SAFETY ANALYSIS REPORT

Manhattan College, Zero Power Reactor

by

Dr. Joseph Augustus
Mr. Robert Berlin
Bro. Gabriel Kane, FSC
Dr. Ronald Kane

Submitted to

United States Nuclear Regulatory Commission
for Renewal of Facility License R-94

Manhattan College Nuclear Engineering Facility
Manhattan College
Riverdale, New York 10471

August 1983

8308300374

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1.0 INTRODUCTION AND GENERAL DESCRIPTION

The Manhattan College Zero Power Reactor (MCZPR) is located on the campus of Manhattan College in Riverdale, a residential section of the Borough of the Bronx in New York City. The reactor is situated in a Nuclear Engineering Facility within the Leo Engineering Building at 3825 Corlear Avenue. The Nuclear Engineering Facility, and particularly the Zero Power Reactor, are however designed for isolation from the rest of the engineering building to provide additional security and safety.

The Nuclear Engineering Facility contains the Zero Power Reactor (a critical reactor), a graphite moderated subcritical reactor, and a light water moderated subcritical reactor. The physical layout includes a separate room containing the top of the critical reactor vessel and the control console, a basement containing the bottom of the critical reactor vessel and auxiliary equipment, a separate room containing the two subcritical reactors, a separate counting room, and a separate classroom.

The critical reactor is a low power, pool type reactor, designed for a maximum power level of 0.1 watt by AMF Atomics of Greenwich, Connecticut. Prior to installation at Manhattan College in 1964, the reactor core had been used in 1961 by AMF Atomics in PTR (pressurized tube reactor) low critical research experiments at the IRL (Industrial Reactor Laboratory) reactor site in Plainsboro, New Jersey.

The reactor is a heterogeneous pool type reactor, light water moderated and fueled with 92 percent enriched uranium. It is intended solely for teaching and training. Consequently the maximum power level of 100 milliwatts authorized first by the Atomic Energy Commission and later by the Nuclear Regulatory Commission is quite adequate to serve these purposes. It also guarantees a high degree of safety. The radiation intensity at the reactor deck level directly above the core is only 1 mR/hr when operated at the maximum allowed power.

There are two control rods in the reactor: one cadmium-stainless steel shim rod and one stainless steel regulating rod. The two detecting instruments in the reactor are a BF_3 neutron detector and an uncompensated ion chamber. Two Geiger-Mueller counters are used for area radiation monitoring. The control console is located near the reactor vessel and contains all the necessary control switches, lights, and instrumentation required to operate the reactor efficiently and safely throughout its designed power range.

2.0 SITE CHARACTERISTICS

2.1 Geographical Location

Manhattan College is situated along Manhattan College Parkway on the heights above Van Cortlandt Park, in the Riverdale section of the Bronx, New York City, just a few blocks south of the Yonkers City line.

The Zero Power Reactor is located on the first floor of the Leo Engineering Building (two blocks from the main campus) on Corlear Avenue. This building has been owned and occupied by Manhattan College since 1963. It was extensively remodeled three years ago with completion of new Chemical Engineering Laboratory and office space and expansion of the Engineering Library. The Zero Power Reactor has been in the same building and location since its installation at Manhattan College. The location of the building andits relationship to its surrounding is indicated in Figure 2-1.

The Leo Engineering Building provides classrooms, laboratories, library and computer facilities for an estimated 1800 students at any one time. Office space for the Dean of the School of Engineering, department heads, and engineering faculty is located in the building.

2.2 Geology

The main Manhattan College campus is situated on one of the highest elevations in New York City. Thirteen of the twenty acres on which the majority of College buildings are constructed, are situated over a rock formation known as the Fordham Schist which extends from this site south into northern Manhattan Borough under the Harlem River. However, the Leo Engineering Building in which the reactor is located is constructed on alluvial fill which extends to a depth of some one hundred and fifty feet.

2.3 Hydrology

No wells have been drilled on the Manhattan College campus nor in its vicinity. The water supply of the College is part of the New York City water system supplied principally through Croton Reservoir in Westchester County.

Surface runoff water is collected in concrete-line storm drains which empty into the New York City sewage disposal system. This drainage system has been adequate to prevent any flooding of the campus by heavy rains. It is conceivable that the Leo Engineering Building in which the reactor is located, constructed as it is on filled creek

bottom land, could have a drainage problem in a very severe rain storm. However, this has not occurred over the 20 years in which the building has been maintained by Manhattan College. Such an occurrence would not create a radiation hazard.

2.4 Seismology

New York City has been seismically inactive in the geologic past and it is extremely improbable that an earthquake will occur here in the near future. The reactor site should be free from any earthquake hazard. However, the Leo Engineering Building (which is structurally independent of any other building) does conform to the building code of the City of New York and should withstand even a severe shock. In the event of a rupture of the reactor vessel, loss of water will reduce moderation and scram the reactor. The water in the vessel would then be contained within an independent overflow area in the basement of the reactor facility.

2.5 Meteorology

New York City has a warmer climate in winter and a cooler climate in summer than most other cities located in the same latitude with the exception of some cities on the Pacific coast. The average annual precipitation is forty-two inches. Northwest winds prevail from November to April. From May to October south or southwest winds are dominant. Light to gentle winds prevail much of the time during the warm months and on many days in the winter season, and winds of gale force are seldom experienced. Occasionally during the months of August and September tropical storms of hurricane force are felt in the City. At these times high winds of almost fifty miles per hour are experienced. Such conditions do not present a danger to the structural integrity of the Leo Engineering Building or the Zero Power Reactor facility.

Since the facility produces no gaseous effluent, the frequent temperature inversions in the area present no radiological hazard to the public from the facility.

2.6 Demography and Land Use

The demographic patterns and land use in the vicinity of the reactor building, including the Manhattan College campus buildings and local residences and businesses, have changed little since initiation of reactor operations in 1964.

Figure 2.2 is a map of the area surrounding the Leo Engineering Building, showing individual residence structures, businesses, and other land use designations. The accompanying Table 2.1 provides data on occupancy for the structures delineated on the map.

Manhattan College

NUMERICAL

1 - Memorial Hall
2 - De La Salle Hall
3 - Manhattan Hall
4 - Hayden Hall
5 - Cardinal Hayes Library
6 - Smith Auditorium/ Chapel of De La Salle and His Brothers
7 - Chrysostom Hall
8 - Alumni Hall
9 - Draddy Gymnasium
10 - Jasper Hall
11 - Thomas Hall (Student Center)
12 - Solomon House
13 - Lavelle Hall (Alumni & College Relations Offices)
14 - Sears Hall (Development Office)
15 - Christian Brothers Center
20 - Paulian Hall
21 - Leo Engineering Building
22 - Farrell Hall
23 - Neumann House
24 - Christian Brothers' Residence (1)
25 - Christian Brothers' Residence (2)
28 - Granville Hall
30 - Lloyd Hall
31 - Mundelein Hall
32 - Birches Cottage
33 - Mitty Hall
37 - St. Joseph's Hall
38 - Rock Ledge
39 - Christian Brothers' Residence (3)
40 - Broderick Hall
41 - Galway House
42 - Dowling Hall
43 - Bluff Cottage
44 - Donohue Hall
45 - Sullivan Hall
46 - Overlook Manor

ALPHABETICAL

8 - Alumni Hall
32 - Birches Cottage
43 - Bluff Cottage
40 - Broderick Hall
5 - Cardinal Hayes Library
15 - Christian Brothers Center
24 - Christian Brothers' Residence (1)
25 - Christian Brothers' Residence (2)
39 - Christian Brothers' Residence (3)
7 - Chrysostom Hall
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12 - Solomon House
45 - Sullivan Hall
11 - Thomas Hall (Student Center)

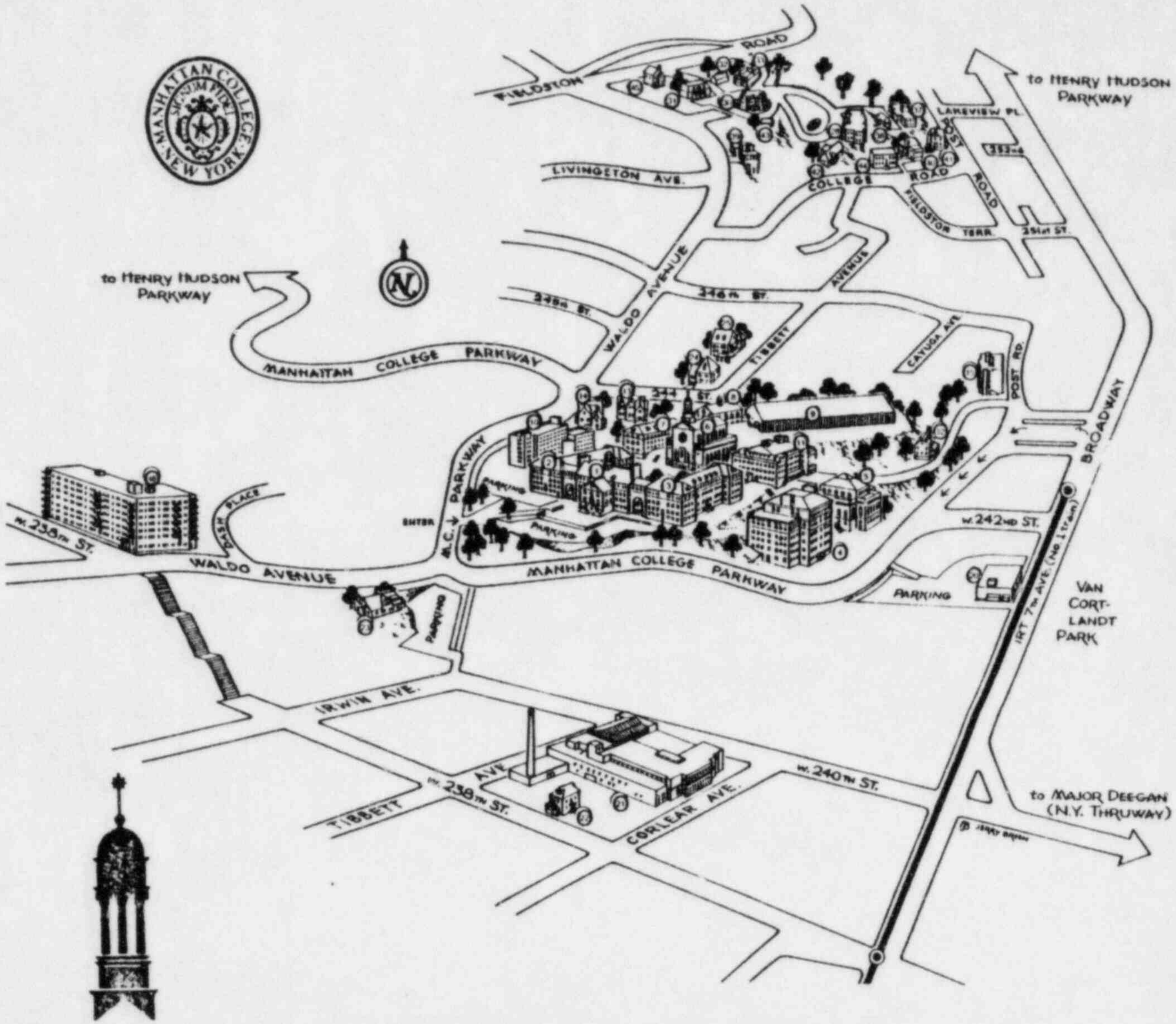
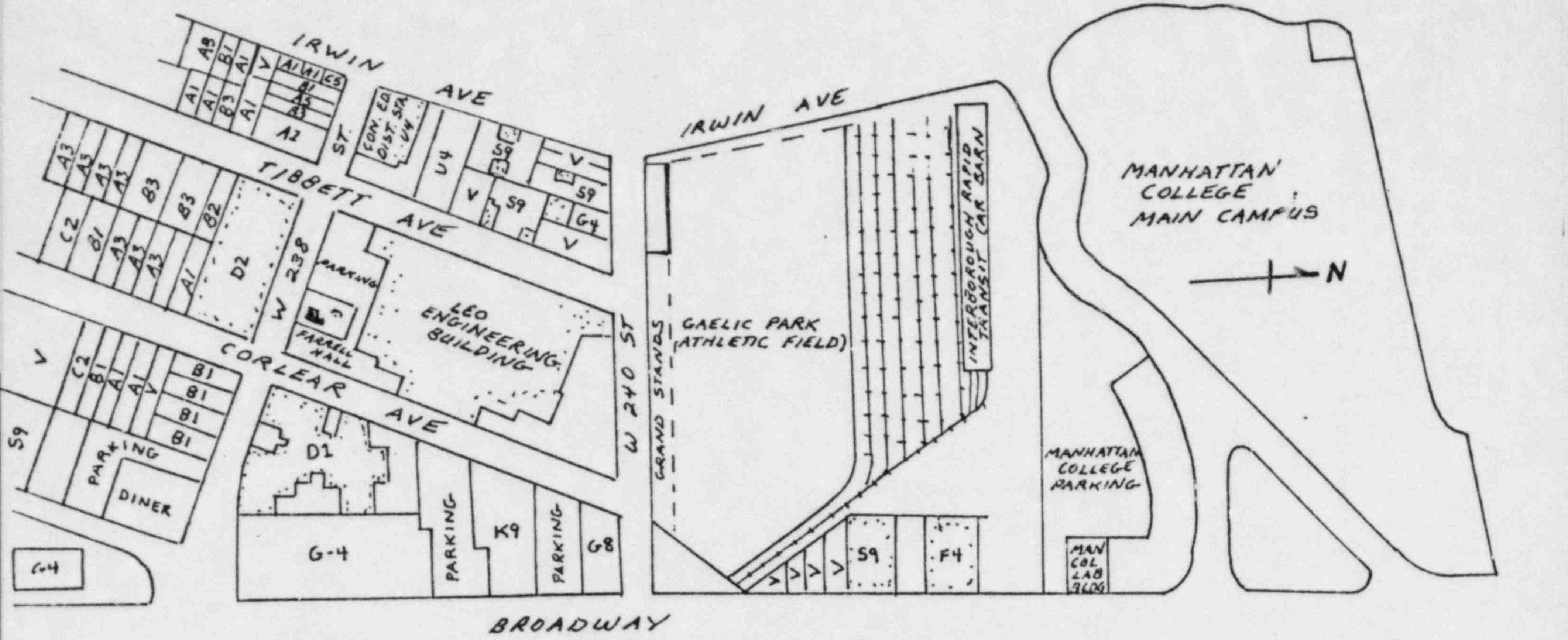


Figure 2-1. Plan of Manhattan College Campus

Table 2.1

Estimated Occupancy of Buildings Shown on Map

Legend	Type of Building		Estimated Occupancy
A1	2 story detached	1 family	5-6
A2	1 story	1 family	7
A3	2 story brick semi-detached	1 family	6-7
B1	2 story brick	2 family	10
B2	2 story frame	2 family	8
B3	Converted dwelling	2 family	8
C2	Walkup apartment	3-6 family	15-25
C5	Walkup converted dwelling		15
D1	Elevator apartment		300
D2	6 story apartment		320
G4	Gas station with Work Shop		5-10 each
G8	Garage with Show Room		10-20
K9	Proposed Manhattan College Research and Learning Center		300-500
S9	Unclassified Miscellaneous Buildings		10-50
U4	Utility Substation		5
V	Vacant Lot		-
None	Manhattan College Main Campus		2000-3000
None	Leo Engineering Building		1000-2000
None	Farrell Hall		10-25
None	Paulian Labs		10-30
None	Gaelic Park		100-500
None	Interborough Rapid Transit (Car Barn)		20-40



LEGEND

A1	2 STORY DETACHED - 1 FAMILY
A2	1 STORY - 1 FAMILY
A3	2 STORY BRICK SEMI-DETACHED - 1 FAMILY
B1	2 STORY BRICK - 2 FAMILY
B2	2 STORY FRAME - 2 FAMILY
B3	CONVERTED DWELLING - 2 FAMILY
C1	WALK UP SEMI FIRE PROOF - 6 FAMILY + OVER
C2	WALK UP APARTMENT - 3-6 FAMILY
C3	WALK UP CONVERTED DWELLING
C5	WALK UP APARTMENT WITH STORES
D1	ELEVATOR APARTMENT
D2	ELEVATOR APARTMENT
F4	FACTORY SEMI FIRE PROOF
G4	GAS STATION WITH LUB PLANT AND WORKSHOP
G8	GARAGE WITH SHOW ROOM
G9	MISC GAS STATION + PUBLIC GARAGE
K1	1 STORY STORE BUILDING
K9	MISC STORE BUILDING
S9	UNCLASSIFIED MISC BLDG.
U4	UTILITY SUB-STATION
V	VACANT LOT

FIGURE 2.2

MAP OF AREA SURROUNDING
THE LEO ENGINEERING BUILDING

3.0 DESIGN OF STRUCTURES, COMPONENTS, EQUIPMENT AND SYSTEMS

This chapter identifies, describes and discusses the principal features of the MCZPR laboratory. This presentation is simplified considerably from that required for a power reactor or most of the research and teaching reactors due to the characteristics of the MCZPR which is a compact, open pool reactor with low power capability (0.1 watt).

3.1 Structural Design

The MCZPR laboratory is located at the southeast corner of the Leo Engineering Building of Manhattan College. The floor plans for the first and second floors of the building are shown in Figures 3.1 and 3.2 respectively, with the ZPR area shaded. The only access to the first (lower) floor of the ZPR area from the first floor of the Leo Engineering Building is through door D1 (Figure 3.1) which is kept locked and bolted from inside at all times. Door D2 on the first floor leads to a staircase to room 221 from which access to the ZPR room is through door D4 (see Figure 3.2)

Access to Room 221 from the second floor of the Leo Engineering Building is through door D3. Access to the control console in the ZPR Room on the second floor is through door D4 from Room 221. Door D4 is visible to the operator at the console. The access doors D2 and D3 to Room 221 are provided with Fox Police locks.

Room 107 on the first floow (Figure 3.1) is used as a Counting Room and Room 108 as a Briefing Room. Room 221 on the second floor contains a graphite moderated subcritical reactor and a water moderated subcritical reactor.

The reactor tank made of aluminum sits on a concrete slab on the first floor. The tank is held in place by five aluminum brackets welded to the side of the tank near the bottom. The brackets are bolted to the concrete floor.

Several concrete piers were added to the first floor of the structure to strengthen it (Figure 3.3). There are concrete walls on three sides of the room. The base of the fourth wall consists of a concrete curb 1'0" high sufficient to permit the room to contain the entire contents of the tank. The remainder of the fourth wall consists of a metal partition to separate the reactor room from the ventilation equipment room for the Leo Engineering Building. The door D1 on this wall serves as access

for bringing heavy items into the room. This door is kept locked and bolted from inside the reactor area.

The south wall of the room is an outside wall. This wall is reinforced and protected by a sloping slab of concrete 6'0" wide. A demineralizing tank sits on the floor next to the tank. Pipes to and from the demineralizer are suspended by supports from the ceiling. The height of this first floor room is 7'4-1/2".

The reactor tank which is 8 ft. high extends upwards through the ceiling of the first floor. The reactor vessel is surmounted by a platform 2' 2-1/2" above the top of the tank and 2' 4-1/2" above the floor. The reactor vessel and the edge of the platform are protected with chain fences. The room is 16' 4" high. A window, W1, 4'3" X 4'3" is located on the south wall 8'0" above the floor. This window is protected by wire mesh and is secured with lock and key.

The control console is 5'3" X 2'0" and 6'1" high. It is located 3'0" from the west wall of the ZPR Room. Plans of the first and second floors of the ZPR facility are shown in Figures 3.3 and 3.4.

3.2 Waste System

The reactor does not produce any radioactive waste either in the form of spent fuel or as radioactive byproduct.

3.2.1 Used Demineralizing Resin

The demineralizing resin is replaced about two or three times a year. The used resin is kept in marked containers for testing by the Health Physicist and appropriate disposal. No radioactivity has ever been found in the resin.

3.2.2 Waste Water

The reactor does not generate any radioactive water. When the demineralizing resin is replaced, a small amount of water (about 3 gallons) is extracted along with the resin. This water is stored in marked containers for testing by the Health Physicist and proper disposal.

3.3 Utilities and Services

3.3.1 Ventilation

The ZPR Laboratory contains a forced circulating ventilation system consisting of a blower and associated duct work which are designed so as not to return air from the laboratory back into the ventilation system of the Leo Engineering Building. A separate blower, controlled by a switch located on the west wall of the ZPR Room, returns air into the atmosphere.

3.3.2 Fire Protection

Conventional fire protection is available throughout the Leo Engineering Building. In addition, carbon dioxide fire extinguishers are available on both floors of the Reactor Laboratory.

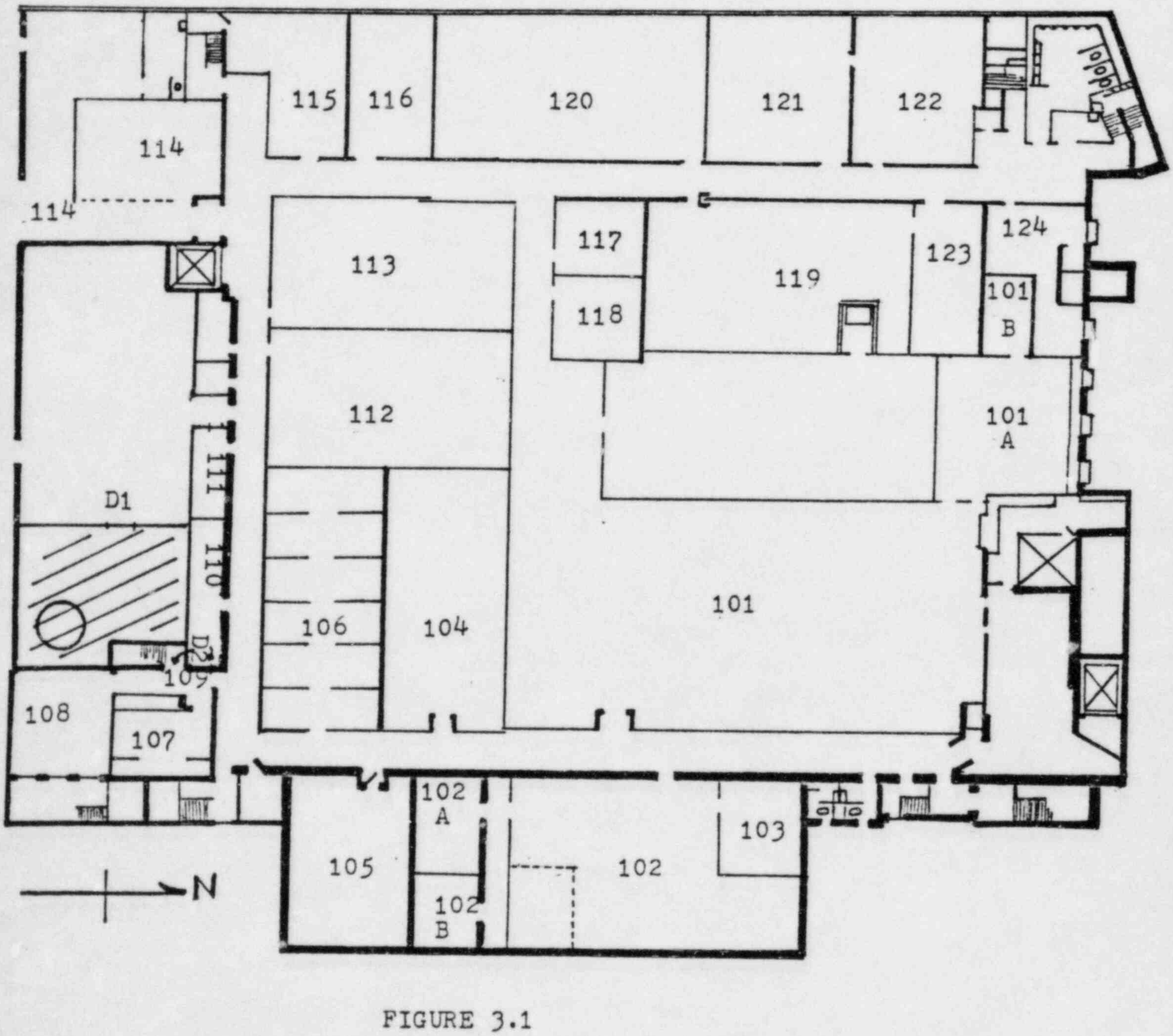


FIGURE 3.1

PLAN OF FIRST FLOOR OF THE LEO ENGINEERING BUILDING

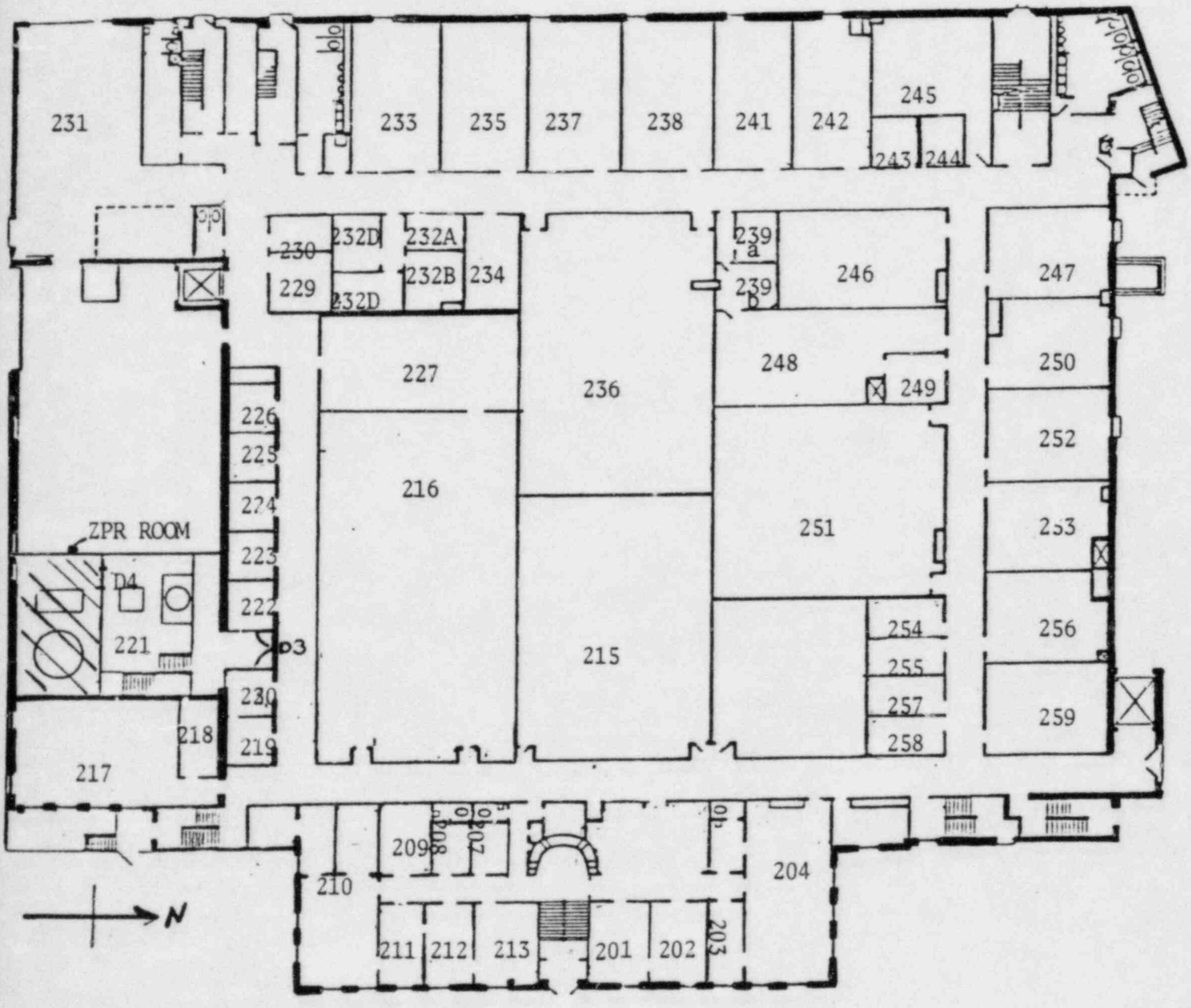


FIGURE 3.2
PLAN OF SECOND FLOOR OF THE LEO ENGINEERING BUILDING

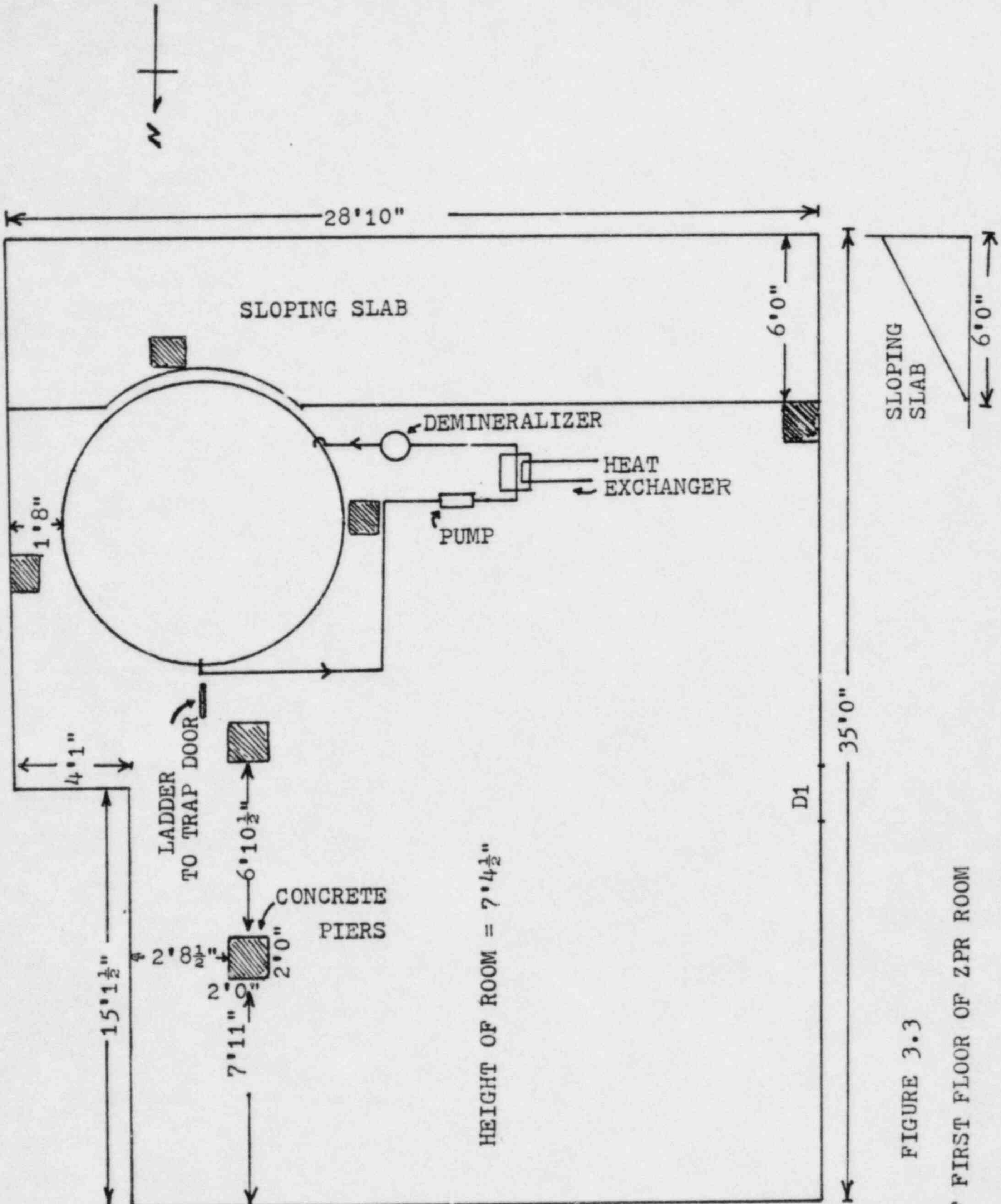


FIGURE 3.3

PLAN OF FIRST FLOOR OF ZPR ROOM

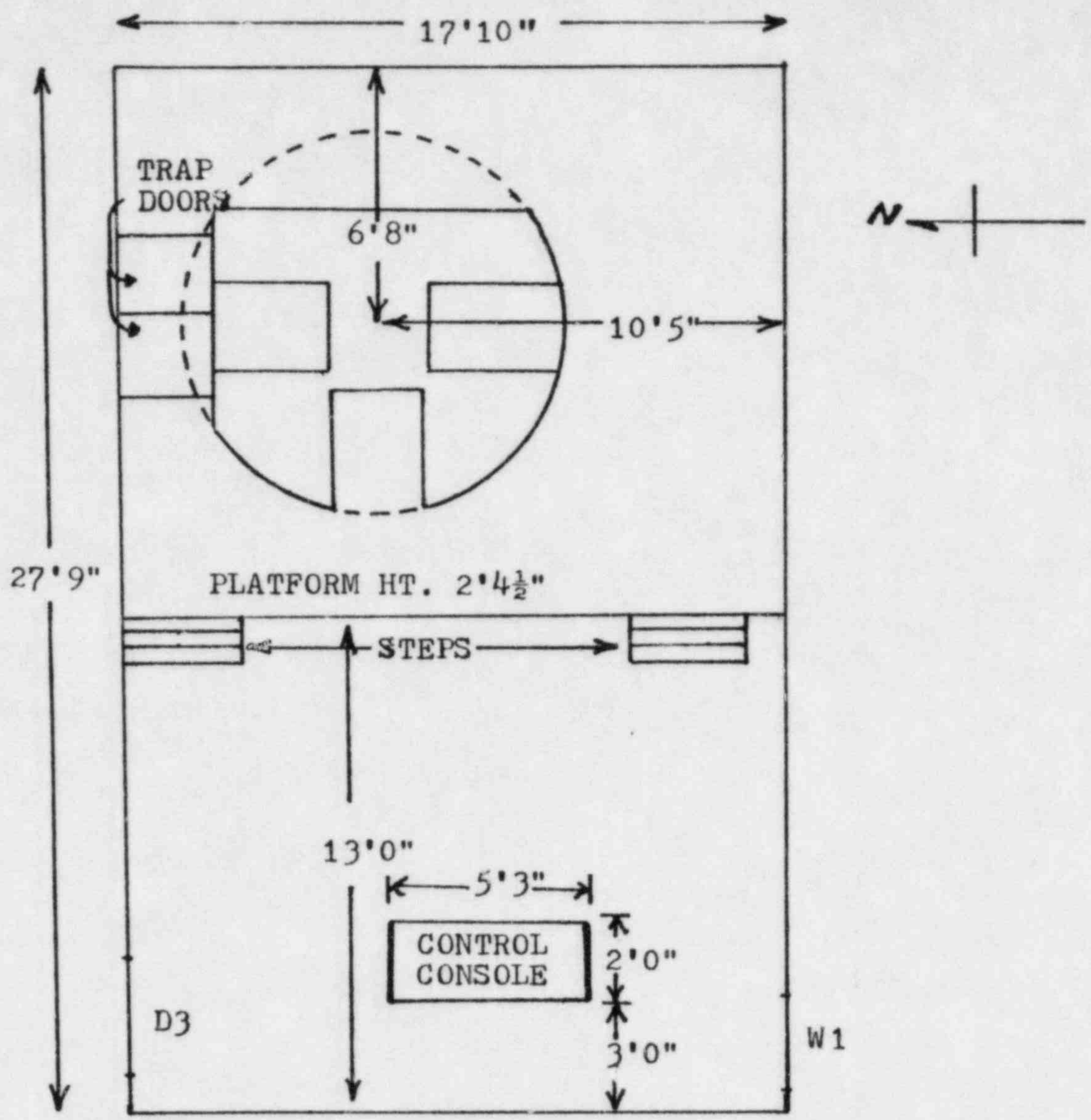


FIGURE 3.4

PLAN OF SECOND FLOOR OF ZPR ROOM

4.0 REACTOR

The Manhattan College Zero Power Reactor (MCZPR) is a heterogeneous, pool-type using solid enriched uranium fuel and is moderated by light water. The principal components of the reactor are the reactor vessel and its associated equipment, the control system, and the demineralizer system. The maximum power allowed by the Nuclear Regulatory Commission is 100 milliwatts.

4.1 Reactor Vessel

The reactor vessel consists of a large aluminum drum eight feet high and ten feet in diameter. The drum wall is one quarter of an inch thick. The reactor core is centrally located at the bottom of the vessel and consists of a grid plate and stand upon which the fuel elements are mounted.

The fuel is 92 percent enriched U-235. There are fifteen full fuel elements and one partial fuel element containing a total of 3024 grams of enriched uranium. Each full fuel element is made up of six concentric cylinders of fuel and is protected by a thick aluminum shield.

Support for the neutron detectors, control rod drive mechanisms, and other control system hardware is provided by the reactor platform above the pool. Neutron and gamma-ray detectors are suspended in the pool while drive mechanisms are located on a mounting plate on the platform.

4.2 Control System

The control console is located near the reactor vessel and contains all the necessary control switches, lights, and instrumentation required to efficiently and safely operate the reactor throughout its designed power range.

There are two control rods, a cadmium-stainless steel shim rod and a stainless steel regulating rod. By operating the control console switches, the operator can drive the neutron-absorbing control rods either into or out of the reactor core, as required to control the reactor power level.

Measured neutron levels from the neutron detectors are amplified and displayed on the control console instruments, thus permitting the operator to monitor reactor performance. Several of these instruments can shut down the reactor automatically by providing a signal that

will cause the control rods to be driven or dropped into the core. These controls insure that the reactor will always operate safely.

4.3 Area Monitors

One area monitor (gamma-1) is located at the level of the reactor deck and a second area monitor (gamma-2) is located at the side of the reactor vessel about the height of the reactor core. When operated at maximum allowed power, gamma-1 reads 1 mR/hr and gamma-2 reads 2 mR/hr.

5.0 REACTOR COOLANT SYSTEM AND CONNECTED SYSTEMS

This chapter describes the cooling system and other systems connected to the reactor. Due to the extremely low power rating of the reactor (0.1 W) these systems are very simple when compared with power reactors and most other research and teaching reactors.

5.1 Primary Coolant System

The water in the reactor has an enormous heat capacity relative to the power rating (0.1 W). No recirculating cooling system is, therefore, provided. The total heat capacity of the pool is about 65 MJ/^{o}C.

5.2 Water Make-Up System

Water lost due to evaporation is replenished with city water. The water from the city system is passed through an electrically controlled Versa check valve, a Barnstead-Bantam demineralizer, a flow meter and a short flexible hose over the top of the reactor tank. The check valve insures no back flow of water from the reactor in case of pressure loss in the water supply system. The flexible hose is removed from the reactor tank when the hose is not in use. The water level in the tank is maintained at about 7 feet.

5.3 Demineralizer System

Figure 5.1 shows a schematic diagram of the demineralizing system. The only tank wall penetration is a 3/4 inch aluminum coupling located 2" from the tank bottom, with a 3/4 inch short nipple and a 3/4 inch aluminum gate valve.

The pump is connected to a 24 hour clock which is used to activate the pump switch. The system is run almost continuously except for daily rest periods. The flow starts at the bottom of the tank and passes through the pump, heat exchanger, demineralizer and into the tank through a goose neck over the edge of the tank. Valves are provided to alter the direction of flow through the demineralizing column. The steam-to-water heat exchanger was installed to study the temperature coefficient of reactivity.

5.4 Sediment Cleaning System

The reactor tank bottom is cleaned several times a year using a pool vacuum. The vacuum head is connected to the inlet of the pump through a flexible hose. The demineralizer column is bypassed (Figure 5.2) and the water returns to the tank through a gooseneck pipe at the end of which a polyester filter bag is attached. The sediments collected in the filter bag and the used bags are retained for testing by the Health Physicist and appropriate disposal. The vacuum head and flexible hose are disconnected and stored when the system is not in use.

