 1966). The proposed safety limits and limiting safety system settings for forced and natural convection cooling were established on the basis of analyses and experiments of the SUNYAB group, as well as the NCSU application, as discussed in the following sections.

4.6.1.1 Forced Convection Cooling

The limiting criterion for safety is the endurance of integrity of the fuel and the cladding. Consequently, for purposes of the analysis, the licensee has assumed that fuel or cladding integrity will be compromised in the event of either fuel centerline melting or departure from nucleate boiling (DNB) in the coolant.

The following conservative assumptions formed the basis of the NCSU analysis for a 25-element core:

- The depth of water above the core was 14 ft (4.3 m).
- The primary coolant flow rate could vary from 0 to 500 gpm (0 to 1893 lpm).
- The coolant inlet (pool) temperature was 120 °F (49 °C).
- The heat flux hot spot factor was 2.9.

With the melting points of uranium-dioxide and zircaloy-2 being 2760°C and 1815°C respectively, the calculations show that fuel damage would not occur at core power levels below about 5.2 MW. On the basis of these calculations, and further setting a DNB ratio (DNBR) of 2, the licensee proposed and applied the safety limits listed in Table 4.2.

In accordance with 10 CFR 50.36, the licensee proposed limiting safety systems settings (LSSSs) designed to ensure that automatic protective action (reactor shutdown) would occur in sufficient time to prevent safety limits from being exceeded. For forced convection coolant flow conditions, those LSSSs are listed in Table 4.2, and are included in TS 2.2.1. The licensee conservatively selected the LSSSs to allow for the most adverse combination of uncertainties in the monitored parameters, including the response time of instrumentation and accuracy of measurements.

The staff has reviewed the NCSU analysis and has determined that the methods used are appropriate for application to the NCSU reactor and are very conservative. The staff, therefore, concludes that the conditions established by the specified safety limits and LSSSs given in the NCSU TSs, Appendix A to the Operating License, and the NCSU safety analysis report give reasonable assurance that fuel and cladding integrity will not be lost during normal reactor operation with forced convection cooling at licensed power levels.

4.6.1.2 Natural Convection Cooling

In 1966, the SUNYAB PULSTAR facility conducted extensive tests on natural convection cooling in that reactor (WNY Technical Note J-435, 1966). These tests demonstrated that PULSTAR fuel can be operated in the natural convection cooling mode at power levels exceeding 1 MW without exceeding the critical heat flux and DNB, and thus without exceeding the fuel integrity criterion established for forced convection cooling. In order to ensure that the results of the referenced tests are applicable to NCSU, the height of water in the pool above the core must be no less than 14 ft (4.3 m), the same as for forced convection cooling. The licensee has conservatively established an LSSS of 250 kW as the maximum operating power using natural convection cooling. The applicable safety limits are given in TS 2.1.2 and the LSSSs are given in TS 2.2.2. Table 4.3 summarizes these safety limits and LSSSs.

The staff concurs with the NCSU analysis and evaluation, and has concluded that operation of the PULSTAR reactor with natural convection cooling at power levels up to and including 250 kW poses no significant risk of fuel or cladding damage resulting from high temperatures.

4.6.2 Pulse-Mode Operation

During 1964–1965, the SUNYAB facility carried out a program to determine the characteristics, limitations, and safety of the PULSTAR low-enrichment (6% uranium-235) uranium-dioxide core during operation in the pulse (power transient) mode. This program proved that the reactor meets most of the original design objectives and showed that the PULSTAR fuel can survive relatively large reactivity insertions and is, therefore, an inherently safe reactor.

The safety limit used for the pulse mode of operation in the SUNYAB program was a maximum energy release of 58 MW-sec. By contrast, the NCSU reactor has been licensed to operate in the pulse mode with a maximum energy release per pulse of 38 MW-sec. On the basis of the startup testing results, NCSU determined that limiting the reactivity addition during pulsing to 1600 pcm (1.60% $\Delta k/k$) would prevent the reactor from exceeding the 58-MW-sec energy release safety limit.

Because the pulse mode of operation has never been extensively used with the NCSU reactor and is not required for the current or planned experimental programs, the licensee has eliminated pulse mode operation from the proposed revised TSs and operating license.

In conjunction with eliminating the pulse mode operation, the licensee has proposed that the transient rod be converted to a non-scramming control blade (shim rod). This would require plugging the inlet ports of the transient operation pneumatic cylinder, thus rendering it inoperative, and rigidly coupling the blade extension to the rod drive. Furthermore, the licensee has established procedures for using the former transient rod so that it is properly accounted for in all operations, including the attainment of the shutdown margin.

The staff concurs with the NCSU evaluation concerning the elimination of pulsing from the TSs and the license. The staff has determined that all available information has proven that the NCSU reactor can be operated safely in both the steady-state and pulse modes, and that elimination of the pulsing feature by the proposed method does not constitute a hazard and would not endanger the environment or the health and safety of the public. Further, the reason for deleting the pulsing capability is consistent with the current and planned programmatic purposes of this licensee. The staff has also concluded that the proposed modification of the pulse-mode electromechanical systems is acceptable, and does not introduce any new safety question.

4.6.3 Shutdown Margin

The proposed TSs prescribe a minimum reactivity shutdown margin of 400 pcm (0.4% $\Delta k/k$) relative to the cold critical core with the highest worth scrammable control blade and the non-scrammable shim rod fully withdrawn. Depending on the actual core loading, the reactivity worth of this maximum control blade is approximately 4000 pcm (4% $\Delta k/k$), and the total worth of all control-safety blades, excluding the non-scrammable control blade, is about 9000 pcm (9% $\Delta k/k$). Generally, any core loading producing higher total worth of all blades will also correspond to a higher worth of the most reactive control blade. Therefore, as long as the total excess reactivity loaded into the core, including that resulting from experiments, is no more than the TSs limit of 3970 pcm (3.97% $\Delta k/k$), the shutdown margin can certainly be achieved. The staff concludes that the shutdown margin of 400 pcm (0.4% $\Delta k/k$), with both the highest worth scrammable rod and the non-scrammable shim rod fully withdrawn is sufficient to ensure that the reactor can be adequately shut down under all credible conditions.

4.6.4 Excess Reactivity

The total excess reactivity that NCSU is authorized to have loaded into the PULSTAR reactor during operation is 3970 pcm (3.97% $\Delta k/k$). This amount provides for the various negative-reactivity effects associated with operation and use of the reactor, as well as operational flexibility. Typical excess reactivity requirements, excluding experiments, as given in the NCSU renewal application are as follows:

Xenon override	600 pcm (0.6% $\Delta k/k$)
Temperature coefficient	140 pcm (0.14% $\Delta k/k$)
Power defect (0–1 MW)	330 pcm (0.33% $\Delta k/k$)
Total	1070 pcm (1.07% $\Delta k/k$)

The excess reactivity limitation of 3970 pcm (3.97% $\Delta k/k$) allows up to 2900 pcm (2.9% $\Delta k/k$) associated with experiments.

It is essential that the fundamental criterion focus on maintaining ensured capability to shut the reactor down (hence, the minimum shutdown margin). Beyond that criterion, imposing a limit on excess reactivity helps ensure that the safety analysis report assumptions and analyses are applicable to the operational core. The staff has concluded that the excess reactivity limit of 3970 pcm (3.97% $\Delta k/k$), when considered with the shutdown margin, is sufficient to ensure that the reactor can be adequately controlled and shut down under all credible conditions.

4.6.5 Experiments

The proposed TSs limit the combined absolute reactivity worths of all experiments to 2900 pcm (2.9% $\Delta k/k$). As discussed above, the excess reactivity limit of 3970 pcm (3.97% $\Delta k/k$) allows up to 2900 pcm (2.9% $\Delta k/k$) associated with experiments.

The proposed TSs for the NCSU reactor define a movable experiment as one that can be inserted, removed, and manipulated while the reactor is operating. The proposed TSs limit the absolute reactivity worth of such experiments to 300 pcm (0.3% Δk/k) per experiment or less than or equal to 100 pcm (0.1% Δk/k) per sec per experiment, whichever is most limiting. Experience at the NCSU PULSTAR reactor facility has shown that this worth is adequate for isotope production needs and that a combination of moderator temperature coefficient, Doppler effect (fuel temperature coefficient), and operator action provides easy control of any change in reactor power resulting from the insertion or removal of such an experiment. In addition, the worth of 300 pcm (0.3% Δk/k) is well below the 1600 pcm (1.6% Δk/k) limit for positive reactivity insertion, which prevents exceeding the energy release safety limit of 58 MW-sec as discussed in Section 4.6.2.

The proposed TSs define non-secured experiments as those that are not mechanically held in position with sufficient force to overcome the expected effects of hydraulic, pneumatic, buoyant, or other forces that are normal to the operating environment or forces arising from likely credible malfunctions. These experiments are not designed to be moved during reactor operation. Non-secured experiments are limited by the proposed TSs to a worth of 1000 pcm (1% Δk/k) per experiment. This worth is below the 1600 pcm (1.6% Δk/k) limit for positive reactivity insertion, which prevents exceeding the energy release safety limit of 58 MW-sec as discussed in Section 4.6.2.

The proposed TSs define secured experiments as those mechanically held in a stationary position relative to the reactor. The restraining forces must be substantially greater than those to which the experiment might be subjected by hydraulic, pneumatic, buoyant, or other forces that are normal to the operating environment of the experiment, or forces arising as a result of credible malfunctions. Secured experiments are limited by the proposed TSs to a worth of 1600 pcm (1.6% Δk/k). This worth is the same as the positive reactivity insertion limit, which prevents exceeding the energy release safety limit of 58 MW-sec as discussed in Section 4.6.2.

The staff reviewed the proposed limitations on the worth of movable, non-secured, and secured experiments. On the basis of this review, the staff concludes that these limitations are conservative and provide reasonable assurance that failure of a single experiment resulting in a positive reactivity insertion would not result in damage to the fuel or reactor components. Also, in the extremely unlikely event of simultaneous multiple failures of an unsecured experiment and up to two movable experiments, or the simultaneous failure of up to five moveable experiments, the positive reactivity insertion would not result in damage to the fuel or reactor components. Further, the staff concludes that reasonable assurance exists that these experiments will not lead to a reactivity insertion that will pose a threat to the health and safety of the public. In particular, the staff based this conclusion on the following safety measures implemented by the licensee:

- a limitation on total absolute experiment reactivity worth of 2900 pcm (2.9% Δk/k)
- a limitation on the absolute reactivity of movable experiments of 300 pcm (0.3% Δk/k) per experiment, or less than or equal to 100 pcm (0.1% Δk/k) per sec per experiment, whichever is most limiting for experiments that may be moved when the reactor is critical
- a limitation on non-secured experiments of 1000 pcm (1% Δk/k) per experiment
- a limitation of 1600 pcm (1.6 % Δk/k) per experiment for secured experiments
- operation in compliance with minimum shutdown margin requirements of the TSs

4.7 Functional Design of the Reactivity Control System

This section of the SER discusses the functional design of the reactivity control system which is comprised of the standard control rod drives and the scram-logic circuitry that initiates a scram.

4.7.1 Standard Control Rod Drives

The drive units for the three standard control rods are inline drive mechanisms consisting of a motor, a gear reduction system and an Acme screw drive that raises or lowers an electromagnet. The drive mechanisms are activated by switches from the control console. The control blade drives could be positioned over any of the spaces in the grid plate. The limits regarding the stroke of the control rods are set by adjustable, cam-operated switches mounted inside the control rod drive mechanism. Except for the shim rod (former pulse rod) drive, the other three control rods may be activated both individually and in groups of two or three. If electrical power is removed from the electromagnets, the rods fall into the core by the force of gravity. (The former pulse rod is discussed in Section 4.6.2.)

4.7.2 Scram-Logic Circuitry

The NCSU reactor is equipped with a scram-logic safety system that receives signals from core instrumentation (neutron flux density detectors) and other reactor parameters to initiate a scram by removing electrical power from the control-safety blade magnets. Specifically, the following reactor parameters can initiate these scrams:

- high reactor power
- low coolant flow (forced convection)
- low pool water level
- flapper valve open (forced convection)
- high pool water temperature
- operator/personnel manual scram

The safety system is discussed in more detail in Chapter 7 of this SER.

4.7.3 Conclusion

The NCSU PULSTAR reactor is equipped with a safety and control system typical of non-power reactors, incorporating multiple control rods and multiple and redundant sensors that can initiate an automatic scram. The design incorporates sufficient control rod redundancy to enable the reactor to be shut down safely from any operating condition, even if the most reactive scrammable control rod fails to insert upon receiving a scram signal with the shim (former pulse) rod fully withdrawn from the core.

In addition to the electromechanical safety controls, the negative moderator temperature coefficient and the large, prompt, negative Doppler effect (fuel) temperature coefficient typical of a low-enrichment uranium core provide an inherent backup safety feature.

In accordance with the above, and the details presented in Chapter 7, the staff concludes that the reactivity control systems of the NCSU reactor are designed and function adequately to ensure safe operation and shutdown of the reactor under all normal operating conditions.

4.8 Operational Practices

NCSU has implemented a preventive maintenance program that is supplemented by a detailed pre-operational checklist to ensure that the reactor is not operated at power unless the appropriate safety-related components are operable. The reactor is operated by NRC-licensed personnel in accordance with explicit operating procedures, which include specified responses to any reactor control signal. All proposed experiments involving the use of the NCSU reactor that could affect reactivity or result in release of radioactivity are reviewed by the Radiation Protection Committee or referred to the Reactor Safety and Audit Committee to identify potential effects on the reactivity of the core, potential damage to any component of the reactor, or possible malfunction of the experiment that might lead to the release of contained radioactivity.

4.9 Conclusions

The staff concludes that the NCSU PULSTAR reactor is designed and built according to good industrial practices. The reactor consists of standardized components representing many reactor-years of operation, and it includes both diverse and redundant safety-related systems.

The staff's review of the reactor facility included studying its specific design, installation, and operational limitations as identified in the original and proposed TSs and other pertinent documents. The basic design features are similar to other pool-type research reactors licensed by the NRC. The fuel, which is zircaloy-2 clad, low-enriched sintered uranium-dioxide is similar to the PULSTAR reactor licensed by the NRC at SUNYAB and is very similar to power reactor fuel and the fuel used in some special power excursion reactor tests (SPERTs). On the basis of its review of the NCSU reactor operating experience since 1972 with the present fuel, and experience with other pool-type facilities, the staff concludes that there is reasonable assurance that the reactor can continue to operate safely, as limited by its proposed TSs for the proposed duration of the license.

Table 4.1 Comparison of PULSTAR Reactors at NCSU and SUNYAB*

	NCSU	SUNYAB
Fuel		
Material	UO_2	Same
Form	Sintered Pellets	Same
Enrichment (weight % U-235)	4%	6%
Design Inventory Core (kg UO_2)	359	285
Density (gm/cm^3)	10.5 to 10.76	10.3
U-235 per Fuel Pin (gm)	20.02	30.7
Fuel Pin		
Pellet (diameter in (cm))	0.423 (1.074)(nominal)	Same
Diametrical Gap (in (cm))	0.0085 (0.0216)(nominal)	Same
Zircaloy-2 Clad Thickness (in (cm))	0.0205 (0.0521)(nominal)	Same
Outside Diameter Pin (in (cm))	0.4725 (1.2002)(nominal)	Same
Rectangular Spacing (center-to-center, in (cm))	0.606 x 0.524 (1.54 x 1.33)	Same
Clearance (pin-to-pin, in (cm))	0.051 x 0.133 (0.130 x 0.338)	Same
Clearance (pin-to-box, in (cm))	0.025 x 0.066 (0.064 x 0.168)	Same
Height of Pellet Stack (in (cm))	24 (61)	Same
Pins per Core	625	500
Height of Pellet (in (cm))	0.60 (1.52)	Same
Fuel Box		
Material	Zr-2	Same
Inside Dimensions (in (cm))	2.620 x 3.030 (6.655 x 7.700)	Same
Wall Thickness (in (cm))	0.060 (0.152)	Same
Clearance between Assemblies (in (cm))	0.040 (0.102)	Same
Clearance between Control Rod Guide and Assemblies (in (cm))	0.060 (0.152)	Same
Fuel Pins per Assembly	25	Same
Weight (pounds (kg))	44 (20)	Same
Moderator, Reflector, and Coolant		
Material	Light Water	Same
Nominal Inlet Temperature (°F (°C))	105 (40.6)	100 (37.8)
Nominal Outlet Temperature (°F (°C))	118.8 (48.2)	111.8 (44.3)
Primary Coolant Flow Rate (gpm (lps))	500 (31.5)	1150 (72.5)
Secondary Coolant Flow Rate (gpm (lps))	700 (44.2)	800 (50.5)
Neutron Source	5 curie Pu-Be	Sb-Be
Control Rods		
Absorber Material	Ag-In-Cd (80%-15%-5%)	Same
Guide Material	Aluminum	Same

TABLE 4.1 (Continued)

	NCSU	SUNYAB
Control Rods (continued)		
Shape	Rectangular	Same
Transverse Dimensions (in (cm))		
Guide	6.30 x 0.43 (16.0 x 1.09)	Same
Absorber	4.85 x 0.18 (12.32 x 0.46)	Same
Clearance Absorber to Guide (in (cm))	0.00625 (0.01588)	Same
Clad Material	Sn/Ni	Same
Number of Control Rods	3	5
Number of Non-Scrammable Rods	1	Same
Core Dimensions		
Overall (in (cm))	15⅞ x 15 (40.3 x 38)	15⅞ by 12⅛ (40.3 x 30.8)
Height (in (cm))	24 (61)	Same
Volume Fractions		
$U0_2$	0.3823	0.3789
Gap (Helium)	0.0155	0.0154
Cladding (includes warts)	0.0803	0.0795
Lattice Water	0.3858	0.3824
Assemblies (Zr-2)	0.0753	0.0747
Water Between Assemblies	0.0255	0.0252
Control Rod Guides (Al)	0.0128	0.0158
Water Inside Guides (rods out)	0.0226	0.0280
Total Volume Fractions		
$U0_2$	0.3823	0.3789
Helium Gap	0.0155	0.0154
H_20	0.4339	0.4356
Zr-2	0.1555	0.1542
Aluminum	0.0128	0.0158
Core Volume Ratios		
H_2/UO_2	1.135	1.150
H_2O/U	2.06	2.11
Physics Parameters		
Effective Neutron Temperature	0.0509 ev	0.0587 ev
Disadvantage Factors		
Moderator-to-Fuel	1.243	1.309
Clad-to-Fuel	1.125	1.163
Neutrons per Thermal Fission (ν)	2.43	same
Capture to Fission Rate (α)	0.18	same
Thermal Utilization	0.951	0.964
Fast Fission Number	1.397	1.050
Fermi Age (cm^2)	43.8	30.7
Resonance Escape (p)	0.558	0.767
Thermal Diffusion Area (L^2)	2.215	1.178
Reflector Savings (cm)	7.81	7.77

TABLE 4.1 (Continued)

	NCSU	SUNYAB
Physics Parameters (continued)		
Bucklings (cm^2)		
Width	0.00342	0.00320
Length	0.00316	0.00260
Height	0.00168	same
k_{eff} (cold clean with H_20 Reflector)	1.0178	1.045
Minimum Critical Assemblies	20	16
Doppler Coefficient (pcm/°F)	-1.40	-2.15
Void Coefficient (pcm/cm^3)	-1.03	-1.1
Moderator Temperature Coefficient (pcm/°F)	-3.2	-8.0
Beam Tube Worths (air to water-filled pcm)		
6 in (15.2 cm) diameter	193	100
8 in (20.3 cm) diameter	45	-
12 in x 12 in (30.5 cm x 30.5 cm)	20	-
Neutron Lifetime (sec)	3.6×10^{-5}	2.9×10^{-5}
β_{eff}	0.0073	0.0076
Steady-State Power Level (MW)	1	2
Original Design Pulse Peak (MW)	2200	2000
Original Design Pulse Total Energy Release (MW-sec)	38	40
Original Design Step Input (pcm)	1720	1740
Maximum Rate of Reactivity Insertion by Control Rods (pcm/sec)	100	same
Reactor Bay		
Dimensions (ft (m))		
Height	55 (17)	52 (16)
Width (diameter for SUNYAB)	37 (11)	70 (21)
Length	94 (29)	-
Free Air Volume (ft^3 (m^3))	86,500 (2,448)	186,000
Ventilation (cfm (m^3/sec))		
Normal	10,050 (4.7)	12,000 (5.66)
Emergency	600 (0.3)	3,200 (1.5)
Type Building	Confinement	
Containment		
Exhaust Stack Height (ft (m))	100 (30)	167 (50)
Pool Volume (gal (l))	15,600 (59,052)	14,592 (55,231)

*Tabulated values for the NCSU PULSTAR reactor are for the 5 x 5 standard core, while values for the SUNYAB PULSTAR reactor are for a 5 x 4 core loading, both water reflected.

