NUREG-0912

Safety Evaluation Report
related to the renewal of the operating license for the Worcester Polytechnic Institute Open-Pool Training Reactor

Docket No. 50-134

U.S. Nuclear Regulatory Commission

Office of Nuclear Reactor Regulation

December 1982

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ABSTRACT

This Safety Evaluation Report for the application filed by the Worcester Polytechnic Institute (WPI) for a renewal of Operating License R-61 to continue to operate the WPI 10-kW open-pool training reactor 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 Worcester Polytechnic Institute and is located on the WPI campus in Worcester, Worcester County, Massachusetts. The staff concludes that the reactor facility can continue to be operated by WPI without endangering the health and safety of the public.

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1 INTRODUCTION

The Worcester Polytechnic Institute (WPI) (applicant) submitted a timely application for renewal of the Class 104 Operating License (OL) R-61 for its open-pool training reactor (reactor or facility) by letter to the U.S. Nuclear Regulatory Commission (NRC) dated July 16, 1979, as supplemented. The letter requested renewal of the WPI OL to permit continued operation at power levels up to and including 10 kW for a period of 20 years. WPI is permitted to operate the reactor within the conditions stipulated in past amendments in accordance with Title 10 of the Code of Federal Regulations (10 CFR) Part 2.109 until NRC action on the renewal request is completed.

The renewal application is supported by information submitted in six appendices. The application was signed and notarized by the Vice President and Dean of Faculty, who is the WPI officer responsible for the reactor. The application was reviewed by the WPI Radiation, Health, and Safeguards Committee before it was submitted to the NRC, Office of Nuclear Reactor Regulation (staff).

The renewal application, as supplemented, contains substantially all the information regarding the design of the facility included in the application for the original operating license. The application included a Safety Analysis Report, an Environmental Impact Appraisal, proposed Technical Specifications, an Emergency Plan, an Operator Requalification Program, a Fiscal Statement, and, under separate cover, a Physical Security Plan, which is protected from public disclosure under 10 CFR 2.790.

The staff's technical safety review with respect to issuing a renewal operating license to WPI has been based on the information contained in the renewal application and supporting appendices plus 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. This Safety Evaluation Report (SER) was prepared by James H. Wilson, Project Manager, Division of Licensing, Office of Nuclear Reactor Regulation, Nuclear Regulatory Commission. Major contributors to the technical review include the Project Manager and H. Bernard (NRC) and A. Blackstock, C. Linder, and D. Whittaker of the Los Alamos Laboratory under contract to NRC.

The purpose of this SER is to summarize the results of the safety review of the WPI open-pool training reactor 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 operation of the WPI facility at power levels up to and including 10 kW. The facility was reviewed against Federal regulations (10 CFR 20, 30, 50, 51, 55, 70, and 73), applicable Regulatory Guides (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 specific accident-related regulations for research reactors, the staff has at times compared calculated dose values with related standards in 10 CFR 20, "Standards for Protection Against Radiation," both for employees and the public.

The Worcester Polytechnic Institute reactor initially was licensed at 1 kW on November 23, 1959. A license amendment authorizing operation at a maximum power level of 10 kW was issued on November 14, 1967. Since the power increase, license amendments concerning changes to the Technical Specifications and the Physical Security Plan were issued on September 21, 1977 and February 5, 1981, respectively.

1.1 Summary and Conclusions of Principal Safety Considerations

The staff's evaluation considered the information submitted by the applicant, past operating history recorded in annual reports submitted to the Commission by the applicant, and reports by the Commission's Office of Inspection and Enforcement. In addition, as part of its licensing review of several Argonaut reactors, the staff obtained laboratory studies and analyses of several accidents postulated for the Argonaut universal training reactor (UTR) that are applicable to other reactors of 100 kW or less using materials testing reactor (MTR)-type fuel as does the WPI reactor. The resolution of principal issues reviewed for the WPI reactor were

(1) The design, testing, and performance of the reactor structure and 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 that could lead to a 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 the reactor room would not exceed 10 CFR 20 doses in unrestricted areas.

(3) The applicant's management organization, conduct of training and research activities, 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 the Commission's regulations and are as low as reasonably achievable (ALARA).

(5) The applicant's Technical Specifications, which provide operating limits controlling 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 financial data provided by the applicant are such that the staff has determined that the applicant has sufficient revenues to cover operating costs and eventually to decommission the reactor facility.

(7) The applicant's program for providing for the physical protection of the facility and its special nuclear material comply with the requirements of 10 CFR 73.

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

(9) The applicant has submitted an Emergency Plan in compliance with the existing applicable regulations. This item is discussed further in Section 13.3.

1.2 Reactor Description

The WPI open-pool training reactor, shown in Figure 1.1, is a 10-kW (thermal) reactor designed and built by the General Electric Company. Primary requirements for safe and flexible operation of the reactor as a student training aid have been met by the use of open-pool design, low excess reactivity, and large negative temperature and void coefficients.

The normal core configuration is based on 24 fuel elements containing approximately 3.3 kg of fully enriched ^{235}U arranged in a rectangular array. The core is suspended from a fixed bridge mounted over an 8-ft square pool, 15 ft deep, that contains 7000 gal of highly pure demineralized water. A 1-curie plutonium-beryllium source occupies one module adjacent to the active core. Three safety blades and a manually actuated regulating blade control the reactivity. Each blade moves vertically in a shroud, extending the length of the core.

The core is moderated, reflected, and cooled by light water that is circulated by natural convection. The thermal column side of the core also is reflected by graphite. Core elements are contained in a grid box enclosed on four sides to confine the flow of cooling water to the channels between and surrounding the elements. The grid box and contents, as well as the blade drive mechanisms, are supported by a suspension frame from a reactor bridge. The cold, clean core with control blades removed has less than 0.5 percent excess reactivity. The safety blades, because of their location and large surface area, have a total shutdown worth of approximately 14-18 percent $\Delta k/k$.

Table 1.1 shows the significant design parameters that are used in this reactor.

1.3 Experimental Facilities

The experimental facilities provided with the reactor are a thermal column, a 6-in. beam tube and a fuel element comparable to Type 1 (Table 1.1) but with eight removable plates.

1.4 Facility Location

WPI is located in Worcester, Massachusetts, approximately 45 mi. west-southwest of Boston, Massachusetts. The reactor is located in Washburn Laboratory on the east side of the WPI campus. Washburn Laboratory, the second oldest building on campus, originally was constructed as a three-story building with concrete basement, wooden interior floors and walls, and a stone exterior. The building was used as a foundry until 1950.

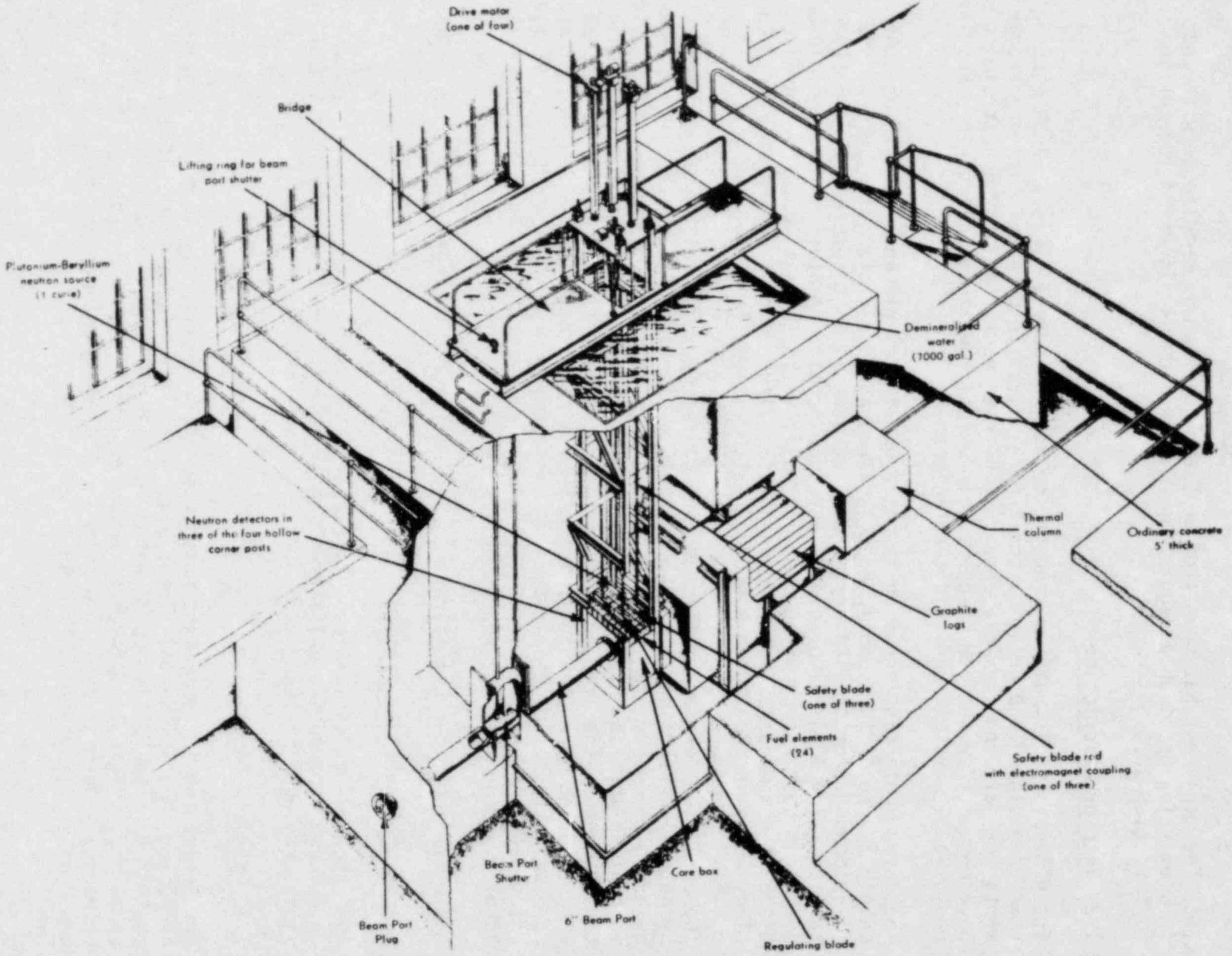


Figure 1.1 Worcester pool training reactor

Table 1.1 Summary of reactor design data

Reactor Materials	
Fuel	Uranium aluminum alloy, fully enriched
Moderator	High purity light water
Reflector	High purity light water and graphite
Coolant	High purity light water
Control	Boral and stainless steel
Structural material	Aluminum
Shield	Water and aluminum-lined concrete
Structural Dimensions	
Pool	8 x 8 x 15 ft deep
Core (active portion)	15 x 15 x 24 in. high
Grid box	9 x 6 array of 3 in. square modules
Beam port	One, 6-in. diameter
Thermal column	One, 40 x 40 in. crosssection
Special Nuclear Material	
Fissionable material	3.3 Kg ^{235}U
Burnup	Approximately 0.1% ^{235}U
Fuel life	Limited by factors other than burnup
Thermal Characteristics	
Operating power	10 kW (maximum)
Temperature, water	130° F (maximum)
Hot-spot factor	2.8
Maximum heat flux	400 Btu/hr-sq ft
Specific power (clean, cold)	3.0 watt/gm ^{235}U
Maximum gamma heat in core	10 watt/liter
Nuclear Characteristics	
Average thermal flux	9×10^{10} nv
Average fast flux	23×10^{10} nv
Maximum operating excess reactivity	0.5% $\Delta k/k$
Critical mass	3.3 kg
Temperature coefficient	-0.5×10^{-4} $\Delta k/k$ per C°
Void coefficient	-2.0×10^{-3} $\Delta k/k$ per 1% void
Prompt neutron lifetime	8.2×10^{-5} sec
Control	
Safety Elements	
Number	3 vertical blades
Dimensions	10.5-in. wide x 40.5-in. long x 0.375-in. thick
Material	Boral
Reactivity control	3.5 of $\Delta k/k$ each, minimum
Total worth, 3 blades	14 to 18% $\Delta k/k$
Maximum withdrawal rate	7.5 in./min, one blade at a time

Table 1.1 (Continued)

Control (Continued)	
Regulating Element	
Number	1 vertical blade
Dimensions	10.65-in. wide x 40.5-in. long x 0.125-in. thick
Material	Stainless steel
Reactivity control	0.7% $\Delta k/k$
Maximum withdrawal rate	3.8 in./min.
Standard Fuel - Types 1 and 2	
Type	Flat plate
Number of elements	24 for minimum critical loading
Fuel alloy	Uranium-alumnimum
Clad material	Aluminum
Fuel	^{235}U fully enriched
Number of plates per element	Type 1 10
	Type 2 18
Plate thickness	Type 1 0.099 in.
	Type 2 0.060 in.
Clad thickness	Type 1 0.030 in.
	Type 2 0.015 in.
Fuel loading per element	Type 1 ~136 g ^{235}U
	Type 2 ~121 g ^{235}U
Cooling System	
Coolant	Demineralized pool water
Type cooling	Natural convection
Temperature	130° F (maximum)
Purification	Recirculating demineralizer
Purity required	1 ppm - 5×10^5 ohm-cm

1.5 Shared Facilities and Equipment (and Special Location Features)

A cooling tower on the roof services room air conditioners located in the materials science and the nuclear laboratories. There are no other exterior electrical or mechanical structures associated with the reactor facility attached to the building other than conventional service connections for electricity, heating, water, and drainage similar to those routinely required in all other campus laboratories.

1.6 Comparison with Similar Facilities

The reactor is similar in design to several other operating pool-type facilities in the United States. All are light water moderated and cooled research reactors using MTR-type plate fuel. A list of these reactors is given in Table 1.2.

1.7 Modifications

Because of a lack of funds, the reactor operated initially without graphite in the thermal column. Graphite logs were purchased and installed in 1961 with money provided by a U.S. Atomic Energy Commission (AEC) grant.

Table 1.2 Open-pool-type nonpower reactors using MTR fuel

Facility	Power
Ohio State University	10 kW
Purdue University	1 kW
Rhode Island AEC	2 MW
Union Carbide	5 MW
University of Kansas	250 kW
University of Lowell	1 MW
University of Michigan	2 MW
University of Missouri(Columbia)	10 MW
University of Missouri (Rolla)	200 kW
University of Virginia	2 MW
Westinghouse NTR	10 kW

In 1969 a large 2½-by-2½-by-5½-ft concrete shield block, weighing about 3 tons, replaced the original concrete beam-port plug. This allows the beam port to be used as a radiography facility.

In 1968 an exhaust system was installed between the graphite logs and the inside face of the shield door of the thermal column to remove ^{41}Ar that is produced during reactor operation as a result of neutron activation of air.

1.8 Operational History

The reactor was licensed originally in 1959 at a power level of 1 kW. In 1967, after approximately 150-kW hours of operation, the WPI reactor was granted a power increase to 10 kW. Since the power increase, the reactor has been operated approximately 1,250 hours. The total thermal energy generated since startup 1959 through May 1981 is approximately 6700 kW hours and the total consumption of ^{235}U is approximately 0.34 g or about 0.01 percent burnup.

Over the last 5 years, the reactor has operated about 3 hours each week, generating approximately 260 kW hours each year.