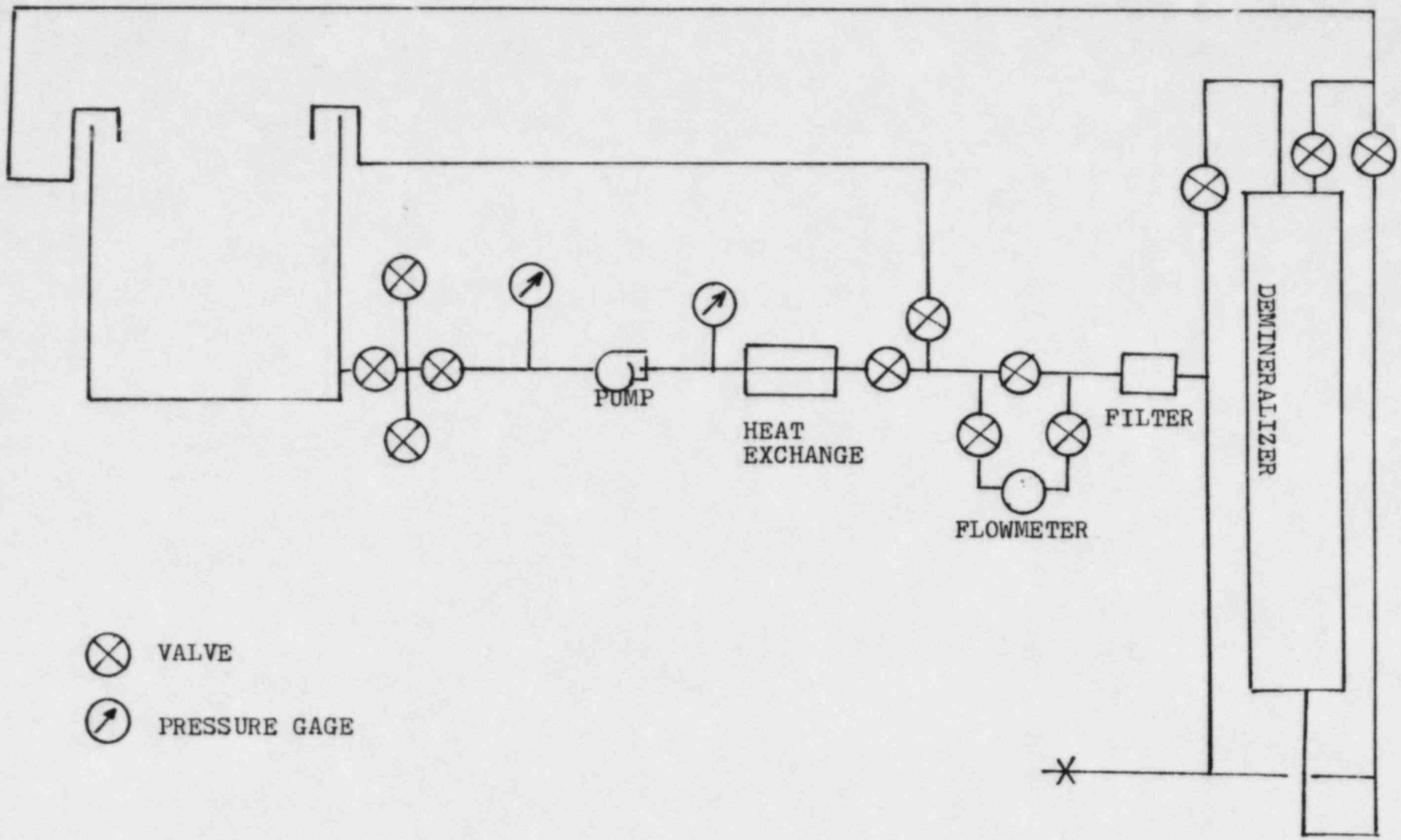


FIGURE 5.1

SCHEMATIC DIAGRAM OF THE DEMINERALIZING SYSTEM

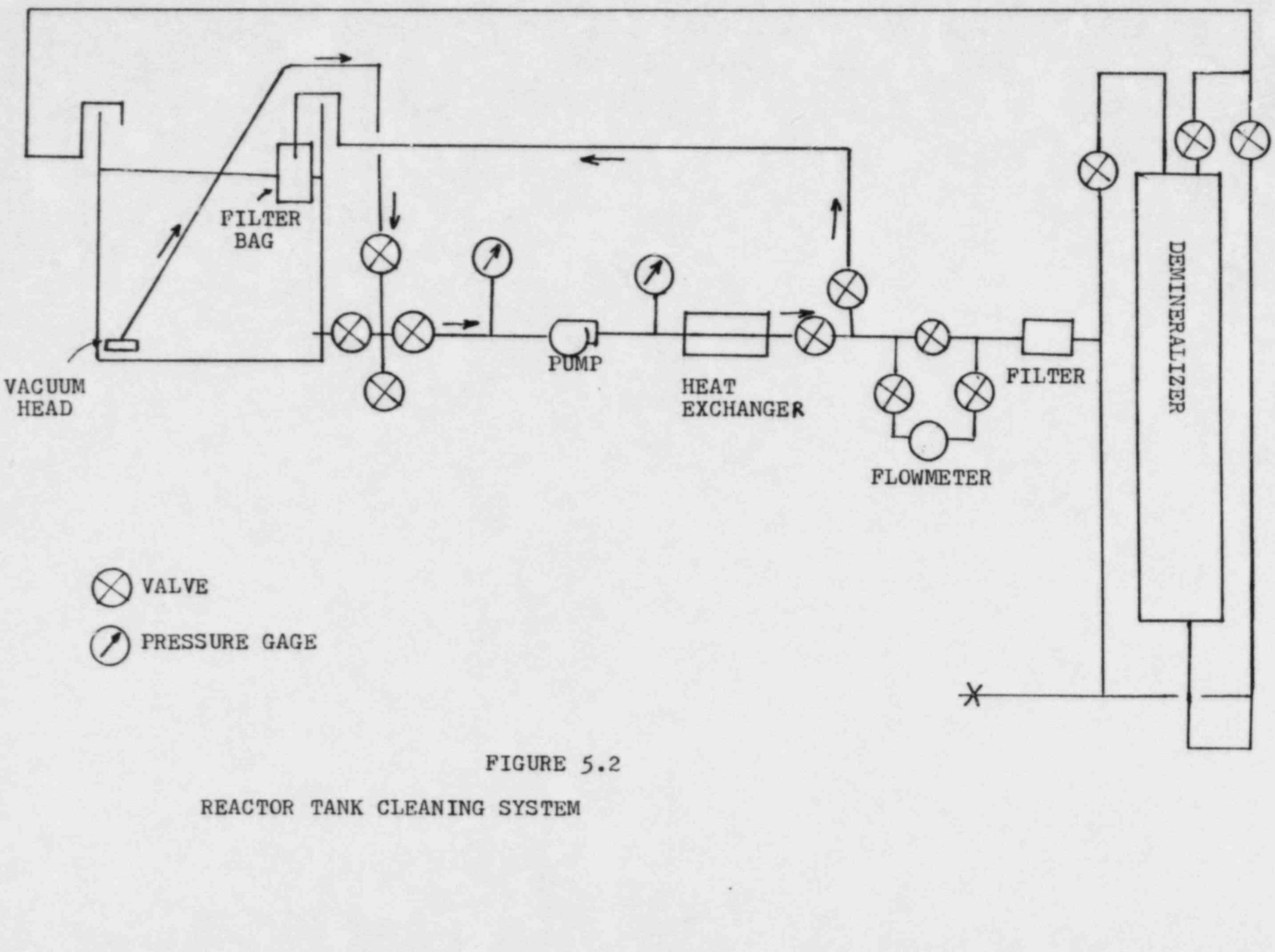


FIGURE 5.2

REACTOR TANK CLEANING SYSTEM

6.0 ENGINEERED SAFETY FEATURES

No features are required in the reactor facility design to maintain safety against normal operations, upset conditions, or the design basis accident other than those described in other sections of this report. The major safety features are the inherent excess reactivity characteristics of the core, the redundant methods available to make the core subcritical, and the extremely low operating power level.

7.0 INSTRUMENTATION AND CONTROLS

7.1 Introduction

The reactor instrumentation monitors several reactor parameters and transmits the appropriate signals to the regulating system during normal operation, and during abnormal and accident conditions to the reactor trip and safety systems. Since the Manhattan College Zero Power Reactor (MCZPR) is an extremely low power (0.1 watt), self limiting reactor, the instrumentation and associated controls are considerably simplified when compared to the instrumentation, and control systems of power reactor or even those of large research reactors.

7.2 Identification of Safety-Related Systems

The safety-related instrumentation and controls for the MCZPR include the control console, the control and safety channels, the facility interlock system, control drive switches, and the reactor scram circuitry. Figure 7.1 shows a block diagram of the nuclear instrumentation and scram logic of the MCZPR.

7.2.1 Console

All functions essential to the operation of the MCZPR are controlled by the operator from a desk-type control console. The reactor console is conveniently located near the reactor to allow the reactor operator to monitor activities in the reactor core during operation. All instruments contained in the console accept signals from or send signals to the control rod drives, the reactor interlock systems and various detectors located around the reactor core and other parts of the reactor system.

The reactor control panel contains the following control and indicating instrumentation:

1. Reactor On-Off key
2. Power On switch
3. Toggle switch for Reg Rod
4. Toggle switch for Shim Rod
5. Coarse control indicator for Reg Rod
6. Coarse control indicator for Shim Rod
7. Fine control indicator for Reg Rod and Shim Rod
8. Log count rate meter scaler
9. Log count rate meter strip chart recorder

10. Linear meter recorder for non compensated ion chamber
11. Range switch for linear recorder
12. Battery test for linear recorder
13. Strip chart recorder for linear meter
14. Meter for gamma 1 detector (above reactor core)
15. Meter for gamma 2 detector (at edge of reactor tank in basement)
16. Strip chart recorder for gamma 1 and gamma 2 detectors
17. Annunciator and annunciator lights for scram, reset, magnet power supply, high flux count, log count rate channel high, linear channel flux high, gamma channels high, and low water level.
18. Resets for gamma 1 and gamma 2
19. Reset for entire console
20. Reactor period meter

The functions of some of these controls and indicating devices are summarized in the following paragraphs.

The console Power On switch controls the AC power to all control circuits. The nuclear instrumentation channels receive power from a circuit breaker located in the rear of the console.

The Reactor On switch activates the power in the electromagnets permitting the operator to move the control rods thereby increasing or decreasing the reactivity.

The coarse control rod indicators determine the position of the control rods to within 2%.

The fine control rod indicators determine the position of the control rods to within 0.1%

A range switch for the linear recorder with 12 allowed steady state positions is located in the lower right-hand corner of the horizontal portion of the control panel. It is used in conjunction with the linear amplifier. A single pen strip-chart recorder is centrally located in the upper center portion of the console. The red pen provides a linear indication of power as a percentage of the range's position.

A log count rate meter ranging from 1 to 10^5 counts/second is located on the left side of the control panel along with the Reactor Period meter.

7.2.2 Nuclear Instrumentation

Whenever fuel is present in the reactor tank the design of the nuclear instrumentation must conform to the specifications of this section.

The following channels of instrumentation are functioning when the reactor is operated or core components are being moved. These channels are of the type and range as specified below:

7.2.2.1 Log Count Rate Channel

The log count rate channel consists of a BF_3 proportional counter, a preamplifier, high voltage power supply, scales, log count rate meter, log count rate recorder, period detector and period indicator. The count rate channel detector is suspended from the reactor platform in the vicinity of the core such that a count rate of at least 2 counts per second is indicated as a result of subcritical multiplication with both control rods fully inserted.

7.2.2.2 Linear Channel

The linear channel consists of an uncompensated ion chamber, high voltage power supply, picoammeter, and a linear recorder. The linear channel detector is suspended from the vicinity of the reactor core such that a current greater than 5% of full scale as indicated on the recorder with the most sensitive scale selected on the amplifier will result with both rods fully inserted. The highest scale setting on the picoammeter is physically set such that 100% of full scale is no more than 0.2 watts.

7.2.2.3 Gamma Channels

1. Two radiation monitoring channels are provided to measure gamma intensity. These channels are also used to monitor reactor operation and are used in the reactor safety system. A strip chart recorder is provided with a selector switch for recording the output of either channel.
2. Each channel consists of a Gamma Detector and a Gamma Indicator.
3. The Gamma Detector is a sealed unit containing a Geiger-Mueller tube, transistorized count rate amplifier, and check source. The output from the Detector is logarithmic with respect to the radiation level. The check source is exposed to the Detector by a solenoid which is actuated by a push-button on the control chassis.

4. One of the Detectors (Gamma 1) is located on the reactor platform directly over the core area while the other Detector (Gamma 2) is mounted on the side of the reactor tank.

5. The Gamma Indicator contains the power supply for the system, the alarm reset check source control, and the output connector for the Detector. Also contained on the front of the Indicator is a logarithmic meter relay for indication and alarm of the gamma level. The alarm is set to give audible annunciation should the radiation level exceed 6 mR /hr for Gamma 1 or 10m R /hr for Gamma 2.

6. The range of both detectors is from .01 to 100 mr/hr. The system is designed so that if the radiation intensity ever exceeds 100mR/hr the detector reads full scale.

7.2.3. Non-Nuclear Instrumentation Channels

The MCZPR is supplied with several process instrumentation channels to monitor the normal operation of various systems; to aid in maintaining a steady-state power level, and also trip the system should an unsafe situation occur or instrument fail. Other channels supply information needed to safely operate the reactor but do not have protective functions. These Non-Nuclear Instrumentation Channels are described in the next three subsections.

7.2.3.1 Control Rod Drive System

The control rod drive circuit is shown in Figure 7.2. It consists of toggle switches and indicating devices used in operating the two control knobs. Six indicator lights are arranged in the center of the control panel in two vertical rows. Each row contains a green DOWN light, an amber UP light, and a white ON (on magnet) light. Push buttons make it possible to release either of the control rods separately and a SCRAM button makes it possible to release both control rods simultaneously. Turning off the Reactor-On key has the same effect as pressing the SCRAM button. The currents in the electromagnets supporting the control rods are regulated by control knobs and measured by 100 milliampere meters.

7.2.3.2 Control Rod Withdrawal Inhibit System

The Control Rod Withdrawal Inhibit System has been shown in Fig. 7.1. This Inhibit System is part of the reactor protection system and functions should the following situations arise:

1. Instrumentation switches are not in proper position to monitor the neutron level increase as the blades are raised.

2. Insufficient neutron source counts are available to insure the proper function of the source level instrumentation. A minimum of 2 counts per second is required by the Technical Specifications.

3. The water level reading drops more than one foot below the normal tank full position.

4. The gamma channel intensity recorded on the strip chart recorder is below 0.2mR/hr and the bypass switch has not been turned on.

7.3 Reactor Trip System

The MCZPR is provided with two types of reactor trips. The reactor trips can be classified into two categories:

1. Scram trips. A Scram system is provided that will cause interruption of the magnet current to the electromagnets should a Scram trip be exceeded. The control rods then fall into the reactor core under the force of gravity.

2. Reverse Circuit trips. A Reverse Circuit system is provided that will cause both control rod drives to drive the control rods into the reactor should a Reverse trip be exceeded. The Reverse action overides any rod selection made by the operator and persists as long as a Reverse trip level is exceeded.

7.3.1 Nuclear Instrumentation Scram Trips

A Scram trip is provided for each of the conditions below, with the trip setting as specified:

1. High neutron flux-Count Rate Channel electronic trip set for 400% or less of Full Power (Full power is equal to 0.1 watt).

2. High neutron flux-Linear Channel electronic trip set for 200% or less of Full Power.

3. High gamma activity-high level signal from either of the two Gamma Channels electronically set for 10m R/hr or less.

4. Manual scram-operates upon actuation of the manual Scram button on the console.

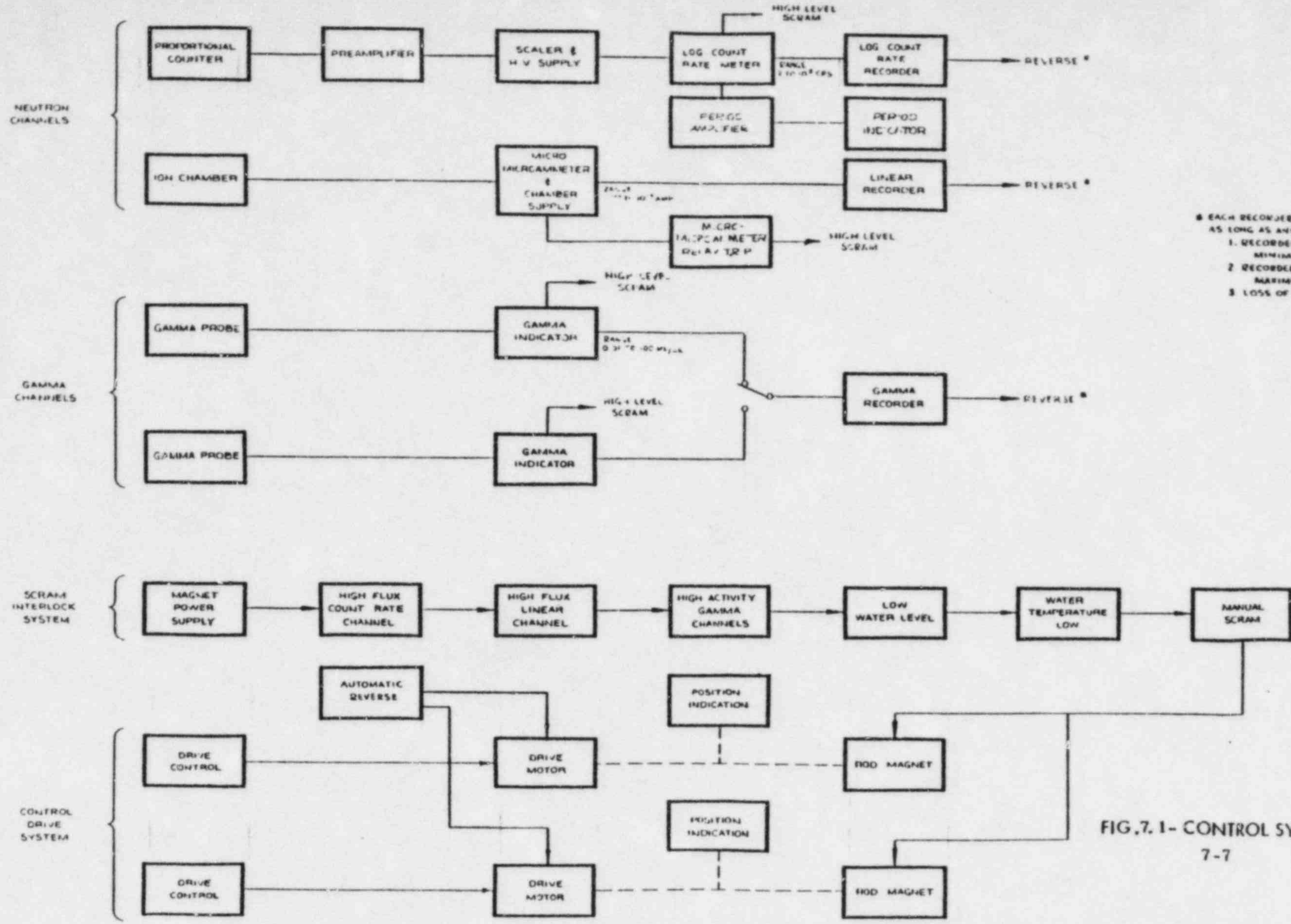
5. Low water level-operates should the tank water drop one foot below the normal tank full operation.

6. Reactor On key switch off -operates when the "REACTOR ON" switch is turned to the off position.

7.3.2 Nuclear Instrumentation Reverse Circuit Trips

Reverse Circuit trips are provided for each condition as below with the trip setting as specified:

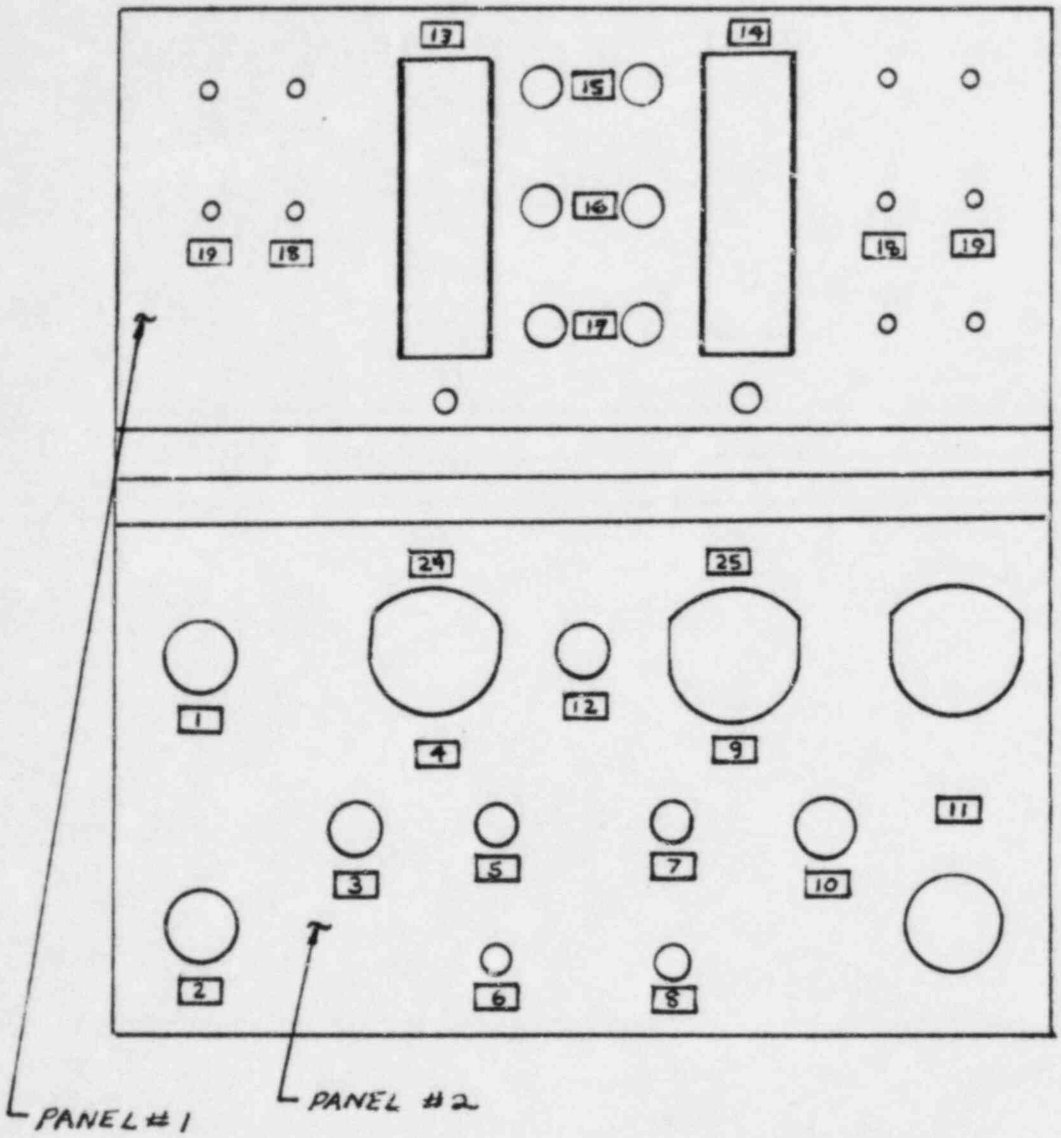
1. A Count Rate Channel Reverse trip occurs for any of the following conditions:
   a. Count Rate recorder off
   b. Count Rate recorder down scale - occurs should the recorder indicate less than 2 counts per second
   c. Count Rate recorder up scale - occurs should the recorder indicate greater than 50,000 counts per second
2. Linear Channel Reverse trips occur for any of the following conditions:
   a. Linear recorder off
   b. Linear recorder down scale - occurs when the linear recorder is less than 5% of full scale
   c. Linear recorder up scale - occurs when the linear recorder is greater than 95% of full scale
3. Gamma Channel Reverse trip occurs for any of the following conditions:
   a. Gamma recorder off
   b. Gamma recorder down scale - occurs should the recorder indicate less than 0.2 mR/hr.
4. Any Scram condition will cause the control rod drives to drive in the electromagnets.
5. Manual run-in trip- occurs upon actuation of the "Run-In" switch on the control console.



* EACH RECORDER WILL DRIVE RODS INTO THE CORE AS LONG AS ANY OF THE FOLLOWING CONDITIONS EXIST:

1. RECORDED LEVEL BELOW AN ADJUSTABLE PRESET MINIMUM LEVEL.
2. RECORDED LEVEL ABOVE AN ADJUSTABLE PRESET MAXIMUM LEVEL.
3. LOSS OF POWER TO RECORDER.

FIG. 7.1- CONTROL SYSTEM BLOCK DIAGRAM



ENGRAVING CHART

1	REACTOR ON
2	POWER
3	MAG. ADJUST
4	MAG. CURRENT
5	ROD RELEASE
6	DRIVE CONTROL
7	ROD RELEASE
8	DRIVE CONTROL
9	MAG. CURRENT
10	MAG ADJUST
11	FINE POSITION INDICATOR
12	SCRAM
13	SHIM ROD
14	REG ROD
15	UP LIMIT
16	ON MAGNET
17	DOWN LIMIT
18	SPAN ADJUST
19	ZERO ADJUST
24	SHIM ROD
25	REG ROD

Figure 7.2
Control Rod Drive Circuit

8.0 ELECTRIC POWER

8.1 Introduction

The MCZPR is a teaching and training reactor presently licensed to operate at only 0.1 watt. It is not used to generate electrical power.

8.2 Offsite Power System

During operation, the electric power requirements for the MCZPR are supplied by the Consolidated Edison Company of New York which services Manhattan College. The reactor facility requires 110 Volt AC at 60 cycles.

Since the system is fail safe, no auxiliary power is needed for the operation of post-shutdown safety systems. The loss of electrical power draws out the scram relays and de-energizes the current in the electromagnets causing the control rods to drop under gravity completely into the core. Therefore, there is no need to consider offsite sources for emergency power.

8.3 Onsite Power System

Interruptions in power from the Consolidated Edison Company are very rare. Although any trip associated with a loss of power is inconvenient, such a loss of power has no bearing on the safe operation of the MCZPR system. When power is lost, the reactor automatically trips. Since such interruptions are usually of short duration, it has not been deemed necessary to install any secondary power systems.

9.0 AUXILIARY SYSTEMS

9.1 Fuel Storage and Handling

9.1.1 New Fuel Storage

Due to the extremely low power rating of the MCZPR (0.1 watt), periodic fuel replacement is not necessary. Hence no built-in provision is made for the storage of new fuel.

During 1965 the excess reactivity was reduced from 0.3 percent to 0.29 percent with removal of three fuel plates from a partial element. These were:

Number	Weight in grams (Element)	Weight in grams (Isotope)
HCF27	13.16	12.27
HCF28	13.22	12.32
HCF29	13.30	12.40

These fuel elements are permanently stored in a locked steel container 8-1/4" X 8-1/2" X 50" made of 1/16 in steel sheet metal. The steel container is fastened to the floor of the first floor of the MCZPR Room. The container has a shelf welded inside it. The three fuel plates are placed on the shelf and secured with metal straps. The metal straps are welded to the shelf. The container has a hinged cover which is kept padlocked.

9.1.2 Spent Fuel Storage

The reactor does not generate any spent fuel that has to be replaced periodically. No provision is, therefore, provided for the storage of spent fuel.

9.1.3 Temporary Storage of Fuel During Preventive Maintenance

If fuel elements need to be removed from the core for purposes of preventive maintenance, they will be stored in their original Sylcor shipping containers on the first floor of the MCZPR Room. The removal and reloading of the fuel elements will be performed in the presence of a reactor supervisor.

9.2 Water Systems

9.2.1 Cooling Systems

The MCZPR does not have recirculating primary or secondary cooling systems.

9.2.2 Demineralizing System

The water in the reactor tank is demineralized by pumping water through a column containing demineralizing resin. Water is drawn through a 3/4" pipe attached to the only tank penetration located 2" from the bottom of the tank and returned back to the tank through a gooseneck pipe over the edge of the reactor tank.

9.2.3 Water Make-Up System

Water lost due to evaporation is replenished with city water. The water from the city water system is passed through an electrically controlled Versa check valve, a Bantam demineralizer, a flow meter and a short flexible hose over the top of the reactor tank. The check valve prevents back flow. The flexible hose is removed from the tank when the hose is not in use.

9.2.4 Cathodic Protection

A cathodic protection system is installed to reduce corrosion in the reactor tank. The system consists of four graphite rods attached to aluminum tubes. The rods are suspended in the reactor water by nylon filament, so that they are just outside the corners of the reactor platform. The rods are maintained at -10V with reference to the reactor tank with the help of a packaged direct current power supply unit.

9.2.5 Potable Water

No potable water connections are provided either in the MCZPR Room or in the Reactor Laboratory.

9.2.6 Sanitary Water

No sanitary water connections are provided in the Reactor Laboratory. A utility sink is located in Room 221 outside the MCZPR Room in the northwest corner of the second floor of the Reactor Laboratory.

9.3 Floor Drainage Systems

There are no floor drainage systems either in the first floor or in the second floor of the Reactor Laboratory.

9.4 Ventilation System

The Reactor Laboratory is provided with a forced circulating ventilation system consisting of a blower and associated duct work which are designed so as not to return air from the laboratory back into the ventilation system of the Leo Engineering Building. A separate blower controlled by a switch located on the west wall of the MCZPR Room returns air to the atmosphere.

9.5 Other Auxiliary Systems

9.5.1 Fire Protection System

A conventional fire protection system is located in the Leo Engineering Building. In addition, carbon dioxide fire extinguishers are available on both floors of the Reactor Laboratory.

9.5.2 Communications System

A full-service telephone is installed at the reactor console within easy reach of the operator at the controls. This provides direct communication within the Leo Engineering Building, outside the building to other telephones (on and off campus) and provides access to the Reactor Supervisor, Reactor Administrator, Health Physicist, and Radiation Safety Officer.

9.5.3 Lighting System

The Leo Engineering Building, including the MCZPR Room and the Reactor Laboratory, is provided with overhead fluorescent lighting. All switches are inside the Reactor Laboratory.

10.0 STEAM AND POWER CONVERSION SYSTEM

The Manhattan College Zero Power Reactor operates at a maximum power level of 0.1 watt. The reactor produces no steam or electrical power and has no working fluid cycle. The power generation is absorbed by the water pool and can produce only a small temperature rise, insufficient to produce steam.

11.0 RADIOACTIVE WASTE MANAGEMENT

Because of its low operating power level (0. 1w maximum) and its design characteristics the Manhattan College Zero Power Reactor does not generate radioactive waste ordinarily produced by test reactors. The extremely low operating power does not result in significant fuel burnup, and thus it is not anticipated that it will ever be necessary to add additional fuel to the reactor or to remove and ship irradiated fuel elements for reprocessing.

In addition, no radioactivity in the form of gases is found within the reactor facility so that there is no gaseous release to the surroundings. At the operating power level the water shield is ample to attenuate the maximum fission product activity.

The following procedures are in effect to handle any small quantities of solid or liquid waste that may be generated as a result of the laboratory experiments performed on the reactor.

11.1 Waste Disposal Criteria

No radioactive effluent is released at any concentration and no waste is disposed of except as authorized by the Reactor Operations Committee. In any event, only concentrations at or below maximum permissible levels listed in Appendix B of 10 CFR20 in air and water would be allowed to escape continuously to the local environment.

11.2 Accumulation of Active Wastes

11.2.1 Dry Waste

Cans marked CONTAMINATED WASTE, COLD WASTE and CONTAMINATED GLASSWARE are to be provided as needed. These cans are polyethylene-lined and are not filled so as to prevent closure of the polyethylene bag liner. They are foot-operated in order to reduce the possibility of spread of contamination by handling the lid. Extreme care is exercised in keeping contaminated waste out of the cold waste cans, and vice versa. The cans are monitored regularly by the staff Health Physicist and marked with the normal radiation sign if the radiation field is greater than 2. 5 mR/hr at any point outside the can. Persons placing material in the can which has sufficient activity to produce such a field must notify the Health Physicist.

11.2.2 Liquid Waste

Five-gallon polyethylene bottles marked CONTAMINATED WASTE are provided as needed. Liquid waste is kept in these containers and not mixed with other waste. A detailed record of the nature of the liquid and the amount and type of activity in the container is kept by the appropriate person. Physical inventories are requested as needed.

11.3 Waste Transfer

The transfer and disposal of all radioactive wastes (if made) is supervised by a Health Physicist in accordance with policies adopted by the Reactor Operations Committee. Transfer and disposal of such wastes are not made without the knowledge and approval of the Health Physicist. The Health Physicist monitors all such wastes and decides on the appropriate method of disposal. Solid wastes found in contaminated waste cans will be packaged for off-site disposal. Liquid waste will be transferred to 50-gallon drums for storage, concentration and subsequent off-site disposal by a licensed waste disposal contractor in accordance with current manufacturing and shipping requirements.

The Health Physicist keeps complete records of the condition and location of all radioactive waste in storage and of final disposition thereof.

11.4 Disposal of Pool Water and Demineralizer Resin

The pool would not be drained until the water has been assayed and shown to be at or below tolerance as specified in 10CFR20. The Health Physicist must be notified in advance as to this action.

The demineralizer is a concentrator of radioactivity, notably short-lived Na-24 and Mg-27. Used resin can never be replaced without Health Physicist coverage and notification. If assay of the resin shows it to be radioactive it will be disposed of in accordance with 10CFR20 par. 20.303, 304. It is not anticipated that this situation will arise.

11.5 Surveys

11.5.1 Wipe samples of the floor and such other areas as selected by the Health Physicist and/or the Chief Reactor Supervisor are performed. The floor areas include the ZPR, graphite, counting and lecture rooms as well as connecting corridors and upper level desk areas. Normally this is performed at six month intervals.

11.5.2 Air sampling is taken of the areas considered in 11.5.1 above. Samples are taken at a rate of at least 2.5 cubic feet per minute for 1/2 to 1 hour at each location. Normally this is performed at six month intervals.

11.5.3 ZPR water is checked at six month intervals. This procedure is accomplished employing a multi-channel analyzer or a scintillation spectrometer. Air and water samples of the reactor area are obtained prior to operation of the reactor. These are the control values. These values are then employed and used for comparison purposes of air and water samples taken at the conclusion of each semester in which the reactor has been operational.

If Iodine-131 is found, Reactor Operator and the Health Physicist will be notified immediately.

11.6 Protective Supplies

A supply of plastic bags are on hand at all times in the counting room. A supply of radiation tape is also maintained.

11.7 Logs

The Health Physicist maintains a bound log book. These logs are maintained:

- radiation surveys
- wipe records
- air and water tests

12.0 RADIATION PROTECTION

Manhattan College is committed to conducting reactor operations and associated experimental activities in a manner that assures the protection of all individuals, both on-site and in the surrounding environs. Radiation protection is carried out in a manner that is consistent with the applicable rules and regulations of the Nuclear Regulatory Commission and the State and City of New York, and with the specific conditions defined in our Special Material and Facility Operating Licenses.

The radiation protection program is based on the following premises:

- The College has a moral obligation to maintain personnel health and safety with respect to all radiological ordinances which can never be compromised
- The Manhattan College Zero Power Reactor (MCZPR) is inherently safe because of its low power operation and built in design features
- There is a need to inculcate reasonable and proper Health Physics procedures by requiring students to know and follow these regulations
- Personnel safety must be the first consideration at all times, and no requirements will be allowed to override safety considerations
- An ALARA (As Low As Reasonably Achievable) program will be conducted in accordance with federal (NRC) guidelines

The components of the Manhattan College radiation protection program relevant to the operation of the reactor are discussed in the following sub-sections.

12.1 Health Physics Program

The objectives of the Manhattan College radiation protection program are accomplished through the implementation of the components of a health physics program. The primary purposes of this program are to assure the radiological safety of all College personnel, and to make certain that all sources of radiation are handled in accordance with Federal, State, and City Regulations.

A Radiation Safety Manual (the complete text of the Radiation Safety Manual is included as Appendix A; much of Section 12. is drawn from the Manual) has been prepared that describes the components of the health physics and related ALARA programs (section 12.2). The Manual guides the activities of faculty members and students using the Reactor, the supporting radiation facilities, and radioactive materials in the Nuclear Engineering Facility.

The procedural and radiation safety aspects of the Zero Power Reactor and isotope program are administered by a Reactor Operations Committee (ROC). The ROC, which is chaired by the Reactor Administrator, receives and evaluates all proposed operations and procedures in order to insure that the reactor facility is operated in a safe and competent manner. An appointed Radiation Safety Officer (RSO) is responsible for enforcement of the rules, regulations, and operating procedures which conform with the NRC regulations (i.e. 10CFR Part 20) and the license conditions. The specific safety responsibilities of the ROC and RSO relative to the ALARA program are described in section 12.2.

The services of a consulting Health Physicist are also employed to provide advice to the ROC and RSO in insuring radiation safety.

12.2 Insuring That Occupational Radiation Exposures Are As Low As Reasonably Achievable (ALARA)

12.2.1 Administration

The Administration of Manhattan College and the Manhattan College Nuclear Engineering Facility are committed to the program described below for keeping exposures (individual and collective) as low as reasonably achievable (ALARA). In accord with this commitment, and as noted in section 12.1, an administrative organization for radiation safety has been established, and new written policy, procedures and instructions to foster the ALARA concept within our institution are being implemented. The organization includes the Reactor Operations Committee (ROC) and Radiation Safety Officer (RSO).

A formal annual review of the radiation safety program, including ALARA considerations is required. This includes review of operating procedures and past exposure records, inspections, etc., and consultations with the radiation protection staff or outside consultants.

Modification to operating and maintenance procedures and to equipment and facilities will be made where they will reduce exposures unless the cost, in our judgement, is considered to be unjustified by the benefits produced. We will be able to demonstrate, if necessary, that improvements have been sought, that modifications have been considered, and that they have been implemented where reasonable. Where modifications have been recommended but not implemented, we will be prepared to describe the reasons for not implementing them.

In addition to maintaining doses to individuals as far below the limits as is reasonably achievable, the sum of the doses received by all exposed individuals will also be maintained at the lowest practicable level. It would not be desirable, for example, to hold the highest doses to individuals to some fraction of the applicable limit if this involved exposing additional people and significantly increasing the sum of radiation doses received by all involved individuals.

12.2.2 Reactor Operations Committee (ROC)

Review of Proposed Users and Uses

The ROC thoroughly reviews the qualifications of each applicant with respect to the types and quantities of materials and uses for which he has applied to assure that the applicant is able to take appropriate measures to maintain exposure ALARA.

When considering a new use of byproduct material, the ROC reviews the efforts of the applicant to maintain exposure ALARA. The user should have systematized procedures to insure ALARA, and shall have incorporated the use of special equipment in his proposed use.

The ROC insures that the user justifies his procedures and that dose will be ALARA (individual and collective).(The judicious delegation of ROC authority is essential to the enforcement of an ALARA program).

The ROC delegates authority to the RSO for enforcement of the ALARA concept. The ROC supports the RSO in those instances where it is necessary for the RSO to assert his authority. Where the RSO has been overruled, the Committee records the basis for its action in the minutes of the Committee's semi-annual meeting.

Review of ALARA Program

The RSO encourages all users to review current procedures and develop new procedures as appropriate to implement the ALARA concept.

The RSO performs a review of occupational radiation exposure with particular attention to instances where Investigational Levels in Table 12.1 (below) are exceeded. The principle purpose of this review is to assess trends in occupational exposure as an index of the ALARA program quality and to decide if action is warranted when Investigational Levels are exceeded.

The RSO evaluates the Nuclear Engineering Facility's overall efforts for maintaining exposures ALARA on an annual basis. This review includes the efforts of the RSO, authorized users, and workers as well as those of the Administration of Manhattan College and the Nuclear Engineering Facility.

12.2.3 Radiation Safety Officer (RSO)

Annual and Quarterly Review

Annual Review of the Radiation Safety Program. The RSO performs an annual review of the Radiation Safety Progra for adherence to ALARA concepts. Review of specific procedures may be conducted on a more frequent basis.

Quarterly review of Occupational Exposures. The RSO reviews at least quarterly the external radiation exposures of authorized users and workers to determine that their exposures are ALARA in accordance with the provisions of Paragraph 12.2.6 of this program.

Quarterly review of records of Radiation Level Surveys. The RSO reviews radiation levels in unrestricted and restricted areas to determine that they were at ALARA levels during the previous quarter.

Education Responsibilities for an ALARA Program

The RSO schedules briefings and educational sessions as needed to inform workers of ALARA program efforts.

The RSO assures that authorized users, workers and ancillary personnel who may be exposed to radiation will be instructed in the ALARA philosophy and informed that administration, the ROC and the RSO are committed to implementing the ALARA concept.

Cooperative Efforts for Development of ALARA Procedures

Radiation workers are given the opportunity to participate in formulation of the procedures that they will be required to follow.

