NUREG-1138

Safety Evaluation Report
related to the renewal of the operating license for the training and research reactor at the University of Michigan

Docket No. 50-2

U.S. Nuclear Regulatory Commission

Office of Nuclear Reactor Regulation

July 1985

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ABSTRACT

This Safety Evaluation Report for the application filed by the University of Michigan (UM) for renewal of the Ford Nuclear Reactor (FNR) operating license number R-28 to continue to operate its research reactor has been prepared by the Office of Nuclear Reactor Regulation of the U.S. Nuclear Regulatory Commission. The facility is located on the North Campus of the University of Michigan in Ann Arbor, Michigan. The staff concludes that the reactor can continue to be operated by the University of Michigan without endangering the health and safety of the public.

TABLE OF CONTENTS

TABLE OF CONTENTS (Continued)

TABLE OF CONTENTS (Continued)

TABLE OF CONTENTS (Continued)

1 INTRODUCTION

By letter dated November 30, 1984 as supplemented, the University of Michigan (licensee/UM) submitted an application to the U.S. Nuclear Regulatory Commission (NRC/staff) for renewal of its Class 104c operating license R-28 for a period of 20 years. The reactor facility is located on the North Campus of the University of Michigan in Ann Arbor. The renewal application is supported by information provided in the Safety Analysis Report, Environmental Report, and the Technical Specifications, dated November 1984, and by a site visit and responses to questions. The UM reactor facility currently is permitted to operate within the conditions authorized in past license amendments in accordance with Title 10 of the Code of Federal Regulations (10 CFR), Paragraph 2.109, until NRC action on the renewal report is completed.

The University of Michigan's Ford Nuclear Reactor (FNR), is a heterogeneous 2-MWt reactor that is light-water cooled and moderated. The core can be surrounded by aluminum-clad graphite elements for additional neutron reflectance. A tank of heavy water is located directly behind the reactor core to provide thermal neutrons for the beam ports. The principal function of the FNR is for teaching, research, activation, and experiments.

The renewal application contains information regarding the original design of the facility and modifications to the facility that have been made since initial licensing. The Physical Security Plan, previously approved October 17, 1983, is protected from public disclosure under 10 CFR 73.21 and 10 CFR 9.5(a) (4).

The purpose of this Safety Evaluation Report (SER) is to summarize the results of the safety review of the FNR and to delineate the scope of the technical details considered in evaluating the radiological safety aspects of continued operation. This SER will serve as the basis for renewal of the license for continued operation of the FNR facility at thermal power levels up to and including 2 MW. The facility was reviewed against the requirements of 10 CFR 20, 30, 50, 51, 55, 70, and 73; applicable regulatory guides (RGs) (Division 2, Research and Test Reactors); and appropriate accepted industry standards (American National Standards Institute/American Nuclear Society (ANSI/ANS) 15 Series). Because there are no accident-related regulations for nonpower reactors, the staff has compared calculated dose values with related standards in 10 CFR 20, Standards for Protection Against Radiation, both for employees and the public.

The staff safety review with respect to issuing a renewal operating license for the FNR has been based on the information contained in the renewal application and supporting supplements, generic studies performed by national laboratories, site visits, and responses to requests for additional information. This material is available for review at the Commission's Public Document Room at 1717 H Street, N.W., Washington, D.C. 20555. This Safety Evaluation Report (SER) was prepared by Harold Bernard, Project Manager, Division of Licensing, Office of Nuclear Reactor Regulation, Nuclear Regulatory Commission. Major contributors to the technical review include the project manager and C. A. Linder, A. E. Sanchez-Pope, and C. L. Faust of the Los Alamos National Laboratory under contract to NRC.

1.1 Summary and Conclusions of Principal Safety Considerations

The staff evaluation considered the information submitted to the Commission by the licensee, past operating history recorded in annual reports submitted by the licensee, reports by the Commission's Office of Inspection and Enforcement, and onsite observations. The principal safety matters reviewed for the FNR and the conclusions reached follow.

(1) The design and performance of the reactor structures, systems, and components important to safety during normal operation are inherently safe, and safe operation can reasonably be expected to continue.

(2) The expected consequences of a broad spectrum of postulated credible accidents have been considered, emphasizing those likely to cause loss of integrity of fuel element cladding. The staff performed conservative analyses of the most serious credible accidents and determined that the calculated potential radiation doses outside of the reactor building would not exceed 10 CFR 20 guideline levels for unrestricted areas.

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

(4) The systems provided for the control of radiological effluents can be operated to ensure that releases of radioactive wastes from the facility are within the limits of 10 CFR 20 guidelines and are as low as is reasonably achievable (ALARA).

(5) The licensee's Technical Specifications, which provide limiting conditions for the operation of the facility, are such that there is a high degree of assurance that the facility will be operated safely and reliably.

(6) The FNR facility is funded within the annual budget of the University of Michigan and the State of Michigan. The staff concludes that sufficient funds will be available for the safe operation of the reactor facility and eventually to decommission the reactor facility.

(7) The licensee's program for providing for the physical protection of the facility was submitted separately. The staff concluded that the FNR Physical Security Plan, which was approved by license amendment 28 of October 17, 1983, complies with the requirements in 10 CFR 73.

(8) The licensee's procedures for training its reactor operators and the plan for operator requalification are adequate; they give reasonable assurance that the reactor facility will be operated competently.

(9) The licensee submitted an Emergency Plan separately by letter and report dated November 2, 1982, that is in compliance with the existing applicable regulations. The FNR Emergency Plan was approved by NRC April 28, 1983.

1.2 History

The University of Michigan obtained a permit in February 1955 for construction of a 1-MWt open-pool research reactor. The reactor achieved criticality in

September 1957. In 1963 an amendment was issued to allow the FNR to increase the power to 2 MWt. The reactor has since been operated at that level.

1.3 Reactor Facility Description

The FNR heterogeneous core consists of aluminum and uranium enriched to less than 20% of ^{235}U. It is suspended 20 ft beneath the surface of a 50,000-gal pool of demineralized water from a movable bridge which is mounted on rails that lie on top of a concrete pool tank. The reactor pool is 21 ft long by 9 ft wide by 27 ft deep.

The reactor operates at a licensed power level up to and including 2 MWt and produces a peak thermal flux of approximately 5×10^{13} n/cm²/s. A typical core configuration consists of 35 to 40, 19.5% enriched, Materials Testing Reactor (MTR) plate-type fuel elements. Standard elements contain 167 grams of ^{235}U in 18 aluminum-clad fuel plates. Control elements, which have control rod guide channels, have nine plates and contain 84 grams of ^{235}U. Overall fuel element dimensions are approximately 3 in. by 3 in. by 26 in.

A heavy water tank, located directly behind the reactor core, provides a thermal neutron flux for beam ports. The core also can be surrounded by aluminum-clad graphite reflector elements which serve as neutron reflectors. Control of the reactor is achieved through the use of three safety control rods and one regulating rod. Cooling below 100 kW is by natural convection. At power levels above 100 kW, forced cooling is required with the heat dissipated in a heat exchanger and a cooling tower.

The reactor is located in a windowless, four-story reinforced concrete building that is approximately a 70-ft cube. The reactor room, designed to restrict leakage, is equipped with its own ventilation system and exhaust stack.

1.4 Design and Facility Modifications

The principal recent design modification was the replacement in 1982 of the high enriched fuel with fuel that is enriched to 19.5% ^{235}U.

1.5 Operation

The FNR operates on a continuous 14-day cycle consisting of 10 days at full power followed by 4 days of shutdown for fuel changing, fuel movement, and maintenance. In a typical year the reactor is operational for 6000 hours while operating at 1-to-2 MWt level for 5000 hours, which results in an average annual energy output of ~9000-MW hours or 375-MW days.

1.6 Shared Facilities and Operation

The building is exclusively used for activities related to the reactor, its various operations, and related education and training programs.

1.7 Comparison With Similar Facilities

The fuel used in the FNR is based on the MTR design and is very similar to the fuel used in approximately 50 other research reactors operating in the United States and at least 25 reactors operating in foreign countries. However, whereas

the fuel in the other MTR-type reactors is enriched to more than 90% ^{235}U (high-enriched uranium fuel), the fuel in the FNR core was replaced with a low-enriched uranium (LEU) fuel, containing 19.5% ^{235}U. This fuel has been in the FNR core since 1982, and since the core has been 100% LEU (October 1984), there has been approximately 4500 MW hours of burnup. Reports from the FNR facility indicate that the nuclear and thermal characteristics are similar to those previously reported when HEU fuel was used. The control and instrumentation systems, while different in detail, are based on the same operating principles used for other research or test reactors.

1.8 Nuclear Waste Policy Act of 1982

Section 302(b)(1)(B) of the Nuclear Waste Policy Act of 1982 provides that the NRC may require, as a precondition to issuing or renewing an operating license for a research or test reactor, that the licensee shall have entered into an agreement with the Department of Energy (DOE) for the disposal of high-level radioactive waste and spent nuclear fuel. DOE has informed the NRC by letter dated May 3, 1983 (R. L. Morgan, DOE, to H. R. Denton, NRC), that it has determined that universities and other government agencies operating nonpower reactors have entered into contracts with DOE that provide that DOE retain title to the fuel and be obligated to take the spent fuel and/or high-level waste for storage or reprocessing. Because the University of Michigan has entered into such a contract with DOE, the applicable requirements of the Nuclear Waste Policy Act of 1982 have been satisfied.

2 SITE CHARACTERISTICS

2.1 Site Description

The city of Ann Arbor lies almost 25 mi due west of the city of Detroit. The FNR site is situated on the newly developed North Campus which is about 1-3/4 mi northeast of the old University of Michigan campus.

2.2 Geography

The North Campus is a tract of nearly 900 acres, approximately 1.5 mi northeast of the center of Ann Arbor. It is bounded on the north by Plymouth Road and on the south partly by Glacier Way and partly by submarginal land. Open land and the Arborcrest Cemetery lie to the east and the Veterans' Hospital and city parks lie to the south. To the west are additional parks and a wooded ridge. The Huron River flows through the land bordering the area on the west and south and some marsh land lies adjacent to the river on the south.

The University of Michigan controls all the land within 1500 ft of the reactor site, with the exception of a small portion of the highway right-of-way along Glacier Way to the southeast and the Arborcrest Cemetery, located 800 ft to the east of the site.

The reactor exclusion area consists of all the land 500 ft to the east, 1000 ft to the west and north, and 1200 ft to the south. This boundary description is the location of roadways around the site where traffic flow into the site can be controlled by university personnel, should such control be desirable.

2.3 Topography

The terrain in the Ann Arbor area is gently rolling, with elevations varying from about 800 to 1000 ft above mean sea level. One of the most prominent topographic features of the area is the Huron River valley. The river flows from west-northwest to east-southeast. The city lies on its southern bank and stretches about 1-1/2 mi to the south-southwest. The sides of the valley rise about 150 ft above the level of the river.

2.4 Demography

The reactor building and the contiguous Phoenix Memorial Laboratory (PML) are located near the center of the North Campus area. The following guidelines were used by the university in developing the North Campus area: (1) only laboratory and research buildings will be constructed within 50 ft of the reactor and (2) no housing or other buildings containing housing facilities will be erected within 1500 ft of the reactor (see Figure 2.1). Therefore, all buildings, except the reactor and laboratory buildings, are generally occupied during normal school hours only. The closest permanent residences are about 1500 ft from the FNR facility.

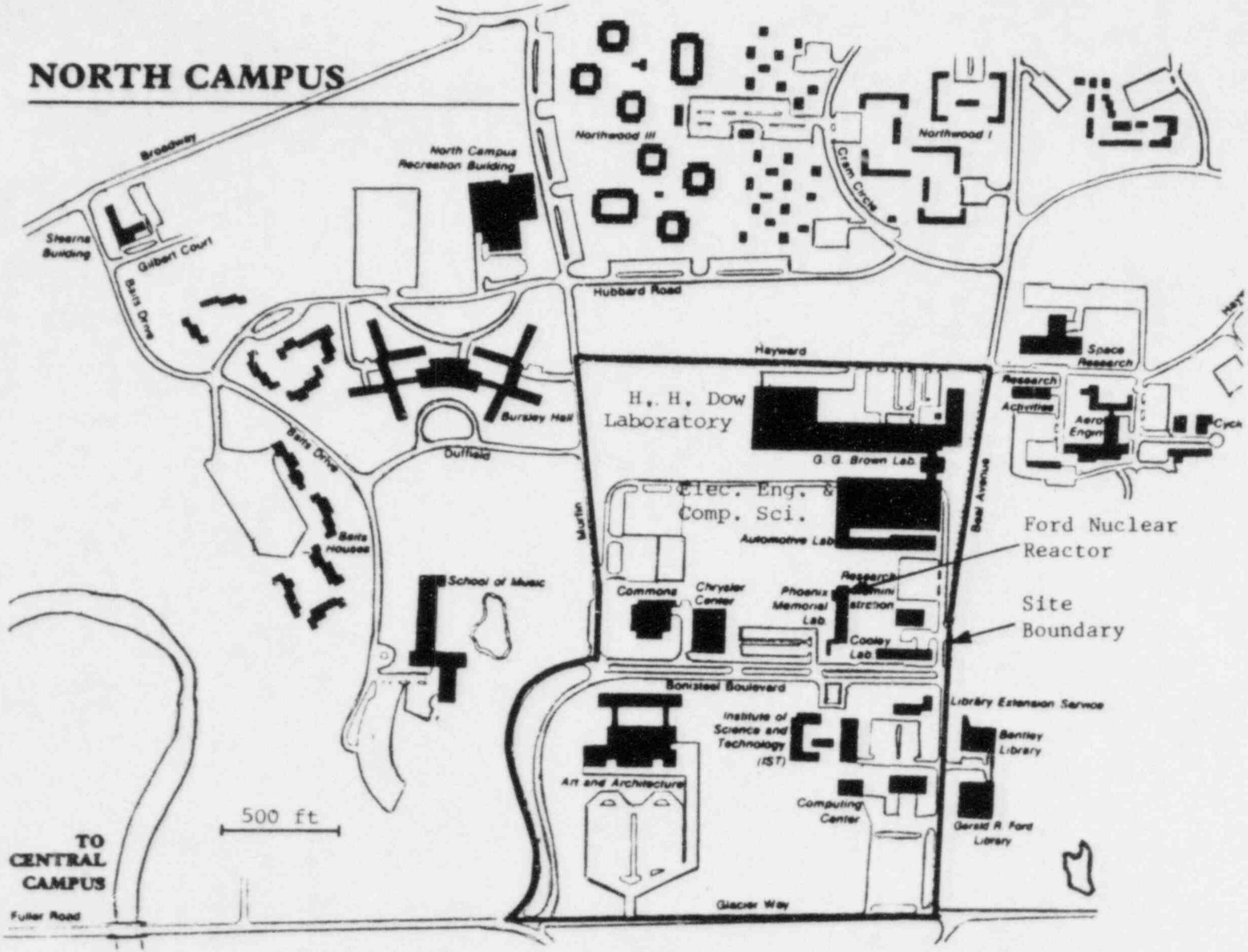

Figure 2.1 North Campus layout showing the FNR facility and exclusion area

2.5 Nearby Industrial, Transportation, and Military Facilities

Roads close to the campus are Plymouth Road and Glacier Way located approximately 2500 ft north and 1500 ft south of the reactor, respectively. These are local roads and generally do not carry extensive, heavy loads of through-traffic.

There are no main railroad lines near the campus.

There are no heavy industries or military facilities near the campus. The Ann Arbor airport is 7 mi from the campus and handles no commercial flights. The Detroit airport is about 20 mi east of Ann Arbor.

2.6 Meteorology

Precipitation is heaviest during the summer months, averaging 58% of the annual total during the April-September period. Heaviest rains are in May, which has an average of 3.34 in. The greatest total monthly precipitation on record is 10.7 in. The heaviest rainfall intensity occurs in connection with thunder-shower activity and the heaviest recorded 24-hour period of rainfall was approximately 5 in. Hourly intensities as high as 1.2 in. occur with a frequency of once every 2 years.

Average annual snowfall is 30.2 in. Annual totals have ranged from 13 to 54 in. The heaviest recorded snowfall for a single day was 6.2 in.

Prevailing wind direction in the Ann Arbor area is from the southwest, with all months showing that direction except March, which has a prevailing direction of west-northwest. Highest average wind velocity is 12.9 mi per hour (mph) in March. The highest wind velocity ever recorded in the Ann Arbor area was 60 mph.

Michigan lies at the northeastern edge of the Nation's maximum frequency belt for tornadoes. Normally, the number of tornadoes in the central United States begins to increase during February and reaches a peak in May or June. For the last decade, Michigan has averaged nine tornadoes per year, 90% of which have been in the southern half of the lower peninsula of the state. The reactor facility is part of a tornado warning system. When notified of a tornado alert, the reactor is shut down.