Plate-type fuel reactors--using essentially the same kind of fuel, similar control rods and drive systems, and similar safety circuitry as the WPI reactor--have been constructed and operated in many countries of the world, including the United States where there are more than 50 such reactors. Since the first of this type of reactor was assembled in 1950, there have been no reported events that caused significant radiation risk to public health and safety. Several plate-type fuel reactors have an annual operation at least a factor of 10^5 greater in MW hours than the WPI reactor, both because of different types of research programs and because of higher operating power levels.

2 SITE CHARACTERISTICS

2.1 Geography and Demography

2.1.1 Geography

WPI is located approximately 15 mi west of 71.5 degrees west longitude, and about 45 mi west-southwest of Boston and the Atlantic Ocean.

2.1.2 Demography

WPI is located in a residential section about 1 mi north of the civic center of Worcester, Massachusetts. Worcester is an important industrial center with a population of 161,799 (1980).

Approximately 2,500 students are enrolled at Worcester Polytechnic Institute. There are about 180 faculty members and about 280 staff workers.

The neighborhood in which WPI is situated is completely residential in character. The campus is bounded on its north side by a pond and a public park, on its west side by a public park, and on the remaining two sides by residences.

The reactor is located in Washburn Laboratory on the east side of the WPI campus. As shown on the campus map, Figure 2.1, Washburn Laboratory is adjacent to Boynton Hall, Stratton Hall, Gordon Library, Salisbury Laboratories, the Project Center, and the Power Plant. Boynton Hall houses the administrative offices, while Stratton Hall is occupied by the Mathematics Department. The campus security police and the power laboratory are located in the lower levels of Stratton Hall. Salisbury Laboratories house the Humanities Department, Life Sciences, Biomedical Engineering, Management Engineering, and the Department of Social Science and Policy Studies. Student workshops are located in the Project Center. The power laboratory is a complete central power station; it once supplied both heat and electricity for the campus but now supplies only heating steam.

There are no private dwellings on West Street from Institute Road to Salisbury Street. The nearest private residence to the reactor is approximately 500 ft away.

The WPI buildings on the west side of campus nearest Washburn Laboratory are Higgins Laboratories, which house the Mechanical Engineering Department, and Olin Hall of Physics. The nearest building used as a dormitory, Sanford Riley Hall, is over 500 ft away.

2.2 Nearby Industrial, Transportation, and Military Facilities

2.2.1 Transportation Routes

The Worcester Municipal Airport is approximately 3.5 mi southeast of the WPI campus. Logan Airport, located in Boston, is 45 mi east-northeast of the

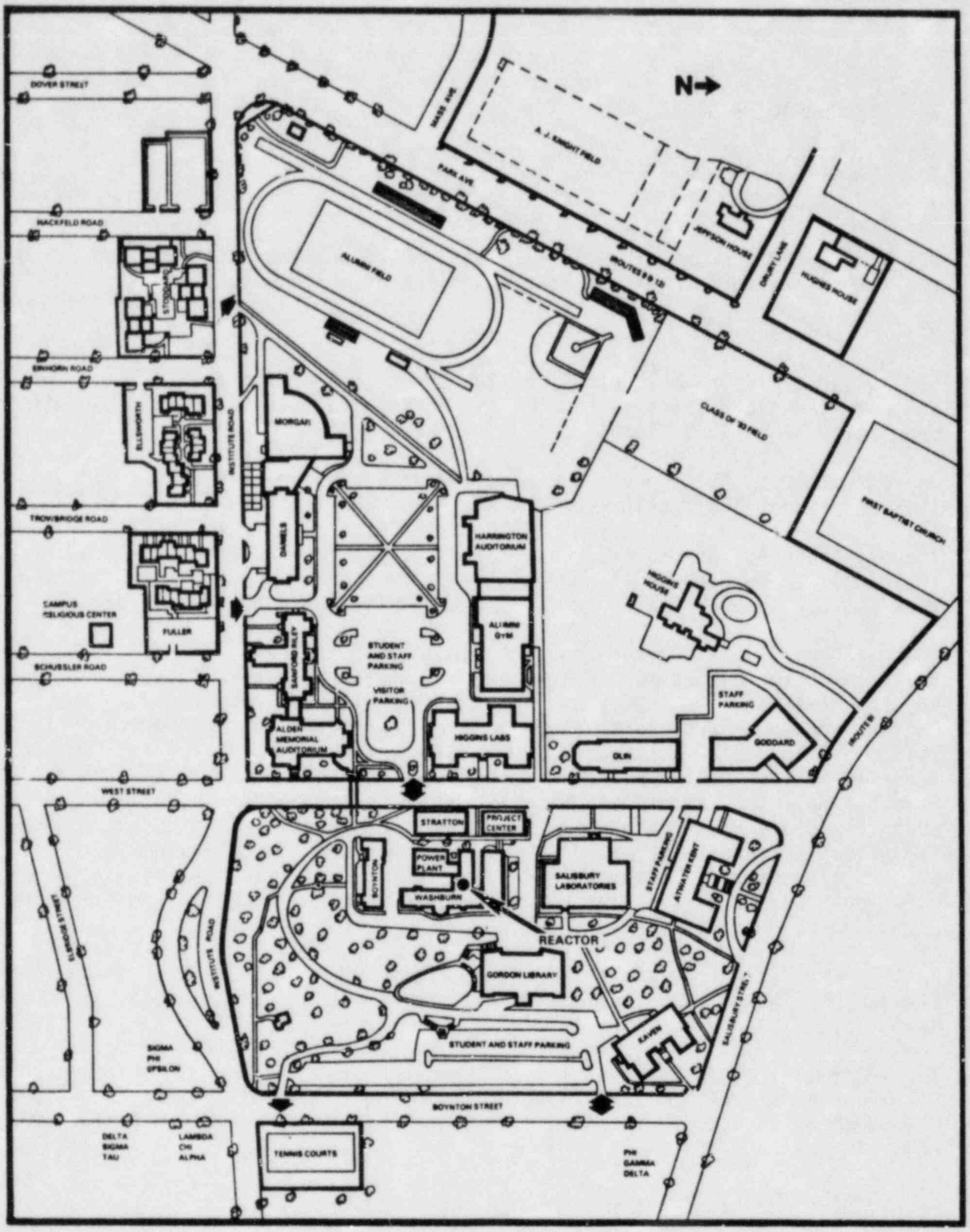


Figure 2.1 Campus map

campus. There are no scheduled airline routes over the campus; there are no operating main railroad lines near the campus; and the campus contains no major through streets.

2.2.2 Nearby Facilities

There are no heavy industries or major military establishments in the vicinity of the WPI campus.

2.2.3 Conclusion

There is no heavy air or railroad traffic, heavy-truck route, or heavy industry close enough to the campus to constitute a threat to safe operation of the reactor. The staff concludes that the facility can be operated with an acceptable degree of safety without risk from accidents occurring as a result of activities at industrial, military, or transportation facilities.

2.3 Meteorology

The following contains excerpts from a narrative climatological summary supplied by the U.S. Department of Commerce for the meteorology of the Worcester Municipal Airport.

> Worcester Municipal Airport is located on the crest of a hill, 1,000 feet above mean sea level and about 500 feet above and 3½ miles northwest of the City proper.
>
> The proximity to the Atlantic Ocean, Long Island Sound, and the Berkshire Hills plays an important part in determining the weather and, hence, the climate of Worcester. Rapid weather changes occur when storms move up the east coast after developing...off the Carolina Coast. In the majority of these cases, the waves pass to the south and east, resulting in northeast and easterly winds with rain or snow and fog....Wintertime cold wave snaps incidental to Canadian High Pressure Areas following cold front passages are quite frequent, but...the temperatures usually [are moderated somewhat]....Summertime thunderstorms develop over the hills to the west, with a majority moving towards the northeast.
>
> Airport site temperatures are moderate, as the normal mean for the warmest month, July, is 70.1°F. Though winters are reasonably cold, prolonged periods of severe cold weather are extremely rare. The three coldest months, December through February, together have an average normal of over 25 °F. The coldest temperature since 1949 was -19°F on January 15, 1957, while the warmest was 99°F on September 2, 1953....The average last freezing temperature in spring at the airport is April 26. The average first freezing temperature in fall is October 15.
>
> Precipitation is usually plentiful and well distributed throughout the year. Monthly normals range from slightly over 3 inches in February, the driest month, to over 4 inches in August and November.

> The snowfall for all Worcester sites since 1901 averages slightly less than 60 inches. Due partly to several unusually heavy March storms in recent years, the airport location now averages considerably higher.

The Commonwealth of Massachusetts has an annual average of 5.7 tornadoes per 10,000 mi or about 4 per year, according to the U.S Department of Commerce, National Oceanic and Atmospheric Administration. A major tornado struck Worcester in 1953, causing severe property damage and loss of life. Most of the tornadoes reported in Massachusetts are of the "mini-tornado" type with winds up to 125 mph, a width of 100 ft, and which touch ground only for a few minutes.

The tornado hazard notwithstanding (see Section 3.1), the staff concludes that there are no meteorological conditions present at the Worcester site that make it unfit for the location of the WPI reactor.

2.4 Geology

There are no capable faults, landslides, karsts, solution basins or other geological hazards in the area of WPI.

The reactor site is on Boynton Hill, a drumlin, composed predominantly of glacial till, which was formed during the Wisconsin state of the Pleistocene epoch. The upper 3 to 5 ft of the hill is composed of Paxton loam, followed by bedrock and by a very compact sand to sandy silt. Bedrock in the area is Oakdale quartzite and Worcester phyllite. Borings on the hill indicate that the ground water table is at least 25 ft below the reactor site. During periods of heavy rain, the development of a temporary water table as high as 10 ft below the surface may occur.

Drainage from the reactor facility flows below the basement floor of Washburn Laboratory into the city sewer system on Boynton Street (see Figure 2.1) and from there to the Worcester Sewage Disposal Works near the Worcester-Millbury line. Water from there flows into the Blackstone, an industrial river.

From the information provided in the application and a site visit, the staff concludes that there is little risk of damage to the reactor building or the reactor that would result from geological hazards and that accidental spills of liquids on the WPI reactor would be unlikely to contaminate the groundwater or local water supplies.

2.5 Seismology

The Worcester Polytechnic Institute is located in the New England-Piedmont Tectonic Province. The New England part of the province has one of the longest records of historical earthquake activity in the United States. WPI is located in an area of New England that, based on the historical record, is relatively quiet seismically. There have been two historical earthquakes reported in the vicinity of the WPI. The largest of these had a modified Mercalli (MM) intensity of II (Stover et al., 1980). There have been no other historical earthquakes within a 20-mi radius of WPI, and the largest historical earthquakes within a 50-mi radius of the site had an MM intensity of V.

It is usual staff practice in the evaluation of nuclear power plant reactor sites to postulate that the maximum expected seismic event within a tectonic province occurs at the reactor site. This would translate to an earthquake with an MM intensity of VII-VIII near WPI. The resulting expected peak ground acceleration of 0.18 g would be used as a high-frequency anchor for a Regulatory Guide 1.60 response spectrum for a structure founded on rock. The staff concludes that an extremely conservative approach, such as this, is inappropriate for evaluating the site of a facility such as WPI, which has such a low power level that it could sustain heavy damage to the reactor itself and still not pose a significant radiological hazard to the public.

As stated in Section 3.3, the staff concludes that the Worcester site is suitable for the location of a research reactor the size and configuration of the WPI reactor.

3 DESIGN OF STRUCTURES, SYSTEMS, AND COMPONENTS

3.1 Wind Damage

Examination of meteorological records indicates that although damaging tornadoes have occurred in the area, they are not considered common, are usually of the "mini-tornado" type with winds up to 125 mph and a width of 100 ft, and touch ground only for a few minutes. There is a very low frequency of other severe storms with wind velocities in excess of 60 mph. Although wind damage to the building housing the WPI reactor is judged to be unlikely, the staff's accident analysis (Section 14) indicates that public health and safety would not be jeopardized even if the reactor itself were to be extensively damaged.

3.2 Water Damage

The reactor site is on the side of a hill in a well-drained location. No special architectural or engineering design features were incorporated to protect the reactor against flooding. The staff concludes, however, that there is little likelihood of flooding of the reactor from precipitation, runoff, or rising ground water.

3.3 Seismic-Induced Core Disruptions

WPI is located in a region that is relatively quiet seismically and where the likelihood of the occurrence of damaging shocks appears slight.

The staff concludes that the risk of seismic damage to the building housing reactor facility is small. Further, based on analyses presented in Section 14, public health and safety do not depend on building integrity and the reactor itself could sustain significant damage without posing a significant radiological risk.

Because the WPI reactor is located in a seismically inactive area, the staff concludes, based on analyses prepared by national laboratories of possible consequences of a severe earthquake to the WPI reactor, that fission product releases would be small fractions of the dose guidelines for power reactors in 10 CFR 100, and would not likely exceed 10 CFR 20 limits (see Section 14). Accordingly, the staff concludes that there is no radiological threat to public health and safety even in the extremely unlikely event of a significant seismic event near the WPI reactor.

3.4 Mechanical Systems and Components

The only mechanical system of importance to safety in the reactor is the control-rod-drive system. The control rods are blades of boron carbide and aluminum. A magnetic clutch between the shaft and the motor located outside the core serves as a rapid disconnect, allowing the control rods to rapidly drop into the core by gravity, i.e., fail-safe under loss-of-power or scram conditions. Thus, the mechanical equipment inside the reactor shield is limited to the control blades and the associated shaft plus the support for the blades and shafts. This arrangement reduces maintenance and other complications in the core area and permits easy and continuous maintenance of the motors and gears.

4 REACTOR

4.1 Building Layout

Classrooms and laboratories assigned to the Materials Engineering Section of the Mechanical Engineering Department are located in the basement and on the first, second, and third floors of Washburn Laboratory, adjacent to the reactor facility.

As shown in Figure 4.1, the reactor base is a concrete slab located in the basement. Access to the thermal column and beam port is on this level. The basement reactor room is partitioned off from the rest of the building and access is restricted by locks on all doors to the reactor room.

The first floor plan is shown in Figure 4.2. A separate office and reception area is provided at the west end of the reactor compartment. The control panel is approximately 20 ft away from the east side of the reactor and within direct sight of it. Access to the reactor room is restricted by partitions and locked doors.

An opening protected by a railing and a stairwell adjacent to the reactor permits visual inspection of the beam-port shield and thermal column door from the first floor operating level.

4.2 Core

4.2.1 Fuel Elements

WPI has two types of fuel elements. Each fuel element consists of equispaced flat uranium-aluminum-alloy fuel plates held vertically between two aluminum side plates as shown in Figure 4.3. The fuel plates are of sandwich construction similar to that of the MTR. Fuel meat is a uranium-aluminum alloy, 93 percent enriched. It is clad in aluminum by the picture-frame technique. The active length of the fuel plates is 24 in. and the overall dimensions of each element, including end boxes, are 3-in. square by nearly 40 in. long. The end boxes position the fuel elements in the grid and provide handles for fuel positioning. The elements may be rotated 180 degrees to achieve more efficient utilization of fuel. Type 1 elements may also be inverted, and minor end-box modification would permit Type 2 elements to be inverted as well. There are 25 Type 1 elements, each of which has 10 plates 25 in. long by 2.79 in. wide. The plates are each 0.099 in. thick including 0.030 in. of aluminum cladding on each side. A space of 0.2 in. between fuel plates provides a passage for the flow of cooling water by natural convection. The two Type 2 elements have 18 fuel plates each 0.060 in. thick including 0.015 in. of aluminum cladding on each side. Type 1 elements contain less than 140 g of ^{235}U per element and Type 2 elements contain less than 125 g of ^{235}U per element. The experimental removable plate element, designated R26, is similar in dimensions and loading to a Type 1 element. Type 1 elements are numbered F1 through F25, and Type 2 elements are numbered F29 and F30.

