NUREG-1084

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

Docket No. 50-294

**U.S. Nuclear Regulatory Commission**

**Office of Nuclear Reactor Regulation**

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ABSTRACT

This Safety Evaluation Report for the application filed by the Michigan State University (MSU) for a renewal of operating license number R-114 to continue to operate the TRIGA Mark I research 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 Michigan State University and is located on the campus of Michigan State University in East Lansing, Ingham County, Michigan. The staff concludes that the TRIGA reactor facility can continue to be operated by MSU without endangering the health and safety of the public.

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# 1 INTRODUCTION

The Michigan State University (MSU/licensee) submitted an application for 20-year renewal of the Class 104 operating license (R-114) (NRC Docket No. 50-294) for its TRIGA research reactor facility to the U.S. Nuclear Regulatory Commission (NRC staff) by letter (with supporting documentation) dated September 19, 1977. The application was signed and notarized by the Vice President for Business and Finance of the Michigan State University. The MSU reactor facility currently is permitted to operate within the conditions authorized in past license amendments in accordance with Title 10 of the Code of Federal Regulations (10 CFR), Paragraph 2.109, until NRC action on the renewal request is completed.

The staff technical safety review, with respect to issuing a renewal operating license to the MSU facility, has been based on the information contained in the renewal application and supporting supplements, plus responses to requests for additional information. The renewal application includes the Safety Analysis Report, Environmental Evaluation Report, Technical Specifications, Reactor Operator Requalification Program, and an Emergency Plan. This material is available for review at the Commission's Public Document Room at 1717 H Street N.W., Washington, D.C.

The renewal application contains the information regarding the original design of the facility and includes information about modifications to the facility made after the initial licensing. The previously approved Physical Security Plan is protected from public disclosure under 10 CFR 2.790(d)(1) and 10 CFR 9.5(a)(4).

The purpose of this Safety Evaluation Report (SER) is to summarize the results of the safety review of the MSU TRIGA Mark I 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 nonpulsing operation of the MSU facility at thermal power levels up to and including 250 kW and for pulsed operation with step reactivity insertions up to 2.00$ (1.40% $\Delta k/k$). The facility was reviewed against the requirements of 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 compared calculated dose values with related standards in 10 CFR 20, the standards for protection against radiation, both for employees and the public.

This SER was prepared by Angela T. Chu, Project Manager, Division of Licensing, Office of Nuclear Regulatory Regulation, U.S. Nuclear Regulatory Commission. Major contributors to the technical review include the Project Manager and J. E. Hyder, K. K. S. Pillay, and A. E. Pope of Los Alamos National Laboratory (LANL) under contract to the NRC.

## 1.1 Summary and Conclusions of Principal Safety Considerations

The staff's evaluation considered the information submitted by the licensee, past operating history recorded in annual reports submitted to the Commission by the licensee, and reports by the Commission's Office of Inspection and Enforcement. In addition, as part of its licensing review of several TRIGA reactors, the staff obtained laboratory studies and analyses of several accidents postulated for the TRIGA reactor. The staff's conclusions, based on evaluation and resolution of the principal issues reviewed for the MSU reactor, are as follows:

(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 standards for unrestricted areas.

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

(4) The system 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 is reasonably achievable (ALARA).

(5) The licensee's Technical Specifications, which provide 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 licensee are such that the staff has determined that the licensee has sufficient revenues to cover operating costs and eventually to decommission the reactor facility.

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

(8) The licensee's procedures for training reactor operators and the plan for operator requalification are acceptable. These procedures give reasonable assurance that the reactor facility will be operated with competence.

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

## 1.2 Reactor Description

The MSU TRIGA Mark I is a heterogeneous pool-type reactor. The core is moderated by zirconium hydride and water and reflected by water and graphite. The core is located near the bottom of a 1/4-in.-thick aluminum tank that has an outside diameter of 6.5 ft and is 25 ft deep. The tank is below ground and surrounded externally by steel-encased concrete.

The reactor contains approximately 2.5 kg of 19.9% enriched uranium-zirconium-hydried (U-$ZrH_x$) TRIGA-type fuel. It is designed for nonpulsing operation at a power level up to and including 250 kW and for pulsed operation of up to 250 MW through rapid step insertions from 0.75% Δk/k up to 1.4% Δk/k. MSU's Technical Specifications limit the excess reactivity to 2.25% Δk/k.

The reactor heat is dissipated by circulation of the reactor pool water through the tube side of a heat exchanger. A secondary water supply system circulates through the shell side of the heat exchanger and to a cooling tower located within a ventilation penthouse on the roof of the reactor building.

The power level of the reactor is accurately controlled by three control rods: a regulating rod, a shim rod, and a safety-transient rod. Experimental facilities include a rotary specimen rack and a central thimble.

The inherent, prompt shutdown mechanism of TRIGA reactors has been demonstrated extensively at the two prototype TRIGA reactors at General Atomic's laboratories in San Diego, California. This demonstrated safety has permitted other TRIGA-type reactors of similar power level and excess reactivity to be located in urban areas.

## 1.3 Reactor Location

The MSU TRIGA Mark I is located in the Engineering Building on the campus of Michigan State University. The campus is located in the southern area of the city of East Lansing, Ingham County, Michigan.

## 1.4 Shared Facilities and Equipment

Electricity and steam for the reactor facility are provided by the MSU power plant, which is located about 1/4 mi south of the reactor site, and are shared by other parts of the Engineering Building and the campus. Water from MSU production wells also is shared with other parts of the campus. The sewer system, which is connected to the city system of East Lansing, is shared with the MSU campus. Compressors located in the basement of the Engineering Building provide compressed air to room 184 where the reactor is located. No gas is supplied to this room.

## 1.5 Comparison With Similar Facilities

The reactor core and control system are similar in design to most of the 58 TRIGA reactors operating throughout the world; 27 of these are in the United States and 24 are licensed by the NRC.

## 1.6 Modifications

In 1974, the MSU reactor was authorized to change fuel by license amendment. The 8 wt % aluminum-clad fuel elements in the core were replaced by the 12 wt % stainless-steel-clad fuel elements. The used aluminum-clad fuel elements are stored on wall-mounted racks inside the reactor tank.

In 1970, Lexan was added to the glass on the outside windows of the reactor room. Lexan is a bullet-proof material used here for the purpose of reactor security.

## 1.7 Operational History

The MSU reactor has a burnup rate of 19.13 MW hours per gram 235U. From January 1, 1975, to September 30, 1983, the MSU reactor was operated for 228.81 MW hours, or an average of 28.6 MW hours per year. The burnup for the same period of time was 11.96 grams of 235U, or an average of 1.36 gram U-235 per year. In recent years, the research activities at the MSU reactor facility have decreased significantly.

## 1.8 Nuclear Waste Policy Act of 1982

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

Because the Michigan State University is such a university, it is in conformance with the Waste Policy Act of 1982.

# 2 SITE CHARACTERISTICS

## 2.1 Geography and Demography

The main campus of MSU, at East Lansing, is a rolling, wooded area of some 1,500 acres with the Red Cedar River winding through it. To the south of the main campus is a spread of more than 3,000 acres devoted to agricultural research. There is mostly farm land to the east of the reactor site. The business district of East Lansing is approximately 4,200 ft north of the reactor site. The city of Lansing is 4 mi west of the MSU campus. The Red Cedar River, which is 1,400 ft north of the reactor site, flows into the Grand River at a point 4 mi west of the reactor site.

The population of the city of East Lansing is approximately 51,000. This includes students who reside in the city. Approximately 44,000 students attend the university. Of this number, about 15,500 are on-campus residents living in residence halls. In addition to the students, there are approximately 8,500 employees working 8 hours per day on the campus. The population characteristics of East Lansing are shown in Table 2.1, including census tract numbers that are used in Figure 2.1 to identify population districts.

## 2.2 Nearby Industrial, Transportation, and Military Facilities

The major industrial facility in the area is an automobile assembly plant (a division of General Motors) located 4 mi west of the MSU campus.

There are two freight lines near the MSU campus: the C&O Railroad is 3,500 ft south of the reactor site, and the Grand Trunk Railroad is 1,400 ft south of the reactor site. The Grand Trunk Railroad also is used by Amtrack for two passenger service runs per day.

Major highways close to the MSU site are Interstate 496, which is 1.5 mi west, Interstate 96, which is 2.5 mi south; and Interstate 69, which is 1.5 mi. north.

The Lansing Capital Airport is located 7.5 mi northwest of the MSU campus. The Abrams Airport, which is an Air National Guard Post, is located 16.5 mi northwest of the MSU campus.

Figure 2.2 shows the transportation routes near the MSU campus.

## 2.3 Meteorology

Meteorological data for the site were obtained from the Department of Commerce's Agricultural Services Office at 1405 South Harrison Road, East Lansing, Michigan. The data were recorded at Lansing Capital Airport. Because the terrain between the site and the airport is flat with no major hills or valleys, the data are considered to be representative of the site.

2.3.1 Climate

The climate at Lansing alternates between continental and semimarine, depending on meteorological conditions. A marine-type climate results from the influence of the lake and the force and direction of the wind. When there is little or no wind, the weather becomes continental in character, which means pronounced fluctuation in temperature--hot weather in summer and severe cold in winter. On the other hand, a strong wind from the lakes may immediately transform the weather into a semimarine-type climate.

The annual average temperature at the reactor site is 46.8°F. February is the coldest month, with temperatures ranging from 14°F to 30°F, and July is the hottest month, with temperatures ranging from 71°F to 82°F. The area's annual precipitation averages 30.65 in. Precipitation rates are highest in the summer months, with June levels averaging up to 3.5 in. Although precipitation is lowest during the winter months, snow accumulations reached 30 in. in January of 1967. During the past 45 years, the average snowfall per winter has been 49 in.

The general area around the MSU reactor site is also susceptible to damaging windstorms. These windstorms may be accompanied by rain, freezing rain, hail, or snow. A review of weather bureau data on damaging windstorms (excluding tornados) shows a total of 27 windstorms creating damage in excess of $500,000 since 1900. Of these storms, only 8 are listed as having winds in excess of 75 mph. Figure 2.3 is a wind rose showing wind direction and speed and the percentage of time the wind blows in any one direction.

2.3.2 Tornados

There is a history of tornados occurring in Michigan. According to the U.S. Weather Bureau, Michigan lies at the northeastern edge of the Nation's maximum frequency belt for tornados. About 80% of the tornados in Michigan occur in the southern half of the lower peninsula where MSU is located. However, data collected between 1930 and 1974, show that the tornados passed north and west or south and east of East Lansing. East Lansing is on the northern edge of a pocket of relative calm. From 1954 through 1981, 191 tornados were observed in the 14,000-mi$^2$ area that includes East Lansing, giving a mean annual frequency of 5.8 tornados.

## 2.4 Hydrology

From the test boring data that appears in Figure 2.4, campus engineers determined ground water level and used this as a factor in designing the Engineering Building. The test boring was made at an elevation of 854.2 ft and showed heavy ground water at 9 ft. The floor of the Engineering Building is at 857 ft; thus ground water level is 11.2 ft. There is a foundation drain tile, laid at an elevation of 843.17 ft, around the entire perimeter of the Engineering Building.

Water moves very slowly through the surrounding moist clay and very little of the water reaching the drain tile is thought to come through the clay layer. The ground water level is not likely to go below the sand-clay interface at approximately 12.2 ft (referenced from the building floor) because the clay is extremely moist and water movement is very slow (estimated to be 0.01 in. per hour). The drain tile around the building footings tends to lower the ground water level. Even if the reactor tank should rupture, all the water would not all drain out of the 25-ft deep tank because of the high ground water level. Approximately 12 ft of water would still remain in the tank.

The only source of flowing water in the area is the Red Cedar River, which is located about 1,400 ft north from the reactor site. The river flows in a westerly direction to join the Grand River. Water in the Red Cedar River is periodically monitored by the MSU Office of Radiation and is not used as a source for human consumption.

## 2.5 Geology

The northwestern corner of Ingham County lies near the center of the Michigan Basin, an intracratonic basin developed on Precambrian crust. The Michigan Basin has a long history as a stable structural basin and is filled primarily with Paleozoic sedimentary rocks reaching thicknesses of approximately 15,000 ft at the basin's center.

In the Lansing area, bedrock, which consists of shales and sandstones of the Saginaw Formation of Pennsylvanian age, are covered with a layer of glacial drift approximately 75 in. thick. The bedrock within the basin shows little deformation and faults do not offset the younger formations. The boring log in Figure 2.4 was made in the immediate area of the reactor site, before reactor tank installation.

## 2.6 Seismology

About 15 seismic events have been reported in southern Michigan since 1870. The largest of these had an intensity of VI on the modified Mercalli scale, i.e., "felt by all; many frightened and run outdoors. Some heavy furniture moved; a few instances of fallen plaster or damaged chimneys. Damage slight." Quantitatively, this translates to Richter magnitude of about 4.75.

Of the 15 events, four are attributed to the Detroit and downriver region and are almost certainly small earthquakes of unknown cause. Of the others, two were likely to be explosions; the February 4, 1883, event listed for the Kalamazoo area is really a rail accident in LaPorte, Indiana (Sleep, 1981); the May 19, 1906, Grand Rapids event is a power mill explosion in Kenosha, Wisconsin. The remaining nine events are listed below:

| Place | Latitude | Longitude | Date | Modified Mercalli Intensity |
|---|---|---|---|---|
| Port Huron | 43.0°N | 82.5°W | March 16, 1922 | III |
| Morrice | 42.8°N | 84.2°W | February 22, 1918 | IV |
| Niles | 41.8°N | 86.3°W | October 31, 1897 | -- |
| St. Joseph | 42.1°N | 86.5°W | October 10, 1899 | IV |
| Kalamazoo | 42.0°N | 85.5°W | November 25, 1982 | -- |
| Coldwater | 42.0°N | 85.0°W | August 9, 1947 | VI |
| Adrian | 41.9°N | 84.1°W | January 27, 1876 | -- |
| Lansing | 42.8°N | 84.6°W | February 2, 1967 | IV (2 events) |

The Michigan Basin is generally characterized as a region of low seismicity and low seismic hazard. The only recorded earthquake in the Lansing vicinity occurred on February 2, 1967, and measured IV on the modified Mercalli scale (felt by many, but no noticeable damage). Sensitive microearthquake monitoring equipment which has been operational for the past 5 to 7 years, has confirmed that the Michigan Basin is a region of very low seismic activity.

## 2.7 Conclusion

The staff has evaluated the MSU reactor site for man-made as well as natural hazards and concludes that there are no significant hazards associated with this site that would render it unfit for continued operation.

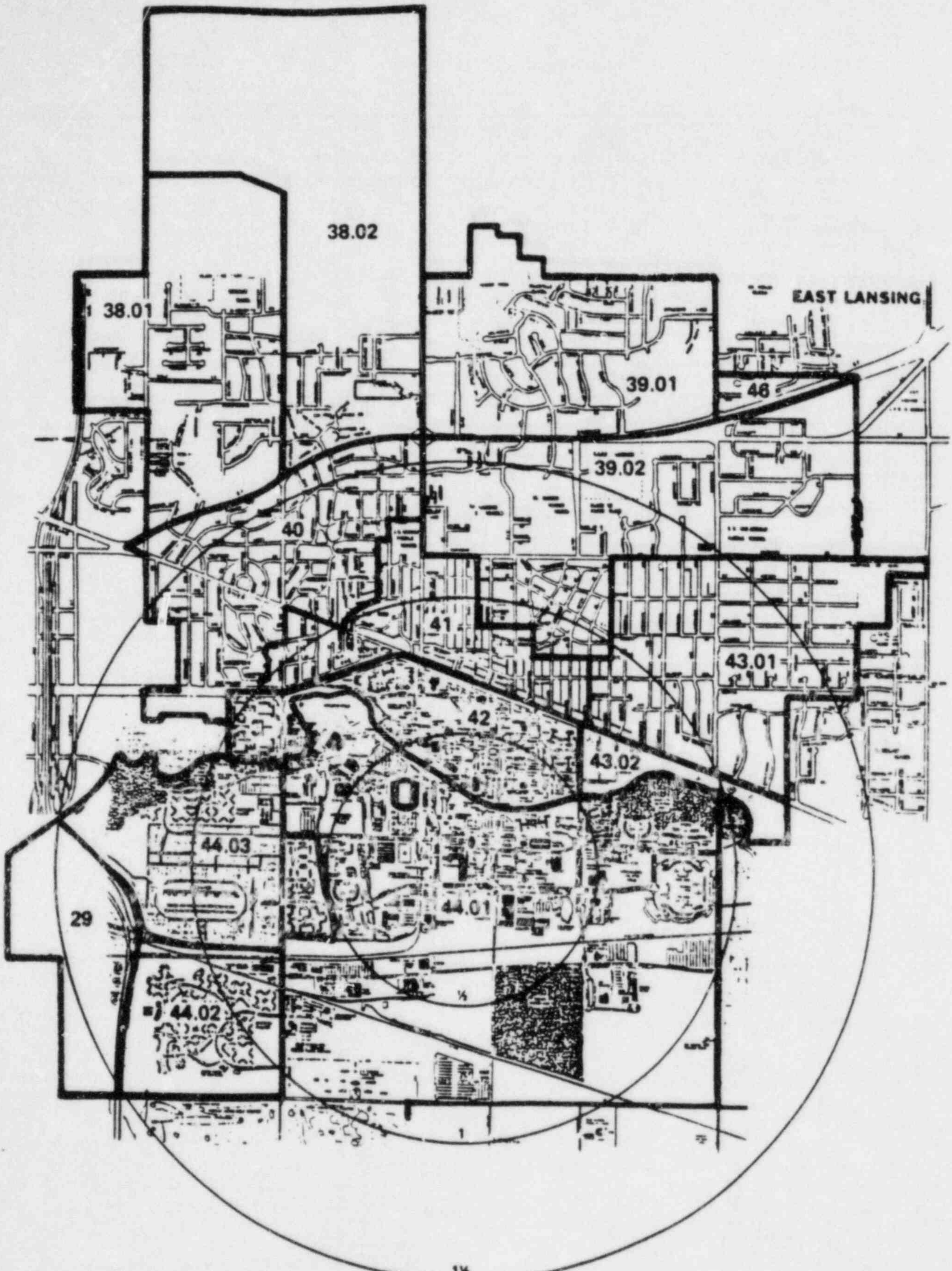



Figure 2.1 City of East Lansing, Michigan, including census tract numbers

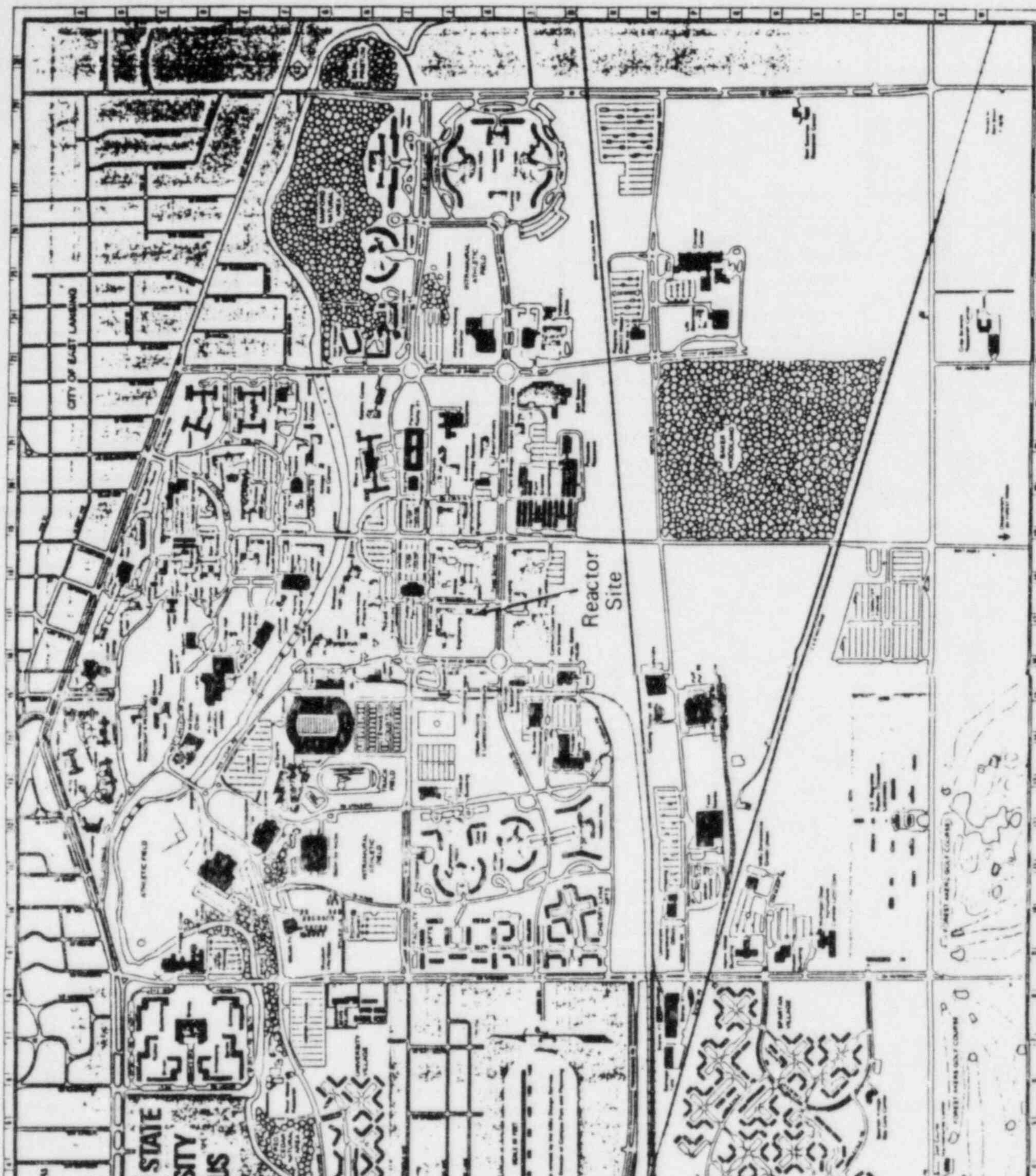
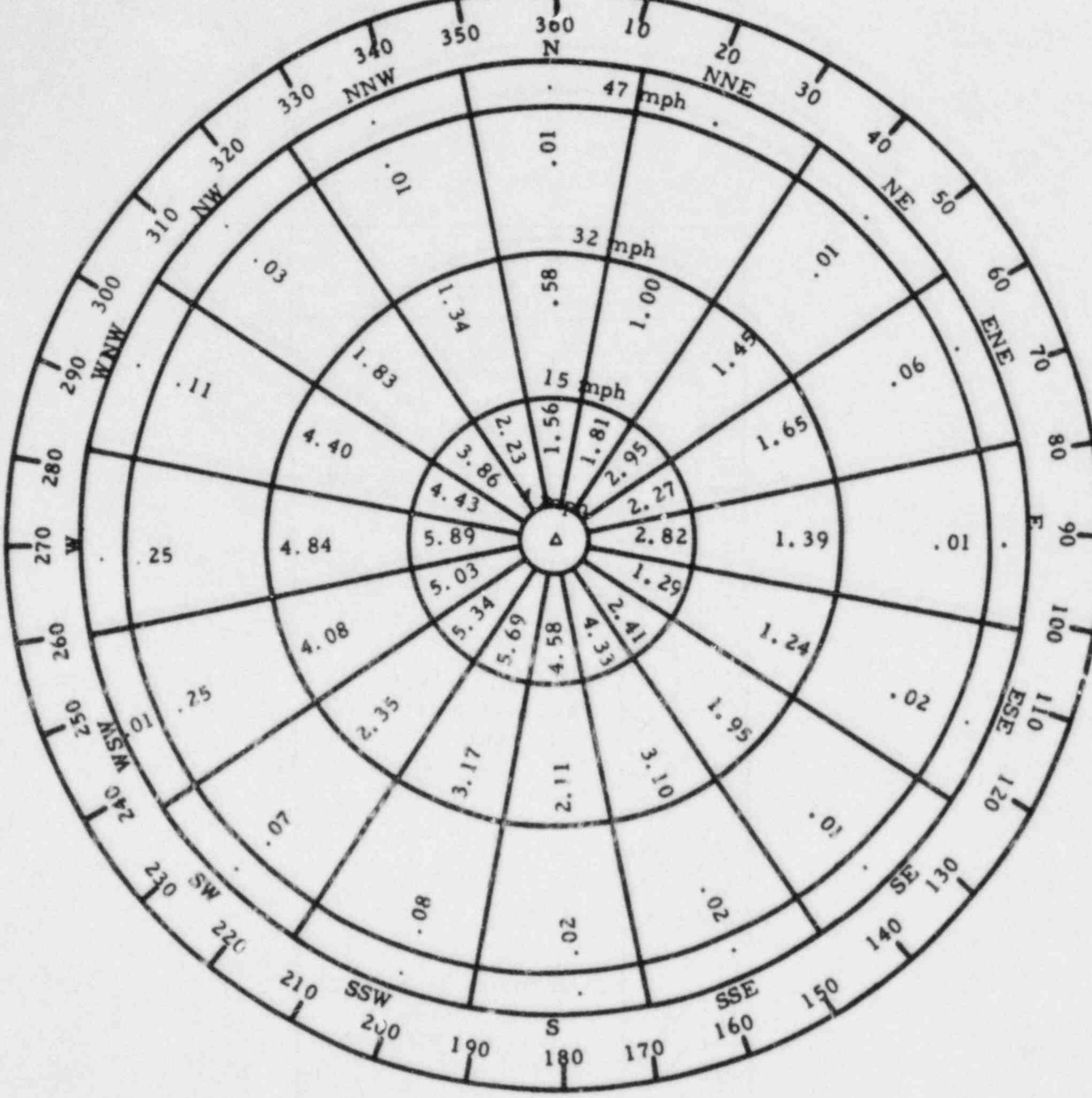