2.7 Geology and Hydrology

The site is located within the Central Stable Region Tectonic Province of North America (Eardley, 1962), whose bedrock geology is characterized by domes, arches, and basins of regional scale. The site is on the southern flank of one of the basins, the Michigan Basin, a broad circular structural depression composed of more than 14,000 ft of relatively undeformed Paleozoic sedimentary rocks. Bedrock in the site region is overlain by a few feet to several hundred feet of soil deposited from glaciers during the Pleistocene Epoch. Faults and folds were formed during the Paleozoic Era, more than 240 million years ago. None of them disrupt overlying glacial soils and are considered to be noncapable within the meaning of Appendix A to 10 CFR 100. The reactor site is situated within the limits of the deposits of the Cary Age, a substage of the Wisconsin Ice Age.

The site lies near the crest of an ice contact deposit known as kame (a conical hill or short ridge). The material is stratified sand and gravel, but contains

lenses and beds of more cohesive soil, as indicated by the rather high static level of the water table in some areas. The surface soils have been mapped by the U.S. Department of Agriculture as Bellfontaine sandy loam, a characteristic soil of this type of terrain.

The predominant lithology of the stratified drift consists of quartz sand, limestone, and quartz gravel, as well as a variety of igneous, sedimentary, and metamorphic rock types. The clay minerals are less abundant but present in varying amounts.

Surface and subsurface drainage is toward the Huron River, and should be fairly rapid because the base soil around the site is kamic which has a fairly high coefficient of permeability. The movement of subsurface water is also facilitated by the lack of flat-lying ground in the area surrounding the site.

Both surface and subsurface drainage from the site eventually reaches the Huron River. At this location, the Huron River has already passed through the city of Ann Arbor, and flows in a southeasterly direction for 6 to 7 mi before reaching the next populated area, the city of Ypsilanti, Michigan. Along this water course, normal river velocities are slowed by the presence of three dams.

The average discharge for the Huron River at Ann Arbor, based on a 33-year period from 1914-1947, is 451 cfs. Minimum flow for the 33-year period was 4 cfs. A flood of 5000 cfs occurs on the average of once in 20 years.

2.8 Seismology

The University of Michigan Ann Arbor site, within the Central Stable Region, is characterized by a relatively low level of seismic activity.

Recent interpretations of geophysical investigations suggest that different areas of the Central Stable Region exhibit different levels of seismic activity (NUREG-0793). For instance, Barstow et al. (NUREG/CR-1577) developed an earthquake frequency map for the Eastern United States that places the Ann Arbor location in a zone where 8-15 earthquakes per 4500 mi^2, having modified Mercalli scale intensities (MMI) of III or greater, have occurred during the time period 1800-1977 (Hadley, 1974). The Anna, Ohio, location experienced a frequency of 32-63 earthquakes/4,500 mi^2 with MMI III or greater for the same time period. The Michigan Basin area, in general, is considered to have had no more than 0-3 earthquakes/4,500 mi^2 of MMI III or greater (Coffman, 1973). A seismicity map developed by the Geological Survey of the State of Michigan (Bricker, 1977) shows that for the time period from 1872-1967, only 34 earthquakes were felt (reported) in the entire State of Michigan. A U. S. Geological Survey seismicity map of the State of Michigan (Stover et al., 1980) shows a total of 83 earthquakes in the state since 1872. The nearest of these to Ann Arbor (March 13, 1978; MMI IV) was about 30 mi away. Only six earthquakes have been reported within 60 mi of Ann Arbor. The Department of Geological Sciences of the University of Michigan (1984) has operated a seismic network in southern Michigan, western Ohio, and eastern Indiana since 1977. During the time period of July 1977 to December 1984 only one recorded earthquake with a magnitude greater than 0.3-0.5 (m_b) was located within the State of Michigan. The risk of damage from earthquakes to well-designed structures is relatively low for the Ann Arbor area. In

addition, the earthquake intensity/magnitude potential is relatively low for the Michigan region and there are no known structures in the Ann Arbor area capable of causing earthquakes.

2.9 Conclusion

The staff has reviewed and evaluated the FNR site for both natural and manmade hazards and concludes that there are no significant risks associated with the site that would make it unacceptable for the continued operation of the reactor.

3 ENVIRONMENTAL EFFECTS ON DESIGN OF STRUCTURES, SYSTEMS, AND COMPONENTS

The licensee's Safety Analysis Report provides information on the design, construction, and functions of the as-built reactor building, reactor systems, and auxiliary systems.

3.1 Reactor Facility

Since 1965, all University of Michigan buildings have been designed and built in accordance with the Building Officials and Code Administrators (BOCA) basic building code for seismic zone 1. The BOCA code is met for the Ann Arbor area by steel framed buildings with the steel I-beams on 12-in. centerlines. In 1956, when the FNR building was constructed, there were no code requirements for earthquake design in Michigan. However, the reactor building is a windowless, reinforced concrete structure. The building has 12-in. walls that are structurally integral with the footings in foundation mats. This type of construction significantly exceeds the strength of buildings currently being constructed to meet seismic zone 1 requirements.

The FNR is housed adjacent to the Phoenix Memorial Laboratory (PML), which is located on the North Campus area of the University of Michigan at Ann Arbor. Figure 3.1 shows the three floor plans of the reactor facility. The reactor building is ~69 ft wide by 68 ft long by 70 ft high. The reactor is housed in a closed room designed to restrict leakage and is equipped with a ventilation system that vents gases in the building to a stack that exhausts ~54 ft above ground level. The ventilation system also provides for venting storage and experimental facilities within the reactor building.

3.2 Wind Damage

Meteorological data indicate a frequency of tornadoes and effects of tropical disturbances and a moderately high frequency of summer thunderstorms. However, the reactor pool is formed by a monolithic reinforced-concrete shield, integrally constructed within a reinforced masonry building located partially below grade. The open pool and reactor building operate at atmospheric pressure, so loss of integrity of either resulting from wind damage could lead to nonexplosive collapse. In turn, loss of pool water might occur; however, the licensee's analysis, with which the staff agrees, provides adequate assurance that loss of coolant would not lead to melting of any fuel. Therefore, the staff concludes that wind or other storm damage to the FNR facility poses no significant risk to the public.

3.3 Water Damage

The reactor building is situated above the flood plain and adequately above the level of potential flash flood waters. Therefore, the staff concludes that there is reasonable assurance that damage to the reactor structures by flood or groundwater is not likely and risk to the public is not significant.

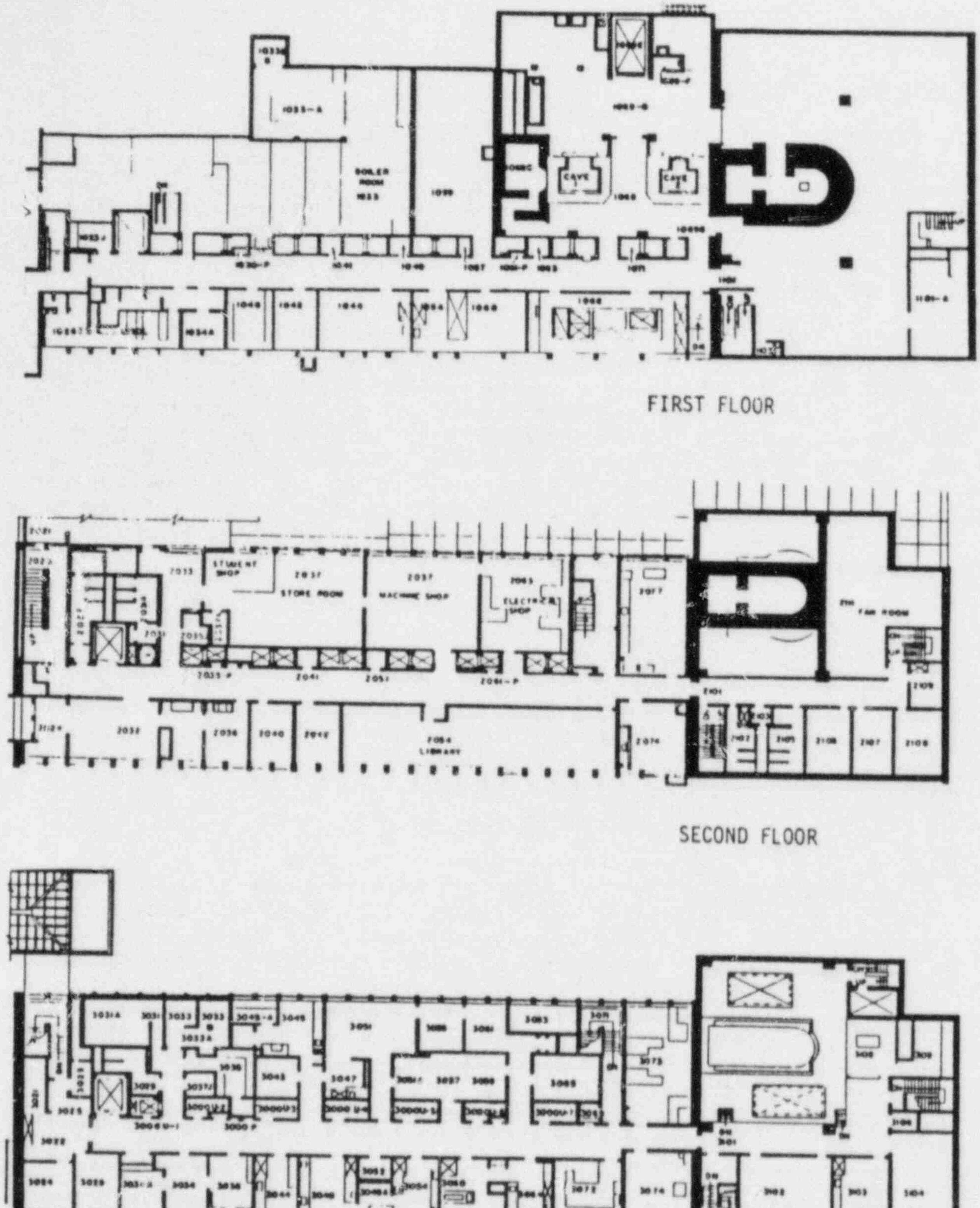

Figure 3.1 Floor plans of the reactor facility

3.4 Seismic-Induced Reactor Damage

The FNR pool is a reinforced-concrete structure embedded partially below grade. These features will resist damage resulting from seismic activity. No seismic analysis has been performed because (1) Ann Arbor is in a region of historically low seismic activity and (2) damage to the reactor and loss of coolant would not result in melting of fuel (see Section 14).

These considerations give the staff reasonable assurance that the risk to the public resulting from seismic damage to the reactor is not significant.

3.5 Mechanical Systems and Components

The mechanical systems of importance to safety are the neutron-absorbing control rods suspended from the superstructure, which also supports the reactor core. The motors, gear boxes, electromagnets, switches, and wiring are above the level of the water and readily accessible for testing and maintenance. The staff has addressed the effects of aging on the performance of these components in Section 17.

3.6 Conclusion

The FNR facility was designed and built to adequately withstand all credible and likely wind and water damage associated with the site. The considerations above and in Sections 14 and 17 indicate that a tornado or seismic event would have relatively small consequences to the reactor.

4 REACTOR

The University of Michigan Ford Nuclear Reactor (FNR) is an open-pool type, heterogeneous research reactor that operates at a maximum licensed power level of 2 MW. The FNR converted from high-enriched uranium (HEU) to low-enriched uranium (LEU) fuel (~19.5% enrichment) in October 1984. Light demineralized water is used for moderation, cooling, reflection, and shielding. Graphite elements also can be used for additional neutron reflection. The reactor is cooled by natural convection for power levels up to 100 kW, and by forced convection cooling for higher power operation. The reactor power is regulated by the insertion or withdrawal of three neutron-absorbing shim-safety rods and one regulating rod.

The FNR is used principally for activation analysis and neutron irradiation studies, isotope production, neutron radiography, and training. The FNR operates an average of ~9000 MWh/yr. The principal design parameters for the current core configuration are listed in Table 4.1.

4.1 Reactor Core

The reactor core is suspended from a movable bridge mounted on rails that span the top of the concrete tank. It consists of 35 to 40 19.5%-enriched MTR-type curved-plate fuel elements, three shim-safety rods, and one regulating rod arranged in a rectangular configuration (6 x 8 fuel element array). A heavy water tank provides a thermal neturon flux for the beam ports and also is used as a startup source. The tank is located directly behind the reactor core. The core can be surrounded by graphite elements that serve as neutron reflectors. Core components are mounted in an aluminum grid plate. Figure 4.1 shows a typical core loading diagram for the FNR.

4.1.1 Fuel Elements

The FNR uses MTR-type fuel elements with overall dimensions of ~3.25 in. by 2.94 in. by 34.78 in. The fuel assemblies consist of curved plates containing uranium aluminide (UAl_x) or uranium oxide (U_3O_8) fuel enriched to less than 20% ^{235}U. Standard 18-plate aluminum-clad elements contain ~167 g ^{235}U. The shim-safety and regulating rods move in a control rod guide channel in a control rod fuel element and, therefore, there are only nine fuel-bearing plates in such an element. These fuel elements each contain ~84 g ^{235}U. The active fueled length of the elements is ~24 in. The plates are fabricated in a sandwich fashion with 0.015-in.-thick aluminum cladding surrounding a 0.03-in. layer of 42 wt% uranium of either uranium-aluminide or uranium oxide fuel.

4.1.2 Neutron Source

The FNR uses the heavy water tank as the primary neutron source; however, a small antimony-beryllium source (~10^4-10^7 n/cm^2/s flux strength) also may be used. A neutron source holder located at the periphery of the core provides for manual insertion and withdrawal of the antimony-beryllium source.

Table 4.1 Principal design parameters

Parameter	Description
Reactor type	Open-pool, MTR-type fuel
Maximum licensed power level	2 MW
Fuel element design	
Fuel/moderator material	$U\text{-}Al_x$ alloy or $U\text{-}O_x$ clad with Al
Uranium enrichment	19.5% ^{235}U
Fuel meat thickness	0.03 in.
Shape	Curved plate
Overall length	34.78 in.
Width	3.25 in.
Thickness	0.060 in.
Cladding thickness	0.015 in.
Uranium inventory	
Weight ^{235}U/fuel element	167.3 g (standard 18-plate element) 84 g (control rod element)*
Number of fuel elements	~38
Reactivity worths	
Excess reactivity	3.8% Δk/k (5.03$) Cold, clean, critical condition
Shim-safety rods (3)	~6.47% Δk/k (8.57$)
Regulating rod (1)	0.38% Δk/k (0.51$)
Reactor cooling	Natural convection of bulk coolant (<100 kW) or forced convection (>100 kW)
Reflector	Graphite and water
β_{eff}	0.755% Δk/k (1.00$)
Reactivity coefficients	
Negative temperature coefficient	-5.5×10^{-5} Δk/k°F
Void coefficient	-6.4×10^{-6} Δk/k/cm^3

*Shim-safety and regulating rods have one-half the number of fuel plates that are in a standard element with a central gap to allow for insertion of an absorber control rod.

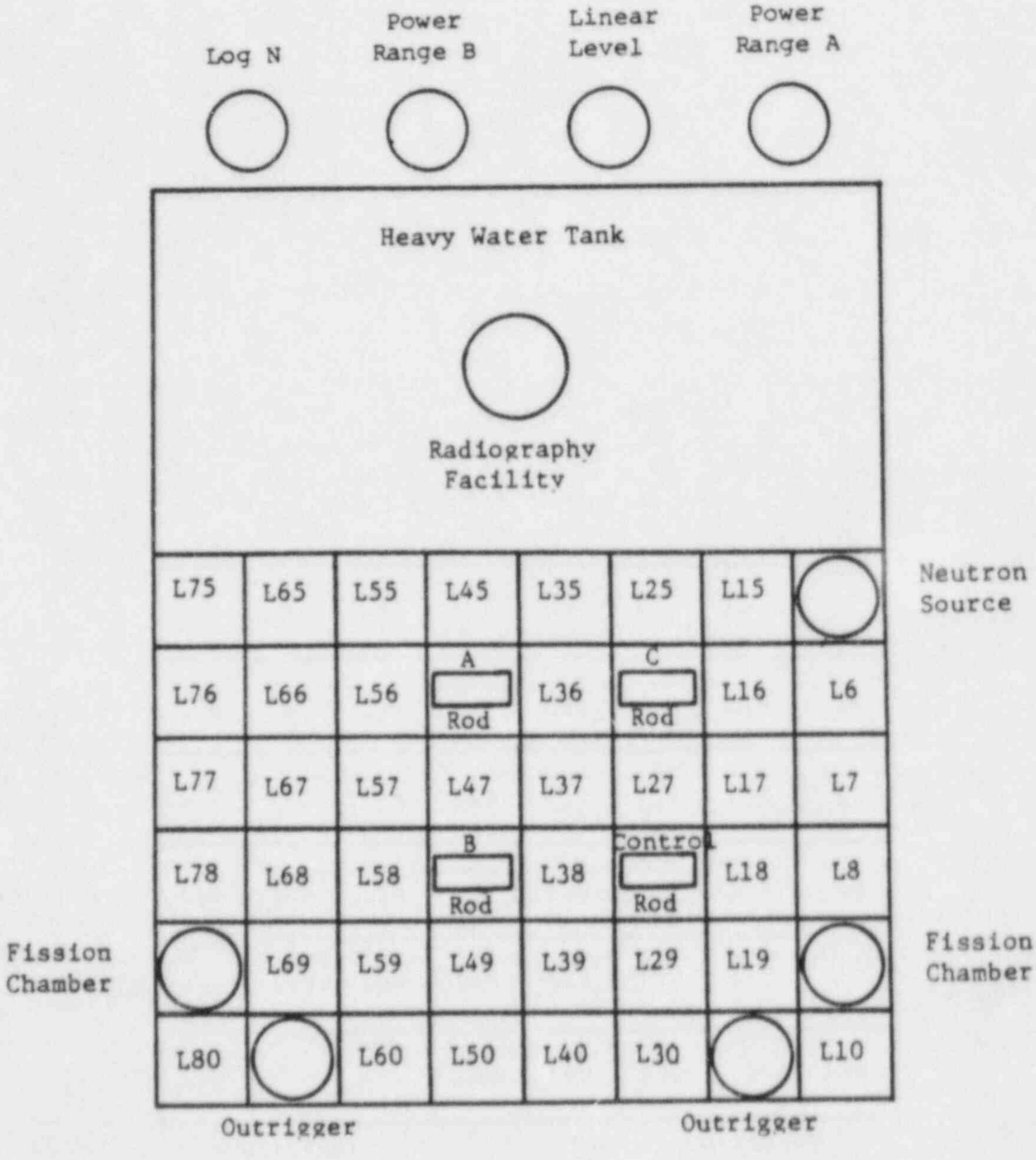

Figure 4.1 FNR core configuration

4.1.3 Control Rods

Four control rods are used to control and regulate the power levels in the FNR: three boron-stainless-steel shim-safety rods and one stainless-steel regulating rod. All of the rods fit into the central gap in any of the control rod fuel elements and may be located in any of the central 16 core positions. The shim-safety rods are normally withdrawn as a group to an approximate height in the core, but they also may be withdrawn individually. Only the regulating rod may be operated either manually or automatically. Additional details on the control system are discussed in Section 7.