Table 4.2 Safety Limits and LSSSs For Forced Convection Cooling

Parameter	Safety Limit	LSSS
Core Power (maximum)	see figure 4.6	1.3 MW(t)
Pool Level Above Core (minimum)	14 ft (4.27 m)	14 ft 2 in (4.32 m)
Coolant Core Inlet Temperature (maximum)	120 °F (49 °C)	117 °F (47.2 °C)
Coolant Flow (minimum)	see figure 4.6	450 gpm (28.4 lps)

Table 4.3 Safety Limits and LSSSs For Natural Convection Cooling

Parameter	Safety Limit	LSSS
Core Power (maximum)	1.4 MW(t)	250 kW(t)
Pool Level Above Core (minimum)	14 ft (4.27 m)	14 ft 2 in (4.32 m)
Coolant Core Inlet Temperature (maximum)	120 °F (49 °C)	117 °F (47.2 °C)

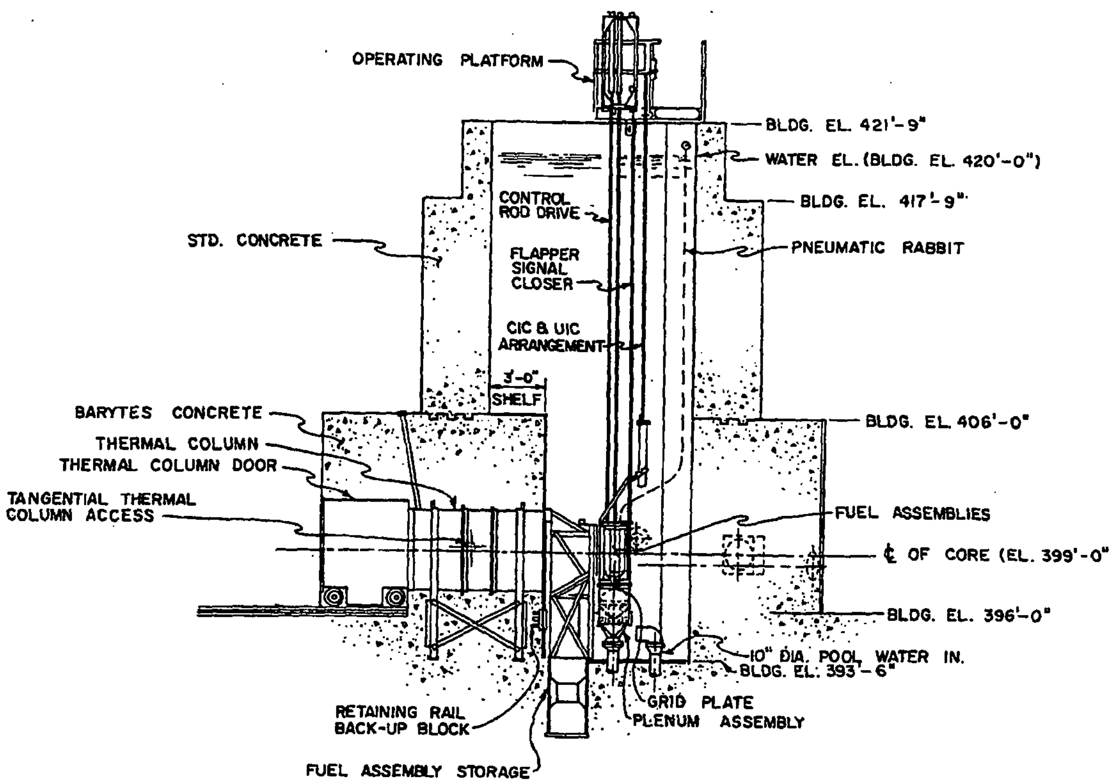


Figure 4.1 Reactor cross-section

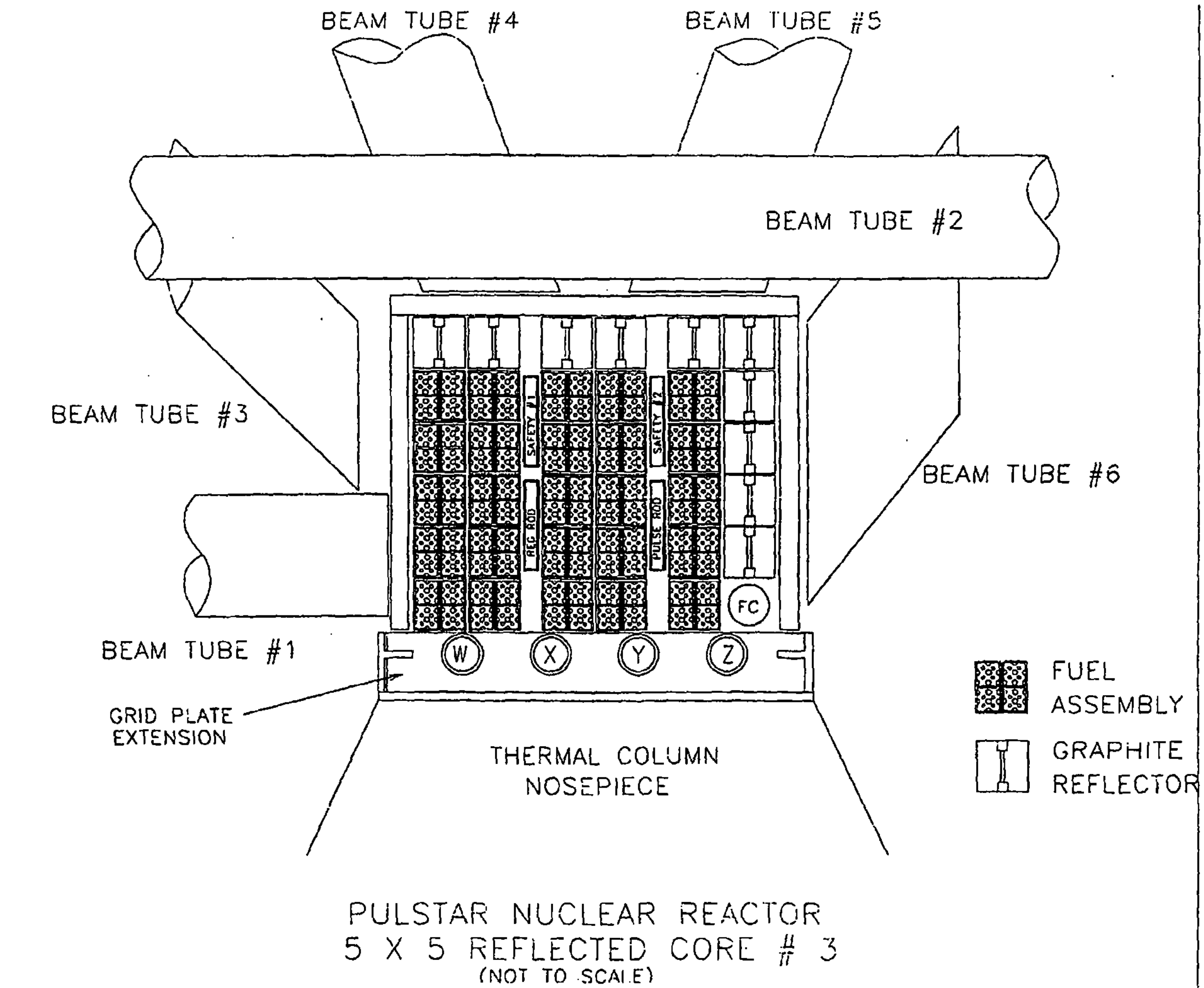


Figure 4.2 PULSTAR reactor core

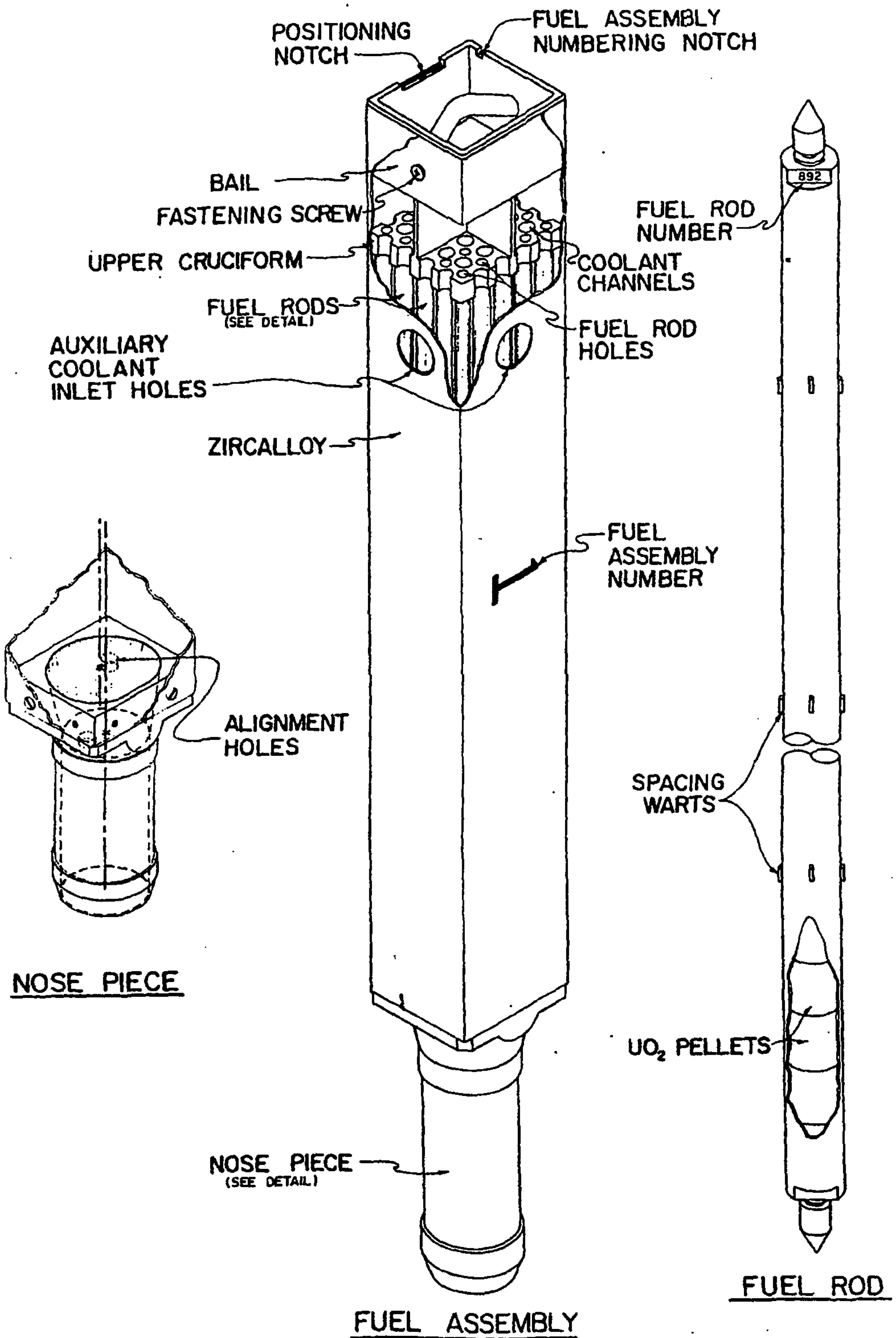


Figure 4.3 PULSTAR fuel

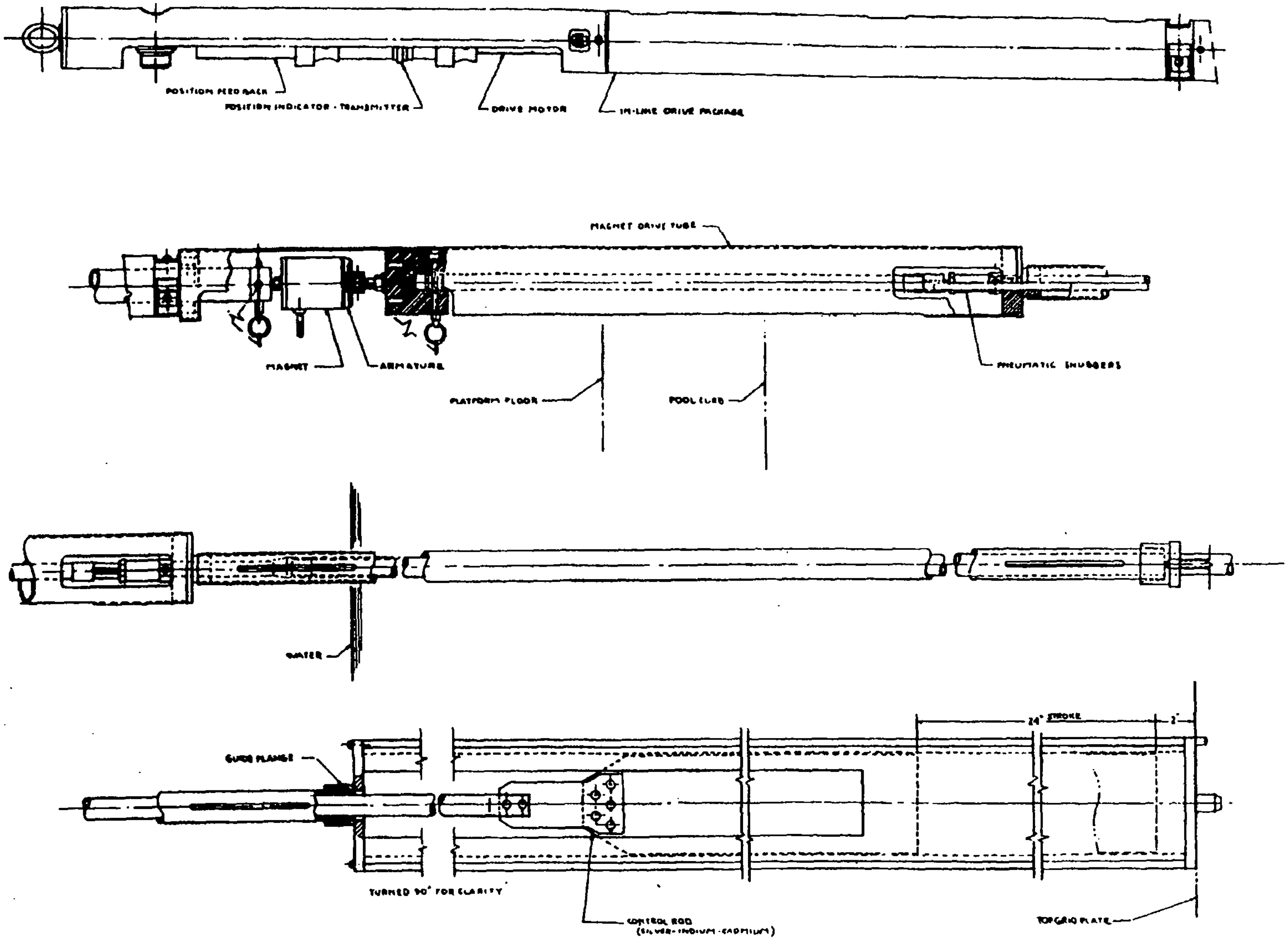


Figure 4.4 PULSTAR control rod assembly

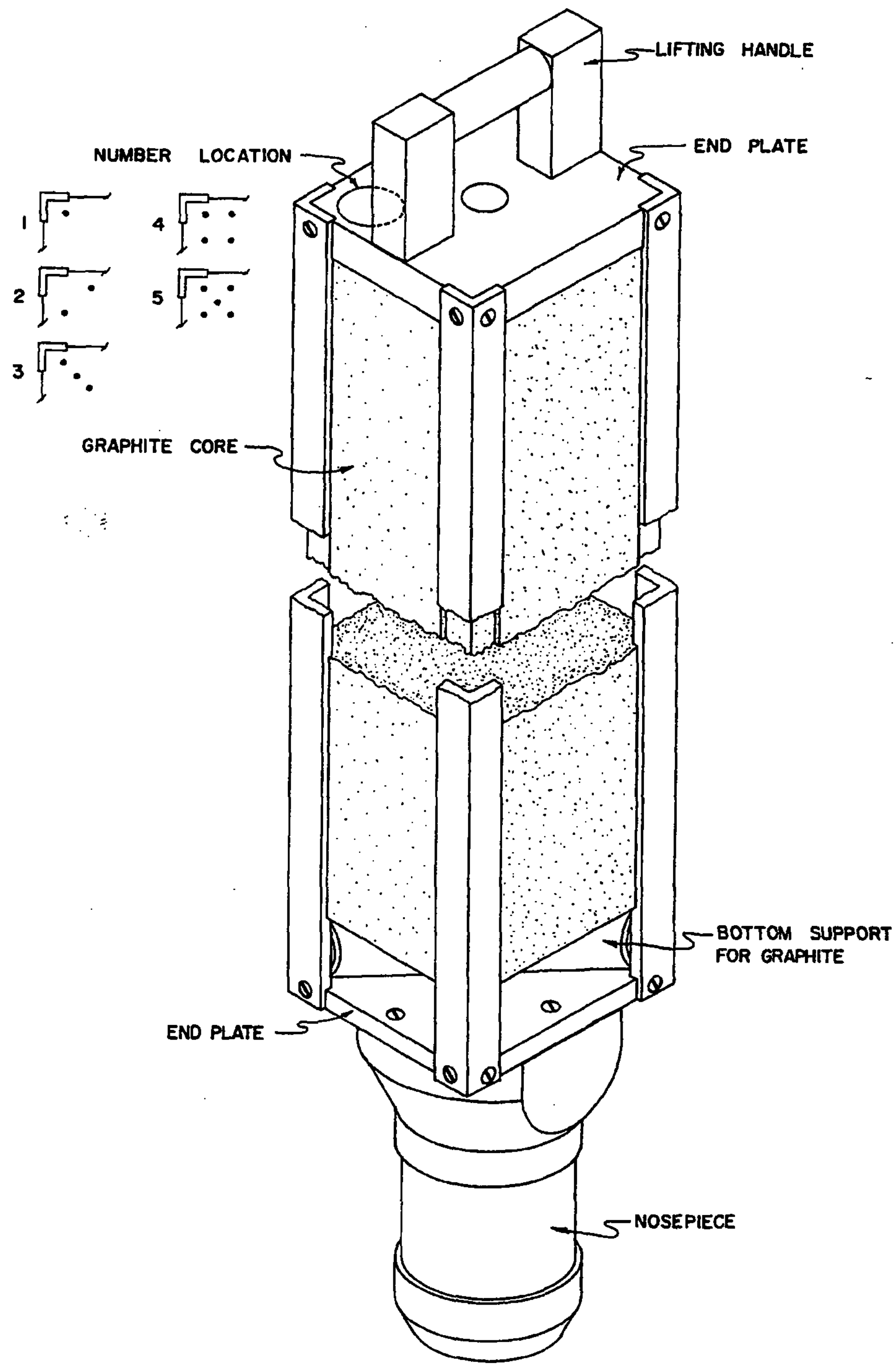


Figure 4.5 PULSTAR reflector element

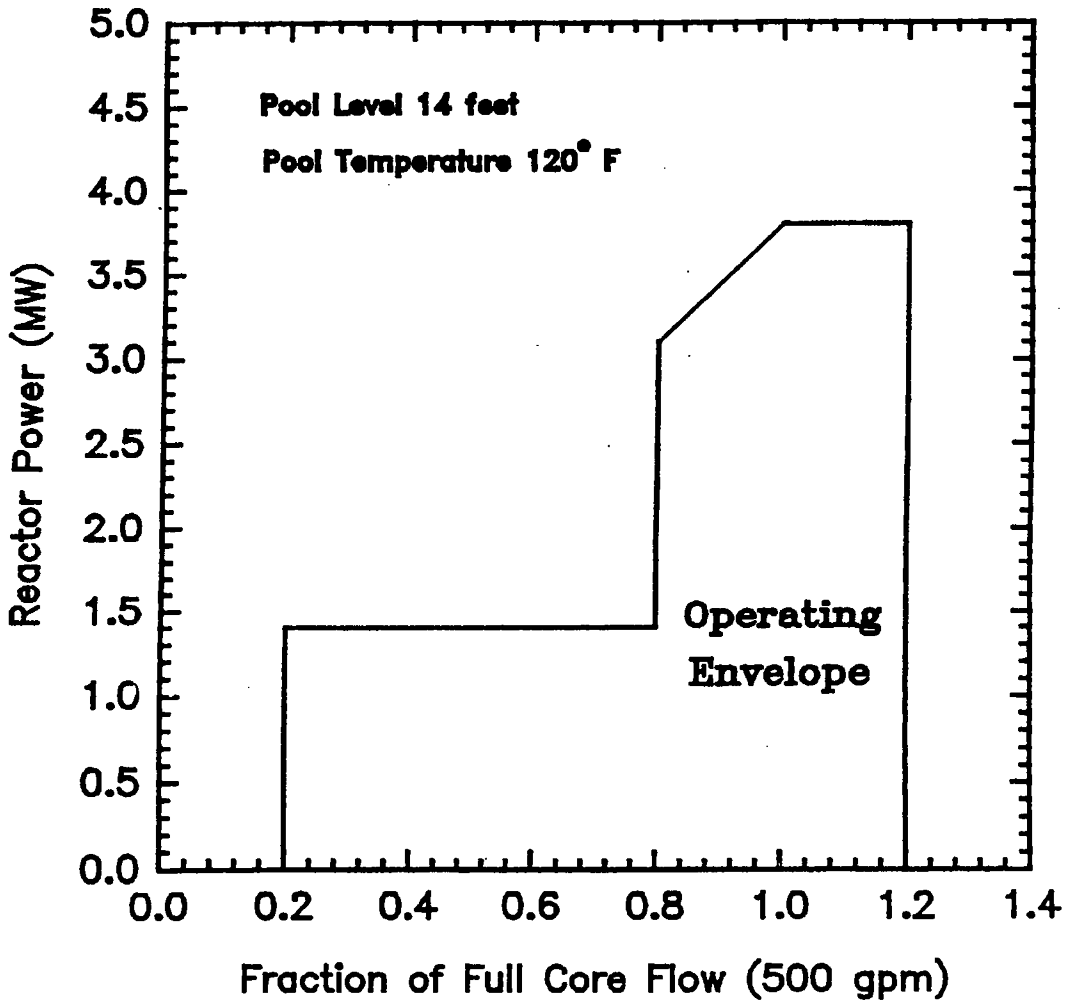


Figure 4.6 PULSTAR reactor power and coolant flow safety limits

5 REACTOR COOLING SYSTEM

The cooling system for the NCSU PULSTAR reactor is composed of three subsystems:

- primary coolant
- secondary coolant
- purification and makeup system.

5.1 Primary Coolant System

The NCSU PULSTAR reactor core is submerged in an aluminum-lined concrete pool filled with demineralized water. In the forced convection mode, coolant water is drawn down through the core into an outlet plenum and out of the pool to a holdup tank (Figure 5.1). The purpose of the holdup tank is to increase the transit time of the water to about 1 minute to allow nitrogen-16 radioactivity to decay to an acceptable level before the coolant is returned to the pool.

The primary coolant pump forces the coolant through the tube side of the tube-and-shell type heat exchanger and back into the pool. A counterbalanced flapper valve in the reactor outlet plenum is held closed by the primary coolant pump suction. If the primary pump or the water flow stops, gravity opens the flapper valve allowing heat transfer from the core to the pool water by natural convection. The primary coolant exits and enters the pool via stainless steel pipes penetrating the bottom of the pool liner. All piping and components in contact with the water in the primary coolant loop are made of stainless steel. The throttled primary coolant loop has a nominal flow capacity of 500 gpm (1890 lpm).

Valves in the pool coolant discharge line and return line can be closed to isolate the pool in case of primary coolant system component failure. These isolation valves are manually operated from a station immediately outside the reactor shield, within the reactor room.

The reactor pool temperature is maintained at the desired value by adjusting the secondary coolant flow with a pneumatically operated bypass valve that allows secondary coolant to bypass the cooling tower and recirculate to the heat exchanger. The valve is controlled by a temperature sensor on the primary coolant outlet on the heat exchanger.

5.2 Secondary Coolant System

The secondary coolant system consists of the shell side of the heat exchanger, the secondary coolant pump, the cooling tower, and associated piping and valves (Figure 5.2). The secondary cooling water removes heat from the primary coolant in the stainless steel heat exchanger and dissipates it through the cooling tower to the outside atmosphere. The coolant is drawn from a sump in the cooling tower basin and is passed through the secondary pump, then the heat exchanger, and finally to the spray trays at the top of the cooling tower.

The primary system pressure can be higher than that of the secondary system when the secondary pump is secure and the primary pump is either running or secured. This condition induces the potential for leakage of radioactive primary coolant into the secondary coolant in the unlikely event of failure of the heat exchanger tubes. To guard against the release of radioactivity, the licensee conducts monthly tests of the radioactivity content of the secondary coolant. In addition, the licensee cleans and carefully inspects the heat exchanger at regular intervals.

In response to an RAI from the staff, the licensee analyzed the event in which a heat exchanger tube develops a leak and primary coolant enters the secondary side of the system. The licensee estimated that a maximum of 1080 gallons (4090 l) of primary coolant could be lost over 5 hours. This would cause the cooling tower to overflow into a storm sewer that flows to the Rocky Branch Creek and ultimately to the Neuse River. The Neuse River, in turn, has a minimum flow of $8.7(10^7)$ gallons per day ($3.8(10^3)$ lps), which results in a dilution of over 1000.

The typical radionuclide concentrations in the primary coolant are about four times those allowed for unrestricted release to the environment. Consequently, the licensee conducted analyses following the guidance in RG 8.34, "Monitoring Criteria and Methods to Calculate Occupational Radiation Doses," and RG 1.109, "Calculation of Annual Doses to Man from Routine Releases of Reactor Effluents for the Purpose of Demonstrating Compliance with 10 CFR 50 Appendix I," in order to determine the dose to an individual resulting from this release. The calculations assumed that the Neuse River is used as the individual's sole source of drinking water and that the total annual consumption occurs over the 5 hours affected by the event. The results of the calculations showed that, for this pathway, the release of radioactive liquid effluents would not cause significant potential radiation exposure to the public.