The RSO is in close contact with all users and workers in order to develop ALARA procedures for working with radioactive materials.

The RSO establishes procedures for receiving and evaluating the suggestions of individual workers for improving health physics practices and encourages the use of those procedures.

Reviewing Instances of Deviation from Good ALARA Practices

The RSO investigates all known instances of deviation from good ALARA practices; and, if possible, determines the causes. When the cause is known, the RSO requires changes in the program to maintain exposures ALARA.

12.2.4 Authorized Users

New Procedures Involving Potential Radiation Exposures

The authorized user is required to consult with, and receive the approval of, the RSO and the ROC during the planning stage before using radioactive materials for a new procedure.

The authorized user is also required to evaluate all procedures before using radioactive materials to insure that exposures will be kept ALARA. This may be enhanced through the application of trial runs.

Responsibility of the Authorized User to Those He Supervises

The authorized user is required to explain the ALARA concept and his commitment to maintain exposures ALARA to all of those he supervises.

The authorized user is required to insure that those under his supervision who are subject to occupational radiation exposure are trained and educated in good health physics practices and in maintaining exposures ALARA.

12.25 Persons Who Receive Occupational Radiation Exposure

The on-site worker is instructed in the ALARA concept and its relationship to his working procedures and work conditions.

The on-site worker is required to know what recourses are available if he feels that ALARA is not being promoted on the job.

12.26 Establishment of Investigational Levels In Order to Monitor Individual Occupational External Radiation Exposures

The Manhattan College Nuclear Engineering Facility has established Investigational Levels for Occupational external radiation exposure which, when exceeded, will initiate review or investigation by the Reactor Operations Committee and/or the Radiation Safety Officer. The Investigational Levels that we have adopted are listed in Table 12.1 below. These levels apply to the exposure of individuals.

TABLE 12.1

	Investigational Levels - (mrems per calendar quarter)	
	LEVEL I	LEVEL II
1. Whole body; head and trunk; active blood-forming organs; lens of eyes; or gonads	125	375
2. Hands and forearms; feet and ankles	1875	5625
3. Skin of whole body*	750	2250

* Not normally applicable to nuclear medicine operations except those using significant quantities of beta emitting isotopes.

The Radiation Safety Officer is required to review and record on Form NRC-5, Current Occupational External Radiation Exposures, or an equivalent form (e.g. dosimeter processor's report), results of personnel monitoring, not less than once in any calendar quarter. The following actions will be taken at the Investigational Levels as stated in Table 12.1:

Quarterly exposure of individuals to less than Investigational Level I.

Except when deemed appropriate by the RSO, no further action will be taken in those cases where an individual's exposure is less than Table 12.1 values for the Investigational Level I.

Personnel exposures equal to or greater than Investigational Level I, but less than Investigational Level II.

The RSO will review the exposure of each individual whose quarterly exposures equal or exceed Investigational Level I. He will report the results of his reviews at the first ROC meeting following the quarter when the exposure was recorded. If the exposure does not equal or exceed Investigational Level II, no action related specifically to the exposure is required unless deemed appropriate by the Committee. The Committee will, however, consider each such exposure in comparison with those of others performing similar tasks as an index of ALARA program quality and will record the review in the Committee minutes.

Exposure equal to or greater than Investigational Level II.

The RSO will investigate in a timely manner the cause(s) of all personnel exposures equaling or exceeding Investigational Level II and, if warranted, take action. A report of the investigation, actions taken, if any, and a copy of the individual's Form NRC-5 or its equivalent will be presented to the ROC at the first ROC meeting following completion of the investigation. The details of these reports will be recorded in the minutes. Committee minutes will be sent to the administration for review. The minutes, containing details of the investigation, will be made available for review.

Re-establishment of an individual occupational worker's Investigational Level II Above That Listed in Table 12.1

In cases where a worker's or a group of workers' exposures need to exceed Investigational Level II, a new, Higher Investigational Level II may be established on the basis that it is consistent with good ALARA practices for that individual or group. Justification for a new Investigational Level II will be documented.

The Reactor Operations Committee will review the justification for, and will approve, all revisions of Investigational Levels II. In such cases when the exposure equals or exceeds the newly established Investigational Level II, those actions listed above will be followed.

12.3 Personnel Monitoring

During routine Reactor and Laboratory operations, external personnel monitoring is accomplished by the use of film badges. Reactor operations personnel normally working in the reactor rooms wear beta-gamma-neutron film badges; students entering the reactor rooms wear beta-gamma film badges; and visitors are required to wear film badges that record gamma radiation. Badges are processed by a commercial vendor, and records of personnel exposures are maintained in the reactor area.

In the event that any significant internal exposure is suspected to have occurred, bioassays of urine samples may be required. If analysis of the sample verifies overexposure, followup medical examinations including blood analysis may be performed. An investigation of the cause of overexposure will be conducted, the situation remedied, and verified by the ROC.

All personnel performing maintenance and alterations in an area of actual or potential radiation exposure are monitored, and area contamination surveys made to assure that no dispersal of radioactive material has occurred. Administrative controls (special work permits) are required for outside contractor personnel working in these areas.

Survey meters, located in the ZPR room, are used for area monitoring, and for monitoring of hands and clothing of individuals, suspected of picking up some contamination during the course of experimental activities.

12.4 Other Radiation Protection Measures

In addition to the program described in sections 12.1-12.3, other radiation protection measures are routinely performed at the Manhattan College Nuclear Facility. These include:

- All personnel using the Facility are instructed in radiation protection prior to participating in any of the activities at the Facility. All students are required to familiarize themselves with the provisions of the Radiation Safety Manual.

- Each area, room, or enclosure in which radioactive materials exist is posted with the specified radiation sign, as defined by Appendix B of 10CFR 20 or NBS69.
- No beverages, smoking, foodstuff, or application of cosmetics is permitted in radiation zones.
- Protective clothing (e.g. gloves) and tools (e.g. tongs) are employed to avoid contact between radioactive material and the skin.
- A contamination control program exists involving the use of designated container and labels, controlled and labelled storage, cleanliness and maintenance standards for laboratory surfaces, and procedures for cleanup of spills, and for decontamination of equipment and structural surfaces.

13.0 CONDUCT OF OPERATIONS

13.1.1 Organizational Structure of the Applicant

The operation of the Manhattan College Zero Power Reactor(MCZPR) is supervised by the Manhattan College Reactor Operations Committee. The members of the Reactor Operations Committee report to the Reactor Administrator. With the issuance of Amendment No. 4 to Facility License R-94, Docket No. 50-199 on March 16, 1977, the Chairman of the Mechanical Engineering Department is constrained to serve as the Reactor Administrator. The administrative reporting line from the Chairman of the Mechanical Engineering Department proceeds to the Dean of the School of Engineering, the Provost, the Executive Vice President, the President of Manhattan College, and the Board of Trustees of the Manhattan College Corporation. The Corporation owns the facility and has final legal and financial responsibility for the operation of the facility. Figure 13.1 shows the Organizational Structure.

The Chief Reactor Supervisor, Radiation Safety Officer, and Health Physicist both report to and are part of the Reactor Operations Committee. They have collateral responsibility with the Reactor Operations Committee for the review and evaluation of all proposed operations and procedures in order to assure that the reactor facility is operated in a safe and competent manner.

13.1.2 Operating Organization, Reactor Operations Committee

The Reactor Operations Committee and its members have primary responsibility for the evaluation of the operations of the facility. The membership of the committee includes the Radiation Safety Officer, the Health Physicist, the Chief Reactor Supervisor, and all subordinate Reactor Supervisors, Reactor Operators, and Reactor Trainees. Because the primary purpose of the facility is to aid undergraduate instruction in nuclear engineering, lecturers in the nuclear engineering courses are also appointed members of the committee. Appointments of the Radiation Safety Officer, Health Physicist, Chief Reactor Supervisor, subordinate Reactor Supervisors and other members of the Reactor Operations Committee are made by the Reactor Administrator.

The Reactor Operations Committee meets semiannually and at other times if deemed necessary by the Reactor Administrator. The semiannual meetings are held in the Spring and Fall semesters during the Manhattan College academic year. A formal agenda is prepared by the Reactor Administrator and minutes of each meeting are written. The task of taking minutes is rotated; however the draft version is reviewed by the Reactor Administrator prior to issuance to the committee for the next meeting. The agenda has been standardized and reflects the duties and

responsibilities of the committee. Each item in the agenda is considered and noted in the minutes. Figure 13.2 shows a sample agenda and the topics that are covered at a meeting.

The duties of the Reactor Administrator, Reactor Operations Committee, Radiation Safety Office Reactor Supervisor, Chief Reactor Supervisor, and Reactor Operators are described in the Technical Specifications which form a part of this license renewal request. The Health Physicist performs all radiation surveys and samples under the supervision of the Chief Reactor Supervisor and other tests as requested by the Reactor Administrator or members of the Reactor Operations Committee. He also is responsible for monitoring records of exposure on film badges, maintenance of a log book on radiation tests and exposure records, and for review of the reactor log book. More detail on his duties can be found in Section 12 of this license renewal request and the appended "Radiation Safety Manual".

13.2 Training

The Chief Reactor Supervisor and Reactor Supervisors must hold a Senior Reactor Operator's License issued by the U. S. Nuclear Regulatory Commission. Regular operators must hold either a Senior Reactor Operator's License or a regular Operator's License also issued by the U. S. Nuclear Regulatory Commission. Training of applicants for service as operators of the Manhattan College Zero Power Reactor is performed as needed for maintenance of a sufficient number of on-campus staff to assure the safe operation of the facility. A detailed plan "Plan for Training Applicants to Prepare for a Reactor Operator's License Examination for Manhattan College Zero Power Reactor" has been prepared and is appended to this license renewal request. Since reactor operator's licenses are issued by the U. S. Nuclear Regulatory Commission for only two-year periods, re-evaluation of the ability of operators to continue service at the facility is done every two years. All applications for operator license renewals require an endorsement letter from the Reactor Administrator and are discussed at the semiannual Reactor Operations Committee meetings. All Senior Reactor Operators and Reactor Operators must participate in a continuing requalification program. The program is detailed in Appendix J.

13.3 Emergency Planning

An emergency plan for the facility has been prepared independently of this license renewal request and is appended to this request. The plan follows the guidelines stated in Appendix E to 10CFR Part 50, U.S.N.R.C. Regulatory Guide 2.6 (Revision 1, March 1983), and ANS 15.16-1982.

13.4 Review and Audit

The members of the Reactor Operations Committee collectively and individually through the duties of their appointed positions review and audit the current and proposed uses of the facility. The primary purpose of the facility is to assist undergraduate instruction in the undergraduate nuclear engineering sequence offered by the mechanical engineering department. This sequence includes a laboratory with some experiments that use the critical reactor. Except for operator training sessions and required tests, the educational function constitutes the primary purpose of the facility. As noted on Figure 13.2, the review of experiments is an agenda item at each semiannual meeting. Figure 13.2 also shows that reports on log book review, compliance with periodic requirements, required documentation and licensing matters, safety procedures, and changes in Technical Specifications are provided semiannually to the Reactor Operations Committee. The Radiation Safety Officer also performs review and audit functions as part of his duties pertaining to the ALARA program. The Health Physicist and Chief Reactor Supervisor perform review and audit of periodic requirements prior to reporting to the committee.

13.5 Plant Procedures

The Chief Reactor Supervisor has prime responsibility for the day-to-day operating procedures within the facility. He maintains a log book which includes the history of all periods of reactor operation, including startup, criticality, and shutdown. Figure 13.2, item 4 shows the type of information which must be recorded. The log book is maintained in a locked cabinet in the facility with records kept indefinitely. Maintenance and inspection records are also recorded in this log.

The procedures for startup, operation, and shutdown are detailed on the "Reactor Console Checkout Sheets". These are appended to this license renewal request. The "Reactor Console Checkout Sheets" are based on the more general description in the Technical Specifications.

The Health Physicist also maintains a log book in which records of all radiation surveys and film badge exposures are kept. This log is updated every six months or sooner if needed. The log book is maintained in a locked file cabinet in the facility. Procedures for radiation protection are described in more detail in Section 12 of this license renewal request and in the appended "Radiation Safety Manual".

13.6 Physical Security Plan

A physical security plan has been prepared and approved independently of this license renewal request and is appended to this request.

ORGANIZATIONAL STRUCTURE
(Effective July 1, 1983)

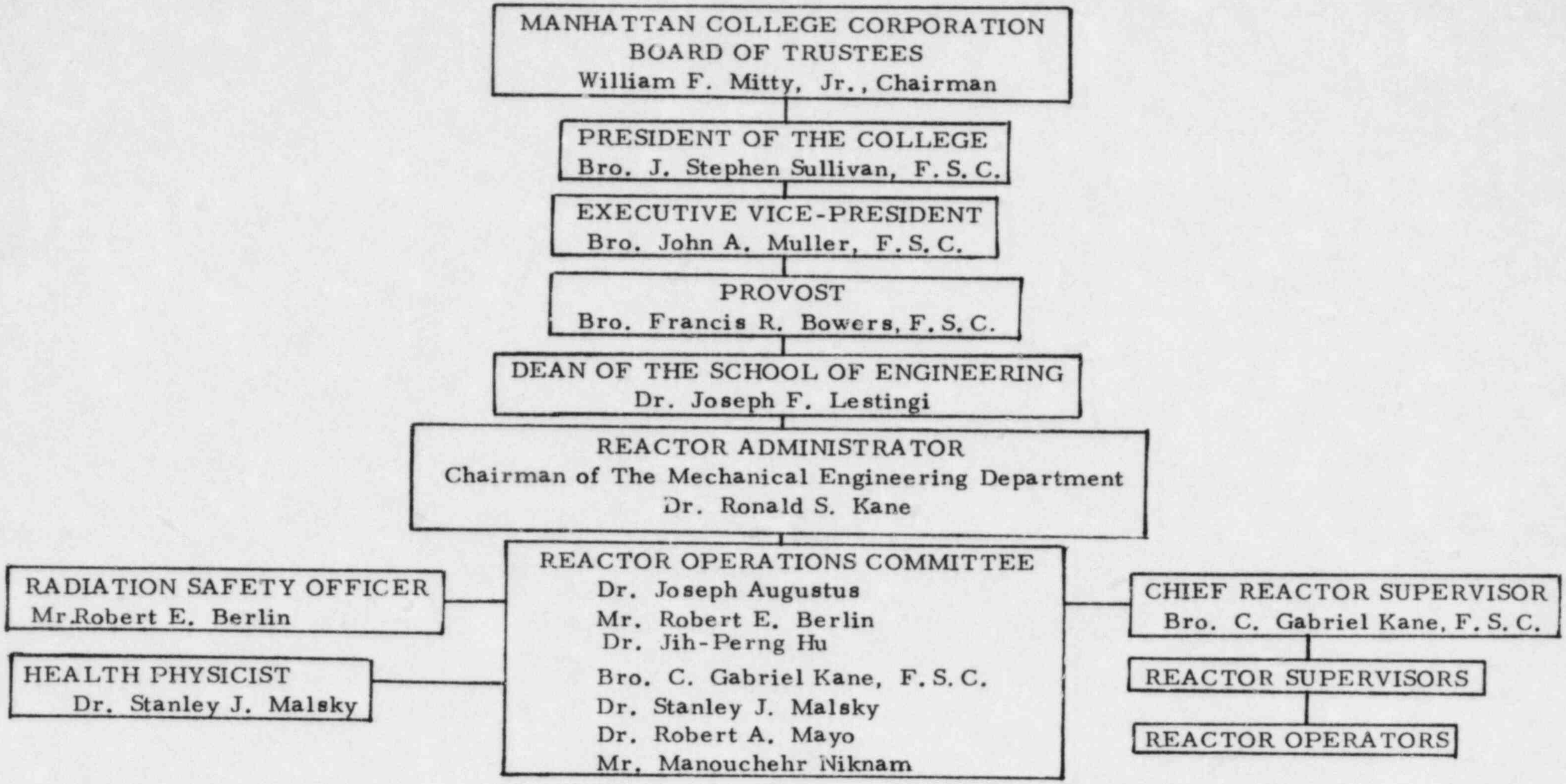


Figure 13.1

AGENDA OF SEMIANNUAL REACTOR OPERATIONS COMMITTEE MEETING

Reactor Operations Committee
(Date)

1. Approval of Agenda
2. Approval of Minutes of (previous meeting date)
3. Committee Membership
4. Log book review
   a) Time duration of irradiation of Indium foils
   b) Signature of approval for irradiation
   c) Completeness of all entries relative to criticality
   d) Time and modes of shut-down of reactor
   e) Time of securing reactor
   f) Hourly instrument recording during period when reactor is critical
5. Check compliance with periodic requirements
   a) Periodic radiation survey
   b) Emergency procedures review (annual review in October)
   c) Scram time measurement (verification every 6 months and prior to operation of the facility if the facility is shut down for 2 months or more)
   d) Reactor moderator sample analysis (done each semester)
   e) Sample check for hold down rods
   f) Calibration of survey instruments (annual calibration in October)
   g) Leak tests on plutonium sources (semi-annual tests in April and October)
   h) Material irradiation other than indium
6. Old Business (as needed, typical items below)
   a) Required documentation for facility
   b) Inspection status
   c) Review of experiments
   d) Other radiation tests, badges
   e) Student safety procedures, non-nuclear safety, access
   f) Budget items
   g) License status
   h) Unanswered or other correspondence
   i) Equipment or other acquisitions
7. Changes in Technical Specifications (if any)
8. New Business

Figure 13.2

14.0 INITIAL TEST PROGRAM

Since the reactor has been licensed and in use since 1964, an initial test program is not needed for the purposes of this renewal request. Test programs will be developed as necessary, if operational changes are planned for the future.

15.0 ACCIDENT ANALYSIS

15.1 Introduction

This chapter discusses the response of the MCZPR facility to postulated disturbances to process variables and to postulated malfunctions and/or failures of equipment, and their effect on the safety of the facility.

15.2 Nuclear Excursions

It is difficult to visualize any circumstances which would result in a reactivity increase of a magnitude sufficient to cause serious degradation of the core of this reactor. The maximum excess reactivity at the MCZPR is a very low 0.29%. Nuclear excursions during operation and during fuel loading may be postulated.

15.2.1 Three possible methods of introducing maximum excess reactivity during operation may be visualized.

1. All the circuits of the reactor protection system were to fail simultaneously, and the operator withdraws both control rods completely. This is extremely unlikely to happen.

2. The operator deliberately withdraws both rods completely allowing the reactor to operate at a power level that would exceed the maximum allowable limit of 0.1 watt.

   Such behavior on the part of an operator is very unlikely to occur. In addition, the presence of a Reactor Supervisor, as required by the operational procedures, will prevent the occurrence of such an event.

3. A sample having very high cross section could be inserted into the core and both control rods could be withdrawn completely without exceeding the allowable power limit. If the sample is withdrawn without reinserting the control rods, maximum excess reactivity could occur.

   All experiments performed in the reactor are very closely monitored by the Reactor Operations Committee. No new experiment involving the reactor is allowed to be performed without the express approval of the Reactor Operations Committee. Thus, the insertion of maximum excess reactivity during an experiment is unlikely.

15.2.2 Nuclear Excursion During Fuel Loading

Fuel replacement in the reactor at any reasonable time in the future is not needed due to the very low power (0.1 watt maximum) and the infrequent use of the reactor. However, if removal of fuel and

subsequent replacement is needed for purposes of maintenance, the personnel involved will be under the supervision of a Reactor Supervisor. Nuclear excursion during this process (if it were needed) is unlikely.

15.3 Effects of Rapid Reactivity Insertion

The rapid insertion of maximum reactivity could produce a power level of 147 KW. This was demonstrated in calculations submitted to Mr. Marvin K. Woodard, Division of Licensing and Regulation, dated October 6, 1966. This communication is given as Appendix G.

15.4 Loss of Coolant Accident

There is no recirculating coolant system in the reactor. Any leaks from the tank would lower the water level which in turn would activate the "Low Water Level Scram" circuit shutting down the reactor.

15.5 Fission Products Release

The MCZPR is designed to operate at a maximum power of 0.1 watt. The chances of the fuel elements melting and releasing fission products are very low.

15.6 Radiation Dose for the Maximum Hypothetical Accident

The radiation dose for the maximum hypothetical accident was computed to be 18.5 roentgens at the water surface above the core center line as reported to Mr. Roger S. Boyd, Research and Power Reactor Safety Branch, Division of Reactor Licensing as part of the communication dated November 15, 1966. This communication is reproduced here as Appendix H. It is noted that these results are unchanged as a result of confirming excess reactivity measurements made in 1967 for the MCZPR. The results of these tests are given in Appendix I.

15.7 Conclusion

The chances for an accident are very low at the MCZPR. Even if a maximum credible accident is hypothesized, the effects are not severe.

16.0 TECHNICAL SPECIFICATIONS

Section 50.36 of 10 CFR Part 50 requires that each operating license issued by the Nuclear Regulatory Commission contain Technical Specifications that set forth the limits, operating conditions, and other requirements imposed on facility operation for the protection of the health and safety of the public and other reasons.

The Manhattan College Zero Power Reactor was licensed by the Atomic Energy Commission on March 24, 1964 under Facility License R-94. On the same day, the AEC approved the Technical Specifications for the Manhattan College Zero Power Reactor as an Appendix to Facility License R-94.

Five amendments to the Facility License and eight changes in the Technical Specifications have been approved by the Atomic Energy Commission and the Nuclear Regulatory Commission since March 24, 1964. All of these changes have been incorporated into the Technical Specifications presented in this section.

16.0 TECHNICAL SPECIFICATIONS

FOR THE

MANHATTAN COLLEGE ZERO POWER REACTOR

TABLE OF CONTENTS

A. Site

1. The Manhattan College Zero Power Reactor (MCZPR) is located in the Leo Engineering Building of Manhattan College at 3825 Corlear Avenue, New York City, New York.

2. The laboratory room where the reactor is located (described in section B. 2.) is considered a restricted area as defined in paragraph 20. 3 (a), 14, of 10 CFR 20.

3. The principal activities carried on within the site are those related to the educational program of Manhattan College. The reactor may be utilized in this program for instructional use and may be used in experiments as described in section E. 4. d.

B. Building

1. The Leo Engineering Building of Manhattan College is a four story, brick building providing space for Engineering and Science Laboratories. The building provides classrooms, computer facilities, and laboratories for an estimated 1800 students at any one time, as well as office space for the Dean of the School of Engineering, chairmen, and faculty members using the building.

2. The laboratory housing the Manhattan College ZPR is completely separated from the remainder of the Reactor Laboratory as shown in figure 1. Security locked doors provide the only access to the Reactor Laboratory.

3. The MCZPR laboratory has the following penetrations:

   a. Electrical conduits
   b. Air circulation system
   c. Door
   d. Window

4. The MCZPR is located in the laboratory as shown in figure 1. The reactor tank shall rest on a concrete slab in the first floor and shall extend upward through the second floor. The first floor room housing the reactor shall have concrete walls extending from the floor to the ceiling on three sides and a metal partition from the retainer wall to the ceiling on the fourth side. The only access to the reactor from the first floor shall be through a metal door which shall penetrate the metal partition as shown on figure 1. The metal door shall be kept locked at all times when there is fuel in the reactor. The only access to the first

floor of the MCZPR room when fuel is in the reactor shall be through a trap door in the reactor platform and down a vertical steel ladder adjacent to the reactor tank.

5. The reactor platform, described in section F. 11, shall be located on the second floor above the tank whenever fuel is located in the reactor. The platform shall be surrounded by a link fence to prevent personnel from inadvertently approaching the open areas in the platform.

6. In addition to the concrete walls extending from floor to ceiling on three sides of the first floor room housing the reactor, a concrete berm has been constructed on the fourth side sufficiently high to contain all the water in the reactor tank.

7. The window to the MCZPR Laboratory shall have a window guard to prevent unauthorized entry into the room, and the door into the facility shall be locked whenever a reactor operator is not in attendance in the room.

8. During times when an operator is not in attendance in the MCZPR Laboratory, the building shall be under the periodic surveillance of members of the faculty or the campus security force.

C. <u>Ventilation</u>

1. The MCZPR Laboratory shall contain a forced circulating ventilation system consisting of a blower and associated duct work. There shall be no connection between this system and any other part of the Leo Engineering Building.

2. A switch shall be provided in the reactor room to turn the ventilation system on and off.

D. <u>Radiation Monitoring</u>

1. Two radiation monitoring channels shall be provided to measure gamma intensity. These channels shall also be used to monitor reactor operation and shall be used in the reactor safety system as described in Section I. A common strip chart recorder shall be provided with a selector switch for recording the output of either channel.

2. Each channel consists of a Gamma Detector and Gamma Indicator Unit.

3. The Gamma Detector shall be a sealed unit containing a Geiger-Mueller tube, transistorized count rate amplifier, and check source. The output from the Detector shall be logarithmic

with respect to the radiation level. The check source shall be exposed to the Detector by a solenoid which is actuated by a pushbutton on the control chassis.

4. One of the Detectors (Gamma 1) shall be located on the reactor platform directly over the core area while the other Detector (Gamma 2) shall be mounted on the side of the reactor tank.

5. The Gamma Indicator shall contain the power supply for the system, the alarm reset check source control, and the output connector for the Detector. Also contained on the front of the Indicator is a logarithmic meter relay for indication and alarm of the gamma level. The alarm shall be set to give audible annunciation whenever the radiation level exceeds 6mR /hr for Gamma 1 and 10 mR/hr for Gamma 2.

6. The range of both detectors shall be from .01 to 100mR /hr. The system shall be designed so that if the radiation intensity is greater than 100mR/ hr the detector shall indicate full scale.

E. Administration and Procedural Safeguards

1. Introduction

The specifications pertaining to the management of the facility and the operating standards and procedures to be used during startup, operation, and refueling of the reactor are in this section. Unless expressly excepted all operations of the reactor shall be in accordance with the provisions of all sections of these technical specifications. As used in these technical specifications, reactor operation shall include all actuation or manipulation of the reactor control and instrumentation systems while fuel is in the reactor tank, movement of reactor fuel or other components or apparatus within the reactor tank, conduct of experiments, and maintenance.

2. Reactor Management

a. Organization

The personnel organization as shown on Figure 2 shall be in effect in order to insure safe operation of the reactor. A staff member shall be assigned to each position to assume responsibility in each functional area. The duties and responsibilities in each area shall be as follows.

b. Description of Duties

(1) Reactor Administrator will provide final policy decisions on all phases of reactor operation and on regulations for the facility as a whole. He

will be advised in all matters concerning the safe operation of the reactor by the Reactor Operations Committee. The Reactor Administrator shall be responsible for the overall administration and supervision of the reactor facility. He shall appoint qualified members to the Reactor Operations Committee from time to time as necessary. He shall designate Reactor Supervisors and name the Chief Reactor Supervisor. The Reactor Administrator shall approve and promulgate all regulations, instructions, and procedures governing the operation of the reactor facility.

(2) Reactor Operations Committee shall be responsible to the Reactor Administrator for the review and evaluation of all proposed operations and procedures in order to insure that the reactor facility shall be operated in a safe and competent manner. Particular emphasis shall be placed on the examination of new and untried operations and procedures, and the Committee shall take action on all new experimental plans. The Committee shall review and evaluate all proposed changes in the experimental plans which involve changes in the reactor system. The Reactor Operations Committee shall advise on and be available for advice and assistance on any problems relative to the safe operation of the reactor facility.

(3) Radiation Safety Officer shall be responsible for the promulgation and enforcement of rules, regulations and operating procedures which conform with the regulations set forth in 10 CFR, Part 20. The Radiation Safety Officer in conjunction with the Reactor Operations Committee shall approve suggested procedures for the purchase, possession, storage use and disposition of all radioisotopes, consistent with general or specific licenses for use of by-product material issued by the Commission to Manhattan College. The Radiation Safety Officer in conjunction with the Reactor Operations Committee, shall be available for advice and assistance on problems involving radiological safety arising from the operation of the reactor facility. The Reactor Operations Committee shall evaluate and approve all proposed procedures leading to the production of

radioisotopes with a half life longer than one (1) hour. All operations leading to the production of more than one (1) millicurie of radioactivity, with any half life, must receive prior approval of the Reactor Operations Committee.

(4) Health Physicist shall be responsible for monitoring records of exposure on film badges, maintenance of a log on radiation tests and exposure records. He also shall review the reactor log. Periodic radiation surveys of the critical reactor laboratory, the subcritical laboratory and the counting room, and other areas where radioactive materials are being used, shall be made by the Health Physicist under the direction of the Chief Reactor Supervisor. The Radiation Safety Officer shall be notified if an abnormal radiation problem is encountered. Results of these surveys shall be recorded or filed in the log. The Health Physicist shall also be responsible for proper disposal of samples and radioactive materials.

(5) Reactor Supervisors shall be appointed by the Reactor Administrator. These individuals shall have general competence in reactor technology and associated fields. Each supervisor shall hold a senior operator's license issued by the Nuclear Regulatory Commission. The Reactor Supervisors shall be responsible to the Reactor Administrator, through the Chief Reactor Supervisor, for the preparation and submission of complete detailed proposed experimental procedures, regulations and administrative rules to insure the maintenance, safe operation, proper and competent use, and security of the reactor equipment. Appointment as a Reactor Supervisor shall in all cases be accompanied by appointment to the Reactor Operations Committee.

The Reactor Supervisors shall be responsible for the preparation and submission of operating schedules of the reactor facility, and shall insure that all activities and experiments involving the facility conform to both local and Commission regulations. They shall establish in coordination with the Reactor Operations Committee, procedures

for experiments to be performed with the reactor. They shall establish procedures and be responsible for the keeping of adequate, complete and currently accurate records for the operation and maintenance of the facility.

A Reactor Supervisor shall be in charge of the facility and, except as provided in E. 4. d. (1), shall witness the startup and intentional shutdown procedures. In addition, he shall be responsible for prompt execution of emergency procedures.

(6) Chief Reactor Supervisor shall hold a valid senior operator's license issued by the Commission. He shall be responsible for the promulgation and enforcement of administrative rules, regulations and operating procedures. He shall inform the Reactor Operations Committee of any unusual operations proposed to be performed on the reactor, or any proposed changes in procedure. He shall not authorize the operation or proceed with the proposed changes until appropriate evaluation and approval has been made by the Reactor Operations Committee, and authorization given by the Reactor Administrator. The Chief Reactor Supervisor shall have the authority to authorize any experiments or procedures which have received prior approval of the Reactor Operations Committee. He shall be directly responsible for enforcing operating procedures and insuring that the reactor facility is operating in a safe, competent and authorized manner at all times. In addition, he shall be directly responsible for the preparation, authentication and storage of all prescribed logs and operating records.

(7) Reactor Operators shall hold a valid operator's license issued by the Commission. They must conform to the rules, instructions and procedures for the start-up, operation, and shut-down of the reactor facilities as set forth in Section 4 a, b, c of the Technical Specifications. They must also conform to the specifications of the Emergency Plan for the Zero Power Reactor. Within the constraints of the administrative and supervisory controls out-

lined above, a reactor operator shall be in charge of the control console at all times that the reactor is operating. The reactor operator shall be required to maintain complete and accurate records of all reactor operations in the operational logs.

All personnel using the facility shall be instructed in the hazards involved, and given a copy of the laboratory regulations concerning use of radioactive material. All personnel working in the vicinity of the reactor shall wear film badges.

3. Operating Standards

The basic premise of all proposed operating standards is the safety of the reactor, its operating personnel, and the immediate surroundings.

a. Operation Limitations

(1) All operations which are conducted with fuel in the core, and that may change core reactivity, shall be conducted in accordance with approved written instructions.

(2) Whenever fuel is present in the core tank and a reactor operator is not in attendance, the control console shall be off and locked; if no one is in attendance, the ZPR Laboratory door shall also be closed and locked. The key to the reactor key switch shall be in the possession of a reactor supervisor.

b. Operating Personnel Requirements

(1) The controls of the reactor shall be operated only (the reactor controls are to be regarded as operating if the "Reactor On" switch is turned to "ON" and fuel is present in the core tank) with the specific authorization of a reactor supervisor. The reactor operator shall be responsible for obtaining the authorizing signature of a reactor supervisor at the top of the checkout sheet. The reactor supervisor signing the authorization is the supervisor "in charge".

(2) Whenever the reactor controls are operated, a licensed reactor operator shall be present and in the immediate vicinity of the console. An up-to-date list of licensed reactor operators will be posted near the reactor console. A person is considered "present" if he is in the console room within view of the instruments on the console.

(3) A Reactor Supervisor shall be present in the Leo Engineering Building at all times that the reactor controls are operated and shall be cognizant of the reactor operation at all times. If the supervisor in charge of the operation must leave the building, the reactor controls must either be turned off and locked or another supervisor must accept responsibility. The reactor operator shall be informed of such a transfer of authority. A list of Reactor Supervisors will be posted near the reactor console.

c. Fuel and Experimental Loading, Personnel Requirements

(1) Any movement of fuel elements or of material into or out of the reactor core can be done only on specific written authorization of or in the presence of a reactor supervisor.

(2) At least two persons, one a licensed reactor operator, shall be in the ZPR laboratory when any fuel elements or any experiment is moved in the reactor core. One person shall be at the reactor console.

(3) Whenever the final fuel element necessary for attainment of criticality is transferred into the core, a reactor supervisor shall be present.

(4) A reactor supervisor shall be present in the ZPR room during the loading of an experiment into the core for the first time, or its removal from the core. A supervisor shall be present in the ZPR room or give his written authorization for repetitive insertions of an experiment. Any object, other than a fuel element or handling tool, which is inserted into the volume formed by projecting the grid plate vertically to the tank surface, is to be regarded as an experiment in the core.

d. Records

(1) The reactor log shall consist of (1) completed checkout and operation forms, (2) completed fuel element transfer forms and (3) entries in the permanently bound log book.

(2) The following information shall be recorded in the log:

(a) all changes in reactor instrumentation and equipment,

(b) all changes in the core, and

(c) any unusual condition.

4. Operating Procedures

Operating procedures for the facility shall be in accordance with the following specifications:

a. Checkout Procedures

(1) A check of the instrumentation shall be made prior to reactor operation on each day that the reactor is to be started. The checkout procedure shall be designed to show the presence of a malfunction in any of the safety circuit or interlocks, to test the response of the log N, linear, and area radiation meters, to check the scram levels, and to determine whether any unusual condition exists. A standard form to be followed shall be provided by the laboratory and becomes part of the reactor log.

(2) In the event the checkout reveals any unusual condition of any instrument not functioning properly, the reactor operator shall inform the reactor supervisor.

b. Startup and Operation

(1) To start operations, the operator shall first turn on all instruments and recorders, marking the recorder chart to identify date and operator, and set the picoammeter at its most sensitive on-scale range. The reactor key switch may then be turned on and magnet current may be established by pressing the RESET pushbutton. Magnet voltage shall be recorded. Warning shall then be made throughout the reactor area that the reactor is being started.

(2) During operation with the reactor critical:

1. Initial critical rod positions shall be recorded using the Fine Position Circuit;
2. Readings of all instruments shall be recorded hourly; and
3. Any unusual conditions shall be recorded.

c. <u>Reactor Shutdown</u>

(1) The reactor may be shut down by either running the rods in under power by pressing the RUN-IN button or by intentionally testing the Linear Channel High Flux or other scram circuits.

(2) The Linear Channel High Flux test may be performed by leaving the picoammeter on its existing range and increasing the power level gradually until the trip level is reached.

d. <u>Use of the Reactor</u>

(1) <u>Teaching Experiments</u>

All experiments except the following experiments for teaching purposes, shall be conducted in the presence of a Reactor Supervisor. The following experiments, while not requiring the presence of a Reactor Supervisor, require the presence of a Reactor Operator.

1. Startup and Operation of Manhattan College Zero Power Reactor: Approach to Criticality
2. Critical Mass Determination
3. Reactor Period and Reactivity
4. Void Coefficient Measurement
5. Flux Distribution in the Manhattan College Zero Power Reactor
6. Determination of Buckling
7. Measurement of Diffusion Length and Age
8. Temperature Coefficient of Reactivity
9. Determination of Disadvantage Factor
10. Danger Coefficient Tests
11. Gamma Ray Energy Spectrum in the Vicinity of the Reactor Core

(2) Limitations on Experiments, Including Material Irradiations

1. No experiment shall be installed in the reactor in such a location that any part of the apparatus will touch or in any way interfere with the action of the control rods.

2. No experiment shall be installed in the reactor that can shadow the nuclear instruments, thereby giving erroneous or unreliable information to the reactor operator.

3. No experiment which has explosive properties shall be irradiated.

4. Experiments containing materials whose release to the water could result in a violent chemical reaction (e.g. Sodium) or would result in chemical or corrosive attack to the reactor components (e.g. Mercury) shall not be irradiated.

5. Experiments containing materials whose release could result in overexposure of personnel to gaseous or particulate radioactivity shall not be irradiated.

6. Each experiment, other than teaching experiments defined in E. 4. d. (1). shall receive the specific approval of the Reactor Operations Committee. In addition, all operations leading to the production of more than one millicurie of any radioisotope outside of fuel elements shall receive the approval of the Reactor Operations Committee.

7. A record of each material irradiation must also be included in the reactor log. The record shall include at least the following data:

   i. Material irradiated
   ii. Position in core
   iii. Reactor Power
   iv. Irradiation time, time in, time out
   v. Dose rate on contact at time of removal
   vi. Supervisor's approval(signature)

5. Emergency Procedures

Written instructions governing emergency and evacuation procedures shall specify the necessary action to be taken in the event of an emergency, such instructions shall be posted in easily accessible locations both inside and outside the ZPR room. Personnel who are responsible for taking emergency action shall be acquainted with these procedures. The emergency procedures shall be reviewed at intervals of not more than once per year by the Reactor Operations Committee and shall be revised as necessary.

F. Design Specifications of Reactor

Whenever fuel is present in the reactor tank, the facility design shall conform to the specifications of this section F. The reactor shall be heterogeneous, tank-type reactor moderated by light water. The principal components shall be the reactor vessel, core, control system, and the purification system. These components shall be as described below:

1. The reactor vessel shall consist of a cylindrical aluminum tank eight feet high and ten feet in diameter. The tank wall shall be one quarter of an inch thick. The only tank wall penetration shall be a 3/4 inch diameter aluminum coupling located near the tank bottom with a 3/4 inch diameter short nipple and a 3/4 inch aluminum gate valve. The inlet to the demineralizer shall be connected to this gate valve. The outlet of the demineralizer feeds into a pipe which shall rise vertically and form a gooseneck loop over the edge of the tank.

2. The reactor vessel shall be located as in Figure 1 and shall be held in place by five aluminum brackets welded to the sides of the tank near the bottom. These brackets shall be bolted to the concrete floor.

3. A grid plate stand as shown in Figures 5 and 6 shall be welded to the bottom of the reactor tank.

4. A grid plate shall be bolted to the grid plate stand. The design of the plate including attachments thereto shall be as shown in Figure 7. Fuel element hold down rods shall be threaded into the grid plate unless an approved experimental program requires their removal. The holes in the support cylinders for the incore fuel elements may be plugged.

   The shafts of these hold-down rods shall be made partly of aluminum and partly of lucite. The lucite portion shall consist of a solid rod one inch in diameter. The threaded base of the hold-down rod shall be made of aluminum tubing having a one-eighth inch wall thickness. The broad top of the hold-down rod, which extends over the top of the fuel element shall also be made of aluminum. The aluminum portions of the hold-down rod shall be securely fastened to the lucite by aluminum pins and epoxy cement.

5. The design of a fully loaded element shall be as shown on Figure 3. The fuel portion of such elements shall consist of six concentric cylinders formed by mechanically joining and positioning eighteen curved fuel plates within grooves of 3 spacer webs. The fuel plates shall be mechanically held on the grooves by roll bonding; the bonding shall yield joint strengths of at least 200 pounds per linear inch. The fueled portion of the element shall be 24 inches long and shall be located within a 1/8 inch thick, 3.51 inch OD support clyinder which is 37 inches long. The support cylinder shall extend 6-1/2 inches beyond the fueled region on either end; this axial position shall be maintained by 3 plug welds joining the spacer webs and the support cylinder. Three lugs shall be provided on the inside of the support cylinder at each end. At one end, these lugs will position the cylindrical fuel element in the slots in the "positioning lug" attached to the grid plate and at the other end will be used to mate with a fuel handling tool. Partially loaded elements shall, except for the number of fuel plates, be designed in accordance with this paragraph.

6. The cylindrical fuel plate shall consist of 0.020 inch thick U-Al alloy of 92% enriched uranium, clad on both sides with 0.015 inches of aluminum making the total plate thickness 0.050 inches. The nominal U-235 content of each full fuel element shall be 200 grams.