4.2 Reactor Pool

The reactor is suspended $\sim$20 ft beneath the surface of a rectangular concrete pool, 10 ft wide by 20 ft long by 27 ft deep. The tank is lined with white ceramic tiles that prevent spalling and aid in visibility and decontamination. Additionally, a graphite-filled thermal column is located in the center of the west wall of the tank. The reactor is limited to a 100-kW operation when it is near the thermal column position because there is only convective cooling in that position.

Fuel storage racks are located along the north and south ends of the reactor pool. The pool is divided by two islands and an aluminum gate that can be used to isolate either half of the pool in the event of a leak. Also, a water-lock system located in the south end of the pool allows for the transfer of fuel, experiments, or samples from the reactor pool to a hot cave.

Twelve aluminum beam ports penetrate the north end of the pool. There are also eight pneumatic irradiation tubes that penetrate the pool floor and terminate adjacent to the west face of the reactor core. Figure 4.2 shows a cross-sectional view of the reactor pool.

4.3 Reactor Support Structure

An aluminum suspension frame supports the grid plate, which contains the fuel elements, the ion chambers, the control and regulating rods, and the fission chamber guide tubes. The grid plate has 48 holes in a 6 by 8 rectangular array for positioning the various core components. In addition, there are several 7/8-in.-diameter holes drilled through the grid plate between the fuel element holes to provide for additional cooling around the fuel elements. Water passes up through these holes during the natural convective cooling mode of reactor operation, and water is forced down through the holes during forced circulation. Additionally, several aluminum plugs are available to fill unused grid core positions and prevent the circulating water from bypassing the fuel elements. Special holddown mechanisms consisting of long extensions between the guide tubes of the control rod fuel elements and the control rod drive mechanisms are used to prevent any inadvertent withdrawal of the control rod fuel elements from the grid plate during reactor startups.

4.4 Reactor Instrumentation

Operation of the FNR is monitored by six neutron detection channels: two start-up channels, two intermediate range channels, and two power range channels.

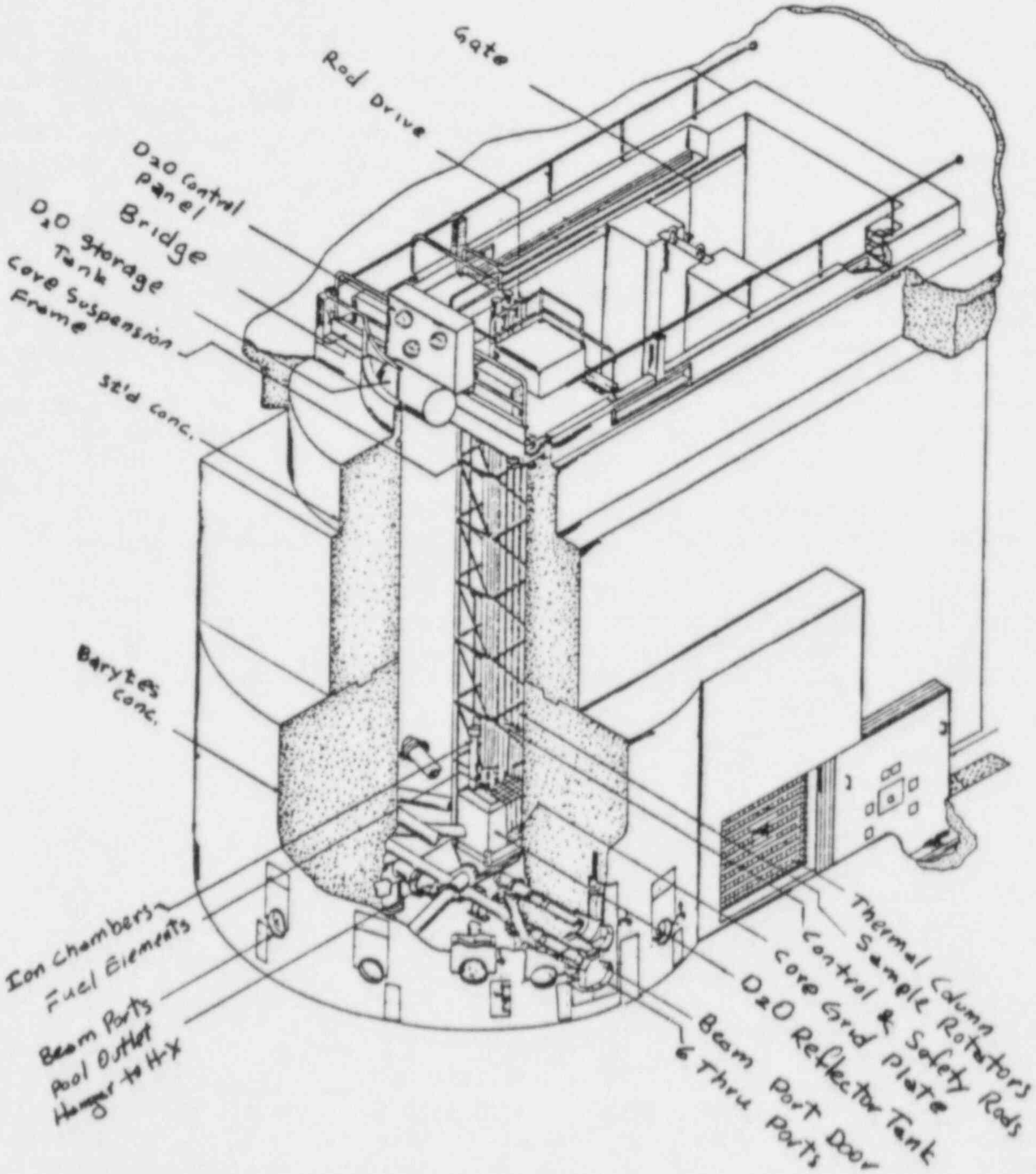

Figure 4.2 FNR reactor pool

Additional instrumentation displayed in the control room provides information on fuel element temperature, primary and secondary coolant flow, radiation levels, rod position indication, and reactor pool level. Additional details on reactor instrumentation are discussed in Section 7.

4.5 Biological Shielding

The FNR pool is constructed of dense barytes concrete 6.5 ft thick to a height of 15 ft to provide biological shielding to minimize exposures to the operating staff. The upper portion of the reactor pool is standard structural concrete ~3.5 ft thick. The Technical Specifications require that the water level be >18 ft above the top of the core during reactor operations to provide adequate core cooling and radiation shielding.

4.6 Dynamic Design Evaluation

Operation of the FNR is accomplished by manipulating control rods in response to changes in parameters such as temperature and neutron flux, which are measured by the instrument channels. Interlocks (including low startup source strength) prevent inadvertent reactivity additions, and a scram system initiates rapid and automatic shutdown when a preset limit has been reached. Additional reactor stability is provided by the negative temperature coefficient of reactivity (-5.5×10^{-5} $\Delta k/k/^{o}F$) and the void coefficient of reactivity (-6.4×10^{-6} $\Delta k/k/cm^3$). These are inherent nuclear safety features that are effective in terminating inadvertent excursions even if the control rods are not activated for any reason, or if operator error violates established operating procedures.

The FNR core was converted in 1982 from an HEU (high-enriched uranium) core composed of 93 wt% enriched fuel to an LEU (low-enriched uranium) core composed of 19.5 wt% enriched fuel. Additionally, the fuel element ^{235}U loading increased from 140 g to 167.3 g per 18-plate assembly. The resulting effects on the specific core physics parameters of the LEU fuel included

(1) a decrease in the core thermal flux
(2) a small decrease in xenon poisoning
(3) a small increase in power defect as a result of increased Doppler effects
(4) a longer cycle length for a given reactivity change and a higher discharge fuel burnup
(5) reduction in control rod worth (may be offset by longer cycle length)
(6) slight changes in power distribution
(7) no significant change in the core shutdown margin
(8) no reductions in any safety margins

4.6.1 Excess Reactivity and Shutdown Margin

The FNR Technical Specifications require that the control rods provide a shutdown margin of at least 0.45% $\Delta k/k$ (0.60$) with the highest worth shim-safety rod and the regulating rod fully withdrawn. With all three shim-safety rods fully inserted and the regulating rod fully withdrawn, the shutdown margin must be at least 2.5% $\Delta k/k$ (3.31$). Additionally, the Technical Specifications limit the maximum excess reactivity to 3.8% $\Delta k/k$ (5.03$). The total control rod worth is ~6.85% $\Delta k/k$ (9.07$), composed of individual shim-safety rod worths of 2.127%, 2.158%, and 2.185% of $\Delta k/k$ and 0.383% of $\Delta k/k$ for the regulating rod.

Therefore, the shutdown margin with the highest worth control rod and the regulating rod fully withdrawn is 0.49% Δk/k (6.85% Δk/k - 2.18% Δk/k - 0.38% Δk/k - 3.8% Δk/k) or 0.65$ (9.07$ - 2.89$ - 0.50$ - 5.03$), which is a more conservative shutdown margin than that required by the FNR Technical Specifications. The shutdown margin with all three safety control rods fully inserted is 2.67% Δk/k (3.54$), which also is greater than the 2.5% Δk/k (3.31$) required by the Technical Specifications.

4.6.2 Experiments

The administrative operating procedures provide specific guidance for reviewing experiments. Unique experiments are reviewed and approved by the Safety Review Committee.

The licensee's Technical Specifications provide limitations on the reactivity worths of secured and movable experiments and on reactivity insertion rates for experiments with moving parts. The Technical Specifications limit a single movable experiment to 0.12% Δk/k (0.159$). This worth is less than β_{eff}, which is 0.755% Δk/k (1.0$) for the FNR. Thus, the failure of a movable experiment with maximum worth would not result in a prompt criticality. Additionally, the total reactivity worth of all experiments is limited to 1.2% Δk/k (1.58$). An accident analysis was conducted to evaluate the extremely unlikely event that all the experiments fail and result in a subsequent step introduction of reac tivity. As shown in Section 14, this incident would not cause fuel melting. Also, the total experiment reactivity worths [1.2% Δk/k (1.58$)] are such that they will either not produce a stable period of less than 30 s or they can be compensated for by the control and safety systems without exceeding any safety limits. As indicated in Section 14.2, the licensee has determined, on the basis of the SPERT and BORAX experiments (Dietrich, 1954; Neyer et al., 1956), that a step reactivity insertion of 1.6% Δk/k (2.10$) would result in the hottest fuel element cladding temperature increasing to about 900°F, about 300F° below the melting temperature. Since 1.2 of Δk/k available reactivity is well below the 1.6 of Δk/k values from the SPERT and BORAX experiments, step reactivity insertions will not produce any damage to the FNR MTR-type fuel elements.

4.6.3 Assessment

The Technical Specifications on excess reactivity and experiment worths ensure that an adequate amount of shutdown margin is available so that even in the unlikely event that the highest worth rod fails to insert when receiving a scram signal, there is still sufficient capability to shut down the reactor. Additionally, the experiment reactivity limits imposed by the Technical Specifications ensure that any reactivity excursions that may be caused by the accidental insertion or withdrawal of an experiment will not cause the reactor to exceed the limiting safety system setting, and the resultant period will not be less than the operational limit. Additional control capability is provided by the inherent safety features (the negative temperature and void coefficients) if the control rods fail to insert.

4.7 Functional Design of Reactivity Control System

The power level of the FNR is controlled by three boron-stainless-steel shim-safety rods and one stainless-steel regulating rod. All rods are moved by electromechanical drive units. The regulating rod is operated either in the

manual or the automatic mode using a servo control motor. Each rod drive system is energized from the control console through its own independent circuit. The shim-safety rods are scrammed as a group; the regulating rod must be driven in as it does not scram. All rods can be withdrawn or inserted either independently or as a group.

4.7.1 Rod Drive Assemblies

Each safety control rod drive assembly for the FNR, located on the reactor bridge, consists of an electric motor coupled to a brake, a speed-reducing gear drive system, and a limit switch. If power to the electromagnets is interrupted for any reason, the magnets are deenergized and the safety control rods fall by gravity into the core, shutting down the reactor. Additional information on the rod drive assemblies, as well as the scram circuitry and interlocks, is discussed further in Section 7.

4.7.2 Assessment

The FNR is equipped with safety and control systems, shim-safety and regulating rods, rod drives, scram-logic circuitry, and interlocks that allow for an orderly approach to criticality and for safe shutdown of the reactor during normal and abnormal conditions. There is sufficient redundancy of control rods to ensure safe reactor shutdown even if the most reactive rod fails to insert when receiving a scram signal. Additionally, the FNR is a <19.5%-enriched ^{235}U reactor. Thus, 80% of the fuel is composed of ^{238}U. Because ^{238}U has a wide Doppler absorption band, its resonance peaks widen as the temperature increases, thereby increasing the neutron capture and reducing the available neutrons that will continue to fission. This inherent feature enhances the prompt, negative temperature coefficient.

4.8 Operational Practices

The FNR operates under Technical Specifications that direct the review, audit, and surveillance of the reactor and provide procedural reviews for all safety-related activities. Written procedures have been established for safety-related and operational activities, which include reactor startup, operation, and shutdown; maintenance; and calibration of equipment and instrumentation. In addition, the reactor is operated by NRC-licensed personnel in accordance with the requirements of 10 CFR 55.

4.9 Conclusion

The staff has reviewed the details of the reactor core, fuel elements, reactivity control systems, and the design features of the reactor. On the basis of the above findings, the staff concludes that they are adequate to provide reasonable assurance that the operation of the FNR, in accordance with its Technical Specifications, does not pose any significant risk to the health and safety of the operating staff or the general public.

5 REACTOR COOLING SYSTEMS

The reactor cooling function is performed by three systems: the primary cooling system, the secondary cooling system, and the purification system. The controls and instrumentation associated with these systems are discussed in Section 7.

5.1 Primary Cooling System

The components of the primary cooling system are shown in Figure 5.1. These components include the header and hopper mechanism, the holdup tank, a 1000-gal/min pump, the heat exchanger, and associated piping and instrumentation. The primary coolant system removes up to 2 MW of heat from the core by forced circulation and maintains the bulk pool temperature at less than 116°F. The flow rate is between 900 and 1000 gal/min.

A funnel-shaped aluminum hopper, bolted to the bottom of the grid plate in the core, is designed to direct primary coolant flow from the fuel elements into a header (see Figure 5.2). Its purpose is to reverse flow for convection cooling requirements. The header is held tightly against the bottom of the hopper by a header latching mechanism. A rotating flange allows the header, when released, to swing down and away from the hopper, providing natural convective cooling up through the grid plate and core.

The header either can be released automatically by a low coolant flow rate signal or can be released manually to operate the reactor in a different pool location. In the convective cooling mode, reactor operation is limited to power levels below 100 kW. The header latching mechanism and associated instrumentation are described in Section 7.

During forced cooling operations, primary coolant flows down through the core fuel elements, grid plate, and hopper and then into the header and the holdup tank. The water is pumped by the 1000-gal/min pump through the heat exchanger for heat removal by the secondary coolant system. Primary coolant is returned to the pool from the heat exchanger.

The holdup tank is a 1200-gal tank located in the basement below the core. A baffle inside the holdup tank provides a flow time lag of ~1 min. The time lag allows the 7.1-s half-life ^{16}N, formed in the core, to decay to a lower level, minimizing exposure of personnel working near primary coolant piping.