Figure 2.2 Major transportation routes near MSU campus




Δ = 6.06% calms, 0-3 miles per hour
period of observation, 5 years

Numbers shown are percentages of time in direction and velocity indicated

Figure 2.3 Wind rose recorded in Lansing, Michigan

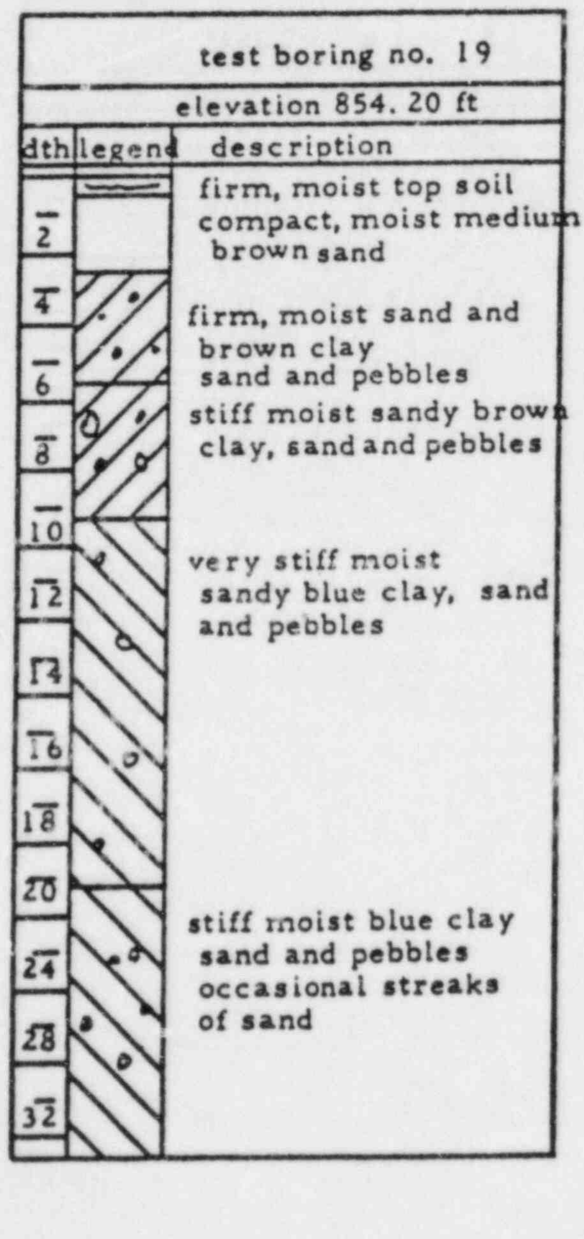



Figure 2.4 Boring log in immediate area of reactor site

Table 2.1 East Lansing population characteristics

| Census Tract | Total Population | Male | Female | Persons Aged 60 and Over | % | Persons Aged 17 And Under | % |
|---|---|---|---|---|---|---|---|
| 29.01 | 14 | 6 | 8 | 2 | 14.3 | 6 | 42.9 |
| 38.01 | 3,648 | 1,800 | 1,848 | 211 | 5.8 | 1,204 | 33.0 |
| 38.02 | 2,002 | 896 | 1,106 | 323 | 16.1 | 376 | 18.8 |
| 39.01 | 1,791 | 854 | 937 | 316 | 17.6 | 432 | 24.1 |
| 39.02 | 3,989 | 1,928 | 2,061 | 447 | 11.2 | 707 | 17.7 |
| 40 | 3,766 | 1,820 | 1,946 | 577 | 15.3 | 766 | 20.3 |
| 41 | 4,882 | 2,449 | 2,433 | 210 | 4.3 | 162 | 3.3 |
| 42 | 5,656 | 2,590 | 3,066 | 1 | 0.0 | 47 | 0.8 |
| 43.01 | 4,253 | 2,136 | 2,117 | 338 | 7.9 | 608 | 14.3 |
| 43.02 | 2,877 | 1,347 | 1,530 | 6 | 0.2 | 11 | 0.4 |
| 44.01 | 11,400 | 5,894 | 5,506 | 3 | 0.0 | 53 | 0.5 |
| 44.02 | 3,852 | 1,879 | 1,973 | 14 | 0.4 | 1,002 | 26.0 |
| 44.03 | 2,993 | 1,492 | 1,501 | 119 | 4.0 | 711 | 23.8 |
| 46 | 269 | 131 | 138 | 8 | 3.0 | 58 | 21.6 |
| Citywide | 51,392 | 25,222 | 26,170 | 2,575 | 5.0 | 6,143 | 12.0 |

Source: 1980 Census Tape SFT 1A

## 3 DESIGN OF STRUCTURES, SYSTEMS, AND COMPONENTS

### 3.1 Description of Confinement or Reactor Building

The MSU Engineering Building is a concrete structure of block walls with brick veneer and was constructed in 1960-1962 (see Figure 3.1). The MSU TRIGA Mark I reactor is housed in room 184, which is located on the first floor in the southeast corner of the building. Adjacent to the room are undergraduate teaching laboratories on the north and south sides; a hall separates the room from faculty offices on the west side, and the east side of the room is an exterior wall that faces a parking lot and street. There is no basement beneath the north half of room 184 where the reactor tank is located below ground. The south end of the room is above a machine shop in the basement; sufficient distance is maintained between the reactor core and this area to be equivalent to 10 ft of concrete.

The second floor over the reactor area houses a classroom (room 284). The reactor pit has been deepened from 21.5 ft to 24 ft 8 in. to ensure that the radiation levels in this classroom are sufficiently low. Thus, the design of the facility is such that only room 184 is a restricted operational area.

Room 184 (Figure 3.2) is a 25 ft x 30 ft area with three concrete block walls and one brick wall and a concrete floor and ceiling (12 ft high). The outside wall of the room contains a continuous row of windows, 5 ft high. Four 16-in. sections of the windows can be opened but are required to be closed during reactor operation. The opposite wall of the room has fixed sash windows, 3 x 4 ft, adjacent to the hallway and a 6-x-6-ft door. The exterior windows are covered with Lexan. An interior hall from the reactor room leads to three small rooms: room 184A is a chemistry laboratory used for chemical preparation and radiochemical separation; room 184B is an instrument room used for sample counting, and room 190 is the office of the reactor supervisor. All three of these rooms have access to the reactor room as shown in Figure 3.2. Directly adjacent to the reactor room is a 9-x-15-ft control room housing the reactor console. This room has glass windows to permit a view of the reactor area.

Figure 3.3 show the floor plans of the three stories and the basement of the Engineering Building southeast wing.

### 3.2 Wind Damage

The Engineering Building was constructed to withstand winds up to 88 mph. Data from the T. T. Fujeta map (University of Chicago, 1976) indicates that although East Lansing is in the southern half of lower Michigan, an area of high tornado frequency, East Lansing has been historically free of tornados. The storms to the north and west have all been of the $F_2$ or $F_3$ intensity on the Fujeta scale (113 to 157 mph). Only one tornado of the $F_4$ or $F_5$ intensity was reported between 1930 and 1974. This was about 10 mi north of the reactor site. It is estimated that, in the case of severe winds (>88 mph), the nonsupporting curtain walls of the building would collapse but the floor/ceiling structure of the building would survive. Damage to the below-ground reactor core would be limited to debris falling into the pool.

Because the building is not designed as a containment structure for the reactor, loss of curtain walls would not be serious. The staff concludes that if strong winds pass through the MSU reactor site, damage to the reactor will be small.

### 3.3 Water Damage

The ground water at the reactor site area is drained to the Red Cedar River (1,400 ft north) and the Grand River (4 mi west). Ground water is found 11.2 ft below the surface of the reactor room floor. Surface water outside the Engineering Building is directed into the university storm sewer system, which in turn, is directed to the Red Cedar River. The reactor room floor is 857 ft above mean sea level (MSL) and the Red Cedar River bed is at an elevation of 850 ft above MSL. There is no record of the river overflowing its banks near the reactor site, and the prospect of the river flooding is unlikely.

### 3.4 Seismic-Induced Reactor Damage

Seismology of the region is discussed in Section 2.6 of this report. The MSU reactor is located in a seismically inactive area. The only recorded earthquake with Lansing as the epicenter occurred on February 2, 1967. The earthquake measured Intensity IV on the modified Mercalli scale, (felt by many, but no noticeable damage). Because the reactor is built below ground level inside a tank surrounded by steel-encased concrete and because the reactor room is on the first floor of a three-story concrete building with concrete ceiling and floor, the staff concludes that damage to the reactor's safety-related components and systems is unlikely from any seismic event.

### 3.5 Mechanical Systems and Components

The mechanical systems of importance to safety are the control rod drive systems. The MSU TRIGA Mark I reactor has a pneumatic drive for the safety-transient rod and rack-and-pinion drives for the shim rod and the regulating rod. These control rod drive systems are controlled from the console in the control room. The three drive mechanisms are mounted on a steel frame that bolts the reactor core to the center channel assembly, which is at the reactor room floor level. The pneumatic safety-transient rod drive mechanism has operated reliably and without failure since its installation. The components of the system consist of compressed air, valves, piston, and bolts connecting the control rod. The rack-and-pinion control-rod drives consists of motors, magnetic rod-couples, rack-and-pinion-gear systems, and micro switches. The only failures experienced in these drive systems have been due to the micro switches that were repaired or replaced before resuming reactor operation.

By adhering to maintenance schedules and the performance requirements of the Technical Specifications, the mechanical systems and components have been maintained in good operational condition. The staff concludes that the same attention will ensure that the mechanical components and systems will be maintained at an acceptable level of performance and will not increase the risk to the public.

### 3.6 Conclusion

On the basis of the above description and evaluation of the reactor facility, the staff concludes that the MSU reactor facility has well-maintained mechanical systems and components and is adequate to withstand potential wind damage, water damage, and potential minor earthquake activity without any significant damage that would increase the risk to the public.

Figure 3.1 Michigan State University Engineering Building

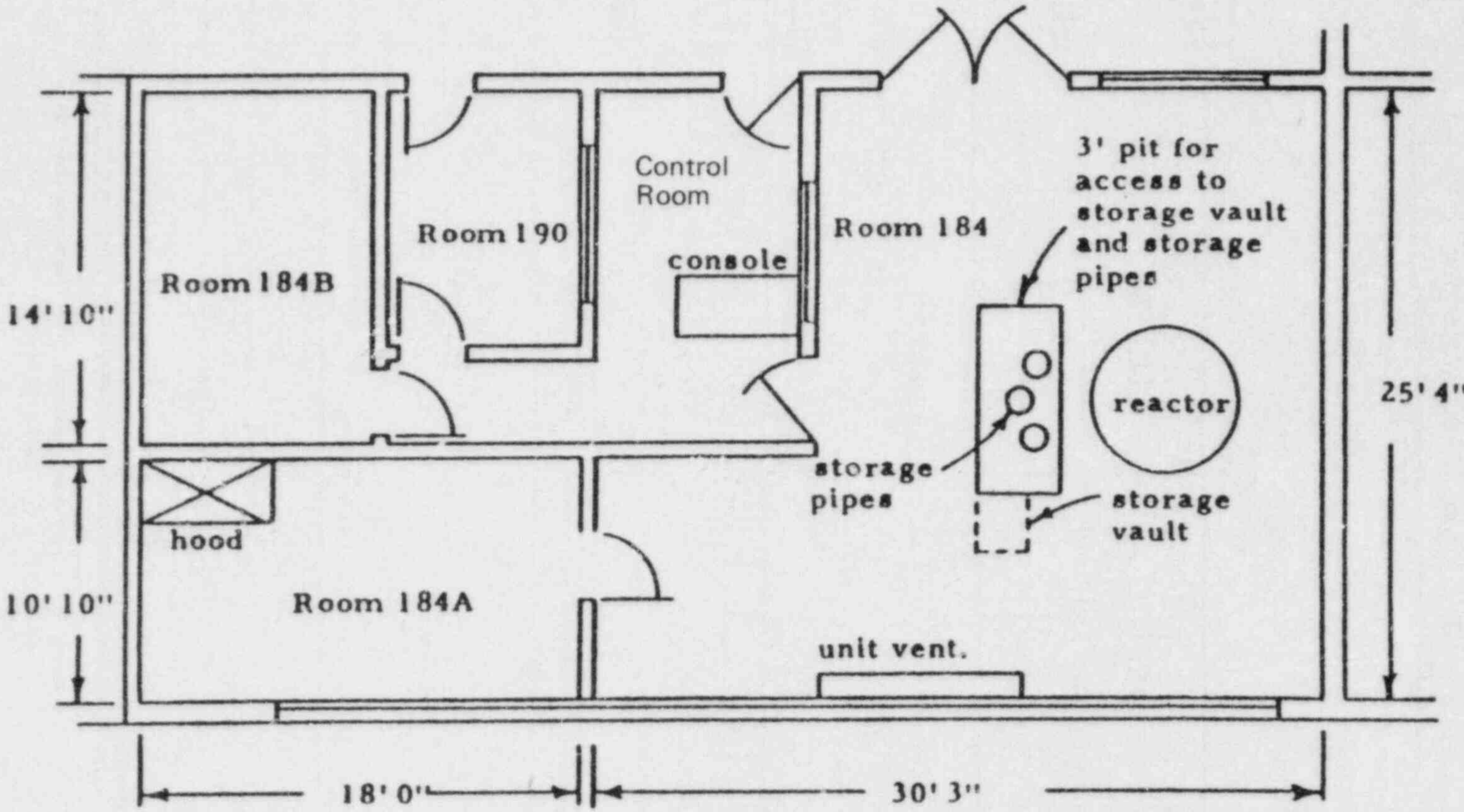



Figure 3.2 Floor plan for reactor room (scale 1/8 in = 1 ft)

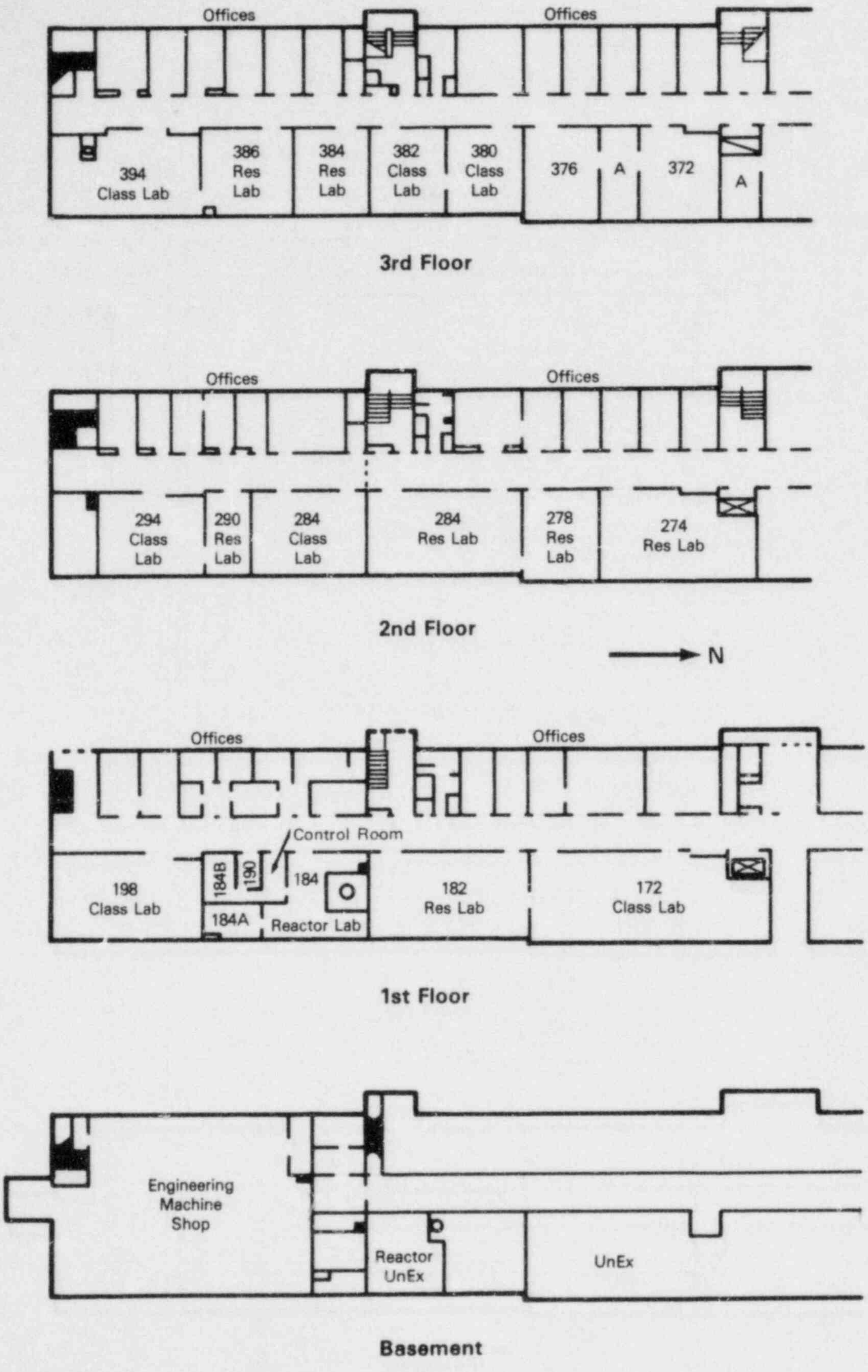



Figure 3.3 Engineering Building (southeast wing) floor plans

# 4 REACTOR

The MSU TRIGA MARK I reactor is a General Atomic Mark I reactor (a standard TRIGA heterogeneous pool-type research reactor) mode that operates at a maximum power level of 250 kW in the nonpulsing mode, and has a 1.4% $\Delta k/k$ (2.00$) pulsing capacity. The reactor uses solid uranium-zirconium-hydride fuel that contains 8.5 and 12 wt % uranium and is enriched to <20% $^{235}U$. Each individual element is stainless-steel clad. Light water serves as the moderator and coolant. The reactor power is controlled by inserting or withdrawing neutron-absorbing control rods. Pulses are initiated by the rapid ejection of the safety-transient rod.

The MSU TRIGA MARK I reactor initially attained criticality in May 1968. It is used principally as a neutron source for activation analysis studies (research) and the limited production of radioactive isotopes. It also is used as a training facility for the engineering program. The principal design parameters for the current core configuration are listed in Table 4.1.

## 4.1 Reactor

The MSU TRIGA MARK I reactor is located in a 25-ft-deep, 6.5-ft-diameter reactor pool. The reactor core heat is dissipated by natural convection to the bulk tank water, which is then circulated through a heat exchanger. The reactor core is a circular configuration of cylindrical, stainless-steel-clad, <20% enriched, $U\text{-}ZrH_{1.7}$ (maximum) fuel-moderator elements and additional cylindrical graphite dummy elements. A 1-ft-thick graphite radial reflector surrounds the core and is supported at the base by an aluminum platform. Four-inch sections of graphite located on the top and bottom ends of the fuel elements serve as additional reflectors for the core.

The maximum total loading of the MSU TRIGA MARK I reactor is 2.25% $\Delta k/k$ (3.21$) excess reactivity above the cold critical condition. Pulsing operations are limited to a step increase of up to 1.4% $\Delta k/k$ (2.00$). The 1.4% $\Delta k/k$ (2.00$) maximum pulsing corresponds to a peak power burst with a 15 MW-s energy release and peak power levels of approximately 250,000 kW with a 30-ms pulse width at half maximum.

### 4.1.1 Reactor Core

Figure 4.1 shows a cutaway view of the reactor assembly. The reflector assembly and reactor core form a 43-in.-diameter by 23-in.-deep cylinder. The reactor core consists of a cylindrical lattice arrangement of 70 cylindrical fuel elements, 16 graphite dummy elements, and 3 control rods held together by the upper and lower aluminum grid plates. The reactor core contains approximately 2.5 kg of <20% enriched $^{235}U$.

### 4.1.2 Reflector Assembly and Core Support Structures

The reflector assembly consists of a ring-shaped block of graphite with a radial thickness of 12 in., an inside diameter of 19-3/8 in., and a height of 22 in. The graphite is contained in an aluminum can. A rotary specimen rack is mounted in a well located on top of the reflector assembly. In addition, four vertical tubes are attached to the reflector assembly to permit the positioning of the three ion chambers and the fission chamber. The reflector assembly (supported by an aluminum platform) is the main support for the top and bottom grid plates. The core and its associated components are supported by the bottom grid plate, and the top grid allows the core components to be vertically aligned.