5.3 Coolant Purification and Makeup Systems

The TSs establish limits regarding the quality of the primary coolant, which is maintained by circulating a portion of the coolant flow through a purification system comprised of a prefilter, a demineralizer, and an after-filter (Figure 5.3). In turn, the quality of the secondary coolant is maintained by periodic bleeding of the system and by the addition of a chemical treatment solution.

The water inventory in the primary coolant system is measured periodically, and certain 10-in (25-cm) diameter piping in the system is pressure tested on a set schedule. Water to replace coolant lost by evaporation from the reactor pool is taken from the city water system and is passed through a filter and demineralizer. This water is introduced into the coolant system in batches by using a quick disconnect fitting that is not normally connected during operation (Figure 5.4). The connection between the service water system and city water contains two check valves, and the city water pressure is greater than that in the primary system. The combination of check valves, pressure difference, and limited connection time ensures that primary water cannot enter the city's water system.

5.4 Conclusion

The staff concludes that the NCSU reactor cooling system is adequate to remove heat from the fuel and prevent loss of integrity under the full range of normal operating conditions. Potential accidental coolant leakage between the primary and secondary systems in the heat exchanger would not lead to significant radiation exposure to the public, and potential leakage would be detected and corrected acceptably. Consequently, there is reasonable assurance that the system can continue to function adequately for the proposed duration of the license renewal.

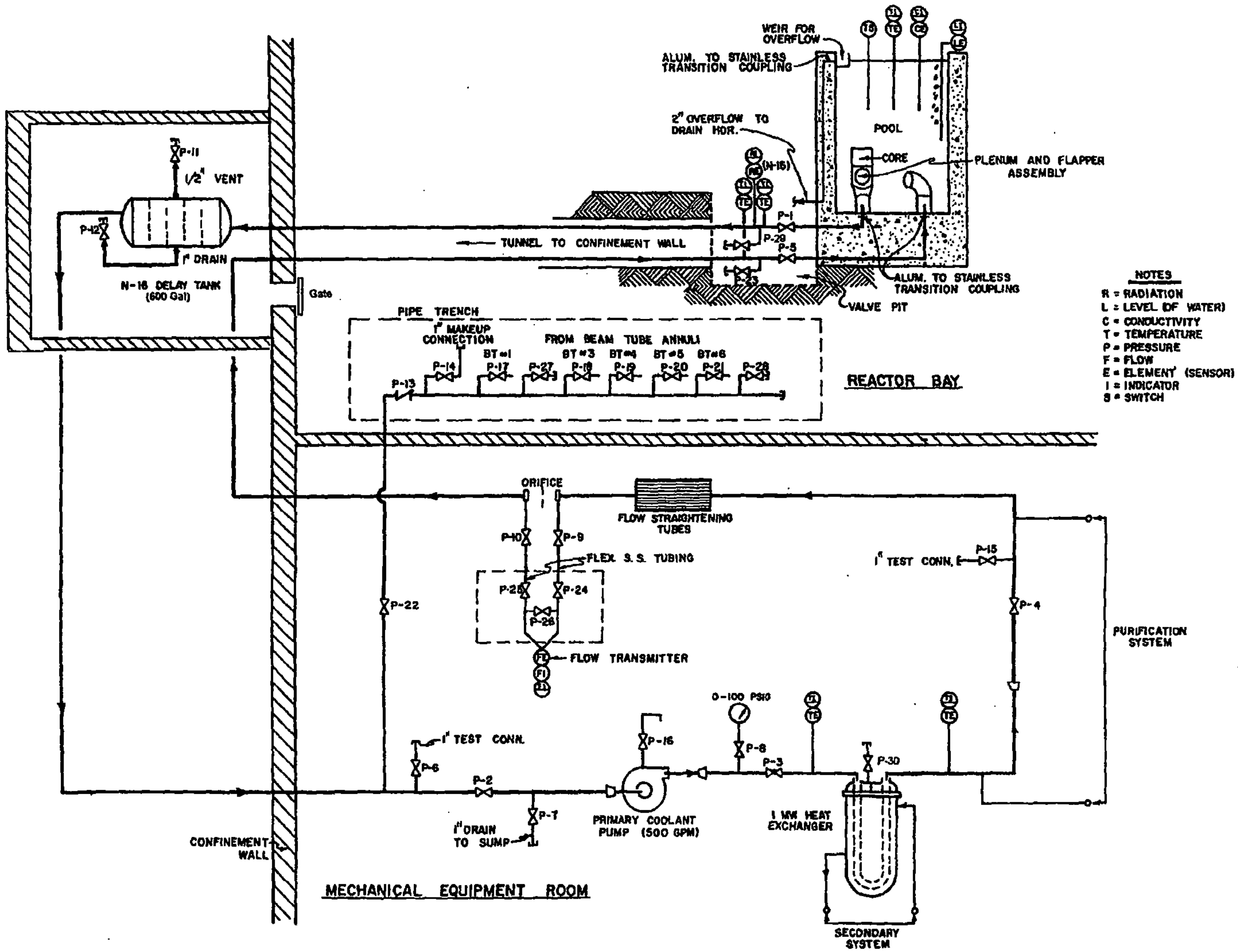


Figure 5.1 Primary coolant system

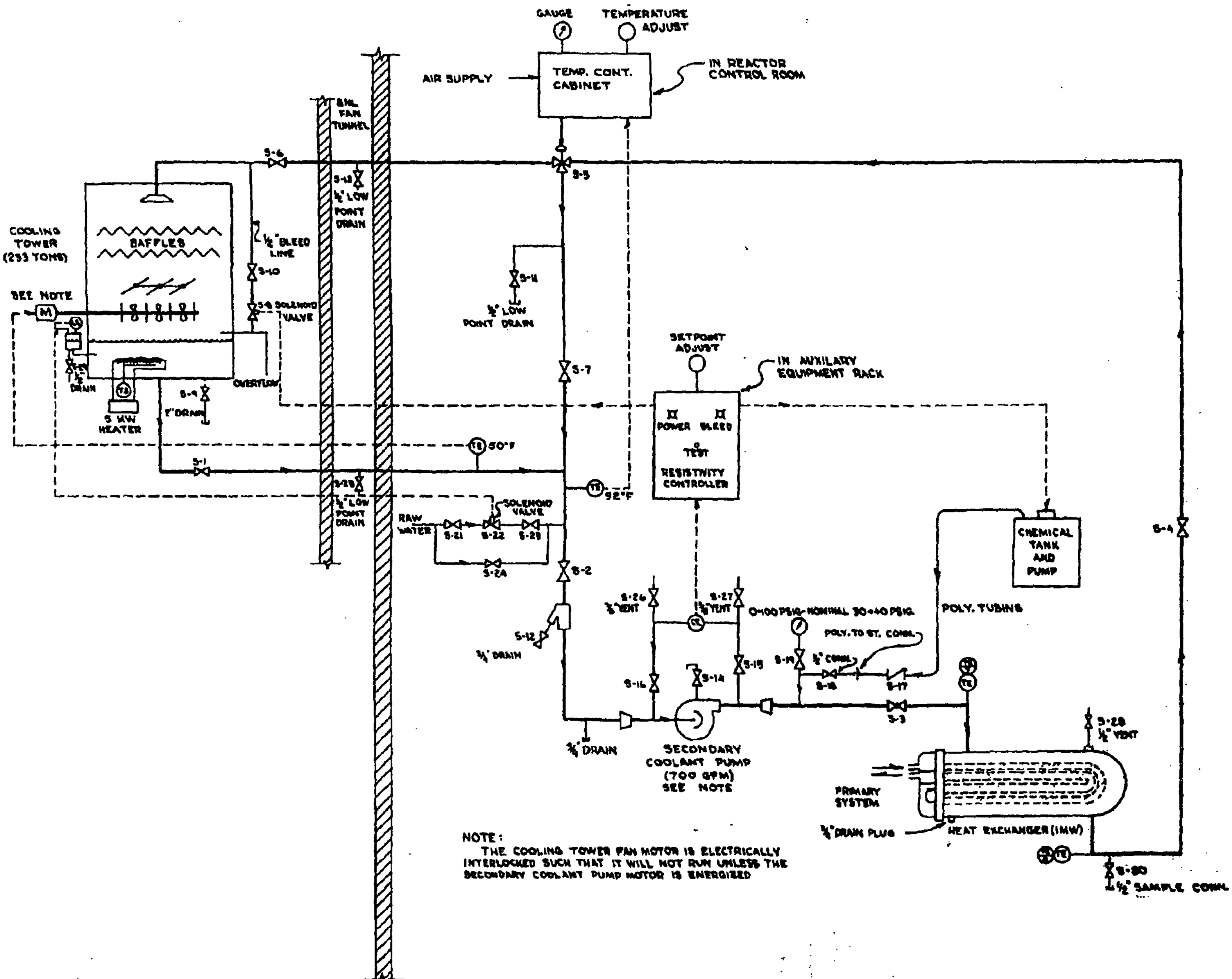


Figure 5.2 Secondary coolant system

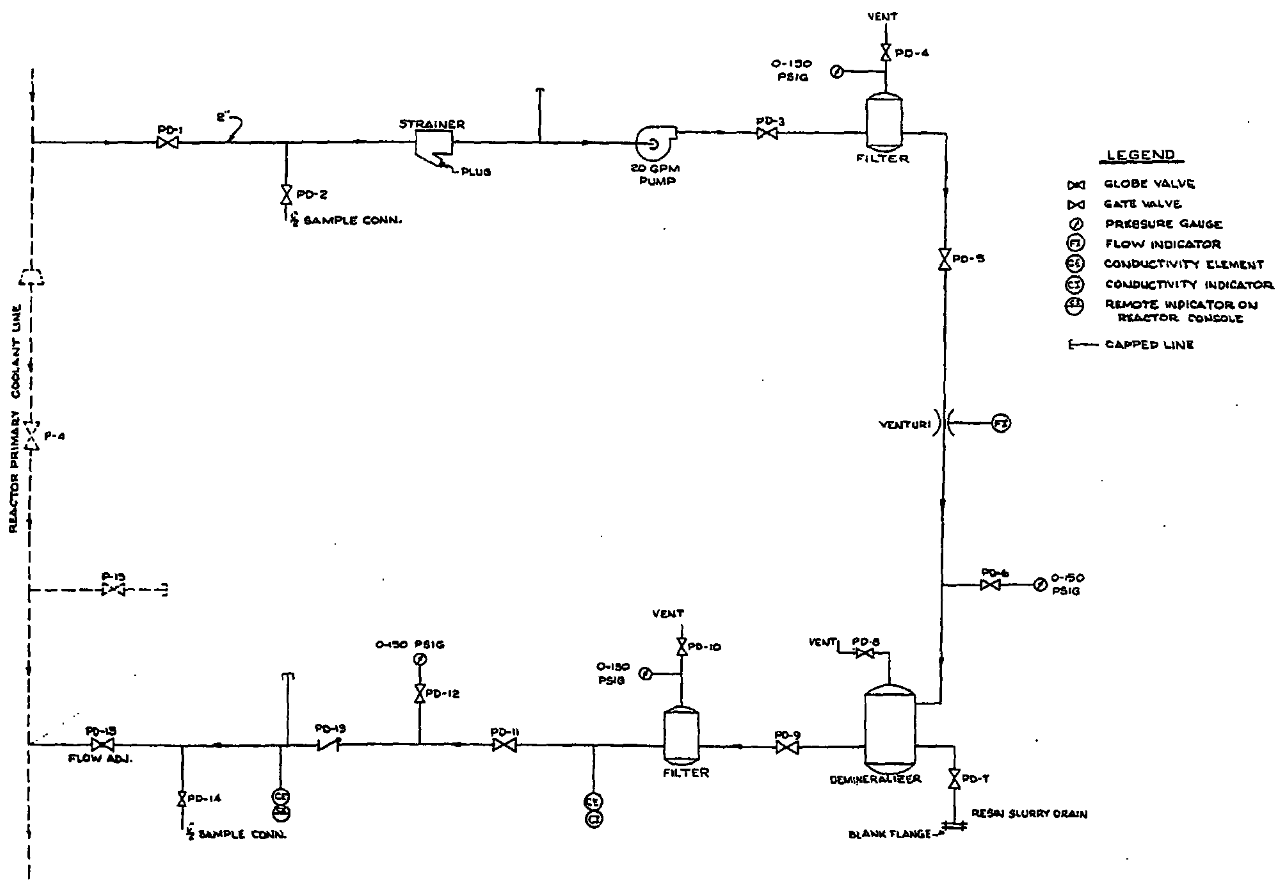


Figure 5.3 Purification system

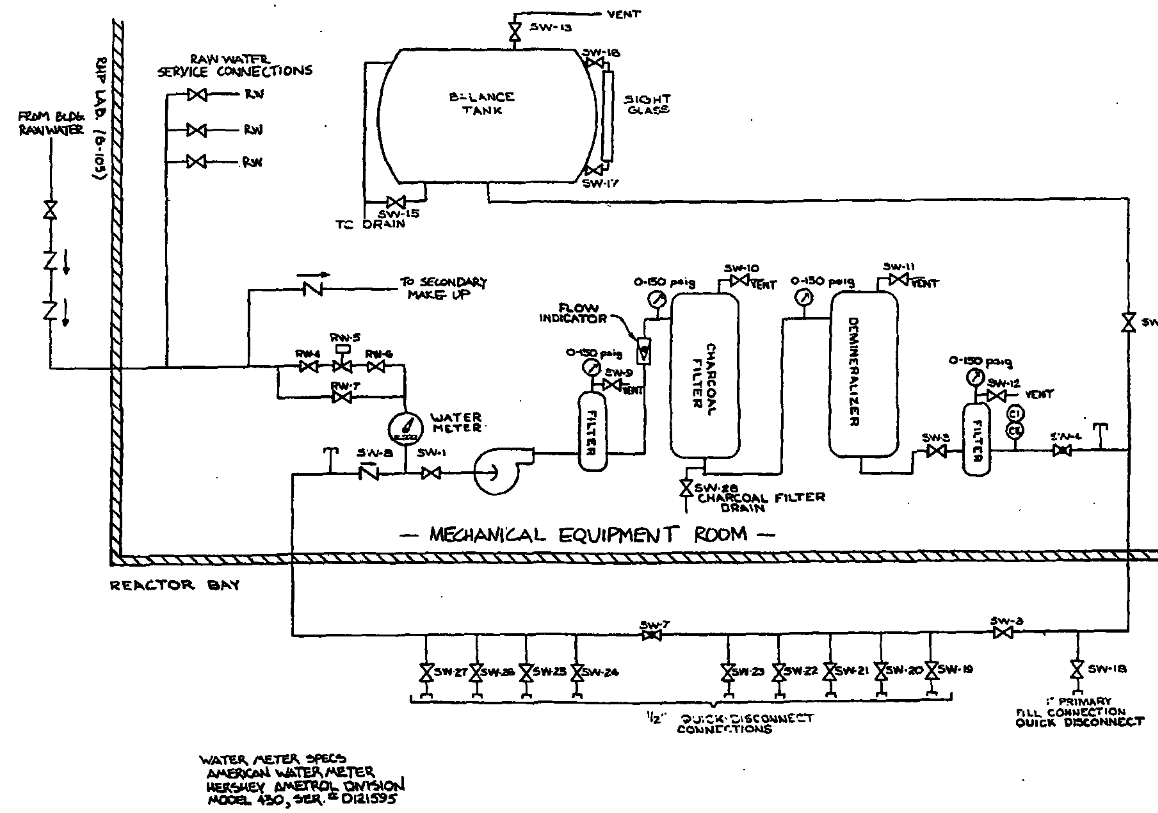


Figure 5.4 Water makeup system

6 ENGINEERED SAFETY FEATURES

The licensee has shown that a loss of coolant would not result in fuel cladding temperatures that would lead to integrity failure or release of fission products (see Section 13.3 of this SER). Therefore, the reactor does not require an emergency core cooling system. However, engineered safety features do provide for natural convection cooling in the event of a loss of forced coolant flow. In addition, these features permit building confinement and controlled filtered release of airborne radioactivity.

6.1 Natural Convection Cooling

During normal operation at power levels above 100 kW, reactor core cooling is attained with a primary coolant flow rate of 500 gpm (1890 lpm). In the event the flow is interrupted as a result of pump failure or some other cause, a flapper valve on the side of the plenum below the grid plate will open by gravity. This provides a flow path for the continued natural convection cooling of the core. Measurements and calculations by the licensee confirm that the reactor could be operated continuously at a power level of at least 1 MW with only natural convection cooling without the occurrence of DNB anywhere in the core. Calculations show that flow reversal, which occurs during the transition from forced convection cooling to natural convection cooling, will also not result in DNB.

6.2 Fuel Assembly Cooling

Each fuel assembly has been fabricated with four 1-in (2.5-cm) diameter holes in the zircaloy box just below the fuel pin support plate. In the event of an accidental blockage of coolant flow into the top of a fuel assembly, the flow would enter these holes and continue down inside of the box to remove heat from the fuel pins. The decrease from normal flow would not be sufficient to cause a loss of fuel integrity even if 1-MW operation were to continue indefinitely.

6.3 Confinement and Ventilation

The NCSU PULSTAR reactor is housed in a concrete confinement structure designed for low air leakage rates. The structure is also equipped with a ventilation system that includes exhaust fans, prefilters, automatically closing dampers, HEPA filters, and charcoal absorbers for gases (Figure 6.1). This system (which includes the reactor room, control room, mechanical equipment room and primary piping vault) is designed to control airborne radioactivity that could be released during accidents. Entrances to the confinement are constructed of steel, gasketed, and equipped with double locks for security. All penetrations through the poured concrete building walls are sealed to prevent air leakage.

During normal operation, filtered reactor room air is discharged out of the 100-foot (30-m) high exhaust stack at about 10,050 cfm (285 m^3/min), and 12,500 cfm (354 m^3/min) of non-contaminated air from the rest of the engineering building is added to it for further dilution. The licensee uses the following methods to initiate confinement:

- control room area monitor
- over-the-pool area monitor
- reactor bay west wall area monitor
- exhaust stack gas monitor
- exhaust stack particulate monitor

- exhaust stack auxiliary monitor
- manual confinement switch in the control room
- manual evacuation switch in the control room
- manual evacuation switch in the nuclear laboratory hallway basement
- loss of power to the radiation alarm panel

In the event of a significant increase in radiation in any of several operating radiation detectors listed above and discussed in Sections 7.3 and 11.1.6.2, the main fans stop, dampers close automatically, and one of two redundant emergency confinement fans is started. This fan purges room air at 600 cfm (17 m^3/min) through all of the normal filters, a 99.97% efficient HEPA filter, and an activated charcoal absorber. In the event of a simultaneous loss of commercial electrical power, the confinement fan and damper motors may be operated by the auxiliary electrical generator.

6.4 Conclusion

The staff reviewed the installation and operability of engineered safety systems employed at the NCSU PULSTAR research reactor facility. As a result of the review, the staff concludes that these systems have all been effectively planned and engineered, and they would mitigate the consequences of postulated accidents in an acceptable manner.

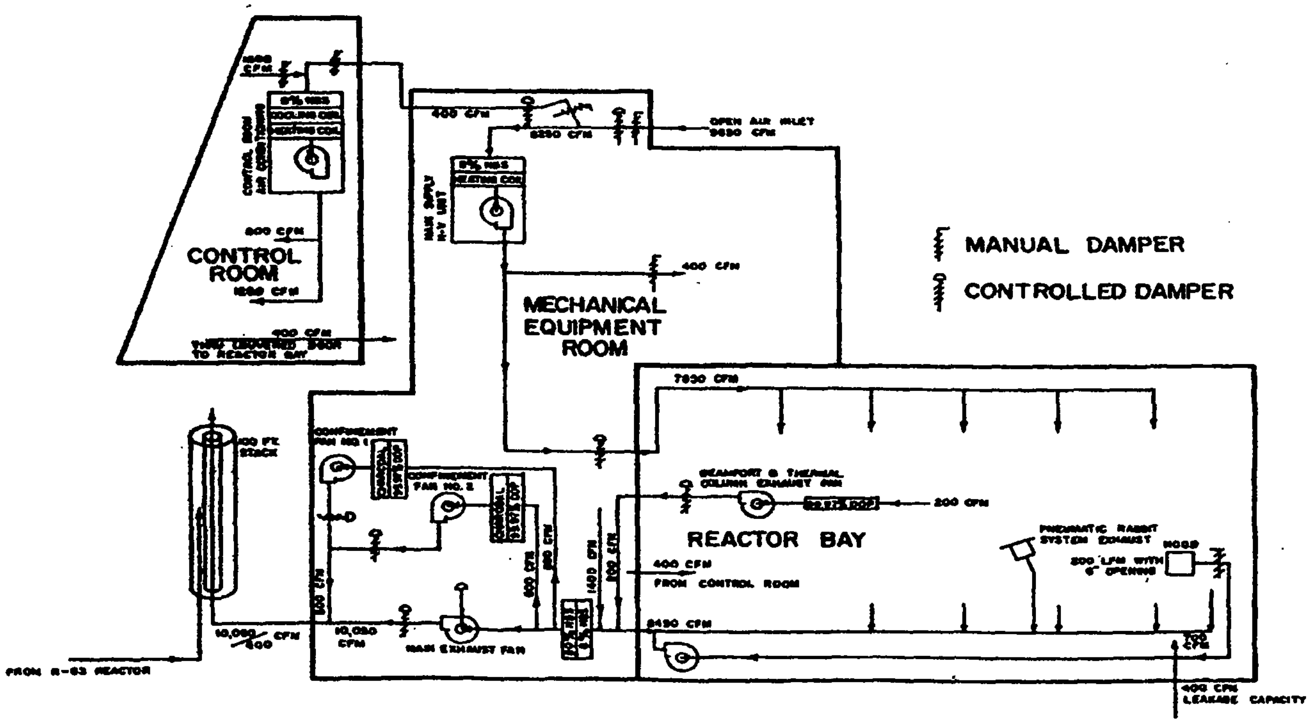


Figure 6.1 Ventilation system

7 INSTRUMENTATION AND CONTROL SYSTEMS

The instrumentation and control (I&C) systems used for the NCSU PULSTAR reactor (Figure 7.1) are similar to those that are widely used for research reactors in the United States. Control of the nuclear fission process is achieved using three control-safety (scrammable) rods and one shim (non-scrammable) rod (former pulse rod). The instrumentation system, which includes the reactor safety system, is composed of nuclear, non-nuclear, and process instrumentation generally characterized by modern components. NCSU has implemented a program to replace older instruments with state-of-the-art systems that provide the same functions in a more reliable manner. Table 7.1 summarizes the I&C systems.

7.1 Instrumentation System

The instrumentation system used in the NCSU PULSTAR reactor is composed of both nuclear control and process instrumentation circuits. The electronics system provides annunciation and/or indication in the control room. In addition, an automatic scram function is provided through the Scram-Logic Unit, discussed below. Additional features of the instrumentation system include alarms, interlocks, rod-drive inhibits, and reverse-drive functions.

7.1.1 Nuclear Instrumentation

The nuclear instrumentation used in the NCSU PULSTAR reactor gives the operator the information needed to properly manipulate the nuclear controls, and provides automatic protective (scram) functions, as follows:

- The source range channel receives data from a movable fission chamber. The primary purpose of this channel is to monitor neutrons in the reactor core during startup. Channel operability ranges from shutdown source multiplication to approximately 10 watts. This channel also provides a measure of reactor period, output on a strip chart recorder, and fail-safe rod withdrawal inhibit if the channel becomes inoperable or if the count rate is out of a predetermined range.

- The linear channel receives a signal from a compensated ion chamber. This channel monitors the reactor power level from the source range to 150 percent of full power and provides the signal for automatic servo-control of reactor power. This channel also provides a control rod reverse at about 1.1 MW, a reactor scram signal at about 1.2 MW, and a signal for strip chart recording.