Primary coolant flows from the pump into the heat exchanger shell; secondary coolant flows into an entrance header, through the U-shaped tubes, to the exit header, and then to the cooling tower. Pressure in the secondary coolant system is greater than in the primary system so any leakage in the tubing will be into the primary coolant, preventing the release of any contaminated primary coolant.

5.2 Secondary Cooling System

The secondary cooling water absorbs heat from the primary water in the heat exchanger. The heated secondary coolant water is pumped to a cooling tower

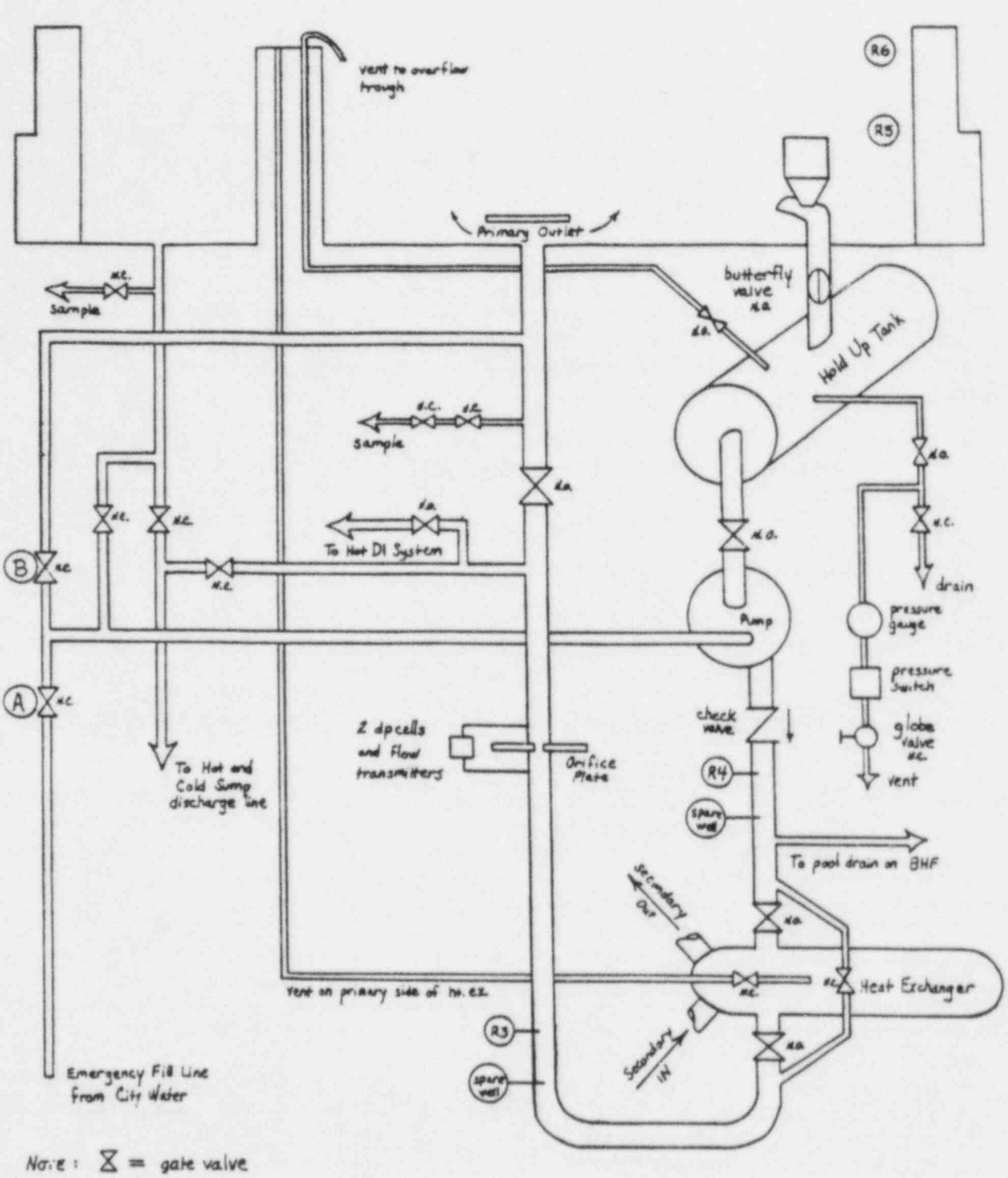

Figure 5.1 FNR primary coolant system

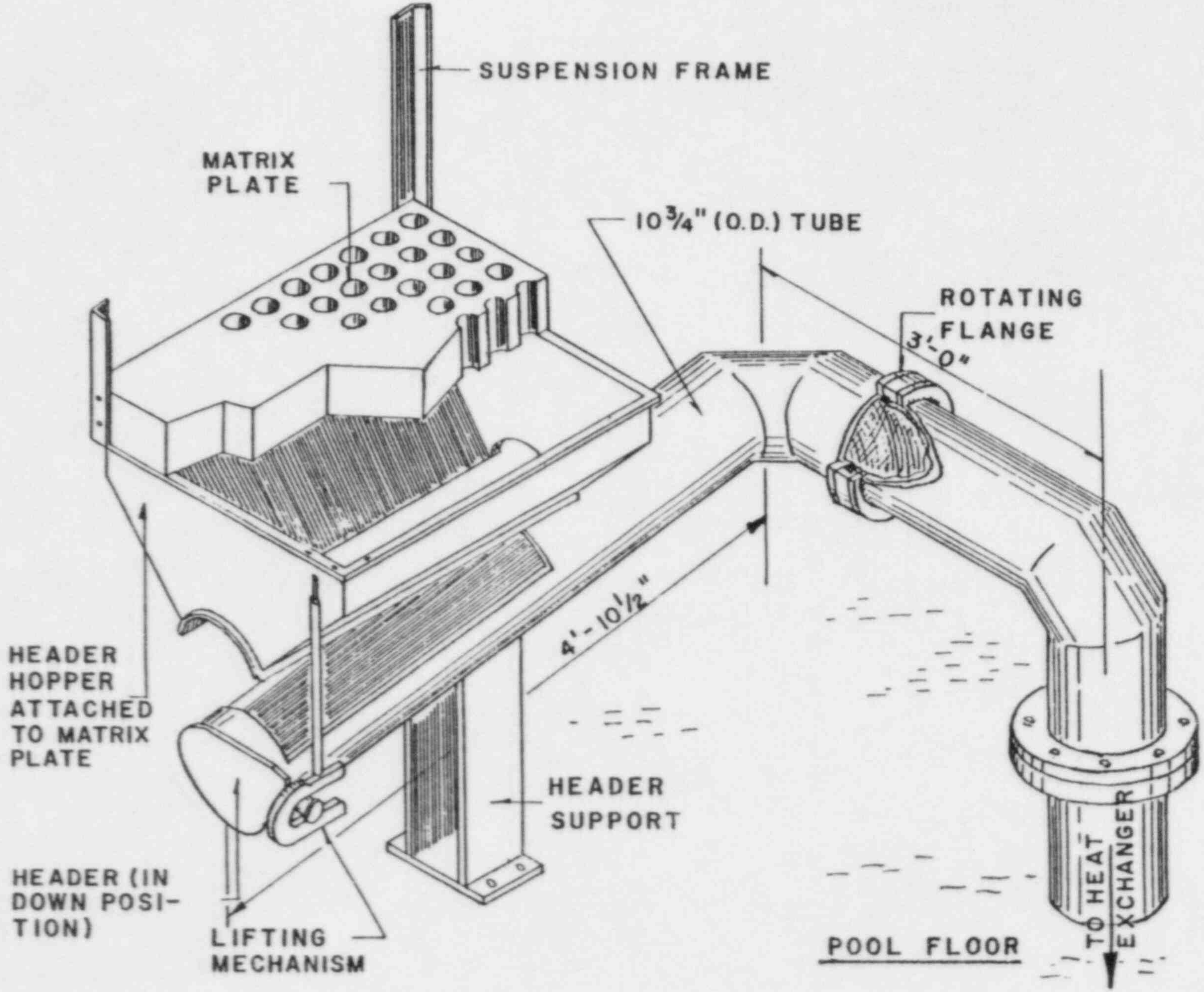

Figure 5.2 Header and hopper mechanism

located on the roof of the reactor building. This is a three-bay, forced-draft cooling tower used to dissipate the heat to the atmosphere. Each of the three cooling tower fans can be reversed for winter ice removal. Secondary makeup water is taken directly from the city water system.

5.3 Coolant Purification System

About 25 gal/min of primary coolant is tapped off the primary coolant return line downstream of the flow orifice and flows to the purification system. Coolant is pumped past a conductivity cell through a filter and into the top of either #1 or #2 hot demineralizer units, which are located in the demineralizer pit in the reactor basement. Coolant leaves the bottom of the demineralizer unit, passes a second conductivity cell and another filter, and is pumped back to the reactor pool. Except for periods not to exceed 1 week, the pool water is maintained at a resistivity greater than 2×10^5 ohm-cm. The pool water pH is maintained between 4.5 and 7.5. Primary coolant conductivity is recorded continually in the control room.

Pool makeup water is supplied by the city water system through a separate filter, cold demineralizer, and conductivity cell and into the primary coolant return line.

5.4 Conclusion

The staff concludes that the reactor cooling systems are adequate to prevent fuel element overheating under all normal and likely off-normal operating conditions and that the coolant purification system can prevent both corrosion and radioactivity problems associated with coolant contamination.

6 ENGINEERED SAFETY FEATURE

The ventilation system is the only engineered safety feature designed to mitigate the consequences of a radiological accident at the FNR facility.

6.1 Ventilation System

There are four exhaust stacks in the Phoenix Memorial Laboratory (PML) and a single exhaust stack in the FNR facility. All stacks exhaust 54 ft above ground level. Most of the components of the ventilation system are located in the FNR fan room, Room 2111, where all supply air enters the building and where most of the exhaust air exits the building. The supply intake and the building exhaust have isolation dampers that act from a common pneumatic cylinder. They are opened and closed simultaneously. Supply air enters the reactor building through the supply damper and passes through a set of filters and into the main supply blower for distribution throughout the building.

Reactor building air is exhausted predominantly through the main reactor building exhaust damper; however, air from the beam port floor, the pneumatic tube system blower; and a hood in Room 3103 is discharged in PML stack #2. A radiation level of >1 mrem/h in the reactor building exhaust air activates the building radiation alarm, which scrams the reactor, shuts all of the supply and exhaust dampers, and turns off the supply and exhaust fans. A radiation level of 5 mrem/h at the reactor fuel vault initiates the same sequence of events.

Building supply and exhaust systems are monitored continuously for radioactivity. Stack #2 has a mobile (moving filter) air particulate (MAP) monitor and a gaseous activity detector (GAD). The reactor building exhaust has a continuous GAD. The pool and beam port floors are monitored continuously by separate MAP monitors. PML exhaust stacks 1, 2, 3, and 4 have isokinetic filtering systems that continuously pass stack gas through filters that are periodically analyzed. In addition, the same sample lines have a charcoal filter to monitor for iodine. The reactor building exhaust has similar isokinetic particulate and charcoal iodine monitoring systems.

6.2 Conclusion

From the above review of the system design and maintenance and the operating history, the staff concludes that the FNR ventilation system will cause reactor shutdown and reactor room isolation in the event of a release of radioactivity into the reactor room and will prevent the release of radioactivity to the atmosphere in excess of the limits imposed by 10 CFR 20.

7 CONTROL AND INSTRUMENTATION

The FNR uses a control and instrumentation system that includes rod controls, annunciators, meters, and recorders, all of which are located in the control console. The instrumentation system, which is interlocked with the control system, is composed of both nuclear and process instrumentation and generally is characterized by modern components. The control system is composed of both nuclear and process control equipment in which safety-related components are designed for redundant operation in case of single failure or malfunction of components essential to the safe operation or shutdown of the reactor.

7.1 Nuclear Control Systems

The FNR uses three boron-stainless-steel shim-safety rods and one stainless-steel regulating rod. The shim-safety rods are connected to electromechanical drive units. The regulating rod is connected to a continuous rod drive; it cannot be scrammed.

7.1.1 Control Rod Drive Assemblies

The electromechanical rod drive assemblies for the shim-safety rods and regulating rod consist of a motor and reduction gears that drive a rack and pinion and are coupled to an extension tube. The shim-safety rod drive units have electromagnets that are attached to the shim-safety rod extension tubes. The drives are controlled from the reactor console by the reactor operator. Whereas the shim-safety rods are used for coarse adjustments of reactor power, the regulating rod is used only for fine adjustments of power. The regulating rod drive assembly does not have an electromagnet and therefore has no scram capability.

The shim-safety rods are connected to the rack through an electromagnet and ferro-nickel armature. When the electric power is lost or interrupted, electromagnetism is removed and the rods separate from the rod drive units and fall by gravity, scramming the reactor.

Limit switches mounted on the drive assembly actuate circuits that stop the rod drive motor at the top and bottom of travel and actuate indicator lights on the control console. The vertical travel length of each control rod is ~24 in. (~61 cm). Figures 7.1 and 7.2 show typical FNR shim-safety rod and regulating rod drive units, respectively.

7.1.2 Operating Modes

The shim-safety rods can be withdrawn only in manual mode and must be actuated positively to be withdrawn. When there is no positive pressure applied to the raise/lower switch on the rod control panel located in the control console, the rods will stop moving (withdrawing). Helipots provide rod position indication on the reactor console. Depressing the scram button causes all of the shim-safety rods to be inserted into the reactor simultaneously.

The regulating rod may be operated in either manual or automatic mode. The regulating rod can be controlled automatically by means of a servo amplifier