The upper grid plate has 91 holes (each 1.5 in. in diameter); 90 are distributed in concentric rings around a center hole. These aid in the positioning of the various core components (instrumented fuel elements, fuel moderator elements, dummy elements, or other core components). The current core loading diagram is shown in Figure 4.2.

### 4.1.3 Fuel Elements

The Mark I reactor uses cylindrical stainless-steel-clad fuel elements in which the fuel is a solid homogeneous mixture of U-$ZrH_x$ alloy. There are two types of fuel elements, one containing 8.5 wt % $^{235}U$ and the other 12 wt % $^{235}U$, both enriched to slightly less than 20%. The nominal weight of the $^{235}U$ in each of the 8.5 wt % fuel elements is ~33 g and in each of the 12 wt % fuel elements is 54 g. Currently, there are eight 12 wt % fuel elements loaded in the MSU reactor core; six are located in the B ring and two are located in the C ring. Sixty-two 8.5 wt % fuel elements are located in the remaining C, D, E, and F rings. In addition, 16 graphite dummy fuel elements are located in ring F (the outermost ring). The hydrogen-to-zirconium atom ratio of the moderator material incorporated into the fuel is ~1.6:1. The actual fuel section of each cylindrical element is 15 in. long with a 1.43 in. diameter. Graphite end plugs, ~4 in. long, are inserted at both ends of the fuel element to serve as radial reflectors. The fueled section of the fuel element and graphite end plugs are contained in a 0.02-in.-thick stainless-steel-walled can that is welded to stainless-steel end fittings at the top and bottom. Each element is 28.5 in. long and weighs ~6.5 lbs. A schematic view of a typical Mark I TRIGA fuel element is shown in Figure 4.3.

Special instrumented fuel elements are placed in two positions in the core. Chromel-alumel-type thermocouples are embedded approximately halfway between the vertical centerline and the outer edge of each special fuel element and are positioned at the midplane and 1 in. above and below this level (see Figure 4.4). In all other respects, the special instrumented fuel elements are identical to the standard fuel elements. The thermocouples monitor the fuel element temperatures during the various modes of reactor operation.

Graphite dummy fuel elements are used to fill grid positions that are not otherwise filled by the fuel elements, control rods, instrumented fuel elements, or other core components. These elements are of the same general dimensions and construction as the fuel-moderator elements but are filled entirely with graphite and are clad with aluminum.

### 4.1.4 Neutron Source

The Mark I TRIGA reactor uses a 1.9-Ci Am-Be neutron source for startup. It is doubly encapsulated in type-304 stainless steel. The neutron source holder is the same size and shape as a fuel element (see Figure 4.5).

### 4.1.5 Control Rods

Three control rods are used to control and regulate the power levels in a Mark I TRIGA reactor: a shim rod, a regulating rod, and a safety-transient rod. Each of the three rods operates within a perforated aluminum guide tube. The neutron poison is solid boron carbide contained in a sealed aluminum tube. Each control rod is 20 in. long and has a vertical travel of 15 in. The regulating and shim rods have a 1.25-in. outside diameter, and the safety-transient rod has a 1-in. outside diameter.

### 4.1.6 Assessment

The staff has reviewed the information regarding the reactor core, experimental facility arrangements, and reactivity control systems and has found that the design and performance capability of the components are adequate to ensure the continued safe operation of the reactor.

## 4.2 Reactor Tank and Biological Shield

The MSU reactor tank is constructed of 0.25-in. welded aluminum surrounded by steel-encased concrete. The tank is cylindrical with an outside diameter of 6.5 ft and an overall length of 25 ft. The outside is coated with bituminous material (tar) for corrosion protection. A detailed cutaway view of the reactor tank is shown in Figure 4.1. In addition, a center channel assembly mounted across the top of the reactor tank provides support for the isotope production facility, the control rod drive assemblies, and the hinged aluminum grating tank covers that are installed flush with the floor. A sheet of clear plastic attached to the bottom of each grating allows observation of the tank interior and prevents debris from falling into the tank.

## 4.3 Reactor Instrumentation

The operation of the MSU reactor is monitored by safety instrumentation channels that measure fuel element temperature, bulk water temperature, neutron flux, and power level.

Thermocouples in an instrumented fuel assembly provide information on fuel temperature during both nonpulsing and pulsing operations. The readings are displayed on the console in the control room and are used to initiate safety functions and interlocks when limits are reached. The bulk reactor coolant temperature is measured by a temperature probe located in the coolant purification loop.

There are four neutron detectors located in water-tight aluminum tubes positioned around the active core region. These detectors (one fission chamber, two compensated ion chambers, and one uncompensated ion chamber and their associated instrumentation) monitor the neutron flux in the reactor from the source range to 110% of full power.

The source range channel, which incorporates a fission chamber, provides power indication from below the source range to ~5 W. It also provides an interlock function that prevents rod withdrawal below a minimum source level. A compensated ion chamber monitors and displays the linear power level and provides a safety scram signal if the associated preset power level is reached.

The logarithmic neutron (log-N) channel (with a period circuit) monitors the reactor power from 0.1 W to greater than full power (>250 kW), provides for a reactor scram when 110% of full scale of the recorder is reached, and monitors the reactor period from -40 to +7 s and also initiates a scram if the period is $\leq$7 s. During the pulse mode of operation, the linear and log-N chambers are automatically disconnected, and a thermocouple that monitors the fuel element temperature is connected to the red pen of the dual-pen recorder (normally reading log-N output). The linear channel monitors the reactor power from 0.1 W to full power and provides for a reactor scram when 110% of full scale of the recorder is reached.

The percent power meter channel, using an uncompensated ion chamber, monitors the power level from ~2.5 kW to >100% of full power (>250 kW) and provides for an adjustable level scram within this range. During the pulse mode of operation, this is disconnected, and the chamber is connected to nv and nvt circuits. The second pen of the dual-pen recorder (normally reading linear power) is then connected to read the output of the nvt circuits.

## 4.4 Dynamic Design Evaluation

The safe operation of the MSU reactor is accomplished using control rods and manipulating them in response to measured changes in parameters provided by the instrument channels such as temperature, power, and neutron flux. Also, there are interlocks that prevent any inadvertent reactivity additions and a scram system that initiates a rapid automatic shutdown when a preset limit has been reached. In addition, the shutdown mechanism of a large, prompt, negative temperature coefficient is an inherent, self-limiting characteristic of the U-$ZrH_x$ fuel-moderator material. It provides for additional stability and safety during both nonpulsing and transient operating conditions. The negative temperature coefficient is a result of the spectral neutron hardening properties of $ZrH_x$ at elevated temperatures, which increases the neutron leakage from the fuel-bearing material into the water moderator where the neutrons are absorbed preferentially. Because of the homogeneous mixing of the fuel and $ZrH_x$, the $ZrH_x$ temperature rises simultaneously with power and the negative temperature coefficient promptly decreases the reactivity. Additionally, the Doppler broadening of the $^{238}U$ resonance peaks at higher temperatures further contributes to the prompt, negative temperature effect as it increases the nonproductive neutrons captured in these peaks (Simnad et. al., 1976; General Atomic Company (GA)-4314, 1980; GA-0471, 1958). This inherent shutdown property of

$U\text{-}ZrH_x$ has been the basis for designing the TRIGA reactors with a pulsing capability as a normal mode of operation. The automatic compensation provided by the prompt, negative temperature coefficient for step excess reactivity insertions is capable of terminating any resulting power excursion in the pulsing mode without the use of any mechanical or electrical safety systems or operator action. In the nonpulsing mode, it serves as a backup safety feature for the safety system's mitigation of accidental reactivity insertion effects (Simnad, et al., 1976; GA-4314, 1980; GA-0471, 1958).

### 4.4.1 Excess Reactivity and Shutdown Margin

The Technical Specifications for the MSU reactor limit the maximum core excess reactivity to 2.25% $\Delta k/k$ (3.21$) above the cold, clean, critical, xenon-free condition and with experiments in their most reactive state in place. The ratio of 2.25% $\Delta k/k$ and 3.21$ results in a $\beta$ effective of 0.007% $\Delta k/k$. The Technical Specifications limit experiment reactivity worths to

1.4% $\Delta k/k$ (2.00$) for any single experiment
2.1% $\Delta k/k$ (3.00$) for the total of all in-core experiments
0.7% $\Delta k/k$ (1.00$) for any single nonsecured experiment

The Technical Specifications require that the control rods provide a shutdown margin greater than 0.4% $\Delta k/k$ (0.57$) with the highest worth control rod fully withdrawn, with the highest worth nonsecured experiment in its most reactive state, and with the reactor in the clean, cold, critical condition (without xenon). The excess reactivity of the current MSU reactor core is 2.17% $\Delta k/k$ (3.10$).

The individual control rod worths are shown in Table 4.1. The total rod worth is 4.78% $\Delta k/k$ (6.83$). The shutdown margin with the highest worth rod fully withdrawn is 0.49% $\Delta k/k$ (= 4.78 - 2.12 - 2.17), or 0.80$ (= 6.83 - 3.03 - 3.00). Therefore, the current core configuration meets the excess reactivity and shutdown requirements. With all rods fully inserted, the core is subcritical by 2.61% $\Delta k/k$ (3.17$).

### 4.4.2 Normal Operating Conditions

The temperature in a standard TRIGA fuel element in the MSU reactor core is limited by the Technical Specifications to a maxmum of 1,000°C under any reactor operating conditions. This limit is imposed to prevent excessive stress buildup on the cladding because of the hydrogen pressure caused by the dissociation of the $ZrH_x$ fuel monitor. On the basis of the theoretical and experimental evidence (Simnad et al., 1976; GA-4314, 1980), the limit of 1,000°C represents a conservative value to provide confidence that the integrity of the fuel elements will be maintained and that no cladding damage will occur. In addition, the reactor power level and pulse reactivity insertions are limited to provide further assurance that the safety limit will not be exceeded. The maximum nonpulsing power level of 250 kW corresponds to a maximum measured fuel temperature of 200°C. During the maximum-allowed 1.4% $\Delta k/k$ (2.00$) pulse, the measured fuel temperatures do not exceed 250°C. In addition, scrams are provided to shut the reactor down whenever the nonpulsing power level exceeds 110% of any range (275 kW) or when the measured fuel temperature is increased to 500°C. On the basis of the radial and local power distributions, these requirements ensure that the safety limit of 1,000°C for the fuel elements will not be exceeded anywhere in the core.

### 4.4.3 Assessment

The staff concludes that the inherent, large, prompt, negative temperature coefficient of reactivity for the $U\text{-}ZrH_x$ fuel moderator provides a basis for the safe operation of the Mark I TRIGA reactor in the nonpulsing mode and is the essential characteristic supporting the capability of reactor operation in the pulsing mode. In addition, the excess reactivity and experiment reactivity worths are limited by the Technical Specifications so that even if the highest worth control rod is removed fully, the reactor can be brought to a subcritical condition. The current core configuration meets all of these limitations.

The safety limits for the MSU reactor are based on theoretical and experimental investigations and are consistent with those used at other similar reactors. Strict adherence to these limits provides sufficient confidence that the integrity of the fuel elements will be maintained. Also, the operating data at the maximum allowable nonpulsing power level and pulse reactivity insertion indicate that the maximum fuel element temperatures will be maintained below the prescribed safety limit. TRIGA reactors similar to the MSU reactor have demonstrated safe and reliable operation at nonpulsing power levels up to 1.5 MW and pulse reactivity insertions up to 5.00$ (Simnad et al., 1976; GA-4314, 1980).

On the basis of the above considerations, the staff concludes that, under normal operating conditions, there is reasonable assurance that the MSU reactor can be operated safely at power levels up to and including 250 kW and with 1.4% $\Delta k/k$ (2.00$) pulses, as limited by the Technical Specifications.

## 4.5 Functional Design of Reactivity Control Systems

The power level of the MSU reactor is controlled by three control rods (one shim, one regulating, and one safety-transient rod), all of which contain boron carbide as the neutron poison. The positions of the three rods are shown in Figure 4.1. Rod movement is accomplished using rack-and-pinion electromechanical drives for the shim and regulating rods and a pneumatic drive for the safety-transient rod. Each rod drive system is energized from the control room console through its own independent circuits; a manual scram is possible for each individual control rod, or they can be scrammed as a group. This minimizes the probability of multiple malfunctions of the rod drives. When a scram signal is received, all three rods will insert by gravity into the core and shut down the reactor.

### 4.5.1 Shim and Regulating Rod Drive Assembly

The control rod drive assemblies for the shim and regulating control rods are mounted on a bridge assembly located over the pool and consist of an electric motor coupled to a rack-and-pinion gear drive system. During nonpulsing operation, the motorized system slowly withdraws and inserts a control rod. If power to the electromagnet is interrupted for any reason, the connecting rod is released, and the control rod falls by gravity into the core, rapidly shutting the reactor down (scramming). Additional information on the standard control rod drive assembly is found in Section 7.1.2.1.

### 4.5.2 Safety-Transient Rod Drive Assembly

The safety-transient rod is mounted on a steel frame that is bolted to the center channel cover plate. The transient control drive is operated by a pneumatic drive system that consists of a single-acting pneumatic cylinder with a piston that is attached to the safety-transient rod through a connecting rod assembly. The safety-transient rod always is inserted fully in the core except when there is compressed air supplied to the cylinder. During nonpulsing operation, this rod is maintained in the fully withdrawn position. Adjustment of the cylinder position controls the extent of the safety-transient rod withdrawal from the core and the corresponding amount of reactivity inserted during a pulse. The safety-transient rod drive assembly is discussed further in Section 7.1.2.2.

### 4.5.3 Scram-Logic Circuitry and Interlocks

The scram-logic circuitry and interlocks ensure that several reactor core and operational conditions are satisfied for reactor operation to occur or continue. The scram-logic circuitry uses an open-on-failure logic; that is, any scram signal deenergizes the electromagnets on the standard control rods and deenergizes the solenoid on the safety-transient rod, causing the rods to scram and shut down the reactor. Details of the in-core detectors are found in Section 7.3. In addition, a scram is initiated if power to the ion chambers is lost or the console power circuit fails. The time, as limited by Technical Specifications, between the activation of the scram logic and the total insertion of the shim and regulating rods is <1 s, and the safety-transient rod insertion time is <2 s. This ensures adequate safety for the reactor and fuel elements for the anticipated operations at the MSU reactor facility.

### 4.5.4 Assessment

The MSU reactor is equipped with safety and control systems typical of most TRIGA reactors. The control rods, rod drives, scram-logic circuitry and interlocks have performed reliably and satisfactorily in the MSU reactor for many years; similar equipment in many other TRIGA reactors has performed satisfactorily over a long period of time.

The control systems allow for an orderly approach to criticality and for safe shutdown of the reactor during normal and abnormal conditions. There is sufficient redundancy of control rods to ensure safe reactor shutdown, even if the most reactive rod fails to insert upon receiving a scram signal. The speed and reactivity worths of the control rods are adequate to allow for complete control of the reactor during shutdown and through full-power operation. In addition, interlocks prevent inadvertent rod withdrawal, thus positive reactivity additions. Independent scram sensors and circuits are incorporated to shut down the reactor automatically and mitigate the consequences of single malfunctions. A manual scram button allows the operator to initiate a scram independently for any condition requiring a scram. In addition to the active electromechanical safety systems, the large, prompt, negative temperature coefficient of reactivity, inherent in the U-$ZrH_x$ fuel-moderator, provides an additional safety feature. The self-limiting feature of this mixture terminates reactor transients that produce large increases in temperature. Because this feature limits the magnitude of possible transient-induced accident, it would mitigate the consequences of such accidents and can be considered to be a fail-safe feature.

Additionally, the MSU reactor uses <20%-enriched $^{235}U$; thus, 80% of the fuel is composed of $^{238}U$. Because $^{238}U$ has a wide Doppler absorption band, the resonance peaks for $^{238}U$ widen as the temperature increases, thereby increasing the neutron capture and reducing the available neutrons that will continue to fission. This inherent safety feature enhances the prompt, negative temperature coefficient.

On the basis of the above discussion, the staff concludes that the inherent safety features coupled with the reactivity control systems of the MSU reactor are designed and function adequately to ensure safe operation and shutdown of the reactor under all credible conditions.

## 4.6 Operating Procedures

The MSU reactor operates under Technical Specifications that require the review, audit, and surveillance of the reactor and provide procedural reviews for all safety-related activities. Written procedures have been established for safety-related and operational activities that include reactor startup, operation, and shutdown; maintenance; periodic inspections; testing; and the calibration of equipment or instrumentation. In addition, the reactor is operated by trained NRC-licensed personnel in accordance with the above-mentioned procedures.

## 4.7 Conclusion

The staff's review of the MSU reactor facility has included the study of its specific design, controls, and safety instrumentation and its specific preoperational and operational procedures. As noted earlier, these features are similar to those typical of TRIGA research reactors currently operating in many countries of the world, of which more than 20 are licensed by the NRC. There are currently 11 TRIGA reactors operating at 1 MW or greater with no safety-related problems. On the basis of its review of the MSU reactor facility and its experience with these other facilities, the staff concludes that there is reasonable assurance that the MSU reactor is capable of continued safe operation as limited by its Technical Specifications.