- The log and linear channel receives a signal from a second compensated ion chamber and has a reactor power level range of from below 1 watt to 10 MW. This channel also provides the signal to the period amplifier for indication of the reactor period, enables the flow/flapper scram, and generates a signal for strip chart recording.

- An uncompensated ion chamber provides a signal for an independent safety channel, which scrams the reactor if preset power levels (1.2 MW) are exceeded, and also enables the flow/flapper scram. This chamber operates on an isolated high-voltage power supply, and voltage and signal cables between the reactor and control room are contained in conduits separated from all others.

- The nitrogen-16 channel uses a gamma-ray sensitive ion chamber to monitor the nitrogen-16 radioactivity in the primary coolant. This channel is used to monitor the reactor power level from about 900 kW to full power. This channel does not provide a scram signal, and it is not affected by changes in the neutron flux shape of the core.

All neutron-sensing ion chambers are located in the pool outside the core and are independently adjustable over a limited distance to allow their respective channels to be calibrated to the reactor thermal power.

7.1.2 Reactor Safety Systems

The control and nuclear instrumentation systems are interconnected through a Scram-Logic Unit (Figures 7.2, 7.3 and 7.4). This unit contains the power supply for the electromagnets that support the control rods, as well as system-level logic for the protective channels that initiate automatic scrams. The logic system voltage is fed through closed scram relay contacts for each of the protective input channels and returned to the Scram-Logic Unit. As long as the voltage is present, there is no scram demand. If the voltage is interrupted when the setpoint of an input channel is reached, the voltage is removed, a scram occurs, and the appropriate scram/alarm circuit is activated. If scram demand occurs, the logic circuits electronically turn off the current to each magnet, and a relay contact interrupts the magnet current bus to provide redundancy. Magnet current cannot be returned until the scram condition clears and the reactor operator manually resets the Scram-Logic Unit.

7.1.3 Inhibits, Interlocks, Alarms, and Annunciation

An inhibit signal that prevents control rod removal (reactor startup) is provided by a low neutron count rate in the startup channel. This inhibit signal also prevents movement of the shim rod (former pulse rod).

An interlock prevents a particular action from occurring until all of the prerequisites for that action to occur are satisfied. The fission chamber can only be moved when the rod gang is not in motion. The rod gang insert switch must be in the out position to withdraw individual control rods or the rods in a gang. Automatic control of the regulating rod can be used if the control rods are withdrawn beyond 13.5 in (34.4 cm), the mode keyswitch is in "steady state," the deviation between actual reactor power and requested power is less than 9 percent and the gang switch is not actuated. If the automatic channel is operating the reactor and any of these interlocks is no longer satisfied, the automatic channel disengages and an annunciator alarm alerts the operator to this condition.

An alarm indicates an abnormal condition that is not serious enough to require an automatic reactor scram, but should be brought to the attention of a reactor operator.

A control console-mounted annunciator panel of lights provides the operator with information regarding conditions involving important variables related to reactor operation (Figure 7.5). Following annunciation of an event, the condition must be corrected and the operator must reset to restore the annunciator to normal operating condition. Table 7.1 summarizes the functions of the various instruments.

7.2 Control System

The NCSU PULSTAR reactor control system is composed of both nuclear and process control equipment in which redundant or diverse safety-related components are designed for independent operation in case of single failure or malfunction of components essential to the safe operation or shutdown of the reactor.

7.2.1 Nuclear Control Systems

Control of the NCSU PULSTAR reactor is achieved by inserting and withdrawing neutron-absorbing control rods using the control drive units that are mounted on the bridge structure over the pool. One control rod (shim rod) has a solid coupling and cannot be scrammed. The other three control rods are supported by electromagnets so that any electrical power interruption causes the rods to fall by gravity into slots in the core, thereby initiating a reactor scram. The control rod drives are manipulated from the control room by the reactor operator in response to indications from various instruments. An automatic channel may also be used to position the regulating rod to maintain reactor power at a specified steady-state level. The flux controller in the automatic channel generates an error signal that shows the difference between the actual power and the power level requested by the reactor operator. The flux controller then actuates relays that drive the regulating rod in or out of the core to adjust the power. Section 4.1.2 discusses the control rod systems in further detail.

7.2.2 Supplementary Control Systems

The supplementary control systems used in the NCSU PULSTAR reactor include non-nuclear and process control systems. These systems are designed to control the various processes involved in reactor operation, but not all of these processes directly relate to safety. This category includes circuits and devices that energize and/or monitor coolant pumps and coolant parameters such as flow rate, temperature, resistivity, and pool surface height.

7.3 Supplementary Instrumentation

Supplementary instrumentation consists of the facility's fixed radiation monitoring systems. Chapter 6 of this SER lists those that are designed to automatically stop the principal air exhaust and supply and initiate the confinement mode. It is notable that this battery of monitors can detect all types of airborne radioactivity or direct radiation that is reasonably credible at the NCSU reactor.

Section 11.1.6.2 discusses additional radiation monitors that supplement those associated and interconnected with the confinement system.

The Nitrogen-16 detector in the primary coolant loop is a reliable monitor of reactor power level, that also serves as an indicator of significant buildup of other gamma-emitting radioactivity in the primary coolant.

7.4 Conclusions

The staff concludes that the I&C systems at the NCSU PULSTAR reactor are well designed and maintained. Redundancy in the important ranges of power measurements by nuclear instrumentation is ensured by overlapping ranges of the log and linear channel and the linear channel. All important nuclear and process variables are monitored and conveniently displayed at the control console.

The I&C systems are designed so that the reactor is automatically and safely shut down if campus electrical power is lost. However, emergency power is provided to functions required to give information on facility status and to maintain confinement (see Chapters 6 and 8). On the basis of the review of the I&C systems, the staff concludes that the NCSU PULSTAR reactor I&C systems are acceptable to ensure safe and reliable operation of the NCSU reactor, within the limits of the TSs and other license conditions, for the proposed duration of the renewed license.

Table 7.1 NCSU PULSTAR Reactor Protective Channels

Protective Channel	Required Protective Action	LSSS
"Reactor On" Keyswitch	Manual Scram	
Manual Scram Button	Manual Scram	
Startup Channel	Inhibit when less than 2 cps (power <4 watts) Inhibit when greater than 90,000 cps (power <4 watts)	
Log and Linear Channel	Enable Flow/Flapper Scram	250 kW
Linear Channel	Automatic Scram	1.3 MW
Safety Channel	Enable Flow/Flapper Scram Automatic Scram	250 kW 1.3 MW
Flow Measuring Channel	Automatic Scram when enabled	450 gpm
Flow Monitoring Channel	Automatic Scram when enabled	
Flow and Flapper Scram Bypass Test Switches	Only one switch operative at a time	
Pool Level Measuring	Automatic Scram	14 ft 2 in
Over-Pool Radiation Monitor	Alarm on radiation level above 100 mR/hr Manual Scram	
Pool Temperature Measuring Channel	Automatic Scram	117 °F
Pool Temperature Monitoring Channel	Alarm/Manual Scram	117 °F

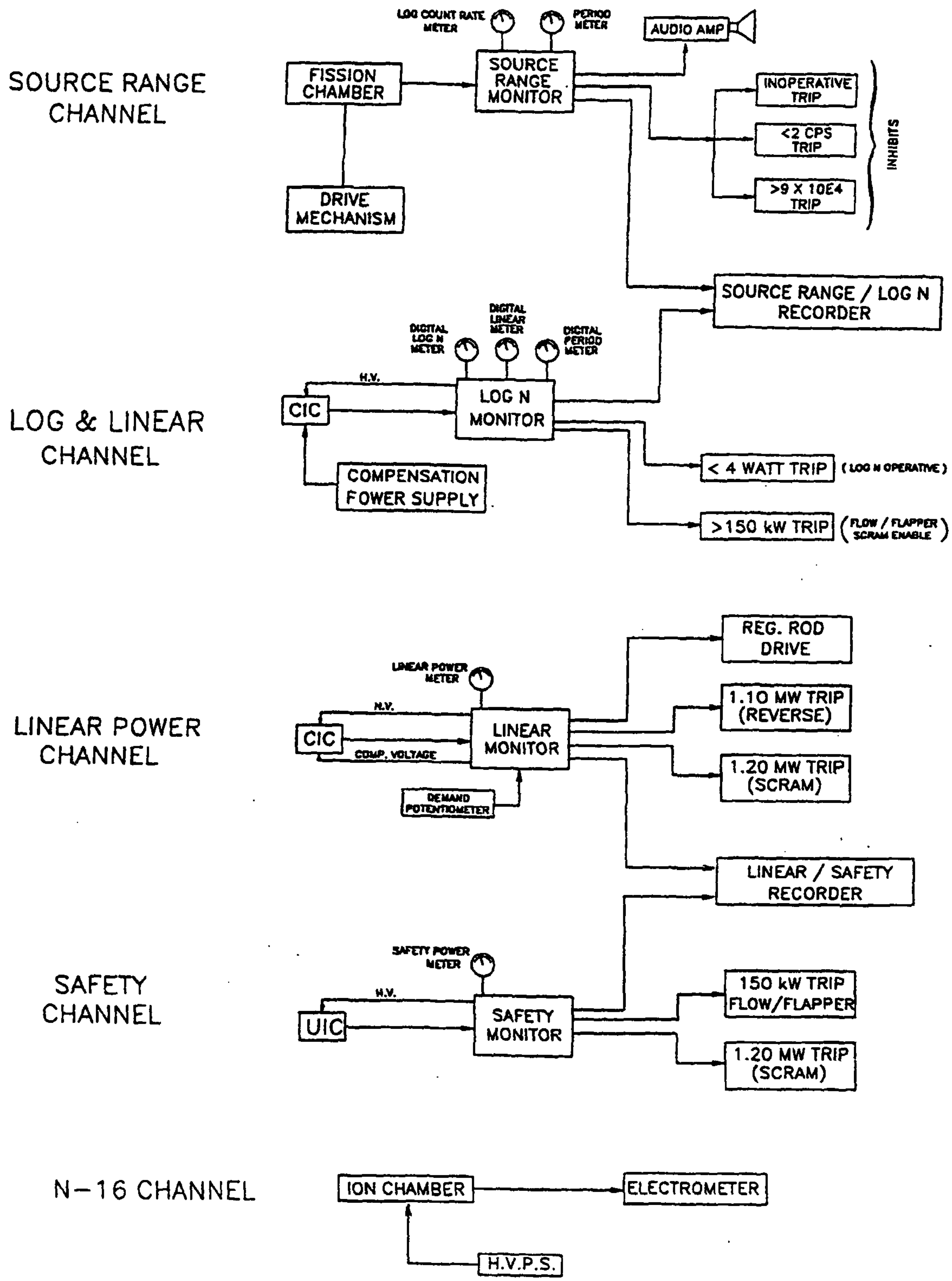


Figure 7.1 NCSU PULSTAR reactor I&C systems

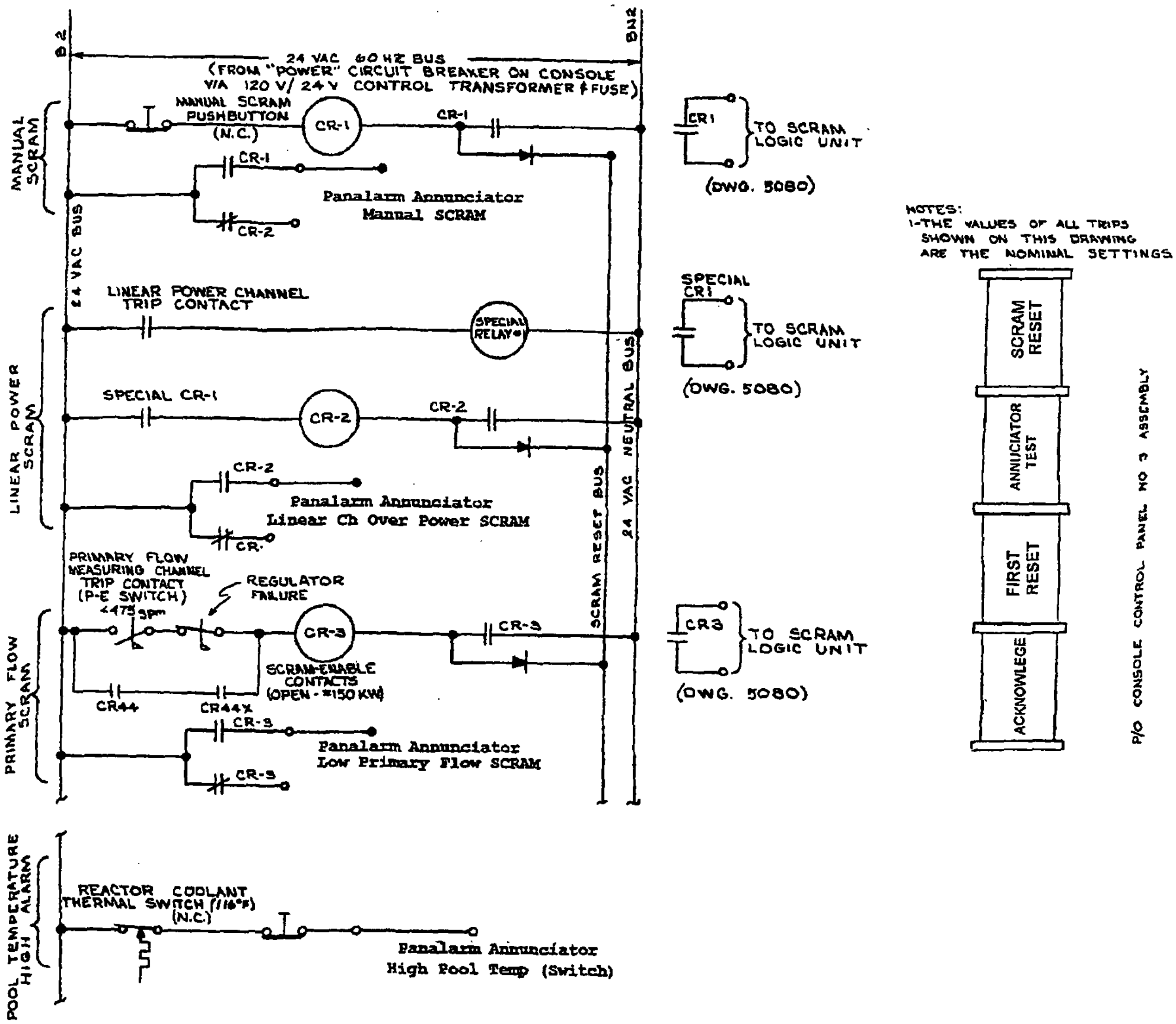


Figure 7.2 Typical scram and alarm control circuits

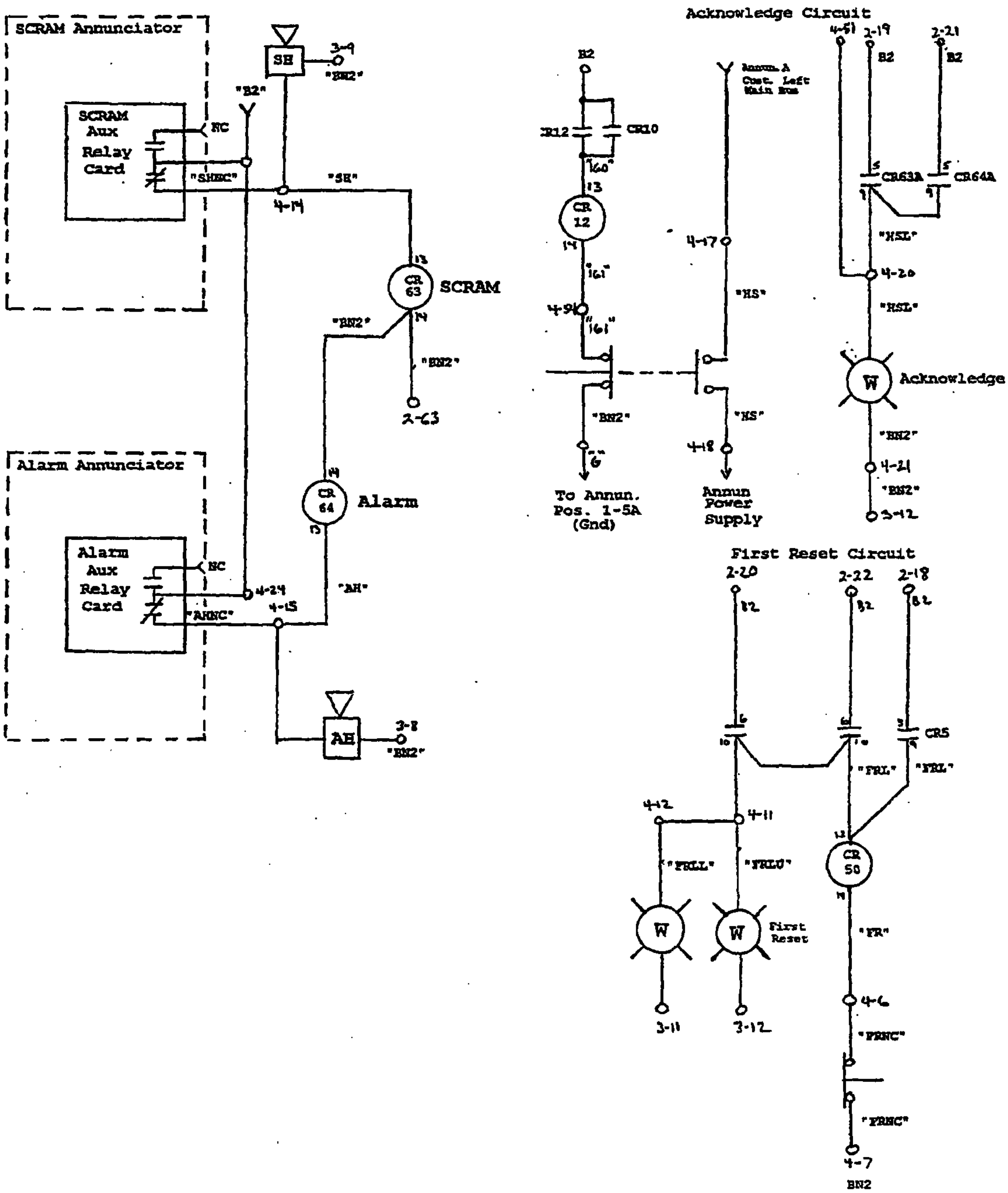


Figure 7.3 Typical scram and alarm control circuit detail

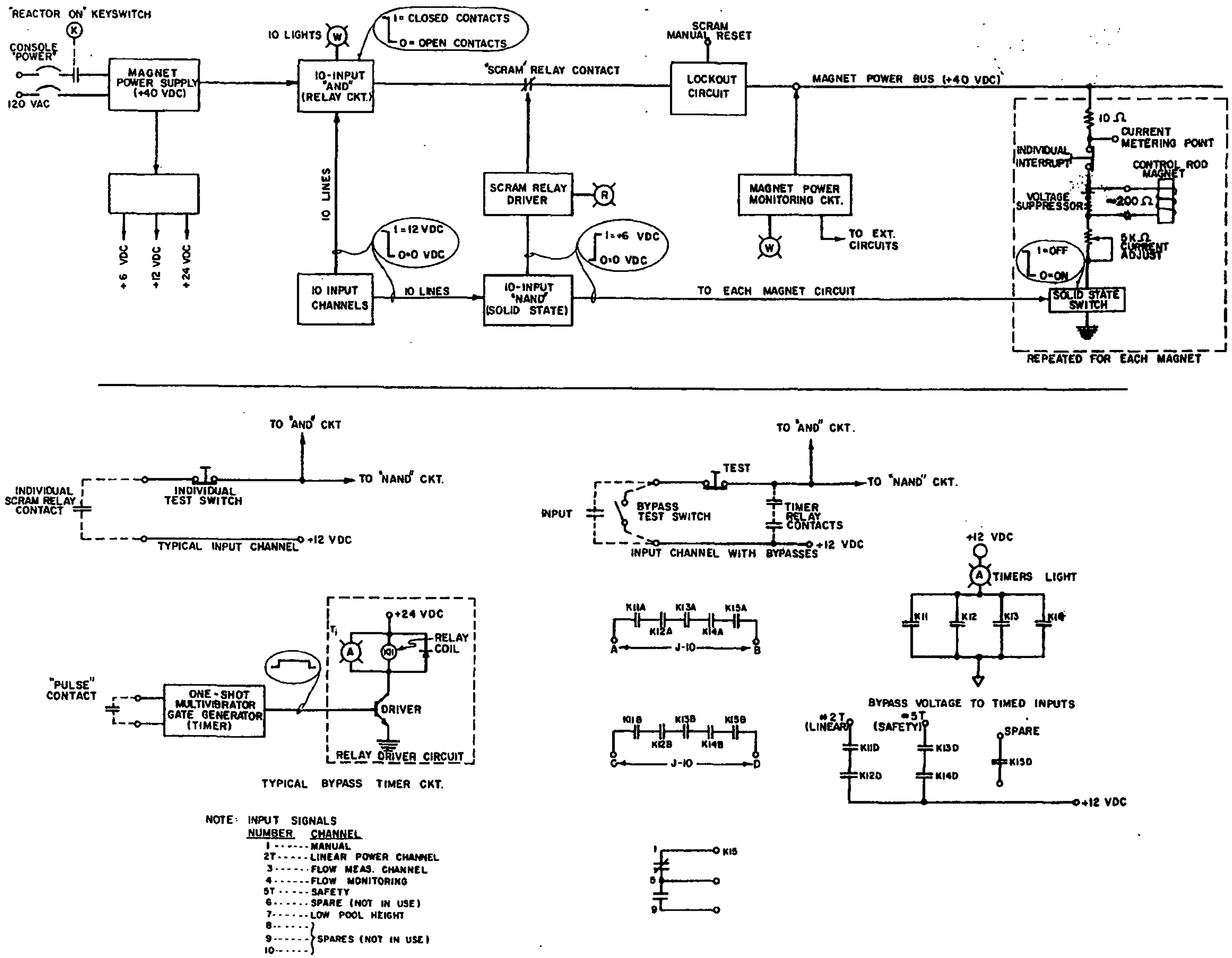
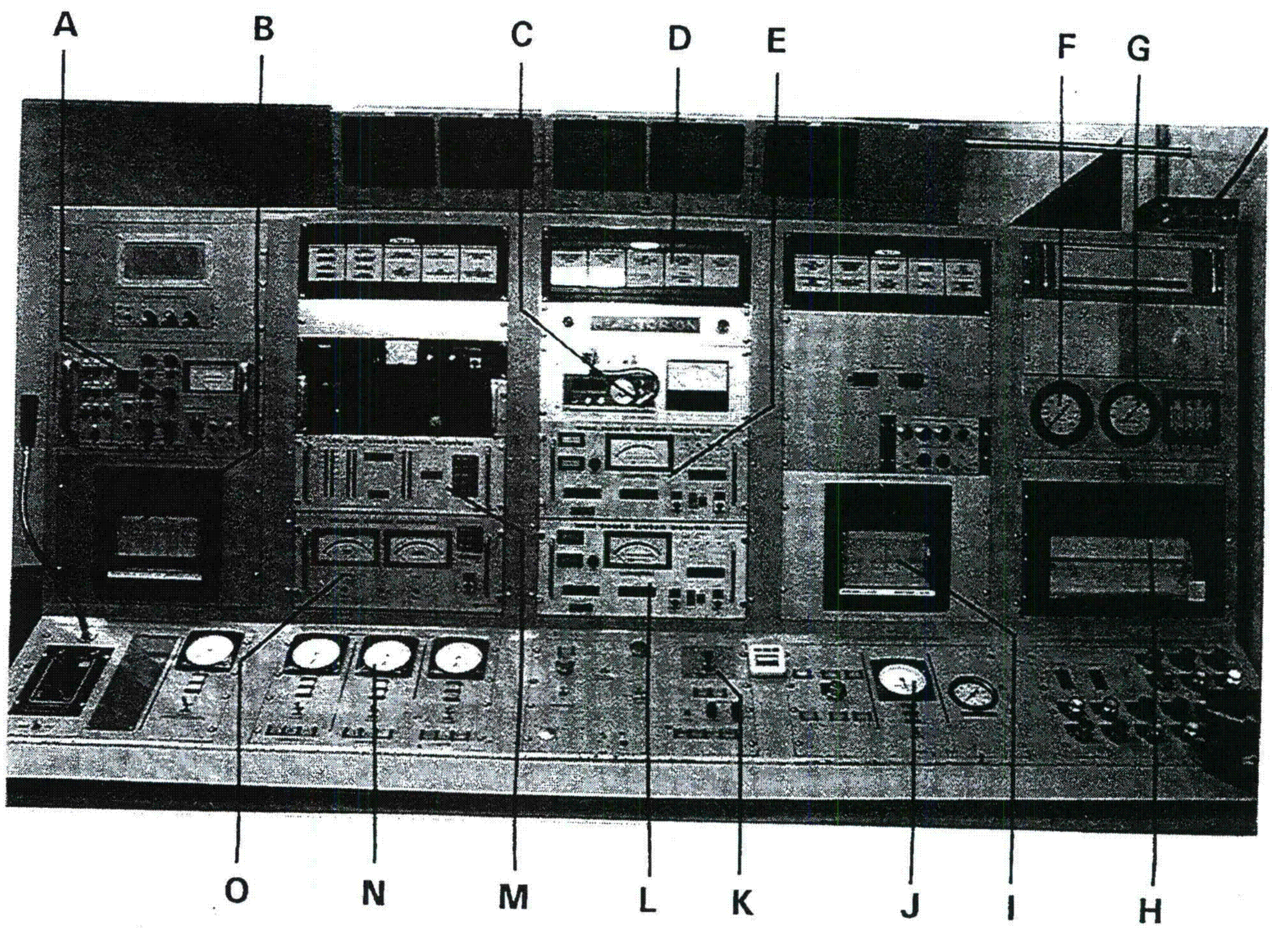


Figure 7.4 Scram logic



KEY

A - SCRAM Logic Unit
B - Source/Log and Linear Recorder
C - N-16 Monitor
D - Annunciator Panel
E - Safety Channel Monitor
F - Primary Coolant Flow Gauge
G - Pool Water Level Gauge

KEY

H - Temperature Recorder
I - Linear and Safety Recorder
J - Shim Rod Position Indicator
K - Flux Controller Demand Potentiometer
L - Linear Channel Monitor
M - Log and Linear Channel Monitor
N - Control Rod Position Indicators
O - Source Range Monitor

Figure 7.5 Control console with annunciator panel

8 ELECTRICAL POWER

This chapter of the SER discusses the sources of electrical power for the NCSU PULSTAR reactor facility. The two types of electrical power at the facility are the normally used main power and emergency power.