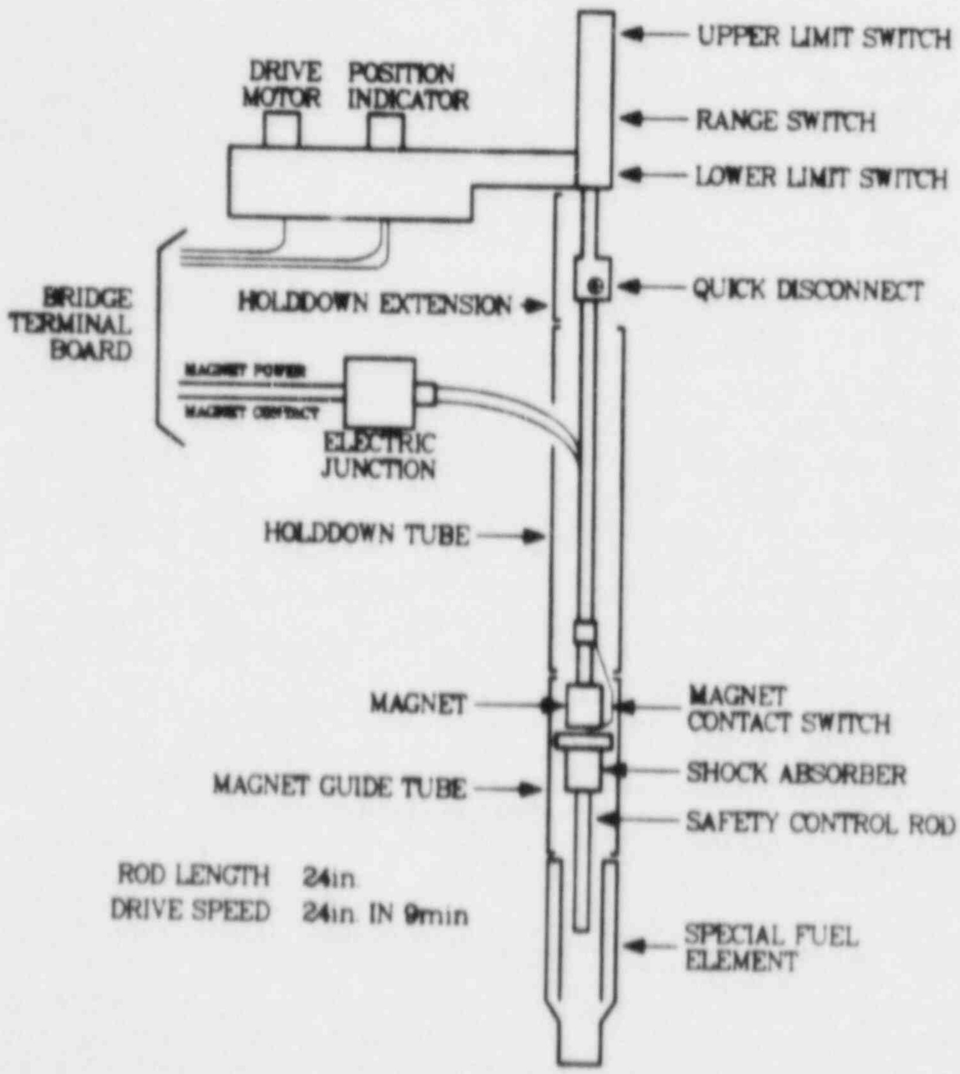

Figure 7.1 FNR shim-safety rod drive unit

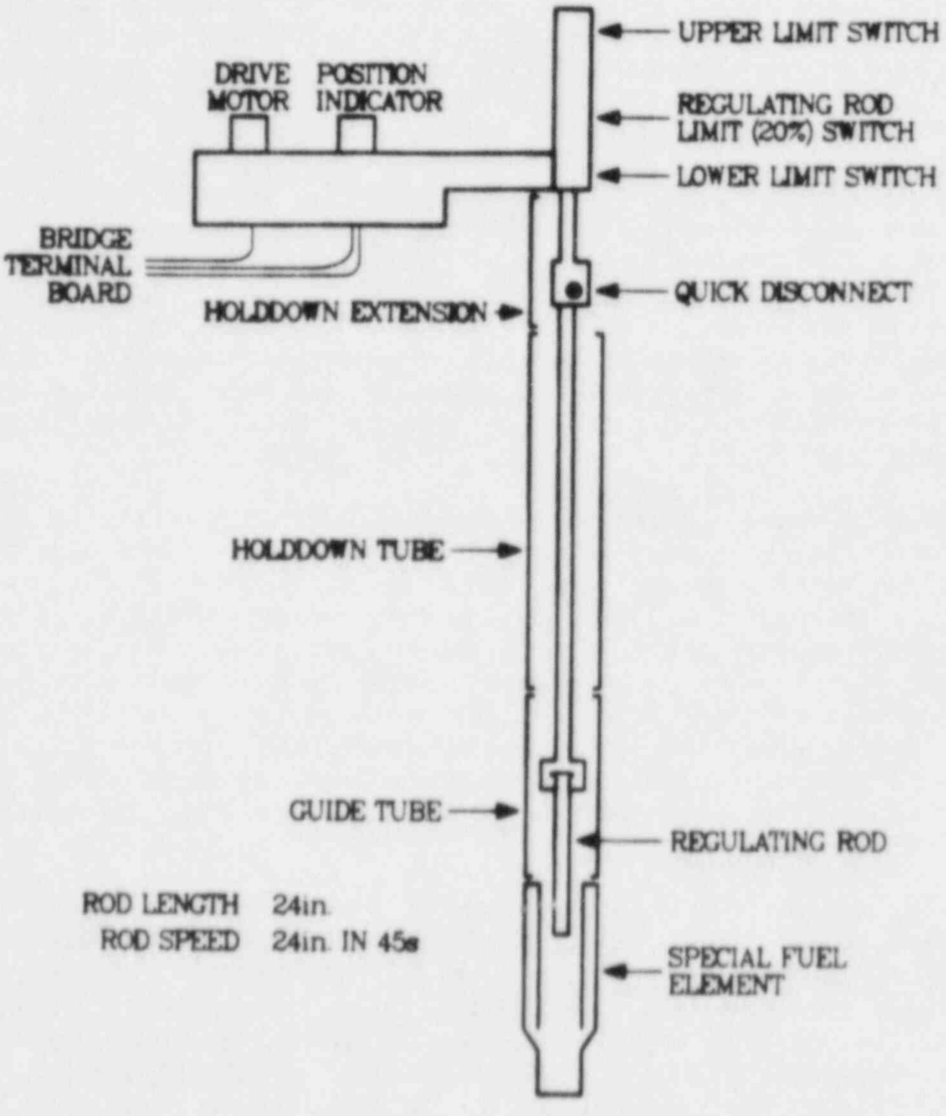

Figure 7.2 FNR regulating rod drive unit

in response to a power level or period signal. The output of the servo demand power level (set by the operator) is compared continuously with the actual power level output signal of the linear channel. The demand level is determined by the range switch and percent demand potentiometer, and the reactor power level is raised to the demand level on a fixed preset period. The period signal that feeds the servo amplifier allows power level changes (within the reactivity operating-range limits of the regulating rod) to be made automatically on a constant period. This feature allows for the preset power level to be maintained automatically during long-term operational runs. Limit switches on the regulating rod inhibit the servo amplifier control when the regulating rod reaches the down limit. Additionally, if the power level indication drops below the set point by a >5% margin, the control system will drop out of automatic servo control, placing the reactor in manual mode. The linear power level recorder must indicate at or above a preset value, or the reactor drops out of automatic servo control. Also, the shim-safety rods must be in contact with their magnets, or the automatic servo control mode will drop out.

7.1.3 Supplementary Control Systems - Primary Coolant System

The supplementary control systems, also designated as process control systems, provide for operation and regulation of the primary and secondary coolant systems. Included in the process control system are circuits and devices that monitor coolant parameters including temperature, pool water level, and conductivity. Interlocks between the process instrumentation system and the scram system provide positive control of the reactor under all operating conditions. These control systems ensure proper operation of the process-related systems and provide information on the status of these systems at the control console or the instrument panel.

During high-power operations when the reactor is located in its beam port position, the primary coolant system removes the decay heat from the core by forced circulation and maintains the bulk coolant temperature below 116°F. A movable header positioned beneath the core provides for forced circulation cooling when it is held tightly against the bottom of the hopper (header-up position), directing the primary flow from the fuel elements into the header and subsequently to a heat exchanger for cooling. The header is latched to the hopper by an electromechanical device consisting of a pressure switch that receives its signal from a flow orifice and associated solenoid and is wired to the primary coolant pump circuit. A more detailed description of the primary coolant system is provided in Section 5.1.

If the pump flow drops below 900 gal/min or if a power failure occurs, the electromagnet on the header-hopper is deenergized and the header is released, causing it to drop to the lowered position. When dropped to the lower position, the header closes a microswitch, producing a "header down" scram signal. Primary coolant flows from the header into the holdup tank and subsequently to the primary pump. From there, it is pumped to the heat exchanger, where the heat can be removed from the primary coolant by the secondary coolant. An isolation valve located at the entrance orifice of the holdup tank causes the reactor to be scrammed if the valve is moved from the open position as a result of a loss of primary coolant flow. Additionally, a pressure switch located in the holdup tank also scrams the reactor if a low pressure condition exists in the tank, which would indicate a substantial leak in the primary coolant system.

7.2 Instrumentation System

The reactor instrumentation system is fully integrated with the reactor safety system (rod control and scram systems) to form a single integrated system. Both nuclear and nonnuclear parameters are measured and monitored by the system. The FNR Technical Specifications require a minimum number of safety channels (shown in Table 7.1) to be operable before the reactor can be made critical. The Technical Specifications also require that additional safety-related instrumentation (identified in Table 7.2) be operable. The reactor instrumentation system consists of neutron detector channels, various controls and alarms, and instrumentation for measuring temperature, flow, pool level, and radiation levels.

Table 7.1 Required safety channels

Channel	Set Point*	Minimum Number Required	Function
Log Count Rate	2 counts/s	1	Rod withdrawal interlock
Log N-Period		1	Wide range power level and input for period scram
Period Safety	5 s	1	Scram
Level Safety	120%	2	Scram
No Water Flow at High Power (≥100 kW)	• 900 gal/min or • Holdup tank isolation valve not fully open, or • Holdup tank static pressure 1 psig below full power value	1	Scram
Control Rods Not in Shim Range	Within 5% of setting		Scram
High Power/ Header Down	<900 gal/min	1	Scram
Header Up/ No Water Flow	900 gal/min	1	Scram
Building Exhaust Radiation Level	1 mR/h	1	Scram

See footnote at end of table.

Table 7.1 (Continued)

Channel	Set Point*	Minimum Number Required	Function
Building Alarm Manual Switch		1	Scram
Manual Scram Switch		1	Scram
Magnet Power Key Switch Scram		1	Scram
Reactor Coolant Exit Temperature	129°F	1	Auto rundown
Pool Level	1 ft below pool overflow	1	Auto rundown
Bridge Not Clamped	When clamps released	1	Scram
Beam Porter Thermal Column Doors Open		1	Scram

*Values listed are limiting set points. For operational convenience, set points may be changed to more conservative values.

Table 7.2 Required safety-related instrumentation

Instrumentation	Set Point	Minimum Number Required	Function
Linear Level Channel	As required	1	Linear power level measurement and input for the automatic control mode
Power Level Deviation Interlock	95% of control point setting	1	Return reactor to manual control mode if set point is reached
Reactor Coolant Inlet Temperature	Not applicable	1*	Provide information for the heat balance determination
Facility Radiation Monitor System**			
1. Building Air Exhaust (2)	1 (1) mrem/h	1	Alarm, scram, initiates confinement evacuation

Table 7.2 (Continued)

Instrumentation	Set Point	Minimum Number Required	Function
2. Reactor Bridge	30 (50) mrem/h	1	Alarm
3. NW Column	10 (5) mrem/h	1	Alarm
4. N Wall	5 (50) mrem/h	1	Alarm
5. NE Column	2 (50) mrem/h	1	Alarm
6. Hot DI	20 (50) mrem/h	1	Alarm

* Not required for natural convection operation.

**The facility radiation monitoring system consists of six radiation detectors that alarm and read out locally and are recorded in the control room. The normal set points for this system are shown. The value in parentheses is the maximum set point that will be used depending on local conditions. Use of higher than normal set points will require approval of the Reactor Manager or the Assistant Reactor Manager. Any reactor staff member may adjust a set point lower than the normal value.

7.2.1 Nuclear Instrumentation

The nuclear instrumentation is designed to provide the operator with the information necessary for proper manipulation of the nuclear controls. The neutron monitoring instrumentation consists of six neutron detection channels that measure the reactor power from the source range to full power. Two fission chamber channels monitor the reactor power from the source range to full power. Two compensated ion chamber channels measure reactor power from the intermediate range through full power, and two uncompensated ion chamber power range channels monitor the power level from 500 kW to >2 MW (full power).

All neutron detectors are sealed in aluminum cans and are mounted on the perimeter of the core so that their positions are manually adjustable for power changes, sensitivity, and calibration. The startup channels can be withdrawn automatically (using winch cable drive motors) to adjust for increasing power levels and have a travel length of 90 in. and a speed of 3 in./s.

The two identical startup channels consist of a power supply, fission chamber, preamplifier, linear amplifier, and log count rate meter and recorder. These channels provide power indication from below source level to full power. In addition, interlocks (during reactor startup), prevent shim-safety rod motion unless the measured source range level indication is greater than 5 counts/s. This ensures that there is a measuring channel indicating neutron flux levels before the approach to criticality.

The intermediate range channels consist of the Log-N/period channel and the linear servo channel. The Log-N and period channel provides reactor period and power level indication from source range to full power. It consists of a compensated ion chamber, power supply, Log-N amplifier, Log-N and period recorders, period channel (Safety System Channel C), and Log-N meter. The detector is located behind the north end of the heavy water tank. The power level signal is converted to a period signal within Safety System Channel C (period channel) and provides for a period scram if the reactor period is 5 s or less. Additionally, the power level signal also enters a period circuit within the Log-N amplifier, and the resultant period is output to a period recorder that is independent of the safety system period channel (Safety System Channel C). The period recorder has two interlocks associated with it. A rod interlock prevents the regulating rod from being withdrawn if the reactor period is less than 30 s, and an automatic rundown of the shim-safety rods is initiated if the period drops to less than 10 s. Also, the Log-N channel provides for reactor scrams at 5% (100 kW) or greater power operation if either the high power/no flow or the high power/header-down signals are received.

The linear-channel/servo-control system consists of a compensated ion chamber, power supply, range-selector switch, recorder controller, and a position-adjusting control unit. It provides for power indication over 15 ranges (~4 decades from 100 W to 5 MW). The operating ranges are: 100 W, 200 W, and 500 W; 1 kW, 2 kW, 5 kW, 10 kW, 20 kW, and 500 kW; and 1 MW, 2 MW, and 5 MW). This channel is used for automatic fine control of reactor power level. The output of the compensated ion chamber provides an output current proportional to the neutron flux at the neutron chamber, which is fed to the range selector that in turn provides a signal to the recorder controller. The controller is coupled to the servo control unit, which provides the input signal that manipulates the regulating rod to maintain the power level at a given set point. The reactor power level is compared continuously with the demand level set by the operator. The demand level is determined by the range switch position and the picoammeter. If the power level is above the demand set point, the regulating rod is inserted into the reactor until the power level is returned to the demand set point. If the power level drops below the demand set point, the regulating rod is withdrawn until the power level is increased to the demand set point. The range selector switch is repositioned periodically during reactor startup and for controlled power level changes, to keep the indicated power level on scale. Interlocks associated with the servo system include an automatic shim-safety rod rundown (insertion) if the reactor power level increases to 2.3 MW (115% power). This interlock function precludes a scram that would occur if the power level reaches 2.4 MW (120% power). Additionally, this rundown function occurs at 115% indication on the recorder regardless of what range has been selected (on the picoammeter).

An alarm signal is provided at a 110% (2.2-MW) power level. The servo control system drops out of automatic control when the indicated power drops below the set point by more than 5%, the range selector switch is repositioned, or the regulating rod is repositioned manually. If the servo system malfunctions, an interlock that inserts the regulating rod (if the indicated power level drops 15% below the control set point) prevents any sudden inadvertent insertion of reactivity, and subsequent step increases in power. Limit switches on the regulating rod further inhibit the servo amplifier control when the regulating rod reaches its upper or lower limit of travel.

The power range channels incorporate two uncompensated ion chambers (located behind the heavy water tank) that monitor the reactor power level from the source range to >2 MW and provide for a reactor scram at 120% of full power (2.4 MW). The two channels are identical and consist of an uncompensated ion chamber, a power supply, a safety amplifier, and magnet amplifiers. If the power level exceeds a scram set point, the safety amplifiers provide for the magnet current to each shim-safety rod to be interrupted, scramming the reactor.

All nuclear safety channels (A, B, and C; A and B are the power range channels and C is the period output of the Log-N channel) include calibrating and testing circuits that are built into the console as part of the safety system monitor and testing unit.

7.2.2 Process Instrumentation

In addition to the nuclear monitoring system described above, there are temperature-, flow-, and water-measuring channels that are additional safety-related instrumentation required by the FNR Technical Specifications for reactor operations.

The temperature system consists of temperature detectors (thermohms) and a temperature recorder that monitor the temperature of the bulk coolant from two positions: 20 ft and 2 ft from the pool surface, primary coolant at the heat exchanger inlet and outlet, and secondary coolant at the heat exchanger inlet and outlet. The recorder has a high temperature switch that is coupled with the reactor safety system and provides for an automatic rundown of the safety control rods if the bulk coolant temperature exceeds 129°F.

The primary coolant flow system is required for reactor power operation in excess of 100 kW. The flow system consists of two primary differential pressure transducers that sense (in parallel) flow across of the primary coolant flow orifice. The pressure signal is transmitted to a square root extractor and translated into a flow signal. A primary low flow scram is actuated if the primary flow drops below 900 gal/min and the reactor is at high power operation. Additionally, alarms provide zero flow signals for the high-power/zero-flow and header-up/zero-flow reactor scrams. Each of the signals is displayed on the digital flow readout.

The secondary flow transducer senses flow across the secondary coolant flow orifice. The signal is measured similarly to the primary coolant flow signal and then transmitted to a digital flow readout.

The pool level monitoring system consists of two float switches. One actuates a local alarm and the other initiates a building alarm when the pool level drops 5 and 12 in. respectively. An automatic rundown of the shim-safety rods that is initiated when the pool level decreases 12 in. is required to be operable before reactor power operation can begin.

The primary coolant conductivity measurement system consists of conductivity cells that measure primary coolant conductivity at three locations, one in the demineralizer inlet line and one in each outlet of the two demineralizers. The conductivity is displayed by the conductivity recorder located in the control room.

7.2.3 Inhibits and Annunciation

Several safety interlocks are incorporated into the control rod circuitry to prevent any inadvertent reactivity insertions. The following interlocks must be satisfied before the shim-safety rods can be withdrawn:

(1) Both log count rate meter indications must be >5 counts/s (adequate source signal).
(2) The regulating rod must be inserted fully.
(3) The magnet current key is on.
(4) Automatic rundown must not be in progress.

An annunciator panel mounted on the control console provides the operator with information on the important reactor operation parameters. The condition initiating an annunciator must be acknowledged and corrected, and the annunciator must be reset to restore it to normal conditions. For scram circuits, the reset restores the scram annunciator. The "thermal column door open" and the "shim range defeat" scrams can be defeated (bypassed) by switches located in the rear of the console.

7.2.4 Reactor Safety System

The scram system circuitry is independent of the other control system circuits. All scram conditions are indicated by the annunciators in the reactor console. The scram system consists of three separate channels, any of which can initiate a scram. Channels A and B monitor reactor power and initiate scram at 120% of full power, and Channel C monitors the reactor period and initiates a scram if a period of 5 s or less is reached.

In addition to the reactor power level or period scrams, the following conditions will cause a scram by deenergizing the magnet power to the rod magnet amplifiers:

(1) radioactivity in building air too high

(2) header up--zero flow (primary coolant system)

(3) bridge not clamped

(4) control rods not in shim range

(5) header down (high-power operations, primary flow <900 gal/min)

(6) zero flow (high-power operation)

(7) beam port door open

(8) thermal column door open

(9) building alarm (caused by high radioactivity readings in the FNR exhaust air or fuel vault)

(10) manual scram

Figure 7.3 shows a block diagram of the FNR safety system.