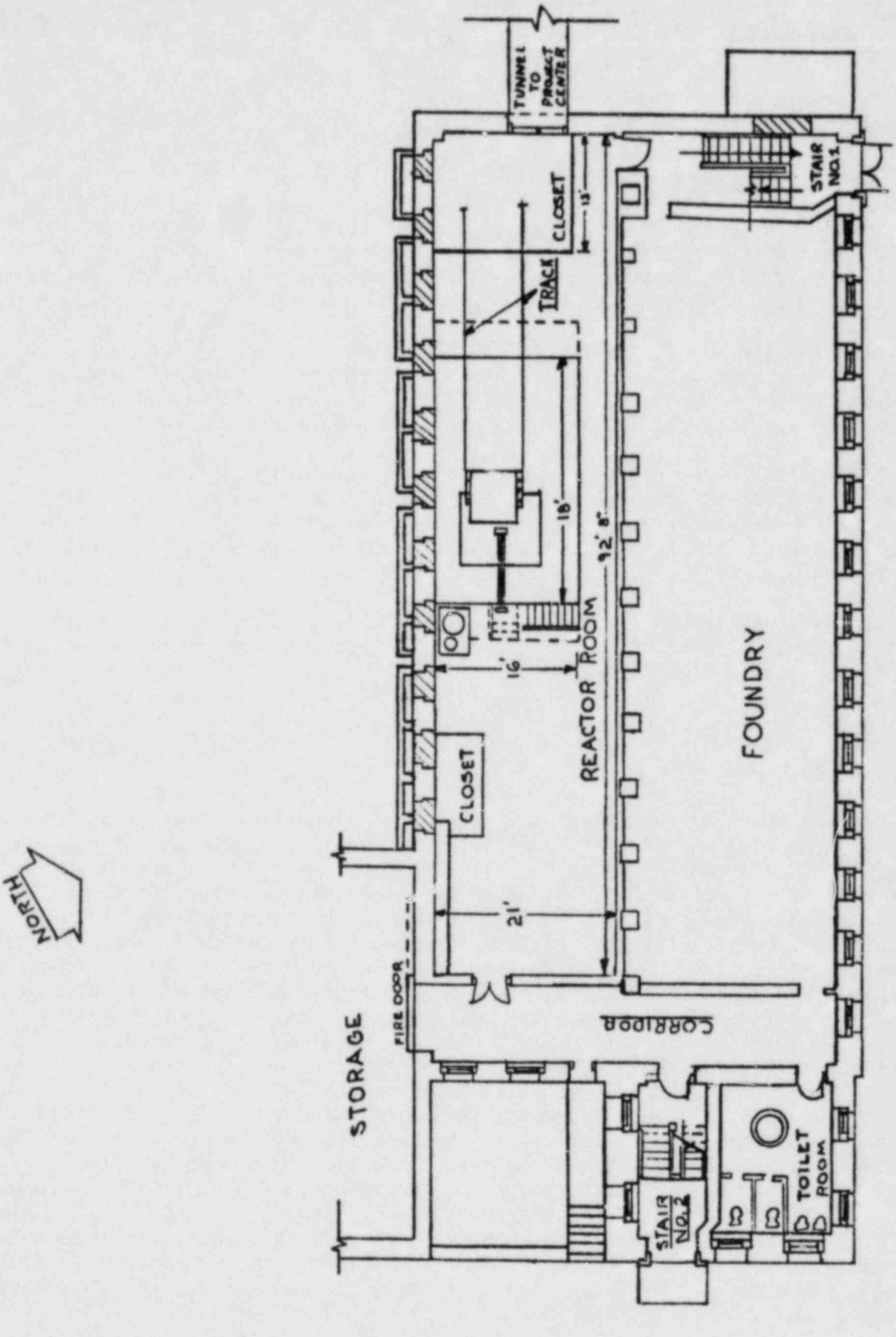


Figure 4.1 Basement floor plan (ceiling height 10 ft 6 in.)

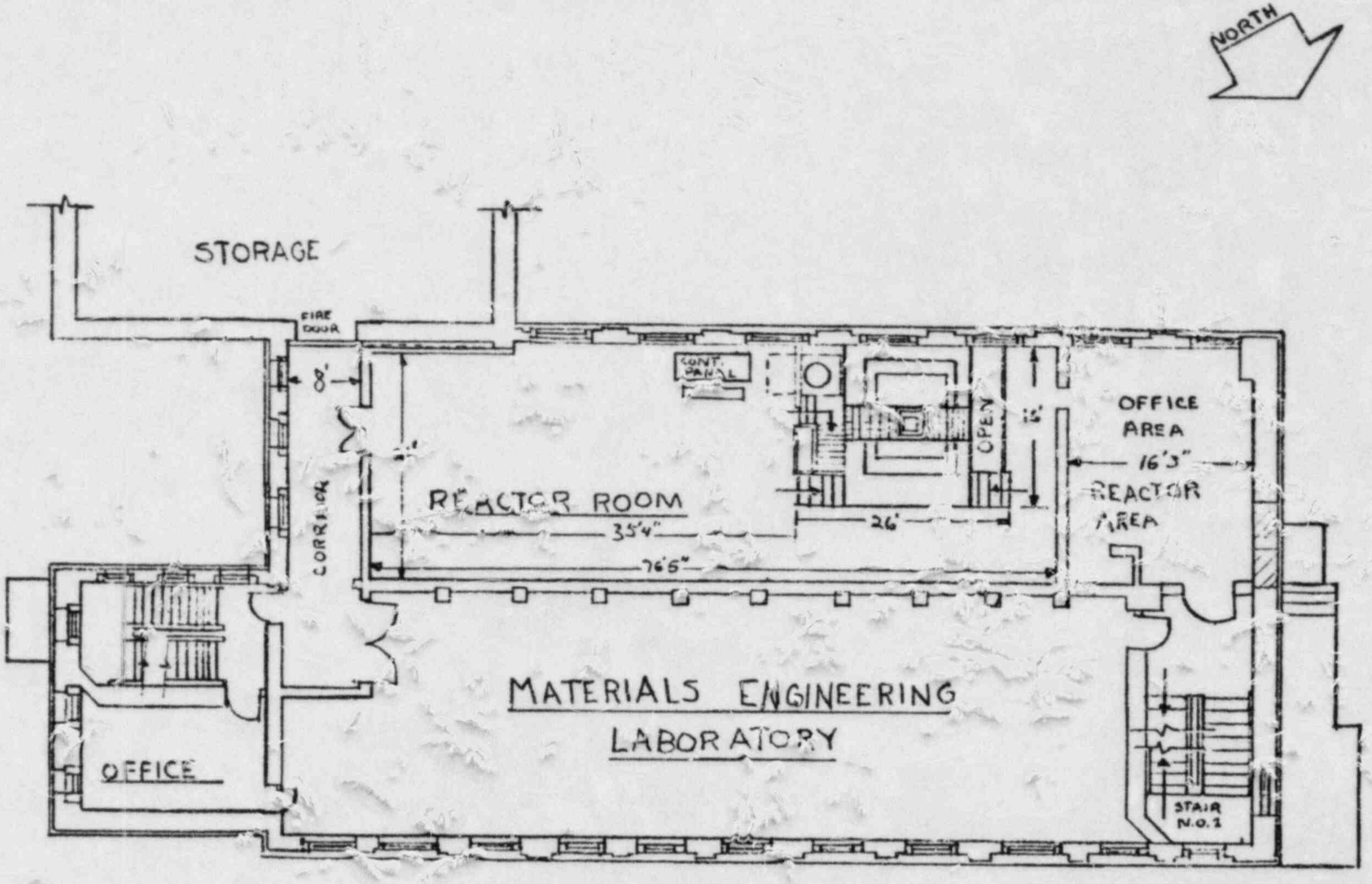


Figure 4.2 First-floor plan (ceiling height 12 ft 0 in.)

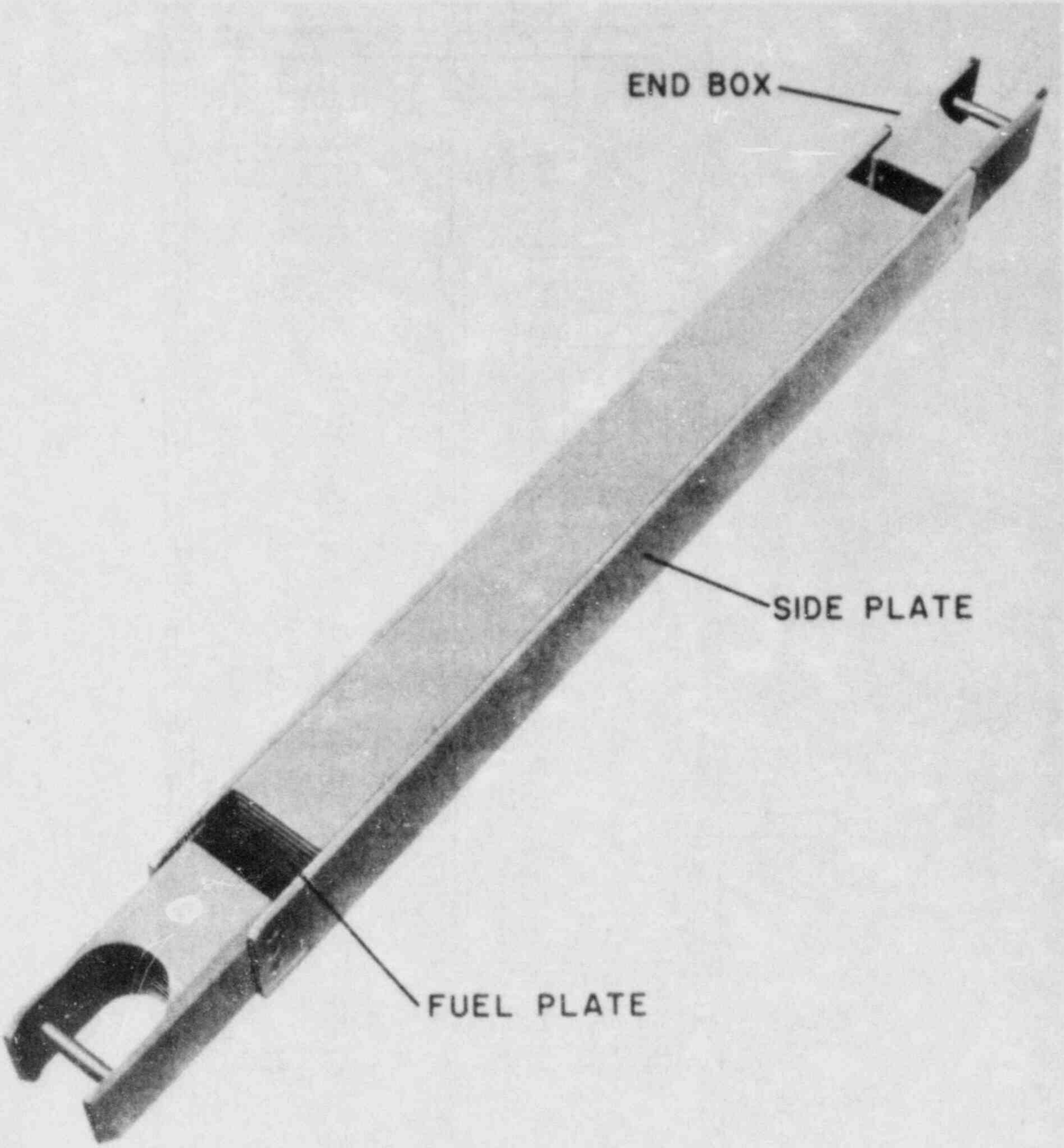


Figure 4.3 Fuel element

4.2.2 Control Blades

Reactor control for startup and shutdown is accomplished by three blade-type control elements (see Figure 4.4) with a total shutdown worth between 14 and 18 percent Δk/k. The poison section, of boron carbide and aluminum, approximately 0.380 in. thick, is sandwiched between aluminum side plates. It is 40.5 in. long; 25 of those inches provide active control of the core, and the remaining 15.5 in. connect the poison section to the drive tube.

Each control blade is guided throughout its travel by a shroud, as shown in Figure 4.5. The shroud consists of two thin aluminum plates 38 in. high, separated by aluminum spacers to provide a 0.125-in. water annulus around the blade. The shroud is latched to the sides of the grid box and can be removed, if necessary, by use of a grapple hook. Small flow holes at the bottom of the shroud minimize the effect of viscous damping on the scram line.

The drive shafts terminate in armatures that are coupled to electromagnets on the drives during normal operation. A dashpot-and-piston arrangement absorbs scram shock during the last 5 in. of travel.