8.1 Main Power

The Burlington Engineering Laboratory receives electrical power from NCSU's 12-kV, three-phase, 60-hertz underground system. This power is stepped down to 480/277 volts by an outdoor, pad-mounted, oil-filled transformer, and is then fed into the engineering building for all normal reactor and other uses (Figure 8.1).

8.2 Emergency Power

A 12-kW natural gas-powered auxiliary generator is available in the event of loss of commercial electrical power. This unit, which must be manually started, supplies power to the two confinement fans, as well as the control room distribution panel and control console, as needed.

Using this generator, emergency confinement of the reactor room and all monitoring and control functions at the control console is provided with emergency electrical power. There is no time constraint for regaining electrical power, as shown in Section 13.4 of this SER, because the reactor is designed to avoid fuel damage in the event of a loss of flow caused by loss of offsite electrical power. (Also see Chapters 4, 6, and 7 of this SER). As noted in Chapters 4 and 7, loss of electrical power to the control rod magnets leads to shutdown of the reactor. Inserting control rods using the scram function is an acceptable method of terminating operations at non-power reactors because a scram does not challenge the safety of the reactor or cause any undue strain on any systems or components associated with the reactor.

Emergency lighting is provided by battery-powered units located in the reactor facility. Selected radiation monitors are supplied by an uninterruptible power supply (UPS).

8.3 Conclusion

On the basis of its review, the staff concludes that the electrical power provisions at the NCSU facility provide reasonable assurance of adequate operation. In addition, the staff concludes that loss of offsite power will lead to safe shutdown of the reactor (Section 7.4), with adequate monitoring functions operable on manually initiated emergency power.

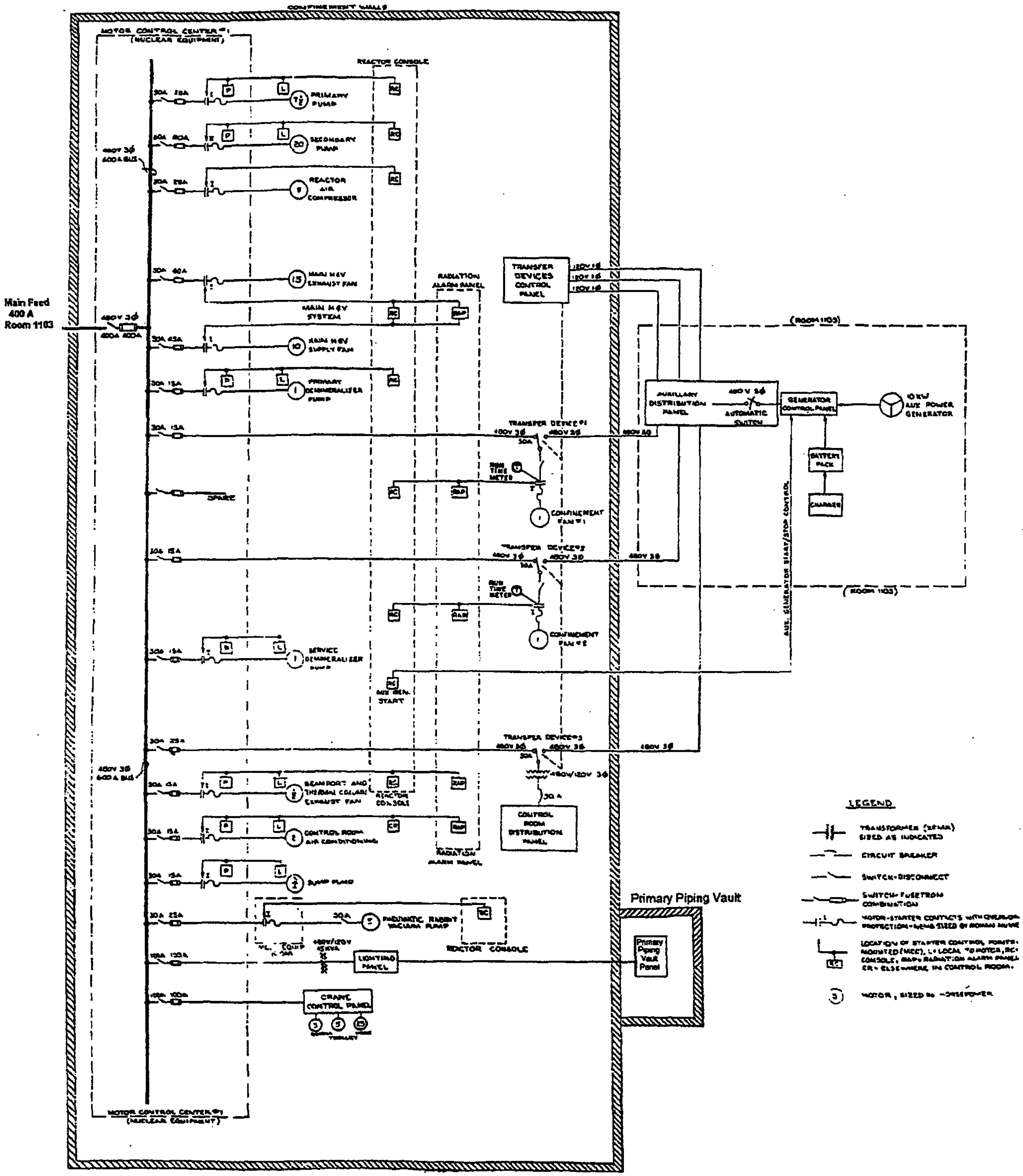


Figure 8.1 NCSU electrical system

9 AUXILIARY SYSTEMS

The auxiliary systems discussed in this section include the fuel handling and storage systems, the compressed air system, the warning and communication systems, and the fire protection provisions. The ventilation system is discussed in Chapter 6, "Engineered Safety Features," the auxiliary electrical generator is discussed in Chapter 8, "Electrical Power," and radioactive waste storage is discussed in Chapter 11, "Radiation Protection Program and Radioactive Waste Management."

9.1 Fuel Handling and Storage

Unirradiated fuel is stored in a locked area, providing both physical security and avoidance of criticality.

Irradiated fuel elements may be stored in either of two racks located in the PULSTAR pool. One rack has a capacity of 13 assemblies, while the other has a capacity of 7 assemblies. These racks augment the fuel storage capacity provided by two 13-assembly pits located at the bottom of the reactor pool. Because the critical mass for optimum fuel spacing is about 20 elements, there is reasonable assurance that the reactivity of each of these storage units would be well below unity. Furthermore, this determination of minimum critical mass was experimentally verified during initial fuel loading in the reactor. Transfer or manipulation of fuel assemblies under water is accomplished using long-handled tools that are specially designed to fit the fuel assembly handling bails.

9.2 Compressed Air System

Reactor service air is supplied by a standard air compressor and moisture separator located in the mechanical equipment room (Figure 9.1). The 100-psi air supply is used for all of the pneumatic instrumentation (pool level and primary coolant flow) and all of the ventilation control dampers within the reactor building. A high-pressure nitrogen tank and regulator are connected by a valve to the air supply line so that reactor operations can continue for approximately one-half hour if the air compressor fails. There is also a method for valving the Burlington Engineering Laboratory air compressor to the reactor air supply line to operate the ventilation control dampers.

9.3 Warning and Communication Systems

In the event of fire, both automatic and hand-pull systems are available to sound a bell alarm. In the event of a radiological emergency, a cyclic horn is sounded. These mechanisms are discussed in detail in the NCSU Emergency Plan.

Several communication methods are available to personnel in the reactor building. Telephones are located in the control room and on the floor level of the reactor bay. An intercom connects the control room with the Associate Director, the Reactor Operations Manager, the Health Physicist, the primary pipe vault, the reactor bridge, the mechanical equipment room, the change room, and the radiochemistry laboratory. A public address system available in the control room can be heard in the mechanical equipment room, the reactor bay, and the basement laboratory hallway. In addition, portable 4-watt UHF transceivers operate on a clear frequency in the Raleigh area that is available to operations personnel. These radios are cycled between a charging mount and the emergency equipment locker. A battery-powered bull horn kept in the control room is also available for use as required.

9.4 Fire Protection Provisions

In case of fire in the Burlington Engineering Laboratory or the reactor building, heat sensors located in the control room, mechanical equipment room, or south wing of the Burlington Engineering Laboratory will automatically activate the fire alarm system, prompting a response from the City of Raleigh Fire Department. In the north wing of the Burlington Engineering Laboratory, manual pull stations must be activated to initiate an alarm that utilizes two types of bells. The first type is located at various places on each floor of the main wing and will chime for four coding sequences and then go silent. The other bell is located in the central stairway and will continue to chime until it is reset by NCSU public safety personnel.

9.5 Conclusions

The fuel handling and storage system designs are adequate to ensure that reactor fuel can be moved, serviced, and stored without danger to operating personnel or the public because of fuel radioactivity or a possible accidental criticality event.

The facility's compressed air system is designed to adequately service the facility under normal and emergency conditions that might occur.

The warning and communication systems are adequate to ensure that sufficient warning can be given of abnormal events and that appropriate communications can be conducted.

The NCSU fire protection provisions are consistent with similar provisions at NRC-licensed non-power reactor facilities that contain very little flammable material in the reactor bay.

On the basis of the above findings, the staff concludes that the NCSU auxiliary systems can provide the necessary service to the reactor facility for the requested license renewal period.

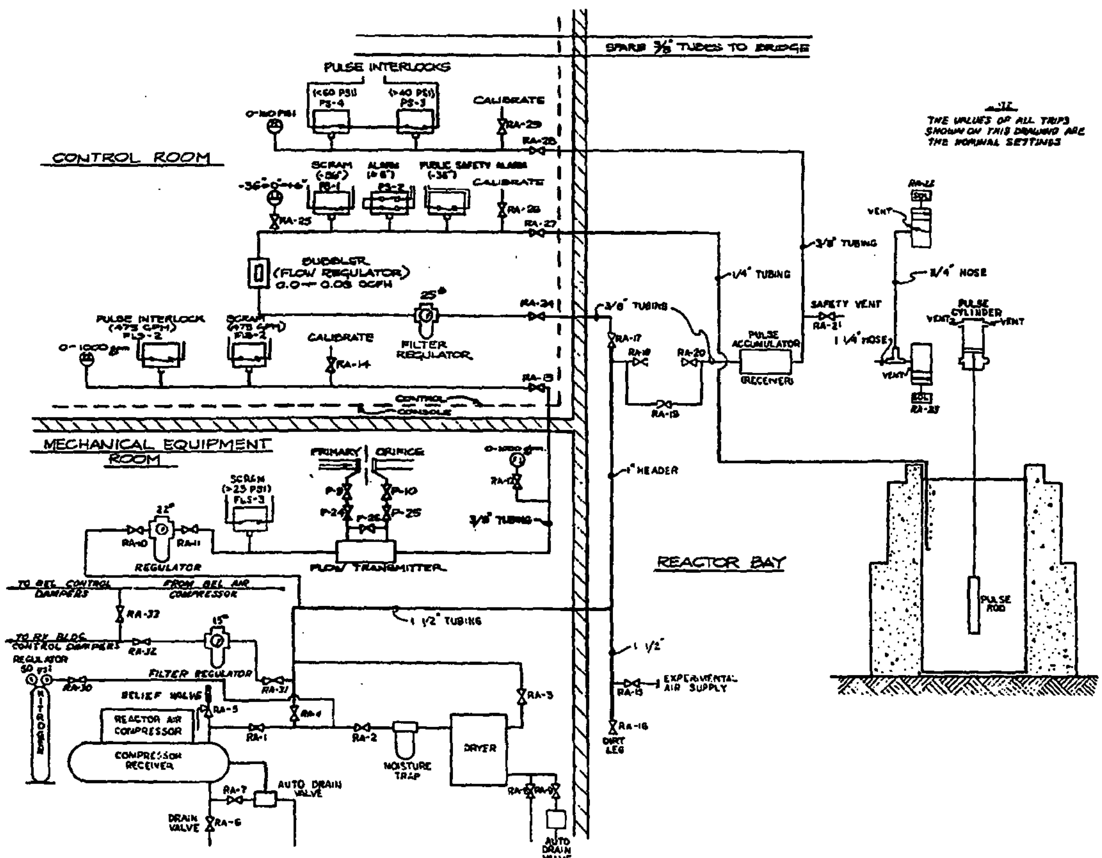


Figure 9.1 Compressed air system

10 EXPERIMENTAL PROGRAMS

The NCSU PULSTAR reactor serves as a source of ionizing and neutron radiation for research, education, and radionuclide production. In addition to in-pool irradiation capabilities, the experimental facilities include a pneumatic transfer system, several beam tubes, and a thermal column with a movable shield door and access ports. The TSs limit the effect on reactivity of all experiments, and provide means for technical and safety review.

10.1 Experimental Facilities

The NCSU PULSTAR reactor has a number of experimental facilities for the conduct of irradiations. These experimental facilities are the reactor pool, pneumatic transfer system, thermal column, and beam tubes.

10.1.1 Pool Irradiation

The open pool of the reactor permits bulk irradiation and provides storage space for irradiated fuel and activated equipment. The decision to perform experiments in the pool is determined by the need for high-neutron fluxes, the integrity of the experiment and the reactor, and the effects on reactivity. Rotating and dry exposure ports are used to irradiate samples.

10.1.2 Pneumatic Transfer System

The 2-in (5-cm) pneumatic transfer tubes facilitate rapid transport of small samples to and from the core region. These samples may be inserted and removed (while the reactor is in operation) by a transport system that is vented to the exhaust stack. The system is designed such that failure will not cause the core to be uncovered by the syphoning of pool water.

10.1.3 Thermal Column

The thermal column (Figure 10.1) consists of a graphite column, 4 ft (1.2 m) wide by 4 ft (1.2 m) high by 5 ft (1.5 m) long, with a door for access to the graphite. The graphite column consists of graphite bars that are 4 in (10.2 cm) wide by 4 in (10.2 cm) high and either 24 in (61 cm) or 36 in (91.4 cm) long. A bulk irradiation space is available between the graphite and the closed outer shield door. Four axial ports in the shielding door and a tangential port that meets the side of the graphite also allow access to the thermal column for sample irradiation. A removable graphite nosepiece, encased in aluminum, displaces pool water in the reactor tank between the reactor core face and the front wall of the thermal column. Air from the thermal column and beam tubes (discussed below) is exhausted by an exhaust fan through a HEPA filter and water separator to the exhaust stack.

10.1.4 Beam Tubes

Six beam tubes of various sizes penetrate the concrete biological shield and the pool liner (Figure 10.2). One of the six beam tubes is a through tube. Piping is provided at each tube to safely remove airborne radioactivity, and provisions are made for filling and draining the tubes with demineralized water to provide shielding.

The basic beam tube assembly (Figure 3) consists of an embedded aluminum sleeve penetrating the concrete shield, and a coaxial re-entrant tube extending through the sleeve and the reflector water up to the core. The beam tubes are provided with removable canned-concrete shield plugs and a gasketed outer door.

10.2 Experimental Review

The NCSU chancellor has established two committees that provide expert technical and safety review of reactor operations, including detailed review of new experiments before they are authorized to be performed. In addition to ensuring safe reactor use in compliance with the license, these reviews provide an opportunity for personnel explicitly trained and experienced in radiological sciences to provide advice and suggest changes in experiments that may help achieve the ALARA objectives.

The NCSU PULSTAR TSs include sections that limit the kinds and quantities of materials, the effects on reactivity, the physical locations and restraints, and the administrative procedures for review and approval of experiments allowed in the reactor and experimental facilities. The specifications cover both fueled (fissile) and non-fueled experimental materials, and are generally consistent with guidance provided by the staff in RG 2.2, "Development of Technical Specifications for Experiments In Research Reactors," and RG 2.4, "Review of Experiments for Research Reactors."

10.3 Conclusion

The staff has determined that the design of the NCSU experimental facilities, combined with the detailed review and administrative procedures applied to all of the licensee's research activities, is adequate to ensure that experiments are unlikely to fail, release significant radioactivity to the environment, or cause damage to the reactor systems or its fuel. Therefore, the staff concludes that reasonable provisions have been made so that the experimental programs and facilities do not pose an unacceptable risk of radiation exposure to the public.