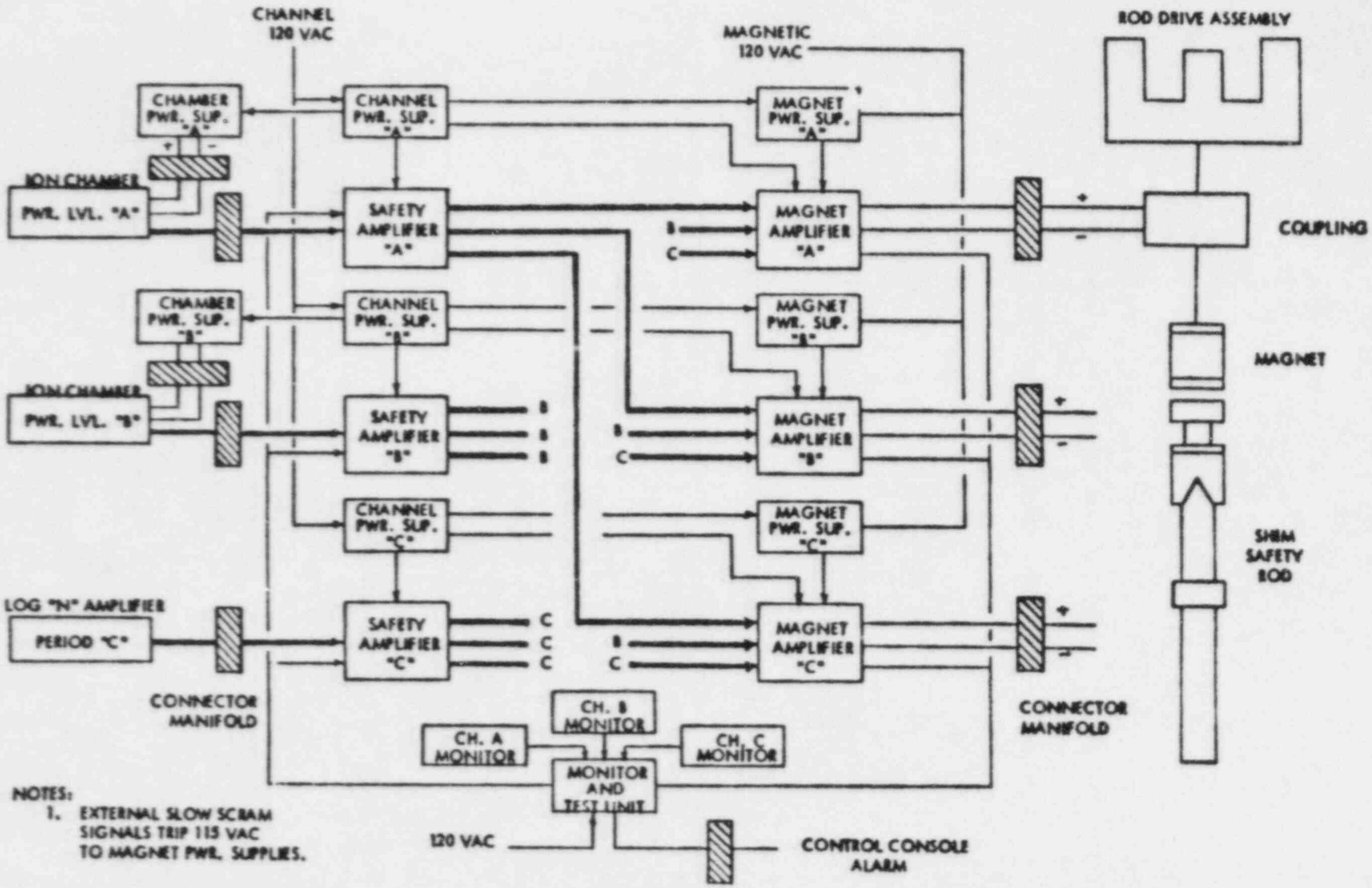

Figure 7.3 FNR safety system

An automatic rundown will insert all of the shim-safety rods if any of the following conditions exist:

(1) Reactor period is less than 10 s.

(2) Temperature recorder indicator exceeds 129°F (core exit).

(3) Reactor pool level decreases more than 12 in.

(4) Linear power level exceeds 115% of recorder indication.

(5) Reactor in automatic mode and regulating rod reaches lower limit.

The automatic rundown of the shim-safety rods continues until all of the shim-safety rods have reached their lower limit positions or an operator resets the rundown after the cause has been identified and corrected.

7.3 Radiation Monitoring Instruments

The FNR has a radiation measurement system to monitor the radioactivity levels in the FNR facility and stack exhaust. The system consists of mobile air particulate monitors for monitoring airborne particulate activity on the pool floor, in the beam port area, and at stack #2; gaseous activity detectors that monitor the exhaust air from the reactor building and at stack #2; and local area monitors that measure gamma radiation levels throughout the facility.

The radiation levels from the local area and gaseous monitors are measured on the radiation recorder in the control room. If the levels exceed 10 mrem/h, a high radiation alarm is actuated. When the radiation levels exceed 1 mrem/h in the building air and exhaust plenum, the building alarm is actuated, the reactor is automatically scrammed, the ventilation fans are shut, and the building exhaust and supply dampers are closed. The fuel vault has a local alarm that actuates at 5 mrem/h and actuates a building alarm and has the same functions as the building air exhaust 1 mrem/h alarm. Other area monitors that have local alarms are the hood exhaust, pool floor, and beam port floor. The PML stack #2 monitors send a signal to the control console.

7.4 Conclusion

The control and instrumentation systems at the FNR facility, which are similar to those installed in many other operating nonpower reactors, are well designed and provide reliability and flexibility. There is redundancy in the crucial nuclear, process, radiation, and temperature monitoring circuits. In particular, nuclear power measurements are overlapped in the ranges of the startup, log-N linear power, and power level channels. The control system is designed to shut the reactor down automatically if electrical power is lost or interrupted.

From the above analysis and the formal administrative controls required in the operation of the FNR, the staff concludes that the control and instrumentation systems at the FNR comply with the requirements and performance objectives of the Technical Specifications and that they adequately ensure the continued safe operation of the reactor.

8 ELECTRIC POWER

The FNR has two separate sources of power: (1) normal operating power, which is utility-furnished, and (2) emergency standby power by a generator that is provided to maintain operation of certain of the ventilation and lighting systems. Neither power system is necessary to shut down the reactor and maintain it in a safe shutdown condition.

8.1 Normal Operating Power

Primary electric distribution to the FNR-PML facility is via a 480-V power line that enters Room 1033. This primary supply line is bus-tied to similar lines in two nearby buildings. Electric power at 480-, 240-, and 120-V ac is distributed from this power distribution center to the reactor building. Separate circuit breakers are provided for reactor control systems and reactor building service.

8.2 Emergency Operating Power

In the event of loss of normal reactor power, emergency power is supplied to certain loads by the gasoline fueled emergency generator. In general, those loads can be classified as radiation monitoring equipment, a limited amount of building lighting, alarm systems, the FNR ventilation system, and auxiliary equipment including the bridge drive circuit, the heavy water tank control circuit, the pneumatic tube air blower system, and the backup reactor air compressor. The emergency generator is in Room 2077. The bus transfer, which automatically switches from the normal building supply to the emergency generator, is located in Room 2074. The emergency distribution panel is located on the beam port floor.

8.3 Conclusion

On the basis of the above analysis, the staff concludes that the normal and emergency power provisions at the FNR are adequate. The emergency generator appears to be well maintained. The power systems (both normal operating and emergency) are well suited to their roles in operation of the facility. Therefore, the staff concludes that the normal and emergency electrical power provisions for the reactor facility are adequate for continued safe reactor operation.

9 AUXILIARY SYSTEMS

The FNR auxiliary systems include the fuel handling and storage system, the compressed air system, and the fire protection system. The portion of the ventilation system not associated with emergency operation normally is considered an auxiliary system, but the entire ventilation and exhaust system has been described in Section 6.

9.1 Fuel Handling and Storage System

New fuel elements are stored in wall-mounted racks in a concrete vault. The fuel element spacing and rack locations are such that a critical assembly would not be possible with the maximum number of elements of the highest possible enrichment stored, even if the vault were to be filled completely with water.

Fuel storage racks in the south end of the pool are used for depleted fuel being prepared for shipment. Fuel storage racks in the north end of the pool are used for partially depleted fuel that can be reused in the reactor core. Two types of long-handled aluminum tools are used to rearrange fuel elements in the core or to move elements to or from storage racks.

9.2 Compressed Air System

The reactor facility compressed air system has two air compressors located in Room 2077. The main compressor is activated at an air pressure of 76 psig, charges the reactor building air reservoir, and cuts out at a pressure 84 psig. A backup compressor actuates at approximately 55 psig in the event of main compressor failure. From Room 2077, reactor air is distributed for use in the reactor building and in the PML for ventilation system pneumatic damper activation, for pneumatic instrumentation and controls, and for service air in the experimental areas.

9.3 Fire Protection System

Fire protection is available from fire hose cabinets located throughout the PML-FNR facility. In addition, portable fire extinguishers are located throughout the PML and FNR buildings. A fire alarm system can be activated manually from stations throughout the facility. This alarm is initiated automatically by smoke detectors located in Rooms 2054, 3051, and 3021. All fire alarms are transmitted via telephone lines to the University Department of Safety and Public Security. The officer on duty contacts the PML-FNR emergency staff and the city fire department.

9.4 Conclusion

The staff concludes the FNR facility's auxiliary systems are adequate to support reactor operations in a safe and reliable manner.

10 EXPERIMENTAL PROGRAMS

The FNR serves as a source of ionizing and neutron radiation for neutron activation analysis, radiochemical production, gamma and neutron irradiation, neutron radiography, materials testing services, and training. Experimental facilities include in-core, pneumatic tube, and beam port facilities for neutron irradiation and radiography, as well as spent fuel storage facilities for gamma-ray irradiation.

10.1 Experimental Facilities

10.1.1 In-Core Irradiation

The open pool of the reactor permits the irradiation of experiments in or near the reactor core in sample holders that may be left in the core for periods ranging from minutes to a year or more (see Figure 10.1).

10.1.2 Pneumatic Tubes

Five pneumatic tubes (four horizontal and one vertical) are available for irradiation of small targets. These 1-7/16-in. outside diameter aluminum tubes penetrate the pool floor and terminate adjacent to the west face of the reactor core (see Figure 10.2). Experiments may be irradiated in this facility from 1 s to 2 h.

10.1.3 Beam Ports

Ten horizontal beam ports penetrate the pool wall and terminate at the heavy water tank that is adjacent to one side of the core (see Figures 10.1 and 10.3). A vertical beam tube functions as a neutron radiography facility.

Nine of the horizontal beam ports have four barriers between the pool and the experimental area. The tenth beam port, which is designated as beam port "I," has two barriers. When the beam ports are not in use, they are closed off by a retractable shield door. This shield door is interlocked, and there are indicators in the reactor control room to prevent inadvertent use. The beam ports normally are kept filled with water when they are not being used.

10.1.4 Large Access Facility

A thermal column penetrates one pool wall. A sealed aluminum flange backed by 4 in. (10.2 cm) of lead and 3 ft (0.9 m) of graphite separates the pool from the experimental area.

10.1.5 Gamma-Ray Irradiation Facilities

Spent fuel storage racks are available for gamma-ray irradiations. Dose rates of up to 10^5 rad/h are available in the reactor pool at this facility.