7. A maximum of 15 fuel tubes described in F.5 and F.6 plus one partial fuel element which may have some of the fuel plates missing, shall be used in the facility.

8. The critical assembly shall be controlled by two Y-shaped control blades which pass in the clearance between adjacent fuel elements. Construction details and dimensions shall be as shown in Figure 4. One control rod (shim rod) shall be constructed so that the blades are formed by sandwiching a 1/16 inch sheet of cadmium between 1/16 inch layers of stainless steel. The other control rod shall be an all stainless steel regulating rod. Either one of these control rods shall be capable of preventing the reactor from becoming critical.

9. Each control blade shall be guided by a guide assembly for the full length of the control rod stroke. These guide assemblies shall prevent any bearing of the control blades on the fuel elements. The guide assemblies, which shall be positioned on the grid by pins, shall also act as sway bracing for the guide tubes. Details of the guide assembly, the methods for positioning on the grid plate, and the method for connection to the guide tube shall be as shown in Figure 4. The guide tube shall be bolted at the upper end to the control rod drive units.

10. Each control rod shall be attached to its associated drive mechanism by an electromagnet and shall fall by gravity to the least reactive position upon decrease of magnet current as a result of scram action. A system shall be provided to give indication at the control console that a control rod is in contact with the magnet.

11. A reactor platform shall be located over the reactor tank on the second floor of the ZPR laboratory. The platform shall be bolted to the concrete floor of the room. The neutron and gamma-ray detectors described in Section H shall be suspended from this platform. The control rod drive mechanisms described in F. 12 shall be bolted to the structural members of the reactor platform.

12. The control rod drive system shall be designed in accordance with the specifications in this subsection. Each control rod drive system shall be the standard American Machine and Foundry (AMF) designed cantilever drives with a design drive speed no greater than 12 inches per minute. Rod motion shall be controlled from the console by individual momentary contact toggle switches having an IN-OFF-OUT selection. Driving the control rods into the core by a reverse action as described in section I. 2 shall override any manual selection. Each drive shall also have position indication from the "full-in" to the "full-out" position.

The position sensing element shall be a potentiometer located in each rod drive mechanism. Coarse position readout shall be provided on the control console in the form of two indicators reading from 0% (full-in) to 100% (full-out). The system shall indicate rod position with an accuracy of 2%. A fine position indication system shall also be provided to indicate rod position with an accuracy of 0. 1%.

13. The control console for the reactor shall be located as shown on Figure 1. The control console shall contain all the necessary switches, lights, and indicating instrumentation required to operate the reactor. Motion of the control rods out of the reactor shall be possible only by actuation of console control switches.

14. A moderator demineralizer system shall be located in the basement of the reactor laboratory. The system shall be a closed loop containing a pump and demineralizer. The flow rate through the demineralizer bed shall be valve controlled between 5 and 20 gallons/min/ft^2.

15. The startup source shall be a Pu-Be source encapsulated in tantalum. The minimum source strength shall be one (1) curie (approximately 10^6 neutrons per second).

G. Core Parameters

Fuel shall be loaded into the reactor tank so as to conform to the specifications of this Section G.

1. The core shall be comprised of no more than fifteen standard fuel elements and one partial element. The number of fuel plates contained in the partial element shall be adjusted so that the most reactive core configuration possible will result in an excess reactivity, with both control rods completely withdrawn, no greater than 0.44% delta k/k.

2. No reflector elements, additional fuel or other material shall be installed or placed in the reactor so as to increase the excess reactivity above that specified in G. 1.

3. No special nuclear materials other than those specified in Section F shall be placed in the reactor tank except the following:

   a. U-235 in foils or fission chambers not to exceed two (2) grams.

4. The core configuration shall be such that the calculated void coefficient shall be negative and shall have minimum absolute values as follows:

   a. Center of core 6.8×10^{-6} $\Delta k/cc$

   b. Edge of core 1.7×10^{-6} $\Delta k/cc$

5. The temperature coefficient of reactivity attributed to heating the moderator within the fuel elements shall be negative with a calculated absolute value not less than 1.5×10^{-4} delta k/k per ^{o}C.

6. Core configurations shall be such that the minimum control rod worths shall be:

   a. Cadmium shim rod - 0.025

   b. Stainless steel rod -0.009

   Both control rods shall be installed and fully inserted before fuel is initially loaded in the core, and subsequently, whenever any component or fuel element is moved that will increase core reactivity.

H. Nuclear Instrumentation

Whenever fuel is present within the reactor tank the design of the nuclear instrumentation system shall conform to the specifications of this section.

1. The following channels of instrumentation shall be functioning when the reactor is operated in the ranges listed or core components are being moved. These channels shall be of the type and range as specified below:

Channel	Type	Detector	Range
Count Rate Channel	Log Count Rate Meter and Period Meter	BF_3 Proportional Counter	Source Level to 150 milliwatts
Linear Channel	Picoammeter	Uncompensated Ion Chamber	Source Level to 200 milliwatts
Gamma Channel # 1	Area Radiation Monitor (.01-100 mR/hr)	Geiger-Mueller Probe	.01 watts to 10 watts
Gamma Channel # 2	Area Radiation Monitor (.01-100 mR/hr)	Geiger-Mueller Probe	.01 watts to 5 watts

2. The count rate channel shall consist of a BF_3 proportional counter, a preamplifier, high voltage power supply, scaler, log count rate meter, log count rate recorder, period detector, and a period indicator. The count rate channel detector shall be suspended from the reactor platform in the vicinity of the core such that a count rate of at least 2 counts per second are indicated as a result of subcritical multiplication with both control rods fully inserted.

3. The linear channel shall consist of an uncompensated ion chamber, high voltage power supply, picoammeter, and a linear recorder. The linear channel detector shall be suspended from the reactor platform in the vicinity of the core such that a current greater than 5% of full scale as indicated on the recorder with the most sensitive scale selected on the amplifier will result with both rods fully inserted. The highest scale setting on the picoammeter shall be physically set such that 100% of full scale shall be less than 0.2 watts.

4. The gamma channels shall be located as described in section D.

5. The control console shall contain the following indicators for the nuclear instrumentation:

   a. A scaler, log count rate meter, period indicator, and a log count rate recorder for the count rate channel.

   b. A picoammeter and linear recorder for the linear channel.

   c. A gamma indicator for each of the gamma channels and a gamma recorder to record the intensity from either channel.

I. Safety System

The following circuits shall be functioning whenever fuel is in the reactor and power is available to the control drives.

1. Scram Circuits

A scram system shall be provided that will cause interruption of the magnet current to the electromagnets supporting the control rods whenever a scram trip is exceeded. Power to the magnets shall be available when the "reactor on" switch is on and there are no scram trip signals. A scram trip shall be provided for each of the conditions below, with the trip setting as specified:

a. High neutron flux - Count Rate Channel electronic trip set for 400% or less of Full Power (Full power shall be equal to 0.1 watt).

b. High neutron flux - Linear Channel electronic trip set for 200% or less of Full Power.

c. High gamma activity - high level signal from either of the two Gamma Channels electronically set for 10 mR/hr or less.

d. Manual scram - operates upon actuation of the manual scram button on the console.

e. Low water level - operates when the tank water level drops one foot below the tank full position.

f. Reactor key switch off - operates when the "REACTOR ON" switch is turned to the off position.

g. Power failure - operates whenever the power supply to the console or to the nuclear instrumentation fails.

2. Reverse Circuits

A reverse system shall be provided that will cause both control rod drives to drive the control rods into the reactor whenever a reverse trip is exceeded. The reverse action shall override any rod selection made by an operator and shall persist as long as a reverse trip level is exceeded. Reverse trips shall be provided for each condition as below with the trip setting as specified:

a. A Count Rate Channel reverse trip shall occur for any of the following conditions:

(1) Count Rate recorder off.

(2) Count Rate recorder down scale - shall occur when the recorder indicates less than 2 counts per second.

(3) Count Rate recorder up scale - shall occur when the recorder indicates greater than 50,000 counts per second.

b. Linear Channel reverse trip shall occur for any of the following conditions:

(1) Linear recorder off.

(2) Linear recorder down scale - shall occur when the linear recorder is less than 5% of full scale.

(3) Linear recorder up scale - shall occur when the linear recorder is greater than 95% of full scale.

c. Gamma Channel reverse trip shall occur for any of the following conditions:

(1) Gamma recorder off.

(2) Gamma recorder down scale - shall occur when the recorder indicates less than 0.2mR/hr. (It should be noted that the minimum reading on the recorder is 0.1 mR/hr while the minimum reading on the instruments on the Gamma Channels for Area Radiation Monitoring is .01 mR/hr).

(3) Gamma recorder up scale - shall occur when the recorder indicates greater than 95 mR/hr.

d. Any scram condition shall cause the control rod drives to drive in the electromagnets.

e. External reverse trip shall actuate for any external reverse conditions which may be added to the reverse circuit.

f. Manual run-trip - shall occur upon actuation of the "Run-In" switch on the control console.

3. <u>Bypass in Safety Systems</u>

The only bypasses in the scram or reverse circuits shall be those described below. The bypasses shall be key operated switches located on the console.

a. A bypass to eliminate a reverse as a consequence of the gamma recorder being down scale may be utilized during startup until the gamma recorder reads on scale.

b. A bypass to eliminate a reverse as a consequence of the linear recorder being down scale may be utilized in the initial fuel loading while conducting experiments to determine subcritical multiplication.

4. <u>Scram Times</u>

The following limits shall be verified every 6 months of operation and prior to operation of the facility if the facility is shutdown for 2 months or more.

a. The maximum time for total insertion from the full out position to the full in position as measured from the generation of the scram signal shall be less than 1.0 second.

J. Operating Limits

1. Reactor Power - The maximum steady state power shall be less than 0. 1 watt. When performing tests as described in Section E. 4. c. 1. , transient power shall not exceed 0. 2 watt.

2. Reactivity Addition Rate - The maximum reactivity insertion rate by control rods shall be less than . 001 $\Delta k/k$ per second.

3. A rod containing sufficient boron, cadmium, or other neutron absorber so as to have a minimum reactivity worth of 0. 030 $\Delta k/k$ when placed in the most effective core position shall be available on the reactor platform to be inserted manually between the fuel elements.

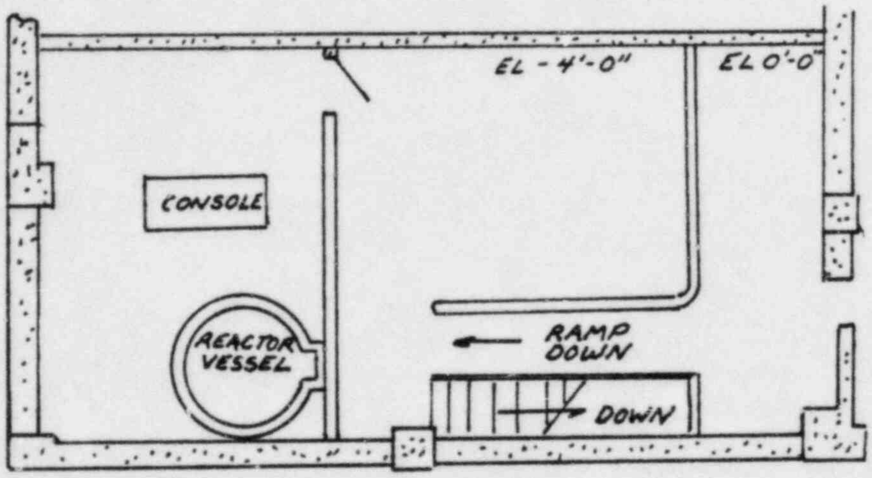
4. The reactor moderator shall be sampled for fission product activity once per semester employing a multi-channel analyzer for analysis.

5. Fuel elements shall be permanently stored on the reactor grid plate with the exception that three fuel plates may be permanently stored in a locked steel container fastened to the floor of the first floor of the MCZPR Laboratory.

6. A sample check of the lucite hold-down rods shall be made for evidence of radiation damage once each semester.

7. All fuel elements may be temporarily removed from the core for purposes of preventive maintenance. All elements shall be placed only in the original shipping containers located on the reactor floor. The Reactor Supervisor shall be present during removal and reloading of the fuel elements.

PLAN (ON SECOND FLOOR OF LEO ENGINEERING BUILDING)



PLAN (ON FIRST FLOOR OF LEO ENGINEERING BUILDING)

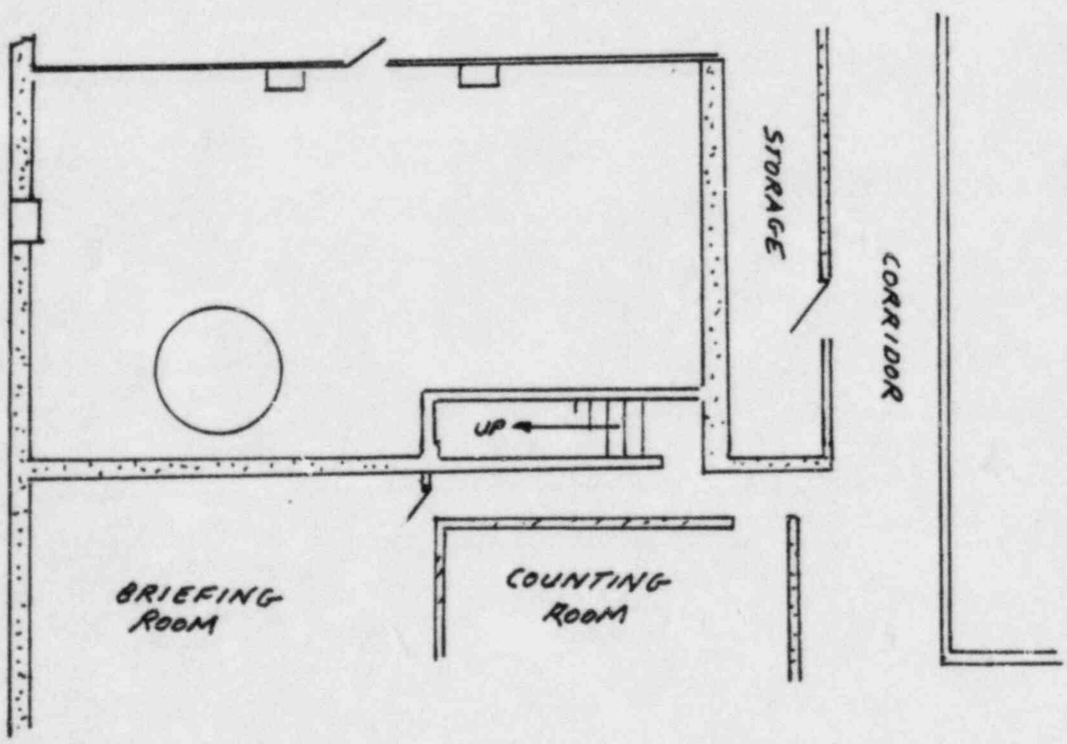


FIGURE 1. MCZPR LABORATORY

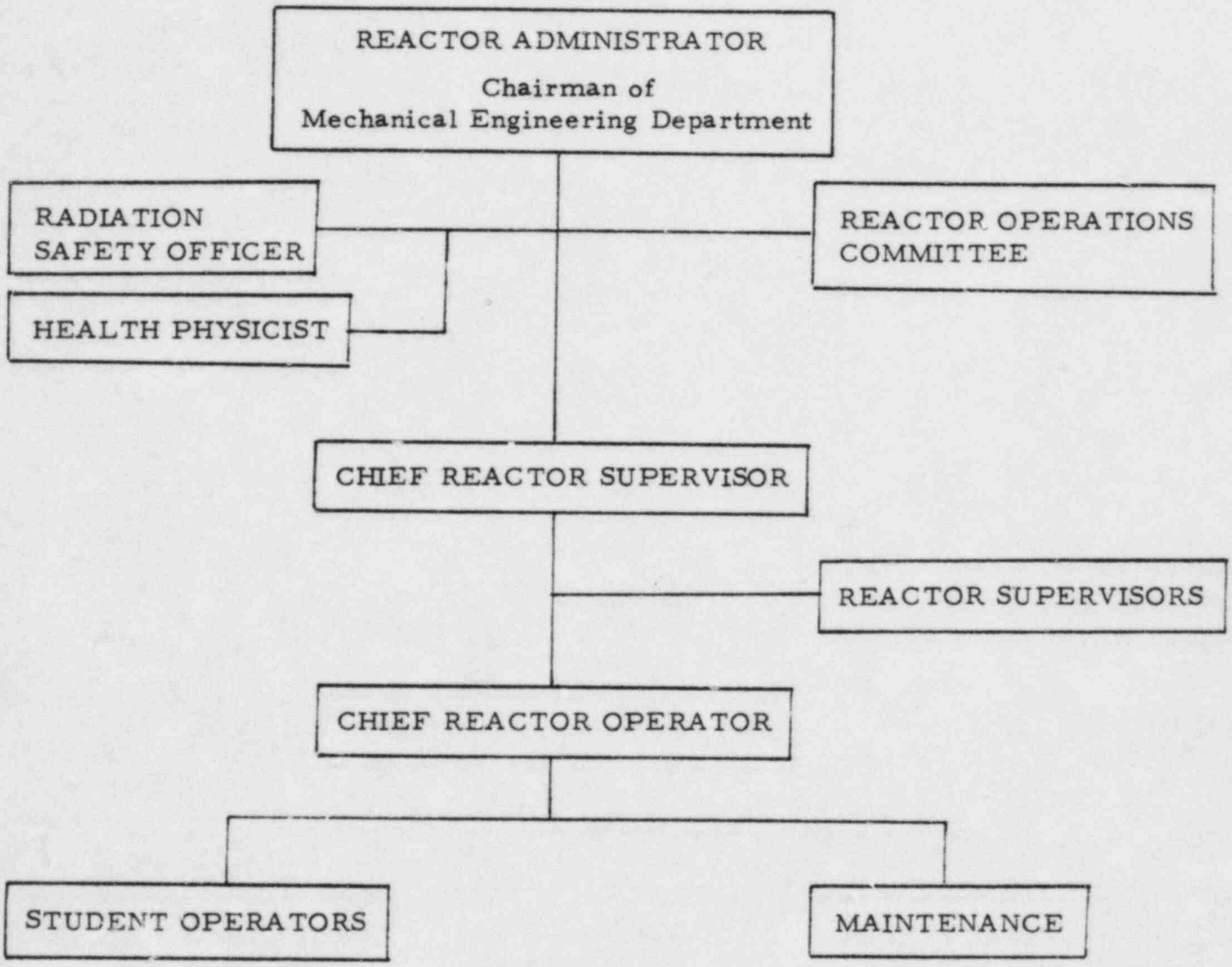


Figure 2. Table of Organization

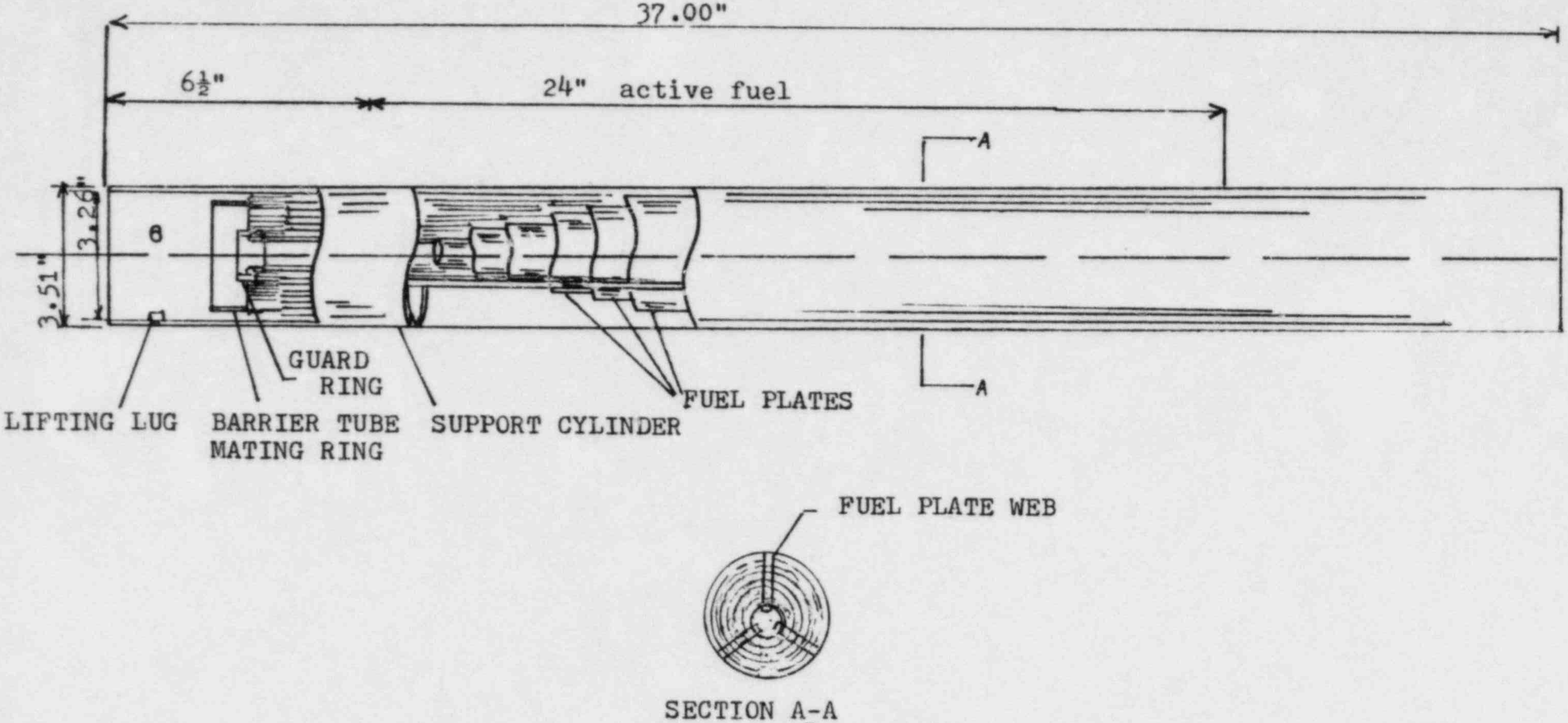


FIGURE 3 FUEL ELEMENT DETAIL

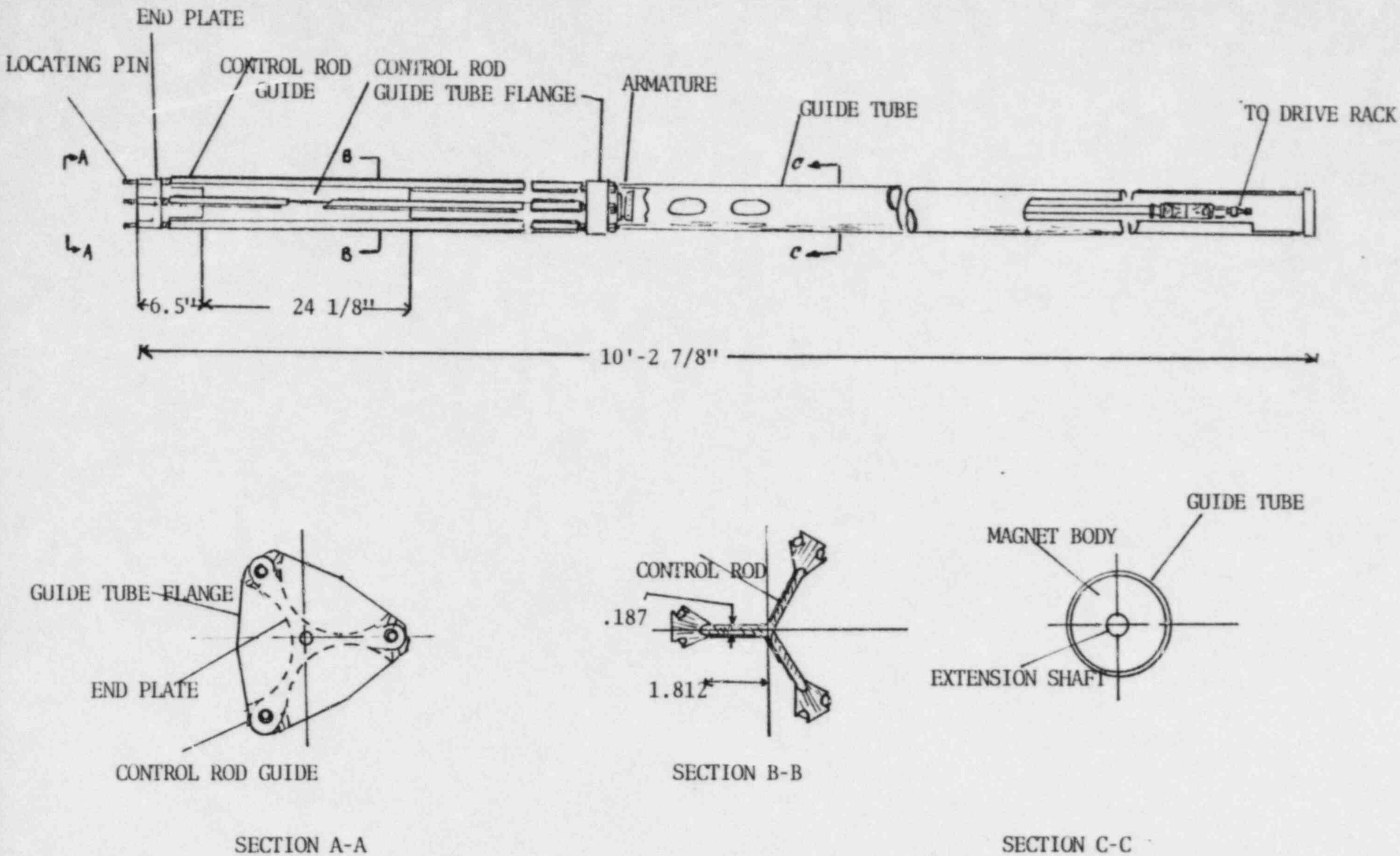


FIGURE 4 CONTROL ROD ASSEMBLY

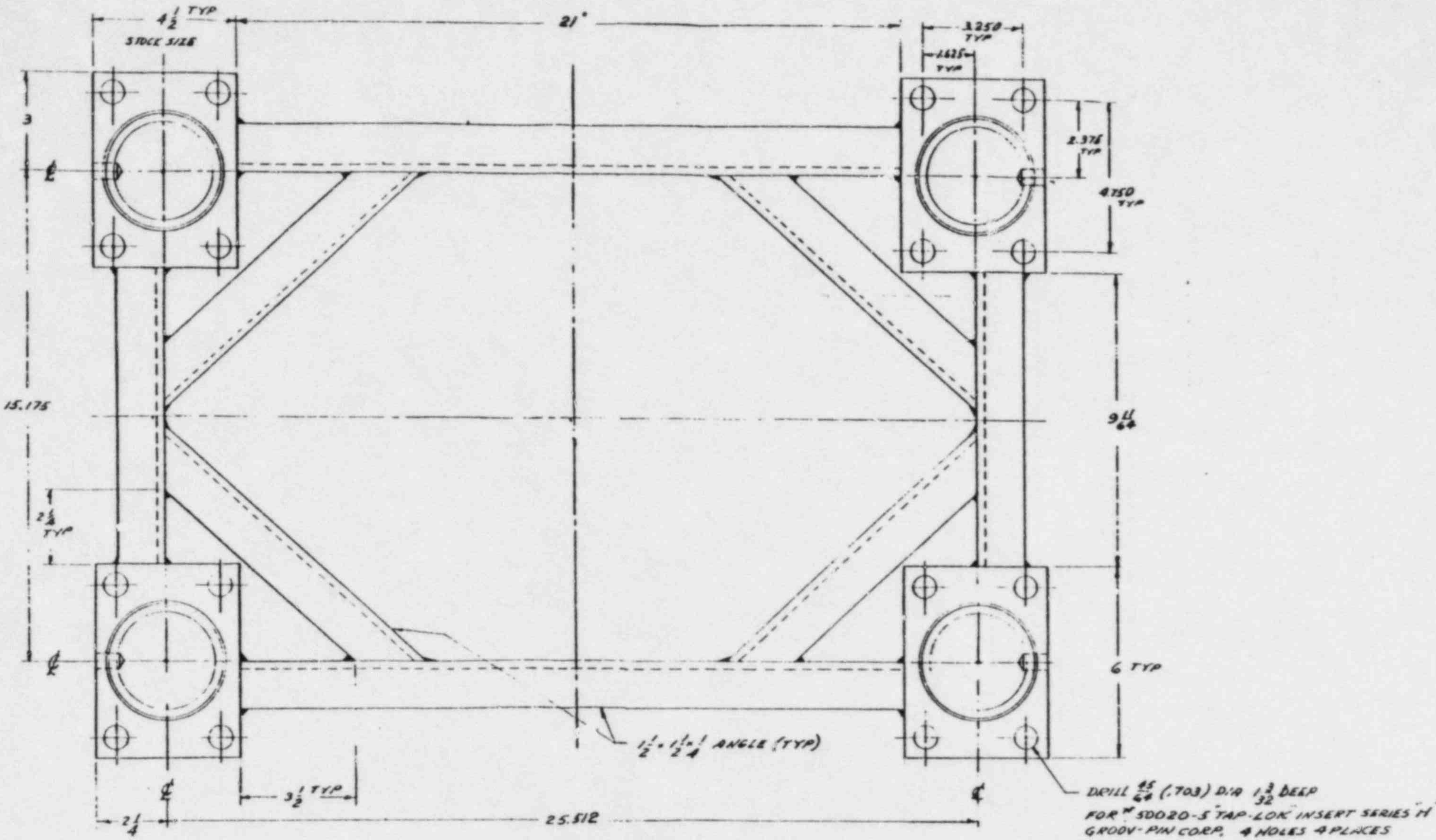


FIG.5 - GRID PLATE STAND (Plan View)

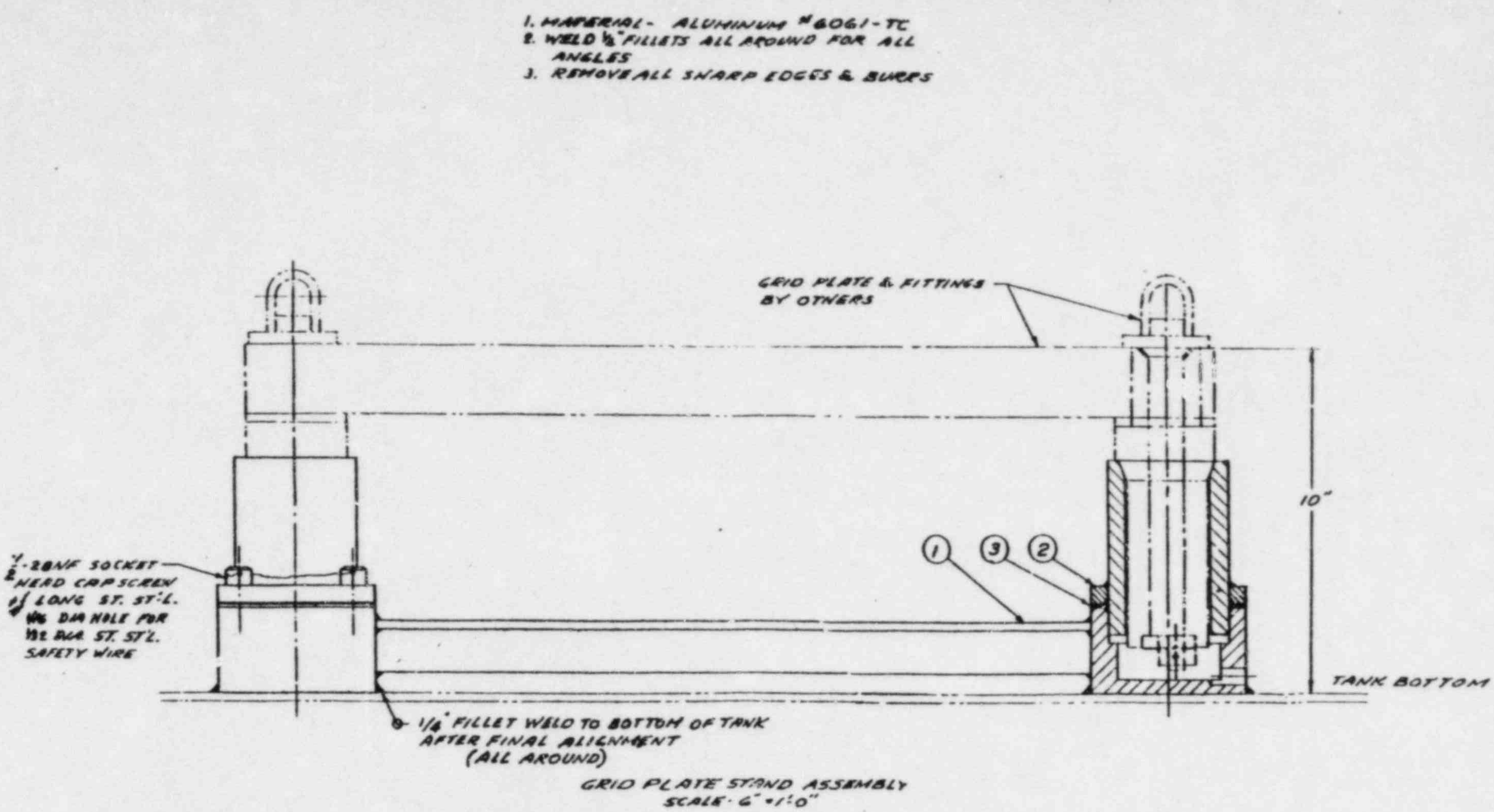


FIG. 6 - GRID PLATE STAND (Section View)

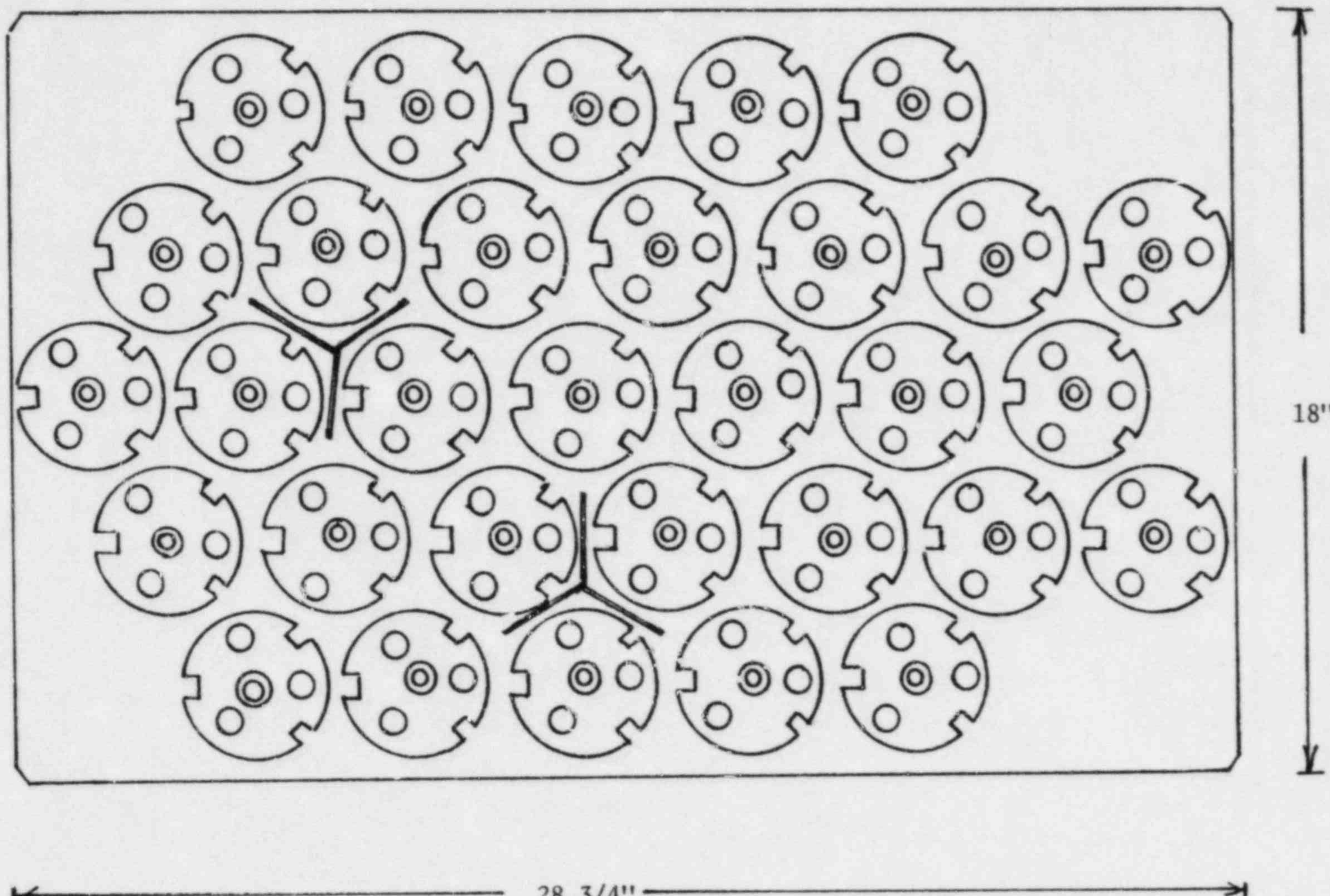


FIGURE 7 GRID PLATE

17. QUALITY ASSURANCE

Since the Manhattan College Zero Power Reactor has been licensed since 1964 and no plans for new construction and design changes are included in this license renewal request, the requirements of 10CFR Part 50 for a description of a Quality Assurance Program for design and construction are not applicable. The organizational structure and the duties of the Reactor Operations Committee provide assurance that all procedures are adhered to and proper documentation is maintained.

REFERENCES

1-1 "Facility License, No. R-94, Docket No. 50-199", March 24, 1964, signed by Robert H. Bryan, Chief, Research and Power Reactor Safety Branch, Division of Licensing and Regulation, Atomic Energy Commission.

1-2 "Amendment No. 1 to Facility License No. R-94", Docket No. 50-199, attachment to September 18, 1973 letter from Donald J. Skovolt, Assistant Director of Operating Reactors, Directorate of Licensing, Atomic Energy Commission.

APPENDIX A

RADIATION SAFETY MANUAL

Manhattan College

Nuclear Engineering Facility

RADIATION SAFETY MANUAL

Rev. 0

January 1, 1983

PREFACE

This Radiation Safety Manual replaces Part IV of the 1964 Manhattan College Reactor Manual.

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Manhattan College
Nuclear Engineering Facility

RADIATION SAFETY MANUAL

Stanley J. Malsky, Ph.D.

1. INTRODUCTION

1.1 Policy

This manual has been prepared to guide the activities of faculty members and students using the reactor, the radiation facilities, and radioactive materials in the Manhattan College Nuclear Engineering Facility. A number of general rules and procedures have been adopted, intended to safeguard all personnel. The Reactor Administrator will approve significant changes after review by the Reactor Operations Committee. The rules and procedures are designed to protect all individuals with a minimum of interference in their activities, consistent with the applicable rules and regulations of the Nuclear Regulatory Commission (NRC), with the terms and conditions of Manhattan College's License for Special Material, with the Manhattan College Reactor Facility License and with applicable regulations of the State and City of New York. This manual is based on the following assumptions:

- the moral obligation to maintain personnel health and safety with respect to all radiological ordinances can never be compromised;

- the low power and inherent safety of the Manhattan College Zero Power Reactor (ZPR);

- the need to inculcate reasonable and proper Health Physics procedures by requiring students to know and follow these regulations;

- personnel safety must be the first consideration at all times, and no requirements will be allowed to override safety considerations.

- An obligation to initiate an ALARA (As Low As Reasonably Attainable) program in keeping with federal (NRC) guidelines.

1.2 Responsibilities and Authority

No set of rules can hope to cover all situations. Administration of and adequate provision for radiation protection and contamination control are the prime responsibilities of the Health Physicist to assure that all radiation protection and contamination control regulations are observed and that the procedures set forth herein are followed. The Health Physicist is responsible for recommending changes in any operation which he feels has not been evaluated realistically, for bringing the situation to the attention of personnel concerned and to the Reactor Administrator for correction.

The Health Physics staff is available to advise and make recommendations

regarding radiological protection. They will initiate radiation surveys, wipe tests, air sampling, Zero Power Reactor water and such other sampling and environmental analysis as may be requested by the Chief Reactor Supervisor, Reactor Administrator, or by the NRC, either as a directive or as part of revised procedures.