4.2.3 Regulating Blade

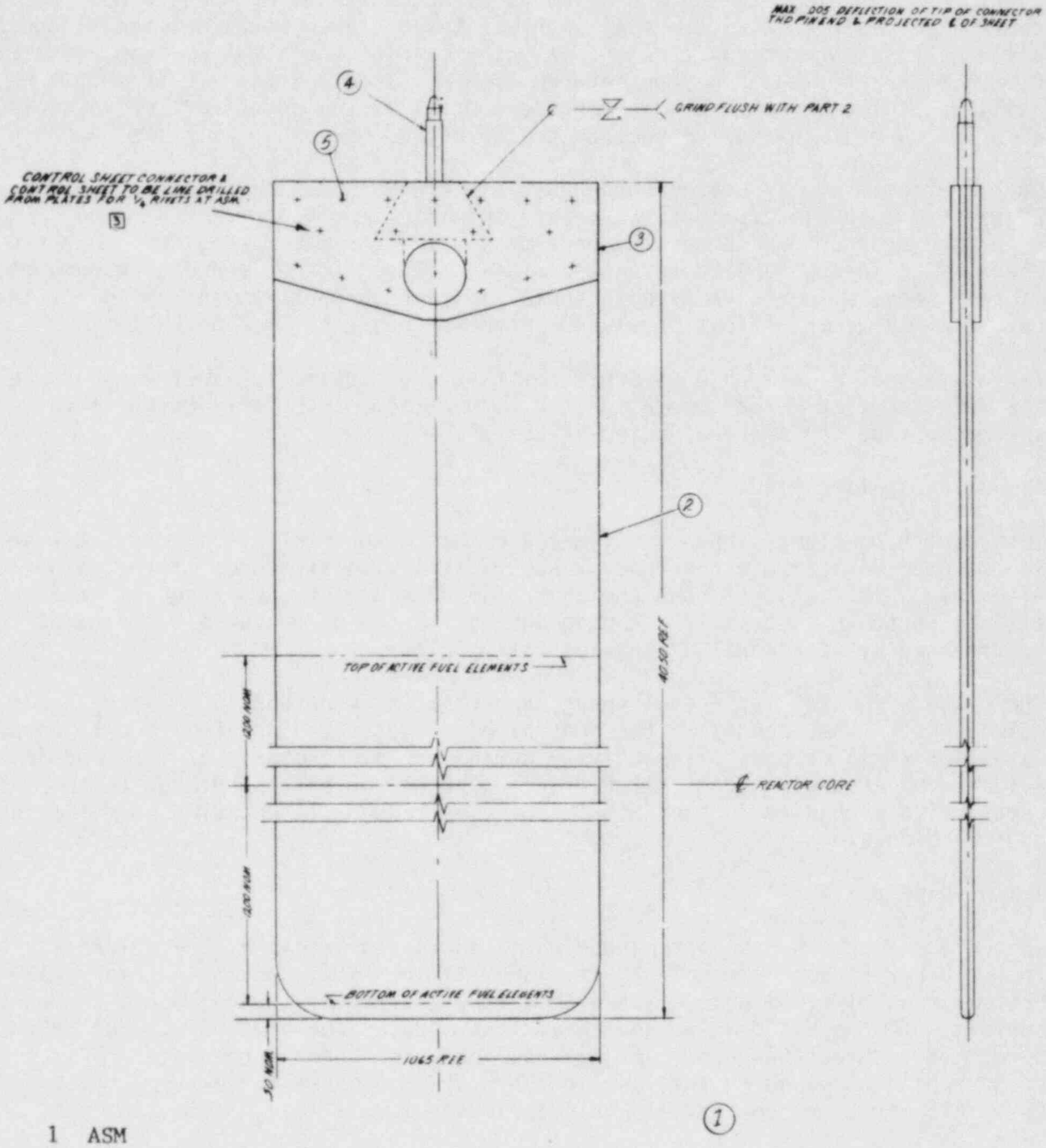
The regulating blade, shown in Figure 4.6, has a worth of 0.7 percent Δk/k and is designed to maintain the reactor subcritical with all three control blades withdrawn. This ensures that the control blades are in a position to insert maximum shutdown control if scrammed during startup or operation. Criticality is attained by withdrawal of the regulating blade.

The blade is a stainless-steel sheet, about 11 in. wide and 40 in. long, and guided in the same manner as the control blade described previously. It compensates for small changes of reactivity during normal reactor operation and is actuated by a manually controlled drive. The drive shaft is pinned to the upper drive mechanism in contrast to the electromagnetic coupling used for the control blades.

4.2.4 Grid Box

The core elements are supported and enclosed on four sides by the grid box. The grid box is approximately 28 in. long, 21 in. wide, and 36 in. high. The bottom is an aluminum grid plate with a 9-by-6 array of square holes, spaced to conform with the basic 3-in. square element module. The sides of the grid box direct the convection current of the cooling water through the core. Four corner posts attached to the lower end of the suspension frame support the grid box. All parts, except for mechanical fasteners, are made of aluminum.

The grid contains 54 spaces; 24 of these are normally used for fuel elements, 1 is used for the startup source, and 1 is used for an irradiation device. The remaining spaces are blocked off with removable plugs for the possibility of future use for reflector and irradiation work. This arrangement prevents the inadvertent placing of extra fuel in the core or improper location of fuel in the core.



1	ASM
2	SHEET
3	PLATE
4	CONNECTOR
5	RIVET

Figure 4.4 Reactor control blade

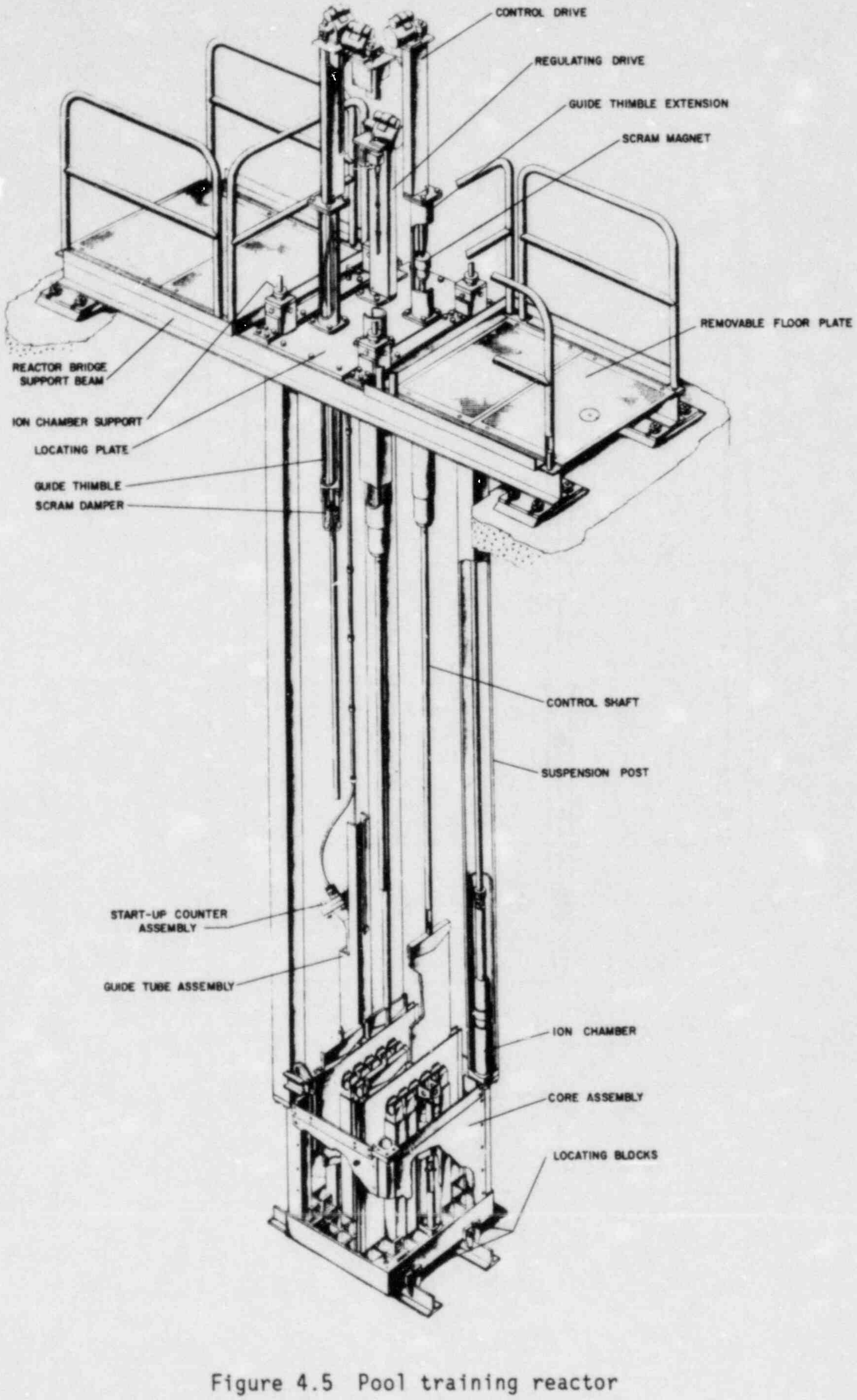


Figure 4.5 Pool training reactor

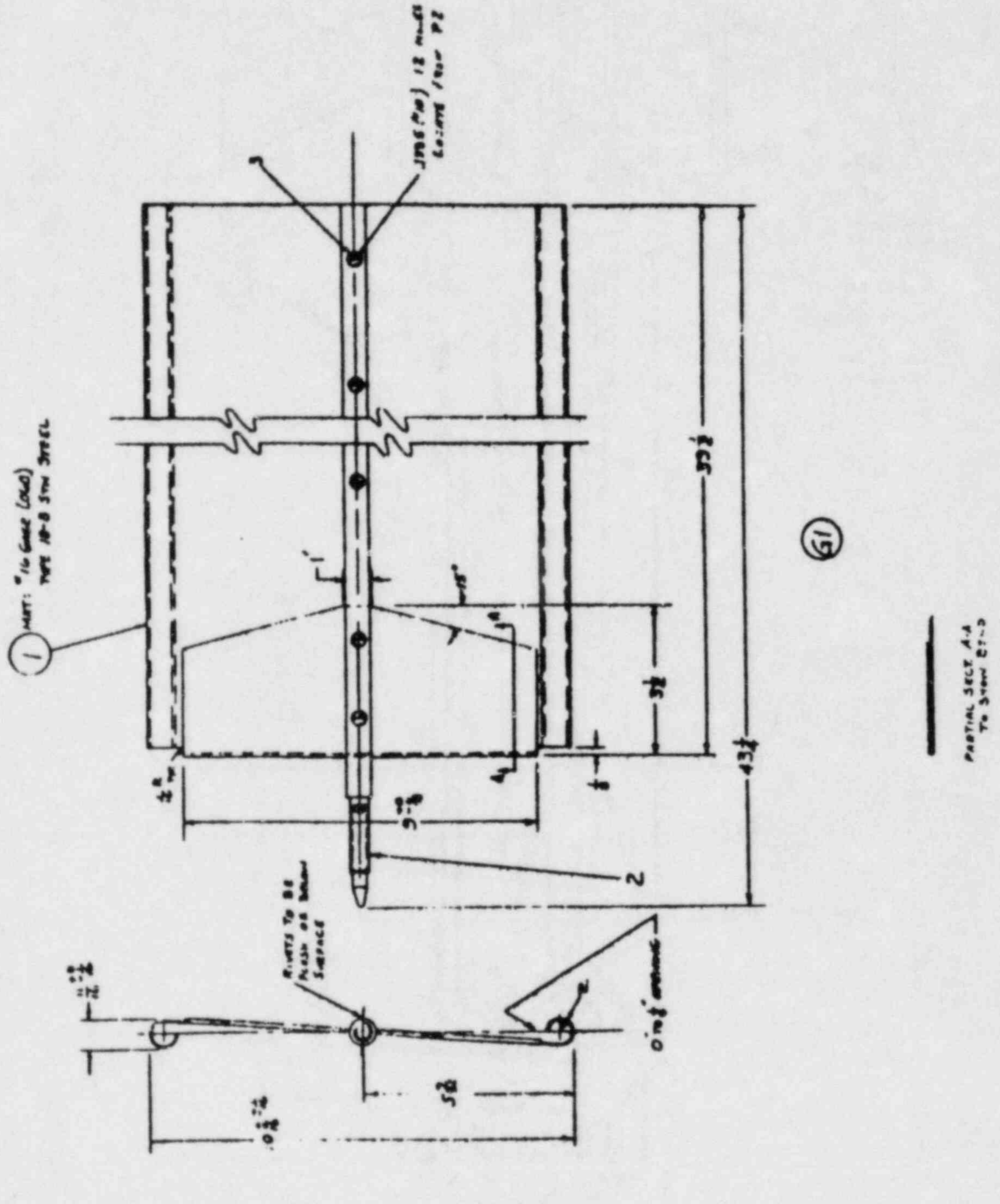


Figure 4.6 Regulating blade assembly

The grid arrangement, shown in Figure 4.7, is based on a 9-by-6 array of modules each 3 in. square. The core is subdivided lengthwise by two 1-in.-wide shrouds containing the control blades. The fuel elements partially form a square near the center of the grid box in the "standard" loading as shown. The neutron source occupies one module adjacent to the active core.

4.3 Suspension System

The core is suspended from an all-aluminum frame, as shown in Figure 4.5, which extends from the grid box to a height about 1 ft above the pool surface. The hollow corner posts of the suspension frame serve as guides for three ion chambers.

A reactor bridge (mounted over the pool) supports the core suspension frame. The all-steel, prefabricated bridge was bolted together at the reactor facility and aligned with shims.

4.4 Locating Plate

A locating plate, made of ½-in. steel, spans the upper end of the suspension frame. It is bolted to the bridge and aligns the four control blade drive mechanisms with the core. The four mechanisms work through individual clearance holes, the base flange of each mechanism being secured to the locating plate. The plate and mechanisms are not removable as a unit, to prevent accidental withdrawal of the control elements.

4.5 Ion Chamber Support Assembly

Three of the four corner posts of the suspension frame contain ion chambers for use in the flux monitoring channels of the control and instrumentation system. As indicated in Figure 4.5, the three compensated ion chambers are connected to adaptors and suspended from the corner posts. A clamp arrangement permits the assembly to be raised or lowered and then secured at the desired elevation.

4.6 Startup Counter Assembly

The proportional counter assembly consists of the ^{10}B detector, enclosed in a watertight container, and the adaptor to which the container is joined. The detector is electrically insulated from the container. The entire assembly is suspended from the reactor bridge by a cable. An electrical cable connects the proportional counter with the preamplifier on the bridge. Three cables connect the preamplifier to the control center cubicle. The startup counter is located directly across the grid box from the regulating blade and is contained in a guide tube and shield. A guide pin in the adaptor is free to slide in a vertical direction within the guide tube slot enabling the counter assembly to be correctly positioned while it is raised or lowered as required.

4.7 Reactor Pool

The reactor is located in the center of a pool of demineralized water 8 ft square by 15 ft deep. The surface of the water is 10 ft above the core. Drains set in the concrete shield are located on two sides of the pool, and the top surface of the concrete shield wall is sloped to the drains. Overflow lines

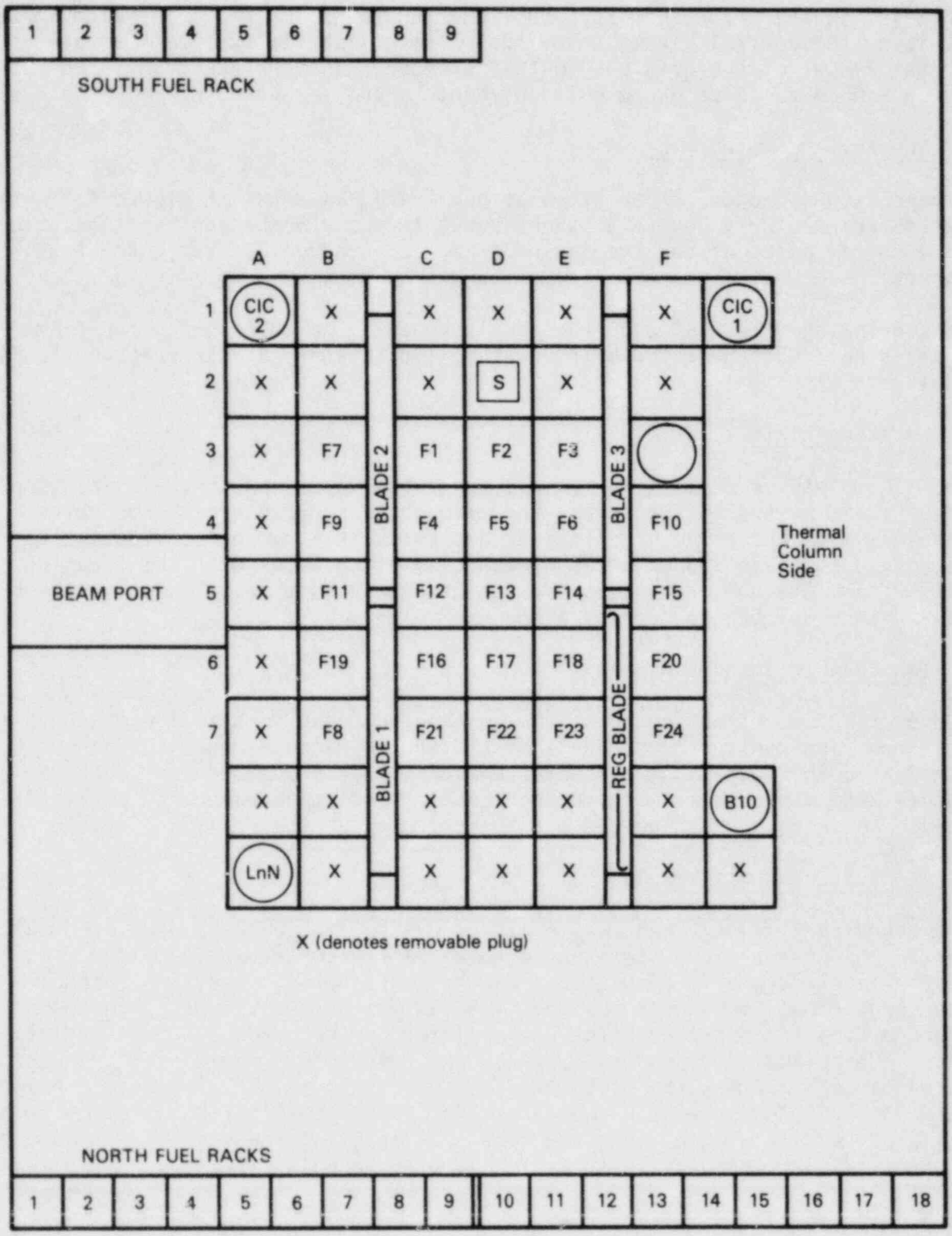


Figure 4.7 WPI open-pool reactor typical arrangement and location of fuel racks

tie into these drains. The drains discharge to a steel drum which may be used as a holdup tank.