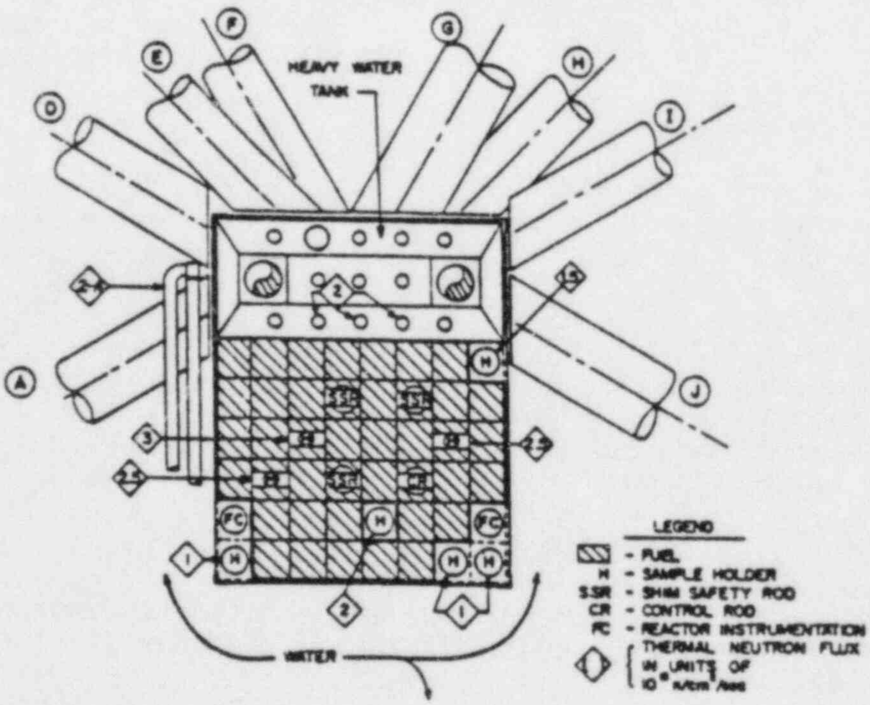

Figure 10.1 FNR beam port penetrations

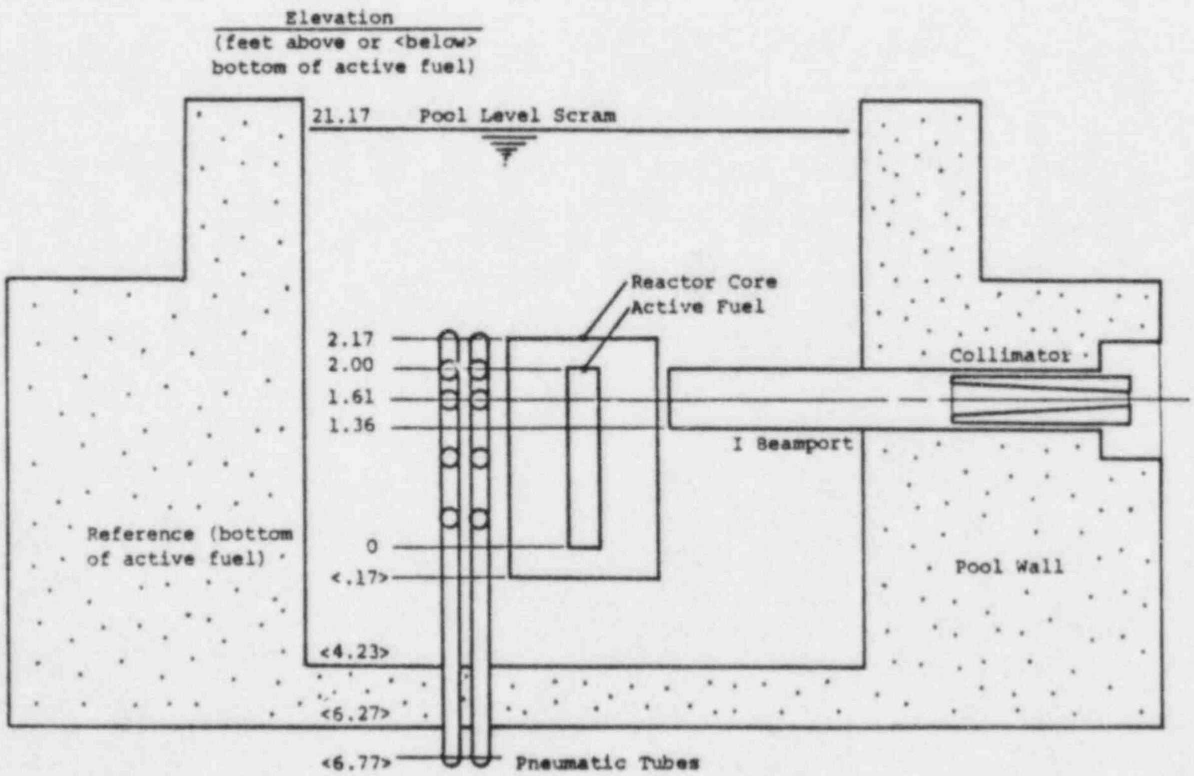

Figure 10.2 FNR pool

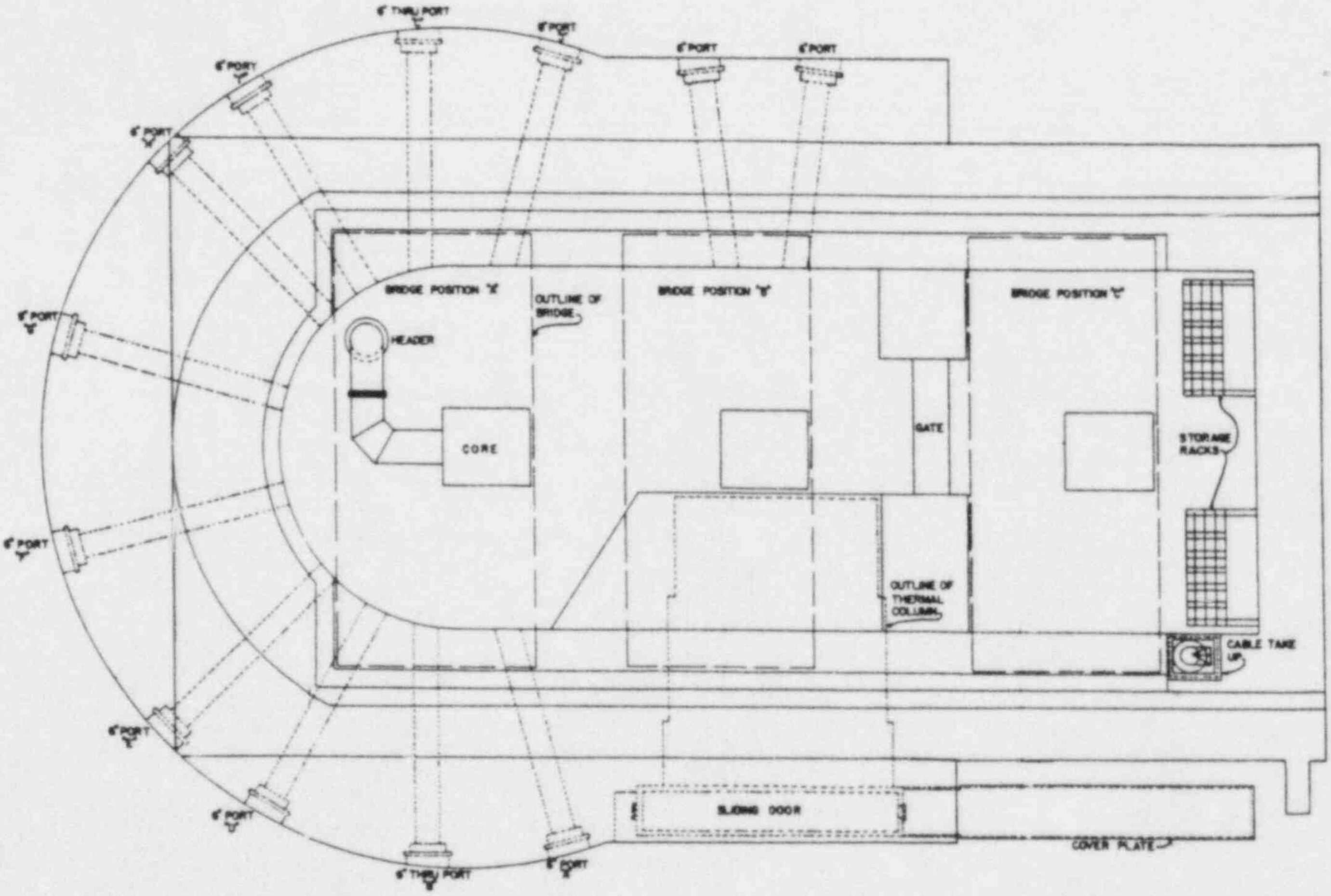

Figure 10.3 Reactor pool cutaway

10.2 Experiment Review

Administrative and operating procedures govern the use of the reactor and associated experimental facilities. Experiments to be placed in the reactor must be reviewed and approved by the Reactor Health Physicist for radiation safety considerations and by the Reactor Manager for compliance with limits in the Technical Specifications.

Unique or unusual experiments must be approved by the reactor Safety Review Committee. This committee consists of eight members from various pertinent disciplines and includes the Director of Radiation Control Services.

Before any experiment is placed in or near the core, the Senior Shift Supervisor verifies that the entire review and approval process has been completed.

10.3 Conclusions

Experimental facility design and Technical Specifications limit the amount of reactivity worths associated with experiments (see Sections 4 and 14), and administrative and procedural controls are adequate to ensure that experiments will be performed without significant risk of radiation exposure to FNR facility personnel or to the public.

11 RADIOACTIVE WASTE MANAGEMENT

The major radioactive waste generated by reactor operation is activated gases, principally ^{41}Ar. A limited volume of radioactive solid waste, primarily liquid waste retention tank sludge, is generated by reactor operations, and some additional solid waste is produced by the research programs involving the use of reactor facilities. Liquid radioactive waste is produced by regeneration of the resin bed in the water demineralizer system.

11.1 Waste Generation and Handling Procedures

11.1.1 Solid Waste

Solid waste generated as a result of reactor operations consists primarily of general laboratory waste, such as potentially contaminated paper and gloves; occasional small, activated items; sludge from the liquid waste retention tanks; and approximately two 55-gal drums per year of spent ion exchange resins. These resins are estimated to have a radioactivity level of ~200 μCi. In 1984, the amount of solid waste generated was 148 ft^3 containing 1.5 mCi of radioactivity. Solid waste is transferred to the University Radiation Control Services before being packaged and shipped to an approved disposal site in accordance with applicable regulations.

11.1.2 Liquid Waste

Liquid radioactive waste generated as a result of reactor operations consists primarily of demineralizer regeneration fluid. The research laboratories in the PML generate the bulk of the volume of liquid waste that is handled at the facility. All of the liquid effluent is collected in sumps and is pumped automatically to one of the three 3000-gal liquid retention tanks.

The liquids are sampled and then discharged to the sanitary sewer in concentrations that are below 10 CFR 20 limits. The reactor facility also has a cumulative annual activity release limit of 0.5 Ci.

11.1.3 Airborne Waste

The potential airborne radioactive wastes are ^{16}N (produced by irradiation of the oxygen in the coolant water), ^{41}Ar (produced by irradiation of the component of argon in the air), gaseous fission products in the fuel, and radioactive iodine generated in the radiochemical production process.

The FNR building exhaust, FNR beam port and hood exhaust, and the PML exhaust stack are monitoried for ^{41}Ar. The average radioactive argon concentration measured at these release points is 5% of the maximum permissible concentration (MPC). The PML exhaust stack and FNR building exhaust are monitored for radioactive iodine. The average radioactive iodine concentration measured at these release points is 0.6% MPC. No fission products escape from the fuel cladding during normal operations. The coolant flow down through the core to the heat exchanger at elevated power levels precludes the release of ^{16}N as this isotope

essentially has decayed within the piping system by the time the water returns to the open pool ($T_{½}$ = 7.1 s).

11.2 Conclusion

As discussed above, ^{41}AR, the most significant radionuclide released by the reactor to the environment during normal operations, has a concentration at the site boundary of less than 1% of the unrestricted area MPC. Liquid and solid wastes are even less significant. Therefore, the staff concludes that the radioactive waste management activities of the FNR have been conducted and are expected to continue to be conducted in a manner consistent with both 10 CFR 20 guidelines and ALARA principles.

12 RADIATION PROTECTION PROGRAM

The FNR has a formal radiation safety program with a health physics staff equipped with radiation detection instrumentation and procedures to determine, control, and document occupational radiation exposures at the facility. The facility monitors liquid effluents before release and monitors gaseous effluents at exhaust points. The FNR facility has developed an environmental monitoring program to verify that radiation exposures in the unrestricted areas around the reactor facility are within regulations and guidelines. The health physics staff is actively involved in the review of experiments and operating procedures.

12.1 ALARA Commitment

The University of Michigan administration has formally established the policy that all operations are to be conducted in a manner to keep all radiation exposures as low as is reasonably achievable (ALARA). All proposed experiments and special procedures are reviewed for ways to minimize exposure. Dosimetry data on reactor personnel is reviewed extensively and, when appropriate, investigated by health physics personnel and reactor operations management.

12.2 Health Physics Program

12.2.1 Health Physics Staff

The normal full-time health physics staff at FNR consists of one full-time health physicist and one full-time health physics technician. All routine radiation safety functions at the reactor facility are performed by this staff. Additionally, the staff provides advice and assistance with any special problems that might arise. The health physics staff has been given the authority, the responsibility, and adequate lines of communication to provide an effective radiation safety program.

12.2.2 Procedures

Written procedures have been prepared that address the health physics staff activities that are required in support of the routine operation of the reactor. These procedures specify administrative limits and action points and appropriate responses and corrective action, if these limits or action points are reached or exceeded.

12.2.3 Instrumentation

The FNR has a variety of radiation detection and measurement devices. The portable instruments that are available are capable of detecting a wide range of intensities of any credible type of radiation. These instruments are present in sufficient quantity to provide adequate coverage with backup. The instrument calibrations are performed to ensure that a sufficient range of intensities of various radiation types can be detected promptly and measured correctly.

12.2.4 Training

Reactor operations personnel receive health physics training as part of the licensing and requalification program. This training program has been approved by the Safety Review Committee and includes documentation of initial training and retraining every 2 years.

Experimenters and frequent or long-term visitors receive health physics training from the Reactor Health Physicist at a level appropriate to their needs and commensurate with the requirements of 10 CFR 19 and 20.

12.3 Radiation Sources

12.3.1 Reactor

Sources of radiation directly related to reactor operation include radiation from the reactor core, water cleanup equipment, and gases dissolved in the reactor coolant that either decay in-line or are released to the reactor room atmosphere.

Radiation exposure rates from the reactor core are reduced to acceptable levels by water and concrete biological shielding. Procedures, protective equipment, and access control serve to limit personnel exposure to radiation in the cleanup system and coolant loop.

Personnel exposure to radioactive ^{41}Ar is limited by the prompt removal of this gas from the reactor room and experimental areas. The gas is discharged to the atmosphere, where it is diluted further. Dose limits at the site boundary are approximately 1% of the guideline limits in 10 CFR 20.

12.3.2 Extraneous Sources

Sources of radiation that may be considered as incidental to normal reactor operation include spent fuel storage; radionuclides produced for research, industry, and medicine; and various activated components and equipment. Personnel exposure to these sources is controlled by the mandatory use of reviewed and approved written procedures.

12.4 Routine Monitoring

The radiation measurement system consists of air particulate monitors, gaseous activity detectors, and area radiation monitors.

The air particulate monitors measure airborne particulate activity at the pool floor, at the beam port floor, and at exhaust stack #2. The gaseous activity detectors monitor the exhaust from the reactor building and at stack #2. The local area radiation monitors measure gamma-ray radiation levels throughout the reactor facility. Several of these detectors send information to the control console and have scram functions.

12.5 Occupational Radiation Exposures

12.5.1 Personnel Monitoring Program

FNR personnel exposures are determined by the use of film badges. These badges are processed and read monthly by a firm that meets NRC standards.

12.5.2 Personnel Exposures

During the past 5 years an average of 135 personnel were monitored with film badges. The annual summaries are shown in Table 12.1. As can be seen, doses are generally small fractions of 10 CFR 20 guidelines.

Table 12.1 Number of individuals in exposure interval

Whole-Body Exposure Range (rem or 10^{-2} Sv)	1980	1981	1982	1983	1984
No measurable exposure	83	62	75	101	46
Measurable exposure					
<0.10	56	40	28	48	33
0.10--0.25	8	12	7	9	8
0.25--0.50	6	8	6	4	0
0.50--0.75	5	3	6	6	7
0.75--1.00	1	2	2	2	2
1.00--2.00	0	0	0	1	0
>2.00	0	0	0	0	0
Totals	159	127	124	171	96

12.6 Effluent Monitoring

12.6.1 Airborne Effluents

Airborne effluents from the reactor facility consist principally of activated gases. The effluents are monitored to determine release concentrations and to ensure that airborne radioactive material released from the FNR is maintained below 10 CFR 20 limits (see Sections 6 and 11).

12.6.2 Liquid Effluents

All radioactive liquids are collected in one of three 3000-gal retention tanks. The liquid in the tanks is sampled and analyzed before it is released to the sanitary sewer system (see Section 11).

12.7 Potential Dose Assessments

Natural background radiation levels in the Ann Arbor area result in an average annual exposure of about 120 mrem/yr. Medical and other man-made exposures may add to this natural background.

An environmental monitoring program for the FNR facility, run by the University of Michigan Radiation Control Service, consists of direct radiation monitors (thermoluminescent dosimeters) and air and water sampling stations. The results of this program and of calculations based on effluent concentrations indicate a maximum potential annual exposure of less than 100 mrem in unrestricted areas with an average annual exposure of less than 10 mrem above background that is attributable to operation of the FNR.

12.8 Conclusions

The staff concludes that radiation protection receives appropriate support from the university administration. The staff also concludes that (1) the program is staffed and equipped properly, (2) the reactor health physics staff has adequate authority and lines of communication, and (3) the procedures are integrated correctly into the research plans. Effluent and environmental monitoring programs conducted by FNR personnel are adequate to identify significant releases of radioactivity promptly and to confirm possible effects on the environment, as well as to predict maximum exposures to individuals in the unrestricted area. These predicted maximum levels are well within applicable regulations and the guidelines of 10 CFR 20. Furthermore, the staff has found no instances of reactor-related exposures of personnel above applicable regulations and no unidentified significant releases of radioactivity to the environment.

For the above reasons, the staff considers that there is reasonable assurance that the personnel and procedures will continue to protect the health and safety of reactor personnel and the public.

13 CONDUCT OF OPERATIONS

13.1 Overall Organization

The University of Michigan FNR facility organization, including the interrelationships between operating and supporting units, is shown in Figure 13.1.

13.2 Staff Responsibilities

The FNR Reactor Manager is responsible for assuring that all operations of the FNR are conducted in a safe manner and within the limits prescribed by the facility license, the Technical Specifications, and the NRC regulations. In all matters pertaining to the operation of the plant and Technical Specifications, the FNR Reactor Manager reports to and is directly responsible to the Director, Michigan Memorial-Phoenix Project.

A health physicist who is organizationally independent of the FNR operations group is responsible for radiological safety at the facility.

A NRC licensed reactor operator or senior reactor operator must be present at the controls whenever the reactor is in operation. The senior reactor operator must be present or readily available on call at any time the reactor is in operation. The minimum operating crew is composed of two individuals, at least one of whom will be so licensed.

13.3 Operational Review

A Safety Review Committee reviews reactor operations and advises the Director of the Michigan Memorial-Phoenix Project in matters relating to the health and safety of the public and the safety of facility operations. The Safety Review Committee has eight members of whom no more than the minority may be from the line organization shown in Figure 13.1 or administratively report to anyone in that line organization below the Vice President for Research. The committee is made up of university staff and faculty.

The Safety Review Committee reviews and approves proposed experiments and tests utilizing the reactor facility which are significantly different from tests and experiments previously performed at the FNR. In addition, the committee reviews reportable occurrences; reviews and approves proposed amendments to the facility license; reviews proposed changes to the facility made pursuant to 10 CFR 50.59; and reviews audit reports on reactor operations prepared by a consultant.

13.4 Operational Audit

A consultant annually audits reactor operations and reactor operational records for compliance with internal rules, procedures and regulations, and with license provisions including Technical Specifications; audits standard operating procedures for adequacy and to assure that they achieve their intended purpose; and audits plant equipment performance with particular attention to operating anomalies, reportable occurrences, and the steps taken to identify and correct their causes.

13.5 Training

The qualifications for key supervisory personnel regarding educational and operating experience, stipulated in Section 6.1.4 of the Technical Specifications, satisfy the requirements of 10 CFR 55.

The minimum qualifications for the FNR Reactor Manager are a bachelor's degree and at least 4 years of reactor operating experience in increasingly responsible positions, or equivalent. Also, within 6 months after being assigned this position, apply for an NRC senior reactor operator's license.

13.6 Emergency Planning

10 CFR 50.54 and Appendix E to 10 CFR 50 require that nonpower reactor licensees develop and submit emergency plans. By letter dated October 29, 1982, UM submitted an Emergency Response Plan for the FNR site, in accordance with NRC and the American Nuclear Society (ANS) 15.16 guidelines.

On the basis of its review and evaluation of the October 1982 submittal and its supplements, the staff found that the emergency plan for the FNR facility demonstrates that the licensee has the capabilities to assess and respond to emergency events, provides the assurance that the necessary emergency equipment is available, and describes a plan of action to protect the health and safety of workers and the public. For the above reasons, the staff concluded that the FNR facility's emergency plan meets the requirements of the regulations and, therefore, is acceptable.

13.7 Physical Security Plan

The licensee has established and maintains a program designed to protect the reactor and its fuel and to ensure its security. The NRC staff reviewed the plan and visited the site. The staff has concluded that the plan, as amended, meets the requirements of 10 CFR 50.34(c) (License Amendment No. 28, dated October 17, 1983). Both the Physical Security Plan and the staff's evaluation are withheld from public disclosure under 10 CFR 2.790(d)(1).

13.8 Conclusion

On the basis of the above discussions, the staff concludes that the licensee has sufficient training, experience, management structure, and procedures to provide reasonable assurance that the reactor will be managed safely and will cause no significant risk to the health and safety of reactor personnel or the public.

14 ACCIDENT ANALYSIS

In establishing the safety of the University of Michigan FNR operation, the licensee analyzed potential accidents to ensure that these events would not result in potential hazards to the reactor staff and the public. The NRC staff has evaluated the licensee's submitted documentation and analysis of the potential accidents and their possible consequences to the facility personnel and the public.