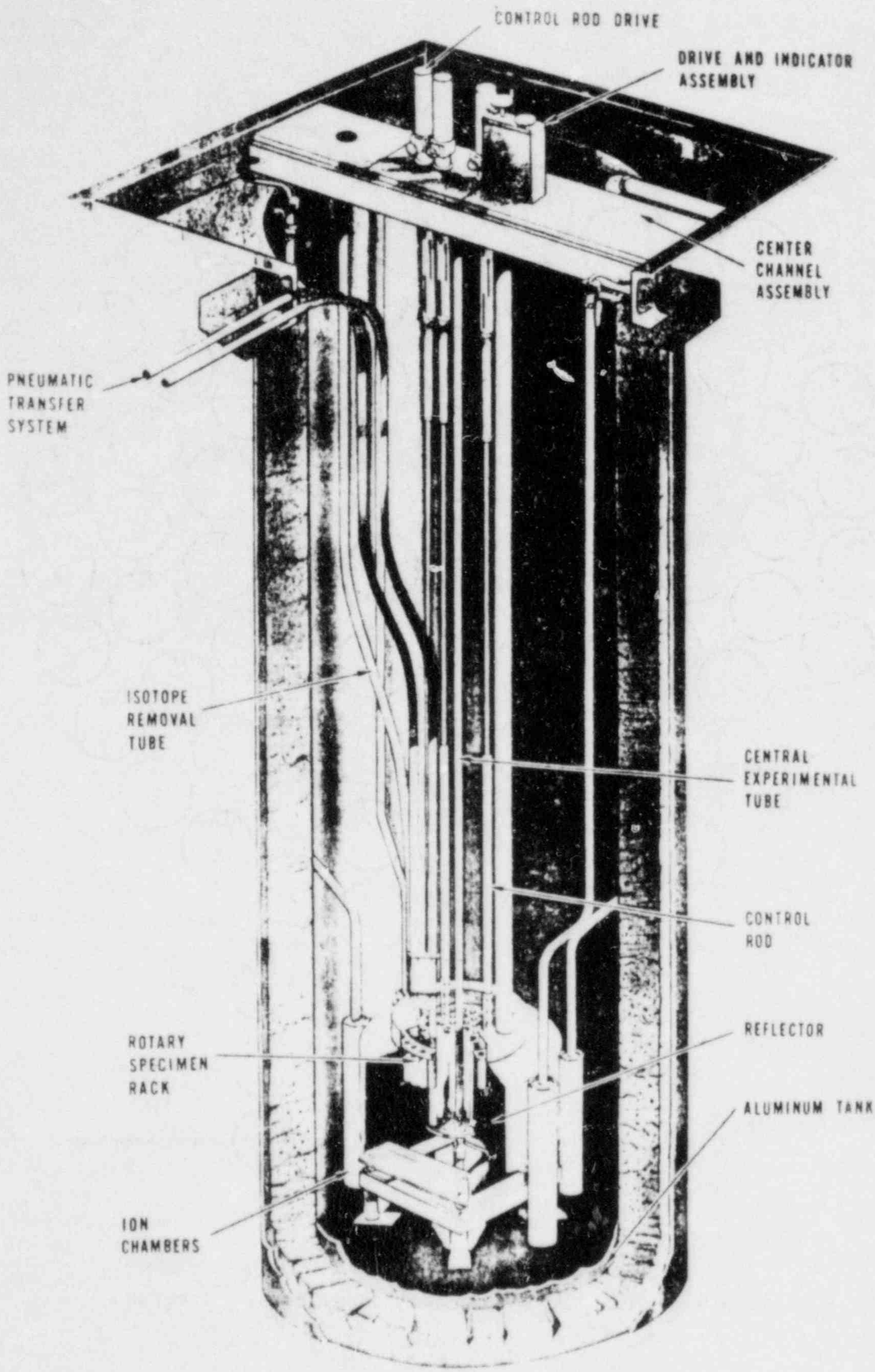



Figure 4.1 Cutaway view of TRIGA Mark I reactor

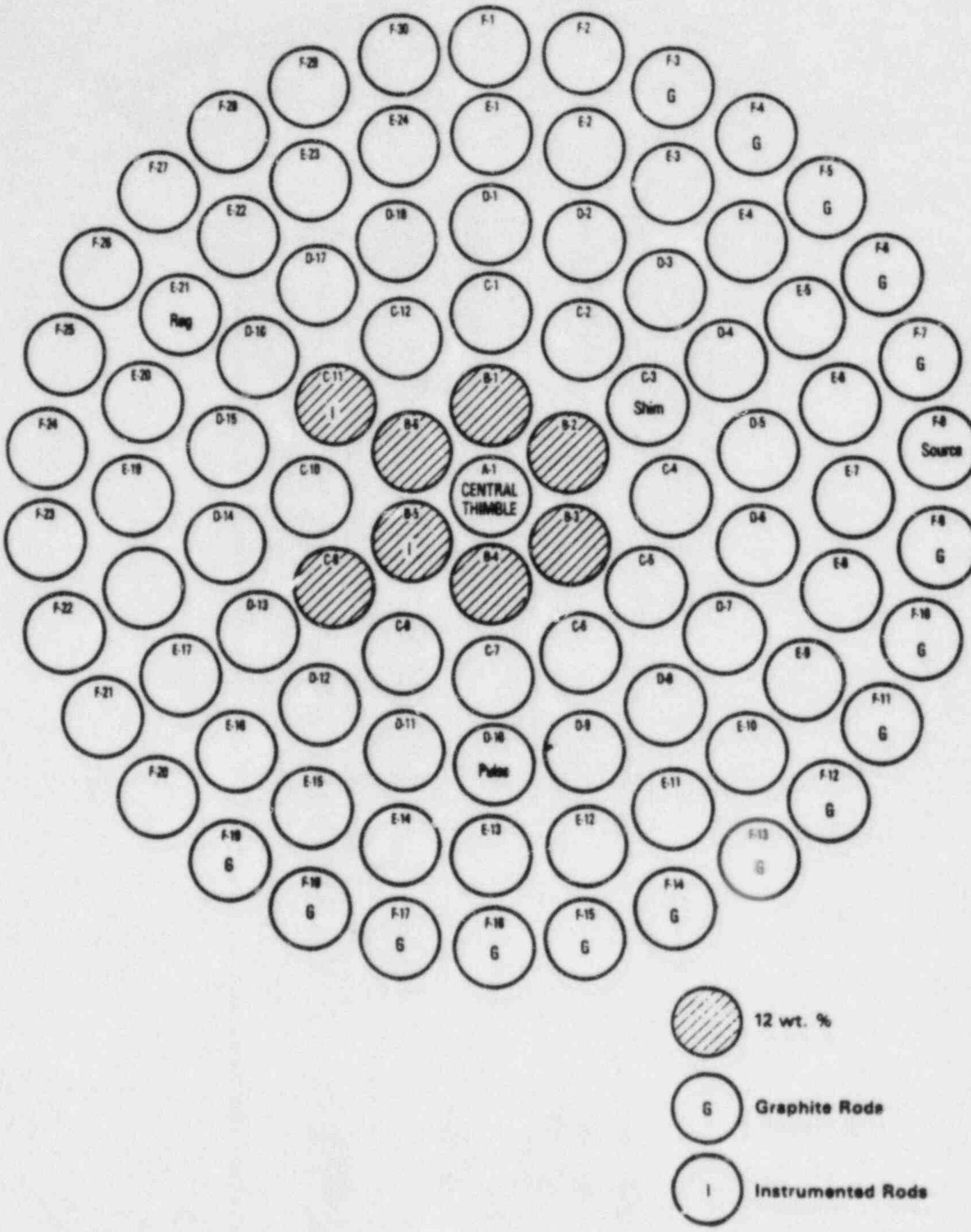



Figure 4.2 MSU reactor current core loading diagram

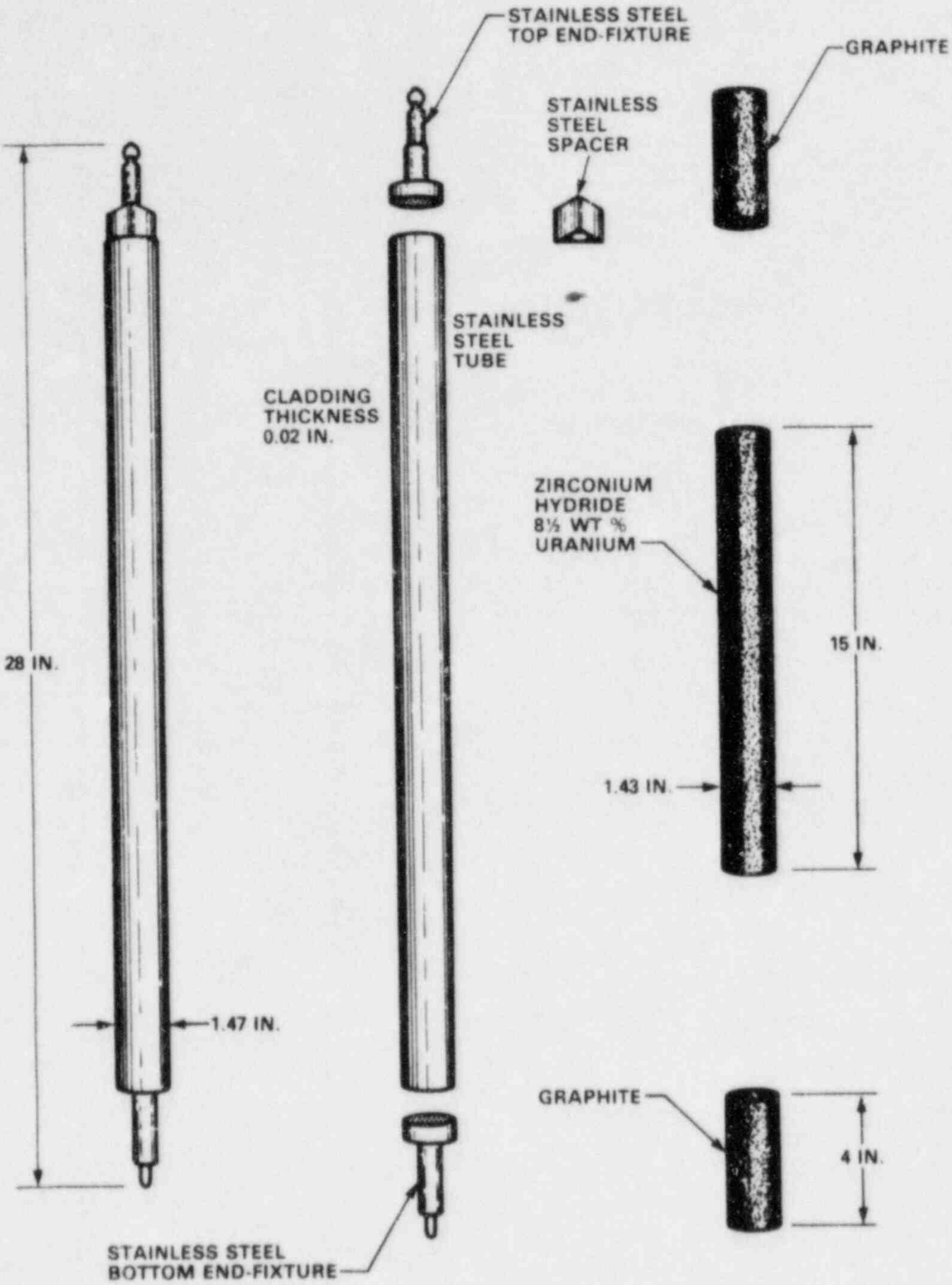



Figure 4.3 Stainless-steel-clad fuel-moderator element

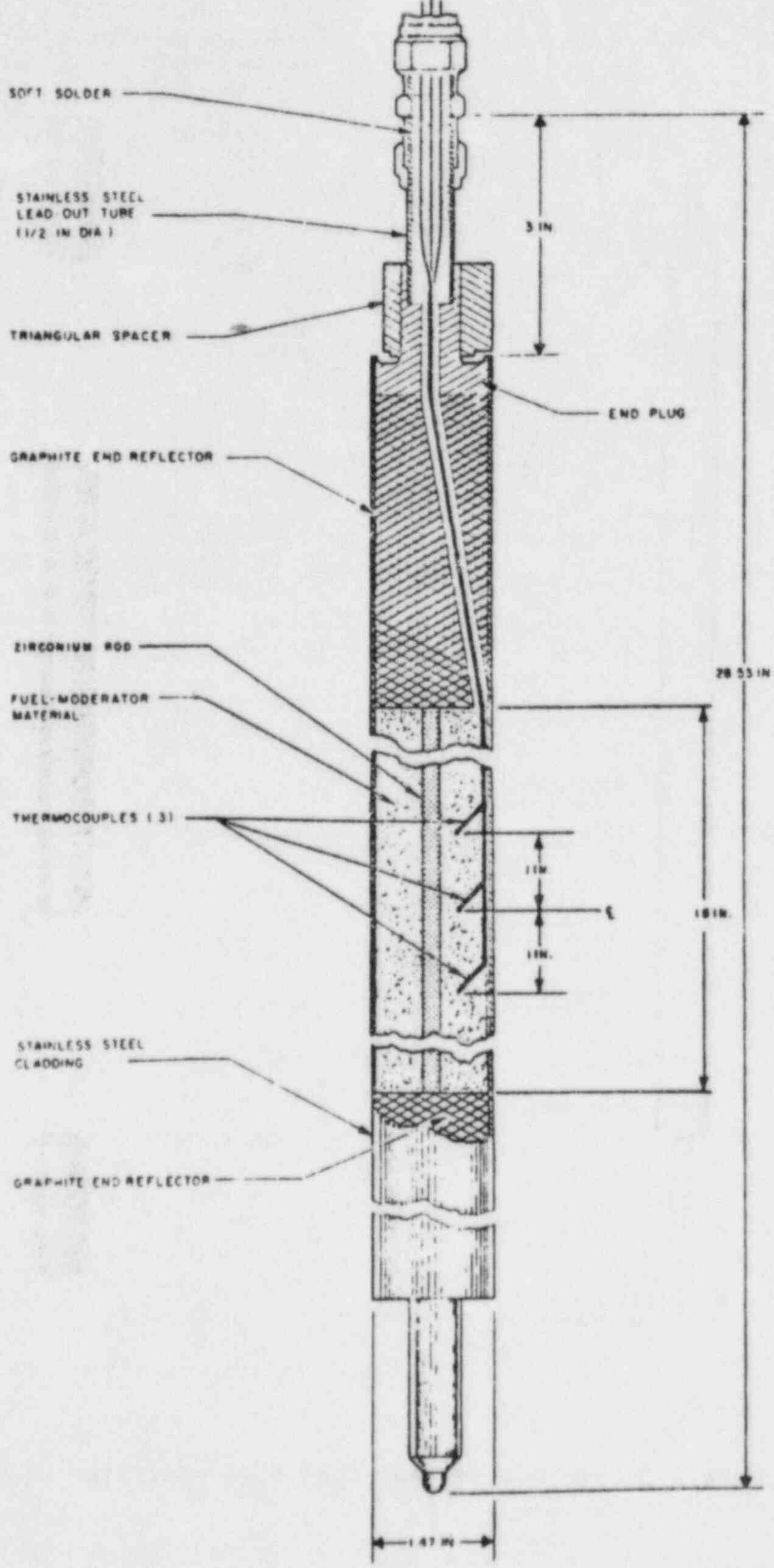



Figure 4.4 Instrumented stainless-steel-clad fuel-moderator element

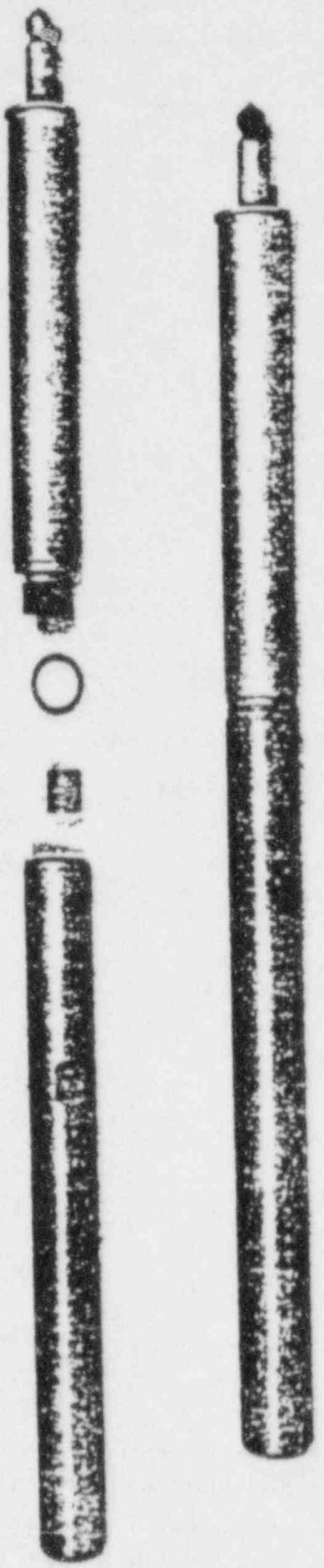


Figure 4.5 Neutron source holder

Table 4.1 Principal design parameters

| Parameter | Description |
|---|---|
| Reactor type | TRIGA Mark I |
| Maximum nonpulsing power level | 250 kWt |
| Maximum pulse | 1.4% Δk/k (2.00$) (25,000 kW pulsing) |
| Fuel element design | |
| Fuel-moderator material | $U\text{-}ZrH_{1.6}$* |
| Uranium inventory (core) | 2.528 kg $^{235}U$ |
| Uranium content | 8.5 and 12.0 wt % |
| Uranium enrichment | <20% $^{235}U$ |
| Shape | Cylindrical |
| Length of fuel | 15 in. |
| Diameter of fuel | 1.43 in. |
| Cladding material and nominal thickness | 304 stainless steel (0.02 in. thick) |
| Weight $^{235}U$/fuel element (stainless-steel clad) | ~33 g (8.5 wt % fuel)** and ~54 g (12 wt % fuel) |
| Number of fuel elements | 66 (minimum core) or 70 (nominal core) |
| Reactivity worths (nominal core) | |
| Excess reactivity (current core) | 2.1% Δk/k (3.00$) (cold, clean, critical condition) |
| Safety-transient rod (1) | 1.37% Δk/k (1.95$) |
| Shim rod (1) | 2.12% Δk/k (3.03$) |
| Regulating rod (1) | 1.29% Δk/k (1.85$) |
| Total reactivity of rods | 4.78% Δk/k (6.83$) |
| Reactor cooling | Natural convection of bulk coolant |
| Reflector | Graphite and water |
| $\beta_{eff}$ | 0.007% Δk/k |

*The nominal ratio is 1.60 and the maximum value is 1.67.

**8.5 wt % fuel was acquired from the University of Illinois. The 33 g content reflects burnup up to the time of the first installation in the MSU reactor. New 8.5 wt % elements would have a 38 to 39 g $^{235}U$ content.

# 5 REACTOR COOLANT AND ASSOCIATED SYSTEMS

The coolant in the MSU reactor is deionized light water that covers the reactor core to a depth of about 20 ft. The heat generated within the fuel during reactor operation is transferred to the pool water by natural convection.

## 5.1 Cooling Systems

The primary cooling system consists of the reactor pool, a cartridge filter, a demineralizer, the primary coolant pump, and a heat exchanger. The coolant water from the pool is withdrawn at a rate of 150 gal/min using a centrifugal pump and circulated through a heat exchanger, where it can be cooled when the coolant temperature is higher than 50°C. Figure 5.1 is a schematic of the primary cooling system. The coolant is passed through the tube side of a stainless-steel shell and tube heat exchanger. Secondary heat removal is accomplished by circulating the water through the shell side of the heat exchanger and up to a forced-convection cooling tower located in the penthouse. Included in the system are siphon breaks in the inlet and outlet lines that prevent draining of the reactor pool in case of pipe rupture. The system also is provided with instruments that allow the reactor operator to monitor the flow, water temperature, and electrical conductivity at the demineralizer inlet. The pool water temperature is maintained below 50°C. The secondary water system for the heat exchangers is a loop originating from the cooling tower and forced through the shell side of the heat exchanger.

## 5.2 Primary Coolant Purification System

The coolant purification system is part of the heat exchanger loop as shown in Figure 5.1. This loop consists of the reactor pool, a pump, a particulate filter, a heat exchanger, and a mixed-bed demineralizer unit. The demineralizer contains ~4 $ft^3$ of mixed-bed resin. Ionized species of water-soluble materials are removed by the demineralizer during the passage of water through this unit. Only a fraction of the water in the coolant loop (~3 gal/min) is diverted through the demineralizer loop. Conductivity probes located at the inlet and outlet of the demineralizer unit determine the effectiveness of the water purification system. The conductivity of the primary cooling water is maintained at <5 mhos/cm.

## 5.3 Primary Coolant Makeup System

The pool water evaporation losses resulting from normal operation of the reactor are made up by manually adding ~50 gal of distilled water to the pool once a month. There is a separate water inlet line from the city water to the pool that also could serve as an emergency coolant makeup source. This latter system is independent of the primary coolant heat exchanger and purification system.

## 5.4 Conclusion

The staff concludes that the cooling system for the MSU reactor is of proper size, design, condition, and maintenance level to ensure adequate cooling of the reactor under routine operating conditions specified in the MSU operating license. The cooling and water purification systems at the MSU reactor facility have the same design features as used in many other operating TRIGA facilities. There is no new or unproven technology involved in the system.

On the basis of the above observations, the staff concludes that the reactor cooling and water purification system at the MSU reactor facility are adequate for continued safe operation.

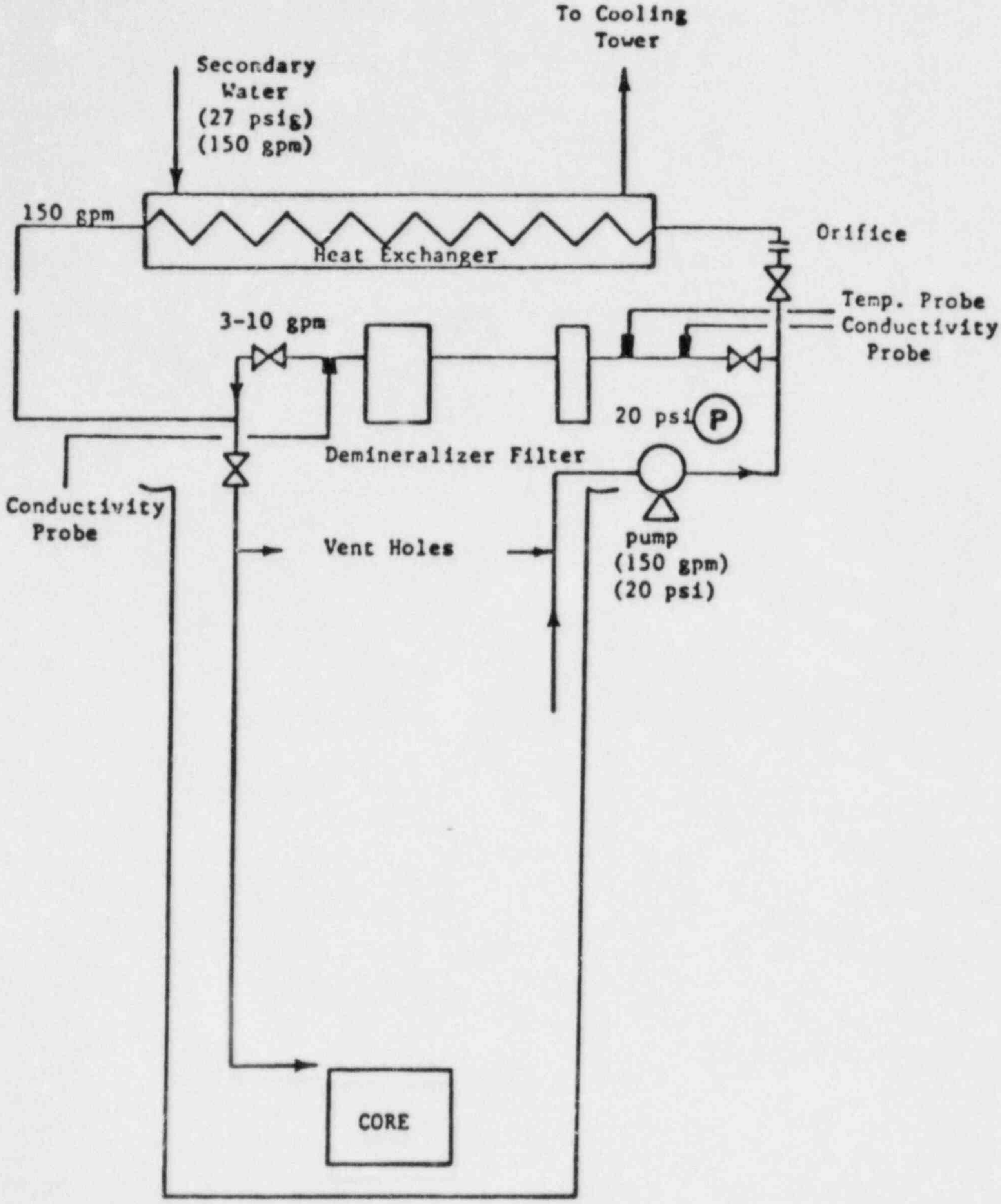



Figure 5.1 Primary cooling system for MSU reactor

# 6 ENGINEERED SAFETY FEATURES

The only system designed to mitigate the consequences of a radiological accident at the MSU reactor facility is the ventilation system.

## 6.1 Ventilation System

The ventilation system in the reactor room (room 184) is separate from that of the rest of the Engineering Building and is designed so that the air in the room changes at least 4 times per hour. Air enters the room from two sources. A unit air conditioner installed on the east wall of the room draws fresh air from outside, heats it to the desired temperature, and discharges it into the room. In addition, air from the building air supply is supplied at $\sim$200 ft$^3$/min to rooms 184B and 190 through ceiling ventilators. This air is released into room 184 through a damper in the control room wall. Both the ventilator on the wall of room 184 and the grills of the air inlets to rooms 190 and 184B are equipped with remotely-operated pneumatic dampers.

Air normally is exhausted from the reactor room through a continuously operating chemical hood in room 184A at a flow rate of >600 ft$^3$/min to a stack that discharges at a height of approximately 39 ft above ground level. There is a provision in the ventilation system to bypass the exhaust air through an absolute filter. In this bypass mode, the air is discharged to the stack at a flow rate of $\sim$150 ft$^3$/min. This reduced flow rate is still sufficient to maintain the reactor room under slight negative pressure. The details of the ventilation bypass system are shown in Figure 6.1.

Two area radiation monitors are located in the reactor room. One of these provides an alarm at the control console in the event of an accidental release of radioactivity. In such an event, the operator can close a single switch that will close all air supply dampers, thereby isolating the reactor room, and venting the exhaust through the absolute filter.

## 6.2 Conclusion

The reactor room ventilation system and equipment are adequate to control the release of airborne radioactive effluents in compliance with applicable standards and to minimize releases of airborne radioactivity in the event of abnormal or accident conditions.