The pool liner is fabricated of ¼-in.-thick aluminum and is watertight.

4.8 Shielding

The reactor is shielded so that during 10-kW operation the maximum radiation levels at 1 meter above the pool surface and at the surface of the concrete shield are less than 50 mrems/hr, when the beam port and thermal column are closed.

To provide adequate shielding, the reactor core is kept covered by 10 ft of water. The shield around the core consists of 3 ft of water followed by 5 ft of concrete in the shield walls.

4.9 Dynamic Design Evaluation

Information on dynamic design, including reactor operating characteristics, was provided by the General Electric Company (GE) in support of the original application for an operating license. No substantive changes have been made in the reactor design or operation since its initial licensing. Measurements and calculations performed since then verify and confirm these values.

4.9.1 Excess Reactivity

The critical mass obtained from two-group calculations and experiments is 3.3 kg of ^{235}U for the 5-by-5 element core surrounded by water. (The initial loading of the reactor consisted of 3.500 kg of uranium containing 3.269 kg of ^{235}U in Type 1 elements. The measured excess reactivity was 0.23 percent $\Delta k/k$.)

4.9.2 Neutron and Gamma Flux

The average thermal neutron flux in the reactor core at 10 kW is 9×10^{10} nv, and the average epithermal flux is 23×10^{10} nv. The average flux above 1 MeV is calculated to be 6×10^{10} nv. The gamma heating in the core has a peak value in the neighborhood of 10 w/l.

The gamma flux at the shield face of the graphite is about 3 rems/hr. The gamma flux at the outside surface of the thermal column door is less than 10 mrems/hr and the maximum neutron flux streaming found also is less than 10 mrems/hr.

4.9.3 Shutdown Margin

The three control blades, as shown in Figure 4.7, cut the core into three sections. One blade will be worth approximately 4 percent $\Delta k/k$. The blades shadow each other, so their combined control effectiveness is less than three times the individual effectiveness of one blade. The total control worth of the three blades is between 14 percent and 18 percent; the uncertainty arises because of the lack of knowledge of the effect of epithermal absorption.

The control blades span almost the full width of the core. As a result, they keep the reactor subcritical even if a loading error were to be made and more fuel included than planned. To go critical with the entire 6-by-9 grid filled with fuel elements and the control blades fully inserted in the core would require at least 300 g of ^{235}U per element, about twice the loading of the fuel elements intended to be used.

4.9.4 Burnup

The fuel burnup through 1981 is estimated to be approximately 0.34 g or about 0.01 percent of the ^{235}U in the core. The fuel life is, therefore, likely to be limited by factors other than burnup.

4.9.5 Temperature and Void Coefficients

Negative temperature and void coefficients aid stable operation of the reactor. Original calculations performed by GE and measurements made at the reactor facility confirm the existence of negative temperature coefficients. Table 4.1 presents the temperature and void coefficients for the WPI reactor using a reference temperature of 20°C.

Table 4.1 Temperature and void coefficients

Condition	Temperature coefficient (10^{-4} per C°) $\Delta k/k$	Void coefficient (10^{-3} per % void) $\Delta k/k$
Normal core loading:		
Core average (blades withdrawn)	-1.7	-2.5
Fuel section alone	-2.2	-2.8
Central fuel element removed:		
Core average	-0.6	-3
Fuel section alone	-0.7	-4

The temperature and void coefficients are positive in the water gap left by the control blades.

4.9.6 Neutron Lifetime

The prompt neutron lifetime has been calculated as 8.2×10^{-5} sec. This value may be compared to the measured value of 6.5×10^{-5} on the boiling reactor experiment (BORAX) reactor, and indicates that for the same amount of reactivity inserted in this reactor, a longer period would result than in the BORAX.

4.9.7 Alteration of Core Geometry

Alterations of core geometry will affect the available reactivity. If the reactor is loaded to criticality with a square array of 25 fuel elements, arranged symmetrically with respect to the control blades, the estimated changes in reactivity will be as shown in Table 4.2.

Table 4.2 Reactivity changes as a result of alterations of core geometry

Alteration	Change
An extra fuel element is added	plus 1% Δk/k
The geometry is changed so that only one of the two control blade shrouds bisects the active core	plus 1/2% Δk/k
A center fuel element is removed	minus 3% Δk/k

None of the changes indicated in Table 4.2 will make the reactor critical if at least one control blade or the regulating blade is in the core.

4.10 Control Drive Mechanisms

Each of three control blades is driven by an electromechanical drive which positions, holds, and scrams its respective blade. The drives are mounted on the locating plate above the reactor pool. They are magnetically coupled to the blades. When the magnets are de-energized, the blades drop into the core by gravity to shut down the reactor.

The drive mechanism includes a motor, worm-gear reducer, slip clutch, ball-bearing screw assembly, limit switches, scram magnet, and housing. The mechanism operates through a stroke of up to 32 in. at a normal speed of less than 7.5 in./min. Limit switches at the ends of the stroke open the motor circuit; they also cause an indication on the control panel. A third limit switch is incorporated within the scram magnet to provide remote indication when the drive shaft is engaged.

After flux decays in the magnet, which takes less than 100 msec, the blades will fall into the core through their first 24 in. of travel in about 500 msec. An indicator on the control panel provides continuous indication of the rod drive magnet position, and a red light is energized if a blade is disengaged from the magnet.

Control of the regulating blade is provided by a manually controlled motor-driven drive mechanism. This drive is directly coupled to the regulating blade and operates at a speed of less than 4 in./min. The total stroke is less than 32 in. Positioning accuracy is approximately 0.05 of 1 percent. The drive is equipped for position indication at the control console.

A control shaft joins the regulating blade to its drive mechanism. The shaft is aligned by polyethylene sleeve bearings similar to those used for the control blade shafts, but without a dashpot. Radial clearance between shaft and bearings is 0.031 in. The guide tube is attached to the suspension frame.

4.11 Neutron Source

A 1-curie plutonium-beryllium source utilizing 16 g of plutonium is contained in a steel, hermetically sealed cylindrical capsule 1 in. in diameter by 1.6 in. long. The capsule is normally kept inside a small plastic bottle weighted down with paraffin and scrap material and fitted with a lifting ring to which a strong nylon line is attached. The source is normally positioned at the midplane of the core. During the instrument checkout preceding each startup the source bottle is swung close to each compensated ion chamber to verify proper operation and scram point setting.

The source normally remains in the reactor pool at all times and is leak tested at least twice a year. On those occasions when the source is removed from the reactor pool, it is stored in a locked paraffin-lined steel drum similar to that used as the original shipping container and the source is leak tested at intervals of no longer than 30 days.

4.12 Operational Practices

WPI has implemented a preventive maintenance program that is supplemented by a detailed preoperational checklist to ensure that the reactor is not operated at power without all of the safety-related components fully operational.

The reactor is operated by trained, NRC-licensed personnel in accordance with explicit operating procedures, which include specified responses to any reactor control signal. All proposed experiments are reviewed by the Radiation, Health, and Safeguards Committee for potential effects on the reactivity of, or damage to, the core, as well as for possible effects on the health and safety of employees and the general public.

4.13 Conclusions

The staff review of the WPI reactor facility has included studying its specific design and installation features and the operational limitations as identified in the Technical Specifications. The staff concludes that the WPI reactor was designed and built according to good industrial practices. The staff further concludes that there is sufficient shutdown margin to ensure that the WPI reactor can be adequately shut down under all normal operating conditions.

The design features of the WPI reactor are similar to those of many pool-type research reactors operating in many countries of the world. Based on its review of the WPI reactor and its experience with similar facilities, the staff concludes that this reactor is capable of safe operation, as limited by its Technical Specifications, for the period of the license renewal.

5 REACTOR COOLANT AND ASSOCIATED SYSTEM

5.1 Primary Cooling System

The energy produced in the core is dissipated to the pool water as heat by the natural convection of the 7000 gal of demineralized water in the reactor pool. The pool water is maintained at the ambient temperature of the environment by heat conduction to the ground and air and by some evaporation of water from the pool surface. In order to raise the temperature of the pool water 10°C, the reactor would have to operate continuously for more than 30 hours at full power (10 kW), assuming no heat loss. Pool heatup poses no constraint on the anticipated operating schedule of the WPI reactor because the reactor has never been operated for 120 hours in a year.

5.2 Primary Water Purification System

The pool water is constantly filtered and passed through a demineralizer to maintain high purity.

Impurities collecting in the pool water are removed by circulating the water through the pool cleanup demineralizer. This demineralizer is a mixed-bed type. The resin in the unit may be regenerated if it is not excessively radioactive. Spent radioactive resin is stored on site (see Section 11.1).

The pump used for circulating pool water to the cleanup demineralizer is a close-coupled, centrifugal pump with a capacity of 10 gpm when pumping against the system head.

5.3 Primary Coolant Makeup Water System

Makeup for the pool is taken from the Worcester city water line and passed through the demineralizer enroute to the pool. A vacuum breaker excludes any possibility of siphoning pool water into the supply line. The pool makeup water system, in addition to the demineralizer, also includes a manual shutoff and throttle valve and a check valve.

5.4 Conclusions

The staff concludes that the reactor coolant system at the WPI reactor is of proper size, design, condition, and is properly maintained to ensure adequate cooling of the reactor at the power level specified in the WPI operating license.

6 ENGINEERED SAFETY FEATURES

Engineering safety features are those features or systems that decrease the probability or consequences of an accident. The only system that could be considered an engineered safety feature at the WPI reactor is the ventilation system, which would not isolate the reactor from the environment, but would reduce exposure to operations personnel if an accident were to occur.

6.1 Ventilation System

The reactor compartment ventilating system is of conventional design and provides more than two changes of air in the reactor room per hour. It operates at over 3000 cfm with a discharge duct velocity of over 800 ft/min. Intake and exhaust are filtered through commercial fiberglass air filters. Air enters through several duct openings along the north wall at the basement and first-floor levels and exhausts through openings also located in the north wall. The exhaust duct outlet is located on the south wall of the reactor compartment at a point about 18 in. above the roof and about 50 ft above the ground.

Experience and calculations show that gaseous wastes will not be generated in any hazardous quantities in a low power reactor of this type. Samples irradiated in the reactor for isotope study are small in quantity and at relatively low radiation levels. A careful review of proposed irradiation is made to ensure that a spill of the most dangerous volatile isotope to be used would be quickly and safely diluted and discharged by the ventilating system at a concentration well below that specified in 10 CFR 20 for release to an unrestricted area. For this reason, the system is not equipped with dampers, and the emergency procedure in case of a spill will be to continue to operate the ventilating system, thus reducing the potential dose to operating personnel.

6.2 Conclusion

The staff concludes that because of the simplicity and proven dependability of this and similar reactors, and because only NRC-licensed personnel operate the facility in accordance with carefully reviewed procedures, the probability of an accident is very low. Also, the facility operates at such a low power level that the consequences of any accident would not be significant. The staff further concludes that engineered safety features are not judged to be necessary at the WPI reactor.

7 CONTROL AND INSTRUMENTATION

7.1 Systems Summary

The control and instrumentation systems at the WPI reactor serve a dual purpose. The first is to provide a means to operate the reactor in a safe and reliable manner. The second is to provide the necessary hardware for the training of students in the practical application of nuclear engineering theory to the operation of a reactor. In keeping with the dual purpose, the control and instrumentation systems are relatively simple, reliable, easily understood, and very stable. The systems are designed and built for ease of maintenance, flexibility, and maximum component interchangeability. The system maintenance and repair history is documented in a log book to provide operational continuity as students participate in the various training and experimental programs.

The control and instrumentation systems at the WPI reactor are relatively simple and have proven to be very reliable. The electronic components represent hybrid "solid-state" and "vacuum tube" technology. The number of individual circuits and components has been minimized to provide for ease of maintenance and to facilitate student instruction. The physical quality of the systems is good and a high level of maintenance is evident. The control console is well designed, with all indicators and controls within easy sight and reach of the reactor operator. An interlock system is designed to scram the reactor upon loss of facility power. The area radiation monitors are provided with emergency backup power so that the facility can be monitored for radiation regardless of the status of the reactor itself. A block diagram of the safety instrumentation is shown in Figure 7.1.

Specific descriptions and analyses of both the control and the instrumentation are given in the following paragraphs.

7.2 Control Center Cubicle

The control center cubicle, a sheet metal cabinet, is 8½ ft long, 6½ ft high. and 2 ft deep from front to back. A front panel and rack-type mounting provides space for reactor controls and nuclear instrumentation. Secured only by screws in the front panels, individual units may be separately removed. Control switches, pushbuttons, indicator lights, recorders, and position indicators occupy a center panel immediately above the operating-desk top. An annunciator; alarm horn; log count rate, period, and scram indicators and two power indicators and their associated multiplier selectors; linear power channel selector; and four switches and the necessary fuses to safeguard these units fill out the upper panel. Two side panels contain amplifiers, a power supply unit, circuit breakers, area radiation monitors, a scaler, and micromicroammeters. Relays are located in the rear of the cubicle.

The control center cubicle is located on the first floor approximately 20 ft from the reactor. The reactor pool, reactor bridge, and associated regulating and control rod drives are clearly visible from the control center.