1.3 Reactor Operations Committee

1.3.1 Functions

The Reactor Operations Committee shall administer the Manhattan College Zero Power Reactor and isotope program. All on-site radioisotope production in the reactor and disposals will be reviewed in advance for conformity with policies adopted by the committee and will be recorded. All proposed procedures for nonroutine or unusual operations, handling and experiments involving radioisotopes shall be reviewed from the point of radiation safety. All radioactive waste disposal procedures shall be determined by this committee.

1.3.2 Frequency of Meetings

The Reactor Operations Committee will routinely meet once a semester or as necessary.

1.3.3 Qualifications of Licensed Isotope Users

Persons proposing to work with radioactive materials must prepare an outline of qualifications and experience in the handling and use of radioactive materials. The information submitted will be reviewed by the Reactor Operations Committee. Committee members will be available as consultants to users, and will directly supervise or arrange for supervision of the use of radioisotopes where considered necessary or advisable. Personnel who are approved to work with radiation shall be placed in one of two categories: 1) certified to work with radioactive materials without supervision; and 2) certified to work with radioactive materials only with supervision. Faculty members and research collaborators who use byproduct materials, in exempt or non-exempt quantities, as defined in Article 175 of the New York City Health Code, must submit and file this information. Students taking courses where radiation is used in the laboratory are exempt from this regulation. Students shall be under the control of qualified faculty when working in the reactor area or with radioactive isotopes.

1.3.4 Procurement and Inventory of Radioisotopes

The Reactor Administrator will authenticate the inventories of licensed radioisotopes in the reactor facility. This will be accomplished through comparison of the written records of the persons in possession of isotopes with those of the Reactor Operations Committee. Confirmation of the records by physical inventory of the licensed radioisotopes in the Reactor Facility will be requested at least annually by the committee.

1.3.5 Records of Committee Meetings

The committee secretary will prepare a permanent written record of committee proceedings for committee approval, such written record to be maintained and presented at the following meeting for approval.

2. PERSONNEL SAFETY

2.1 Definitions

2.1.1 Units of Radiation

Each type of ionizing radiation has its own degree of biological hazard depending on its energy, intensity, and specific ionization ability. The roentgen is a unit which is an indication of the exposure to X and gamma radiation up to 3 MEV.

2.1.1.1 Roentgen

A roentgen is that quantity of X or gamma radiation such that the associated corpuscular emission per 0.001293 gm of air (1 cc of dry air at STP) produces, in air, ions carrying 1 esu of quantity of electricity of either sign corresponding to the absorption of 84 ergs of energy in 1 gram of dry air. The specific absorption of tissue is greater than that of air, so 1 R (of X or gamma radiation) imparts 93 ergs of energy to 1 gram of tissue rather than 84 ergs. The roentgen is also equal to 2.58×10^{-4} coulombs per kilogram of air. Since radiations other than X and gamma radiation are frequently encountered, more generalized units are required. The most frequently used is the radiation absorbed dose (rad).

2.1.1.2 Rad (Radiation - Absorbed - Dose)

A rad is the amount of radiation which imparts 100 ergs of energy to 1 gram of material. Other radiations have biological effects which do not depend entirely on the amount of energy absorbed, and it is useful to define a further unit, the roentgen equivalent man (rem). 1 rad = 0.01 J kg^{-1} = 0.01 Gy of absorbing material.

2.1.1.3 Rem (Roentgen - Equivalent - Man)

The rem accounts for differences in biological effect due to the differences in qualities of the various radiations. The rem is a measure of the actual biologic effect produced by radiation and as such, is a more practical unit than the roentgen. The rem is the special unit of dose equivalent (H). The rem is related to the absorbed dose (rad) by a quality factor (Q).

2.1.1.4 Dose Equivalent (H)

Dose Equivalent is the product of the absorbed dose (D), quality factor (Q) and the product of any modifying factors other than Q (N) at the point of interest in tissue. For this discussion N = 1. The special unit of dose equivalent is the rem with D expressed in rads, H in rems.

2.1.1.5 Quality Factor (Q)

A factor which is used in radiation protection to weigh the absorbed dose with regard to its presumed biological effectiveness insofar as it depends upon the LET of the charged particles. The quality factor is a function of the LET of the charged particles that deliver the absorbed dose.

2.1.1.6 Relative Biological Effectiveness (RBE)

Biological potency of one radiation as compared with another, in terms of the inverse ratio of the respective absorbed doses that produce the same biological effect. The use of this term is to be restricted to radiobiology, and it should be distinguished from the Quality Factor (Q), which is employed in radiation protection.

2.1.1.7 Linear Energy Transfer (LET)

A measure of the ability of biological material to absorb ionizing radiation; the radiation energy lost per unit length of path through a biological material. In general, the higher the LET value, the greater is the relative biological effectiveness (RBE) of the radiation in that material.

2.1.1.8 Kerma

The sum of the initial kinetic energies of all the charged particles liberated by indirectly ionizing particles per unit mass of specified material. The special unit of Kerma is the rad.

2.1.1.9 Absorbed Dose Index (Di)

The maximum dose within a 30 centimeter diameter sphere centered at the point of interest and consisting of material equivalent to soft tissue with a density of 1 gm/cm^3.

2.1.2 Summarization

The concept of dose equivalent (H) has been defined as the product of absorbed dose (D), quality factor (Q), (formerly called the relative biological factor, same as RBE) dose distribution factor and other necessary modifying factors:

$$H = D \times Q \times DF \times \ldots\ldots$$

The unit of dose equivalent is the rem.

Average Q Values for Different Types of Radiation

EXTERNAL EXPOSURE

Radiation	Q
X & gamma rays	1.0
beta (except of very low energy)	1.0
Thermal neutron	3.0
Neutrons, E = 0.0001 MeV	2.0
Neutrons, E = 0.005 MeV	2.5
Heavy particles	20.0

INTERNAL EXPOSURE

Radiation	Q
X & gamma rays	1.0
b+, b-, electrons $E > 0.03$ MeV	1.0
b+, b-, electrons $E \leq 0.03$ MeV	1.7
Alpha particles	10.0
Other heavy particles	20.0

2.1.3 Systeme Internationale (SI)

"The currently used radiation units - roentgen. curie and rad - are scheduled for obsolescence. To provide a common set of units for these in all branches of the physical sciences, an extension of the metric system termed Le Systeme International d' Unites (SI, The International System of Units) was adopted in 1960." [1,2] The International Commission of Radiological Protection (ICRP) has adopted radiological units based on the metric system. All countries are expected to be using these units by 1986, and drop the present units. Table 2.1 below identifies the old and new units.

Table 2.1

UNITS

QUANTITY	OLD UNIT	NEW UNIT
Activity	Curie (Ci)	Bequerel (Bq)
Absorbed Dose (D)	rad	Gray (Gy)
Dose Equivalent (H)	rem	Sievert (Sv)
Exposure (E)	Roentgen (R)	Exposure (E) -not named

The definitions of the SI units in metric units are presented in Table 2.2

Table 2.2

SI UNITS - DEFINITION

QUANTITY	S.I. UNIT	DEFINITION
Activity	Bequerel (Bq)	sec^{-1}
Absorbed Dose (D)	Gray (Gy)	joule/kg of medium
Dose Equivalent (H)	Sievert (Sv)*	joule/kg of medium
Exposure (E)	Exposure	coulomb/kg of air

*Although the units for the Gray and Sievert are the same, the Sievert is calculated as follows (this is the same relationship as between rems and rads):

Dose Equivalent (H) = Absorbed dose in Gy (D) x Quality Factor (QF) x Modifying Factors (MF)

Only for the case where QF = MF = 1 will the number of Sieverts equal the number of Grays. This is the case only for gamma rays, x-rays or beta rays. The rad to Gray conversions appear in Table 2.3 below.

Table 2.3

RAD TO GRAY (Gy) CONVERSIONS

1 mrad =	10μGy =	0.01	mGy
10 mrad =	100μGy =	0.1	mGy
100 mrad =	1000μGy =	1.0	mGy
1 rad		= 10.0	mGy
10 rad		= 100.0	mGy
100 rad		= 1.0	Gy

For radionuclides, certain prefixes are convenient multiples when describing activity. For example, megabequerels (MBq) are used in the microcurie (uCi) and millicurie (mCi) levels. Terabequerels (TBq) are used in the kilocurie (kCi) level.

Table 2.4

SI PREFIXES

FACTOR	PREFIX	SYMBOL
10^{18}	exa	E
10^{15}	peta	P
10^{12}	tera	T
10^{9}	giga	G
10^{6}	mega	M
10^{3}	kilo	k
10^{2}	hecto	h
10	deka	da
10^{-1}	deci	d
10^{-2}	centi	c
10^{-3}	milli	m
10^{-6}	micro	µ
10^{-9}	nano	n
10^{-12}	pico	p
10^{-15}	femto	f
10^{-18}	atto	a

Table 2.5 demonstrates the relationship between curies (Ci) and Bequerels (Bq).

Table 2.5

CURIE TO BEQUEREL CONVERSIONS

CI	Bq	Bq	Ci
1 nCi	37.00 Bq	1 Bq	27.0 pCi
1 µCi	37.00 kBq	10 Bq	270.0 pCi
10 µCi	370.00 kBq	100 Bq	2.7 nCi
30 µCi	1.11 MBq	1 kBq	27.0 nCi
100 µCi	3.70 MBq	10 kBq	270.0 nCi
1 mCi	37.00 MBq	100 kBq	2.7 µCi
10 mCi	370.00 MBq	1 MBq	27.0 µCi
100 mCi	3.70 GBq	10 MBq	270.0 µCi
1 Ci	37.00 GBq	100 MBq	2.7 mCi
10 Ci	370.00 GBq	1 GBq	27.0 mCi
100 Ci	3.70 TBq	1 TBq	27.0 Ci
1 kCi	37.00 TBq	1 PBq	27.0 kCi
1 MCi	37.00 PBq	100 PBq	2.7 MCi
30 MCi	1.11 EBq	1 EBq	27.0 MCi

The sievert (Sv) is the term for dose equivalent. The relationship of sievert to rems is presented in Table 2.6.

Table 2.6

RELATIONSHIP OF SIEVERT (Sv) TO REM

1 mrem	=	10 μSv.	=	0.01	mSv.
10 mrem	=	100 μSv.	=	0.1	mSv.
100 mrem	=	1000 μSv.	=	1.0	mSv.
1 rem			=	10.0	mSv.
10 rem			=	100.0	mSv.
100 rem			=	1.0	Sv.

To summarize:

$1 \text{ rad} = 0.01 \text{ JKg}^{-1} = 0.01 \text{ Gy}$

$1 \text{ curie} = 3.7 \times 10^{10} \text{ s}^{-1} = 3.7 \times 10^{10} \text{ Bq}$

Table 2.7 presents the current radiation protection guidelines in SI units as recommended by the National Council on Radiation Protection (NCRP).

Table 2.7

RADIATION LIMITS IN SI UNITS

Body Organ	Annual Limit (mSv)	Inferred Weekly Limit(mSv)
Total body, head and trunk, bone marrow, gonads or eye lens	50	1.0
Hands and feet	750 (250)*	15.0 (5)*
Forearms and ankles	300 (125)*	6.0 (2.5)*
Any other organ (including skin)	150	3.0
Fetus in gestation period (9 months)	5	0.13

*ICRP has proposed reducing extremity limits to values shown in parentheses. NCRP will probably accept them.

2.2 External Radiation

2.2.1 Permissible doses

The Maximum Permissible Dose (MPD) of radiation, as established by the NRC in regulations appearing in the Federal Register, Title 10, Chapter 1, Part 20, "Standards for Protection Against Radiation" (herein-after referred to as 10CFR20), and as recommended by the NCRP in National Bureau of Standards Handbook 69, "Maximum Body Burdens and Maximum Permissible Concentrations of Radionuclides in Air and Water for Occupational Exposure" (NBS69), will govern at Manhattan College, whichever is lower. Exposures are stated in rems for the present; future dose values will be presented in sieverts (Sv).

2.2.2 NVT

NVT represents the neutron fluence (n/cm^2), which is the time integral of the neutron flux density. (n = neutron flux density; n/cm^3, v = neutron velocity, cm/sec. and t = time of exposure in seconds). Many neutron survey meters are calibrated against the neutron flux density (n/cm^2-sec). Table 2.8 presents the relationship between neutron energy and either neutron fluence or neutron flux density for a particular dose equivalent. [3,4]

Table 2.8

NEUTRON ENERGY - NEUTRON FLUENCE & NEUTRON FLUX DENSITY

Neutron Energy (MeV)	Neutron Fluence for 100 mrems (n/cm^2)	Neutron Flux Density for 2.5 mrems/hr (n/cm^2-sec) (40 hrs = 100 mrems)
Thermal	970×10^5	670
0.0001	720×10^5	500
0.005	820×10^5	570
0.02	400×10^5	280
0.10	120×10^5	80
0.50	43×10^5	30
1.0	26×10^5	18
2.5	29×10^5	20
5.0	26×10^5	18
7.5	24×10^5	17
10.0	24×10^5	17
10-30	14×10^5	10

A NVT of 1.4×10^4 neutrons/cm^2 shall be considered equal to 1 mrem (therefore, a flux of $4 n/cm^2$ - sec equals 1 mrem/hr) unless there exists sufficient information to establish with reasonable accuracy the approximate distribution in energy of the neutrons in which case a higher flux per mrem may be authorized by Health Physics in accordance with 10CFR20, Paragraph 20.4. From the above-referenced sources, the whole body limits currently in effect, including any internal dose, are: 100 mrems per week, 1250 mrems per 13 weeks, and 5000 mrems per year (i.e., approximately 100 mrem per week continuous exposure). It must be stressed that the minimum possible dose commensurate with efficient working conditions must be a prime objective of all personnel: see ALARA program.

2.2.3 Personnel Monitoring

Personnel monitoring devices are required. Body type film badges, as supplied by a commercial vendor, shall be issued to those individuals working with radiation. Records indicating absorbed doses from radiation received on the site will be maintained in the reactor area for review by the Chief Reactor Supervisor, the Health Physicist and by the Reactor Operations Committee. A record of personnel exposures, similar to that provided by NRC Form 5, will be maintained or incorporated in the film badge record sheets.

2.2.3.1 Beat-gamma film badges

These badges contain beta-gamma film only and are developed regularly. They are worn by student personnel who normally enter the reactor rooms.

2.2.3.2 Beta-gamma-neutron film badges

These badges contain both beta-gamma and neutron film and are developed regularly. They are worn by all reactor operator personnel normally working in the reactor rooms.

2.2.3.3 Visitors film badges

Each group of visitors will have body gamma badges distributed within the group. The escort shall wear a special film badge to be worn only while escorting visitors. One badge shall be issued per 10 visitors.

2.2.4 Special Protection Procedures

Normally no special precautions are necessary for personal safety in radiation fields where the total body dose rate is less than 1 mrem/hr. However, it must be remembered that the field at a short distance from a radioactive source will be much greater than the field at normal working distances. Some sources must be handled with tongs or other remote handling equipment. It is also recommended that no person should plan to work for extended periods of time in a field where total body dose rate is greater than 1 mrem/hr. Any field of 2.5 mrem/hr must be clearly defined and posted with signs containing the radiation symbol and the words, "CAUTION - RADIATION AREA". The Health Physicist shall be notified of any changed circumstances which may be expected to alter the radiation field.

2.2.5 Maintenance and Alterations

When maintenance and alteration is planned, the Health Physicist will be notified in advance, so that radiation and contamination surveys can be made, and planning for necessary film badges, monitoring, tool decontamination, protective clothing, etc., can be carried out.

Special work permits may be required when a person is working in an area where actual or potential radiation or contamination hazard exists. Such permits will be issued only for outside contractor personnel.

2.3 Internal Radiation

2.3.1 Permissible Dose

The permissible occupational averaged annual dose for internal radiation is limited to 5,000 mrem (100 mrem per week) for those isotopes which tend, when ingested, to distribute themselves to the whole body, 15,000 mrem (300 mrem per week) for those isotopes which tend to concentrate in any one critical organ, and to an amount of bone seeking isotopes which releases the same energy to the bone as 0.1 μg Ra-226 plus daughters (approximately 25,000 mrem/year or 500 mrem/week). Appendix B, Table I, 10CFR20, and also NBS Handbook 69 list most of the harmful isotopes with maximum permissible occupational and non-occupational concentrations in air and water and their maximum body burdens. The lowest concentration listed in either of these sources will be used at Manhattan College. The dose from internal exposures will be considered additive to dose received from external radiation when calculating total whole body exposures. See ALARA section dealing with reduction of exposure concepts.

2.3.2 Control of Internal Radiation Hazards - Conditions

The list of radioisotopes given in Appendix B of 10CFR20 and in NBS 69 show a wide variety of substances and range of tolerance levels involved in the control of internal radiation. Toxicity is only indirectly related to measured activity since the degree of absorption into a critical organ is dependent for some substances on the method of entry into the body, e.g., ingestion, inhalation, contamination of wounds, or absorption through the skin, especially when solvents are involved. For these reasons, it is not possible to set up general rules to cover all situations and Health Physics must be consulted whenever the possibility of the intake of more than 1/10 maximum body burden of any isotope exists or is anticipated. The following regulations must be observed as a basic minimum for the control of internal radiation hazards.

2.3.2.1 Use and Storage of Radioactive Materials

Each area or room in which radioactive material is used or stored and which contains an amount exceeding ten times the quantity of such material as specified in Appendix B of 10CFR20 or greater than the maximum body burden shown in NBS 69, whichever is lower, shall be posted with a sign or signs bearing the radiation symbol and the words, "CAUTION - RADIOACTIVE MATERIALS".

2.3.2.2 Food stuffs

No beverages, foodstuffs, or application of cosmetics are allowed in the ZPR, graphite or counting areas.

2.3.2.3 Smoking

Smoking is allowed per College regulations in certain designated areas, but is specifically prohibited in all radiation zones.

2.3.2.4 Pipetting

No radioactive liquid is to be pipetted by mouth.

2.3.2.5 Special handling equipment

Some special portable equipment, such as long-handled tongs, remote pipetters, lead carriers, etc., are available for general use in the Counting Room.

2.3.2.6 Contact with hands

Rubber gloves are to be worn in cases where radioactive material or solutions of radioactive material may come in contact with the hands unless their use introduces a greater hazard or extreme inconvenience. Persons with breaks in the skin must not attempt to work with radioactive substances without consulting with the Health Physicist for suitable protective measures.

2.3.2.7 Air contamination

Any room, enclosure, or operating area in which radioactive material exist in concentrations in excess of the amounts specified in Appendix B, Table I, Column I, 10CFR20, or in NBS 69, or in which they exist in concentrations which, averaged over the number of hours in any week during which individuals are in the area, exceed 25 percent of the amount specified in 10CFR20 or NBS 69 shall be conspicuously posted with a sign or signs bearing the radiation symbol and the words, "CAUTION - AIRBORNE RADIOACTIVITY AREA". No person is to enter a room or area where it is known or suspected that the permissible limit for airborne activity is exceeded. No operation is to be performed which might cause radioactivity to become airborne in excess of permissible levels.

2.3.2.8 Movement of radioactive materials

No radioactive material is to be moved from the Engineering Building in such a manner that is possible for the material to escape from the container. Liquids, gases, and dispersible solids must be transported in suitable vessels with a protective sheath of shatterproof material. Surface contamination on articles for decontamination or waste disposal can usually be contained by wrappings of polyethylene sealed with adhesive tape. The outside surface of packages which are to be transported must be free from removable contamination so as to smear below 10 alpha dpm and 100 beta dpm on a standard smear. Materials and equipment to be transferred from a designated shoe cover area must carry HP-2 "Approved for Cold Areas" tags. These tags will be issued by the Health Physicist if surface contamination is below 100 dpm beta and 10 dpm alpha for standard wipe smear and if object has no activity detectable with a survey meter.

2.3.2.9 Accidental contamination

Any person who believes that he may have absorbed radioactive materials into his body should immediately consult the Health Physicist, who will initiate appropriate bioassay samples and summon medical aid, if these procedures are deemed necessary. Absorption through the unbroken skin is possible when large amounts of active material are involved.

2.3.2.10 Bioassays

Reactor personnel other than students may be required to submit urine samples for radioactive analysis. Such samples will be requested at the discretion of the Health Physicist or Reactor Operator when any significant internal exposure of radioisotopes is suspected to have occured. If the sample or samples indicate an overexposure to internal radiation, the Health Physicist will investigate and a report of findings will be prepared. This report will also include recommendations to remedy the situation. The report is to be submitted to the Reactor Operations Committee for review and implementation.

2.3.2.11 Blood counts

Personnel described in part 2.3.2.9 above may be required to provide a blood sample. The results of the blood count will be received by the Health Physicist and included in the documented report mentioned in part 2.3.2.9. above.

2.3.2.12 Student Limitations

Student irradiation of samples will be restricted to solids. This regulation may be modified to include gas or liquid samples. Such modifications are provided by the Reactor Operations Committee, which will review the reasons for the modification and shall demonstrate the radiological safety of the procedures.

2.4 ALARA

The NRC has introduced the ALARA program as a further measure for reducing radiation exposure to radiological workers. The ALARA program is a commitment on the part of each radiological facility to closely monitor all dosimetry values and seek methods or techniques to further reduce the radiation levels that their staff may receive. The Manhattan College Nuclear Engineering Facility subscribes to this program. Section 3 presents the ALARA program as it relates to the Manhattan College Nuclear Engineering Facility.

2.5 References Cited

1. Wyckoff, Harold O; The International System of Units (SI). Editorial, Radiology 128:833-835, Sept 1978.

2. The International Commission on Radiation Units & Measurements, Washington, D.C. Mar 31, 1978.

3. New York State Sanitary Code, Part 16.2

4. 10CFR20.3(C)(4)

3. A L A R A PROGRAM

3.1 Administration Commitment

3.1.1 We, the Administration of Manhattan College and the Manhattan College Nuclear Engineering Facility are committed to the program described below for keeping exposures (individual and collective) as low as reasonably achievable (ALARA). In accord with this commitment, we hereby describe an administrative organization for radiation safety and will develop the necessary written policy, procedures and instructions to foster the ALARA concept within our institution. The organization will include the existing Reactor Operations Committee (ROC) and an appointed Radiation Safety Officer (RSO).

3.1.2 We will perform a formal annual review of the radiation safety program including ALARA considerations. This shall include reviews of operating procedures and past exposure records, inspections, etc., and consultations with the radiation protection staff or outside consultants.

3.1.3 Modification to operating and maintenance procedures and to equipment and facilities will be made where they will reduce exposures unless the cost, in our judgement, is considered to be unjustified. We will be able to demonstrate, if necessary, that improvements have been sought, that modifications have been considered, and that they have been implemented where reasonable. Where modifications have been recommended but not implemented, we will be prepared to describe the reasons for not implementing them.

3.1.4 In addition to maintaining doses to individuals as far below the limits as is reasonably achievable, the sum of the doses received by all exposed individuals will also be maintained at the lowest practicable level. It would not be desirable, for example, to hold the highest doses to individuals to some fraction of the applicable limit if this involved exposing additional people and significantly increasing the sum of radiation doses received by all involved individuals.

3.2 Reactor Operations Committee (ROC)

3.2.1 Review of Proposed Users and Uses

3.2.1.1 The ROC will thoroughly review the qualifications of each applicant with respect to the types and quantities of materials and uses for which he has applied to assure that the applicant will be able to take appropriate measures to maintain exposure ALARA.

3.2.1.2 When considering a new use of byproduct material, the ROC will review the efforts of the applicant to maintain exposure ALARA. The user should have systematized procedures to ensure ALARA, and shall have incorporated the use of special equipment in his proposed use.

3.2.1.3 The ROC will ensure that the user justifies his procedures and that dose will be ALARA (individual and collective).

3.2.2 Delegation of Authority

(The judicious delegation of ROC authority is essential to the enforcement of an ALARA program.)

3.2.2.1 The ROC will delegate authority to the RSO for enforcement of the ALARA concept.

3.2.2.2 The ROC will support the RSO in those instances where it is necessary for the RSO to assert his authority. Where the RSO has been overruled, the Committee will record the basis for its action in the minutes of the Committee's semi-annual meeting.

3.2.3 Review of ALARA Program

3.2.3.1 The RSO will encourage all users to review current procedures and develop new procedures as appropriate to implement the ALARA concept.

3.2.3.2 The RSO will perform a quarterly review of occupational radiation exposure with particular attention to instances where Investigational Levels in Table 3.1 (below) are exceeded. The principle purpose of this review is to assess trends in occupational exposure as an index of the ALARA program quality and to decide if action is warranted when Investigational Levels are exceeded (see paragraph 3.6).

3.2.3.3 The RSO will evaluate our Nuclear Engineering Facility's overall efforts for maintaining exposures ALARA on an annual basis. This review will include the efforts of the RSO, authorized users, and workers as well as those of the Administration of Manhattan College and the Nuclear Engineering Facility.

3.3 Radiation Safety Officer (RSO)

3.3.1 Annual and Quarterly Review

3.3.1.1 Annual Review of the Radiation Safety Program. The RSO will perform an annual review of the Radiation Safety Program for adherence to ALARA concepts. Reviews of specific procedures may be conducted on a more frequent basis.

3.3.1.2 Quarterly review of Occupational Exposures. The RSO will review at least quarterly the external radiation exposures of authorized users and workers to determine that their exposures are ALARA in accordance with the provisions of Paragraph 3.6 of this program.

3.3.1.3 Quarterly review of records of Radiation Level Surveys. The RSO will review radiation levels in unrestricted and restricted areas to determine that they were at ALARA levels during the previous quarter.

3.3.2 Education Responsibilities for an ALARA Program

3.3.2.1 The RSO will schedule briefings and educational sessions as needed to inform workers of ALARA program efforts.

3.3.2.2 The RSO will assure that authorized users, workers and ancillary personnel who may be exposed to radiation will be instructed in the ALARA philosophy and informed that administration, the ROC and the RSO are committed to implementing the ALARA concept.

3.3.3 Cooperative Efforts for Development of ALARA Procedures

Radiation workers will be given opportunities to participate in formulation of the procedures that they will be required to follow.

3.3.3.1 The RSO will be in close contact with all users and workers in order to develop ALARA procedures for working with radioactive materials.

3.3.3.2 The RSO will establish procedures for receiving and evaluating the suggestions of individual workers for improving health physics practices and encourage the use of those procedures.

3.3.4 Reviewing Instances of Deviation from Good ALARA Practices

The RSO will investigate all known instances of deviation from good ALARA practices; and, if possible, determine the causes. When the cause is known, the RSO will require changes in the program to maintain exposures ALARA.

3.4 Authorized Users

3.4.1 New Procedures Involving Potential Radiation Exposures

3.4.1.1 The authorized user will consult with, and receive the approval of, the RSO and the ROC during the planning stage before using radioactive materials for a new procedure.

3.4.1.2 The authorized user will evaluate all procedures before using radioactive materials to ensure that exposures will be kept ALARA. This may be enhanced through the application of trial runs.

3.4.2 Responsibility of the Authorized User to Those He Supervises

3.4.2.1 The authorized user will explain the ALARA concept and his commitment to maintain exposures ALARA to all of those he supervises.

3.4.2.2 The authorized user will ensure that those under his supervision who are subject to occupational radiation exposure are trained and educated in good health physics practices and in maintaining exposures ALARA.

3.5 Persons Who Receive Occupational Radiation Exposure

3.5.1 The worker will be instructed in the ALARA concept and its relationship to his working procedures and work conditions.

3.5.2 The worker will know what recourses are available if he feels that ALARA is not being promoted on the job.

3.6 Establishment of Investigational Levels In Order to Monitor Individual Occupational External Radiation Exposures

The Manhattan College Nuclear Engineering Facility hereby establishes Investigational Levels for Occupational external radiation exposure which, when exceeded, will initiate review or investigation by the Reactor Operations Committee and/or the Radiation Safety Officer. The Investigational Levels that we have adopted are listed in Table 3.1 below. These levels apply to the exposure of individuals.

TABLE 3.1

	Investigational Levels- (mrems per calendar quarter)	
	LEVEL I	LEVEL II
1. Whole body; head and trunk; active blood-forming organs; lens of eyes; or gonads	125	375
2. Hands and forearms; feet and ankles	1875	5625
3. Skin of whole body*	750	2250

* Not normally applicable to nuclear medicine operations except those using significant quantities of beta emitting isotopes.

The Radiation Safety Office will review and record on Form NRC-5, Current Occupational External Radiation Exposures, or an equivalent form (e.g. dosimeter processor's report), results of personnel monitoring, not less than once in any calendar quarter. The following actions will be taken at the Investigational Levels as stated in Table 3.1:

3.6.1 Quarterly exposure of individuals to less than Investigational Level I.

Except when deemed appropriate by the RSO, no further action will be taken in those cases where an individual's exposure is less than Table 3.1 values for the Investigational Level I.

3.6.2 Personnel exposures equal to or greater than Investigational Level I, but less than Investigational Level II.

The RSO will review the exposure of each individual whose quarterly exposures equal or exceed Investigational Level I. He will report the results of his reviews at the first ROC meeting following the quarter when the exposure was recorded. If the exposure does not equal or exceed Investigational Level II, no action related specifically to the exposure is required unless deemed appropriate by the

Committee. The Committee will, however, consider each such exposure in comparison with those of others performing similar tasks as an index of ALARA program quality and will record the review in the Committee minutes.

3.6.3 Exposure equal to or greater than Investigational Level II.

The RSO will investigate in a timely manner the causes of all personnel exposures equaling or exceeding Investigational Level II and, if warranted, take action. A report of the investigation, actions taken, if any, and a copy of the individual's Form NRC-5 or its equivalent will be presented to the ROC at the first ROC meeting following completion of the investigation. The details of these reports will be recorded in the minutes. Committee minutes will be sent to the administration of this institution for review. The minutes, containing details of the investigation, will be made available for review.

3.6.4 Re-establishment of an individual occupational worker's Investigational Level II Above That Listed in Table 3.1.

In cases where a worker's or a group of workers' exposures need to exceed Investigational Level II, a new, higher Investigational Level II may be established on the basis that it is consistent with good ALARA practices for that individual or group. Justification for a new Investigational Level II will be documented.

The Reactor Operations Committee will review the justification for, and will approve, all revisions of Investigational Levels II. In such cases, when the exposure equals or exceeds the newly established Investigational Level II, those actions listed in paragraph 3.6.3 above will be followed.

3.7 <u>Signature of Certifying Official</u>

I hereby certify that the Manhattan College Nuclear Engineering Facility has implemented the ALARA Program set forth above.

Stephen Sullivan FSC

Brother Stephen Sullivan, F.S.C.
President, Manhattan College

1.19.83

Date

4. CONTROL OF CONTAMINATION

4.1 Containment

All radioactive material must be contained in an appropriate vessel, when not in use and in such condition is known as a source of radiation.

Each container in which there is transported, stored, or used a quantity of radioactive material greater than the quantity shown in Appendix C of 10CFR20 or greater than the maximum body burden shown in NBS 69, whichever is lower, shall bear a durable, clearly visible label bearing the radiation caution symbol and the words, "Caution - Radioactive Material".

However, such a label shall not be required:

- If the concentration of the material in the container does not exceed that specified in Appendix B, Table I, Column 2, 10CFR20, or in the occupational RPC for 40 hour week shown in NBS 69.
- For laboratory containers such as beakers, flasks and test tubes used transiently in laboratory procedures, when the user is present.

When containers are used for storage, a "Caution, Radioactive Material" tag or equivalent shall state also the quantities and kinds of radioactive materials in the container and the date of the measurement of the quantities. In addition to the above requirements, encapsulated sources and any other vessels inside such a container will also be labelled whenever practicable and whenever there is any reasonable possibility of the source or vessel being left outside its container or of being separated from it in transit.

The label of sources in transit for use outside the laboratory shall also certify that there is no contamination on the outside of the container. The person dispatching a source is responsible for planning a safe method of transport and for ensuring that adequate warnings are given to all personnel likely to come in contact with the source until it reaches its destination and is turned over to the custody of the recipient.

Sources not in current use should be shielded so that the radiation field at one foot anywhere outside the shield does not exceed 2.5 mrem/hr.

The Manhattan College Reactor Operations Committee shall provide properly controlled and labelled storage for sources larger than those which can be stored in the laboratories. The radiation field at any accessible point outside the storage area shall not exceed 2 mrem/hr. All containers containing radioactive sources shall be labelled with the source strength, and type of source in accordance with 10CFR, Part 20.

4.2 Radiation Areas

The Manhattan College Reactor Operations Committee is responsible for requesting the Health Physicist for surveys so that properly marked radiation signs and tags are prominently displayed in all radiation areas. The necessity and

extent of isolation and type of radiation sign will be determined by the Health Physicist in accordance with Title 10, Chapter 1, Part 20, Section 20.203 of the Nuclear Regulatory Commission Guidelines.

4.3 Laboratory Control

The Chief Reactor Supervisor or other persons approved by the ROC shall be responsible for the control of contamination in the facility. Working surfaces, walls, and floors must be "clean on wipe" i.e., there must not be removable contamination in excess of 100 dpm beta or 10 dpm alpha per standard smear. Fixed contamination must not exceed 2.5 mR/hr on contact. Since fixed contamination will be gradually liberated by wear of surfaces, the following should be considered:

4.3.1 Special Regulations

The following regulations are useful for general laboratory conditions.

4.3.1.1 Containers

Containers of active material and all possible equipment shall be placed in auxiliary containers such as pans or trays, lined with absorbent materials.

4.3.1.2 Contaminated glassware

Contaminated articles such as used pipetters or stirring rods shall not be laid on a table. They shall be placed in a stainless steel or enamel tray or other suitable container, lined with absorbent material.

4.3.1.3 Cleanliness

Good general laboratory and plant housekeeping shall be maintained. Practices which are undesirable in an ordinary laboratory shall not be tolerated in a laboratory containing radioactive material.

4.3.1.4 Spills

In the event of a spill, place, do not drop absorbent material on the spill. Advise others in the area to leave the immediate area . Use a survey meter (Geiger-Mueller type) to determine areas of contamination and undertake personnel decontamination action if necessary. The area shall be surveyed and the contaminated area closed off. The spread of contamination will be arrested and then decontamination procedures effected. The area will not be opened until wipes indicate no contamination.

5. DECONTAMINATION

5.1 Equipment

Equipment that has been surveyed, wipe tested and found to be contaminated shall not (mandatory) be used until decontamination procedures are performed. The specific decontamination procedure will depend on the type of equipment and extent of contamination. All equipment, apperatus or tools that are contaminated shall be placed in plastic bags and sealed. Other articles too large for bags shall have plastic sheeting applied about each item and all running edges shall be sealed with tape. Personnel performing decontamination are to wear gloves and other protective apparel as recommended by the Health Physicist. The Health Physicist shall perform such surveys and wipe tests to determine the level of radioactivity and several decontamination procedures may have to be performed before equipment is released for use. All materials and water or detergents used in the decontamination procedures shall be retained until surveyed by the Health Physicist and appropriate disposal modes approved.

In all cases the Health Physicist shall decide upon either a suitable method of decontamination or disposal. Decontamination of all contaminated materials that are not disposed of shall be performed by personnel responsible for the articles.

5.2 Hands and Other Body Parts

5.2.1 Survey meters located in the ZPR room shall be used for monitoring of hands and clothing of individuals suspected of being contaminated.

5.2.2 If hands or face are contaminated: then carry out thorough washing with water and a mild detergent. This may have to be repeated a number of times. Each time (after washing) survey the areas that were contaminated.

5.2.3 If clothing only has been contaminated remove the item in question and wash down the material. When washing, use plastic gloves and take care not to splash any of the rinsing water onto the body. This may have to be repeated a number of times. After each washing survey the contaminated area.

6. WASTE STORAGE AND DISPOSAL

6.1 Waste Disposal

The chief cause of radiation exposure to the public is contamination of air and water and great care must be taken in the disposal of radioactive waste. Appendix B of 10CFR20 lists the maximum permissible concentrations of radioisotopes in air and water for discharge to the environment. No effluent shall be released at any concentration and no waste shall be disposed of except as authorized by the Reactor Operations Committee. In any event, only concentrations at or below maximum permissible levels listed in Appendix B in air and water will be allowed to escape continuously to the local environment.

6.2 Accumulation of Active Wastes

6.2.1 Dry Waste

Cans marked CONTAMINATED WASTE, COLD WASTE and CONTAMINATED GLASSWARE will be provided as needed. These cans shall be polyethylene-lined and shall not be filled so as to prevent closure of the polyethylene bag liner. They should be foot-operated in order to reduce the possibility of spread of contamination by handling the lid. Extreme care should be exercised in keeping contaminated waste out of the cold waste cans, and vice versa. The cans will be monitored regularly by the Health Physicist and shall be marked with the normal radiation sign if the radiation field is greater than 2.5 mR/hr at any point outside the can. Persons placing material in the can which has sufficient activity to produce such a field must notify the Health Physicist.

6.2.2 Liquid Waste

Five-gallon polyethylene bottles marked CONTAMINATED WASTE shall be provided as needed. Liquid waste should be kept in these containers and not mixed with other waste. A detailed record of the nature of the liquid and the amount and type of activity in the container must be kept by the appropriate supervisor. Physical inventories will be requested.

6.3 Waste Transfer

Health Physicist will supervise the transfer and disposal of all radioactive wastes in accordance with policies adopted by the Reactor Operations Committee. Transfer and disposal of such wastes must not be made without the knowledge and approval of the Health Physicist. The Health Physicist will monitor all such wastes and will decide on the appropriate method of disposal. Solid wastes found in contaminated waste cans will be packaged for off-site disposal. Liquid waste will be transferred to 50-gallon drums for storage, concentration and subsequent off-site disposal by a licensed waste disposal contractor.

The Health Physicist will keep complete records of the condition and location of all radioactive waste in storage and of final disposition thereof.

6.4 Manuals and Codes

Each person, student or faculty, certified to work with radioactivity shall acquire a copy of this manual.

Copies of 10CFR20, 10CFR50, and the codes of the State and City of New York, as well as copies of this manual, will be available for inspection at all times upon request. This material will be maintained in the office of the Reactor Administrator or in the Nuclear Facility files.

6.5 Survey Instrumentation

Survey instruments shall be maintained in operating condition at all times in the counting room and/or in the zero power reactor room (ZPR room). The equipment shall include:

- low level beta-gamma Geiger-Mueller survey meters;
- cutie pie ionization chambers, (portable), calibrated to read in mR/hr having a range of 1 mR/hr to 20 R/hr;
- one portable neutron survey meter for both facilities.

Equipment shall be calibrated once per year.

6.6 Surveys

6.6.1 Wipe samples of the floor and such other areas as selected by the Health Physicist and/or the Chief Reactor Supervisor shall be performed. The floor areas include the ZPR, graphite, counting and lecture rooms as well as connecting corridors and upper level desk areas. Normally this is performed at six month intervals.

6.6.2 Air sampling shall be taken of the areas considered in 6.6.1 above. Samples shall be taken at a rate of at least 2.5 cubic feet per minute for 1/2 to 1 hour at each location. Normally this is performed at six month intervals.

6.6.3 ZPR water shall be checked at six month intervals. This procedure shall be accomplished employing a multi-channel analyzer or a scintillation spectrometer. Air and water samples of the reactor area will be obtained prior to operation of the reactor. These will be control values. These values will then be employed and used for comparison purposes of air and water samples taken at the conclusion of each semester in which the reactor has been operational.

If Iodine-131 is found, Reactor Operator and the Health Physicist will be notified immediately.

6.7 Protective Supplies

A supply of plastic bags shall be on hand at all times in the counting room. A supply of radiation tape will also be maintained.

6.8 Disposal of Pool Water and Demineralizer Resin

The pool shall not be drained until the water has been assayed and shown to be at or below tolerance as specified in 10CFR20. The Health Physicist must be notified in advance as to this action.

The demineralizer is a concentrator of radioactivity, notably short-lived Na-24 and Mg-27. Used resin can never be replaced without Health Physicist coverage and notification. If assay of the resin shows it to be radioactive it will be disposed of in accordance with 10CFR20 par. 20.303, 304.