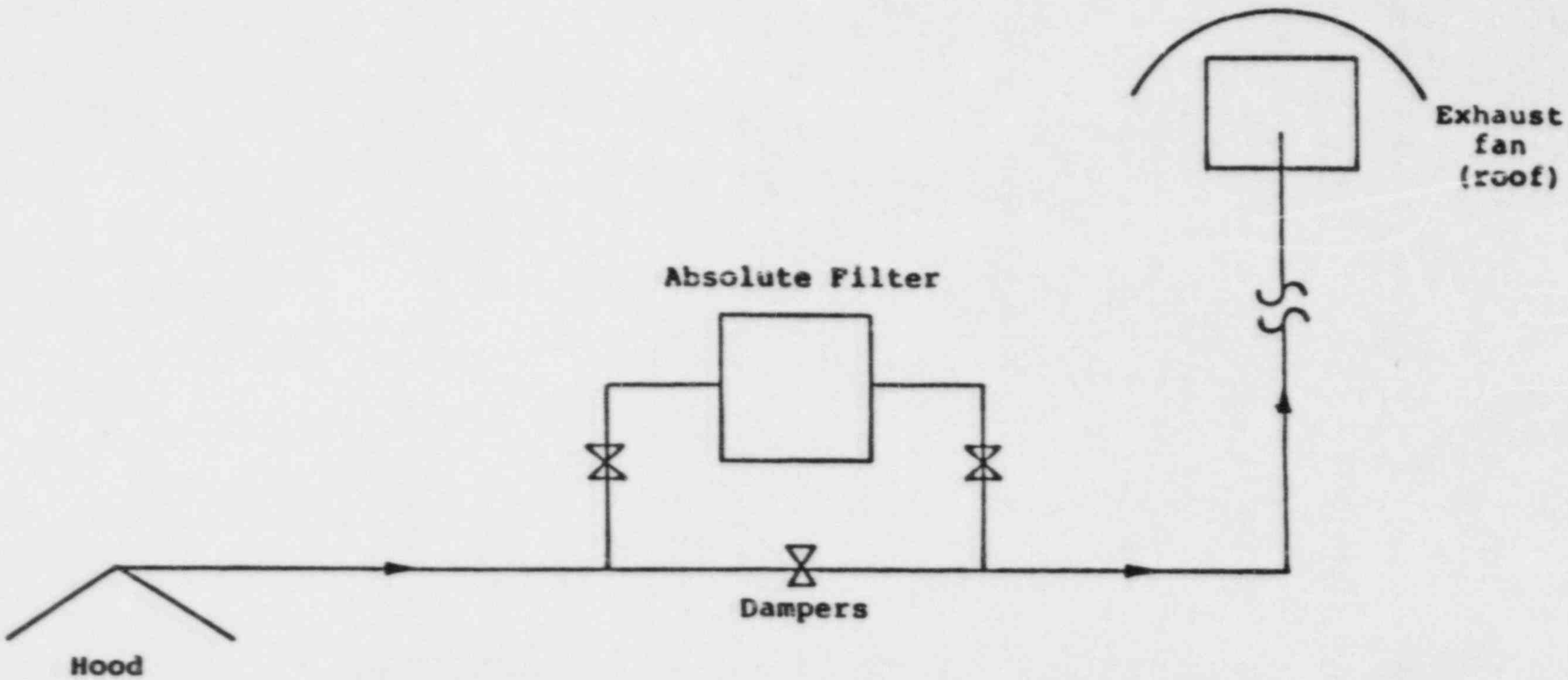



Figure 6.1 Ventilation bypass system for MSU reactor facility

# 7 CONTROL AND INSTRUMENTATION SYSTEM

The MSU reactor facility uses a control system similar in design to other TRIGA reactors. The major components of the MSU reactor control and instrumentation system, including pen recorders, meters, rod controls, and annuciators, are located in the control console in the control room.

The major functions and design of the control console in the control room are to satisfy the following conditions:

(1) Individual components are readily accessible at the back of the control console or by removing individual panel sections. This facilitates maintenance and trouble-shooting.

(2) The console instruments and the reactor experimental area are easily observable by the reactor operator during reactor operation.

(3) The important and necessary information for reactor operation and safety is readily available to the operator and is displayed and annunciated in such a manner that it minimizes the chances of confusing the information with other less essential information.

## 7.1 Reactor Control System

The control system at the MSU reactor facility provides reactor control during nonpulsing and pulsing operations. In addition, interlocks are provided between the instrumentation system and the scram system to provide positive control of the reactor and to minimize the chances of a radioactive release during accident conditions.

### 7.1.1 Control Rods

The reactor uses three separate control rods: (1) a safety-transient rod, (2) a regulating rod, and (3) a shim rod. The shim and regulating rods are connected to an electromechanical drive unit. The safety-transient rod is operated by a pneumatic drive unit. The vertical travel of each rod is ~15 in. The descriptions, core positions, and reactivity worths of the rods are given in Section 4.

### 7.1.2 Control Rod Drive Assemblies

The control rods used to control the fission process in the reactor are operated by electromechanical (shim and regulating) and pneumatic (transient) drive units. The drives are controlled from the reactor console by the reactor operator.

#### 7.1.2.1 Shim and Regulating Rod Drive Assemblies

The electromechanical control rod drive assemblies for the shim and regulating rods consist of a motor and reduction gear driving a rack and pinion. A helipot connected to the drive unit generates the rod position indication. Each control rod drive has a tube that extends to a dashpot below the surface of the water to provide a shock-absorbing effect. The control rod assembly is connected to the rack through an electromagnet and iron armature. During power failures or scram signals, the control rod magnets are deenergized and the rods fall by gravity into the core. The time required for a rod to fall into the core from the "full-out" position following a scram signal is <1 s. The rod drive motor is nonsynchronous, single-phase, and electrically reversible and will insert or withdraw the regulating or shim rod at a rate of ~11 in./min. Electrical, dynamic, and static breaking on the motors provide fast stops and limit the coasting or overtravel on the rods. A key-locked switch on the control console power supply prevents the unauthorized operation of all control rod drives. Furthermore, limit switches are mounted on the drive assembly and actuate circuits that stop the rod drive motor at the top and bottom of travel and also provide switching for console indicator lights that indicate (1) the magnet "up" and "down" positions and (2) the magnet contact with the control rod armature.

#### 7.1.2.2 Transient Control Rod Drive Assembly

The safety-transient rod drive is operated with a pneumatic drive unit. The rod drive is a single-acting pneumatic cylinder with its piston attached to the safety-transient rod by a connecting rod assembly (Figure 7.1). Air from an accumulator tank supplies 75-psig compressed air to the transient rod pneumatic cylinder. During pulse operations, compressed air supplied to the lower end of the cylinder drives the piston upward and causes the rapid withdrawal of the rod. At the end of its travel, the piston strikes the anvil of an oil-filled hydraulic shock absorber that decelerates the piston at a controlled rate. When the solenoid is deenergized, as in the case of a reactor scram, the compressed air supply is cut off, relieving the cylinder pressure, and the piston drops by gravity to its original position, inserting the safety-transient rod into the core. The pneumatic cylinder is set manually to this predetermined position at the rod-drive housing. Two limit switches indicate the position of the air cylinder and safety-transient rod.

Any amount from 0 to 15 in. of rod may be withdrawn from the core; administrative control is used to limit the safety-transient rod travel so as not to exceed the maximum licensed step insertion of reactivity [1.4% $\Delta k/k$ (2.00$)].

### 7.1.3 Rod Control Circuits

Rod control is accomplished at the control console in the control room. There are three modes of control currently available at the MSU reactor facility; manual, automatic, and pulse. The manual and automatic control modes are used during nonpulsing operation. The manual mode of control with the safety-transient rod inserted is used for pulsing operation, only until the reactor achieves criticality. The mode selector switch then is positioned to the pulse mode, which prevents further withdrawal of the shim and regulating rods.

#### 7.1.3.1 Manual Rod Control Circuit

The rods are controlled manually by a series of pushbuttons on the rod control panel on the control console. Annunciators indicate the upper ("up") and lower ("down") limit positions of the rods and whether the magnet is in contact with the control rod armature. The following interlocks prevent the upward movement of the rods:

(1) source channel instrumentation below preset level (<2 counts/s)
(2) two "up" switches depressed at same time
(3) magnet not in contact with armature
(4) mode switch in automatic position (regulating rod only)
(5) mode switch in pulse position (all rods, except safety-transient rod)
(6) mode switch in nonpulsing position rods not down--safety-transient rod only)

Helipots provide indication on the console of the regulating and shim rod positions. Rod position readout is accurate to within 0.2%. Depressing the scram bar causes all the rods to be inserted simultaneously into the reactor, causing a manual scram.

#### 7.1.3.2 Automatic Rod Control

Currently, the automatic control mode at the MSU reactor facility is not in use because the automatic control circuitry is not functional. However, when it is repaired, the following paragraph is a description of the type of automatic rod control system and its operation, should it become functional again.

Automatic rod control can be obtained by switching from manual to automatic operation. All of the instrumentation, safety, and interlock circuitry previously described applies to and is in operation in this mode. However, the regulating rod is controlled automatically in response to a power level or period signal by means of a servoamplifier, where the reactor power is brought to the demand level with a fixed, preset period. The reactor power level is compared continuously with the demand level set by the operator. The demand level is determined by the range-switch position and the percent-demand potentiometer. The period control signal that feeds the servoamplifier allows power level changes within the reactivity operating-range limits of the regulating rod to be made automatically on a constant period. The purpose of this feature is to maintain the preset power level automatically during long-term power runs. Limit switches on the regulating rod inhibit the servoamplifier control when the regulating rod reaches the down limit.

#### 7.1.3.3 Pulse-Mode Control

Pulsing involves a step insertion of excess reactivity to a maximum of 1.4% $\Delta k/k$ (2.00$) to produce a pulse. This is accomplished by leaving the safety-transient rod fully inserted and withdrawing only the shim and regulating rods to achieve criticality. Once criticality is attained and a power level of ~10 W is reached, the transient rod may be pulsed as follows. The MODE SELECTOR switch is placed in the pulse range selected to give an on-scale reading for the flux level of the pulse to be produced. The MODE SELECTOR switch automatically connects the uncompensated ion chamber to the safety channel and connects dual pen recorder inputs to the flux and fuel temperature channels and removes the high-voltage input from the compensated ion chamber. The adjustable safety-transient rod "up" position indicator is moved to a preselected position for the desired total reactivity insertion (depending on the peak flux desired). The safety-transient rod position is indicated by a revolution counter attached to the ball-nut worm drive. When the mode switch is placed in the pulse position, it arms the safety-transient rod air solenoid circuit. When all the transient operation conditions have been met, air may be supplied to the safety-transient rod cylinder when the transient rod "up" button is depressed. From the time the safety-transient "rod" up button is depressed, the operation and control of the reactor is automatic. The reactor flux and temperature increase to a peak value and then decrease rapidly. After a preselected time ($\leq$15 s), the safety-transient rod is released and falls by gravity back into the core. The timer that controls the safety-transient rod release is located inside the control console. The peak and integrated fluxes and fuel temperatures attained during the pulse are indicated on the dual-pen recorder located on the control console. The peak fuel temperature also is indicated on the fuel temperature meter.

## 7.2 Scram System and Interlocks

The scram system circuitry is independent of the other control system circuits. All scram conditions are indicated automatically by the annuciators located in the control console. The Technical Specifications for the MSU reactor require the operability of one fuel element temperature scram and two reactor power level scrams in the nonpulsing mode. In addition, two fuel element temperature scrams are required in the pulse mode. A manual scram also is required for both modes of operation to allow the operator to shut down the reactor for any reason. A detector power supply loss-of-voltage scram in the nonpulsing mode is required; a preset timer scram is required in the pulse mode of operation. In addition to the scrams required by the Technical Specifications, a reactor period scram, a console power circuit failure scram in the nonpulsing mode, and a control console power circuit failure scram are available. Appropriate checks, tests, and calibrations also are required to verify continued operability and satisfactory performance of the scram functions.

A manual scram also may be used for normal fast shutdown of the reactor. The manual scram may be initiated for either individual control rods or for all control rods together. A set of four bistable trip-operated circuits are located on the startup, fuel temperature, level, and percent power channels, and another set of two relay-operated annunciators are located on the control console panel. The reactor scram system is designed to interrupt the magnet current and result in the immediate insertion of all rods under any of the following conditions:

(1) high neutron flux on safety channels (110% of full power)

- (a) uncompensated ion chamber, percent power
- (b) compensated ion chamber, 110% scale range
- (c) linear recorder

(2) power supply failure

- (a) ionization chambers, high voltage
- (b) fission chamber, high voltage

(c) power to scram relay busses
(d) console power circuit failure

(3) high fuel temperature (450°C)

(a) nonpulsing, 1 of 1
(b) pulse mode, 1 of 2

(4) high rate of change of power (period scram) (~7 s) adjustable between -40 and +7 s

(5) manual initiation

## 7.3 Instrumentation System

The reactor instrumentation system is fully integrated with the control and scram systems to form a single comprehensive system. Both nuclear and non-nuclear parameters are measured and monitored by the system. The minimum reactor safety channels are given in Table 7.1.

Instrument power to the console instrumentation consists of three systems. With the instrument chassis power on, the neutron detector power supply, source range count-rate circuit, water conductivity, and bulk water temperature monitor circuits are continuously active. The console power supply switch provides power to the remaining circuits except for control rod magnet power supply. Rod drive magnet power is obtained only with a key switch that is mounted on the console. Key operation ensures that only authorized operation of the reactor is performed without impeding the checkout and calibration of the instrument channels. Important monitoring circuits remain continuously active, which allows rapid evaluation of reactor conditions while checkouts and calibrations are performed. The instrumentation system is designed to enable the operator to initiate various safety and control circuits for optimum system performance during the different operational modes of the reactor. Figures 7.2 and 7.3 show the block diagrams of the reactor instrumentation for the reactor nonpulsing and pulsing operational modes.

### 7.3.1 Neutron Monitoring Channels

The nuclear instrumentation is designed to provide the operator with the necessary information for proper manipulation of the nuclear controls. The neutron monitoring channels consist of a startup channel, a log-N and period channel, a linear safety channel, and a wide-range percent power level channel. Table 7.2 gives the operating ranges and trip set points of these neutron detectors. All neutron-sensing chambers are sealed in aluminum cans and mounted on the outside of the reflector so that their positions are adjustable vertically to change sensitivity and for calibration.

The startup channel consists of a fission chamber, power supply, preamplifier, linear amplifier, and log-count rate meter. The channel provides power indication from below source level (~50 counts/s) to ~10 W. In addition, a minimum source-count interlock prevents rod withdrawal unless the measured source level exceeds a predetermined value.

The log-N and period channel consists of a compensated ion chamber, a power supply, a log-N amplifier, a period circuit and meter, and a log-N recorder. Log-N power is indicated on one pen of the dual-pen recorder and covers a range from <1 W to above full licensed power (>250 kW). Over this range, the period is indicated on a meter from -40 s through infinity to +7 s. The period scram in the range from infinity to +7 s is obtained from this circuit, as is the derivative control for the servoamplifier in the automatic regulating circuit.

The power level and scram channel incorporates a compensated ion chamber, a power supply, a microammeter with range switch amplifier, and a linear power level recorder (second pen of the dual-pen recorder). It provides power level indication from ~1.0 W to above full licensed power (>250 kW) and has a range switch with two ranges per decade for accurate measurements of the compensated ion chamber current. If the power level increases to 110% of full scale on any range, a linear power level scram occurs. The output of the linear power level channel is recorded on the second pen of the recorder; it also furnisher power-level information to the automatic regulating servochannel.

The percent power level and automatic regulating channel consists of an uncompensated ion chamber, power supply, power level monitor, servoamplifier, scram bus, power demand control unit, and percent power recorder. Power level indication is provided from a few percent to >110% (>275 kW) of licensed power. This circuit provides for an adjustable level scram within this range. The automatic regulating channel consists of a servoamplifier (currently nonfunctional) that controls the regulating rod and keeps the power level constant. The servoamplifier is initiated by an error signal that is generated by the differences in the setting of the power-demand control in relation to the actual reactor power level as measured by the power level monitor. The period information also is fed to the servoamplifier to allow for bringing the reactor up to a desired power level automatically within the limits of the worth of the regulating rod on a preset period of 30 s.

In the pulse mode of reactor operation, the normal neutron channels are disconnected and the high-level pulsing chamber is connected to indicate the peak power of the pulse. The uncompensated ion chamber is the only active neutron-sensing chamber during pulsing operations. Its output is modified to measure peak power and total energy release, which is recorded several seconds after the pulse is completed.

All nuclear channels include a means of calibrating and testing their trip levels. These calibration and test circuits are built into the console as part of each channel. Figure 7.4 indicates the operating ranges of the neutron detectors.

### 7.3.2 Temperature and Water Monitor Channels

A fuel temperature channel with a meter readout and associated scram circuitry is mounted in the control console. The channel is provided with a test switch on the front panel to allow checkout of the fuel temperature scram circuits. In addition, a second fuel temperature meter readout and supplemental scram are provided.

The water temperature monitoring signal is generated from a thermistor that senses the recirculation line temperature, which is indicated on the control console. The system is required to be operational whenever the reactor is operating; the reactor is shut down if the temperature exceeds 50°C. The water conductivity monitor consists of a conductivity probe and Wheatstone bridge circuit. The conductivity is measured daily during reactor operation and displayed on the lower right panel of the control console.

### 7.3.3 Operational Modes Instrumentation

The reactor can be operated in three modes: manual, automatic, and pulse. The manual and automatic modes are the nonpulsing power operating modes and are chosen by setting the mode selector switch to the "manual" or "automatic" position. The reactor power level is controlled by a servoloop when in the automatic mode. The desired power level is set on the percent-demand dial, and power changes are made automatically (using the servochannel) on a constant period of approximately 30 s. The manual and automatic reactor operation modes are used for reactor control from source level to 100% of full licensed power (250 kW). These two modes are used for manual reactor startups, changes in power level, and nonpulsing operation. The pulse mode generates high power levels for short periods of time (30-ms pulse width).

## 7.4 Conclusion

The control and instrumentation systems at the MSU reactor facility, which are similar to those in other operating TRIGA reactors, are well designed and provide for reliability and flexibility. All power and instrumentation wiring is protected from physical damage by conduits and is well identified. There is redundancy in the crucial nuclear and temperature monitoring circuits. In particular, nuclear power measurements are overlapped in the ranges of the log-N, linear power, and percent power level channels. The control system is designed to shut down the reactor automatically if electrical power is lost or interrupted.