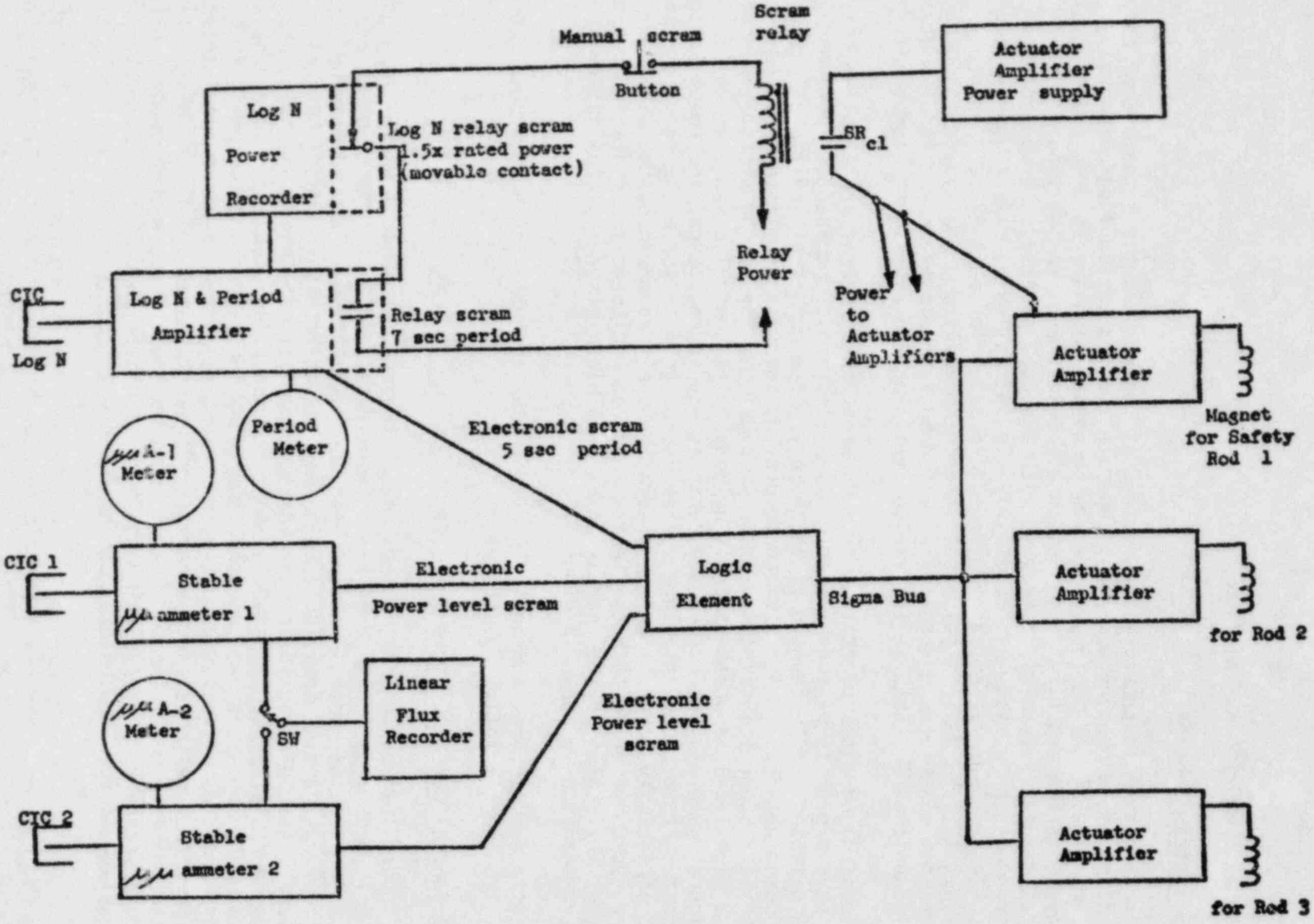


Figure 7.1 Block diagram of safety instrumentation

7.3 Control Power Distribution System

Power for operation of the reactor equipment is supplied from a 115-V, 60-cycle, grounded single-phase source. Power for the control blade drives and the safety magnets is controlled from the master switch. The master switch is key locked in the "OFF" position. The switch also provides "ON" for normal operation and a "TEST" position in which the control drives may be exercised without energizing the scram magnets and withdrawing the blades. Whenever the master switch is first turned "ON" from "TEST" or "OFF," an interlock causes the alarm horn to sound for 7 sec to warn personnel of impending startup. A time-delay mechanism prevents the control drive motors from withdrawing the blades during the 7-sec-delay interval.

7.4 Auxiliary Control Power Supply

No auxiliary power supply is used except for the area monitors, which are supplied by a continually charged battery system.

7.5 Instrumentation Power Supply

Power to operate the control and instrumentation systems is supplied from a facility 115-V, 60-cycle line through a 30-ampere circuit breaker. Two branch circuits, protected by separate fuses, supply power to the amplifiers, meters, recorders, and associated components of the reactor instrumentation system. These precision components are protected from line-voltage fluctuations. A third power branch provides power to the annuciators, scram relays, and alarm horn; the fourth branch furnishes power to the position indicators, switches, and drive motors of the regulating and control blades. Emergency backup power is provided (by a battery system) only to the area radiation monitors.

Power to operate the reactor equipment is supplied from a grounded, 115-V, 60-cycle, single-phase facility source routed through a key-locked master switch.

7.6 Flux Level Safety Channels

Two redundant safety channels provide power level monitoring over the entire flux range from 10^{-3} watt to full power. Each safety channel contains one micromicroammeter and a trip actuator. Each safety channel also is provided with a two-position channel-select switch that permits recording of the output on the linear power recorder mounted on the control console. The scram limit-of-flux level is preset at a value corresponding to 15 kW.

7.7 Log-N Period Channel

This channel monitors the power level of the reactor over the range from 0.1 watt to full power. The system integrates the current in a gamma-compensated ionization chamber, amplifies this signal by means of an amplifier having a logarithmic characteristic covering a 6.3-decade range, and differentiates the log-N signal to give the reactor period. One recorder permanently records log N and is equipped with a high flux scram adjustable contact.

7.8 Startup Channel

The startup channel measures neutron flux in the "shutdown" condition, with the source present, up to a flux corresponding to 1 watt. A ^{10}B proportional counter serves as the sensing element. Amplified counter output is monitored by a scaler and a log count rate meter on the control center cubicle. The scaler gives a direct reading of the number of pulses, or counts, occurring during a preset time interval. The scaler is intended primarily for the lowest flux levels. An audible indication of flux level also is provided. During full-power (10-kW) operation, the proportional counter is fully withdrawn to its uppermost position to prevent radiation damage to the counter.

7.9 Area Radiation Monitors

Radiation monitors are located at the bridge near the thermal column door, near the beam port plug, and near the demineralizer. They each give audible and visual indication when radiation levels exceed the currently preset level of 50 mrems/hr, except for the one on the bridge which monitors fuel storage and is set for 20 mrems/hr. The area monitors are connected to a 24-hour-per-day monitoring service located external to Washburn Laboratory; therefore, they provide continuous around-the-clock protection. These area monitors are supplied with backup power in case of power failure.

During reactor operation, portable survey instruments also are readily available to the reactor operator for measuring beta-gamma exposure rates in the range 0.01 mrems/hr to 50 mrems/hr and fast/thermal neutron dose rates from 0.04 to 1000 mrems/hr.

7.10 Control Blade Control

The reactor facility is provided with three control blades, which are driven into the reactor core or raised from the core with a maximum speed of less than 7.5 in./min. Only one control blade can be raised at a time; a limit switch/indicator arrangement shows the operator when the control blades have reached either limit of travel. The normal control of the control blades is overridden by either or both the automatic or manual scram. If a scram signal is initiated, the control blades will drop by gravity into the core from any position during a withdrawal or a rundown cycle. The control-blade drive motors are interlocked against withdrawal of the blades from the core under the following conditions:

(1) during a 7-sec-delay period after reactor startup

(2) with the log count rate meter below 50 counts per second

(3) if the regulating blade is withdrawn from its lowest position

(4) if the flux rises above a preset level before the control blades are completely withdrawn

(5) if the reactor is in the scram condition

A position indicator accurate to 0.02 in. is provided for each control blade drive system to show the position in the core relative to the fully inserted position. The positions are presented in digital form on the control console.

7.11 Regulating Blade System

In addition to the three control blades, the reactor is provided with a regulating blade. This unit is designed to maintain the reactor in a subcritical mode with all three control blades fully withdrawn from the core. Criticality is achieved by withdrawal of the regulating blade. Control of the regulating blade is provided by a manually controlled motor drive mechanism that is permanently attached by pinning to the regulating blade. The unit is controlled from the reactor operator's position at the control console. Adjustments to the regulating blade can be made in increments of 0.02 in.

7.12 Scram Circuits

The scram circuits initiate either relay ("slow") or electronic ("fast") scram. The "fast" or electronic scram is initiated when the reactor flux level exceeds 1.5 times the normal preselected value in any safety channel, or if the reactor period becomes less than 5 sec. The "electronic" scram de-energizes the power to the control blade magnets, causing the control blades to fall by gravity into the reactor core. The "slow" or "relay" scram is accomplished by de-energizing the scram relay under one of the following conditions:

(1) short period (if the period becomes less than the preselected value, which is adjustable between 5 and 30 sec)

(2) manual scram initiated by the reactor operator

(3) high voltage failure in control console

(4) high neutron flux

7.13 Alarm and Trouble Monitor System

The annunciator and the alarm horn are located on the control center cubicle and inform the operator of abnormal conditions developing in the reactor system. Green lights indicate normal operation.

Trouble in a particular phase of the system is indicated by lighting of the appropriate red light and the sounding of the alarm horn. The horn is silenced by pressing the "ANNUNCIATOR ACKNOWLEDGE" button that also turns off the green light. The red light remains on until the fault is cleared and the green light again appears.

Abnormal conditions within the following areas will actuate a safety alarm:

(1) reactor scram
(2) high neutron flux
(3) fast period
(4) low pool water level

(5) disengagement of control blade
(6) area radiation
(7) ^{41}Ar concentration in ventilation discharge above preset level

7.14 Conclusions

The WPI reactor control and instrumentation systems make use in many cases of modern, solid-state components. Reliability, predictability, and redundancy are built into the system. Rigid administrative controls and knowledgeable personnel complete the overall operations approach. Configuration control is maintained through proper documentation, and the quality of individual components composing the various systems is generally higher than the minimum required. In addition, upgrading of the systems and components is encouraged by management and forms an integral part of ongoing activities.

Based on its review and analysis of the control and instrumentation systems at the WPI reactor, the staff concludes that these systems are adequate to ensure the reliable and safe operation of the WPI reactor within the limits of approved Technical Specifications for the time period of the requested license renewal.

8 ELECTRIC POWER SYSTEM

8.1 Main Power

Operating power for the reactor is taken from the Worcester power grid. No onsite emergency power system is required because a power interruption scrams the reactor and the natural convection of primary water in the pool prevents damage to the fuel.

8.2 Backup Power

A backup electrical system, in the form of a battery and trickle charger, is provided to run the area radiation alarm system in the event that a power outage occurs.

8.3 Conclusion

The staff concludes that the primary and backup electrical power sources provided to the reactor facility are adequate to ensure safe operation and shutdown of the reactor.

9 AUXILIARY SYSTEMS

Auxiliary systems are those systems that are used to aid or in conjunction with the more significant main systems directly related to reactor operation. They include the various subunits of the fuel-handling system, the heating and air conditioning systems, the fire protection system, and the ventilation system.

9.1 Fuel Storage and Handling

Unirradiated fuel elements are stored outside the pool in a cabinet that is equipped with a padlock and secured to the railing around the reactor bridge with a lock and cable device. There are currently four fuel elements in the storage cabinet: one Type 1, two Type 2, and one similar to Type 1 but with removable fuel plates.

Irradiated fuel is manipulated under water in the pool with the aid of long-handled tools. Two fuel storage racks, with a combined capacity sufficient to completely unload the core, are located on opposite sides of the reactor pool. These racks are typically empty, as all irradiated fuel is in use in the core. However, if these inpool storage racks are used, a lock and cable device permits securing the elements to the racks.

9.2 Heating and Air Conditioning Systems

The reactor facility shares its heating and air conditioning system with the rest of Washburn Laboratory. The ventilation system is a safety feature that is discussed in greater detail in Section 6 of this report.

9.3 Fire Protection Systems

Washburn Laboratory, the building that houses the WPI reactor, has a masonry shell and wooden interior walls and floors. The building is equipped with an automatic sprinkler system to combat large fires and to protect the structure. Manually operated fire extinguishers are available to combat small fires. If additional firefighting equipment is needed, two nearby stations are available to serve the reactor facility. Fire chiefs from these stations have been made familiar with Washburn Laboratory and the reactor facility as well as the risk of radiation. To provide early warning of a fire, the staff has determined it would be appropriate to include smoke detectors in the reactor room. Accordingly, Section 5.4 of the Technical Specifications now requires smoke detectors to be installed in the reactor room.

9.4 Ventilation System

The ventilation system is described in detail in Section 6 of this report.

9.5 Conclusion

The staff concludes that the auxiliary systems at the WPI reactor are adequately designed and maintained and are capable of performing their intended functions.

10 EXPERIMENTAL PROGRAM

In addition to being used as an adjunct to other facilities in the education and training program of the university, the WPI reactor supports various types of experimental programs of the reactor staff and students. Most of the experimental work uses the neutrons available from the reactor to induce radioactivity in various materials. These irradiated materials may be foils or small samples to evaluate reactor parameters or material composition (neutron activation analysis) or tracers in engineering or biomedical studies.

All proposed new experiments must be reviewed by the WPI Radiological Safety Officer, who functions as a member of and in cooperation with the Institute's Radiation, Health, and Safeguards Committee to

(1) ensure that accidents causing changes in composition and geometry of the experiments will not cause positive step changes or ramps in reactivity that might place the reactor on unsafe periods

(2) provide assurance of mechanical integrity, chemical compatibility, and adequate protection against any other potential hazard

10.1 Thermal Column

The thermal column is a graphite-filled, horizontal penetration through the biological shield that provides neutrons in the thermal energy range (about 0.025 ev) for irradiation of experiments. The column consists of an aluminum case, 40 in. square in cross section and about 6 ft long; it is filled with graphite. Personnel in the building are protected against radiation from the column by a dense, concrete door that closes the column at the biological shield. The door is mounted on wheels that run on rails set into the concrete floor. The door can be moved perpendicular to the shield face. The door is provided with a lock and is visible from the reactor operating level. Experimental access is granted only to authorized personnel.

10.2 Beam Port

The beam port provides a source of neutrons that are primarily outside the thermal energy range. The beam port is an air-filled aluminum tube extending from the reactor core face and terminating in a flange at the biological shield face. A shutter and removable shield plug, or shield block, protect personnel in the building against radiation from the port. The plug is an aluminum casing, filled with concrete and containing spiral conduits for passage of instrument leads. The shield block, a massive 2½-by-2½-by-5½-ft concrete structure, weighs about 3 tons and contains a cavity to permit its use as a radiographic facility.

Provision is made for ventilating the port and collecting and draining away any seepage that may accumulate between the port tube and the surrounding concrete.