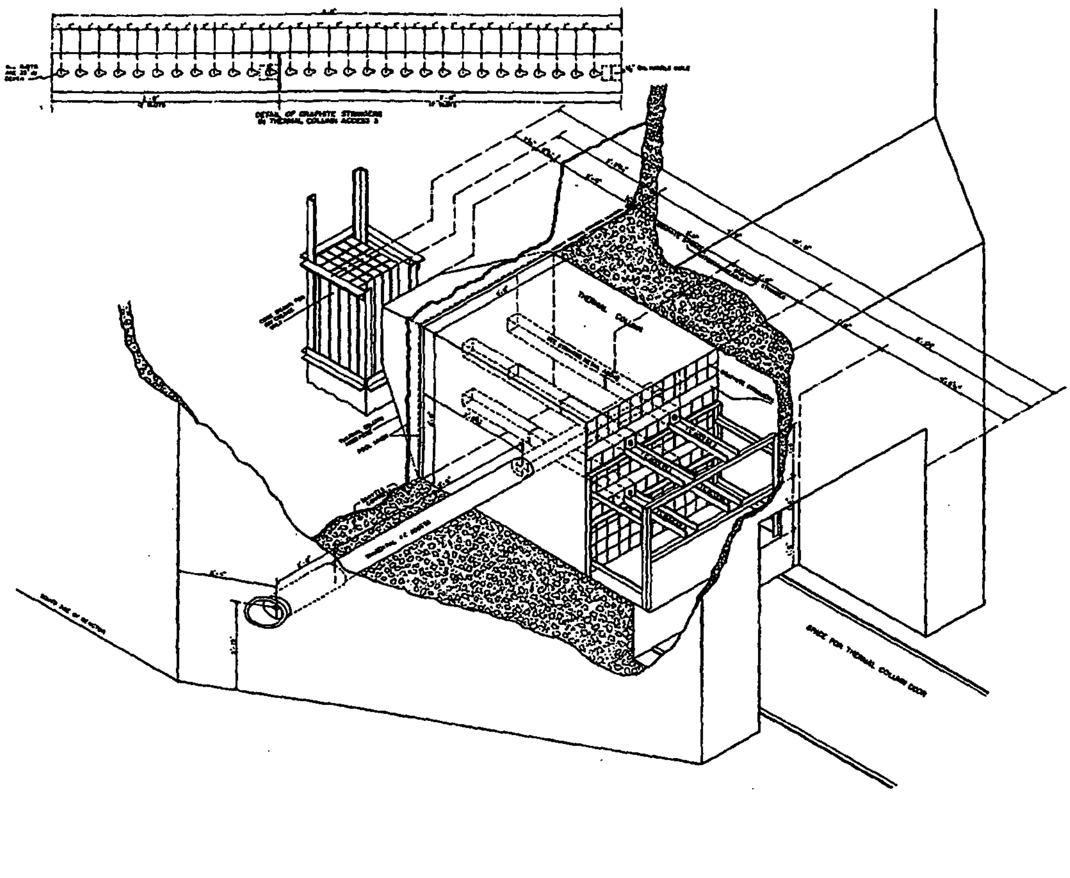


Figure 10.1 Thermal column

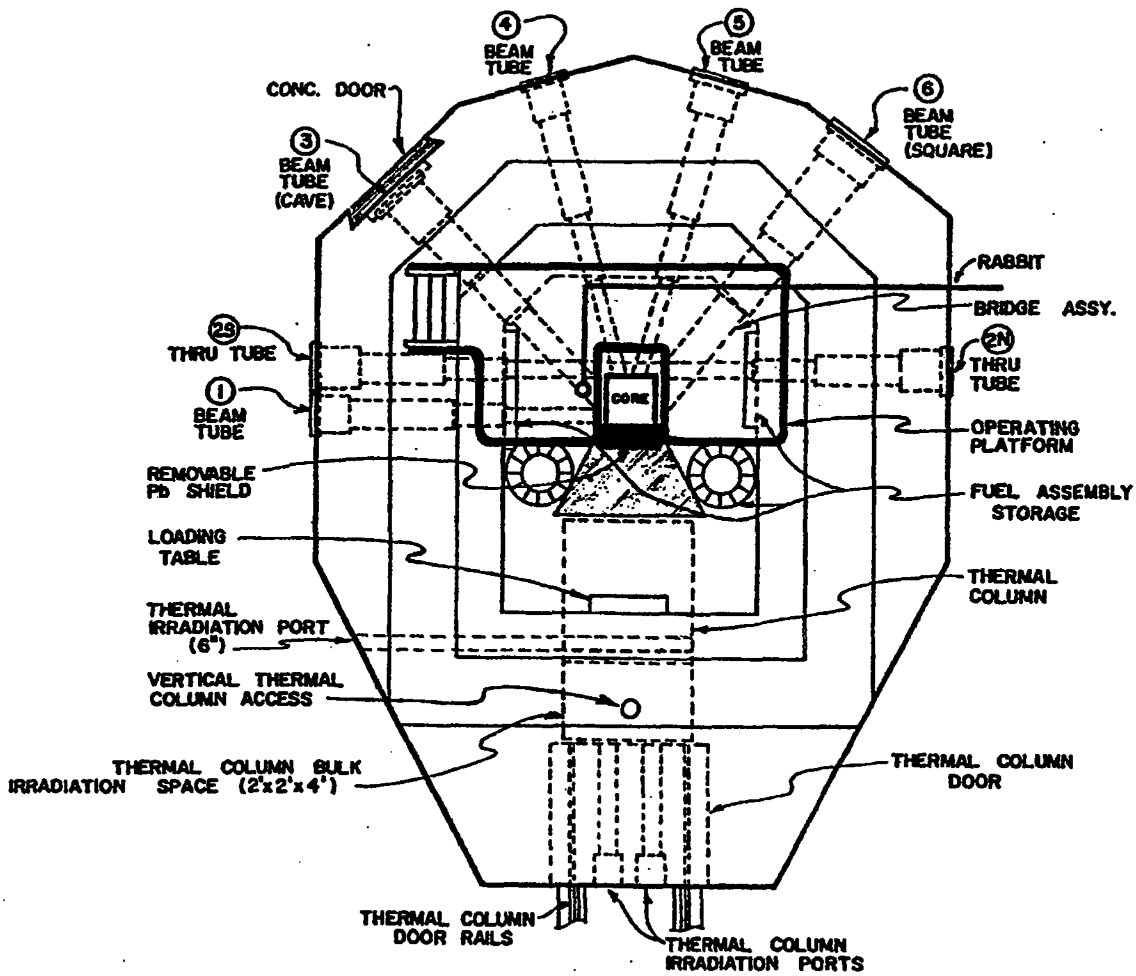


Figure 10.2 Beam tube arrangement

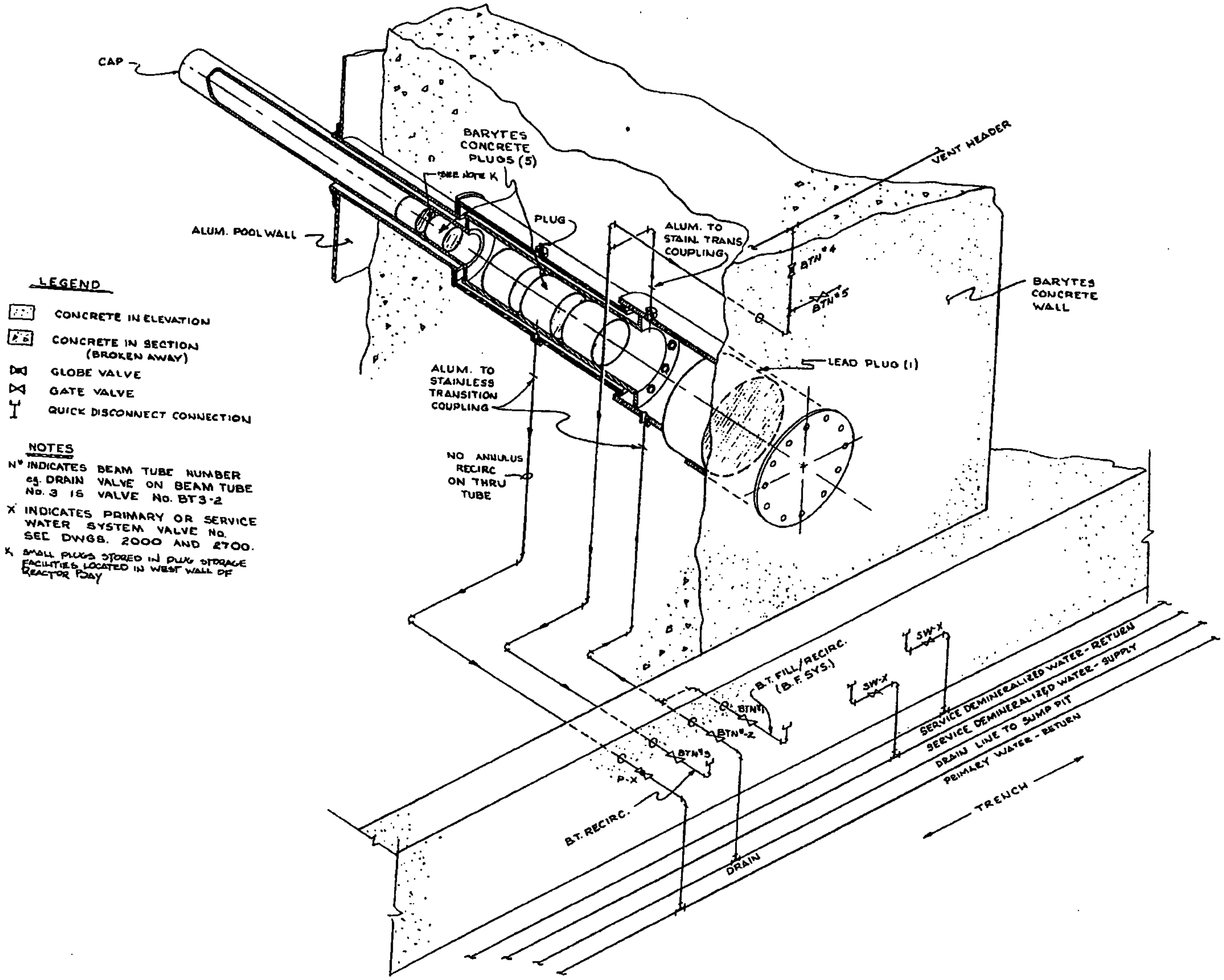


Figure 10.3 Typical beam tube

11 RADIATION PROTECTION PROGRAM AND RADIOACTIVE WASTE MANAGEMENT

11.1 Radiation Protection Program

NCSU has a structured radiation protection program with a health physics staff equipped with radiation detection equipment to determine, control, and document occupational radiation exposures at all university facilities. The Department of Nuclear Engineering provides a Reactor Health Physicist for the NCSU PULSTAR reactor facility.

NCSU monitors both liquid and airborne effluents at the points of release to comply with applicable regulations. The university's Radiation Protection Division, which is responsible for radiation protection on the NCSU campus, has an environmental monitoring procedure to verify that potential radiation exposures in the unrestricted areas surrounding the reactor facility are well within regulations and guidelines.

11.1.1 ALARA Commitment

The NCSU Chancellor and the Radiation Protection Committee have established and implemented the policy that all operations are to be planned and conducted in a manner to keep all radiation exposures as low as is reasonably achievable (ALARA). This policy is implemented through a set of guidelines and procedures. The licensee has committed that all proposed experiments and procedures at the reactor are reviewed for ways to minimize the potential exposures of personnel. All unanticipated or unusual reactor-related exposures are investigated by both the health physics and reactor operations staffs to develop methods to prevent recurrences.

11.1.2 Health Physics Staffing

The health physics staff at the reactor is comprised of at least one professional with additional support as needed. The reactor health physicist reports to the Head of the Department of Nuclear Engineering and has primary responsibility for health physics at the reactor facility. If additional support is needed, health physicists are available from the University Radiation Protection Division. The onsite staff has sufficient training and experience to direct the radiation protection program for a research reactor. In addition, the health physics staff has been given the responsibility, the authority, and adequate lines of communication to implement and conduct an effective radiation safety program within the guidelines promulgated by the handbook published by the Radiation Protection Council (which became the Radiation Protection Committee).

11.1.3 Health Physics Procedures

The licensee has prepared written procedures that address health physics activities and the support that the health physics staff is expected to provide for routine operation of the PULSTAR reactor. These procedures identify the interactions between the health physics staff and the operational and experimental personnel. They also specify administrative limits and action points, as well as appropriate responses and corrective actions for use when these limits or action points are reached or exceeded. Copies of these procedures are readily available to the operational and research staffs, as well as the health physics and administrative personnel.

11.1.4 Health Physics Training

All NCSU reactor facility personnel receive an indoctrination in radiation safety before they assume their work responsibilities. Additional radiation safety instruction is provided to those who will work directly with radiation or radioactive materials. This training program is designed to identify the particular hazards of each specific type of work to be undertaken, as well as methods to be used to mitigate the consequences of those hazards. The licensee also provides retraining in radiation safety, and periodically reviews health physics and personnel protection practices in the reactor operator requalification program.

11.1.5 Radiation Sources

The major radiation sources at the reactor facility that the radiation protection program has been established to guard against are discussed below.

11.1.5.1 Reactor

Sources of radiation directly related to reactor operations include radiation from the reactor core and ion exchange equipment, as well as radiation from primary piping containing coolant with nitrogen-16 and radioactive gases (primarily argon-41).

The reactor fuel and all fission products are completely contained in zircaloy-2 cladding. Radiation exposure from the reactor core is reduced to acceptable levels by water and concrete shielding. In addition, the ion exchange equipment is located in a shielded area.

Portions of the primary piping that carry coolant with high levels of nitrogen-16 are located in the primary piping vault, along with the nitrogen-16 decay tank. The primary piping vault is located below grade on the south side of the reactor building, where it is shielded by the primary piping vault structure and soil. The area above the primary piping vault is grassy.

The licensee has measured a maximum radiation level of 0.04 mrem per hour above the primary piping vault with the reactor at 950 kW. If someone were to continuously stay above the primary piping vault for 24 hours a day for an entire year, their total effective dose equivalent would be 350 mrem (3.5 millisievert) which exceeds the limit of 100 mrem per year (1 millisievert) specified in 10 CFR 20.1301. The licensee has taken into account occupancy times in determining the radiation exposure for persons in the area above the primary piping vault. Assuming an occupancy time of 1/16 (1.5 hours per day or 547.5 hours per year), the maximum total effective dose equivalent for a person would be 22 mrem per year (0.22 millisievert). The staff concludes that the use of occupancy times is acceptable, the occupancy time chosen by the licensee is conservative, and the licensee has complied with 10 CFR 20.1301 by using 10 CFR 20.1302(b)(1).

Personnel exposure to the radiation from chemically inert argon-41 is limited by dilution and prompt removal of this gas from the reactor room and experimental areas and its discharge to the atmosphere, where it is further diluted and diffused before reaching occupied offsite areas. Section 11.2 further discusses gaseous radioactive waste.

11.1.5.2 Extraneous Sources

Sources of radiation that may be considered incidental to normal reactor operation but are nonetheless associated with reactor use include radioactive isotopes produced for research, activated components of experiments, and activated samples or specimens.

Personnel exposure to radiation from intentionally produced radioactive material, as well as from the required manipulation of activated experimental components, is controlled using rigidly developed and reviewed operating procedures that employ the standard protective measures of time, distance, and shielding.

11.1.6 Routine Monitoring

Aspects of the NCSU radiation protection program concerning the routine monitoring of radiation are discussed in this section of the SER.

11.1.6.1 Health Physics Instrumentation

The NCSU PULSTAR facility has a variety of detection and measurement instruments available to monitor potentially hazardous radiation. Established instrument calibration procedures and techniques ensure that any credible type of radiation and any significant radiation intensities will be promptly detected and correctly measured.

11.1.6.2 Fixed-Position Monitors

The NCSU PULSTAR facility uses several fixed-position radiation monitors (Figure 11.1) in addition to portable monitors. Area radiation monitors are placed at strategic locations in the reactor building where radiation levels might be significant or where increases might indicate abnormal or hazardous conditions. These include area monitors in the control room, over the pool, on the west wall in the reactor bay, near the primary coolant demineralizer, and adjacent to filters in the main exhaust system. The three liquid waste tanks also have radiation monitors. Certain monitors can be bypassed to prevent alarms for short periods of time in order to accommodate the needs of the experimental program.

The exhaust stack system measures both radioactive gases and particulates using an isokinetic probe in the exhaust stack. An auxiliary Geiger-Müller (GM) monitor is also used to indicate gross radiation levels in the air stream leaving the facility.

Monitors used to initiate isolation of the confinement building were discussed in Section 6 of this SER. Remote readouts of these monitors are located in the control room. These monitors can be powered by the UPS, which in turn can be powered by the emergency electrical generator. An additional monitor on the reactor bridge may be used to provide pool-top radiation information and alarm, and a continuous air monitor may be used to sample reactor bay air for airborne radioactive particulates. Other monitors may be employed throughout the facility, as needed.

11.1.6.3 Experimental Support

The Reactor Health Physicist is involved in the review and approval process for experiments at the reactor facility. The Reactor Health Physicist participates in experiment planning by reviewing and approving all proposed new experiments or classes of experiments. The reactor Health Physicist also reviews all proposed experiments to determine if they are covered by existing approvals or must be reviewed as new, untried experiments. The Reactor Health Physicist also reviews and approves substantive changes to previously approved experiments.

11.1.6.4 Non-Routine Tasks

One-of-a-kind, short-term tasks (such as non-routine maintenance activities) are occasionally performed in potential radiation or contamination areas, but only after detailed staff review. The work is then performed with health physics coverage.

11.1.7 Occupational Radiation Exposures

The reactor personnel monitoring program is described in the "NCSU Handbook for Protection Against Ionizing Radiation." To summarize the program, the licensee measures personnel exposures using film badges assigned to individuals who might be exposed to radiation. In addition, the licensee uses thermoluminescent dosimeters (TLDs) and self-reading pocket ion chambers, as well as instrument dose rate and time measurements to ensure that administratively established occupational exposure limits are not exceeded. These limits conform with the limits specified in 10 CFR Part 20.

Table 11.1 summarizes the annual NCSU reactor personnel exposure history for the last several years. The result of applying the ALARA principle is evident in the licensee's control of personnel exposures.

11.1.8 Effluent Monitoring

As noted in Section 11.1.5.1, argon-41 is the primary airborne radioactive effluent during normal operation of the NCSU PULSTAR. This gas is continuously swept from the reactor bay and experimental facilities, and is discharged from the 100-ft (30-m) high stack. An isokinetic probe in the stack feeds an air sample to a particulate monitor, and a GM-type detector system is used to monitor gases. The latter is periodically calibrated with a known, prepared source of argon-41. These measures enable the licensee to maintain continuous direct measurement of the principal airborne radioactive effluent.

No radioactive liquids are directly released from the reactor during normal operation. All potentially radioactive liquids are collected and stored temporarily before being monitored and released to the sanitary sewer. Before release, samples are collected and analyzed for gross beta-gamma, tritium, and principle gamma-emitting nuclide concentrations to help ensure compliance with regulatory requirements.

11.1.9 Environmental Monitoring

NCSU has an extensive environmental monitoring program, and the results are transmitted to the NRC in the licensee's annual operating report.

Areas outside the reactor building and the Burlington Engineering Laboratory are periodically monitored by air monitoring stations to detect radiation. TLD badges are also placed in areas outside the reactor building. In addition, NCSU collects samples from nearby surface water and vegetation, and carefully analyzes for alpha, beta and gamma contaminants, as appropriate. NCSU also analyzes milk samples to detect the presence of iodine-131. Since initial reactor commissioning, the program has not detected any measurable reactor-related radioactive contamination in the unrestricted area.

11.2 Radioactive Waste Management

Radioactive waste resulting from reactor operations is either discharged to the environment in gaseous form, released as liquid to the NCSU sanitary sewer system, or packaged as solids and transferred to the university's Radiation Protection Division for disposal, all in accordance with applicable regulations. Further, the NCSU reactor administration and staff closely follow the principles of their ALARA policy in handling radioactive materials and in considering the release of such materials to the unrestricted environment.

11.2.1 Waste Generation and Handling Procedures

Operation of the NCSU PULSTAR reactor and conduct of the facility experimental program generates liquid, solid, and airborne radioactive waste. This section of the SER discusses waste generation and handling procedures.

11.2.1.1 Liquid Waste

Several activities associated with operation and use of the NCSU PULSTAR reactor are capable of generating low-level radioactive liquid wastes. Liquid wastes from the reactor building derive from such operations as filling and draining the beam tubes and changing the resins in the primary coolant cleanup system. Liquid waste from the nuclear laboratories consists of residues from cleaning contaminated glassware or other experimental apparatus. The total liquid waste collected is about 12,000 gal (45,000 l) per year. These types of liquid waste are collected in a waste handling system, but any liquid high-level radioactive waste or radioactive biological specimens are separately collected, packaged, and appropriately disposed of through the Radiation Protection Division.

Designated hot waste drains in the facility drain to the installed liquid radioactive waste handling system (Figure 11.2), which consists of sumps and pumps in the mechanical equipment room and primary piping vault that are connected to three tanks buried in a vault outside the building. After hold-up for appropriate intervals, the contents of these tanks are sampled and analyzed. When certain compliance with all applicable regulations can be ensured, the licensee releases the liquid to the campus sanitary sewage system. The tank system and all controls are maintained locked, with the key controlled by the reactor facility health physicist.

11.2.1.2 Solid Waste

Occasionally, low-level solid waste results from reactor operations and the experimental program. This may consist of experimental residues, cleaning materials (such as paper towels), and small contaminated components. The average annual amount of solid waste produced by reactor operation and utilization is about 15 ft^3 (1.4 m^3) of de-watered resins and 30 ft^3 (2.8 m^3) of compacted dry active waste. Such waste is monitored, classified as to radioactive characteristics, and routinely disposed of by the university's Radiation Protection Division in accordance with approved procedures and applicable regulations. No need has yet arisen to dispose of spent fuel assemblies or rods.

11.2.1.3 Airborne Waste

Radioactive airborne waste is principally produced by the neutron irradiation of the coolant water and air dissolved in the pool water, as well as the air and airborne particulates in the thermal column, pneumatic transfer system, and beam tubes. The potential airborne radioactive wastes during normal operations include gaseous nitrogen-16, argon-41, and neutron-activated dust particulates. The amount of nitrogen-16 that escapes the pool is very small, as is the activation of dust particulates. The predominant airborne waste from the reactor is argon-41. The reactor is not allowed to operate, except at low power to search for a leaking element, if fission products escape from the fuel cladding during normal operations.

Occupational exposure of personnel in the restricted area as a result of airborne radionuclides is limited by constantly sweeping the air from the reactor bay and discharging it to the atmosphere. An additional ventilation system with a HEPA filter and exhaust fan is provided for areas with higher potential argon-41 production (such as the thermal column and beam tubes). During operation, air is exhausted through filters to remove most of the airborne particulates and is monitored for residual radioactivity before being discharged from the 100-foot (30-m) high stack.

On the basis of a calibrated radioactive gas monitor, the licensee estimated that the average annual release of argon-41 from the facility was about 6.8 curies (2.5×10^{11} Bq) per year over the last several years. More than 80 percent of this argon-41 was produced by operation of the pneumatic transport system, which, in accordance with ALARA principles, is used to the minimum extent consistent with the research program. This system is purged with nitrogen when not in use to displace air whenever the reactor is operated above 500 kW. Furthermore, air from the pneumatic transport system is confined and released directly out the facility exhaust stack, rather then being released to the reactor bay.

If the reactor were continuously operated at full power, a very conservative assumption, the amount of argon-41 produced in a year would be approximately 44 curies (1.6×10^{12} Bq). Argon-41 produced in the facility is diluted by the ventilation system intake air before it is discharged from the stack. Furthermore, there is additional dilution by diffusion before the discharged air reaches potentially occupied spaces in the unrestricted area. Potential doses from the production of argon-41 are discussed in Section 11.2.2.

The licensee calculated the dose rate from argon-41 in the restricted areas of the reactor facility for an annual argon-41 production of approximately 44 Curies (1.6×10^{12} Bq). The licensee assumed that 16.5 percent of the total production entered the restricted area with the balance of the argon-41 exhausted directly from the pneumatic transfer system to the environment.

If the normal ventilation system were to fail, the reactor would be scrammed, and buildup of argon-41 in the reactor bay would be prevented by the emergency (confinement) ventilation system.

During normal operation at 1 MW, the forced convection flow of the coolant is downward through the core into a shielded, baffled tank that provides for radioactive decay of the nitrogen-16, which has a 7-second half life. The nitrogen-16 is produced by the $O^{16}(n,p)N^{16}$ reaction by fast neutrons as the coolant passes through the reactor core. When the coolant water reenters the pool more than a minute later, nitrogen-16 radioactivity is very small.

11.2.2 Potential Dose Assessments

Natural background radiation levels result in an average exposure of about 120 mrem/yr to each individual residing in the Raleigh area. At least an additional 7 percent (approximately 8-9 mrem/yr) will be received by those living in brick or masonry structures. Any medical diagnosis and x-ray examinations will add to these natural background radiations, thereby increasing the total cumulative annual exposure.

As noted above, argon-41 and nitrogen-16 are the two principal airborne radionuclides formed during routine operation of the NCSU PULSTAR reactor. Nitrogen-16 decays with a 7-second half life, so no significant quantities escape or are released from the reactor building, leaving argon-41 as the principal, and usually the only, airborne radionuclide that could pose a routine radiological risk in both the restricted and unrestricted areas.

The staff expects licensees to conduct a detailed examination regarding the formation, release, and exposure parameters of argon-41. The purposes of this examination are to assess the potential doses with acceptable accuracy, and to demonstrate that the methods used to analyze radiologic effects in both the restricted and unrestricted environments are sufficiently understood and available for the licensee to assess doses resulting from possible inadvertent releases of other airborne radioactive materials.

The licensee has estimated (using applicable methods) the formation of both of these nuclides, in various reactor operations. The licensee also monitors the release of argon-41 from the 100-ft (30-m) high exhaust stack.

11.2.2.1 Unrestricted Area

The staff requested that the licensee analyze the potential annual doses to the individual receiving the maximum exposure, at the nearest permanent residence, and at other locations of special significance. The licensee added the nearest on-campus residence hall (Carroll Hall at 850 ft (260 m)), because of its high occupancy rate and the fact that it has floors as high as the reactor stack, as well as the Hill Library (at 460 ft (140 m)), because it is near the reactor and its upper floors are at least as high as the reactor exhaust stack. The licensee based their calculations on an annual release of about 44 curies of argon-41, which represents continuous operation of the reactor. The licensee assumed that the wind maintained a constant direction the entire year toward the point of interest and that a person was present at the location of interest for the entire year. The licensee averaged over three different atmospheric conditions (Pasquill class C, D, and E). These assumptions are very conservative.

The staff independently estimated the potential doses (exposures) for an annual release of 7 curies, which represents the average actual release from the facility for the last several years, at the above locations by realistic yet conservative methods on the basis of NUREG-0851, ANSI/ANS-15.7, RG 1.109, and the International Commission on Radiological Protection (ICRP) Standard 26. The results can be summarized as follows:

- The exposure conditions were consistent with calculating only whole-body external exposures to the gamma rays from the noble gas, for which inhalation and ingestion doses would be relatively insignificant.

- The exposure conditions and geometries are too complex to model exactly, but conservative assumptions about plume sizes and concentrations (chi/que) used by the licensee indicated that the maximum exposure rate would be at the Hill Library, at an elevation corresponding to the plume axis. The licensee estimated a whole body dose (total effective dose equivalent) of about 25 mrem per year for continuous reactor operation. For the same location assuming releases from actual operation, the staff considered such factors as changes in wind speed and direction, building shielding, and occupancy times, and concluded that exposure would be less than 1 mrem.