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

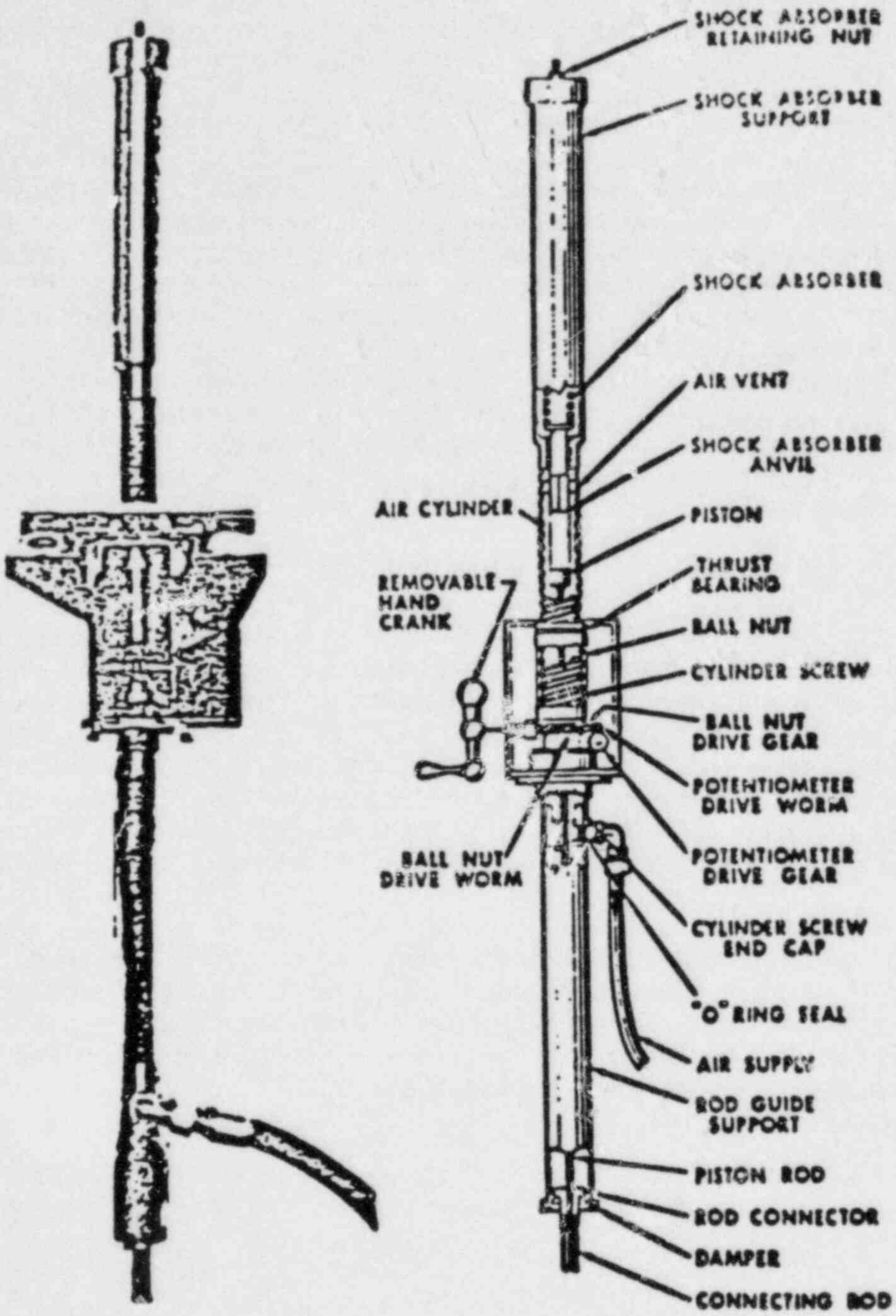



Figure 7.1 Pneumatic safety-transient rod drive

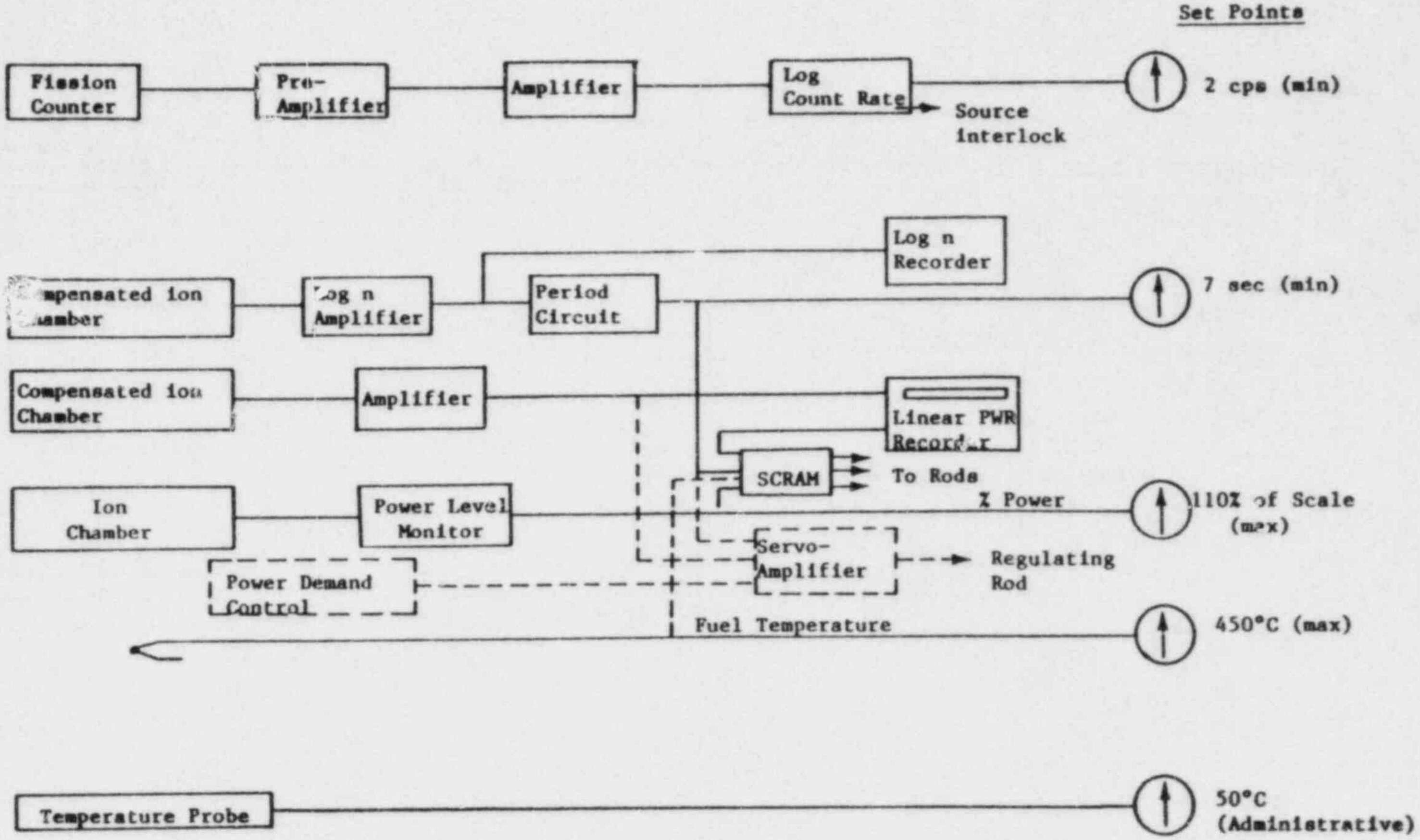



Figure 7.2 Block diagram of reactor instrumentation for nonpulsing operation

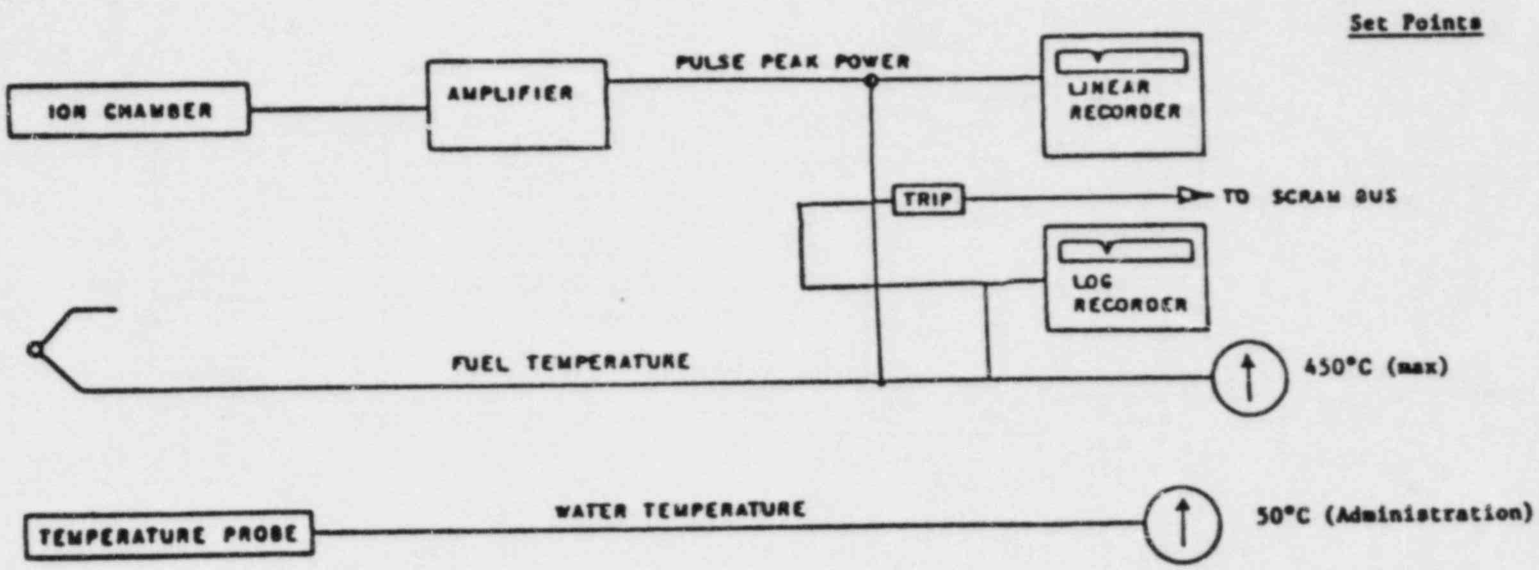



Figure 7.3 Block diagram of reactor instrumentation for pulsing operation

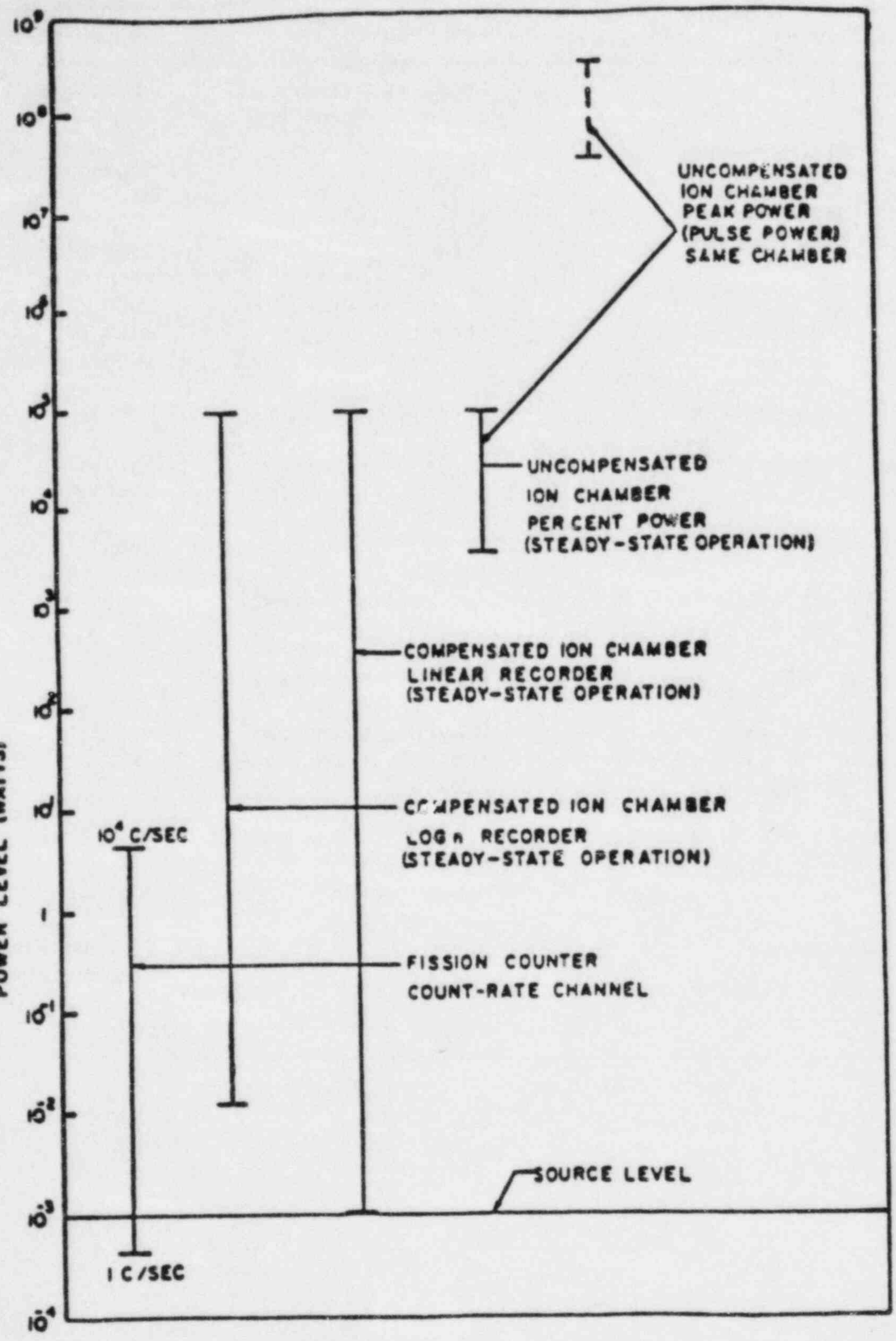



Figure 7.4 Operating range of in-core nuclear detectors

Table 7.1 Minimum reactor safety channels

| Safety Channel | Function | Set Point |
|---|---|---|
| Startup | Prevents withdrawal of any control rod | >2 counts/s |
| Log-N and period | Scram | Minimum period of 7 s |
| Linear power level | Scram | 110% of full-scale recorder |
| Percent power | Scram | 110% of licensed power |
| Console scram button | Scram | Manual |
| Chamber high voltage | Scram | Failure of power supply |
| Magnet current key switch | Scram | Manual |
| Simultaneous withdrawal of two rods | Prevents withdrawal | - - - |
| Withdrawal of shim rod | Prevents withdrawal | - - - |
| Withdrawal of safety-transient rod with shim and regulating rods not seated | Prevents withdrawal (only in nonpulsing mode) | - - - |
| Bulk pool temperature | Meter indication manual scram | - - - |
| Fuel temperature | Scram | If fuel element temperature $\geq$500°C (450°C ΔT hot to cold) |

Table 7.2 Operating ranges of TRIGA Mark I pulsing reactor neutron detectors

| Channel | Chamber or Detector | Ranges | Alarms and Trip Points |
|---|---|---|---|
| Startup - log count rate | Fission chamber | <50 cps to 10 W | 2 counts/s |
| Log-N and period | Compensated ion chamber | <1 W to >250 kW | +7 s |
| Linear power level | Compensated ion chamber | 1 W >250 kW | 110% scale (275 kW) |
| % power level | Uncompensated ion chamber | 1% >110% | 110% scale (275 kW) |

# 8 ELECTRICAL POWER SYSTEM

The electrical power system at the MSU reactor facility is a standard electrical supply system designed and constructed to specifications similar to those at other nonpower reactor facilities.

## 8.1 Normal Power

Electrical power for building lighting and equipment power is 110/220/440 V three phase, four wire 60 Hz. The total estimated power requirement for the reactor facility is 15 kVA. The main power control panel is located in the electrical utility room with subpanels located in other areas, as required.

## 8.2 Emergency Power

Power from a battery system will supply the intrusion alarm and radiation monitors (area monitor, particulate monitor, and $^{41}Ar$ monitor) under emergency conditions for ~15 hours. Because the MSU reactor will scram in case of a power interruption and the decay heat generated in the core after scram will not cause fuel overheating, no emergency power is necessary to operate reactor systems.

The reactor building ventilation system is considered an engineered safety feature in that, in the bypass mode, any accidently released radioactive particulate material will be trapped in the exhaust absolute filter. Emergency ac power is not available for this system because it is considered extremely unlikely that this type of accident would occur simultaneously with a power failure. However, if this occurs, the reactor building would be evacuated until power was restored and cleanup operations were initiated.

## 8.3 Conclusions

The staff concludes that the electrical power system at the MSU reactor facility is a standard electrical supply system typical of nonpower reactor facilities and is adequate for continued operation. The staff also concludes that emergency power, in addition to that currently available, is unnecessary.

# 9 AUXILIARY SYSTEMS

## 9.1 Heating and Ventilation System

The ventilation system is considered to be an engineered safety feature and is discussed in Section 6.1. The heating system for the reactor room (184) is integrated with the ventilation system of the reactor facility. The intake air (which enters through the ventilator on the east wall of room 184) is preheated to a desired temperature by steam coils before it is exhausted into the room.

## 9.2 Liquid Waste Collection System

The liquid waste collection and disposal system and procedures are described in Section 11.2.2.

## 9.3 Fire Protection System

Fire protection is provided by external fire hydrants and portable fire extinguishers located throughout the facility. The East Lansing Fire Department, which is responsible for campus fire protection, has surveyed the facility, and they have been given information that will allow a rapid and safe response to a fire alarm.

## 9.4 Communications System

Standard commercial telephone service, which is part of the main university-wide communication system, serves the reactor facility. The campus Department of Safety continuously monitors some of the vital radiation monitors and intrusion alarms at the reactor facility.

## 9.5 Facility Compressed Air System

Compressed air is used in the reactor room to operate the safety-transient rod (see Figure 9.1). A compressor outside the facility provides 90-psig air that is piped in through a pressure reducer valve, a solenoid, and a surge tank to provide 70-psig air pressure to operate the safety-transient rod.

## 9.6 Fuel Handling and Storage

Fuel storage consists of four in-pool storage racks for irradiated fuel elements. These racks have a combined maximum capacity of 31 elements, and there are 26 fuel elements currently in storage on these racks. The fuel storage racks are designed to prevent criticality.

There are no built-in cranes at this facility. Specialized tools and equipment designed by General Atomic Technologies, Inc., are used to service the reactor core and the irradiation facilities.

## 9.7 Conclusion

The staff concludes that the auxliary systems at the MSU reactor facility are well designed and maintained and are adequate for their intended purposes.

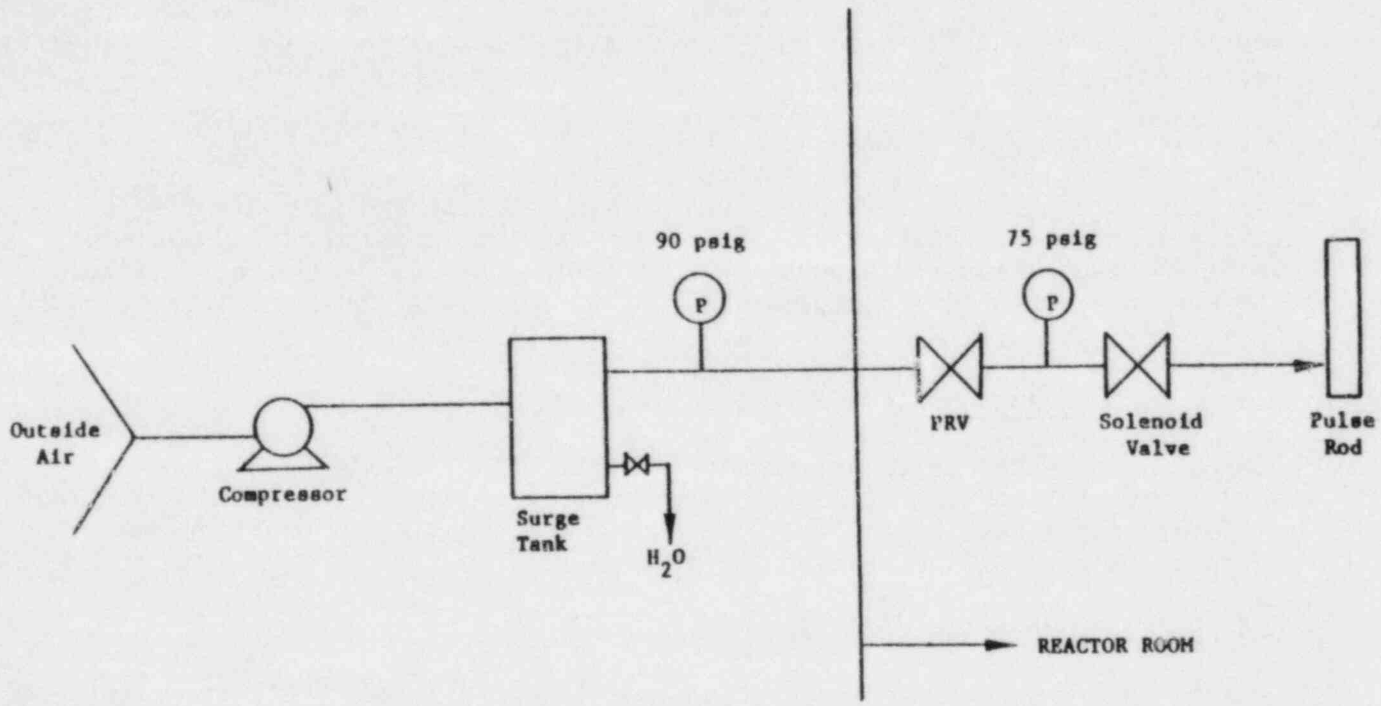



Figure 9.1 Compressed air system

# 10 EXPERIMENTAL PROGRAMS

The MSU reactor facility serves as a source of ionizing radiation and neutrons for various research programs and radioisotope production. The reactor also serves as a tool for training students in the principles of reactor operation. The experimental facilities at MSU include a rotary specimen rack and a central thimble. In addition, the reactor pool can serve as a bulk irradiation facility.

## 10.1 Experimental Facilities

### 10.1.1 Pool Irradiation

The open pool of the reactor permits the irradiation of experiments submerged in the vicinity of the core but outside the cylindrical graphite reflector. The decision to perform experiments in the reactor pool as opposed to using the rotary specimen rack or the central thimble is dictated by the nature and size of the specimen and the type and intensity of radiation fields desired. The actual placement of experiments or samples in the core region of the pool is limited by their potential effect on reactivity, which is limited by the Technical Specifications.

### 10.1.2 Rotary Specimen Rack

A rotary specimen rack (see Figure 10.1), which is located in a well on top of the graphite reflector, provides for the production of radioisotopes and for the activation and irradiation of small samples in a dry atmosphere. When the rotary specimen rack is in use, all of its 40 positions are exposed to neutron fluxes of comparable intensity. Samples are loaded and extracted from the top of the reactor through a water-tight tube and a specimen lifting device. The rotary rack can be turned manually or by using a motor located on the reactor bridge.

### 10.1.3 Central Thimble

The reactor is equipped with a central thimble for conducting experiments or irradiating small samples in the core at the point of maximum neutron flux. The central thimble is a 1.5-in. outside diameter aluminum tube that fits through the central hole of the top and bottom grid plates. Holes in the tube ensure that it normally is filled with water; however, a special cap can be attached to the top end, compressed air can be applied, and the water column can be removed to obtain a well collimated beam of neutrons.

Vertical irradiation tubes similar to the central thimble may be placed in any of the fuel element positions. The actual placement of experiments or samples in the core region is limited by the Technical Specifications.

## 10.2 Experimental Review

Before any new experiment using the reactor or the associated experimental facilities can be conducted, it is reviewed by the Reactor Safety Committee (RSC), which has at least five members. The membership of the RSC is designed to provide a spectrum of expertise to review the experiments and their potential hazards. The MSU Radiation Safety Officer and the Reactor Supervisor are permanent members of this committee. The review and approval process for experiments allows personnel trained in reactor operations to consider and suggest alternative operational conditions (such as different core positions, power levels, and irradiation times) that will minimize personnel exposure and/or potential release of radioactive materials to the environment.

## 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 the experiments are (1) not likely to fail, (2) not likely to release significant radioactivity to the environment, and (3) not likely to cause damage to the reactor system or its fuel. Therefore, the staff concludes that reasonable provisions have been made so that the experimental programs and facilities do not pose a significant risk to the facility staff or the public.

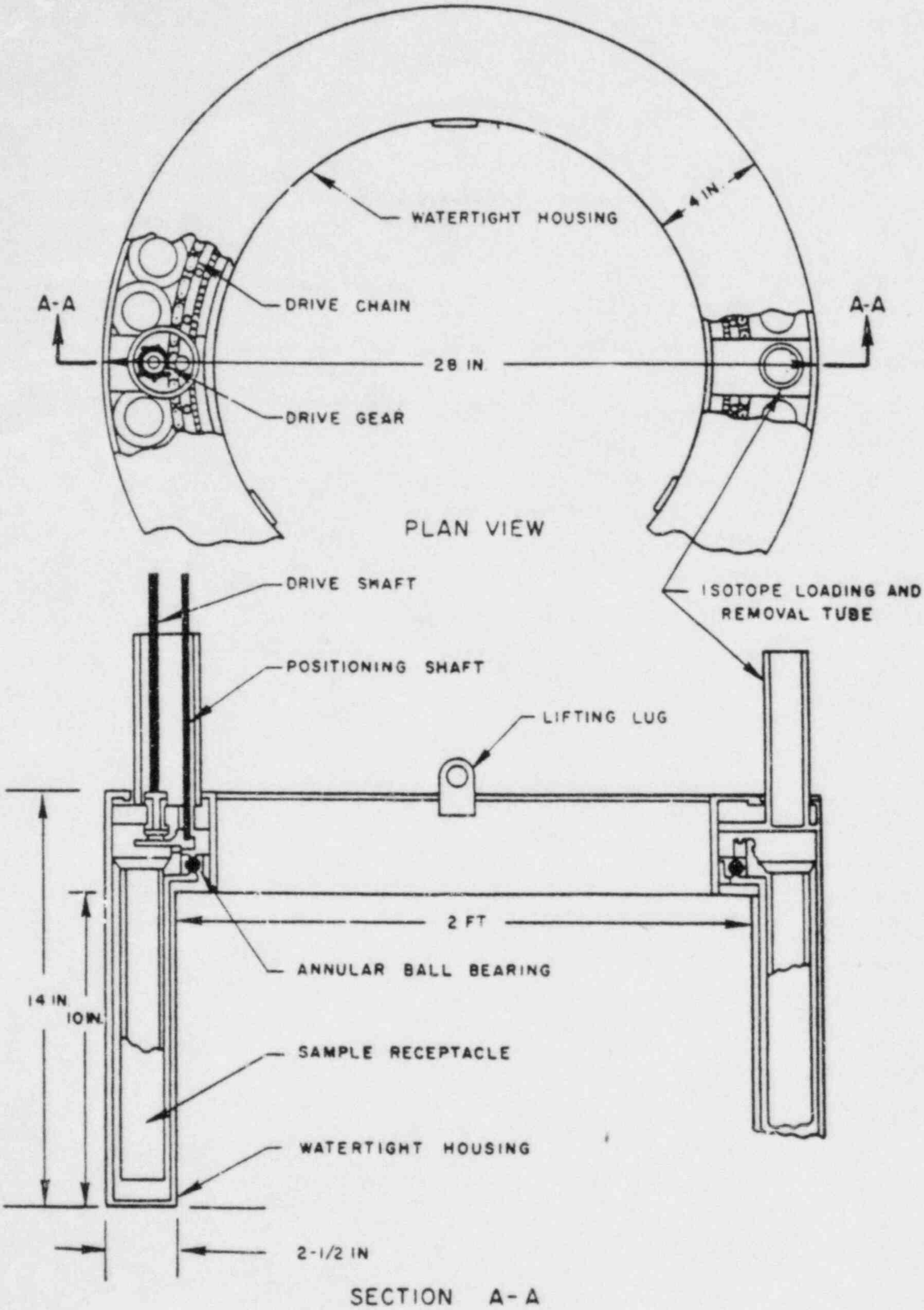



Figure 10.1 Rotary specimen rack schematic

# 11 RADIOACTIVE WASTE MANAGEMENT

The major radioactive waste generated by reactor operations is activated gases, primarily $^{41}Ar$. A limited volume of radioactive solid waste, principally spent ion exchange resins, is generated by reactor operations, and some additional solid waste is produced by associated research programs. The facility does not regenerate the coolant purification ion exchanger resin beds; thus, very little liquid waste is generated.