The following potential accidents and their consequences were considered to be sufficiently credible by the staff for evaluation and analysis.

(1) failure of a fueled experiment
(2) step reactivity insertion (step nuclear excursion)
(3) loss of reactor pool water
(4) minor accidents

Of these potential credible accidents, the staff concluded that the only one with the potential of releasing radioactive material to the FNR facility and to the unrestricted area outside the reactor facility is the failure of a fueled experiment (one containing fissile material intended for neutron irradiation) and the subsequent release of its fission product inventory into the reactor room. This event has been designated the maximum hypothetical accident (MHA). None of the reactor transients or other accidents analyzed posed a significant risk of fuel cladding failure and therefore would not result in a release of radioactive material.

14.1 Failure of a Fueled Experiment

The FNR Technical Specifications limit the maximum reactivity worth of unsecured experiments to 0.12% $\Delta k/k$ (0.16$) to limit the amount of instantaneous positive reactivity addition so that the fuel element integrity would not be breached and no fuel melting could occur. Additionally, the radioactive material content of an experiment (including the fission products) is limited for single- and double-encapsulated experiments so that the complete release of all the gaseous, particulate, or volatile components from the capsule could not result in exposures exceeding guidelines in 10 CFR 20. The limits of exposure are given in the Technical Specifications. These are:

(1) Single Encapsulation

Doses in excess of 10% of the equivalent annual dose guidance of 10 CFR 20 (<5 rem whole body and <15 rem thyroid for restricted areas and <0.5 rem whole body and <1.5 rem thyroid for unrestricted areas) for

(a) persons occupying unrestricted areas continuously for 2 h immediately following the release; or

(b) persons in restricted areas during the length of time required to evacuate the restricted area.

(2) Double Encapsulation or Vented Experiments

Doses in excess of the equivalent annual dose guidance of 10 CFR 20 for

(a) persons occupying unrestricted areas continuously for 2 h immediately following the release; or

(b) persons in restricted areas during the length of time required to evacuate the restricted area.

These limits are placed on the experiments to ensure that exposures subsequent to the unlikely occurrence of an experiment failure will result in doses below the 10 CFR 20 guidelines.

The licensee calculated the experiment activity limits for both the restricted and unrestricted areas for single and double encapsulations based on 10 CFR 20, Appendix B. This calculation indicated that the most restrictive case was the activity limits for the restricted area and these were used to define the licensee's experiment limitations. In the calculations, the licensee made the following assumptions:

(1) The volatile activity in the experiment was dispersed uniformly in the lower 1/4 volume of the reactor room floor.

(2) A person within the restricted area would be exposed to the radioactivity for ~6 min before evacuating the building.

(3) The volume of the reactor room is ~58,000 ft^3.

(4) Unrestricted areas were exposed continuously for a period of 2 hours following the experiment failure.

(5) The airflow from the exhaust duct has a maximum flow rate of 300 ft^3/min which is further diluted by the 11,000 ft^3/min exhaust flow rate in the PML exhaust. The stack dilution factor is 400.

(6) No radioactive decay was assumed for the activity released from the experiment.

For all of the experiment limits, the licensee conservatively assumed that the entire fission yield was ^{133}I. ^{133}I was selected because of its most restrictive limit (based on 10 CFR 20) as a result of its biological impact. Table 14.1 provides the calculated experiment activity content limits that were determined by the licensee based on the 10 CFR 20 guidelines. In other words, the activity indicated in Table 14.1, if released, will not exceed MPC.

The staff has reviewed the licensee's analysis of the experiment failure and found it to be extremely conservative for the following reasons:

(1) No credit was assumed for the dissolution, washout, or plateout of radionuclides in the reactor room.

(2) No radioactive decay was assumed; thus a maximum source term was used.

Table 14.1 Experiment activity limits (based on 10 CFR 20)

	Activity Limits on Experiments	
Encapsulation	Nonfueled	Fueled
Single	8×10^{11} MPC_R	$w\phi t = 3.12 \times 10^{16}$
Double	8×10^{12} MPC_R	$w\phi t = 3.12 \times 10^{17}$

Notes: MPC_R: maximum permissable concentration for restricted areas μCi/mℓ.

$w\phi t$: w = sample weight, ϕ = thermal neutron flux n/cm³/s, t = time/s.

(3) It was assumed for the restricted area exposures that 6 min would be required to exit the reactor room, and for the unrestricted areas that personnel were exposed to the discharge plume for 2 hours.

(4) For the unrestricted area exposures, it was assumed that no scrubbing by ventilation filters occurred and the maximum discharge flow rates were used.

On the basis of the above analysis, the staff concurs with the licensee and concludes that the restrictions stated in the Technical Specifications for the single- and double-encapsulated experiments will limit the potential consequences and subsequent fission product releases from the failure of a fueled experiment in air. The resultant maximum doses will not exceed the 10 CFR 20 guidelines. The staff further concludes that fueled experiments can be performed at the FNR facility in accordance with the limitations imposed by the Technical Specifications without undue risk to the health and safety of the public.

14.2 Step Nuclear Excursion

The total reactivity worth of all experiments is limited by the Technical Specifications to 1.2% (1.58$). To be conservative in its consideration of the effect on fuel element integrity of instantaneous reactivity insertion, the licensee has analyzed a step nuclear excursion in which 1.6% Δk/k (2.12$) reactivity is inserted into the core instantaneously. Because of this limitation and the maximum rate of mechanically inserting reactivity into the core with the control and regulating rod drives, the staff has not been able to identify a credible method for instantaneously inserting 1.6% Δk/k (2.12$) reactivity; however, it is assumed for purposes of the analysis that it can occur. The reactor is assumed to be operating at a power level between 0 and 2 MW, at which time 1.6% Δk/k (2.12$) reactivity is inserted instantaneously into the core. The potentially significant consequences associated with the rapid insertion of reactivity accident are the melting of the fuel or cladding material.

Tests conducted by the Idaho National Engineering Laboratory on the SPERT-I reactor containing fuel elements similar to those in the FNR indicate that an instantaneous reactivity addition, ~1.6% Δk/k (2.12$), produces an energy release of ~10 MW/s (9500 Btu). The SPERT and BORAX tests (Miller et al., 1964; Zeisaler, 1983; Forbes et al., 1956; Edlund and Norderer, 1957) concluded that

no melting or fission product release occurred from that level of reactivity insertion.

Additionally, the licensee has reviewed the data of the BORAX tests, which indicated that the instantaneous addition of about 1.8% $\Delta k/k$ (2.38$) to the FNR would melt the meat of the hottest fuel element if the ambient coolant temperature were as low as 70°F. The minimum FNR coolant temperature is ~90°F making the peak energy less than at 70°F. As indicated in Section 4.6.2, the instantaneous addition of 1.6% $\Delta k/k$ (2.12$) available in the FNR, which is less than 1.8% $\Delta k/k$ (2.38$), was estimated to cause the fuel temperature in the hottest fuel element to increase to ~900°F, ~300F° below the melting point.

From the above analyses, the staff concludes that the nuclear excursion from a step insertion of 1.2% of $\Delta k/k$ would not pose any significant hazard to the operating personnel, the environment, or the public.

14.3 Loss of Reactor Pool Water

The loss of reactor pool water was postulated for the FNR. The FNR has eight 6-in.-diameter and two 8-in.-diameter aluminum beam ports that penetrate the pool wall at four different heights and terminate in the heavy water pool. Additionally, there are eight 1-7/16-in.-diameter pneumatic tubes that penetrate the FNR pool floor and terminate at the face of the reactor core.

The licensee analyzed the loss of reactor pool water as a result of the damage of beam ports and rupture of the pneumatic tube below the bottom of the core. If the water level dropped to the lowest elevation in the lowest beam port, the active fuel would remain immersed in approximately 2 in. of water. The beam tubes are configured with at least two barriers to prevent the loss of coolant, with the exception of the I beam port, which has a 29-in.-long collimator that is open at both ends.

The I beam port also has a collimator that extends beyond the pool wall. (All other beam port collimators would remain intact within the concrete pool if the beam tubes were sheared.) However, if the pool level drained to just below the centerline, the active fuel would remain immersed in ~18 in. of water. The licensee performed calculations to determine the maximum consequences expected from an accident in which a pneumatic tube was damaged and the entire tube below the bottom was sheared. The maximum flow rate from a pneumatic tube rupture, assuming an initial pool level of ~28 ft above the opening where the drainage would occur, was determined to be ~210 gal/min. Additionally, it was assumed that no emergency makeup water was available and that a low water scram occurred. The time required to drain the pool water to the top of the core was calculated to be ~3 hours. By the time the core started to uncover, the fission product decay heat would have decreased, from ~7% of full power at shutdown to <1% of full power. The flow rate from the I beam port rupture was significantly less than that resulting from the pneumatic tube rupture.

From an analysis submitted by the licensee that accompanied the request to amend the license to permit replacement of the core with LEU fuel elements (J. B. Bullock, June 1962) the decay heat remaining in the fuel elements 10 min following a scram would be low enough to permit cooling of the fuel elements with air. This analysis assumed all the decay heat to be absorbed in the core

and that the after-heat power density distribution remained constant. The maximum temperature would be below 650°F, which is 550F° below the melting temperature of the fuel elements.

The licensee also analyzed the dose rates expected from the loss of pool water as a result of a pneumatic tube rupture. The dose rates would be zero during the incident because a building alarm would occur when the pool level dropped to 19 ft above the top of the core. The reactor building would be evacuated in <0.1 hour, and any exposure that would result would come subsequent to the event during the reentry and recovery, which would be controlled administratively. Additionally, the refilling of the reactor pool would be done remotely following repairs and before reactor room reentry.

Because of the concrete block shield wall surrounding the reactor tank, the staff also has not been able to identify a credible method for an instantaneous loss of the reactor pool water. Furthermore, the operator can take corrective action remotely without any radiation exposure. There also would be sufficient time to evacuate the restricted areas of the building, thus minimizing the exposure to the occupants. In the case of a reactor coolant accident, the reactor core is cooled mainly by natural convection airflow. Additionally, the emergency makeup water to the reactor pool is capable of supplying emergency makeup coolant at a flow rate of ~600 gal/min, which is almost three times greater than the maximum rate of coolant loss.

On the basis of the above analysis, the staff concludes that the residual heat resulting from a loss of reactor pool water can be dissipated by the natural convection airflow in the reactor pool and no fuel melting would result. The time needed to drain the tank (~3 h) to the top of the core would allow for mitigating actions by the reactor operator, and the resulting consequences would not pose a significant threat to the health and safety of facility personnel or the public.

14.4 Minor Accidents

Minor accidents are those whose results are less severe than those identified above. These are discussed briefly in the following sections.

14.4.1 Loss of Beam Tube Ventilation

If the ventilation system fails, radioactive gases from the beam tubes can contaminate the reactor room atmosphere. The major source of the contamination is ^{41}Ar from the $^{40}Ar(n,\gamma)\ ^{41}Ar$ reaction. If the content of an 8-in. beam tube (assumed unplugged volume of 0.75 ft^3) is released to the reactor building atmosphere by removal of the beam port cover, the resulting ^{41}Ar concentration would be above that of Table 1 of Appendix B of 10 CFR 20. To prevent this (1) the reactor is equipped with a warning light that indicates beam tube ventilation failure and (2) administrative rules allow the beam ports to be opened only after reactor has been shut down and the ^{41}Ar has decayed to safe levels.

14.4.2 Loss of Pool Surface Ventilation

Failure of the pool-top ventilating system does not constitute a health hazard. If fission product gases are released from damaged fuel elements at the same time, the high radiation monitor located under the bridge would indicate "high

radiation" at much lower activity levels than if the sweep ventilation system were operating.

14.4.3 Loss of Fuel Cladding Integrity

This accident assumes loading of a damaged or defective fuel element or the cladding being corroded or eroded from the fuel element. This accident would result in an increase in radioactivity in the pool primary coolant. The regularly scheduled water sampling and analysis program would detect the increase before the activity level became significant. In addition, the pool top detectors or the continuous stack and building monitors would detect increases in the airborne radioactivity.

14.4.4 Fuel Handling Accident

A fuel handling accident was considered. It included dropping a fuel element out of a transfer cask onto the operating floor. Since the fuel would have significantly decayed prior to removal into the cask, it was concluded that any fuel cladding rupture resulting from the drop would not result in a release of fission products or a dose that would be greater than that considered for the MHA.

14.4.5 Explosions

The reactor concrete biological shield is an extremely efficient explosion barrier. An explosion external to the shield could not damage the core.

14.5 Conclusion

The staff has reviewed the potential accidents for the FNR. On the basis of the review, the most significant event that is postulated to result in a release of fission products to the environment is the total failure of a fueled experiment. The analysis has demonstrated that even if this unlikely event should occur, the resultant doses would not exceed the guidelines of 10 CFR 20. Therefore, the staff concludes that the design of the facility together with the Technical Specifications provide reasonable assurance that the FNR can continue to be operated without significant risk to the health and safety of reactor personnel or the public.

15 TECHNICAL SPECIFICATIONS

The licensee's Technical Specifications for the FNR that have been evaluated in this licensing action define certain features, characteristics, and conditions governing the operation of this facility. These Technical Specifications are explicitly included in the renewal license as Appendix A. Formats and contents of these Technical Specifications have been reviewed using the ANSI/ANS 15.1-1982 standard, "The Development of Technical Specifications for Research Reactors," as a guide.

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

16 FINANCIAL QUALIFICATIONS

The FNR is operated by the University of Michigan, an agency of the State of Michigan, in support of its assigned educational and research mission. Therefore, the staff concludes that funds will be made available as necessary to support continued operations, and eventually to shut down the facility and maintain it in a condition that would constitute no risk to the public. The licensee's financial status was reviewed and found to be acceptable in accordance with the requirements of 10 CFR 50.33(f).

17 OTHER LICENSE CONSIDERATIONS

17.1 Prior Reactor Utilization

Previous sections of this SER concluded that normal operation of the reactor causes insignificant risk of radiation exposure to the public and that only an off-normal or accident event could cause some significant exposure. The maximum hypothetical accident (MHA) was shown to result in radiation exposures within applicable guidelines and regulations (10 CFR 20).

The staff has reviewed the impact of prior operation of the facility on the risk of radiation exposure to the public. Although the staff has concluded that the reactor was initially designed and constructed with both inherent safety and additional engineered safety features, the staff considered whether continued operation would cause significant degradation in these features. Furthermore, because loss of integrity of fuel cladding is possible, the staff considered mechanisms that could increase the likelihood of failure. Possible mechanisms are (1) radiation degradation of cladding strength, (2) corrosion or erosion of the cladding leading to thinning or other weakening, (3) mechanical damage as a result of handling or experimental use, and (4) degradation of safety components or systems.

The staff's conclusions regarding these parameters, in the order in which they were identified above, are

(1) As all the fuel in the core is replaced with new fuel at intervals of about 2 years, radiation damage to the cladding is unlikely.

(2) The relatively short time that the fuel is in the core, coupled with the high purity of the coolant, make corrosion damage of the fuel cladding unlikely.

(3) Mechanical damage as a result of fuel handling is a possibility if fuel elements are dropped during fuel relocation manipulations. However, as fuel is moved about under water, incidents involving dropping of fuel have never resulted in any damage to the fuel. See Section 14 for additional potential fuel handling incidents.

    Damage to the core resulting from experiments is remote because all experiments are reviewed by the Nuclear Safeguards Committee.

(4) FNR receives regular preventive and corrective maintenance and replaces components, as necessary. Nevertheless, there have been some malfunctions of equipment. However, the staff review indicates that most of these malfunctions have been random one-of-a-kind incidents. There is no indication of significant degradation of the instrumentation, and the staff further concludes that the FNR procedures, calibration, testing, and preventive maintenance program would lead to adequate identification and replacement before significant degradation occurred. Therefore, the staff concludes that any future degradation will lead to prompt remedial action by the FNR

personnel, and 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.

17.2 Conclusion

On the basis of the above considerations, the staff concludes that there are no other credible events that could produce effects greater than those already analyzed in Section 14.

18 CONCLUSIONS

On the basis of its evaluation of the application as set forth above, the staff has determined that

(1) The application for renewal of Operating License R-28, filed by the University of Michigan, dated November 30, 1984, as supplemented, complies with the requirements of the Atomic Energy Act of 1954, as amended (the Act), and the Commission's regulations set forth in 10 CFR Chapter I.

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

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

(4) The licensee is technically and financially qualified to engage in the activities authorized by the license in accordance with the regulations of the Commission set forth in 10 CFR Chapter I.

(5) 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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13. ABSTRACT (200 words or less)

This Safety Evaluation Report for the application filed by the University of Michigan (UM) for a renewal of the Ford Nuclear Reactor operating license R-28 to continue to operate a training and research reactor facility has been prepared by the Office of Nuclear Reactor Regulation of the U. S. Nuclear Regulatory Commission. The facility is owned and operated by the University of Michigan and is located at the North Campus of the University in Ann Arbor, Michigan. The staff concludes that this training reactor facility can continue to be operated by UM without endangering the health and safety of the public.

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