The beam-port plug and shutter each has a lock and each is visible from the reactor operating level. Experimental access is granted only to authorized personnel.

The thermal column and beam-port cavities are exhausted and monitored as described in Section 11.1.3, to minimize exposure of personnel to ^{41}Ar.

10.3 Conclusion

The staff concludes that the design of the experimental facilities, combined with the detailed review and administrative procedures applied to all research activities, is adequate to ensure that experiments (1) are not likely to fail, (2) are unlikely to release significant radioactivity to the environment, and (3) are unlikely to cause damage to the reactor systems or to the fuel. Operating experience provides further assurance that the experimental program at WIP will be conducted safely in the future. Therefore, the staff concludes that reasonable provisions have been made so that the experimental programs and facilities do not pose a significant risk of radiation exposure to the public.

11 RADIOACTIVE WASTE MANAGEMENT

11.1 General Summary

Solid, liquid, and gaseous wastes are generated at the facility. The following subsections provide the details of how each type of waste is treated.

11.1.1 Solid Waste

Virtually all of the radioisotopes produced in the reactor for laboratory use fall into one of three categories. Metallic foils of gold, vanadium, copper, etc. are irradiated, counted, cooled, and stored for reuse. Short-lived isotopes, such as aluminum, sodium, chlorine, and manganese, are produced for various laboratory purposes in a number of forms and then stored until their activity is undistinguishable from natural background. The third category of byproduct materials consists of trace amounts of a wide variety of elements. Since the neutron flux at the core center is only about 1×10^{11} neutrons per square centimeter per second and operations are usually limited to a 3-hour irradiation, the number of microcuries of long-lived trace elements is very small.

Other solid wastes resulting from reactor operation also are stored until the radioactivity in them has decayed. The demineralizer resins have been changed once (in 1978) since initial operation began. The spent resins are stored on site. By using a trash compactor for all gloves, paper, plastic, disposable samples, and experiment components that have any radioactive contamination, WPI is able to store such materials until long after their activity has become indistinguishable from natural background. Thus, no radioactive solids, measurably above background, are or have ever been released to the environment outside the facility.

11.1.2 Liquid Waste

Liquid wastes resulting from reactor operation are collected in a holding tank and monitored or sampled. If the liquid in the holding tank does not contain radioactivity above normal background levels (city tap water), it is discharged to the sanitary sewer system. No liquid wastes with activity above background levels are or ever have been released from the WPI reactor facility.

11.1.3 Gaseous Waste

The most significant gaseous effluent is ^{41}Ar, a beta-gamma emitter with a half-life of 1.8 hours. It is produced from the neutron irradiation of air in the beam port and thermal column while the reactor is in operation. It is gathered and injected into the ventilation system and is discharged through the stack located on the roof of Washburn Laboratory. A monitor located in a line that discharges to the stack will cause the reactor to scram if the ^{41}Ar level reaches 2.6×10^{-5} μCi/cc in the line. More than a 200-fold dilution occurs when the vent line exhaust mixes with the main ventilation system exhaust in the stack and further dilution occurs after release from the stack to the environs.

11.1.4 Conclusion

The staff concludes that the waste management activities of the WPI reactor facility are operated and can continue to be operated in a safe manner consistent with NRC requirements.

11.2 Process and Effluent Radiological Monitoring and Sampling

The WPI radiation monitoring system components are placed in locations and have set points to ensure that 10 CFR 20 requirements are not exceeded for restricted and unrestricted areas. Liquid effluents are sampled before being released to ensure that no discharges above natural background are made. Section 3.3 of the Technical Specifications describes the minimum acceptable radiation monitoring instrumentation required for reactor operation.

11.3 Dose Assessment

Traces of ^{41}Ar are produced in the beam-port and thermal column cavities during reactor operation. At power levels in excess of 1 kW, air is drawn from these locations and discharged into the building ventilation system exhaust. The ^{41}Ar injected into the ventilating system is monitored and conservative interpretation of the data based on 200 hours of operation at 10 kW (in 22 years of reactor operation, the reactor has never been operated 120 hours during a year) indicates an annual average specific activity release rate of 0.003 μμCi/cc of ^{41}Ar in the discharge from the ventilation stack to the atmosphere. This figure of 3×10^{-9} μCi/ml is 7.5% of the 4×10^{-8} μCi/ml value specified in 10 CFR 20, Appendix B, Table II Column 1 as 1 maximum permissible concentration.

11.4 Conclusions

The staff concludes that the waste management activities at the WPI reactor facility have been conducted and will be conducted in a manner consistent with 10 CFR 20 and with as-low-as-reasonably-achievable principles. Among other guidance, the staff review has followed the methods of ANSI/ANS 15.11, 1977, "Radiological Control at Research Reactor Facilities."

Because ^{41}Ar is the only potentially significant radionuclide released by the reactor to the environment during normal operations, the staff has reviewed the history, current practice, and future expectations of operations. The staff concludes that the doses in unrestricted areas as a result of actual releases of ^{41}Ar have never exceeded or even approached the guideline values specified in 10 CFR 20 when averaged over a year. Furthermore, the staff's conservative computations of the dose beyond the limits of the reactor facility give reasonable assurance that potential doses to the public as a result of ^{41}Ar would not be significant, even if there were a major change in the operating schedule of the reactor.

12 RADIATION PROTECTION PROGRAM

12.1 ALARA Commitment

The WPI administration has formally established the policy that all operations are to be conducted in a manner to keep all radiation exposures ALARA (as low as reasonably achievable). This policy is implemented by a set of specific guidelines and procedures. All proposed experiments and procedures at the reactor are reviewed for ways to minimize the potential exposures of personnel. All unanticipated or unusual reactor-related exposures are investigated by both the health physics and the operations staff to develop methods to prevent recurrences.

12.2 Radiation, Health, and Safeguards Committee

A Radiation, Health, and Safeguards Committee (RHSC) has been established by the President of the Institute to develop policies and procedures relative to health hazards from radiation to comply with the Code of Federal Regulations. It is the function of this committee to establish maximum dose limits; survey, monitoring, and handling procedures; access regulations and procedures; and emergency regulations and procedures. The committee reviews isotope applications and experimental procedures and maintains records.

12.3 Radiation Monitoring

A detailed description of the WPI radiation monitoring system is given in Section 7.9 of this report.

All persons entering a radiation area are required to wear film badges and/or pencil-type dosimeters, depending on the classification of the area. Permanent records are kept for each person using such a device.

Periodic surveys are made throughout the reactor facility during critical operations, using a portable survey instrument for gamma detection and paying particular attention to the beam-port shield, thermal column face, demineralizer, and holdup tank.

The reactor facility ventilating system filters are checked periodically, and whenever necessary, removed or changed. General environmental checks are made from time to time to provide long-term background records.

12.4 Procedures

Detailed written procedures have been prepared that address the health physics aspects of the operations staff's various activities and the support that it is expected to provide to the routine operations of the University's research reactor facility. These procedures identify the interactions between the Health Physics staff and the operational and experimental personnel. They also specify numerous administrative limits and action points as well as appropriate responses and corrective action if these limits or action points are reached or exceeded.

Copies of these procedures are readily available to the operational and research staffs and to the health physics and administrative personnel.

12.5 Conclusions

The staff has confirmed that radiation protection receives appropriate support from the administration. The staff concludes that (1) the program is properly staffed and equipped, (2) the WPI personnel have adequate authority and lines of communication, and (3) the procedures are correctly integrated into the research plans.

The staff concludes that the effluent and environmental monitoring programs conducted by WPI personnel are adequate to promptly identify significant releases of radioactivity and confirm possible impacts 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 guidelines of 10 CFR 20.

Additionally, the staff concludes that the WPI radiation protection program is acceptable. The staff has found no instances of reactor-related exposures of personnel above those in applicable regulations and no unidentified significant [illegible] of radioactivy to the environment. Furthermore, the staff considers [illegible] there is reasonable assurance that the personnel and procedures will continue to protect the health and safety of the public during the requested renewal period.

13 CONDUCT OF OPERATIONS

13.1 Organizational Structure and Qualifications

13.1.1 Overall Organization

Responsibility for the safe operation of the reactor facility lies within the organizational structure shown in Figure 13.1. Management level personnel, in addition to having responsibility for the policies and operation of the reactor facility, are responsible for safeguarding the public and facility personnel from radiation exposures and for adhering to all requirements of the OL and Technical Specifications.

13.1.2 Reactor Staff

The reactor facility staff consists of one permanent faculty member; a permanent six-member technical, technician, and secretarial staff; and students.

13.2 Training

The applicant's operator requalification plans have been reviewed by the NRC staff, which finds that they meet the requirements of 10 CFR 50.34(b)(7) and (8).

13.3 Emergency Planning

10 CFR 50.54(q) and (r) require that a licensee authorized to possess and/or operate a research reactor follow and maintain in effect an emergency plan that meets the requirements of Appendix E to 10 CFR 50. At the staff's request, as part of the application for license renewal, the applicant submitted a plan following guidance contained in Regulatory Guide 2.6 (1978 For Comment Issue) and in ANS 15.16 (1978 Draft). In 1980, new regulations were promulgated, and licensees were advised that revised guidance would be forthcoming. Thus, revised ANS 15.16 (November 29, 1981 Draft) and Regulatory Guide 2.6 (March 1982 For Comment) were issued. On May 6, 1982, an amendment to 10 CFR 50.54 was published in the Federal Register (47 FR 19512, May 6, 1982) recommending these guides and establishing new submittals dates for emergency plans from all research reactor licensees. The deadline for submittal from a licensee in the WPI reactor class (<2 MW) was November 3, 1982. The applicant transmitted an updated emergency plan by letter dated October 26, 1982, thereby complying with existing applicable regulations.

13.4 Operational Review and Audit

The WPI Radiation, Health, and Safeguards Committee reviews and approves new experiments and proposed alterations to the reactor. The committee reviews and audits reactor operations for safety. It is composed of the reactor supervisor and the radiation health physicist (both ex-officio, but voting) and at least three other members having expertise in radiation technology.

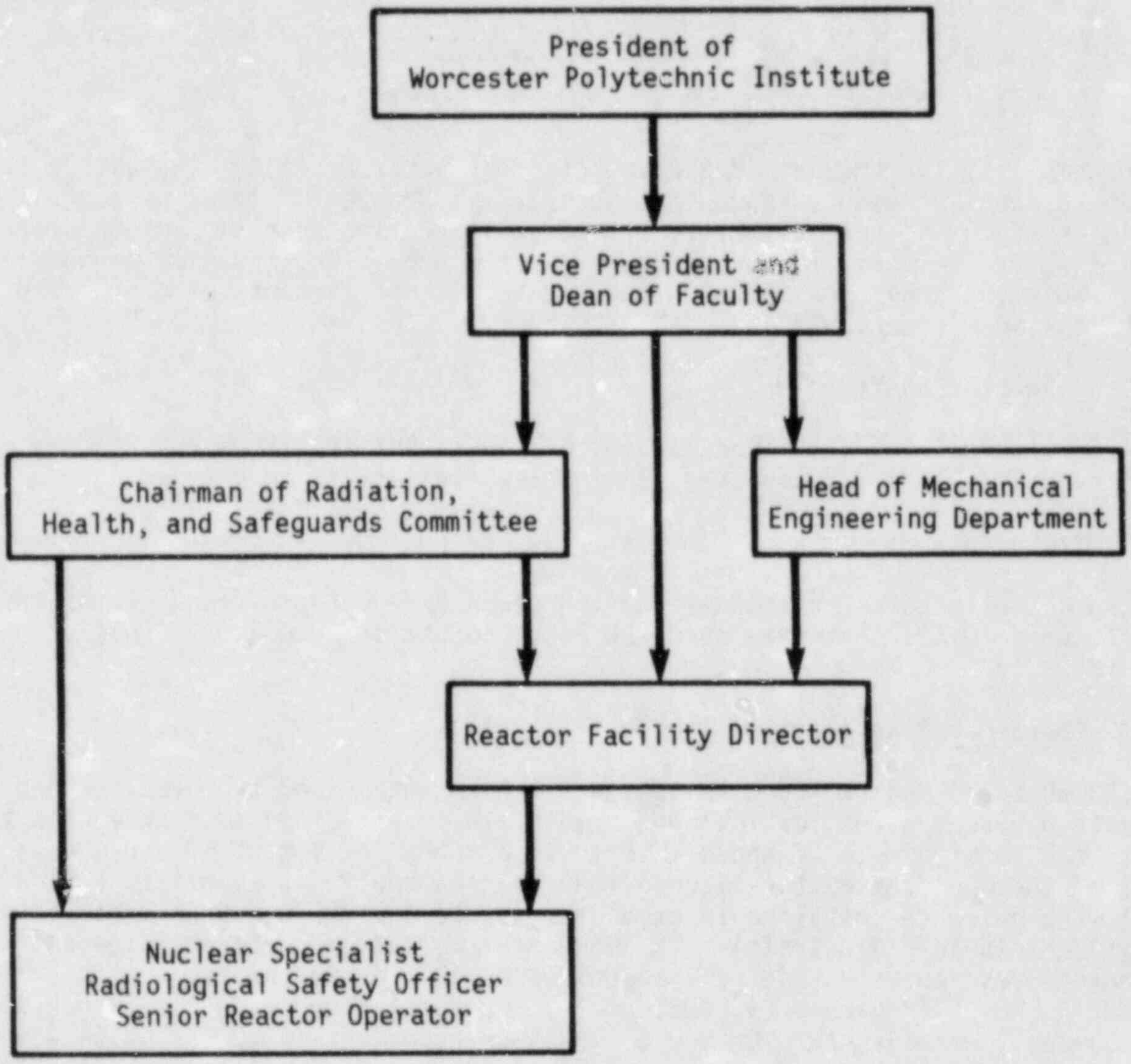


Figure 13.1 Worcester Polytechnic Institute functional relationships

The committee reviews

(1) proposed changes in equipment, systems, tests, experiments, or procedures to determine that they do not involve an unreviewed safety question

(2) all new procedures and major revisions having safety significance, proposed changes in reactor facility equipment, or systems having safety significance

(3) tests and experiments in accordance with Technical Specifications

(4) proposed changes in Technical Specifications or license

(5) violations of Technical Specifications or license, or violations of procedures or instructions having safety significance, as well as remedial actions to ascertain that the violations do not recur

(6) operating abnormalities having safety significance and audit reports

(7) reportable occurrences listed in the Technical Specifications

The committee also has audit functions that include selective (but comprehensive) examination of operating records, logs, and other documents.

13.5 Facility Procedures

The applicant has committed to the development and maintenance of procedures that are appropriate for continued safe operation. The current procedures are documented and filed within the reactor facility.

13.6 Physical Security

The applicant, in accordance with 10 CFR 73, submitted a Physical Security Plan. The plan was reviewed and was approved on February 5, 1981. A site visit was made to verify measures with the applicant. Based on its review and site visit, the staff finds that the applicant's Physical Security Plan is acceptable.

13.7 Reports and Records

Annual reports are submitted to include (1) reactor operating experience, unscheduled shutdowns, and corrective actions that have safety significance; (2) changes to facilities, procedures, or experiments or tests that were carried out before NRC approval; (3) amounts and nature of radioactive discharges to the environment; and (4) any significant personnel exposures.