## 11.1 ALARA Commitment

The MSU reactor is operated with the philosophy of minimizing the release of radioactive materials to the environment. The university administration, through the Radiation Safety Officer, instructs all operating and research personnel to develop procedures to limit the generation and subsequent release of radioactive materials.

## 11.2 Waste Generation and Handling Procedures

### 11.2.1 Solid Waste

The generation of high-level radioactive waste in the form of spent fuel is not anticipated during the term of this license renewal. The only solid waste generated as a result of reactor operations consists primarily of ion exchange resins and filters, potentially contaminated paper and gloves, and occasional small activated components. Some of the reactor-based research results in the generation of solid low-level radioactive wastes in the form of contaminated paper, gloves, and glassware. The solid wastes generated at the MSU reactor facility typically contain about 6 mCi of radionuclides in a volume of 7.06 $ft^3$ per year.

The solid waste is collected by the university's health physics staff in specially marked barrels. The waste is held temporarily before being packaged and shipped to an approved disposal site in accordance with applicable regulations.

### 11.2.2 Liquid Waste

Normal reactor operation produces no radioactive liquid waste other than the coolant with minute amounts of tritium and waterborne activation products. The coolant maintenance system is adequate to purify it on a continuous basis. Some of the cleaning activities or irradiations may generate limited volumes of liquid wastes. These solutions generally are collected in portable carboys and retained for decay. There is no liquid waste sump or holdup tank to collect liquid wastes. Two sinks in the laboratory (room 184A) are drained directly into the sanitary sewer system.

### 11.2.3 Airborne Waste

The $^{16}N$ produced within the coolant passing through the core of the reactor is an activation product that can become airborne. When the pool temperature is elevated as a result of a long run, $^{41}Ar$ also is released to the environment. Calculations by the licensee indicate the $^{16}N$ dose rate at the pool surface is <0.05 mrem/hour.

To minimize the $^{16}N$ gas that becomes airborne, the vertical convective core water currents are deflected by a downward-slanted discharge of water through a diffuser nozzle on the water inlet to the pool. This increases the transport time of the short-lived $^{16}N$ (7.1-s half-life) from the core to the surface of the pool and allows additional decay time. No fission products escape from the fuel cladding during normal operations. The radioactive airborne waste of concern is $^{41}AR$, which is produced principally by the neutron irradiation of air dissolved in the cooling water. When actual measurements are extrapolated to the maximum reactor use at 250 kW, the concentration of $^{41}Ar$ at saturation calculated by the licensee in the reactor room (a restricted area), will only approach the value of $2 \times 10^{-8}$ μCi/ml when the reactor is operating.

The air filters used in the exhaust ventilation system eventually are disposed of as potentially radioactive solid waste. The MSU reactor facility has measured the release of airborne radioactivity (mostly $^{41}Ar$) at ~400 μCi/year. The licensee's and the staff's evaluations show that this amount of release would lead to exposures in the unrestricted areas that are well within the limits specified in 10 CFR 20.

## 11.3 Conclusions

The staff concludes that the waste management activities at the MSU reactor facility have been conducted and are expected to continue to be conducted in a manner consistent with 10 CFR 20 and the as low as is reasonably achievable (ALARA) principles. Among other guidance, the staff review has followed the methods of American National Standards Institute/ American Nuclear Society (ANSI/ANS) 15.11, "Radiological Control at Research Reactor Facilities."

Because $^{41}Ar$ is the only significant radionuclide released by the reactor to the environment during normal operations, the staff has reviewed the history, current practices, and future expectations of reactor operations with respect to this radionuclide. 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 limits specified in 10 CFR 20 when averaged over a year. Furthermore, the <50 mrem/year dose beyond the limits of the reactor facility resulting from reactor operation gives reasonable assurance that the potential doses to the public as a result of $^{41}Ar$ release are not significant.

## 12 RADIATION PROTECTION PROGRAM

Michigan State University has a structured radiation safety program with a health physics staff equipped with radiation detection instrumentation to determine, control, and document occupational radiation exposures at its reactor facility. In addition, the reactor facility monitors airborne effluents at the point of release to comply with applicable guidelines.

### 12.1 ALARA Commitment

The university administration, through the Advisory Committee on Radiation, Chemical, and Biological Hazards, has formally established the policy that operations are to be conducted in a manner to keep all radiation exposures ALARA. All proposed experiments and procedures at the reactor are reviewed for ways to minimize the potential exposure of personnel. All unanticipated or unusual reactor-related exposures are investigated by the health physics and the operations staffs to develop methods to prevent recurrences.

### 12.2 Health Physics Program

#### 12.2.1 Health Physics Staffing

The normal radiation safety staff at MSU consists of three professional health physicists. This staff provides radiation safety support to the entire university complex, including a cyclotron facility and many radioisotope laboratories. The routine health physics-type activities at the reactor are performed by the operations staff with additional surveys by the health physics staff. The health physics staff is available for consultation, and the MSU Radiation Safety Officer is a member of the Reactor Safety Committee. The staff believes that the radiation safety support is adequate for the research efforts within this reactor facility.

#### 12.2.2 Procedures

Detailed written procedures have been prepared that address the radiation safety support that is expected to be provided to the routine operation of the university's research reactor facility. These procedures identify the interactions between the operational and experimental personnel and also specify numerous administrative limits and action points, as well as appropriate responses and corrective actions 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 administrative and radiation safety personnel.

#### 12.2.3 Instrumentation

Michigan State University has acquired a variety of detecting and measuring instruments for monitoring potentially hazardous ionizing radiation. The instrument calibration procedures and techniques ensure that any credible type of radiation with any significant intensities will be detected promptly and measured correctly.

### 12.2.4 Training

All reactor-related personnel are given an indoctrination in radiation safety before they assume their work responsibilities. Additional radiation safety instructions are provided to those who will be working directly with radiation or radioactive materials. The training program is designed to identify the particular hazards of each specific type of work to be undertaken and methods to mitigate their consequences. Retraining in radiation safety also is provided. As an example, all reactor operators are given an examination on health physics practices and procedures at least every 2 years. The level of retraining given is determined by the examination results.

## 12.3 Radiation Sources

### 12.3.1 Reactor

Sources of radiation directly related to reactor operations include radiation from the reactor core, filters in the water cleanup systems, and radioactive gases (primarily $^{41}Ar$).

The fission products are contained in the fuel's stainless-steel cladding. Radiation exposures from the reactor core are reduced to acceptable levels by water and concrete shielding. The filters are changed routinely before high levels of radioactive materials have accumulated, thereby limiting personnel exposure.

Personnel exposure to the radiation from chemically inert $^{41}Ar$ is limited by dilution and prompt removal of this gas from the reactor area and its discharge to the atomosphere, where it diffuses further before reaching occupied areas.

### 12.3.2 Extraneous Sources

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

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

## 12.4 Routine Monitoring

### 12.4.1 Fixed-Position Monitors

The MSU reactor facility has two fixed-position radiation monitors: one on the ceiling above the reactor and another on the wall below the heat exchanger. All monitors have adjustable alarm set points, and the unit above the reactor reads out in the control room and also at the office of the Department of Public Safety.

12.4.2 Experimental Support

The health physics staff participates in experiment planning by reviewing all proposed procedures for methods of minimizing personnel exposures and limiting the generation of radioactive waste. Approved procedures specify the type and degree of radiation safety support required by each activity.

## 12.5 Occupational Radiation Exposures

12.5.1 Personnel Monitoring Program

The MSU personnel monitoring program is described in the MSU Radiation Safety Manual. Personnel exposures are measured by the use of film badges assigned to individuals who might be exposed to radiation. Visitors also may be provided with film badges for monitoring purposes. In addition, instrument dose rate and time measurements are used to administratively keep occupational exposures below the applicable limits in 10 CFR 20.

12.5.2 Personnel Exposures

The MSU reactor facility personnel annual exposure history for the last 5 years is given in Table 12.1.

## 12.6 Effluent Monitoring

12.6.1 Airborne Effluents

As discussed in Section 11, airborne effluents from the reactor facility consist principally of low concentrations of $^{41}Ar$. The small amount of $^{41}Ar$ released into the reactor room is diluted by the almost 7,000 $ft^3$ volume of air. The calculated maximum concentration in the reactor room will be on the order of $1.6 \times 10^{-8}$ µCi/ml per the MSU reactor operating schedule. In actual operation, this concentration is seldom, if ever, achieved. The average concentration will be on the order of $3.5 \times 10^{-11}$ µCi/ml. Reactor room air is discharged at a rate of about 600 $ft^3$/min at a point approximately 39 ft above ground level, resulting in additional dilution before reaching occupied areas at ground level.

12.6.2 Liquid Effluents

The reactor generates very limited radioactive liquid waste during routine operations. The small quantity of liquid waste resulting from reactor-related research is collected in a 5-gal carboy and transferred to the health physics office for disposal after adequate decay.

Before any releases of potentially contaminated waters to the sanitary sewer system are made, representative samples are collected and analyzed by standard techniques. When the concentrations of radioactive materials in the waste are less than the guideline values of 10 CFR 20.303, the liquids can be discharged directly to the sewer.

## 12.7 Environmental Monitoring

The environmental monitoring program for the MSU reactor facility consists of air particulate effluent monitoring and gross alpha and beta analysis of the Cedar River water both upstream and downstream of the MSU campus. The effluent discharges all have been extremely low, and water samples collected downstream of the campus are usually almost identical to samples obtained upriver. The infrequent positive (but low-level) activity levels cannot be correlated with reactor use or maintenance work.

## 12.8 Potential Dose Assessments

Natural background radiation levels in the central Michigan area result in an exposure of about 115 mrems/year to each individual residing there. At least an additional 7% (approximately 8 mrems/year) will be received by those living in a brick or masonry structure. Any medical diagnosis X-ray examination will add to the natural background radiation, increasing the total accumulative annual exposure.

Conservative calculations by the staff, based on the amount of $^{41}Ar$ released during normal operations from the reactor facility stack, predict a maximum annual exposure of less than 1 mrem in the unrestricted areas.

## 12.9 Conclusions

The staff concludes that radiation protection receives appropriate support from the university administration. The staff further concludes that (1) the program is staffed and equipped properly, (2) the university health physics staff has adequate authority and lines of communication, (3) the procedures are integrated correctly into the research plans, and (4) surveys verify that operations and procedures follow ALARA principles.

The staff concludes that the effluent monitoring programs conducted by university personnel are adequate to identify significant releases of radioactivity promptly so that maximum exposures to individuals in the unrestricted area can be predicted. These predicted maximum levels are well within the applicable regulations and guidelines of 10 CFR 20.

Additionally, the staff concludes that the MSU radiation protection program is acceptable because the staff has found no instances of reactor-related exposures of personnel above applicable regulations and no unidentified significant releases of radioactivity to the environment. Furthermore, the staff considers that there is reasonable assurance that the personnel and procedures will continue to protect the health and safety of the public during routine reactor operations.

Table 12.1 Number of individuals in exposure interval

| Whole-body exposure range (rem) | Number of individuals in each range | | | | |
|---|---|---|---|---|---|
| | 1979 | 1980 | 1981 | 1982 | 1983 |
| No measurable exposure | 3 | 3 | 2 | 2 | 2 |
| Measurable exposure | | | | | |
| less than 0.1 | 1 | 0 | 0 | 1 | 1 |
| 0.1 to 0.25 | 0 | 0 | 1 | 0 | 0 |
| more than 0.25 | 0 | 0 | 0 | 0 | 0 |
| Total number of individuals monitored | 4 | 3 | 3 | 3 | 3 |

# 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 chain of command shown in Figure 13.1. Individuals at the various management levels, in addition to having responsibility for policies and operation of the facility, are responsible for safeguarding the public and facility personnel from undue radiation exposures and for adhering to all requirements of the operating license and Technical Specifications.

In all instances, responsibilities at one level may be assumed by designated alternates or by personnel at higher levels, conditional on appropriate qualifications.

### 13.1.2 Reactor Staff

When the reactor is not secured, the minimum staffing shall be a licensed reactor operator at the console. A licensed senior reactor operator and a health physicist shall be readily available from the Office of Radiation, Chemical, and Biological Safety.

## 13.2 Selection and Training of Personnel

The operators and senior operators for the MSU TRIGA reactor are trained inhouse by the facility staff. The licensee's Operator Requalification Program has been reviewed, and the NRC staff has concluded that it meets applicable regulations and guidance, therefore, is acceptable.

## 13.3 Emergency Planning

10 CFR 50.54(q) and (r) require that a licensee authorized to possess and/or operate a research reactor shall follow and maintain in effect an emergency plan that meets the requirements of Appendix E to 10 CFR 50. At the staff's request, as part of the application for license renewal, the licensee submitted a plan following guidance contained in RG 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 RG 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 submittal dates for emergency plans from all research reactor licensees. The licensee transmitted an updated emergency plan by letter dated November 1, 1982, thereby complying with existing applicable regulations.

## 13.4 Operational Review and Audit

The Reactor Safety Committee (RSC) reviews and approves new experiments and proposed alterations to the reactor. The committee, which is appointed by the University Radiation Safety Committee, reviews and audits reactor operations for safety. It is composed of the Reactor Supervisor, an MSU Radiation Safety Officer, and three other members having expertise in nuclear safety.

The Reactor Safety Committee reviews

(1) determinations that propose changes in equipment, systems, test, experiments, or procedures that do not involve an unreviewed safety question

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

(3) tests and experiments in accordance with requirements in the Technical Specifications

(4) proposed changes to the Technical Specifications or license

(5) violations of the Technical Specifications or license; violations of internal procedures or instructions having safety significance

(6) audit reports

(7) operating abnormalities having safety significance

(8) reportable occurrences

The RSC or a subcommittee audit reactor operations, at least quarterly, including a comprehensive selective examination of operating records, logs, and other documents.

## 13.5 Facility Procedures

The facility is operated and maintained in accordance with approved written procedures. All procedures and major changes thereto are reviewed and approved by the Reactor Safety Committee before becoming effective. Changes that do not alter the original intent of a procedure may be approved in writing by the Reactor Supervisor. Such changes are recorded and submitted to the Reactor Safety Committee for routine review.

## 13.6 Physical Security

The MSU has established and maintains a program designed to protect the reactor and its fuel and to ensure its security. The staff has reviewed the Physical Security Plan to compare it with the requirements of 10 CFR 73.67 for special nuclear material of low strategic significance. The staff has concluded that the licensee's Physical Security Plan, submitted by letter dated January 2, 1980, as amended by letter dated March 13, 1981, meets the requirements of the regulations and will be incorporated as a condition of the operating license.

The Physical Security Plan and the staff's evaluation are withheld from public disclosure under 10 CFR 2.790(d)(1) and 10 CFR 9.5(a)(4).

## 13.7 Conclusion

On the basis of the above considerations, the staff concludes that the licensee has sufficient experience, management structure, and procedures to provide reasonable assurance that the reactor will be managed in a way that will cause no significant risk to the environment or to the health and safety of the public.

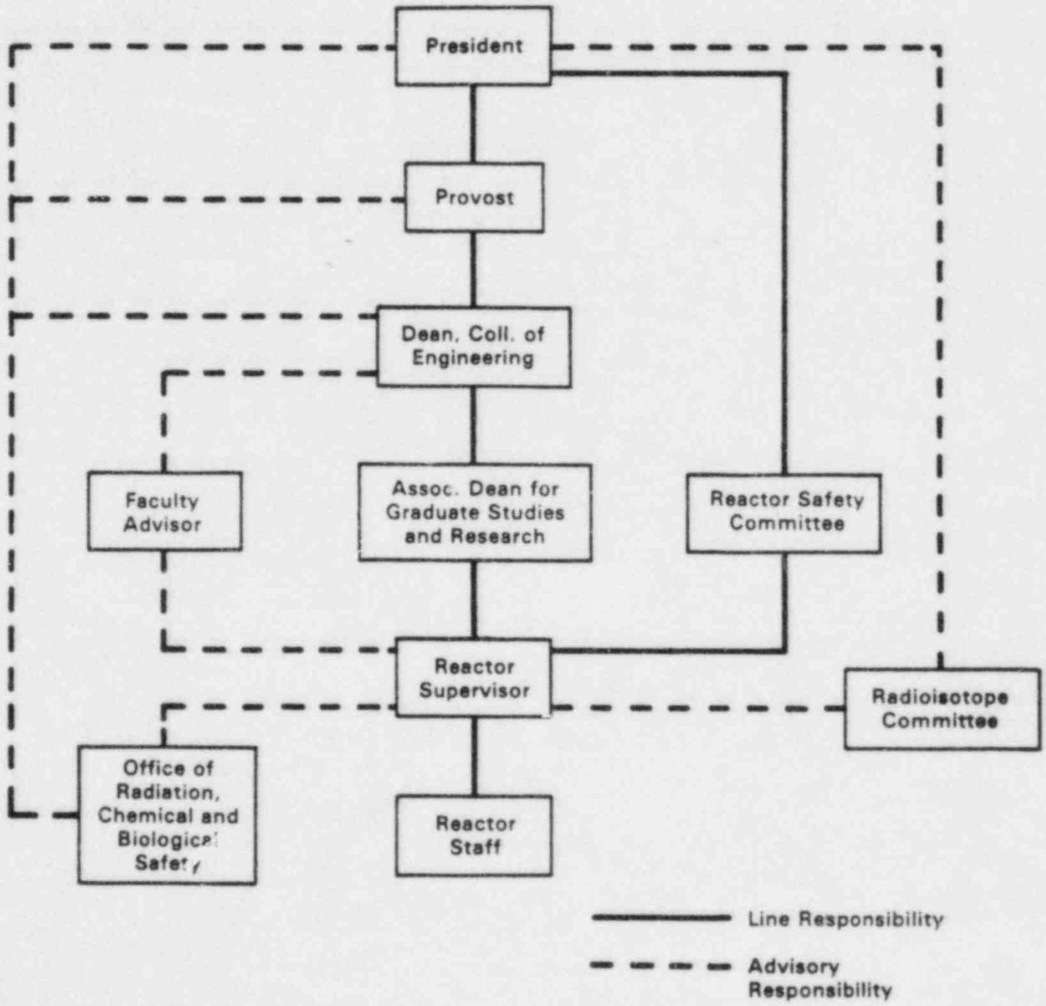



Figure 13.1 MSU reactor facility organizational structure

## 14 ACCIDENT ANALYSIS

In establishing the safety of the operation of the MSU Mark I TRIGA reactor, the licensee analyzed potential accidents to ensure that these events would not result in potential hazards to the reactor staff or the public. In addition, the NRC staff has asked Pacific Northwest Laboratory to perform an independent analysis of generic reactor accidents for TRIGA-type uranium-zirconium-hydride fueled reactors (NUREG/CR-2387) and has asked the Los Alamos National Laboratory to evaluate the licensee's documentation and analyses of the various types of possible accidents and their potential consequences to the public.

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

(1) fuel handling accident
(2) rapid insertion of reactivity (nuclear excursion)
(3) loss of coolant
(4) misplaced experiments
(5) mechanical rearrangement of the fuel
(6) effects of fuel aging

Of these potential credible accidents, the one with the potential for releasing the highest level of radioactive material to the MSU reactor facility and unrestricted area outside the reactor facility is the fuel handling accident, which postulates the loss of all the cladding on an irradiated fuel element and the subsequent release of fission products. Therefore, this accident will be designated the maximum hypothetical accident (MHA).

The results of the analyses of accidents with less severe consequences than the MHA are included to demonstrate the extent of the staff investigation.

### 14.1 Fuel Handling Accident

The fuel handling accident, designed as the maximum hypothetical accident (MHA), includes various incidents to one or more irradiated fuel elements in which the fuel cladding might be breached or ruptured. The licensee has postulated the possibility that an operator, while removing an irradiated fuel element from the core or relocating one previously removed following extended irradiation, might experience an accident that could breach or rupture the fuel element cladding. If this cladding were ruptured, the noble gases and fission products in the fuel gap could escape into the environment.

The staff did not try to develop a detailed scenario of how such an accident might occur, but rather assumed that the cladding of one fuel element completely fails and that this accident occurs outside the reactor pool, instantly releasing all of the available volatile fission products and noble gases that have accumulated in the free volume (gap) between the fuel and the claddng. Furthermore, the staff's worst-case scenario conservatively assumes that an accident occurs following an extended run at full licensed power such that the inventories of all significant radionuclides are at their maximum (saturation) values.

The staff assumed that the accident occurred but did not attempt to describe or evaluate all of the mechanical details of the accident or the probability of its occurrence. For purposes of this document, only the consequences of this accident were considered.

Several series of experiments at General Atomic (GA) have given data on the species and fractions of fission products released from $U\text{-}ZrH_x$ under various conditions (GA-8597, 1968; Foushee and Peters, 1971; GA-4314, 1980; Simnad et al., 1976). The findings indicated that the noble gases were the principal fission product species to be released, and when the fuel specimen was irradiated at temperatures below 350°C, the fraction released could be summarized as a constant equal to $1.5 \times 10^{-5}$, independent of the temperature. At temperatures greater than 350°C, the species released remained the same, but the fraction released increased significantly with increasing temperature.

GA has proposed a theory describing the release mechanisms in the two temperature regimes that appears plausible, although not all data agree in detail (GA-8597 1968; Foushee and Peters, 1971). It seems reasonable to accept the interpretation of the low-temperature results, which implies that the fraction released for a typical TRIGA fuel element will be a constant, independent of operating history or details of operating temperatures, and will apply to fuel whose temperature is not raised above 400°C. This means that the $1.5 \times 10^{-5}$ release fraction reasonably could be applied to TRIGA-type reactors operating at continuous power levels up to at least 800 kW and, therefore, is applicable to the MSU 250-kW reactor. The theory in the fuel temperature regime above 400°C is not as well established. The proposed theory of release of the fission products incorporates a diffusion process that is a function of temperature and time. Therefore, in principle, details of the operating history and temperature distributions in fuel elements would be required to obtain actual values for release fractions at the higher temperatures. In situations where a fuel cladding failure was assumed, the staff used the GA results to estimate the fission product release fractions. The staff considers these results conservative in that they represent a theoretical maximum release greater than corresponding experimental observations.

For the fuel handling accident, the staff used the above described release fraction of $1.5 \times 10^{-5}$ of the available noble gas and halogen inventories. Based on the extrapolation of the GA analysis, this fraction is a conservative estimate of the release following a 1.4% $\Delta k/k$ (2.00$) pulse with a maximum local temperature of ~50°C performed following prolonged nonpulsing operation at 250 kW. Because the GA analysis assumes infinite operating time, it is likely that this approach gives a conservatively high release value. Also, the activity released is weighted toward the shorter half-lived nuclides and will decrease rapidly after the pulse.

Because the noble gases do not condense or combine chemically, it is assumed that any noble gases released from the cladding will diffuse in air until their radioactive decay. Conversely, the iodines are chemically active and are not volatile at temperatures below 180°C. Therefore, some of the radionuclides will be trapped by materials with which they come in contact, such as water and structures. Evidence indicates that most of the iodines either will not become, nor remain, airborne under many accident scenarios that are applicable to nonpower reactors (NUREG-0771). However, to be certain that the fuel-cladding failure scenario discussed below leads to the upper-limit dose estimates for all events, the staff assumed that 100% of the iodines in the gap become airborne. This assumption will lead to computed thyroid doses that may be at least a factor of 100 too high in some scenarios; for example, those in which the pool water is present.