6.9 Logs

The Health Physicist will maintain a bound log book. All entries will be in ink. No erasures are ever to be made. Incorrect entries are to be crossed out, (they must still be legible), and the correction noted above. These logs will be maintained:

- radiation surveys
- wipe records
- air and water tests

6.10 Activation Estimates

The literature contains a number of tables and short cut procedures enabling one to make rapid calculations of induced activity as a function of irradiation time and flux. Values for several materials are given below for irradiation in a flux of $10^6 n_{th}/cm^2$-sec. These values are based on data reported by Kohl, Zentner and Lukens. [1]

TABLE 6.1

Isotope	2200 m/s activation cross section, (barns) (σ)	Specific Saturation Activity (d/sec-gr)	Fractional Saturation 5 min	Fractional Saturation 1 hr
A^{41}	1.2	1.8×10^{4}	3.2^{-2}	3^{-1}
Ag^{108}	30	8.7×10^{4}	7.8^{-1}	1.0
Ag^{110}	96	2.6×10^{5}	1.0	1.0
Ag^{110m}	2.3	6.2×10^{5}	1^{-5}	1^{-4}
Al^{28}	0.18	4.0×10^{3}	7.7^{-1}	1.0
Au^{198}	96	2.9×10^{5}	9^{-4}	1.1^{-2}
Cl^{36}	53	6.9×10^{5}	2.5^{-12}	3^{-11}
Cl^{38}	0.6	2.4×10^{3}	9.2^{-2}	6.7^{-1}
Cu^{64}	4.3	2.8×10^{4}	4.5^{-3}	5.4^{-2}
Cu^{66}	2.1	6.0×10^{3}	5.4^{-1}	1.0
Dy^{165m}	2700	2.71×10^{6}	9.4^{-1}	1.0
Dy^{165}	2700	2.71×10^{6}	2.4^{-2}	2.5^{-1}
Fe^{55}	2.1	1.4×10^{3}	2^{-8}	2.2^{-7}
Fe^{59}	0.32	1.0×10^{1}	5^{-5}	6.1^{-4}
H^{1}	0.00065	3.1×10^{-3}	6.2^{-7}	7.7^{-6}
In^{114m}	61	1.4×10^{4}	5^{-5}	6.4^{-4}
In^{114}	2	4.5×10^{2}	9.5^{-1}	1.0
In^{116m}	145	7.0×10^{5}	6.4^{-2}	5.3^{-1}
In^{116}	52	2.6×10^{5}	1.0	1.0
Mn^{56}	12.8	1.4×10^{5}	2.2^{-2}	2.4^{-1}
Na^{24}	0.5	1.3×10^{4}	4^{-3}	4.6^{-2}
Pb^{209}	0.00045	6.8×10^{-1}	1.7^{-2}	1.9^{-1}
S^{35}	0.26	1.9×10^{2}	3.3^{-5}	3.3^{-4}
S^{37}	0.14	3.7×10^{-1}	5^{-1}	1.0
P^{32}	0.2	3.9×10^{3}	1.7^{-4}	2^{-3}
Cd^{107}	1.0	6.9×10^{1}	8^{-3}	1^{-1}
Cd^{111}	0.2	1.4×10^{2}	7^{-2}	5.7^{-1}
Cd^{115m}	0.14	2.1×10^{2}	6^{-5}	7^{-4}
Cd^{115}	1.1	1.7×10^{3}	1^{-3}	1.2^{-2}
Cd^{117}	1.4	5.5×10^{2}	2^{-2}	2.2^{-1}

[1] Radioisotope Applications Engineering by Kohl, Zentner and Lukens, D. Van Nostrand Nuclear Science Series 1961.

Values apply for a flux of 10^{6} n_{th} / cm^{2}-s.

6.11 Example Problems

An example will illustrate the use of this table. One gram of natural In is irradiated for one hour in a flux of 10^6. What is the activity due to 54 min In^{116m} immediately post irradiation?

Solution: One gram of In contains 0.9562g of the parent isotope In^{115}. From the above table, the specific saturation activity is 7×10^5 dps/g and the fractional saturation 0.53. The In^{116m} activity is then:

$$(7 \times 10^5)(9.562 \times 10^{-1})(5.3 \times 10^{-1}) = 3.55 \times 10^5 \text{ dps}$$

The curiage is:

$$\frac{3.55 \times 10^5}{3.7 \times 10^{10}} = 9.59 \times 10^{-6} \text{ Ci}$$

or 9.6 µC of In^{116m}. It is the curie value which must be reported.

These tables can and should be used to arrive at an estimate of count rate. The best irradiation time can then be computed and scheduled.

Example:

The above Indium specimen will be counted 54 minutes post irradiation using a NaI(Tl) well crystal and a single channel analyzer set to "see" only the 0.87 MEV gamma, (28% abundant). What is the anticipated count rate per minute if the detector efficiency is 24%?

Solution:

Let CR = Count rate.

$$CR = (3.55 \times 10^5)(5 \times 10^{-1})(2.8 \times 10^{-1})(2.4 \times 10^{-1})(6 \times 10^1)$$

$$CR = 7.158 \times 10^5 \text{ cpm} = 715{,}800 \text{ cpm.}$$

The table should also be used to estimate dose rate. This is an excessively high count rate. Under certain conditions deadtime corrections may be necessary and spectrum distortion is possible in scintillators at high count rates. Since only the amount of radioactivity necessary to achieve a given goal should be generated, the activity of the Indium specimen should be reduced. The variables controlling induced activity are: irradiation time; flux; and exposure time. If a milligram of Indium is exposed instead of one gram, the count rate will drop to 716 cpm. Under the stipulated counting conditions, assuming a background of 10 cpm, the sample can be easily counted. The sample percent error as a function of a background and the total counts should be calculated and an optimum count determined using the curve published by Loevinger & Mones, (Nucleonics, July 1951).

Example:

10 g of Al are irradiated for one hour in a flux of 10^6 and removed 2.3 minutes after irradiation ceases. What is the dose rate?

Solution:

Assume a point source and no flux depression in the target.

Apply the formula:

$$D = 6CE$$

where C is in curies, E in MEV and D in R/hr.

Al^{28} is formed by the (n, gamma) reaction with 100% abundant Al^{27}; the half life is 2.3 minutes. Al^{28} decays by beta emission to stable Si^{28} emitting a 1.8 MEV gamma in 100% abundance.

From the above table, the saturated activity of Al^{28} will be 4×10^3 dps/g.

$$C = \frac{(4 \times 10^3)(1 \times 10^1)(5 \times 10^{-1})}{3.7 \times 10^{10}} = \frac{2 \times 10^4}{3.7 \times 10^{10}}$$

$$C = 5.4 \times 10^{-7} \text{ Ci}$$

$$D = 6CE = (6)(5.4 \times 10^{-7})(1.8)$$

$$D = 5.8 \times 10^{-6} \text{ R/hr.}$$

$$D = 5.8 \times 10^{-3} \text{ mR/hr.}$$

The 10g of Al^{28} do not represent an external hazard and a good count rate even for 1% efficiency and the lapse of two additional half lives can be obtained, (3,000 cpm).

Inhalation hazards may also be estimated.

Problem:

A 1 cu. in. chamber containing air is irradiated for one hour in a thermal flux of 10^6 and opened immediately post irradiation in a confined space providing a volume dilution of 100. Does an inhalation hazard exist due to A^{41}?

Solution:

Air contains 0.94% by volume of A, (density is 1.78 g/l at STP). At STP, the chamber contains 2.74×10^{-4} g of A. The saturation activity is 1.8×10^4 d/sec-g or $(1.8 \times 10^4)(2.74 \times 10^{-4})(3 \times 10^{-1}) = 1.479$ dps.

The unit volume activity is 9.03×10^{-2} dps/cc. Since the dilution factor is 100, this becomes 9.023×10^{-4} dps/cc. The unit volume curiage is 2.44×10^{-14} Ci/cc or 2.44×10^{-8} μc/cc. The MPC for A^{41} as given in Table II of Appendix B of 10CFR20 is 4×10^{-8} μc/ml and 2×10^{-6} in Table I of this reference. Assuming one ml equals one cc, a non-occupational hazard exists while an occupational one does not.

APPENDIX B

PLAN FOR TRAINING APPLICANTS TO PREPARE FOR A REACTOR OPERATOR'S LICENSE FOR MANHATTAN COLLEGE ZERO POWER REACTOR

Plan for Training Applicants to Prepare for a
Reactor Operator's License Examination
for Manhattan College Zero Power Reactor

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Manhattan College Zero Power Reactor

Preliminary Phase

If the applicant has not had a course in Nuclear Reactor Engineering, he should be guided through an intensive study of "Elementary Introduction to Nuclear Reactor Physics" by S. E. Liverhant, (Wiley, 1970). This study should include multiple problem solving as well as theory. (It should be noted that some of the units used by Liverhant are obsolete). The study of Liverhant's text should be complemented by a study of chapters 5, 6, 7, and 9 of "Introduction to Nuclear Engineering" by John R. Lamarsh, (Addison-Wesley, 1975). When the instructor is satisfied that the applicant has sufficient mastery of the above material, the applicant may proceed with the exercises indicated below.

If the applicant has already completed a course in Nuclear Engineering, he may pursue the following exercises and studies without the preliminary procedure outlined above.

Familiarity with all Physical Aspects of the Manhattan College Zero Power Reactor

The applicant should become so familiar with all the physical aspects of the Manhattan College Zero Power Reactor as to be able to diagram any component or set of components from memory. To achieve this end, the following printed material on file should be used as guides: (1) The lecture demonstration experiment for M. E. 433 entitled, "Startup and Operation Procedures of the Manhattan College Zero Power Reactor"; and (2) "Reactor Console Checkout Sheets".

Operational Training

The operational training should be conducted by a licensed Senior Reactor Operator.

Reactor Console Checkout

It is very important not to hurry the candidate during the early stages of his training. Thoroughness of understanding rather than speed of comprehension should be stressed during this period. At least four sessions should be spent on the Reactor console using the checkout sheets before any entry is made in the

Reactor Operations log book. Each of these sessions should carry the candidate a little further in the checkout until he is able to complete the entire checkout in one session.

Achievement of Criticality

After the candidate has been able to complete the entire checkout in one session, one or two additional periods should be devoted to nothing more than this with entries made in the Reactor Operations log book. Next, there should be two periods devoted to making the reactor critical with the picoammeter reading about 5.0×10^{-9} amperes. This current reading will guarantee that the needle of the picoammeter and the pen of the linear strip chart recorder are both near the middle of their respective scales, thus guarding against a high or low trip causing an unintentional scram or reverse. After having completed the checkout and before starting to raise the control rods the stamp marked "Reactor Critical" should be used on the Reactor Operations log book, each of the strip chart recorders should be initialed, marked with the date and time and the chart drive turned on.

As the control rods are raised, the picoammeter will indicate an increase in the reactor power. When the needle goes above 7 on the upper scale, the scale selector should be raised to the next higher setting; as for instance, from 10×10^{-10} amp to 3×10^{-9} amp, from 3×10^{-9} amp to 10×10^{-9} amp. Close attention should be paid to recording the times for "Source Out" and "Source In". The Reactor will be considered critical when the neutron source has been withdrawn and the pen mark on the linear strip chart recorder has continued in a vertical direction for at least one quarter inch.

Shutting Down and Securing Reactor

After criticality has been achieved, the supervisor will direct the trainee to shut down the Reactor. This will be done by pushing the "Run In" button and flipping the toggle switch for the Source Control to the "Down" position. As the control rods are inserted, the picoammeter will indicate a decrease in reactor power. When the needle reaches a point slightly above 2 on the upper scale, the scale selector should be switched to the next lower setting; as for instance, from 10×10^{-9}amp to 3×10^{-9} amp, from 3×10^{-9} amp to 10×10^{-10} amp, etç. When the green "Down Limit" lights go on, the time should be recorded in the Reactor Operations log book with the notation: Reactor shut down by "Run In". The supervisor should then direct the trainee to secure the Reactor. This is done by first turning off

the "Reactor On" key, then the "Power" switch and all other switches including the Master switch and finally locking the doors on the back of the console. After delivering the key to these doors and the "Reactor On" key to the supervisor, the trainee should record the time in the Reactor Operations log book and enter the notation: "Reactor secured". The supervisor should then enter his approval and signature in the Reactor Operations log book.

Bypass Switch for Gamma Ray recorder

The next exercise for the trainee goes one step beyond the simple achieving of criticality with the picoammeter reading about 5×10^{-9} amperes. After criticality has been achieved at this setting, the reactor is made supercritical and again made just critical with the picoammeter reading about 1.5×10^{-8} amperes. The trainee should be alert to raise the scale selector to the next higher setting as the reading rises above 7.0×10^{-9} amperes.

The selector switch is set so that the Area Radiation Monitor #2 feeds into the Gamma Ray strip chart recorder. The low level trip on the recorder is at 0.2 mr/hr. In order to avoid a reverse during the early stages of operation, the gamma recorder low value reverse bypass switch is turned on as specified in B-2 of the Reactor Console Checkout Sheets. It will be noticed that when the picoammeter reading is about 1.5×10^{-8} amperes, the reading on the Gamma Ray recorder is considerably above 0.2 mr/hr. Technical Specifications I3a states: " A bypass to eliminate a reverse as a consequence of the gamma recorder being down scale may be utilized during startup until the gamma recorder reads on scale". The clear implication here is that once the recorder pen "reads on scale", the bypass switch must be turned off. However, this cannot be safely done as soon as the average position of the pen passes above the 0.2 mr/hr mark, since there would still be considerable "noise" below the 0.2 mr/hr mark. Therefore, the operator must wait until he judges that all of the "noise" is also above the 0.2 mr/hr mark before turning off the bypass switch. After pressing the "Run In" button to shut down the Reactor, the opposite situation holds. The operator must be careful to turn on the bypass switch before the "noise" reaches the 0.2 mr/hr mark.

This exercise involving criticality with a reading of about 1.5 X 10^{-8} amperes on the picoammeter should be repeated at least three times.

Reactor Period and Reactivity

The next series of exercises for the trainee is based on the experiment for M. E. 434 entitled, "Reactor Period and Reactivity". There are three steps in the Procedure of this experiment. Step 1 should be followed during two training periods; Steps 1 and 2 should be followed during two additional training periods; and Steps 2 and 3 should be followed during another two training periods. Steps 2 and 3 should be repeated many times during the preparation for the written examination.

Preparation for the Written Examination

NRC Operator Licensing Guide

The Office of Nuclear Reactor Regulation of the Nuclear Regulatory Commission has prepared an "NRC Operator Licensing Guide", which is "A Guide for the Licensing of Facility Operators, Including Senior Operators". Pages 4 to 6 and 18 to 23 of this Guide (1976 Edition) describe in general terms the content of an Operator written examination. The applicant should read over this material without attempting to memorize any of it.

Pages 90 to 98 of this Guide contain typical sample questions for Operator examinations. The applicant should write the answers to all of these questions in a notebook, including the questions marked with asterisks. To obtain the answers to these questions, the following references may be used:

Introduction to Nuclear Engineering by John R. Lamarsh (Addison-Wesley, 1975)

Basic Nuclear Engineering (second edition) by Arthur R. Foster and Robert L. Wright, Jr. (Allyn and Bacon, 1973)

The Elements of Nuclear Reactor Theory by Samuel Glasstone and Milton C. Edlund (Van Nostrand, 1952)

Nuclear Reactor Engineering by Samuel Glasstone and Alexander Sesonske (Van Nostrand, 1967)

10 CFR Part 20, Standards for Protection Against Radiation

After the applicant has written the answers to all the questions contained on pages 90 to 98 of the Guide, these questions should be used repeatedly by the supervisor in catechising the applicant.

Facility License No. R94 and Technical Specifications

The applicant should also be thoroughly familiar with the contents of the Facility License No. R-94, the Technical Specifications for the Manhattan College Zero Power Reactor, and all of the changes which have been made in these two documents.

Application Procedure

The following letters should be sent to Mr. Paul F. Collins, Chief of the Reactor Licensing Branch, Division of Project Management, U. S. Nuclear Regulatory Commission, Washington, D. C. 20545.

From the applicant stating that he wishes to take the Reactor Operator licensing examination.

From the Chief Reactor Supervisor, stating that the applicant has received sufficient training and is qualified to take this examination.

From the Reactor Administrator stating that the services of the applicant are needed for the efficient operation of the Reactor facility.

The applicant and his physician must fill out the Certificate of Medical History, which he will receive from NRC.

The date for the examination is fixed to suit the convenience of the applicant and the NRC examiner.

Final Preparation for Examination

Shortly before the time for the Reactor Operator examination, the applicant should be quizzed on all aspects of the examination by someone competent in Nuclear Engineering other than his training supervisor. During the week prior to the examination, he should perform three times steps 2 and 3 of the Procedure of the experiment "Reactor Period and Reactivity".

Plan for Training Applicants to Prepare for a Senior Reactor Operator's License Examination for MCZPR

The following directives are in addition to those made for the Reactor Operator examination.

Pages 6 to 8 of the Guide describe in general terms the content of a Senior Reactor Operator written examination. The applicant should read over this material without attempting to memorize it. Pages 99 to 106 of the Guide contain typical sample questions for Senior Reactor Operator examinations. The applicant should write in a notebook the answers to the following questions:

Section H Nos. 1 thru 4, 7a, 7c, and 8
Section I Nos. 1, 2, 5, 6, 7, and 8
Section J Nos. 4, 5, and 7
Section K Nos. 2, 4a, 5, 6, and 7
Section L Nos. 4, 5, 6, 7 and 8

The questions omitted are intended for operators of nuclear power plants.

APPENDIX C

CURRENT OPERATOR'S LICENSES

U.S. NUCLEAR REGULATORY COMMISSION

SENIOR OPERATOR LICENSE

Pursuant to the Atomic Energy Act of 1954, as amended, the Energy Reorganization Act of 1974 (Public Law 93-438), and subject to the conditions and limitations incorporated herein, the Nuclear Regulatory Commission hereby licenses:

Brother Gabriel Kane
Manhattan College
Bronx, New York 10471

(RENEWAL)
LICENSE NO. SOP — 1428-6

DOCKET NO. 55 — 2928

EFFECTIVE DATE November 18, 1982

AMENDED DATE

to direct the licensed activities of licensed operators at, and to manipulate all controls of, the following facility or facilities:

Manhattan College Zero Power Reactor, Facility License No. R-94, located at Bronx, New York

This license is subject to the provisions of Section 55.31 of the U.S. Nuclear Regulatory Commission's regulations, Title 10, Code of Federal Regulations, Chapter 1, Part 55, with the same force and effect as if fully set forth herein.

In directing the licensed activities of licensed operators and in manipulating the controls of the above facility or facilities the licensee shall observe the operating procedures and other conditions specified in the facility license which authorizes operation of the facility or facilities, and shall comply with the following conditions:

☐ The licensee shall wear corrective eyeglasses while performing the activities for which he is licensed.
☒

The issuance of this license is based upon examination of the licensee's qualifications, including the representations and information contained in his application for license filed under the docket number indicated above.

Unless sooner terminated, this license shall expire two years from the effective date.

A copy of this license has been made available to the facility licensee indicated below.

Manhattan College
ATTN: Reactor Administrator
Physics Department
Bronx, New York 10471

For the Nuclear Regulatory Commission

~~Don H. Beckham, Chief~~
Director, Division of Human Factors Safety
~~Office of Nuclear Reactor Regulation~~
Operator Licensing Branch

RM NRC 78 (9-76)
CFR 55

FACILITY LICENSEE'S COPY

U.S. NUCLEAR REGULATORY COMMISSION

SENIOR OPERATOR LICENSE

Pursuant to the Atomic Energy Act of 1954, as amended, the Energy Reorganization Act of 1974 (Public Law 93-438), and subject to the conditions and limitations incorporated herein, the Nuclear Regulatory Commission hereby licenses:

Dr. Joseph Augustus
110 Delaware Road
Yonkers, NY 10710

(RENEWAL)
LICENSE NO. SOP — 3551-1

DOCKET NO. 55 — 6366

EFFECTIVE DATE December 7, 1982

AMENDED DATE

to direct the licensed activities of licensed operators at, and to manipulate all controls of, the following facility or facilities:

Manhattan College Zero Power Reactor, Facility License No. R-94,
located in the Bronx, New York

This license is subject to the provisions of Section 55.31 of the U.S. Nuclear Regulatory Commission's regulations, Title 10, Code of Federal Regulations, Chapter 1, Part 55, with the same force and effect as if fully set forth herein.

In directing the licensed activities of licensed operators and in manipulating the controls of the above facility or facilities the licensee shall observe the operating procedures and other conditions specified in the facility license which authorizes operation of the facility or facilities, and shall comply with the following conditions:

XX ☐ The licensee shall wear corrective eyeglasses while performing the activities for which he is licensed.

☐

The issuance of this license is based upon examination of the licensee's qualifications, including the representations and information contained in his application for license filed under the docket number indicated above.

Unless sooner terminated, this license shall expire two years from the effective date.

A copy of this license has been made available to the facility licensee indicated below.

Manhattan College
ATTN: Reactor Supervisor
Mechanical Engineering Department
Manhattan College Parkway
Bronx, New York 10471

For the Nuclear Regulatory Commission

for Don H. Beckham, Chief
~~Director, Division of Human Factors Safety~~
~~Office of Nuclear Reactor Regulation~~
Operator Licensing Branch

U.S. NUCLEAR REGULATORY COMMISSION

OPERATOR LICENSE

Pursuant to the Atomic Energy Act of 1954, as amended, the Energy Reorganization Act of 1974 (Public Law 93-438), and subject to the conditions and limitations incorporated herein, the Nuclear Regulatory Commission hereby licenses:

Dr. Robert A. Mayo
62 Woodland Avenue
Verona, New Jersey 07044

(RENEWAL)
LICENSE NO. OP - 5270-1

DOCKET NO. 55 - 7287

EFFECTIVE DATE July 15, 1982

AMENDED DATE

to manipulate all controls of the following facility or facilities:

Manhattan College Zero Power Reactor, Facility License No. R-94, located in Riverdale, New York

This license is subject to the provisions of Section 55.31 of the U.S. Nuclear Regulatory Commission's regulations, Title 10, Code of Federal Regulations, Chapter 1, Part 55, with the same force and effect as if fully set forth herein.

In manipulating the controls of the above facility or facilities, the licensee shall observe the operating procedures and other conditions specified in the facility license which authorizes operation of the facility or facilities and shall comply with the following conditions:

- [x] The licensee shall wear corrective eyeglasses while performing the activities for which he is licensed.
- [ ]

The issuance of this license is based upon examination of the licensee's qualifications, including the representations and information contained in his application for license filed under the docket number indicated above.

Unless sooner terminated, this license shall expire two years from the effective date.

A copy of this license has been made available to the facility licensee indicated below.

Manhattan College
ATTN: Reactor Administrator
Mechanical Engineering Department
Manhattan College Parkway
Riverdale, New York 10471

For the Nuclear Regulatory Commission

Don H. Beckham, Chief
XXXXXXXXXXXXXXXXXXXXXXXXXX
Operator Licensing Branch

FACILITY LICENSEE'S COPY

APPENDIX D

REACTOR CONSOLE CHECKOUT SHEET

MANHATTAN COLLEGE ZERO POWER REACTOR

REACTOR CONSOLE CHECKOUT SHEETS

(Revised: July 1983)

Reactor console checkout is to be performed once on each day during which the reactor is to be operated (i.e. with control rod movement more than 10%) and before all reactor operation.

At the end of these checkout sheets, space has been provided for notations on CORRECTIVE ACTIONS AND ADDITIONAL COMMENTS.

Any variation from normal conditions for a particular entry in the checkout sheets should be marked with an asterisk (*). This asterisk will signify: See CORRECTIVE ACTIONS AND ADDITIONAL COMMENTS.

Date ____________________ Checkout # ______________

Checkout started ______________

Authorizing Supervisor ________________

Reactor Operator on duty ______________________

Pre-checkout - Groups A, B, C and D
(REACTOR key switch off)

Group A. General	Check/Note
A-0. Check the Operation and Maintenance Record Book	________________
A-1. Turn on the console circuit breaker and all instrument power	________________
A-2. Make an inspection tour of the reactor to check that	
(a) the tank water level is normal (about 7')	________________
(b) all physical facilities of the reactor normal	________________
(c) check that the reactor basement door is closed and latched	________________

A-3. Record loading number. The core loading shall be #13, #13A or any other loading specifically approved by the reactor supervisor on duty ______________

A-4. Check that the portable radiation survey instruments are functioning properly ______________

A-5. Check that the neutron source is in the most effective position (IN). ______________

A-6. Record

(a) UIC (uncompensated ion chamber) voltage (normal reading 28 corresponding to 270 V) ______________

(b) BF-3 counter voltage ______________ V. D. C.

(c) Water temperature ______________ deg. F

(d) Reactor water resistivity ______________ MΩ-cm

Group B - Magnet Power and Annunciator Lights

B-1. Turn POWER switch on. The audible alarm should sound. ______________
Silence it by pressing the green ACKNOWLEDGE button. All annunciator lights should go on. ______________

B-2. Turn the gamma recorder low value reverse bypass switch on ______________

Reset the two gamma radiation AREA RADIATION MONITORS (the two large red ALARM lights should go out). ______________

Press the black RESET button. All annunciator lights should go off except the SCRAM light. If the REVERSE light stays on, press the red RUN-IN button once. ______________

The 2 green DOWN LIMIT lights should be on. ______________

B-3. Record the magnet power supply voltage (normally 24 V). ______________ V D C

Group C - Calibration of Rod position Indications

C-1. Set the FINE POSITION INDICATOR TO 00.0%. While pressing the black button under the coarse indicator for the Reg Rod, adjust the ZERO ADJUST potentiometer R2 so that the NULL INDICATOR indicates zero (center of scale). Adjust the REG. ROD ZERO ADJUST potentiometer R6 so that the REG. ROD coarse indication indicates 0%. __________

NOTE: Sometimes it may be necessary to recycle the above several times. Under certain conditions, the use of the potentiometers R8 and R9 may be necessary.

C-2. Repeat C-1 for the SHIM ROD using potentiometers R12 and R16. __________

C-3. Drive the magnets to the uppermost position (the UP LIMIT amber lights should go on) while setting the FINE POSITION INDICATOR TO 100.0%. While pressing the black button under the coarse indicator for the Reg Rod, adjust the REG. ROD SPAN ADJUST potentiometer R1 so that the NULL INDICATOR indicates zero. Adjust the REG. ROD SPAN ADJUST potentiometer R3 so that the REG. ROD corase indicator indicates 100% __________

NOTE: Sometimes it may be necessary to recycle the above several times. Under certain conditions, the use of the potentiometers R8 and R9 may be necessary.

C-4. Repeat C-3, for the SHIM ROD using potentiometers R11 and R13. __________

C-5. Press RUN-IN button and check that the REVERSE light comes on and that the magnets are driven down until the DOWN LIMIT green lights come on. Restore the REVERSE circuit to normal by pressing the RUN-IN button. __________

Group D - Instrument Calibration and Readings

D-1. Linear Channel

With the picoammeter range switch at the most sensitive position for on-scale reading (3×10^{-10}A), press the ZERO CHECK button while turning the ZERO dial so that the red pointer of the meter indicates zero. Meter reading after zero check. ______________

D-2. Scaler

Turn the TEST switch on (up). Reset the scaler. (Press the black button first, then reset the register). Take a one-minute count (normally about 3600). ______________

Turn off (down) the TEST switch. Reset the scaler. With the source in the most effective (IN) position take a one-minute count. ______________

D-3. Log count rate meter

Check that the range switch is on 10^5 counts/sec. Push CAL switch lever to 100 (right). The stable meter reading will be close to 100. If it is not exactly 100, use the adjustment screw in the slot below "F.S. AOJ", to bring it to this position. ______________

Push CAL switch lever to 10 (middle). Record the stable meter reading (it should be close to 10). Do not use the adjustment screw here. ______________

Turn the CAL switch lever to INPUT ______________

D-4. Gamma monitor

Check that the meters on the two AREA RADIATION MONITORS indicate nearly zero. ______________

Checkout - Groups E, F and G
(REACTOR key switch on)

Group E - Control Rods

E-1. Turn the REACTOR key switch on. The REVERSE light will go on. Press the RESET button. The SCRAM and REVERSE lights should go out. The 2 MAG CURRENT meters should indicate a current. The 2 white ON MAGNET lights should be on. ______________

E-2. Drive the two control rods up 10% (DOWN LIMIT lights out, ON MAGNET lights on) by pushing the two DRIVE CONTROL switches up. Turn the MAG. ADJUST potentiometer for the REG. ROD counterclockwise until the control rod falls off by gravity. Record the minimum rod holding magnet current. ________

Repeat the same for the SHIM ROD ________

Drive the magnets back to the lowest position. Increase the magnet current to approx. 25 ma above the minimum holding current. ________

E-3. Drive the control rods up 10%. Press the ROD RELEASE button for the REG. ROD. Note the dropping of the rod. The ON MAGNET light should go out. ________

Repeat the same for the SHIM ROD ________

Press the RUN-IN button once. When the magnets reach the down position, press the button again. REVERSE light should go out. ________

Group F - Scram Circuit Tests

In each test, press RESET button, drive both rods to 10%, initiate the particular scram condition and note the dropping of the two control rods. When the scram condition is removed, the magnet drive is automatically put on REVERSE.

Scram condition	Test OK
F-1. Loss of magnet power: Turn REACTOR switch off. After the rod drop, turn it on. (Audible alarm does not sound).	________
F-2. Manual scram: Press the red SCRAM button.	________

F-3. Water level low: Using a rod, push lightly downward the float switch in reactor water. ______

F-4. Gamma channels intensity high: Turn the alarm setting on the meter of the #1 gamma monitor to 1 mR/h. Press the CHECK button and hold until the meter indicator reaches 1 mR/h and sets off the scram. ______

After pressing the ACKNOWLEDGE button, press the RESET button on the #1 gamma monitor. Return the alarm setting of the meter to 6 mR/h. ______

Repeat the same for the #2 gamma monitor. ______

Return the alarm setting of the meter to 10 mR/h. ______

F-5. Linear channel flux high: By use of microwave switch in back of console, disconnect the input cable to the Keithley picoammeter and connect the current source for linear channel testing to the input. Turn the potentiometer connected with Current Source fully counterclockwise. While pressing the black button on the Current Source, press the Reset button on the console and drive the rods to 10%. While continuing to press the black button on the Current Source, increase the current indicated on the picoammeter by turning the potentiometer on the current source clockwise until the reactor is scrammed. The scram should occur at 90% point of the meter range. ______

~~After the test~~ disconnect the current source and connect the cable to the picoammeter by means of the microwave switch. ______

F-6. Log count rate channel flux high: Turn on the two toggle switches of the Heath Audio Oscillator in back of console. With OSCILLATOR FREQUENCY on front of console fully counterclockwise, press the RESET button on the console and drive the rods to 10%. Increase the indication on the log count rate meter or the LCR recorder by using the OSCILLATOR FREQUENCY and OSCILLATOR AMPLITUDE controls until the reactor is scrammed. The scram should occur at 10,000 cps. ______

Turn the two toggle switches on the Heath Audio Oscillator to the OFF positions ______

Group G - Reverse Circuit tests

Three reverse conditions for each recorder are to be tested:

a) Loss of power to the recorder: This is simulated by turning INST. POWER switch off.

b) Recorder indication too low - A backset switch is actuated.

c) Recorder indication too high - A backset switch is actuated.

The last two conditions can be obtained by turning the MAIN DRIVE GEAR (See Instruction Manual Electronik 18 Strip Chart Recorder) manually when the recorder power is off. But to test the corresponding reverse circuits, it is necessary to bypass the REVERSE interlock contact due to the condition a). This is achieved by flipping down a bypass switch in the rear of the console. (Switch K101 for LCR recorder, K102 for LIN recorder, K103 for GAMMA recorder).

In each test, press RESET button, drive both rods to 10%, initiate the particular reverse condition and note the driving in of the two control rods.

After the tests, the bypass switches should be returned to normal (up) position.

G-1. Log count rate channel (a) (OFF)____________________

(b) (2 cps)____________________

(c) (50, 000 cps)____________________

G-2. Linear channel recorder (a) (OFF)____________________

(b) (5%)____________________

(c) (95%)____________________

G-3. Gamma channel recorder (a) (OFF)____________________

(b) (0. 2 mR/h)____________________

(c) (95 mR/h)____________________

Have the bypass switches been flipped back to normal position? K101_____ K102_____ K103_____

Gamma Recorder _____

If the reactor is not to be operated right after the checkout and the operator has to leave reactor room, secure the reactor by turning off

(a) the REACTOR ON switch and remove the key

(b) the POWER switch

(c) all instrument power switches, high voltage switches, chart drive switches

(d) the console power circuit breaker and locking the console doors. Surrender all reactor keys to the Reactor Supervisor in charge.

CORRECTIVE ACTIONS and ADDITIONAL COMMENTS
(Refer to group letter and number for all entries).

____

____

____

____

____

____

____

____

Checkout completed at ______________

Record the completion of checkout on the log book. ______________

Approved by ______________________________ Reactor Supervisor

APPENDIX E

EMERGENCY PLAN: ST. JOSEPH'S HOSPITAL AGREEMENT

(St. Joseph's Agreement is Appendix 3A of Emergency Plan)

THE EMERGENCY PLAN

FOR THE

MANHATTAN COLLEGE ZERO POWER REACTOR

Facility Operating License: R-94

Docket No: 50-199

August 1983

TABLE OF CONTENTS

LIST OF FIGURES

1.0 INTRODUCTION

1.1 This Emergency Plan applies to the Manhattan College Zero Power Reactor (MCZPR). The reactor is owned and operated by the Manhattan College Corporation of Bronx, New York, 10471. Under Facility Operating License R-94, Docket No. 50-199.

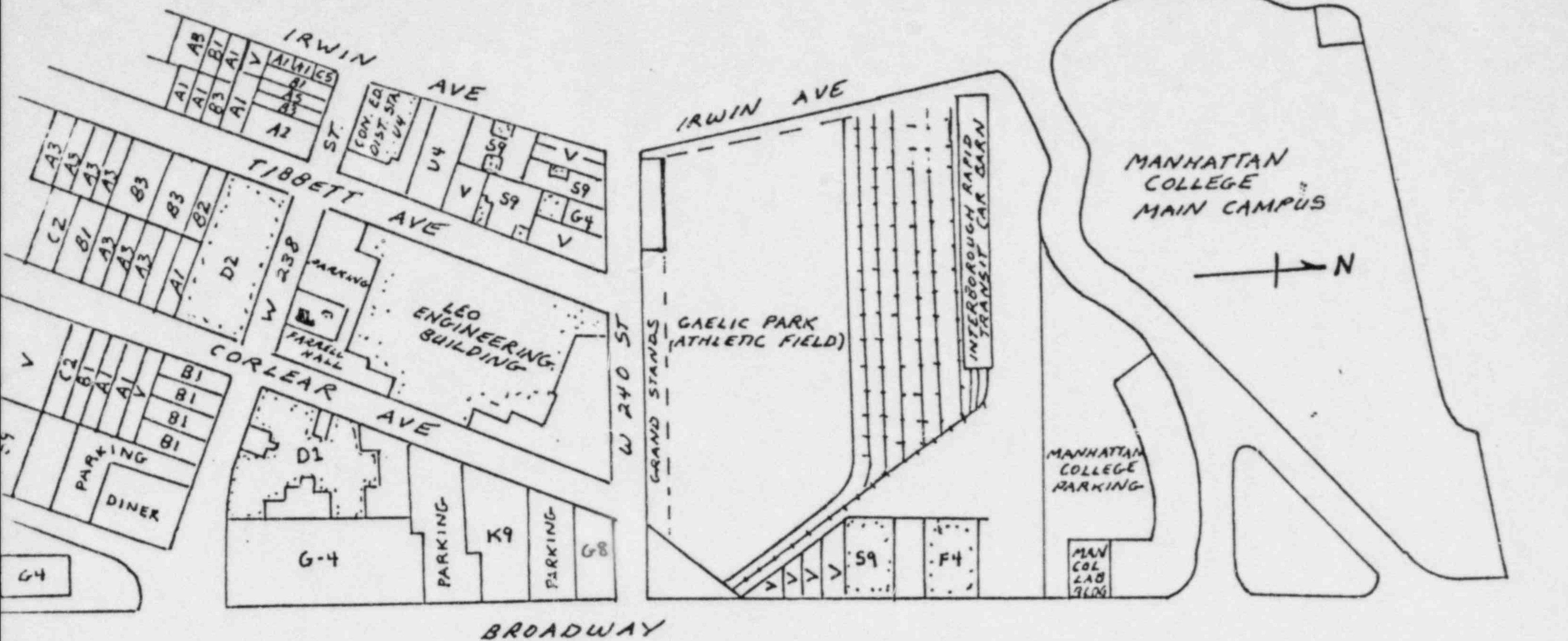
1.2 The objectives of this plan are to designate responsibility among the reactor personnel and establish guidelines of action in the event of an accident or incident at the reactor that may present undue risk to the health and safety of individuals, or result in damage to the property. The plan also identifies off-site support organizations that may be activated if required.

1.3 The MCZPR is a U-235 fueled light water moderated open pool type heterogeneous reactor with plate type fuel elements. The reactor tank is 8 ft. high and 10 ft. in diameter. The core consists of 15 full fuel elements and one partial fuel element. Each full element consists of six fuel plates containing 200 gm of uranium and the partial element contains 25 gm making a total of 3025 gm of uranium. The reactor is licensed to operate at a continuous maximum power of 0.1 watt. Because of the very low power level, no recirculating cooling system is provided.

1.4 The MCZPR is a research reactor. The major functions of the reactor are training of reactor operators and for experimentation as part of Nuclear Engineering courses offered at Manhattan College.

1.5 The reactor is operated whenever needed for training or for class experiments. All experiments performed on the reactor require prior approval of a Reactor Operations Committee. The Committee closely monitors all experiments performed on the reactor. Based on the operating history of the past three years, the reactor was made critical about 34 times a year with each critical operation lasting an average of 16 minutes. The power levels were most often well below the licensed level of 0.1 watt.

1.6 The MCZPR is located in the Bronx, New York. It is easily accessible from Interstate Highway 87 and the Henry Hudson Parkway by connecting roads. An area map is given in Figure 1.1. The reactor is housed in the Leo Engineering Building on Corlear Avenue between 238 Street and 240 Street. Figure 1.2 shows the location of the Leo Engineering Building. The reactor facility occupies portions of the first and second floors of the Leo Engineering Building. The floor plans are shown in Figures 1.3 and 1.4. Access to the facility is either through door D_1 on the first floor or through D_4 on the second floor. Access door D_3 is kept locked and bolted from inside at all times.