Special reports will be submitted as required by the Technical Specifications.

The staff's review of past WPI violations, as described in the Office of Inspection and Enforcement reports, indicated that none of the violations posed a threat to reactor safety. They were all violations of the licensee's procedures, guidelines, or administrative and procedural requirements of the Technical Specifications.

13.8 Conclusion

Based on the above descriptions, the staff concludes that the applicant has sufficient experience in management structure and procedures to provide reasonable assurance that the reactor will be operated in a way that will cause no significant risk to the health and safety of the public.

14 ACCIDENT ANALYSIS

14.1 General Summary

The WPI core consists of MTR-type fuel with a uranium-aluminum alloy sandwiched between aluminum side plates. The WPI core is similar to the Argonaut-type reactor core in that the fuel is similar and the cores are water cooled and moderated, graphite reflected, and operate at a maximum power level of 100 kW or less. Because of these similarities, portions of the NRC Safety Evaluation Report for the UCLA Argonaut Reactor as well as the three analyses of Argonaut-reactor accidents and safety (NUREG/CR-2079; NUREG/CR-2198; and Carew, 1981) were used to help analyze the safety of the WPI reactor. The accident scenarios in these reports have been modified to be facility-specific for WPI. The accidents considered include inadvertent excess reactivity insertion; metal-water reactions; graphite fire; mechanical damage, including crushing of the core; water damage; and a fuel-handling accident.

14.2 Accidents

The staff requested Los Alamos National Laboratory (LANL) to provide a thermodynamic analysis and evaluation of an Argonaut-UTR core that was assumed to be severely damaged by an earthquake (NUREG/CR-2198). Additionally, the Commission requested Battelle to conduct an analysis and evaluation of various postulated accidents that could be considered credible for Argonaut-UTR reactors (NUREG/CR-2079). The staff also requested that Brookhaven National Laboratory (BNL) utilize a computer program to verify spent-fuel accident data and to evaluate Argonaut accident consequences from a ramp excess reactivity insertion of 3.00$ (Carew, 1981).

14.2.1 Core Damage (Crushing) from Fuel-Cask-Drop Accident

The analysis performed for the 100 kW Argonaut MTR-fuel (NUREG/CR-2198) indicates that no fuel melting would occur from complete crushing of the core resulting from a severe seismic event. Because the WPI reactor is not located in a seismically active area, a core-crushing accident could only occur as the result of a heavy object being dropped onto the core. Because the floors and roof above the WPI reactor are constructed of wood, and because the fuel cask is the only heavy object that is ever over the pool, the core-crushing accident is assumed to result from a full cask being dropped onto the core. This accident, however, is not considered credible because of the protection provided by the bridge structure that supports the core. Any object would have to be swung under the bridge, between the corner supports and control drives, in order to drop onto the grid box surrounding the core. Because the potential crushing of the WPI core as a result of a cask-drop accident would be much less severe than that postulated in the Argonaut accident scenario and because the WPI power level is only 10 kW, rather than 100 kW, temperatures in the WPI fuel would be much lower than those calculated for the Argonaut fuel. Thus, the most severe hypothetical accident postulated for the WPI reactor will not result in fuel melting and subsequent release of fission products to the environment.

14.2.2 Analysis and Evaluation of Postulated Accident Scenarios for Argonaut Research Reactors (NUREG/CR-2079)

The following are postulated accidents for Argonaut-UTR reactors in the Battelle Report (NUREG/CR-2079).

Excess Reactivity Insertion

The Battelle report used a maximum excess reactivity available for an inadvertent stepwise insertion of 2.6 percent Δk/k (3.90$), which is similar to that considered in the BORAX/SPERT tests. This would produce a pulse of 12 MW seconds, which would heat the fuel to an average temperature of 500°C with a possible hot spot of 590°C. The BNL memorandum on a ramp insertion of 3.00$ of excess reactivity into an Argonaut reactor concluded that the peak clad temperature for an Argonaut transient would be ~400°C [750°F]. The aluminum fuel cladding melts at 660°C and the fuel melts at 640°C. Inasmuch as the current excess reactivity in the WPI research reactor is 0.5 percent Δk/k (0.75$), the fuel and cladding temperatures would be much less than those values indicated above. Therefore, the fuel cannot melt and there is no safety hazard from a rapid insertion of reactivity.

Metal-Water Reaction

The only chemical reaction that can theoretically produce an explosion in the core at this reactor is the metal-water reaction between the aluminum in the fuel and the coolant water and the subsequent potential explosion of any generated hydrogen gas. For this reaction to occur fast enough to produce an explosion would require that the cladding be in the form of aluminum filings. As there is no mechanism to produce this degree of abrasion, this situation cannot occur in the WPI reactor. Therefore, this explosion cannot occur in the WPI reactor.

Graphite Fire

The Battelle report indicated that a sequence of events that could lead to the initiation of a graphite fire in this reactor would require (1) the failure of an experimental apparatus, (2) a building fire, and (3) the exposure of the graphite blocks to a free flow of air. Since the occurrence of these three events, which are necessary for a graphite fire, are extremely unlikely, the staff considers this scenario to be such a remote possibility that it poses virtually no risk at the WPI reactor.

Core Damage and Flooding

The Battelle report considered mechanical rearrangement of the core and simultaneous flooding, as well as crushing of the core as a result of an assumed accident involving dropping the shield blocks into the core during core maintenance operations. The analysis indicated that the most severe consequences from these events would result in no fuel melting at any operating conditions. However, they could result in an accident scenario in which a heavy object is dropped onto the core, which could result in mechanical damage similar to that emanating from the postulated seismic event. In all cases examined, no fuel melting or melting of the cladding occurred in the 100-kW Argonaut reactor.

Fuel-Handling Accident

As described in Section 14.2.1, the most serious hypothetical accident to the 10-kW WPI reactor involving crushing of the core would not result in melting of the fuel cladding or fuel meat. The most serious fission product release considered is dropping the fuel-handling cask, containing a fully irradiated fuel element, leading to a breach of cladding integrity and subsequent release of fission products to the atmosphere. A detailed analysis of this type of accident performed for an MTR-type fuel element (NUREG/CR-2079) extrapolated to the WPI reactor's 10-kW power level would result in whole-body and thyroid doses that are small fractions of 10 CFR 20 requirements, as indicated in Table 14.1. This analysis is covered to be very conservative because

(1) It is assumed that the fuel element drops out of the cask and is broken into many pieces so that the exposed area of fuel surface would be equivalent to stripping all the cladding from every fuel plate in the bundle. It is extremely unlikely that fuel damage this extensive would result from dropping the fuel element.

(2) It is assumed that fuel transfer operations begin immediately after shutdown of the reactor. The normal procedure at WPI is to shut down over the weekend before beginning any fuel-handling operations to allow the short-lived fission product isotopes to decay.

(3) It is assumed that the reactor has been operating at full power for an extended period of time so that fission product equilibrium is reached. Examination of the operating history of the WPI reactor indicates that the reactor is used only a few hours per week at most. Therefore, the inventory of fission products will not be anywhere near equilibrium. Referring to the noble gases and iodines listed in Table 14.1, the 10-kW WPI reactor would have to operate continuously for approximately 40 hours to reach krypton equilibrium and more than 50 days for ^{131}I equilibrium.

Conclusion

Based on the extremely conservative assumptions and the analyses set out above, the staff concludes that an instantaneous reactivity insertion, a fire in the reactor room, mechanical damage to the core, or a severe fuel-handling accident inside the reactor room would not pose a threat to the health and safety of the workers or the public.

14.2.3 Applicant's Accident Analyses

The applicant performed accident analyses without the benefit of the above mentioned reports. The accidents considered were power failure, fuel element failure resulting from hydraulic or thermal imbalances, loss of coolant, startup accident, flooding a beam port, consequences of sequential accidents, loss of coolant with damaged fuel (dropping a fuel element), and collapse of an incore experiment.

The consequences of all of the accidents analyzed by the applicant fall within the envelope of accidents analyzed by the NRC staff and by the national laboratories under contract to NRC.

Table 14.1 Activity and potential exposures from a maximum credible fuel-handling accident (based on NUREG/CR-2079)

Nuclide	Curies released*	Dose concentration, Ci/m^3**	Resulting potential exposure, rem
Whole-body exposure			
Noble gases			
^{85m}Kr	0.21	5.9×10^{-7}	0.011
^{85}Kr	0.003	8.3×10^{-9}	--
^{87}Kr	0.38	1.1×10^{-6}	0.104
^{88}Kr	0.58	1.6×10^{-6}	--
^{133m}Xe	0.03	8.4×10^{-8}	--
^{133}Xe	1.08	3.0×10^{-6}	0.019
^{135m}Xe	0.17	4.7×10^{-7}	--
^{135}Xe	1.07	3.0×10^{-6}	0.063
Total whole-body dose equivalent			0.197
Thyroid dose			
Radioiodines			
^{131}I	0.44	1.2×10^{-6}	2.17
^{132}I	0.66	1.8×10^{-6}	0.12
^{133}I	1.08	3.0×10^{-6}	1.51
^{134}I	1.14	3.2×10^{-6}	0.10
^{135}I	1.02	2.5×10^{-6}	0.43
Total thyroid dose commitment			4.33

*Assumes no decay after shutdown and 2.7-percent release from a single fuel element containing 7 percent of the core inventory following operation for 36.5 MWd.

**Assumes 1-hour release time and $\chi/Q = 0.01$.

14.3 Conclusion

Based on the preceding analyses, the staff concludes that the hypothetical accidents involving the WPI reactor do not pose a significant hazard to the public or to the environment. The analyzed event with the greatest potential impact on the public is the fuel-handling accident leading to loss-of-cladding integrity and release of fission products to the atmosphere. The analysis has demonstrated that even if that unlikely event were to occur, the resultant doses would be below limits specified in 10 CFR 20 for release to unrestricted areas. No event, credible or otherwise, including one accompanied by complete loss of coolant, will lead to fuel melt. The conservative analyses discussed above give reasonable assurance that the operation of the reactor for the 20-year renewal period does not pose significant risk to the health and safety of the public.

15 TECHNICAL SPECIFICATIONS

The Technical Specifications define certain features, characteristics, and conditions governing the continued operation of the WPI facility. The Technical Specifications will be made a part of the renewed OL. The Technical Specifications follow the most recent industry guidance, American Nuclear Society Standard 15.1, "Standard for the Development of Technical Specifications for Research Reactors."

On the basis of its review, the staff concludes that normal plant operation within the limits of the Technical Specifications will not result in offsite exposures in excess of the 10 CFR 20 limits. Furthermore, the limiting conditions for operation and surveillance requirements will ensure that necessary engineered safety features will be available in the event of malfunctions within the facility.

16 FINANCIAL QUALIFICATIONS

In support of the license renewal application, WPI supplied financial information that described sources of funds necessary to cover the estimated cost of operation plus the estimated costs of permanently shutting down the facility and maintaining it in a safe condition. The staff reviewed the financial information supplied by the applicant in the application and concluded that WPI possesses or can obtain the necessary funds to meet the requirements of 10 CFR 50.33(f).

Therefore, the applicant is considered financially qualified to operate the reactor for the time period requested.

17 OTHER LICENSE CONSIDERATIONS

17.1 Prior Reactor Utilization

The previous sections concluded that only a postulated fuel-handling accident or damage to the core from dropping a heavy object onto it could cause failure of the fuel cladding and the consequent release of fission products. As explained in previous sections, the design of the reactor, the small amount of fuel, and the low power level and part-time utilization of the reactor prevent serious consequences from any postulated multiple failures, simultaneously or sequentially. Failure of two or more instruments might prevent the shutdown of the reactor, but the inherent safety features of the small pool reactor do not provide a mechanism that can lead to catastrophic fuel-cladding failure.

The staff considered the effects of the past 20 years of reactor use on continued safe operation of the facility. Significant factors that minimize the effect of past use are

(1) The average WPI reactor utilization for the past 20 years has been less than 5 percent of the normal available time and much less than experienced by some other reactors containing similar components (for example, University of Michigan, National Bureau of Standards). Accordingly, operating parts received comparatively low wear. (It should be noted that licenses for power reactors are issued for a term of 40 years from the date the construction permit is issued.)

(2) The operators of the WPI reactor perform regular preventive maintenance to discover potential failures or to preclude the failure of components. At appropriate times, components with degraded performance are replaced before failure occurs.

(3) Startup procedures that check critical components also evaluate component performance before reactor operation. Inoperative components are attended to before starting reactor operation. This is the procedure that has been followed since the reactor first received its OL in 1957.

(4) The Technical Specifications are performance specifications and are not predicated on the age of the components. If a component does not meet the requirements of its particular specification, the reactor is not permitted to operate until the specification requirement is satisfied.

Because the reactor has had such an infrequent use factor, and because the Technical Specifications require periodic testing and/or calibration of components, there is no reason for concern about the age of the reactor or the performance of its components.

17.2 Corrosion

As stated in the Technical Specifications, reactor coolant water is maintained at a very high purity of not less than 5 x 10^5 ohm-cm resistivity. Conductivity is checked before a reactor startup day. Corrosion products that may be circulating in the core and activated are removed by ion-exchange equipment. Inordinate or changing rates of buildup of this source of radiation in the core circulating system would be noted in the cleanup system monitors. The Technical Specifications (Section 3.0) stipulate a rate of testing and calibration that will ensure the operability, validity, and reliability of the equipment or instrument between testing and calibration intervals.

Moreover, besides indicating intervals of testing and calibration, the Technical Specifications reflect the performance requirement of the equipment or instrumentation. If the performance of the reactor safety components does not meet the requirements in the Technical Specifications, the reactor is not permitted to operate or the reactor is shut down.

The combination of primary coolant water purity, testing frequency, instrumentation, purity equipment, and performance requirements in the Technical Specifications precludes corrosion products becoming a safety factor or detrimentally affecting performance of the reactor.

17.3 Multiple or Sequential Failures of Safety Components

Of the many accidents hypothesized for the WPI reactor, none produce consequences more severe than the postulated accident in which mechanical damage to the core results in cladding failure and fission products are released into the reactor room. The only multiple mode failure possible would be all the rods stuck out of the core. This would merely cause the water in the pool to boil and evaporate and thus reduce the reactivity until fission stops. Accordingly, other multiple or sequential accidents were not analyzed.

18 CONCLUSIONS

Based on its evaluation of the application as set forth above, the staff has determined that:

(1) The application for renewal of the operating license for the Worcester Polytechnic Institute research reactor filed by the Vice President and Dean of Faculty, dated July 16, 1979, as amended, 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 1;

(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 1;

(4) The applicant 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 1; and

(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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16. ABSTRACT *(200 words or less)*

This Safety Evaluation Report for the application filed by the Worcester Polytechnic Institute for a renewal of operating license number R-61 to continue to operate their 10 KW open-pool training reactor 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 Worcester Polytechnic Institute and is located on the WPI campus in Worcester, Worcester County, Massachusetts. The staff concludes that the reactor facility can continue to be operated by WPI without endangering the health and safety of the public.

17. KEY WORDS AND DOCUMENT ANALYSIS

17a. DESCRIPTORS

17b. IDENTIFIERS/OPEN-ENDED TERMS

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