- When the staff considered such factors as changes in wind speed and direction, building shielding, and occupancy times, the location of maximum potential annual dose was found to be on the ground, some tens of meters from the reactor stack. At this location, the concentration of argon-41 is not significant, but the principal exposure mechanism is argon-41 gamma ray shine down from the plume passing overhead. In this location, averaging over changes in atmospheric conditions (Pasquill conditions), and wind speed and direction during an entire year shows that the predicted average annual whole body dose would not exceed 1 mrem per year. The licensee calculated a whole body dose at this location of less than 2 mrem per year for continuous operation.

- The staff and licensee calculated that average annual doses at ground level at the nearest permanent residence would not exceed 1 mrem per year. For the nearest student dormitory, the staff calculated that whole body doses would not exceed 1 mrem per year and the licensee calculated that whole body doses would not exceed 9 mrem per year.

- Nitrogen-16 levels at the top of the pool are very small, and a limited amount of nitrogen-16 escapes the pool water. Given the short (7-second) half life of nitrogen-16 and the additional decay that occurs during transport from the pool top to the environment, doses associated with nitrogen-16 in the unrestricted area are very small.

The differences in results between staff and licensee calculations arise from the assumed reactor operating time (average actual operation of about 1400 hours for staff calculations, compared to continuous operation of 8760 hours for licensee calculations) and other assumptions concerning wind direction, atmospheric conditions, and occupancy time at the point of interest.

The staff concludes that the licensee has developed procedures for monitoring argon-41 releases, as well as methods for evaluating potential doses from finite clouds in the unrestricted area, that are applicable and acceptable. The projected annual doses for continued operation of the reactor are well within the regulatory limits of 10 CFR Part 20, and would not pose significant or unacceptable risk to the public or the environment.

11.2.2.2 Restricted Area

The licensee provided information concerning the sources of argon-41 and nitrogen-16 in the restricted area during normal operation of the reactor. The reactor is designed so that the coolant is pumped down through the core, and enters a baffled tank in a buried shielded vault. The coolant requires nearly a minute to emerge from the shielded area, by which time the nitrogen-16 radioactivity has decayed by at least nine half lives and its high-energy gamma rays are not readily detectable.

Radiation measurements of about 1 mrem per hour at the pool surface (primarily from direct radiation from the core) with the reactor operating at 1 MW attest to the effectiveness of the system in precluding significant doses at this location from nitrogen-16. During natural convection flow upward through the core with the reactor operation at 100 kW, nitrogen-16 is carried toward the pool surface by natural convection of the coolant, causing an exposure rate of about 3 mrem per hour on the pool top. However, the duration of occupancy at this location during reactor operation is short, so potential accumulated doses from nitrogen-16 are not significant for operation in either forced or natural convection modes.

The licensee discussed measured sources of argon-41, and estimated by conservative methods that the whole body dose rate on the reactor bay floor is about 0.05 mrem per hour. The staff calculated the expected dose rates by conservative but more-realistic methods (e.g., not invoking an infinite cloud formalism) arriving at a maximum dose rate in the reactor bay not exceeding 0.01 mrem per hour.

Because any one individual never occupies the reactor bay for a large fraction of the working day, these predicted maximum dose rates would not be expected to lead to significant occupational doses to the facility's staff or users of the reactor. The exposure history discussed in Section 11.1.7 verifies these predictions. Concentrations of argon-41 in the reactor bay are limited by both selective and general air ventilation systems that continuously exhaust room air through the 100-ft (30-m) high stack. The discussions in the previous section show that the resultant exposures in the unrestricted area are acceptably small.

11.3 Conclusions

The staff concludes that radiation protection receives appropriate support from the NCSU administration. Among other guidance, the staff's review considered the guidance of ANSI/ANS 15.11, 1993, "Radiation Protection at Research Reactor Facilities." On the basis of this review, the staff reached the following conclusions:

- The NCSU radiation protection program is acceptably staffed and equipped.

- The NCSU reactor health physics staff has adequate authority and lines of communication.

- The radiation protection procedures are integrated into the research plans.

- Surveys verify that operations and procedures achieve ALARA principles.

- The effluent monitoring programs and environmental monitoring program conducted by personnel from the NCSU Radiation Protection Division are adequate to promptly identify significant releases of radioactivity and to predict maximum exposures to individuals in the unrestricted area. (These measured and predicted maximum levels are a very small fraction of applicable regulations and guidelines specified in 10 CFR Part 20.)

- The NCSU reactor radiation protection program is acceptably implemented because there have been no instances of reactor-related exposures of personnel above applicable regulations and no unidentified or uncontrolled significant releases of radioactivity to the environment during the past years of reactor operation.

- There is reasonable assurance that NCSU personnel and procedures will continue for the duration of the license renewal to protect the health and safety of the public, the facility staff, and the environment from significant radiation exposures related to normal reactor operations.

- Waste management activities at the NCSU reactor facility have been conducted and can be expected to continue to be conducted in a manner consistent with both 10 CFR Part 20 and ALARA principles.

- The NCSU systems and procedures limit the production of argon-41 and nitrogen-16, and control potential exposures of facility staff. Conservative computations (by both the licensee and the staff) of the quantities of these gases released beyond the limits of the reactor facility give reasonable assurance that potential doses to the public as a result of argon-41 would not be significant, even if there were a major increase in the operating schedule of the reactor.

Table 11.1 Annual NCSU Reactor Personnel Exposure History

(Deep Dose-Equivalent) Exposure Range (rems)	Number of Individuals in Each Range									
	FY* 85–86	FY 86–87	FY 87–88	FY 88–89	FY 89–90	FY 90–91	FY 91–92	FY 92–93	FY 93–94	FY 94–95
Not Detected	16	1	3	2	5	2	15	9	1	11
Less Than 0.1	10	28	25	27	22	22	8	14	22	14
0.10 to 0.25	1	0	0	0	1	1	0	0	2	0
0.25 to 0.50	1	0	0	0	0	0	0	0	0	0
More than 0.50	0	0	0	0	0	0	0	0	0	0

*FY is fiscal year (July 1 to June 30)

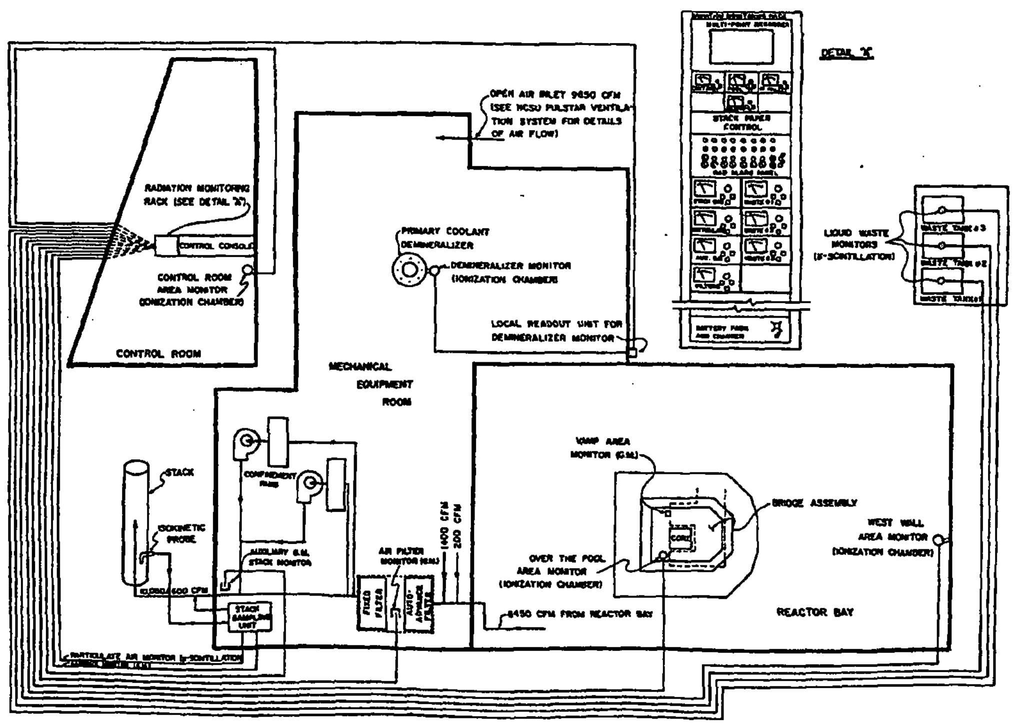


Figure 11.1 Radiation monitoring system

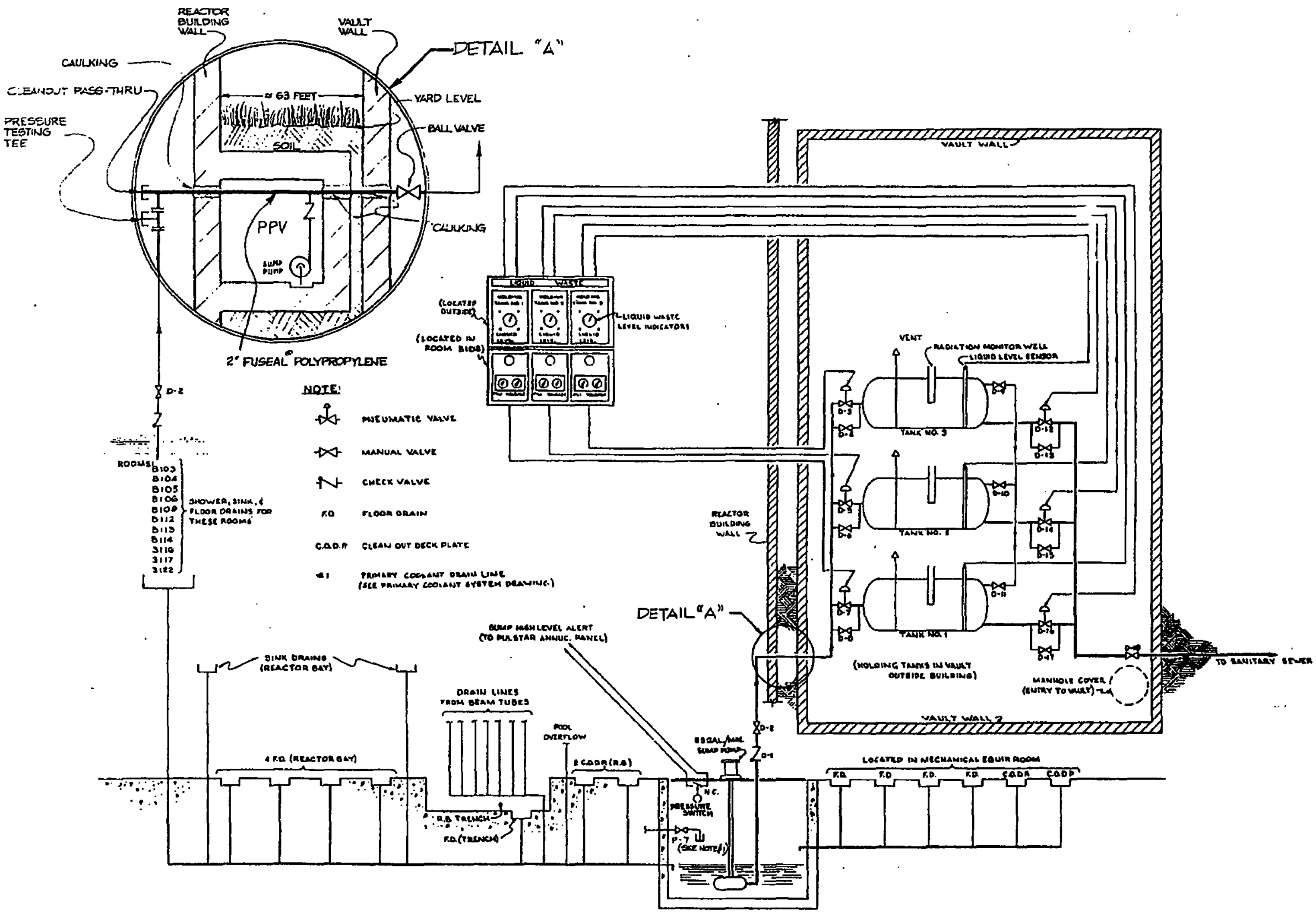


Figure 11.2 Liquid radioactive waste handling system

12 CONDUCT OF OPERATIONS

The conduct of operations involves the administrative aspects of facility operation and the facility emergency and security plans. The administrative aspects of facility operations are the facility organization, training, operational review and audits, and procedures.

12.1 Overall Organization

Responsibility for the safe operation of the reactor facility is vested within the chain of command shown in Figure 12.1. The Director of the Nuclear Reactor Program is responsible for long-range development of the Nuclear Reactor Program and the general conduct of program operations. The Associate Director of the Nuclear Reactor Program is responsible for facility development, as well as safe and efficient operation of the reactor facility.

12.2 Training

The training of reactor operators is conducted by NCSU personnel. The Chief Reactor Operator is the program administrator of the facility's requalification program. The staff has reviewed Revision 6 of "The PULSTAR Operator Requalification Program," submitted as part of the renewal application, and concludes that the program meets the applicable regulations in 10 CFR Part 55. The program discusses the schedule of training, lectures, quizzes and written examinations, on the job training, oral and operating examinations, document review requirements, overall evaluation of operators, absence from licensed activities, exemptions to the program, recordkeeping, and administration of the program.

12.3 Operational Review and Audits

The Radiation Protection Committee has responsibility to ensure that the use of radioactive materials and radiation producing devices, including the reactor, is conducted safely with minimum impact on members of the university and the public. The Reactor Safety and Audit Committee is a permanent committee of the Radiation Protection Committee, which assists the Radiation Protection Committee and has responsibility for ensuring that the reactor is operated in compliance with the facility's license and applicable regulations. The Reactor Safety and Audit Committee conducts independent appraisals of reactor operations and performance of the reactor program.

The TSs outline the qualifications that members of each committee must possess and discuss the committees' operational aspects (such as minimum membership, quorum, and meeting frequency). The Radiation Protection Committee reviews and approves directly or by referral to the Reactor Safety and Audit Committee each of the following aspects of reactor operation:

- determinations that proposed safety-significant changes in equipment, systems, tests, experiments, or procedures do not involve an unreviewed safety question

- all new procedures (and major revisions thereto)

- proposed reactor facility equipment and systems changes having safety significance
- all new experiments or classes of experiments that could affect reactivity or result in the release of radioactivity
- proposed changes to the TSs or facility license
- violations of the TSs, license, or safety-significant internal procedures or instructions
- safety-significant operational abnormalities
- reportable events (as defined by the facility's TSs)
- audit reports

The Reactor Safety and Audit Committee is responsible for auditing the following aspects of reactor operation:

- reactor facility operations (for conformance to the TSs and license)
- retraining and requalification program for the operating staff
- results of actions taken to correct deficiencies that may occur in the reactor facility equipment, systems, structures, or methods of operations that affect reactor safety
- the emergency plan and procedures
- radiation protection

Identified deficiencies that affect reactor safety are immediately reported to the Radiation Protection Committee, the Head of the Department of Nuclear Engineering, and the Director and Associate Director of the Nuclear Reactor Program.

12.4 Procedures

The licensee has developed a comprehensive set of written operating procedures for all aspects of reactor facility operation. These procedures address (1) startup, operation and shutdown of the reactor; (2) fuel loading, unloading, and movement within the reactor; (3) maintenance of major components of systems that could have an affect on reactor safety; (4) surveillance checks, calibrations, and inspections required by the TSs or those that may have an affect on reactor safety; (5) personnel radiation protection, consistent with application regulations and that include commitment or programs or both to maintain exposures and releases ALARA; (6) administrative controls for operations and maintenance and for the conduct of irradiations and experiments that could affect reactor safety or core reactivity; and (7) implementation of the emergency plan and security plan.

Substantive changes to these procedures require review by the Radiation Protection Committee or Reactor Safety and Audit Committee and approval by the Associate Director of the Nuclear Reactor Program. Minor modifications to procedures that do not change their original intent may be made by the Reactor Operations Manager, but need to be approved by the Associate Director of the Nuclear Reactor Program within 14 days. Temporary deviations from procedures may be made by the Senior Reactor Operator or Reactor Operations Manager to deal with circumstances that may arise, but such deviations must be documented and reported to the Associate Director of the Nuclear Reactor Program.

12.5 Emergency Planning

10 CFR 50.54(q) and (r) require that a licensee authorized to possess and/or operate a research reactor shall follow and maintain in effect an emergency plan that meets the requirements of Appendix E to 10 CFR Part 50. Consequently, the staff reviewed Revision 3 of "The PULSTAR Emergency Plan," effective September 15, 1995. The staff concluded that this plan maintains compliance with applicable portions of Appendix E to 10 CFR Part 50.

The licensee subsequently submitted Revision 4 of the plan under 10 CFR 50.54(q), which allows changes to emergency plans without prior NRC approval if the licensee determines that the changes do not decrease the effectiveness of the plan. The licensee concluded that the changes do not decrease the effectiveness of the plan, and the changes became effective November 11, 1996. The staff initial review of these changes indicates them to be in accordance with 10 CFR 50.54(q). Implementation of these changes by the licensee will be subject to inspection to confirm that they have not decreased the overall effectiveness of the emergency plan.

12.6 Physical Security Plan

The licensee has established and maintains a program to protect the reactor and its fuel and to ensure its security. Accordingly, the staff reviewed Revision 8 of the "NCSU PULSTAR Physical Security Plan," dated January 10, 1996, that was submitted under 10 CFR 50.54(p). The staff concludes that the plan meets the requirements of 10 CFR 73.67(f) as it relates to the fixed-site protection of special nuclear material of low strategic significance. The NCSU inventory of special nuclear material for reactor operation falls within that category.

The NCSU PULSTAR Physical Security Plan is withheld from public disclosure under 10 CFR 2.790(d)(1). The amendment renewing Facility Operating License R-120 incorporates the physical security plan as a condition of the license.

12.7 Conclusion

On the basis of the above discussions, the staff concludes that the licensee has sufficient experience, management structure, and procedures to provide reasonable assurance that the NCSU PULSTAR reactor will continue to be managed in a way that will not cause any significant radiological risk to the health and safety of the public.

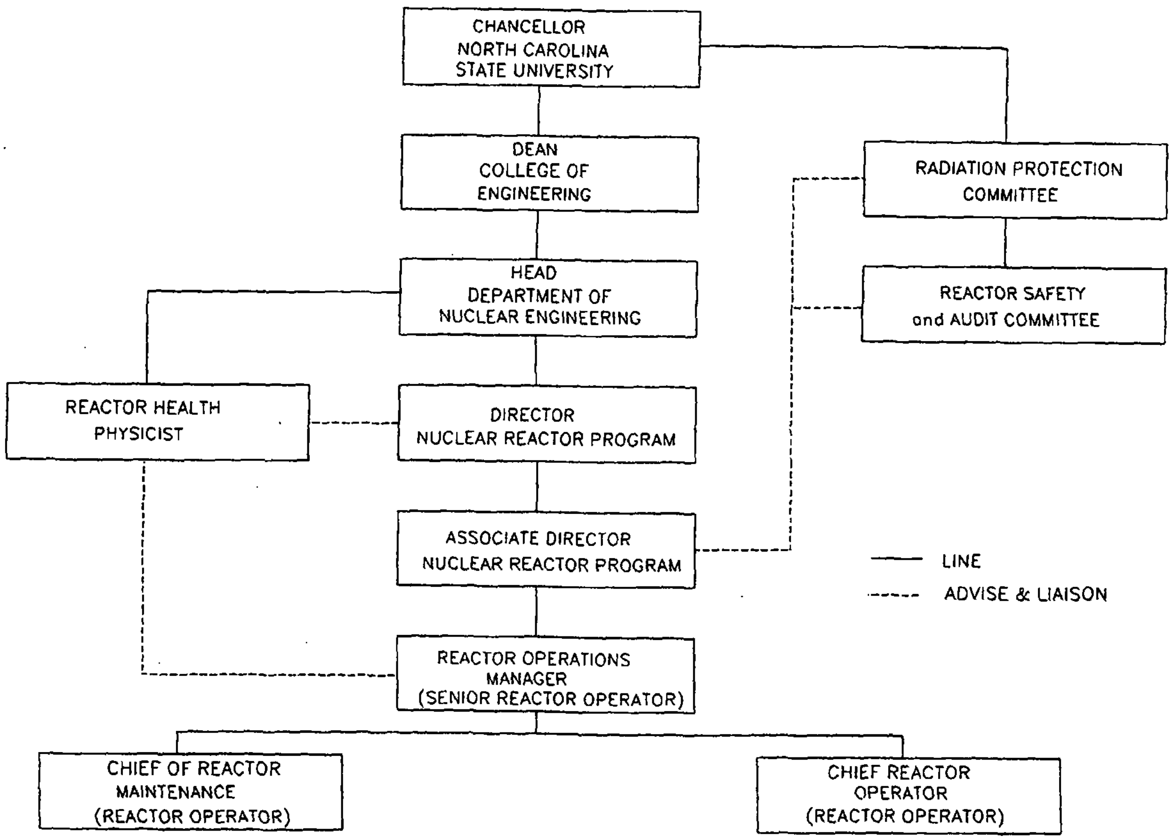


Figure 12.1 NCSU PULSTAR reactor organizational chart

13 ACCIDENT ANALYSIS

To help establish safety limits, LSSSs and limiting conditions for operation (LCOs) of the NCSU PULSTAR reactor, the licensee analyzed potential reactor transients and other hypothetical accidents. Specifically, the licensee analyzed the potential effects of such events on the reactor fuel and the health and safety of the public. The staff then evaluated the licensee's analytical assumptions, methods, and results, and added some considerations of its own, as discussed below.

None of the credible accidents postulated would lead to the failure of the cladding of any fuel pins or the uncontrolled release of fission products. However, the licensee postulated an enveloping event involving the rupture of the cladding of three fuel pins. This event would lead to the maximum potential radiation hazard to personnel. The licensee assumed that some type of mechanical damage occurred that impacted a fuel assembly on its side, thereby causing the failure of the three fuel pins. The licensee evaluated only the potential consequences of this event (not the likelihood or mechanisms of the event's occurrence). The staff has designated this event to be the maximum hypothetical accident. In addition, because the initiation and planned operation of the confinement system is relied on to mitigate the consequences, this event may also be considered to be a design-basis accident. The licensee and the staff also considered the following types of potential accidents:

- loss of coolant flow
- loss of coolant
- waterlogging of a fuel pin
- fuel loading accident
- startup accident
- cold primary coolant slug
- experiment failure

13.1 Fuel Pin Clad Failure

The licensee postulated that the integrity of the cladding of three fuel pins was suddenly lost after a long sustained operation at 1 MW. Therefore, the shorter-lived fission products would be at radioactive equilibrium at the time of failure. The licensee further assumed that the core had operated to the maximum authorized burnup, namely 20,000 Megawatt-days per metric-ton uranium (MWD/MTU), which corresponds to 6320 MW-days of operation. In addition, the licensee made the following assumptions:

- The reactor was operating normally at 1 MW at the time of cladding failure, and coolant flow continued so that no fuel pellets melted.

- Only the fission products in the gap between the cladding and the fuel pellets were released, and the coolant flow carried all of them into the delay tank, piping, heat exchanger, and pump, with some of them reentering the reactor pool.

- During the transit of the primary cooling system, all of the normally solid fission products were trapped in the coolant system; 3 percent of the halogens and 100 percent of the noble gases survived to enter the reactor room air above the pool surface.