LEGEND

A1	2 STORY DETACHED - 1 FAMILY
A2	1 STORY - 1 FAMILY
A3	2 STORY BRICK SEMI-DETACHED - 1 FAMILY
B1	2 STORY BRICK - 2 FAMILY
B2	2 STORY FRAME - 2 FAMILY
B3	CONVERTED DWELLING - 2 FAMILY
C1	WALK UP SEMI FIRE PROOF - 6 FAMILY + OVER
C2	WALK UP APARTMENT - 3-6 FAMILY
C3	WALK UP CONVERTED DWELLING
C5	WALK UP APARTMENT WITH STORES
D1	ELEVATOR APARTMENT
D2	ELEVATOR APARTMENT
F4	FACTORY SEMI FIRE PROOF
G4	GAS STATION: WITH LUB PLANT AND WORKSHOP
G8	GARAGE WITH SHOW ROOM
G9	MISC GAS STATION + PUBLIC GARAGE
K1	1 STORY STORE BUILDING
K9	MISC STORE BUILDING
S9	UNCLASSIFIED MISC BLDG.
U4	UTILITY SUB-STATION
V	VACANT LOT

FIGURE 1.1

MAP OF AREA SURROUNDING
THE LEO ENGINEERING BUILDING

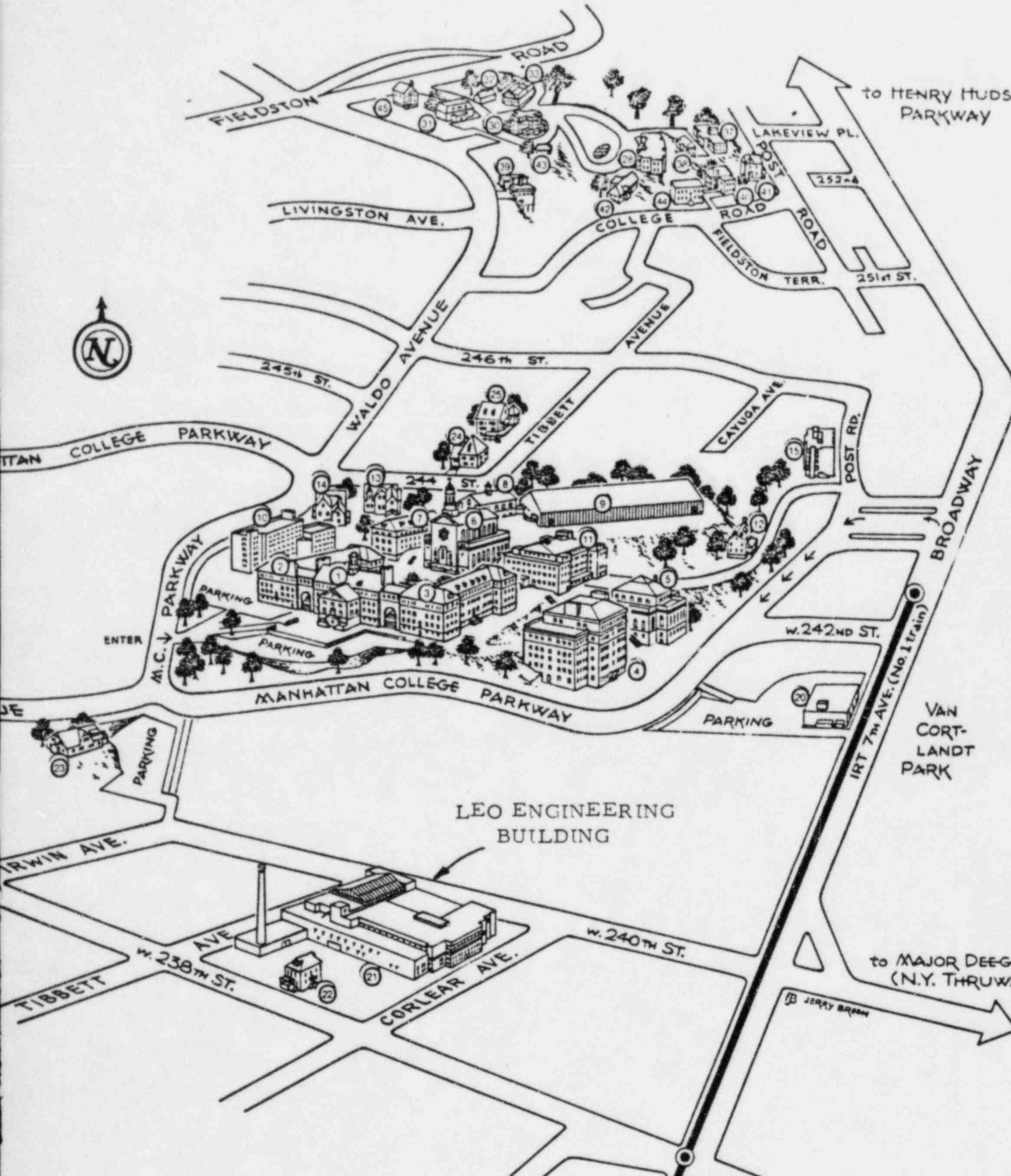


FIGURE 1.2
LOCATION OF LEO ENGINEERING BUILDING

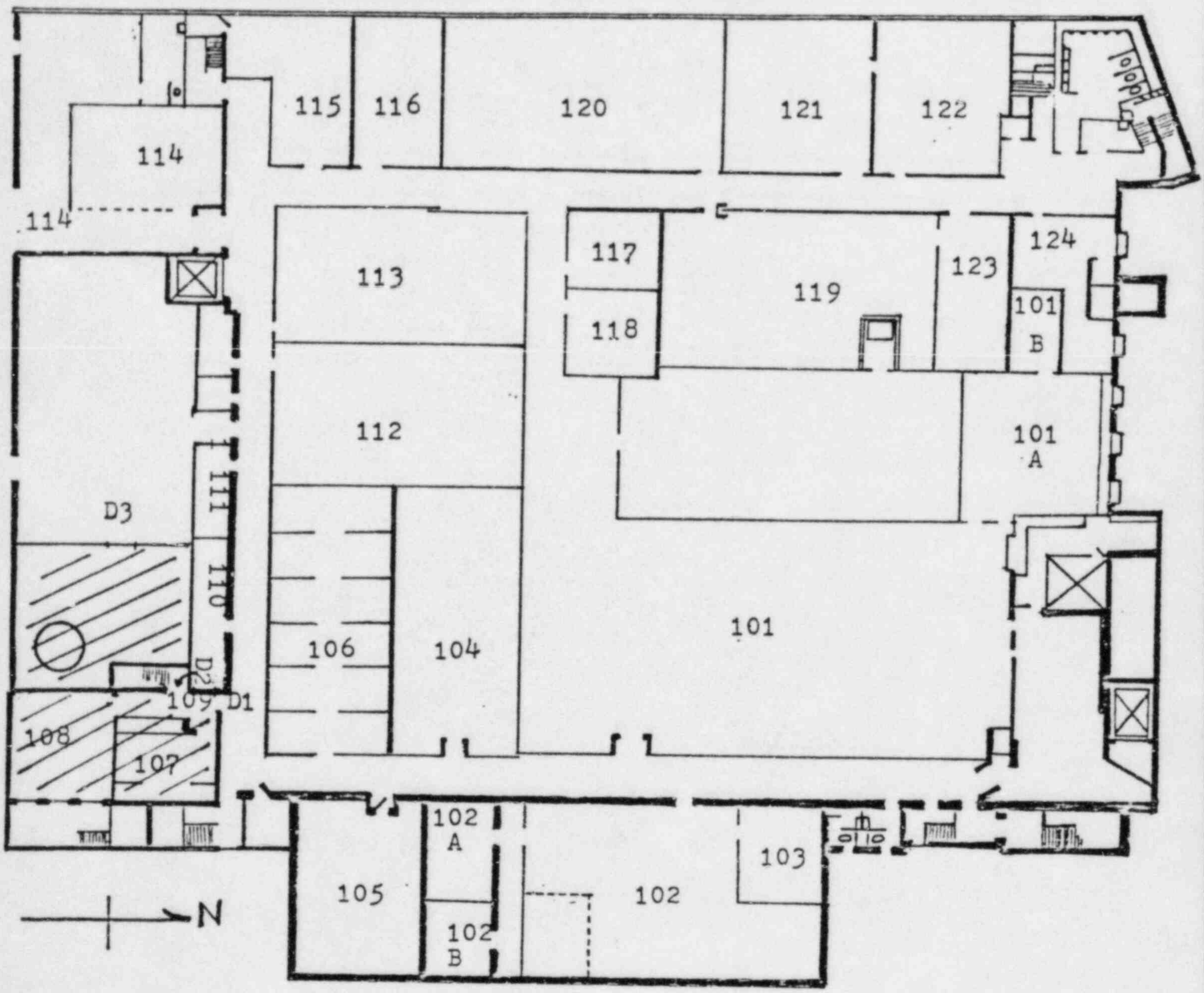


FIGURE 1.3

PLAN OF FIRST FLOOR OF THE LEO ENGINEERING BUILDING
(REACTOR FACILITY SHOWN SINGLE HATCHED)

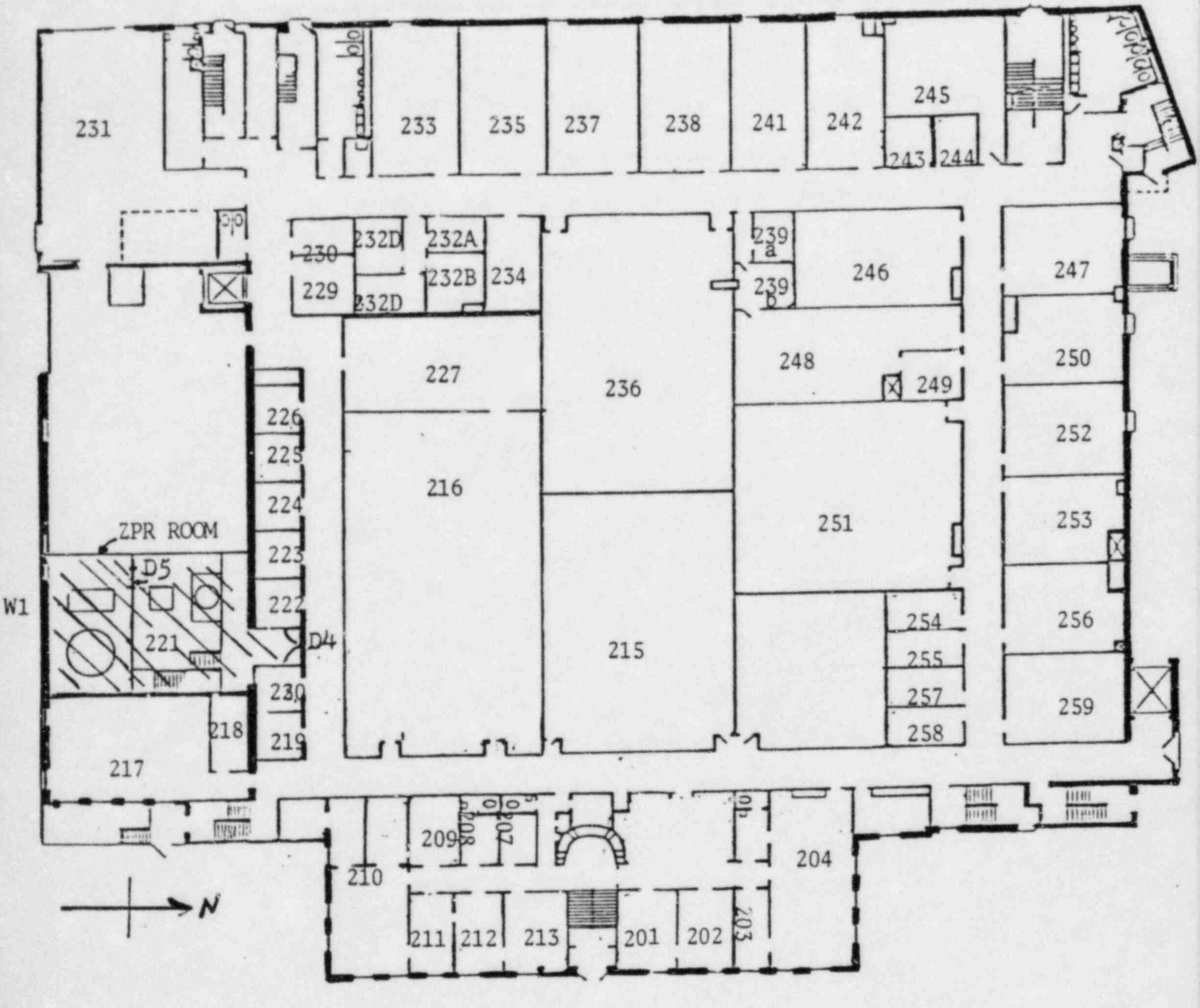


FIGURE 1.4
PLAN OF SECOND FLOOR OF THE LEO ENGINEERING BUILDING

2.0 Definitions

2.1 MCZPR

MCZPR stands for the Manhattan College Zero Power Reactor located in the Leo Engineering Building of Manhattan College.

2.2 ZPR Room or Reactor Room

Consists of rooms on the first and second floors in the Leo Engineering Building in which the reactor is built. The area is shown cross hatched in Figures 2.1 and 2.2.

2.3 MCZPR Facility or Reactor facility

Consists of the ZPR room and rooms 107, 108 and 109 on the first floor and room 221 on the second floor which are shown single hatched in Figures 2.3 and 2.4.

2.4 Emergency Support Center

Consists of the platform area of room 221. This is shown in Figure 2.5.

2.5 Reactor Operations Committee (ROC)

The ROC consists of the Reactor Administrator who acts as the Chairman of the Committee, the Chief Reactor Supervisor, Health Physicist, Radiation Safety Officer and others who might be helpful in the operation of the reactor and appointed to the Committee by the Reactor Administrator.

2.6 NRC

Nuclear Regulatory Commission.

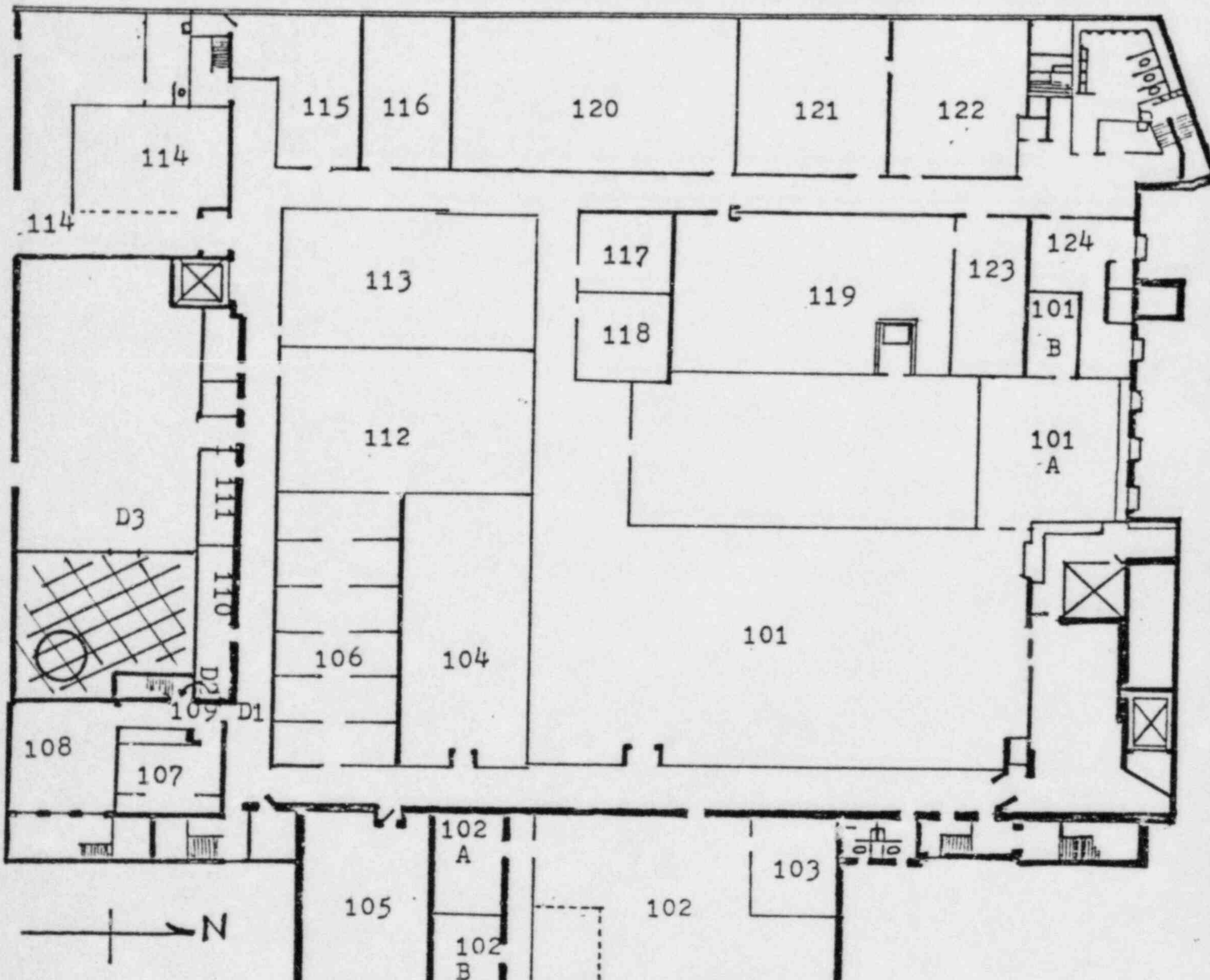


FIGURE 2.1

PLAN OF FIRST FLOOR OF THE LEO ENGINEERING BUILDING
SHOWING THE ZPR ROOM (CROSS HATCHED)

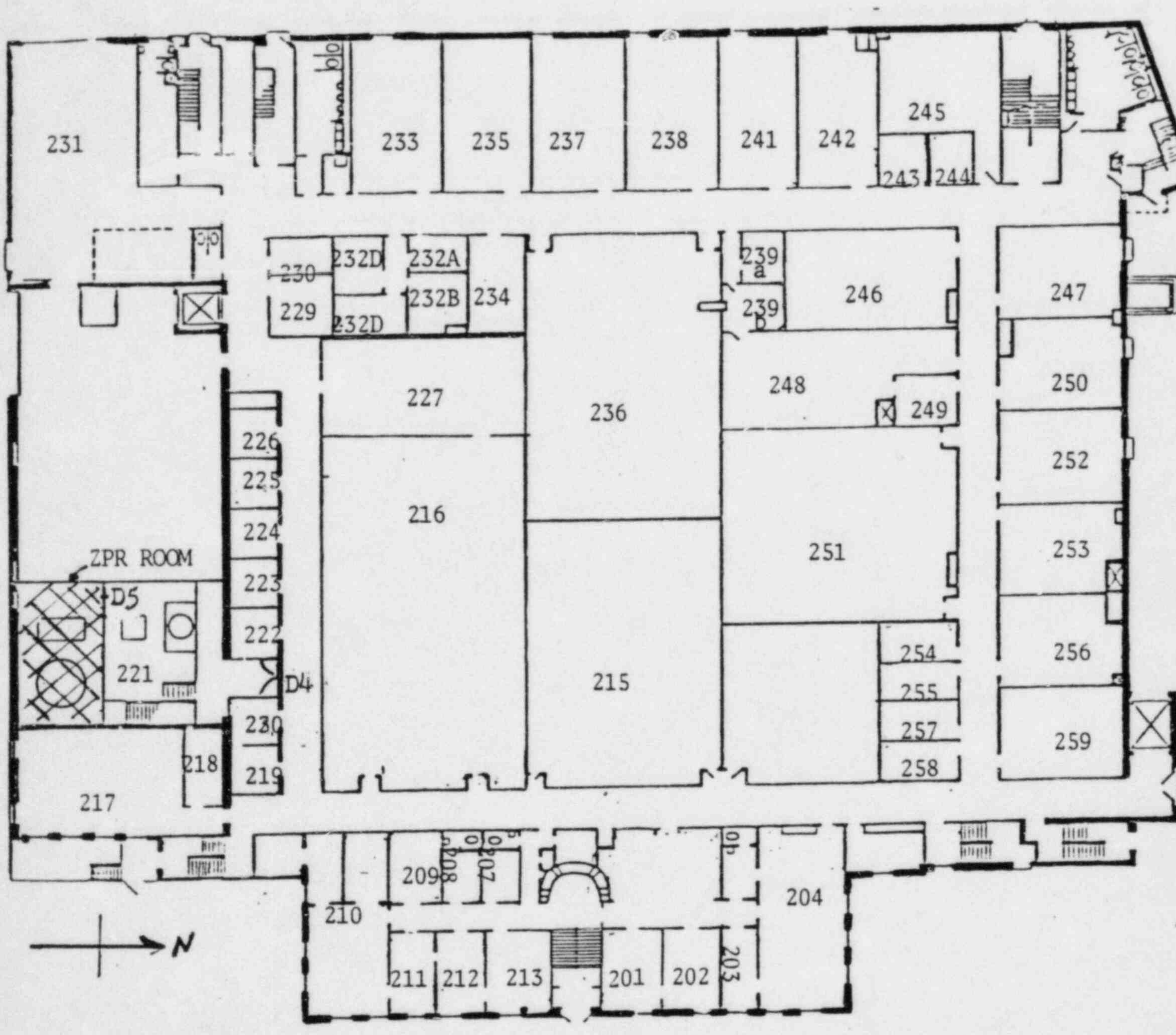


FIGURE 2.2
PLAN OF SECOND FLOOR OF THE LEO ENGINEERING BUILDING
SHOWING THE ZPR ROOM (CROSS HATCHED)

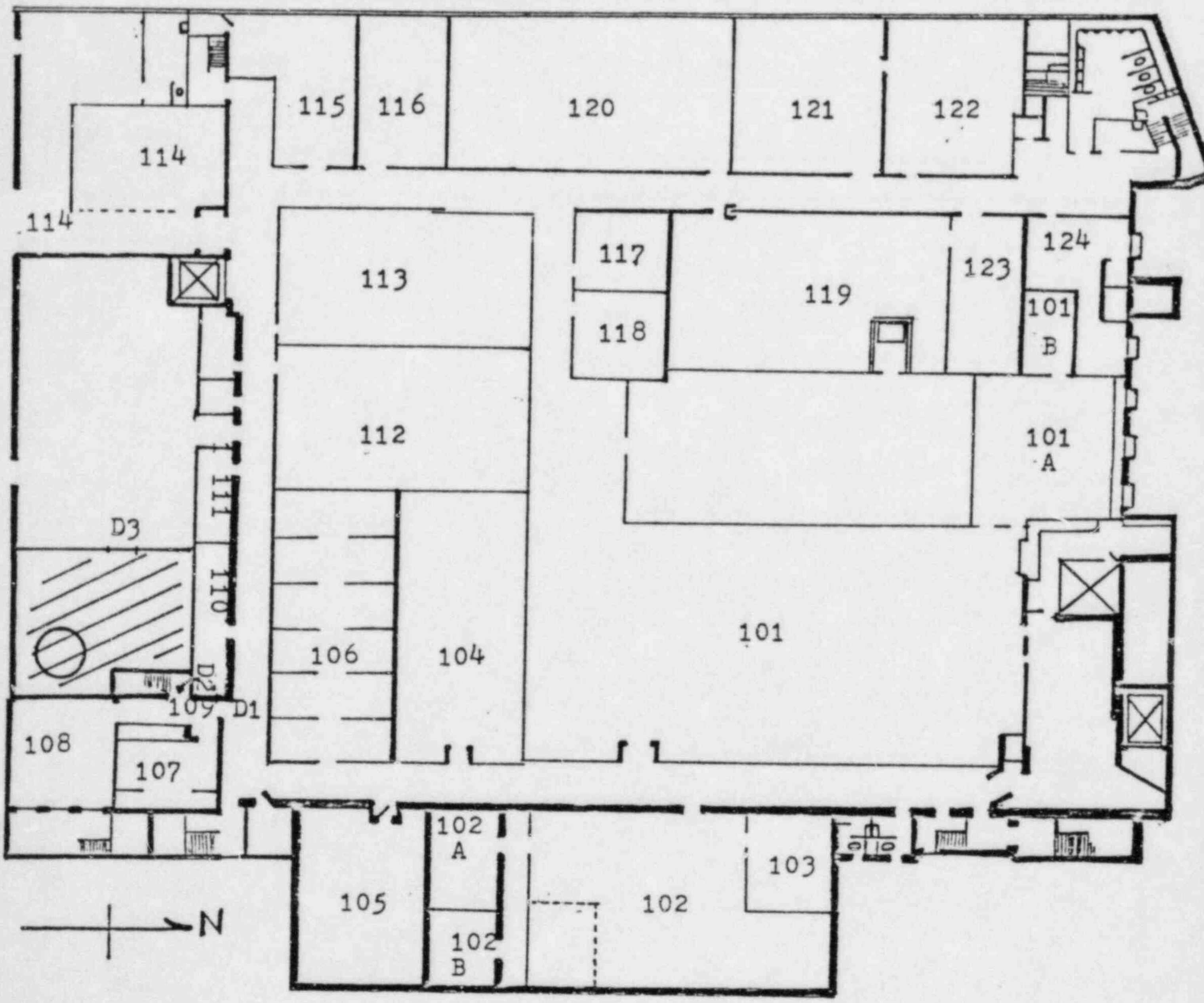


FIGURE 2.3

PLAN OF FIRST FLOOR OF THE LEO ENGINEERING BUILDING SHOWING THE MCZPR FACILITY (SINGLE HATCHED)

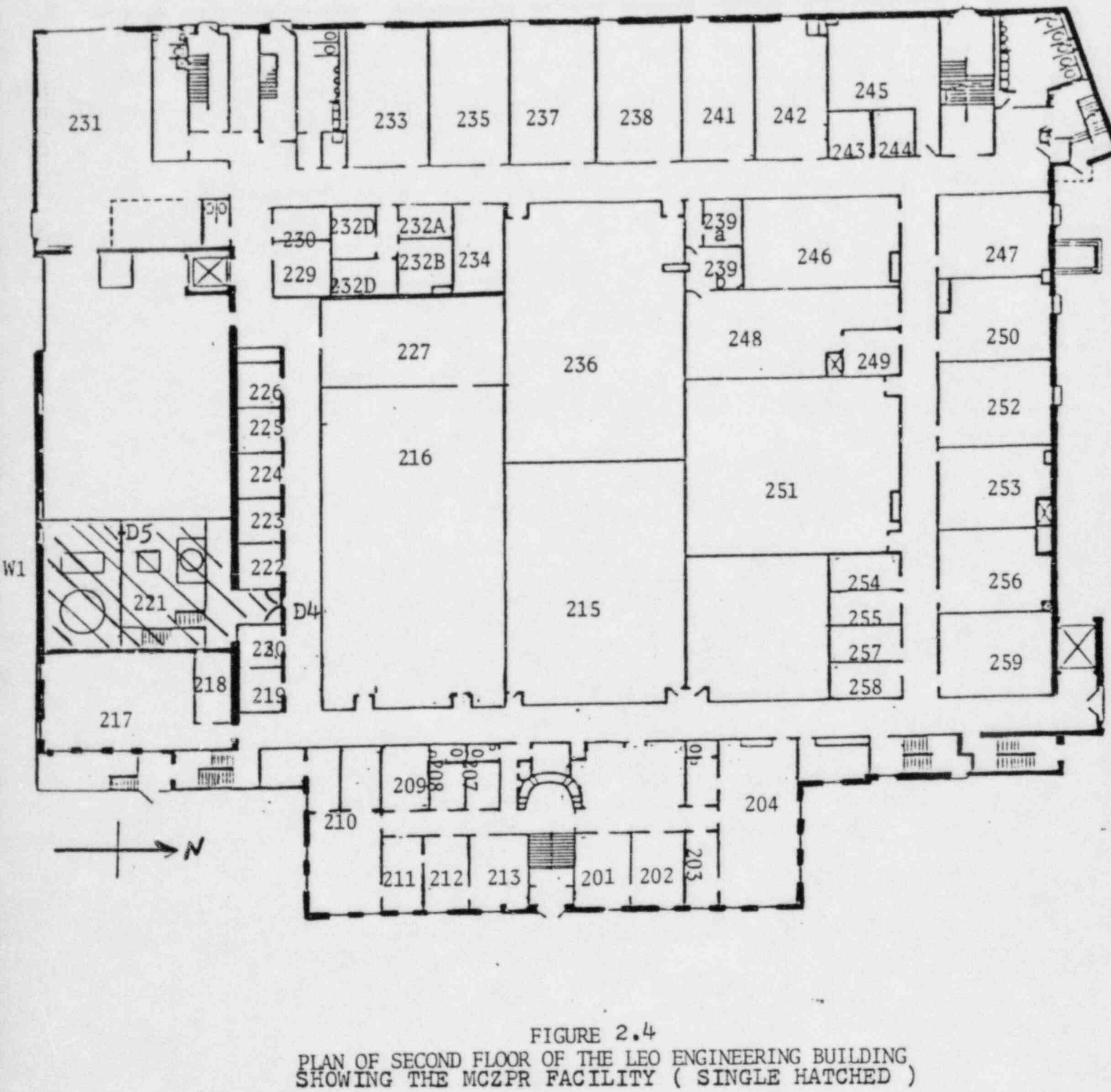


FIGURE 2.4
PLAN OF SECOND FLOOR OF THE LEO ENGINEERING BUILDING
SHOWING THE MCZPR FACILITY (SINGLE HATCHED)

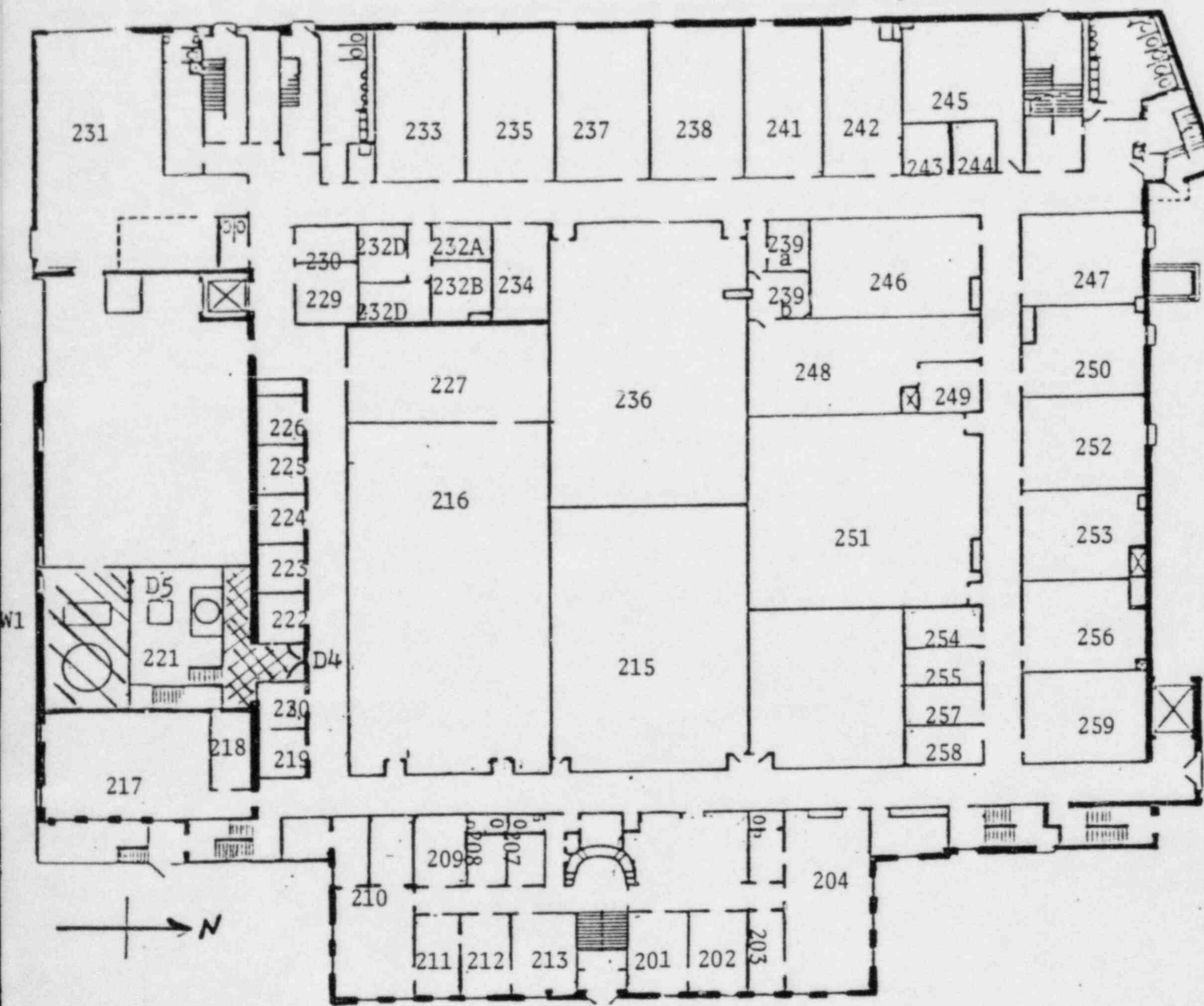


FIGURE 2.5
PLAN OF SECOND FLOOR OF THE LEO ENGINEERING BUILDING
SHOWING EMERGENCY SUPPORT CENTER (CROSS HATCHED)

3.0 Organization and Responsibilities

The Manhattan College Zero Power Reactor Emergency Plan is designed to provide a means of meeting the additional demands that would be encountered if an emergency situation arises. To effect this goal an Emergency Organization drawn primarily from the normal operating personnel is identified. One single individual is assigned the responsibility to direct all emergency related activities.

3.1 Normal Organization Structure

Figure 3.1 shows the normal operating organization of the MCZPR.

3.2 Emergency Organization Structure

Figure 3.2 shows the Emergency Organization.
This organization is formed from the normal operating organization so that a smooth transition is possible.

3.2.1 Emergency Director

The Reactor Administrator will be the Emergency Director. In his absence, the Chief Reactor Supervisor, Reactor Supervisor on duty or the Reactor Supervisor to arrive first on the scene will be the Acting Emergency Director, in that order.

Basic Function

The Emergency Director is responsible for taking all action necessary to manage any reactor related emergency.

Primary Responsibilities

The Emergency Director

1. Coordinates and directs activities of the MCZPR Emergency Organization.
2. Classifies and declares an emergency when needed.
3. Assures notification of College, local and federal agencies as delineated in the procedures required. The actual notification of outside agencies will be made, if time allows, only by the Reactor Administrator.
4. Issuing instructions to the Emergency Organization and assuring that appropriate action is taken.
5. Insures health physics activities on campus.
6. Declares termination of emergency.
7. Authorizes re-entry into the ZPR Room after an emergency.
8. Authorizes volunteer emergency workers to incur radiation exposure in excess of 10CFR20 limits.

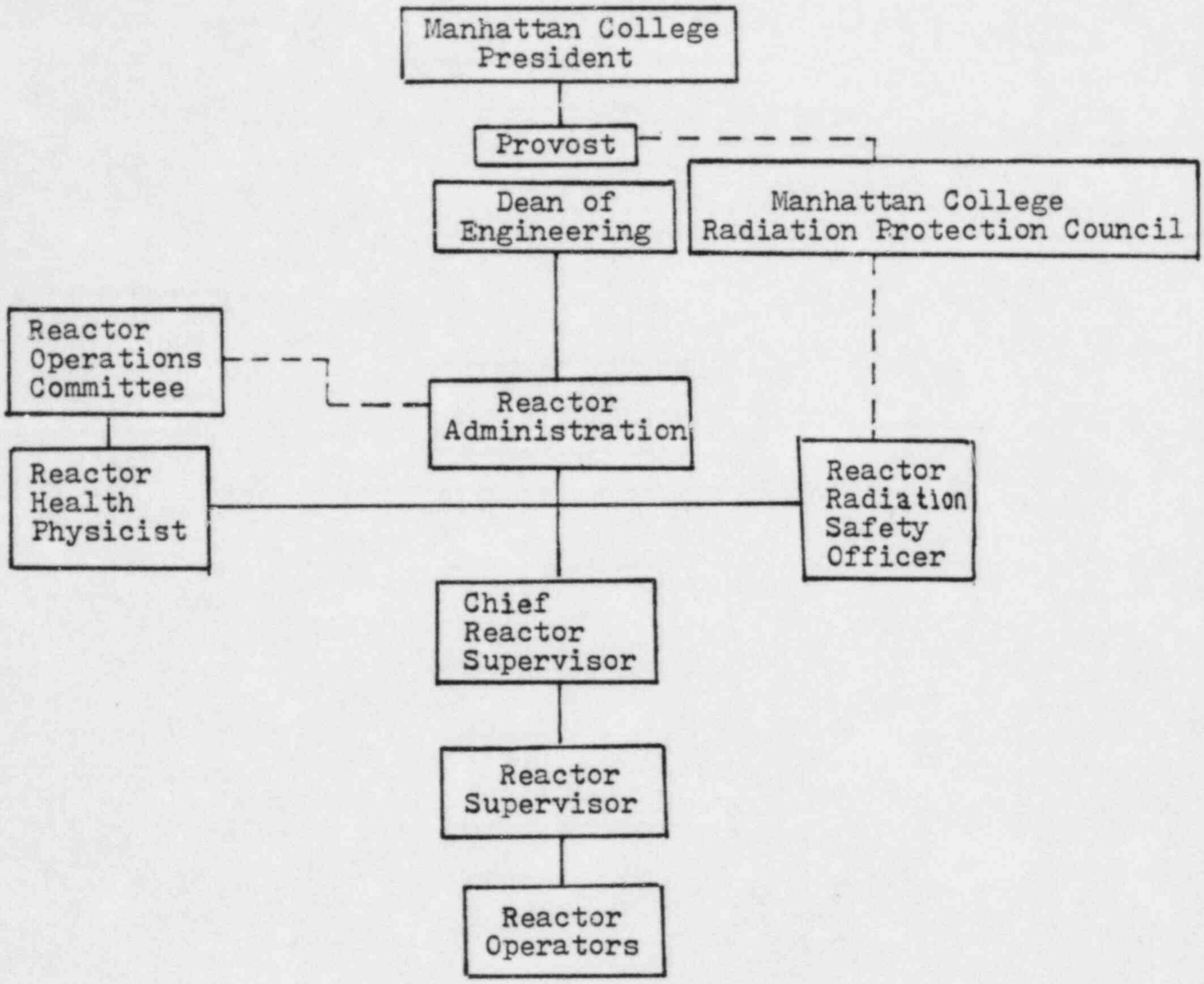


Figure 3.1
MCZPR ORGANIZATION CHART

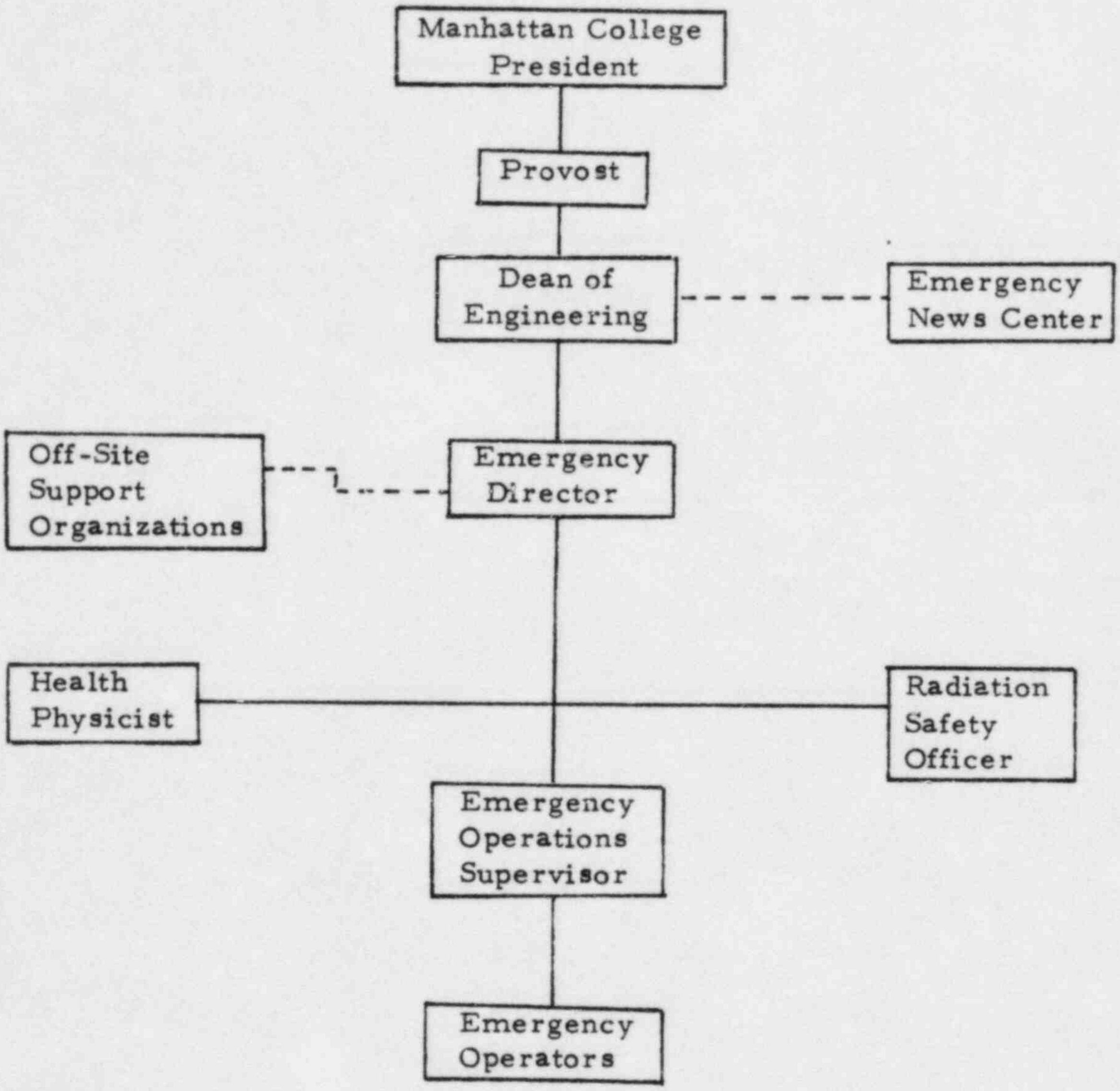


Figure 3.2
MCZPR Emergency Organization Chart

9. Prepares news releases to the public when requested by the Dean of Engineering.

10. Reports to the Dean of Engineering.

3.2.2 Emergency Operations Supervisor

The Chief Reactor Supervisor will be the Emergency Operations Supervisor. In his absence, the Emergency Director will appoint one of the reactor supervisors to act as the Emergency Operations Supervisor.