In the SAR dated June 1967, the applicant analyzed a cladding failure in water and calculated the resultant doses immediately outside the reactor building. However, the staff assumed the failure occurred in air and calculated doses to individuals both in the reactor room and in the unrestricted area.

The staff analysis assumed that a cladding failure occurs in a B-ring fuel element following an extended run at the authorized maximum power. The calculations assumed all fission products had reached their saturated activity levels, a conservative assumption considering the typical operating history at the MSU reactor facility. Normally, a significant amount of time elapses before any fuel is removed from the reactor; however, no activity decrease was taken into account for the radioactive decay during the time between reactor shutdown and removal of the fuel element from the pool into the air. All the noble gases and halogens in the fuel cladding gap are assumed to be released from the fuel element and are distributed uniformily in the reactor room; no plate-out was assumed. Scenarios incorporating realistic estimates of the above conservative assumptions would reduce the resulting doses significantly. Using this scenario as a basis, the staff calculated the whole-body gamma-ray (immersion) and thyroid doses by iodine inhalation to an individual in the reactor room and in an unrestricted area immediately outside the reactor building.

For the occupational doses, it was assumed that the ventilation system was shut down at the time of the accident and all the fission products remained in the reactor room. For the outside doses, it was assumed that the ventilation system was operating at its rated capacity. All dose calculations assumed immersion in a semi-infinite cloud (a very conservative assumption that produces the highest calculated exposures) (RG 3.34, Rev. 11, July 1979, AFFRI-SAR June 1981, NUREG/CR-2079, April 1981). The calculated doses for the above assumptions and locations are presented in Table 14.1.

Because there is no credible way that the postulated MHA could occur without operating personnel being alerted immediately, orderly evacuation of the reactor bay would be accomplished within minutes. As a result of the underlying calculative and atmospheric assumptions, the calculated operational and public doses shown in Table 14.1 are higher than could occur realistically. On the basis of the above discussions and analysis, the staff concludes that even if one fuel rod from the MSU reactor were to release all its noble gases and halogen fission products accumulated in the fuel-cladding gap, radiation doses to both occupational personnel and to the public in unrestricted areas would be below the limits stipulated in 10 CFR 20 guideline values.

These assumptions correspond to an extremely conservative scenario. Furthermore, from the results the staff obtained, even if one-half of the fuel rods failed simultaneously, the expected whole-body doses in unrestricted areas outside the reactor building would be less than 6.3 mrem and thus still would be well below the 10 CFR 20 guideline values.

For the above conservative assumptions, the staff concludes that a single or multiple fuel element accident would result in doses to the public that are less than the 10 CFR 20 guideline values for normal operations. Accordingly, there would be no sigificant risk to the health and safety of the public.

## 14.2 Rapid Insertion of Reactivity (Nuclear Excursion)

Based on theoretical calculations and experimental measurements, the U-$ZrH_x$ fuel in the MSU reactor exhibits a strong, prompt, negative temperature coefficient of reactivity, as discussed in Section 4.5. This temperature coefficient terminates any pulse or nuclear excursion and decreaes the amount of reactivity as the steady-state temperature of the fuel increases. These results have been verified at many operating TRIGA reactors. Although it may be possible theoretically to rapidly insert sufficient excess reactivity under accident conditions to create an excursion such that fuel damage would occur before the excursion could be terminated, the limits imposed by the design and Technical Specifications of the MSU reactor make such an event incredible. In some reactor configurations, the full withdrawal of the safety-transient rod could result in a reactivity insertion greater than the authorized maximum pulse insertion. In such cases, administrative controls are imposed on the adjustment of the safety-transient rod stroke to ensure that the maximum allowed pulse reactivity is not exceeded. The Technical Specifications for the MSU reactor limit the maximum allowed safety-transient rod worth for a pulse to 1.4% $\Delta k/k$ (2.00$).

The maximum power excursion transient that is postulated to occur is the event in which the total available amount of excess reactivity is inserted into the core instantaneously. The MSU reactor is limited by the current license to 2.25% $\Delta k/k$ (3.21$) excess reactivity above a cold, critical condition. However, the staff has not been able to identify a credible method for instantaneously inserting all of the available excess reactivity.

The staff has considered the scenario of the reactor operating at some continuous power level between 0 and 250 kW, at which time all the remaining excess reactivity is inserted rapidly into the core. The analysis conservatively neglected the reactivity loss as a result of the xenon ($^{135}Xe$) buildup. The staff found that the higher the core temperature when the rapid reactivity insertion is initiated, the lower the subsequent fuel temperatures will be immediately following the pulse. Therefore, the worst case would be the initiation of a 2.25% $\Delta k/k$ (3.21$) step insertion with the core at ambient temperature and essentially zero initial power. The potential significant reactivity insertion accident consequences that were considered by the staff are melting of the fuel or cladding material and failure of the cladding as a result of high internal gas pressures and/or phase changes in the fuel matrix. The major cause of fuel element cladding failure at elevated temperatures in the stainless-steel-clad elements is a result of excessive stress buildup in the cladding that is caused by the hydrogen pressure from the disassociation of the $ZrH_x$. Calculations performed by GA and confirmed by several pulses indicate that the fuel cladding integrity is maintained at peak fuel temperatures as high as 1,175°C for $U\text{-}ZrH_{1.7}$-type stainless-steel-clad-fuel elements (GA-6874, 1966; Simnad et al., 1976; GA-4314, 1980.) Beyond this temperature, substantial volume changes associated with the phase transformations occurred (GA-7882, 1967).

The staff also has reviewed the literature for large reactivity insertions into reactor cores similar to the MSU reactor and has found that GA has performed many experiments with reactivity insertions as high as 5.00$ in an 85-element (stainless-steel-clad) TRIGA core. The fuel temperature in the hottest core position was measured by GA, and the fuel elements were examined after the reactivity insertion (GA-6874, 1966; Simnad et al., 1976). There was no indication of stress in the cladding and no indication of either fuel or cladding melt. The maximum measured temperature associated with the 5.00$ pulse insertion was approximately 750°C, and the estimated peak transient temperature at any localized fuel point was found to be 1,175°C. Because the radial temperature distribution found in a fuel element immediately following a pulse is similar to the radial power distribution, the peak temperature immediately after a pulse is located at the periphery of the hottest fuel element. This temperature decreases rapidly (within seconds) as the heat flows toward the cladding and the fuel center. It also was observed that for 5.00$ pulse, the maximum pressure increase within an instrumented fuel element was far below the expected equilibrum value at the peak temperature (GA-9064, 1970; GA-6874, 1966; Simnad et al., 1976). Therefore, the staff concludes that the rapid insertion of the 2.25% $\Delta k/k$ (3.21$) excess reactivity available into the MSU reactor core would not cause the fuel temperature to rise above acceptable levels.

## 14.3 Loss-of-Coolant Accident

The rapid loss of shielding and cooling water following reactor operation is considered to be a potential accident that would result in the increase of fuel and cladding temperatures. Because the water provides for the major moderation of the neutrons, the loss of coolant in the reactor would terminate any significant neutron chain reaction and thus terminate the power excursion. However, the residual radioactivity resulting from fission product decay would continue to deposit heat energy into the fuel. The licensee's analysis indicates that the loss-of-coolant accident can occur by only two mechanisms: (1) the tank may be pumped dry or (2) a tank failure may allow the water to drain.

The tank inlet and outlet water lines have 1/2-in.-diameter holes located 1 ft below the normal water level that act as siphon breakers if the tank water level drops below them. Thus, even if the water system is operated carelessly (for example, if it was operated when the pump discharge line was disconnected for repairs), the tank could not be pumped dry accidentally. This can be done only by deliberate action.

The recirculating pump does not have sufficient suction head to drain the tank. Therefore, another more powerful pump would have to be installed with its suction line inlet below the core to drain the shielding and cooling water below the level of the core.

Tank failure possibly could be caused by a severe earthquake or major settling of the reactor building foundation. The ground water level in the vicinity of the reactor building is 12.5 ft below the top of the reactor tank; thus, even if the reactor tank should rupture, the water level within the tank would only drop to a level corresponding to about 9 ft of water still shielding the reactor. The reactor tank also has three barriers that prevent leakage. The welded aluminum tank, the 1.5 ft of concrete surrounding the tank, and the surrounding soil present a very high resistance to water leakage. The test-boring sample made at the reactor location showed the soil to be comprised of moist clay, moist sand, and stiff moist sandy brown and blue clay, all of which are somewhat (0.01 in./hour movement) impermeable to water.

Even though the loss of cooling and shielding water is an exceedingly low probability event, the licensee performed a calculation evaluating the hazards to the fuel elements associated with this accident. It is assumed conservatively that the reactor has been operating at the licensed power of 250 kW for an extended time (long enough to achieve fission product equilibrium) before losing all of its shielding/cooling water down to the ground water level (corresponding to a minimum of 9 ft of water shielding the core) and that the reactor is shut down manually at the initiation of a cooling water leak. It is assumed that decay heat is removed by convective water cooling until the top of the core becomes uncovered, after which heat removal is accomplished only by air convection.

The licensee performed calculations to determine the maximum temperature rise in the reactor's hottest fuel element upon the rapid loss of cooling water. The calculations indicated that the maximum fuel element temperature following an instantaneous and complete loss of coolant would be $\sim$225°C. The resulting pressure in the fuel element cladding that would be exerted on the cladding by trapped air, hydrogen from decomposition of the $Zr\text{-}H_x$, and fission product gases would result in a corresponding stress of about 1,200 psi, which is well below the strength of the stainless-steel cladding at this temperature. Therefore, the expansion of the gases in the fuel element would not result in the rupture of the cladding, and the fission products would be retained in the fuel elements.

Several investigations have evaluated such scenarios under various assumptions (GA-9406, 1970; GA-0722, 1959; Reed College, 1967; GA-6596, 1970) with prolonged operation peak temperatures reaching up to 460°C, and have shown that the radiative loss of the core heat would be sufficient to ensure the integrity of the fuel cladding.

The Technical Specifications require that the reactor be shut down if the pool water level is less than 5.48 m (17.97 ft) above the top grid plate of the core. Radiation monitors would alert the operating staff of a low reactor water level condition. Furthermore, because of the ground water level in the vicinity of the building, a loss-of-coolant accident in which the core becomes uncovered is impossible.

On the basis of the above considerations, the licensee stated that the possibility of the loss of coolant/shielding water is an extremely unlikely event and that the consequences from such an event would be unlikely to cause damage to the reactor or result in serious radiation exposures to the operating staff or occupants of the building.

The staff concurs with the above analysis and concludes that the reactor cannot experience a loss-of-coolant accident following extended reactor operation at 250 kW that would result in temperatures above 250°C. Because the postulated accident would not expose the core to air, the consequences would not result in the melting of the fuel or cladding or the loss of cladding integrity from other causes.

## 14.4 Misplaced Experiments

The potential misplacement of experimental samples or devices in another experimental facility could result in an irradiation condition that could exceed the design specifications. In this situation, the sample could become overheated or develop pressures that could cause a failure of the experiment container. As discussed in Section 10, all experiments at the MSU reactor facility are reviewed before insertion, and all experiments in the region of the core are isolated from the fuel cladding by at least two barriers, such as the central thimble, or the reflector assembly.

The staff concludes that the experimental facilities and the procedures for experimental review at the MSU reactor facility are adequate to provide reasonable assurance that failure of experiments is not likely, and even if such a failure occurred, breaching of the reactor fuel cladding would not occur. In addition, if an experiment should fail and release radioactivity within an experimental irradiation facility, there is reasonable assurance that the amount of radioactivity released to the environment would not be more than that from the accident (MHA) discussed in Section 14.1. In addition, no fueled experiments or explosives are allowed and, thus, providing an additional margin of safety from the loss or misplacement of an experiment.

## 14.5 Mechanical Rearrangement of the Fuel

This type of potential accident would involve the failure of some reactor system, such as the support structure, or could involve an externally originated event that disperses the fuel and in so doing breaches the cladding of one or more fuel elements.

During the removal of irradiated fuel from the MSTR, a 400-lb lead cask is lowered into the pool by means of a chain fall and A-frame superstructure. Irradiated fuel elements (three maximum) are loaded into the cask, and the cask is removed from the pool.

The licensee has postulated the possibility of the cask being dropped into the pool during the handling process, affecting the fuel element integrity by either crushing the fuel element itself or damaging the fuel cladding. The staff concurs with the licensee's findings that, because of the dissolution of the halogens in the pool water, the fission products released as a result of this accident would be considerably lower than those released during a fuel element failure in air. Furthermore, the presence of pool water would greatly reduce the iodine releases to the room. Therefore, the staff concludes that there is no credible mechanical rearrangement of fuel that would result in an accident with more severe consequences than those accidents considered in Sections 14.1 and 14.2

## 14.6 Effects of Fuel Aging

The staff has included a discussion on the phenomena of fuel aging in this section for the purpose of addressing all credible effects. However, as discussed in more detail in Section 17, fuel aging should be considered normal with reactor operation and is, in fact, expected to occur gradually.

There is evidence that the U-$ZrH_x$ fuel tends to fragment with use, probably because of the stresses caused by high temperature gradients and the high heating rates observed during pulsing operations (GA-9064, 1970; GA-4314, 1980). Possible consequences of fragmentation include: (1) a decrease in thermal conductivity across cracks leading to higher central fuel temperatures during nonpulsing operation (temperature distributions during pulsing would not be affected significantly by the changes in thermal conductivity because a pulse is completed before any significant heat redistribution by conduction occurs) and (2) an increase in the amount of fission product migration into the cracks in the fuel.

With respect to thermal conductivity effects, hot cell examination of thermally stressed hydride fuel bodies has shown relatively widely spaced radial cracks that would cause minimal interference with radial heat flow (GA-9064, 1970; GA-4314, 1980). However, after pulsing, TRIGA reactors have exhibited an increase in both nonpulsing fuel temperatures and power reactivity coefficients. At power levels of 500 kW, temperatures have increased by $\sim$20°C and power reactivity coefficients have increased by $\sim$20% (GA-5400, 1965; AFRRI, 1960). GA has attributed these changes to an increased gap between the fuel material and cladding--caused by rapid fuel expansion during pulse heating--that reduces the heat transfer coefficient. Experience has shown that the observed changes occur primarily during the first several pulses and have essentially saturated after 100 pulses. Because these effects are small and have been observed in many TRIGA-type reactors operated at pulses up to 5.00$ and power levels as high as 1.5 MW and because the MSU reactor experiences only 1.4% $\Delta k/k$ (2.00$) maximum pulses, they are not considered to pose any hazard or result in any further changes in the fuel-cladding gap during continued operation of the MSU reactor.

Two mechanisms for fission product release from TRIGA fuel meat have been proposed (GA-4314, 1980; GA-8597, 1968). The first mechanism is fission fragment recoil into gaps within the fuel cladding. This effect predominates up to about 400°C and is independent of fuel temperature. Because the MSU reactor fuel has never exceeded 300°C, this will be the main effect. GA has postulated that in a closed system such as exists in a TRIGA fuel element, fragmentation of the fuel material within the cladding will not cause an increase in the fission product release fraction (GA-8597, 1968). The reason for this is that the total free volume available for fission products remains constant within the confines of the cladding. Under these conditions, the formation of a new gap or the widening of an existing gap must result in a corresponding narrowing of an existing gap at some other location. Such a narrowing allows more fission fragments to traverse the gap and become embedded in the fuel or cladding material on the other side. In a closed system, the average gap size, and, therefore, the fission product release rate, remains constant, and it is independent of the degree to which fuel material is broken up.

At temperatures greater than 400°C, the controlling mechanism for fission product release is diffusion, and the amount released depends on fuel temperature and the surface-to-volume ratio of the fuel. However, release fractions used in the accident analyses are based on a conservative calculation that assumed a degree of fuel fragmentation greater than expected in actual operation.

As the two likely effects of aging of the U-$ZrH_x$ fuel moderator will not have a significant effect on the operating temperature of the fuel or on the assumed release of gaseous fission products from the cladding, the staff concludes that there is reasonable assurance that fuel aging will not significantly increase the likelihood of fuel cladding failure or the calculated consequences of an accidental release in the event of a loss of cladding integrity.

## 14.7 Conclusion

The staff has reviewed the credible transients and accidents for the MSU reactor. On the basis of this review, the postulated accident with the greatest potential effect on the environment is the loss of cladding integrity of one irradiated fuel element in air in the reactor room. The analysis of this accident had indicated that even if several fuel rods failed simultaneously, the expected dose equivalents in unrestricted areas still would be below the 10 CFR 20 guideline values. Therefore, the staff concludes that the design of the facility and the Technical Specifications provide reasonable assurance that the MSU reactor can be operated with no significant risk to the health and safety of the public.

Table 14.1 Doses resulting from postulated fuel handling accident

| Dose and Location | Whole-body Immersion Dose | Thyroid Dose |
|---|---|---|
| 10-min occupational dose in reactor bay | 31.5 mrem | 1.89 mrem |
| 1/2-hour public dose immediately outside the reactor building | 0.18 mrem | 8.3 mrem |

# 15 TECHNICAL SPECIFICATIONS

The licensee's Technical Specifications, evaluated in this licensing action, define certain features, characteristics, and conditions governing the continued operation of this facility. These Technical Specifications are explicitly included in the amended license as Appendix A. Formats and contents acceptable to the NRC have been used in the development of these Technical Specifications, and the staff has reviewed them using the Standard ANSI/ANS 15.1-1982 as a guide.

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

## 16 FINANCIAL QUALIFICATIONS

In support of the license renewal application, MSU 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 licensee in the application and concluded the MSU possesses or can obtain the necessary funds to meet the requirement of 10 CFR 50.33(f). Therefore, the staff concludes that the licensee is financially qualified to continue to operate the reactor.

## 17 OTHER LICENSE CONSIDERATIONS

### 17.1 Prior Reactor Utilization

Previous sections of this SER concluded that normal operation of the reactor causes insignificant risk of radiation exposure to the public and that only an off-normal or accident event could cause some significant exposure. Even a maximum hypothetical accident (MHA) would not lead to a dose to the most exposed individual greater than applicable guidelines or regulations in 10 CFR 20.

In this section, the staff reviews the impact of prior operation of the facility on the risk of radiation exposure to the public. The two parameters involved are the likelihood of an accident and the consequences if an accident occurred.

Because the staff has concluded that the reactor was initially designed and constructed to be inherently safe the staff must also consider whether operation, in time, will cause significant degradation in these features. Furthermore, because loss of integrity of fuel cladding is the MHA, the staff must consider mechanisms that could increase the likelihood of such a failure. Possible mechanisms are (1) radiation degradation of cladding strength, (2) high internal pressure caused by high temperature leading to exceeding the elastic limits of the cladding, (3) corrosion or erosion of the cladding leading to thinning or other weakening, (4) mechanical damage as a result of handling or experimental use, and (5) degradation of safety components or systems.

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

(1) Some of the standard TRIGA fuel in the core has been in use since 1968, and has been subjected to a maximum of 15% burnup of $^{235}U$. Some TRIGA fuel at more extensively used reactors has received at least four times as much burnup with no observable degradation of cladding as a result of radiation. It is not likely that the MSU reactor program will change during the renewal period and alter this conclusion.

(2) The possibility of approaching high enough pressures to rupture the cladding would occur only if the entire fuel element, including the cladding, were to be heated to more than 930°C (GA-4314, 1980; Simnad, Foushee, and West, 1976). Although some points in the fuel may approach this temperature for a few seconds following a 2.00$ (1.4% $\Delta k/k$) pulse, only a simultaneous and instantaneous total loss of coolant could cause the cladding temperature to exceed a few hundred degrees. Because the Technical Specifications limit excess reactivity to 3.21$ (2.25% $\Delta k/k$) and design and operation reflect these limitations, the staff concudes that there is no realistic event that would cause the elastic limit of the cladding to be exceeded.

(3) Water flow through the core is obtained by natural thermal convection; so the staff concludes that erosion effects as a result of high flow velocity

will be negligible. High primary water purity is maintained by continuous passage through the filter and demineralizer system. With conductivity below ~5 μmhos/cm, corrosion of the stainless-steel cladding is expected to be negligible, even over a 40-year period.

(4) The fuel is handled as infrequently as possible, consistent with periodic surveillance. Any indications of possible damage or degradation are investigated immediately. The only experiements that are placed near the core are isolated from the fuel cladding by a water gap and at least one metal barrier, such as the central thimble. Therefore, the staff concludes that loss of integrity of cladding through damage does not constitute a significant risk to the public.

(5) The MSU personnel perform regular preventive and corrective maintenance and replace components as necessary. Nevertheless, there have been some malfunctions of equipment. However, the staff review indicates that most of these malfunctions have been random one-of-a-kind incidents, typical of even good quality electromechanical instrumentation. There is no indication of significant degradation of the instrumentation, and the staff further concludes that the preventive maintenance program would lead to early identification and replacement before significant degradation occurred. Therefore, the staff concludes that there has been no apparent significant degradation of safety equipment and, because there is strong evidence that any future degradation will lead to prompt remedial action at the MSU reactor facility, there is reasonable assurance that there will be no significant increase in the likelihood of occurrence of a reactor accident as a result of component malfunction.

The second aspect of risk to the public involves the consequences of an accident. Because the MSU reactor has not and is not expected to operate on the maximum available schedule, the inventory of radioactive fission products will be far below that postulated in the evaluation of the MHA by the applicant and the NRC staff (see Section 14.1). Therefore, the staff concludes (1) that the risk of radiation exposure to the public has been acceptable and well within all applicable regulations and guidelines during the history of the reactor and (2) that there is reasonable assurance that there will be no increase in that risk in any discernible way during this renewal period.

## 17.2 Multiple or Sequential Failures of Safety Components

Of the many accident scenarios hypothesized for the MSU reactor, none produce consequences more severe than the MHA reviewed and evaluated in Section 14.1. The only multiple-mode failure of more severe consequences would be failure of the cladding of more than one fuel element. No credible scenario developed by the staff has included a mechanism by which the failure of integrity of one fuel element can cause or lead to the failure of additional elements. Therefore, if more than one element should fail, the failures would either be random, or a result of the same primary event. Additionally, the reactor contains redundant safety-related measuring channels and control rods. Failure of all but one control rod and all but one safety channel would not prevent reactor shutdown to a safe condition. The staff review has revealed no mechanism by which failure or malfunction of one of these safety-related components could lead to a nonsafe failure of a second component.

## 18 CONCLUSIONS

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

(1) The application for renewal of Operating License R-114 for its research reactor filed by the Michigan State University dated September 19, 1977, 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 I.

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

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

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

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

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This Safety Evaluation Report for the application filed by the Michigan State University (MSU) for a renewal of operating license number R-114 to continue to operate the TRIGA research 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 Michigan State University and is located on the campus of Michigan State University in East Lansing, Ingham County, Michigan. The staff concludes that TRIGA reactor facility can continue to be operated by MSU without endangering the health and safety of the public.

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