- When these radioactive materials became airborne, they rapidly diffused and caused radiation detectors to alarm, initiating the confinement mode of ventilation system operation and causing the operator to scram the reactor.

- The confinement-mode HEPA filters have a removal efficiency of 99.97 percent, and the activated charcoal filter has a removal efficiency of 99 percent. These filters would reduce the concentration of halogens by another factor of about 100 as the room air was released from the exhaust stack to the unrestricted environment. The licensee assumed that the additional dilution of reactor room air (about a factor of 20) that would occur because of air exhausted up the stack from the south wing of the Burlington Engineering Laboratory did not occur. This is a conservative assumption.

- With the confinement blowers and filter system functioning, the system would require about 2.4 hours to effect a complete turnover of the reactor bay air. The licensee conservatively assumed that all of the radioactive material was continuously released during this time, with no decrease in source strength resulting from radioactive decay and no gradual dilution from inflow of air.

The licensee performed calculations of potential doses to facility staff, assuming that they remained in the reactor bay for the entire 2.4 hours, and to members of the public who remained at locations of interest in the unrestricted area for the entire 2.4 hours. The locations of interest in the unrestricted area are the location of the individual receiving the greatest exposure at about 160 ft (50 m) from the stack, the nearest permanent residence at about 650 ft (200 m) from the stack, the nearest on-campus residence hall (Carroll Hall at 850 ft (260 m)) because of its high occupancy rate and the fact that it has floors as high as the reactor stack, and the Hill Library (at 460 ft (140 m)) because it is near the reactor and its upper floors are at least as high as the reactor exhaust stack.

The licensee calculated the potential doses from the noble gases krypton and xenon using assumptions and methods similar to those employed in Chapter 11 for analyzing doses associated with argon-41. For example, the licensee assumed that doses from radioactive noble gases result from whole body gamma ray exposures caused by submersion in the contaminated air, as well as gamma ray shine from the elevated plume. For the postulated accident, the licensee assumed the short-term atmospheric conditions giving the highest doses, instead of averaging over a year, as was done for the argon calculations. For the halogens, inhalation and accumulated body burden are expected to be the principal exposure modes, so the licensee employed applicable methods of estimating potential dose commitments.

The staff reviewed the assumptions proposed by the licensee and considers them to be acceptably realistic and conservative. Because the postulated accident could lead to consequences to the public, the staff reviewed and evaluated the analytical methods of the licensee in detail, and also made independent calculations of the scenario and the consequences. The NCSU results are acceptably consistent with the doses calculated by the staff, and the staff concludes that the licensee has sufficient understanding and techniques to analyze such events.

Table 13.1 summarizes the results of the licensee's calculations for the unrestricted area. The accident scenario assumes a diffusing plume as it moves downwind essentially at the height of the stack. Assuming that plume moves towards the Hill Library building 460 ft (140 m) from the stack, the highest concentration of iodine in the unrestricted area would be at the upper floors of the library at the elevation of the plume axis. Thus, Table 13.1 shows the potential dose commitment estimated at that point. The concentration of iodine at the nearest dormitory, Carroll Hall, at 850 ft (260 m) also shows the effect of having the exposed individual elevated to the level of the stack. If there were no nearby tall buildings, the maximum iodine inhalation dose would be beyond the point where the expanding plume first reaches the ground at a distance of about 820 ft (250 m). However, at that point on the ground, approximately where the nearest permanent residence is, the iodine concentration would be orders of magnitude lower than on the plume axis. Therefore, thyroid dose commitments would be reduced.

As for the argon-41, the individual receiving the greatest exposure on the ground in the unrestricted area would be not far from the exhaust stack, where the principal dose would result from gamma rays shining down from the plume about 100 ft (30 m) above. Other points analyzed in the unrestricted area show the effect of dispersion of the plume with increased distance.

In the restricted area (reactor bay), Table 13.2 shows that the principal dose commitment would be caused by inhalation of the iodine isotopes. The whole-body doses associated with the finite-sized room full of air contaminated with gamma emitting noble gases and halogens are orders of magnitude less. The licensee calculated the doses in the restricted area using several different methods. The results given in Table 13.2 uses the method that gives the largest doses. The licensee has made the very conservative assumption that the reactor staff remains in the reactor bay for 2.4 hours instead of evacuating in accordance with the facility Emergency Plan. Any decrease in exposure time below the assumed 2.4 hours could decrease all doses proportionately.

The calculational methods employed by the licensee and by the staff both include some simplifying conservative assumptions. In general the agreement between licensee and staff calculations was acceptable. The licensee also analyzed for doses from bromine isotopes, but the results are not included in Table 13.1 and 13.2 because the results were not significant compared to the radionuclides listed.

In neither the restricted nor unrestricted areas would the projected doses from the postulated maximum hypothetical accident exceed 10 CFR Part 20 limits in effect at the time of initial licensing in 1972 (10 CFR 20.1 through 20.602 and Appendixes) established for routine operations. The doses also meet the 10 CFR Part 20 limits in effect as of the date of this SER (10 CFR 20.1201 through 20.1302 and Appendixes). The staff concludes the projected doses are acceptable for this very unlikely event, and that the licensee has the capability to analyze the consequences of a radioactivity release event if one should occur.

13.2 Failure of Fueled Experiment

The licensee analyzed the postulated failure of a fueled experiment in the reactor. Fueled experiments are rarely conducted in the reactor. The licensee used the fission product releases from the failure of three fuel pins analyzed above to set limits on the conduct of fueled experiments. The licensee established limits on the maximum mass of uranium an experiment can contain, the maximum fission rate in the experiment, and the total exposure of the experiment. The limits on these parameters were chosen so that failure of a fueled experiment would results in doses in the restricted and unrestricted areas less than those calculated for the maximum hypothetical accident. These limits on the conduct of fueled experiments are TS limits. As an additional conservatism, the licensee has a TS that requires the ventilation system to be operated in the confinement mode during the conduct of fueled experiments. The staff concludes that the failure of a fueled experiment would result in doses that are within those calculated for the maximum hypothetical accident and are therefore, acceptable.

13.3 Loss of Coolant

The licensee analyzed the postulated loss of all coolant from the primary system. This is a credible event because there are several penetrations through the pool liner. But because the primary system is open to the reactor room atmosphere, it operates at low pressure, and rapid loss of water is very unlikely. The accident scenario assumes a core of 25 fuel elements operating at 1 MW for sufficient time that most fission product concentrations had reached equilibrium. The analysis submitted by the licensee was predicated on experiments performed with a research reactor at the Lawrence Livermore Laboratory. The Livermore Pool Type Reactor, consisting of a MTR plate-type core, was operated at 1 MW. Shutdown was caused by intentional rapid release of pool water, and fuel plate temperatures were measured. The only cooling was natural convection of the ambient air in the open tank. The maximum plate temperature was reached approximately one hour after the core was uncovered, but the aluminum cladding did not lose integrity. NCSU made acceptable adjustments in the cooling parameters to account for the differences between the MTR and PULSTAR fuel geometries and materials. The predicted maximum fuel temperature of the PULSTAR was 765 °F (407 °C), which is well below the melting temperature of zircaloy of about 3300 °F (1815 °C) and the melting temperature of uranium-dioxide of approximately 5000 °F (2760 °C).

The licensee also calculated in a strict theoretical fashion the consequences of a loss of coolant accident. Not all of the structural details of the core were reproduced by the calculation, nor were actual maximum temperatures computed. However, a likely maximum fuel temperature following a loss of coolant after a 48 hour run at 1 MW was computed to be approximately 1040 °F (560 °C) and after 12960 hours of continuous operation, 1270 °F (688 °C). Both results are well below the softening temperature of zircaloy and the melting temperature of uranium-dioxide. Considering the differences in assumptions between the comparison with the Livermore Pool Type Reactor and the calculated conditions, this is deemed to be reasonable agreement, giving a likely maximum fuel temperature well below the zircaloy softening temperature.

The licensee also analyzed the potential exposure rates associated with both direct and scattered gamma rays from the uncovered core. The predicted exposure rate at the top of the pool near the control room is approximately 250 mrem/hr, and on the reactor room floor is approximately 175 mrem/hr about 10 minutes after reactor shutdown. Dose rates outside the reactor building against the reactor bay walls are predicted to be about 4 mrem/hr. The licensee has developed plans for remedial action in the event of a loss of coolant.

The staff has reviewed the NCSU analyses of a loss of coolant accident, and considers the methods, results, and interpretations to be applicable and acceptable. On the basis of these considerations, the staff concludes that even an instantaneous loss of coolant at the NCSU PULSTAR reactor would not lead to fuel temperatures that would cause loss of integrity of the cladding. Direct radiation exposure of personnel has been adequately considered by the licensee and there is reasonable assurance that the health and safety of the public would not be endangered by such an event.

13.4 Loss of Coolant Flow

In the event that the forced convection coolant flow stops while the reactor is operating (e.g., from loss of normal electrical power), the low-flow condition would cause the reactor to scram, and gravity would open the flapper valve on the plenum below the core, allowing natural convection cooling of the fuel. Within 2 sec after the onset of loss of flow the scram signal is initiated, and flow continues to decrease until the flapper valve automatically opens at approximately zero flow, within a few more seconds.

The licensee analyzed the loss-of-flow accident assuming that the flow dropped to zero instantaneously, but that the flapper valve did not open, so convection cooling of the fuel did not occur. Additional assumptions included:

- 1 MW steady-state operation,
- continued operation for 20 seconds after the flow rate has dropped to zero,
- the film coefficient for heat transfer from fuel clad to coolant dropped to a conservatively low value and remained at that value throughout the event,
- the temperature coefficients of reactivity did not contribute further to the negative reactivity of the core following the scram, and
- the reactor scram is accomplished with the safety rod of maximum worth remaining in its fully withdrawn position.

The maximum temperature reached by the clad hot spot in the core was calculated to be approximately 380 °F (193 °C) and the peak fuel centerline temperature is approximately 1240 °F (671 °C). This is well below the melting point of the zircaloy cladding of about 3300 °F (1815 °C) and the melting temperature of uranium-dioxide of approximately 5000 °F (2760 °C). The staff has reviewed the methods and assumptions of the NCSU analysis, and concludes that they are applicable and conservative, and would result in calculated temperatures in excess of those reasonably expected as a consequence of any loss of coolant flow event. Therefore, the staff further concludes that there is reasonable assurance that such an event would not lead to loss of integrity of fuel or release of fission products.

13.5 Waterlogging

Waterlogging is a term often used to refer to an event in which water can leak through a small hole into the space between the fuel pellets and the fuel cladding. A subsequent rapid increase in temperature of the fuel (such as that occurring during pulsing) can cause transient high steam pressure which could result in cladding failure. This event is considered here because pulsing tests of PULSTAR fuel at SUNYAB were accompanied by one waterlogging event in test fuel in 1971. No waterlogging event has occurred with any standard PULSTAR fuel since. Because NCSU is removing pulsing authorization and capability at the time of this license renewal, the staff considers that the only time a waterlogging fuel-pin failure could occur would be if an inadvertent transient and an independent fuel clad leak were to occur simultaneously. Not only is the likelihood of this event very small, but because this event would lead to the failure of one fuel pin, any radiological consequences would be within the envelope of the three pin failure considered in fuel pin clad failure scenario in Section 13.1. Therefore, the staff concludes that the results of a waterlogging accident is within the constraints of the fuel pin clad failure accident and is acceptable.

13.6 Fuel Loading Accident

Written procedures and policies at NCSU would preclude attempts at handling fuel above the core while it is critical. However, because it is physically possible, the licensee and the staff have considered an accident scenario starting with the following initial conditions. The postulated accident occurs when the extra fuel assembly falls from the handling tool and enters a vacant position that adds the maximum reactivity available for a fuel assembly in a critical core. The rapid insertion of the fuel assembly causes a rapid insertion of excess reactivity, and a resultant power excursion. The PULSTAR reactor was developed to obtain a safe pulsing reactor neutron source, so it is only necessary to determine if the expected inadvertent transient would be within analyzed or tested limits. The licensee has found by measurement that the maximum worth of a fuel assembly in the present core is 1130 pcm (1.13% $\Delta k/k$). It is estimated that the present 25 assembly core can withstand a reactivity insertion of 1600 pcm (1.60% $\Delta k/k$) without fuel pin failure occurring. The TSs contain a value of 1590 pcm (1.59% $\Delta k/k$) as a limit on the worth of a single fuel element. Extensive pulsing tests at SUNYAB have demonstrated that insertions of up to 1450 pcm (1.45% $\Delta k/k$) can be safely accommodated by an even smaller reactor core than that at NCSU. Therefore, the licensee concludes that the postulated fuel-handling event does not jeopardize the integrity of the fuel or the radiological safety of operating personnel or the public. The staff has reviewed the methods and considerations used in the analysis, and concurs that transients caused by such fuel handling would cause no significant radiological risk to the operating staff or to the public.

13.7 Startup Accident

In this postulated accident, the licensee has assumed that all three shim/safety rods are withdrawn continuously and simultaneously in gang mode from below critical so that the reactor power level increases on a ramp excursion until the high-power level scram terminates the event at 1.2 MW. Assuming that the rate of increase of reactivity corresponds to the maximum possible rate in the most effective region of the shim rods, the licensee computed a minimum period for power increase of 29 milliseconds. Using measured values for circuit response times and safety rod scram times, the licensee calculates a peak power of less than 120 MW, with a total energy release of less than 17 MW-sec. The reactor was previously authorized to be operated in pulsed mode with pulses up to 38 MW-sec, so this start-up excursion would not cause unreviewed or unacceptable radiological conditions. Furthermore, the licensee did not rely on the high count rate control rod withdrawal inhibit in the startup channel, the control rod reverse at the 1.1 MW power level or the known strong negative Doppler coefficient of reactivity of the PULSTAR fuel to help mitigate the effects of the reactivity insertion, so the calculated energy release is larger than that realistically expected. The staff has reviewed the assumptions and methods used in the analysis, and concurs that they are applicable and conservative. Therefore, the staff concludes there is reasonable assurance that a start-up accident, as postulated, would not lead to reactor operation outside of limits previously evaluated and found to be acceptable.

13.8 Cold Primary Coolant Slug

The licensee postulated two events in which a sudden initiation of cold water flow could occur while the reactor is just critical. The first event assumed the reactor was operating in a steady-power mode at 150 kW with natural convection cooling and the flapper open.

On the basis of start-up tests, it is estimated that the temperature change of the coolant as it passes through the core is 27 °F (15 °C). It is assumed that the pump is operating and the flapper suddenly closes, converting the reactor from natural convection to forced convection cooling and sending a slug of cold water through the core, decreasing the temperature 27 °F (15 °C). The change in core temperature would increase reactivity about 105 pcm (0.1% $\Delta k/k$), starting the reactor on a 60 second positive period. In the absence of operator response, and failure of the natural convection power level scram, the temperature coefficient would cause the reactor power level to stabilize at about 320 kW. Because full normal coolant flow would continue, the reactor is in an acceptable condition.

The second cold primary coolant slug event postulated by the licensee assumed the reactor to be operating at 1 MW steady power in the forced flow mode. The flapper is assumed to be closed and the pump operating normally. The licensee assumes that a cold slug of coolant flows through the core, lowering its temperature suddenly, inserting excess reactivity corresponding to the same 27 °F (15 °C) assumed above. The 60 second period would raise the reactor power to 1.2 MW, at which point the power level safety channel would initiate a reactor scram and safe shutdown. The mechanism for causing the cold slug is not specified, but it is plausible that short-term malfunction of the secondary coolant system could possibly lead to it. The staff concludes that neither of these cold slug events could lead to operation of the reactor outside of analyzed safe limits.

13.9 Experiment Failure

The licensee postulated an accident scenario in which an experiment involving negative reactivity fails, is suddenly removed from the core region, and thereby causes a positive excess reactivity insertion equal to the maximum amount allowed by TSs for a non-secured experiment, namely 1000 pcm (1% $\Delta k/k$). This amount of reactivity insertion would be less than the amount postulated and analyzed in Section 13.6 and found acceptable. The staff has determined that this type of analysis is also valid for the maximum amount of 1600 pcm (1.60% $\Delta k/k$) allowed by TSs for a secured experiment. Therefore, the staff concludes that this mode of experiment failure would cause no damage to the reactor or its systems.

13.10 Conclusions

The staff concludes that the licensee has postulated and analyzed sufficient accident initiating events and scenarios to demonstrate that the reactor is designed acceptably to avoid inadvertent reactor damage that could prevent safe shutdown, so there is reasonable assurance that no credible accident would cause significant or undue radiological risk to the facility staff, the environment, or the public.

Table 13.1

Doses Resulting from the Postulated Fuel Cladding Failure Accident
in the Unrestricted Environment

Location	Fission Gas Doses (mrem)	
	Whole-Body	Thyroid
Maximum Ground Location 160 ft (50 m) from stack	0.005	0.0004
Nearest Permanent Residence 650 ft (200 m) from stack	0.002	$4(10^{-11})$
Carroll Hall Dormitory 850 ft (260 m) from stack at elevated location	0.008	0.01
D. H. Hill Library 460 ft (140 m) from stack at elevated location	0.02	0.03

Table 13.2

Doses Resulting from the Postulated Fuel Cladding Failure Accident
in the Restricted Environment (Reactor Bay)

Dose Type	Calculated Value (mrem)
Total Effective Dose Equivalent (TEDE)	50
Total Organ Dose Equivalent (TODE)	2000

14 TECHNICAL SPECIFICATIONS

In the course of this licensing action, the staff reviewed and evaluated the TSs submitted by the licensee. These TSs define certain features, characteristics, and conditions governing the operation of the NCSU PULSTAR research reactor facility and are explicitly included in the renewal license as Appendix A. In addition, the staff reviewed the format and content of the TSs using guidance from ANSI/ANS 15.1-1990, "The Development of Technical Specifications for Research Reactors."

On the basis of its review, the staff finds the NCSU TSs to be acceptable and concludes that normal plant operation within the limits of the TSs will not result in offsite radiation exposures in excess of 10 CFR Part 20 limits. Furthermore, the limiting conditions for operation and surveillance requirements will limit the likelihood of malfunctions and mitigate the consequences to the public in regard to accident events.

15 FINANCIAL QUALIFICATIONS

The NCSU PULSTAR reactor facility is owned and operated by a state educational institute in support of its role in education and research.

The staff reviewed the financial status of the licensee and concludes that the necessary funds will be made available to support continued operations and, when necessary, to shut down the facility and carry out decommissioning activities. The licensee's financial status is in accordance with the requirements of 10 CFR 50.33(f). Therefore, the staff concludes that NCSU's financial qualifications are acceptable for continued operation of the PULSTAR research reactor facility.

16 OTHER LICENSE CONSIDERATIONS

In this section of the SER, the staff discusses other license considerations not found in other chapters. In the case of the NCSU PULSTAR reactor review, the only issue discussed in this section is prior utilization of the reactor.

16.1 Prior Reactor Utilization

As documented in previous sections of this SER, the staff concludes that normal operation of the NCSU PULSTAR reactor causes insignificant risk of radiation exposure to the public. The maximum hypothetical accident would result in potential radiation exposures within applicable guideline values of 10 CFR Part 20.

The staff concludes that the reactor was initially designed and constructed to operate safely. During the review for license renewal, the staff considered whether prior operation would cause significant degradation in the capability of components and systems to continue to perform their safety functions. Because fuel cladding is the component most responsible for preventing release of fission products to the environment, the staff considered mechanisms that could possibly lead to detrimental changes in cladding integrity. Prominent among these considerations were (1) radiation degradation of cladding integrity, (2) high fuel temperature or temperature cycling leading to changes in the mechanical properties of the cladding, (3) corrosion or erosion of the cladding leading to thinning or other weakening, (4) mechanical damage resulting from handling or experimental use, and (5) degradation of safety components or systems.

The staff reached the following findings regarding these parameters (in the order in which the parameters were identified above):

(1) Nearly identical fuel has been exposed, in similar irradiations, to higher total radiation doses in the reactor at SUNYAB. No significant degradation of cladding or fuel has resulted in any of these exposures.

(2) The power density and maximum temperatures reached in the NCSU PULSTAR fuel are below similar parameters in the SUNYAB PULSTAR reactor and in power reactors using similar fuel. The performance of the fuel in these reactors has been acceptable.

(3) The coolant flow rate at the NCSU PULSTAR reactor is lower than that used at the SUNYAB PULSTAR reactor and at commercial power reactors using zircaloy-clad uranium-dioxide fuel. No significant erosion problems have been observed. At NCSU, corrosion is kept to a reasonable minimum by carefully controlling the conductivity and pH of the primary coolant water.

(4) The fuel is handled as infrequently as possible, consistent with required surveillance and experimental program requirements. Any indications of possible damage or degradation are promptly investigated, and damaged fuel will be removed from service. All

experiments placed in or near the core are isolated from the fuel cladding by a water gap and at least one encapsulation barrier.

(5) The NCSU PULSTAR reactor staff performs regular preventive and corrective maintenance and replaces components as necessary. Nevertheless, some equipment malfunctions have occurred. The staff's review, however, indicates that most of these malfunctions have been one-of-a-kind incidents, typical of even good-quality electromechanical instrumentation. There is no indication of significant degradation of the instrumentation, and there is strong evidence that any future degradation will be met with prompt remedial action by the NCSU PULSTAR reactor staff. Therefore, there is reasonable assurance that there will be no significant increase in the likelihood of occurrence of a reactor accident as a result of component malfunction during continued operation under the renewed license.

16.2 Conclusion

In addition to the considerations discussed above, the staff reviewed licensee event reports and inspection reports and informal comments prepared by NRC Region II. On the basis of this review and the above considerations, the staff concludes that there has been no significant degradation of equipment and that facility management will continue to maintain and operate the reactor so that there is no significant increase in the radiological risk to facility employees or the public.

17 CONCLUSIONS

On the basis of its evaluation of the application as set forth in the previous sections, the staff has reached the following conclusions:

- The application filed by NCSU for renewal of Operating License R-120 for the PULSTAR research reactor complies with the requirements of the Atomic Energy Act of 1954, as amended (the Act), as well as the Commission's regulations set forth in 10 CFR Chapter I.

- The facility will operate in conformity with the application (as amended), as well as the provisions of the Act and the rules and regulations of the Commission.

- There is reasonable assurance that (a) the activities authorized by the operating license can be conducted without endangering the health and safety of the public, and (b) such activities will be conducted in compliance with the Commission's regulations as set forth in 10 CFR Chapter I.

- The licensee is technically and financially qualified to engage in the activities authorized by the license in accordance with the Commission's regulations as set forth in 10 CFR Chapter I.

- The renewal of this license will not be inimical to the common defense and security or to the health and safety of the public.

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11. ABSTRACT *(200 words or less)*

This safety evaluation report (SER) summarizes the findings of a safety review conducted by the staff of the U.S. Nuclear Regulatory Commission (NRC), Office of Nuclear Reactor Regulation (NRR). The staff conducted this review in response to a timely application filed by North Carolina State University (the licensee or NCSU) for a 20-year renewal of Facility Operating License R-120 to continue to operate the NCSU PULSTAR research reactor. The facility is located in the Burlington Engineering Laboratory complex on the NCSU campus in Raleigh, North Carolina. In its safety review, the staff considered information submitted by the licensee (including past operating history recorded in the licensee's annual reports to the NRC), as well as inspection reports prepared by NRC Region II personnel and first-hand observations. On the basis of this review, the staff concludes that NCSU can continue to operate the PULSTAR research reactor, in accordance with its application, without endangering the health and safety of the public.

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