Basic Functions

The Emergency Operations Supervisor is responsible for the implementation of activities connected with safe shutdown and maintaining of conditions that would minimize the effect on health and safety of the public.

The Emergency Operations Supervisor

1. Reports to the Emergency Director

2. Implements reactor emergency procedures

3. Supervises reactor emergency personnel in work at the reactor connected with the emergency

4. Supervises recovery operations

3.2.3 Emergency Operators

Emergency Operators are drawn from the Reactor Operating personnel.

Basic Function

The basic function of the Emergency Operators is to assist the Emergency Operations Supervisor in his activities connected with an emergency. They report to the Emergency Operations Supervisor.

3.2.4 Radiation Safety Officer

The Reactor Radiation Safety Officer will continue to function as the Radiation Safety Officer during an emergency.

Basic Function

The basic function of the Radiation Safety Officer during an emergency is to advise the Emergency Director on matters of radiation safety during an emergency. He reports to the Emergency Director.

3.2.5 Health Physicist

The MCZPR Health Physicist will continue to function as the health physicist during an emergency.

Basic Function

The basic function of the Health Physicist during an emergency is to implement procedures that would minimize the radiological effects on the health and safety of the personnel involved in an emergency work and that of the public.

The Health Physicist

1. Reports to the Emergency Director

2. Develops plans and procedures for checking for contamination

3.2.6 Emergency News Center

The College Relations office of Manhattan College will serve as the Emergency News Center. Any news pertaining to an emergency will come to the Emergency News Center for the Dean of Engineering or his designate.

3.3 Off-Campus Service Support

To assist Manhattan College Emergency Organization, outside agencies may be called to actionby the Emergency Director.

3.3.1 Medical Assistance

St. Joseph's Medical Center, Yonkers, New York has medical facilities needed to render immediate treatment to contaminated and non-contaminated injured personnel. Appendix 3A is a copy of the letter of understanding between Manhattan College and St. Joseph's Medical Center.

3.3.2 Ambulance Service

St. Joseph's Medical Center will provide ambulance service when needed.

3.3.3 Police

The Manhattan College Security Department will provide routine security for the reactor. If additional security is needed, the Police Department of the City of New York will provide the needed extra security.

3.3.4 Fire Assistance

The Fire Department of the City of New York may be called for assistance if the need arises.

3.3.5 Nuclear Regulatory Commission

If the need arises assistance may be sought from the Nuclear Regulatory Commission, Region I office in King of Prussia, Pa.

St. Joseph's Medical Center

127 South Broadway, Yonkers, New York 10701

June 13, 1983

Dr. Ronald Kane
Director of Mechanical Engineering
Manhattan College
Manhattan College Parkway
Riverdale, N.Y. 10471

Dear Dr. Kane,

This letter is to confirm St. Joseph's Medical Center's ability to handle potential radiation hazards from your college due to its reactors. Currently our department along with the hospital's Radiation Safety Committee is updating and modifying both the internal and external Radiation Safety policies and procedures. Once this process has been completed, I will forward a copy to your office for your records.

Again, St. Joseph's has procedures and protocols designed to handle most Radiation Emergencies 24 hours per day, seven days per week. Our Nuclear Medicine and selected Radiologic technical personnel are trained in Radiation Emergencies. The Emergency Room personnel also have procedures to follow in case an accident occurs during evening and weekend hours. In the meantime, I have supplied you some information that may be beneficial in case an emergency occurs (attached).

If after reviewing this letter you have additional questions or concerns, please call me. A copy of our final report will be sent to you when completed.

Sincerely,

Robert Kleinbauer
Administrator-Radiology Services
St. Joseph's Medical Center

BK/sr

CC: Dr. Puljic
Dr. Marsden
Mr. Hyde
Radiation Safety File
BK File

ATTACHMENT I

NUCLEAR MEDICINE DEPARTMENT:

HOURS OF OPERATION:	MONDAY - FRIDAY 7:30 AM - 5:30 PM
EMERGENCY COVERAGE:	CALL ADMINISTRATOR ON CALL OR RADIOLOGIST ON CALL
PHONE NUMBERS:	(914) 965-6700 EXT. 687,688

PERSONNEL:

MS. JEANINE WYKA - NUCLEAR MED. TECHNICIAN

MR. GENE TOLENTINO - NUCLEAR MED. TECHNICIAN

MR. ROBERT KLEINBAUER - ADMINISTRATOR

DR. SMILJAN PULJIC - DIRECTOR OF RADIOLOGY

IN CASE NUCLEAR MEDICINE DEPARTMENT IS CLOSED CALL RADIOLOGY DEPARTMENT (EXT. 683) OR EMERGENCY ROOM (EXT. 471), EXPLAIN SITUATION, LEAVE NAME AND PHONE NUMBER; THEY WILL CONTACT ALL APPROPRIATE STAFF.

4.0 Emergency Classification System

4.1 Conceptually, all possible emergencies at any research and test reactor have been classified into four groups. Appendix I of the Standard Review Plan [1] (repeated on the next few pages) lists them as

1. Notification of Unusual Events
2. Alert
3. Site Area Emergency
4. General Emergency

For the MCZPR licensed at 0.1 watt and with no recirculating cooling requirements, only the first class of emergency, viz: Notification of Unusual Event is hypothesized as the most severe credible accident.

4.2 Notification of Unusual Events

The emergency class "Notification of Unusual Events" is hypothesized to exist at MCZPR if events are in progress or have occurred which indicate potential degradation of the safety of the reactor. Specific action levels are detailed in Section 5.0, Emergency Action Levels for Notification of Unusual Events.

[1] E.F. Bates, B. K. Grimes and S. L. Ramos
Standard Review Plan for the Review and Evaluation of Emergency Plans for Research and Test Reactors
U.S. Nuclear Regulatory Commission
NUREG-0849, May 1982.

APPENDIX I

EMERGENCY CLASSES AND EXAMPLE EMERGENCY ACTION LEVELS

Emergency Class		Example Action Levels
Notification of Unusual Events	1.	Actual or projected radiological effluents at the site boundary exceeding 10 MPC for unrestricted areas when averaged over 24 hours or 15 mrem whole body accumulated in 24 hours. 1/
	2.	Report or observation of severe natural phenomenon that are imminent or existing such as: (1) earthquakes that could adversely affect the reactor safety systems, (2) high or low natural water sources that could adversely affect reactor safety systems and; (3) tornado or hurricane winds that could strike the facility.
	3.	Threats to or breaches of security.
	4.	Fuel damage accident that could release radionuclides to confinement or containment.
	5.	Fire within the facility lasting more than 10 minutes.

1/ It should be noted that the radiation dose levels of the emergency action levels established for the various emergency classes are slightly different from those specified for power reactors. However, in the judgment of the NRC staff, the radiation dose levels specified are adequate for the credible accidents associated with the operation of research and test reactors, and the specified action levels provide reasonable assurance that protective measures associated with the action levels specified can and will be taken, provided appropriate emphasis is also given to developing emergency action levels that relate directly to facility parameters (e.g., pool water levels and area radiation monitors).

Emergency Class		Example Action Levels
Alert	1.	Actual or projected radiological effluents at the site boundary exceeding 50 MPC for unrestricted areas when averaged over 24 hours or 75 mrem whole body accumulated in 24 hours. 1/
	2.	Radiation levels at the site boundary of 20 mrem/hr for 1 hour whole body or five times this level to the thyroid. 1/
	3.	Abnormal loss of water used for shielding or coolant to irradiated reactor fuel at a rate which either exhausts the initial backup system capacity or exceeds makeup capacity.
	4.	Loss or radioactive material control that causes radiation dose rates or airborne radionuclides to increase ambient exposure levels by a factor of 1000 throughout the reactor building.
	5.	Fire that may affect any reactor safety system(s).
	6.	Other imminent or existing hazards such as (1) missles impacting on the reactor facility, (2) explosion that affects facility operation, and (3) uncontrolled release of toxic or flammable gases into the facility environs.
	7.	Radiation dose rates in the reactor building requiring evacuation of all personnel (e.g., 100 mrem/hr for one hour throughout the reactor building.

1/ It should be noted that the radiation dose levels of the emergency action levels established for the various emergency classes are slightly different from those specified for power reactors. However, in the judgment of the NRC staff, the radiation dose levels specified are adequate for the credible accidents associated with the operation of research and test reactors, and the specified action levels provide reasonable assurance that protective measures associated with the action levels specified can and will be taken, provided appropriate emphasis is also given to developing emergency action levels that relate directly to facility parameters (e.g., pool water levels and area radiation monitors).

Emergency Class		Example Action Levels
Site Area Emergency	1.	Actual or projected radiological effluents at the site boundary exceeding 250 MPC for unrestricted areas when averaged over 24 hours or 375 mrem accumulated in 24 hours. 1/
	2.	Actual or projected radiation levels at the site boundary of 100 mrem/hr for 1 hour whole body or five times this level to the thyroid. 1/
	3.	Abnormal continuing loss of reactor coolant, to fuel requiring coolant, at a rate greater than the capacity of the backup system(s).
	4.	Imminent loss of physical control of the reactor.
	5.	Several natural events being experienced. Examples include: a) earthquake that is causing observable damage to the reactor safety equipment within the building. b) high or low natural water levels that are affecting the operability of any reactor safety system; and c) tornado or hurricane winds that are damaging the reactor structure.

1/ It should be noted that the radiation dose levels of the emergency action levels established for the various emergency classes are slightly different from those specified for power reactors. However, in the judgment of the NRC staff, the radiation dose levels specified are adequate for the credible accidents associated with the operation of research and test reactors, and the specified action levels provide reasonable assurance that protective measures associated with the action levels specified can and will be taken, provided appropriate emphasis is also given to developing emergency action levels that relate directly to facility parameters (e.g., pool water levels and area radiation monitors).

Emergency Class		Example Action Levels
General Emergency [2/]	1.	Sustained actual or projected radiation levels at the site boundary of 500 mrem/hr.
	2.	Actual or projected doses radiation levels at the site boundary in the exposure pathway of 1 rem whole body or 5 rem thyroid.
	3.	Loss of reactor coolant that could lead to fuel melt.
	4.	Loss of physical control of the reactor building or reactor control room and areas housing vital equipment.
	5.	Events that have caused or will cause massive facility or reactor system damage that could lead to fuel melt.

2/ Generally not specified for facilities with authorized power levels less than or equal to 2 MW thermal and determined on a case by case basis above the level.

5.0 Emergency Action Levels for Notification of Unusual Events

1. Indication of fuel damage by increased concentration of radionuclides in the reactor water

2. Loss of Confinement integrity

3. Threats to or breaches of security

4. Fire within the facility lasting more than 10 minutes

5. Report or observation of severe natural phenomenon that are imminent or are existing such as:

   a) earthquake
   b) hurricane
   c) flood

6. Other hazards or events at the facility such as:

   a) aircraft crash
   b) explosion
   c) release of toxic or flammable gas

7. Injury to personnel (contaminated or not) that requires transportation to an off-campus medical facility

It is recognized that the above items have very low probability of occurrence at the MCZPR facility.

6.0 Emergency Planning Zone

No radiological emergency that could result in off-site plume exposures exceeding 1 rem whole body or 5 rem thyroid is plausible at MCZPR and hence no Emergency Planning Zone is identified for MCZPR.

7.0 Emergency Response

Emergency classes of Alert, Site Area Emergency and General Emergency are not postulated to occur at MCZPR. Hence, the emergency response is given only for the emergency class, Notification of Unusual Events.

7.1 Activation of Emergency Organization

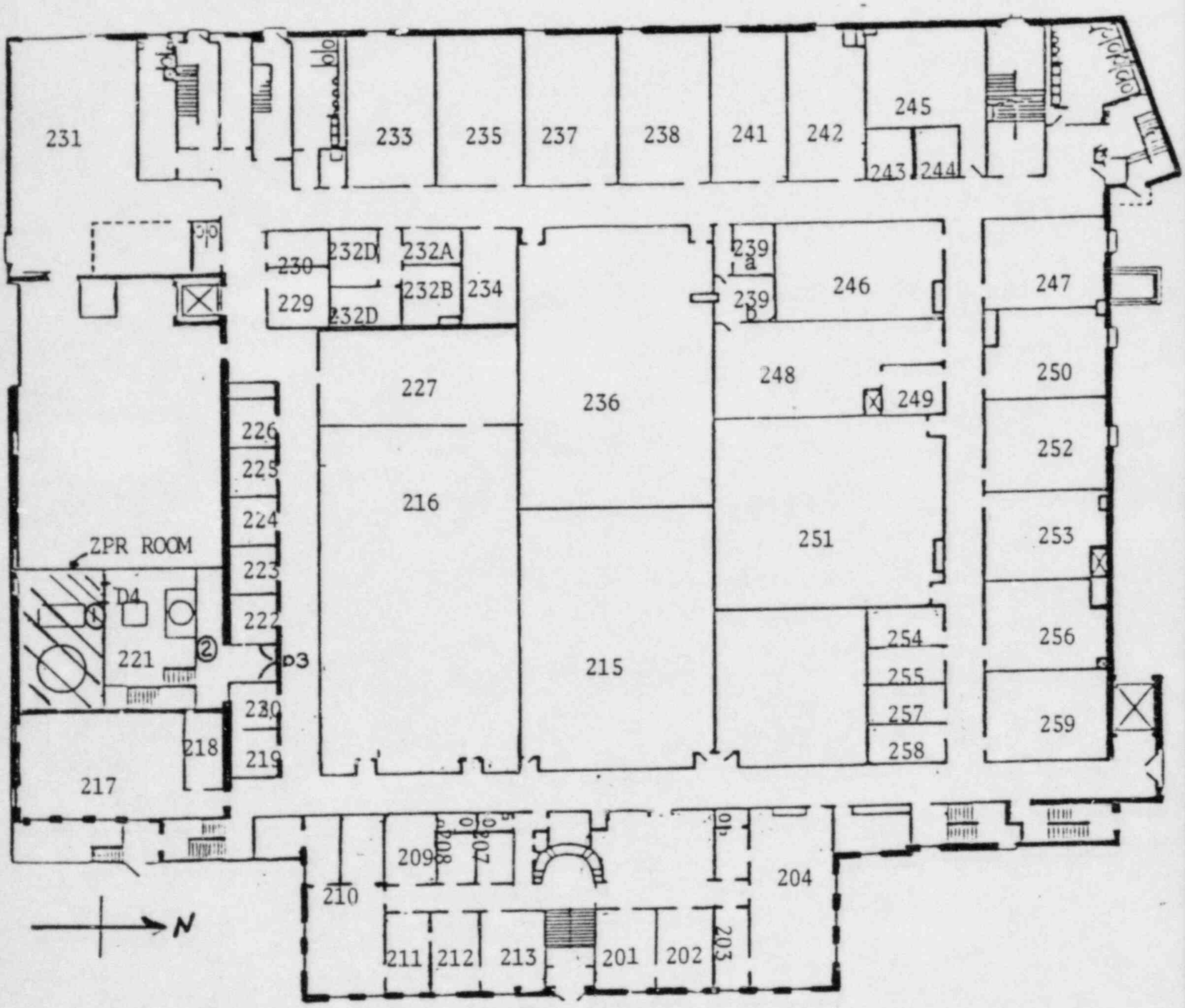
The Emergency Organization will be activated by the following steps:

1. If and when a MCZPR staff member becomes aware of or is informed of the possible existence of an emergency, he notifies the Reactor Administrator, the Chief Reactor Supervisor or a Reactor Supervisor, whoever he can reach in that order.
2. The first person who is entitled to act as the Emergency Director to reach the Reactor Facility verifies the existence of an emergency, declares an emergency and assumes the role of the Emergency Director.
3. A Reactor Supervisor who assumes the role of the Emergency Director will relinquish that role to the Chief Reactor Supervisor when the latter reaches the facility. The Chief Reactor Supervisor will relinquish the role of the Emergency Director when the Reactor Administrator arrives at the facility.
4. The Emergency Organization is activated by the Emergency Director. The call-out roster of the members of the Emergency Organization with their telephone numbers (both home and office) shall be posted at the Control Console of the reactor and at the Emergency Support Center. These locations are shown in Figure 7.1. The roster will also contain telephone numbers of the off site agencies such as NRC, ambulance, hospital, police and fire department that may be activated if necessary.

Telephones are provided at the Reactor Control Console and at the Emergency Support Center. Telephones are also available in faculty and department offices and in the Dean's office.

7.2 Assessment Action

The reactor operations staff are provided with film badges. Extra badges are also available. These may be used to assess radiation doses, if any, to personnel during an emergency.



① CONTROL CONSOLE

② EMERGENCY SUPPORT CENTER

FIGURE 7.1

LOCATION OF EMERGENCY ORGANIZATION CHART

Calibrated portable radiation meters are available at the reactor facility. An assessment of radiation levels may be made using these instruments. If deemed necessary, the health physicist will take wipes and air samples and assess the extent of the contamination, if any.

7.3 Notification

"Notification of an Unusual Event" shall be made no later than the next working day to NRC, Region 1, King Of Prussia, Pa. by the Reactor Administrator. If this cannot be accomplished by the Reactor Administrator in the allotted time due his absence, then the Emergency Director who acts in that capacity on behalf of the Reactor Administrator will accomplish the notification process.

7.4 Leaving the Facility Before the Termination Of An Emergency

If the Emergency Director has to leave the facility for any reason, he may do so only after appointing a qualified substitute to act as the Emergency Director.

7.5 Termination of Emergency

When appropriate, the Emergency Director shall declare the termination of emergency.

7.6 Emergency Log

An Emergency Log will be maintained by the Emergency Director. The log should contain the time date of the declaration of every emergency, the name of the Emergency Director, action taken during an emergency, time and date of the declaration of the termination of the emergency. The Emergency Log should be kept at the Emergency Support Center.

8.0 Emergency Facilities and Equipment

8.1 Emergency Support Center

The platform in Room 221 (shown double hatched in Figure 8.1) will serve as the Emergency Support Center.

8.2 Emergency Equipment

Portable Radiation Survey meters are available in the ZPR room.

8.3 First Aid Facilities

First aid supplies are available in cabinets at the Emergency Support Center.

8.4 Communications Equipment

Telephones are provided at the Reactor Control Console and at the Emergency Support Center. Additional phones are available in the offices of the Dean of Engineering and faculty and department offices.

8.5 Decontamination Equipment

Decontamination equipment is provided at the Emergency Support Center.

8.6 Handling of Injured and/or Contaminated Personnel

Arrangements have been made with a medical center (Appendix 3A) for the handling of injured and/or contaminated personnel.

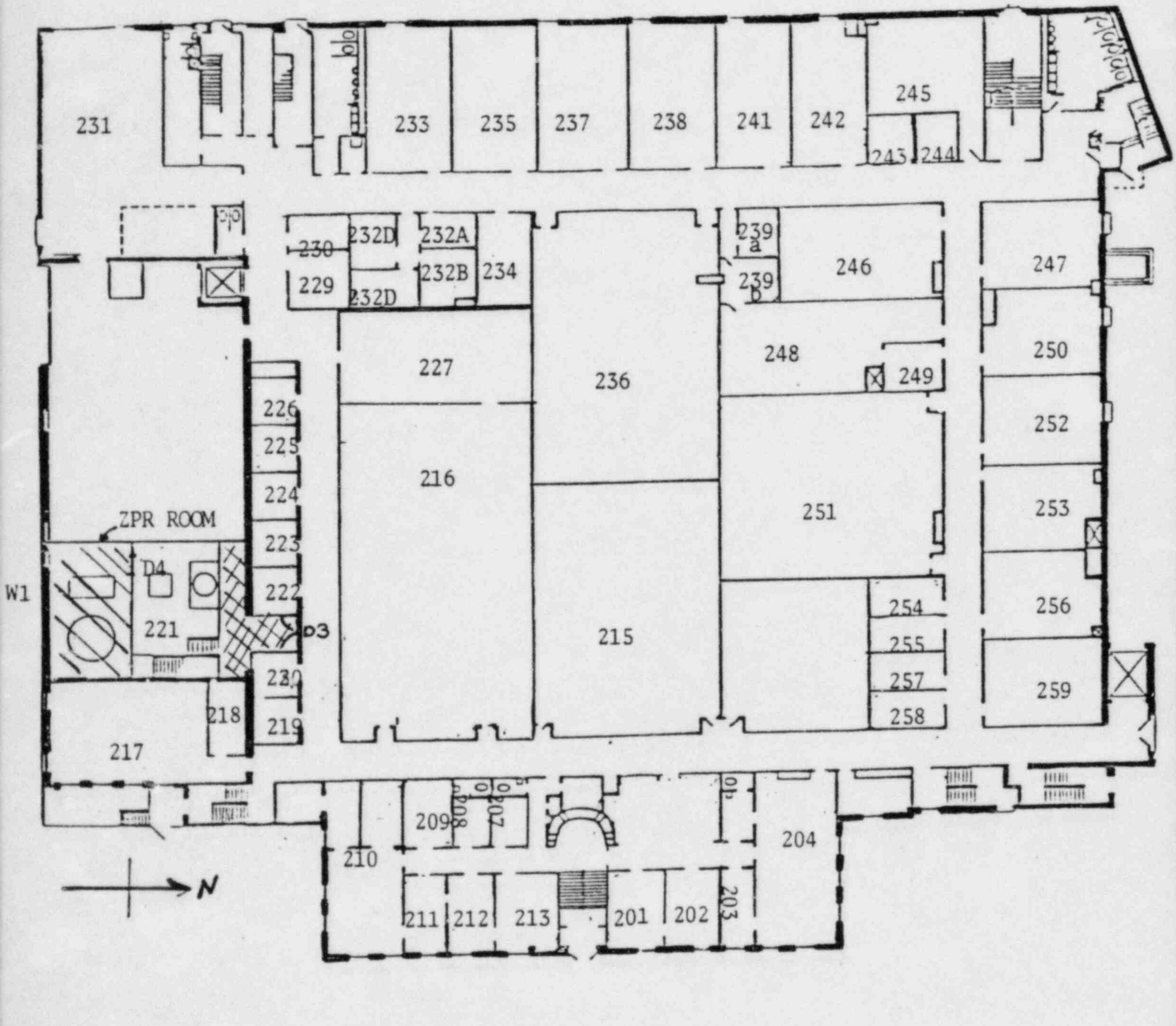


FIGURE 8.1

EMERGENCY SUPPORT CENTER (SHOWN CROSS HATCHED)

9.0 Recovery

9.1 Recovery Manager

The Chief Reactor Supervisor, or in his absence, a Reactor Supervisor will act as the Recovery Manager.

The Recovery Manager will:

1. See that the facility is brought back to normal for the normal operation of the reactor

2. Perform the normal checkout procedures of the reactor.

3. Enter in the Reactor Operations Log book that the reactor has been recovered after the emergency and that the reactor is ready for normal operation.

10.0 Maintaining Emergency Preparedness

10.1 Annual Review

These emergency plans shall be reviewed by the Reactor Operations Committee at least once a year.

10.2 The Emergency Organization chart and the call out roster shall be corrected whenever necessary and the updated charts should be posted and distributed as needed.

10.3 Implementing procedures affected by any emergency plan changes shall be revised, approved and distributed to authorized recipients within 30 days after the revised plans have been issued.

APPENDIX J

OPERATOR REQUALIFICATION PROGRAM

OPERATOR REQUALIFICATION PROGRAM

Since the Manhattan College Zero Power Reactor is a research and test reactor licensed only for 0.1 watt maximum, the requalification program is guided by paragraph 7 of 10CFR55, Appendix A. The requalification program will be operated by Bro. Gabriel Kane, FSC, Ph. D. who has been reappointed Chief Reactor Supervisor, effective July 1, 1983. Bro. Gabriel Kane had been Chief Reactor Supervisor until June 30, 1980. Dr. Joseph Augustus served as Chief Reactor Supervisor from July 1, 1980 to June 30, 1983. In order to requalify Bro. Kane, Dr. Augustus (who remains on the Reactor Operations Committee) will evaluate any necessary requalification examinations administered to Bro. Kane. The requalification examination for Bro. Kane will be administered on September 1, 1983. We note that Bro. Kane holds a Doctorate in Physics from the Catholic University of America, has held a Senior Reactor Operator's License from November 6, 1968 to the present, and served as Chief Reactor Supervisor from November 6, 1968 to January 13, 1972 and again from May 4, 1973 to June 30, 1980.

On successful completion of the requalification examination by Bro. Kane, Bro. Kane will then operate requalification programs thereafter. In accordance with paragraph 7 of 10CFR55, Appendix A, the requalification program will conform generally but will not be identical to paragraphs 1 through 6 of 10CFR55, Appendix A.

1. Schedule. The requalification program will be conducted continuously over two year cycles. The program will be revised as needed for each succeeding cycle to account for changes in equipment or operating procedures. For any individual whose operator or senior operator license approaches expiration during the two year cycle, a written examination illustrating the effectiveness of the program will be administered.

2. Lectures. In consideration of the primary use of the Manhattan College Zero Power Reactor (MCZPR) as a teaching and demonstration tool for nuclear engineering courses, each licensed operator or senior operator normally must prepare and present lectures each semester on the theory, operation, and safety features of the MCZPR and nuclear facility. As part of the requalification program, the preparation and presentation of at least one lecture each semester on these subjects will be required of each licensed operator or senior operator.

3. On-the-Job Training. Since the MCZPR is a small research and test reactor, the requalification program requirements for production or utilization facilities do not strictly apply. However all licensed operators and senior operators will be required to make a complete checkout of the reactor and bring it to criticality at least once every four months. As has been the practice, all licensed operators and senior operators will serve on the Reactor Operations Committee. This insures that each licensed operator and senior operator is cognizant of facility design changes, procedure changes, facility license changes and is aware of emergency procedures. The Reactor Operations Committee meets at least once each semester and maintains complete records of its meetings and activities.

4. Evaluation. Each licensed operator and senior operator shall be required to submit biennially to a written examination. The examination will include the following topics:

a) Fundamentals of reactor theory, including fission process, neutron multiplication, source effects, control rod effects, and criticality indications.

b) General design features of the core, including core structure, fuel elements, control rods, and core instrumentation.

c) General operating characteristics including effects of temperature and reactivity changes.

d) Design, components and functions of safety systems, including instrumentation, signals, automatic and manual features.

e) Components, capacity and functions of reserve and emergency systems.

f) Standard and emergency operating procedures for the facility.

g) Purpose and operation of radiation monitoring system including survey equipment.

h) Radiological safety principles and procedures.

i) Conditions and limitations in the facility license or authorization.

j) Facility license procedures required to obtain authority for design and operating changes in the facility.

4. (continued)

k) Reactor theory, including details of fission process, neutron multiplication, source effects, control rod effects, and criticality indications.

l) Procedures and limitations involved in initial core loading, determination of various internal and external effects on core reactivity.

Any licensed operator or senior operator who scores less than 80% in the biennial examination will be required to take a make-up examination. All examinations will be kept on file for at least two years.

As administrator of the requalification program, the Chief Reactor Supervisor will be exempt from the requirement to submit to an annual examination. However, a newly appointed Chief Reactor Supervisor must submit to a written examination (administered by the outgoing Chief Reactor Supervisor) at some time during the first three months of his appointment. Operators or senior operators possessing at least a Master's Degree in Nuclear Engineering and who have taught an under-graduate or graduate nuclear engineering course during the preceding or current academic year may be exempted by the Chief Reactor Supervisor from the theoretical part of the written examination.

Licensed operators or senior operators shall be observed by the Chief Reactor Supervisor, at least once every four months, in checking out the reactor and bringing the reactor to criticality. A newly appointed Chief Reactor Supervisor, upon certification by the previous Chief Reactor Supervisor that his performance in checking out and operating the reactor is satisfactory, shall be exempt from further observation.

5. Records. Records documenting the participation of each licensed operator and senior operator in the requalification program will be maintained for a minimum of two years from the date of each recorded event. The records shall contain copies of all examinations and evaluations.

6. Alternative training programs. Such programs are not required for the MCZPR.

APPENDIX G

OCTOBER 6, 1966 CORRESPONDENCE

MANHATTAN COLLEGE BRONX, NEW YORK 10471
PHYSICS DEPARTMENT [illegible]

October 6, 1966

Mr. Marvin K. Woodard
Division of Licensing and Regulation
U.S. Atomic Energy Commission
Washington, D.C. 20025

Dear Mr. Woodard:

As of our letter of October 29, 1965, we submitted a proposal to your Division for a change in technical specifications for the operation of our reactor facility under License R-94. We requested then that Section G-1 of Appendix A be changed to read:

> "The core shall be comprised of no more than sixteen standard fuel elements and one partial element. The number of fuel plates contained in the partial element shall be adjusted such that the excess reactivity at 60°F shall not exceed .003 and at 75°F shall not exceed .0035 with both control rods "full out".

We proposed also at that time that a limitation of 80°F be placed on the maximum operating temperature except during an experiment to determine the temperature at which the turn around to a negative temperature reactivity coefficient takes place.

In order to substantiate our proposal, the MCA of the Hazards Summary Report had to be reevaluated based on the assumption that the MCA would occur at the turn around temperature when the core had the maximum excess reactivity. It was necessary, then, to determine this maximum reactivity by an experiment which would require us to heat the pool water to approximately 120°F. The cost of the required heating units was prohibitive at that time and we suggested the possibility of a correlative study of the MZPR with IRL for which temperature coefficient data was available.

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We wish to submit for your study at this time, such conclusions as we have drawn from the data available from the operational log of MZPR and the experimental data obtained from IRL.

Submitted by:

Brother B. Francis Rolston, F.S.C.
Reactor Supervisor

Approved:

Brother C. Gabriel Kane, F.S.C.
Chairman, Committee for Nuclear Science and Engineering

CERTIFICATE

The applicant and any official executing this certificate on behalf of the applicant certify that these applications are prepared in conformity with Title 10, Code of Federal Regulations, Parts 50 and 70, and do so solemnly swear (or affirm) that all information contained herein, including any supplements attached hereto, is true and correct to the best of our knowledge and belief.

Manhattan College, New York, N. Y.
Applicant

By ______________________________
Brother Gabriel Kane, Chairman
Committee for Nuclear Studies

Approved: ______________________
Brother C. Stephen, F. S. C.
Academic Vice President

State of New York

County of Bronx

Subscribed and sworn to before

me this _____ day of __________

Notary Public

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Void Coefficient Measurement

Detailed information regarding the void coefficient measurement of the IRL core was available thru the courtesy of Mr. Richard Canfield, IRL Reactor Supervisor. It was possible for us, then, to make a similar measurement of the reactivity effects of voids in the MZPR core and correlate the results with IRL.

A special lucite hold-down rod was prepared which had a void volume of approximately 164 cm^3. This replaced the ordinary hold down rod when the void effect was being measured for a particular core position. The results for the MZPR are tabulated below and indicated on the accompanying core diagram.

Core Position	$\frac{\Delta k}{k} \times 10^{-6}$
34	-7.24
12	-4.3
22	-6.7

Core Position	$\frac{\Delta k}{k} \times 10^{-6}/cm^3$
35	-4.9
55	-6.7
45	-5.5
46	-3.7
44	-7.3
24	-6.1
Average Void Coeff.	$-5.83 \times 10^{-6} \frac{\Delta k}{k}$

The average void coefficient measured for the IRL core loading 55 was $-5.94 \times 10^{-6} \frac{\Delta k}{k}$. It would be reasonable to assume, then, that in the event of an excursion, the MZPR will respond in a fashion similar to the pool reactor and the void effect will help to terminate the excursion.

With a water volume of 3237 in^3 in the core, a volume coefficient of expansion of $1.95 \times 10^{-4}/^oC$ and a void reactivity coefficient of $-5.83 \times 10^{-6} \frac{\Delta k}{k}$ $/cm^3$, there will be a total negative reactivity effect of $-.36\% \frac{\Delta k}{k}$ in the

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Void Coefficient Measurement (cont'd)

of an excursion of the MZPR. This is approximately the same amount of positive reactivity we assumed would result from the positive temperature effect between 60°F and 110°F. Again it is seen that we can rely upon the negative void coefficient to assist in shutting down the reactor.

Prompt Temperature Coefficient of IRL and MZPR

Using the Method of Meem, the prompt temperature coefficients for the IRL and MZPR were calculated. For the MZPR the calculated temperature coefficient was $-1.31 \times 10^{-4} \frac{\Delta k}{k} /^{o}F$ and for the IRL reactor $-1.135 \times 10^{-4} \frac{\Delta k}{k} /^{o}F$.

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I. Conclusions drawn from data obtained from the Operational Log Book of M ZPR.

The following excess reactivity measurements were made on the M ZPR. It must be borne in mind that since these measurements were made at different times during the year by different experimental groups, the error involved might be appreciable. Calibration of the fine position indication system of the Regulating Rod was made before each measurement, but this adjustment is a very delicate operation and could vary appreciably over several weeks or months.

Temperature	$\% \frac{\Delta k}{k}$	Date
$60^{\circ}F$	.290	2/18/65
$63^{\circ}F$	.314	3/18/65
$63^{\circ}F$	.323	3/18/65
$63^{\circ}F$	.295	3/16/65
$72^{\circ}F$	.340	8/5/65
$75^{\circ}F$	.350	8/6/65
$75^{\circ}F$	.355	8/12/65
$68^{\circ}F$	.321	10/8/65

This data is represented on the following graph where the reactivity is plotted as a function of pool water temperature and normalized at a nominal room temperature of $70^{\circ}F$ for a comparison with the behaviour of the IRL pool reactor.

As the graph seems to indicate the variation in reactivity peaks at a value of .030 and at a temperature of $110^{\circ}F$. Since the curve is normalized at $70^{\circ}F$ this would indicate that the excess reactivity in the core will not exceed .369 $\% \frac{\Delta k}{k}$.

II. Reevaluation of MCA based upon M ZPR data.

(a) Assuming that the MCA occurs when the excess reactivity has reached a maximum of .450 $\% \frac{\Delta k}{k}$ (this allows for some possible error in the estimated experimental value of .369 $\% \frac{\Delta k}{k}$) at $110^{\circ}F$, we first calculated the peak power rise from a steady operational power of .1 watt. This was done assuming the following reactor constants:

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II. Reevaluation of MCA based upon M ZPR data (cont'd).

$P_o = .1$ watt

$(\delta k_e)_o = .0045$

$B_{eff} = .0084$

$\bar{\ell} = .1068$ sec.

$\alpha(T) = -1.5 \times 10^{-4} \frac{\Delta k}{k} /^oC$

$C_p = 2.185 \times 10^5$ watt/gm/^oC

and employing the basic equations:

$$\frac{1}{P} \frac{dP}{dT} = \frac{\delta k_e}{\bar{\ell}}$$

$$\frac{dP}{dT} = \frac{C}{\bar{\ell}} \left[(\delta k_e)_o - |\alpha| T \right]$$

$$P = P_o + \frac{C}{\bar{\ell}} \left[(\delta k_e)_o T - \frac{|\alpha| T^2}{2} \right]$$

when $T = \frac{(\delta k_e)_o}{|\alpha|}$ $P = P_{max}$

$$P_{max} = P_o + C \frac{(\delta k_e)_o^2}{2 |\alpha| \bar{\ell}}$$

This yields a value of P_{max} of 147 kw.

From these same basic equations time plots of $(\delta k)_e$, P and T were made which appear on a separate graph. In order to make these graphs it was assumed that P_o = 10 kw since $(\delta k)_e$ and hence P was a slowly varying function of time. Corrected times were then calculated. The following data was used in making the graphs:

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II. Reevaluation of MCA based upon M ZPR data (cont'd).

t(sec)	$\delta k_e (\times 10^{-3})$	T(°C)	P(kw)
0	4.5	43.3	10^{-4}
116.8	4.334	44.4	10
126.8	4.254	44.9	14.84
136.8	4.144	45.7	21.4
156.8	3.714	47.4	44.8
176.8	2.894	53.9	83.9
196.8	1.434	63.6	121
216.8	-0.433	76.0	147
236.8	-2.186	87.6	118
256.8	-3.386	94.9	72
276.8	-4.216	101.1	31
316.8	-4.716	105	0

From these graphs it is seen that the reactor peak power of 147 kw would be reached in 3.6 min. after the beginning of the excursion and the power would be essentially zero again after approximately 5.3 min. The core temperature will rise to 105° C indicating there might be some boiling of the water moderator in the center of the core.

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III.

A correlative study of the MZPR and the pool reactor at IRL was made. The nuclear parameters of the MZPR and IRL are not too different as can be seen from the following table. Similarities of volume fractions of fuel, water and aluminum and equivalent core size should be noted. The primary difference between the two cores is the clustering of fuel in the MZPR which results in a somewhat lower thermal utilization.

	MZPR	IRL
Volume of Unit Cell.	156 in^3	216 in^3
Volume Composition of Unit Cell		
H_2O	.6393	.623
Al	.3584	.375
U-235	.002084	.002394
U-238	.000156	

The clustering of the fuel was considered in the MZPR core calculations by the original designers using computer code methods proven to be reliable. The MZPR core can, we feel, be fairly well represented by a measured IRL core, after proper normalization.

Prompt Temperature Coefficient

The prompt temperature coefficient of the MZPR core was originally calculated by repeating the reactivity calculation, using P_3 and DMM codes, at two different temperatures 70^oF and 270^oF. The difference in reactivity at these two temperatures was then divided by 200^oF to obtain the temperature coefficient. This resulted in a value of -9×10^{-5} $\Delta k/^oF$. It has been argued that this method was invalid for a zero power reactor since two such widely separated temperatures were assumed and conceivably a positive temperature coefficient could exist in the normal temperature range of 60^oF to 78^oF.

Though limited by lack of proper computer codes we made a two-group calculation of the reactivity at three different temperatures 60^oF, 78^oF and 90^oF. The method of calculation assumed that the predominant effect upon the reactor due to an excursion would be the loss in moderation. An increase in temperature will cause a decrease in the density of

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Prompt Temperature Coefficient (cont'd)

the moderator which results in a loss of slowing down power. More neutrons will tend to leak out of the system with a corresponding reduction in the thermal fission rate.

The temperature coefficient was defined as

$$\alpha_T = \frac{1}{k_{eff}} \frac{d\,k_{eff}}{dT} \cong \frac{1}{\mathcal{L}_f} \frac{d\mathcal{L}_f}{dT} + \frac{1}{\mathcal{L}_{th}} \frac{d\mathcal{L}_{th}}{dT}$$

Two group theory was used considering the change in the effective multiplication factor at various temperatures. According to two group theory the effective multiplication factor is equal to

$$k_{eff} = k_\infty \frac{1}{\left[(1+L^2\mu^2)\Lambda_x + (1-L^2\nu^2)\right]} \left[\frac{\Lambda_x}{1+L_2^2\mu^2} + \frac{\Lambda_y}{1+L_2^2\nu^2} \right]$$

where $\Lambda_x = -\frac{\alpha}{\mu^2}(\beta - \rho_1\gamma)$; $\alpha \equiv -\frac{\bar{\mu}\, J_1(\bar{\mu} R)}{J_0(\bar{\mu} R)}$

$\Lambda_y = \frac{\beta}{\nu^2}(\rho_1\gamma - \alpha)$; $\beta = \frac{\bar{\nu}\, I_1(\bar{\nu} R)}{I_0(\bar{\nu} R)}$

$\gamma = -\frac{\bar{k}_1\, K_1(\bar{k}_1 R)}{K_0(\bar{k}_1 R)}$ $\quad \rho_1 = \frac{D_{1b}}{D_1}$

The primary and secondary bucklings are defined as

$$\mu^2 = \frac{1}{2}\left[-\left(\frac{1}{L_1^2} + \frac{1}{L_2^2}\right) + \sqrt{\left(\frac{1}{L_1^2} + \frac{1}{L_2^2}\right)^2 + \frac{4(k-1)}{L_1^2 L_2^2}} \right]$$

$$-\nu^2 = \frac{1}{2}\left[-\left(\frac{1}{L_1^2} + \frac{1}{L_2^2}\right) - \sqrt{\left(\frac{1}{L_1^2} + \frac{1}{L_2^2}\right)^2 + \frac{4(k-1)}{L_1^2 L_2^2}} \right].$$

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<u>Prompt Temperature Coefficient</u> (cont'd)

The change in the effective multiplication was obtained by considering the change in the parameters in the equation at 78^{0} and 90^{0}F and then calculating the values of the effective multiplication factor at these temperatures.

For the variation of the thermal diffusion length we used the expression

$$L^2 = L_o^2 \left(\frac{T_o}{T}\right)^{.612}$$

The fast diffusion length was approximated by the fermi age. The temperature variation of this parameter was obtained by the expression

$$\tau = \tau_o (1 + 2\alpha_v \Delta T)$$

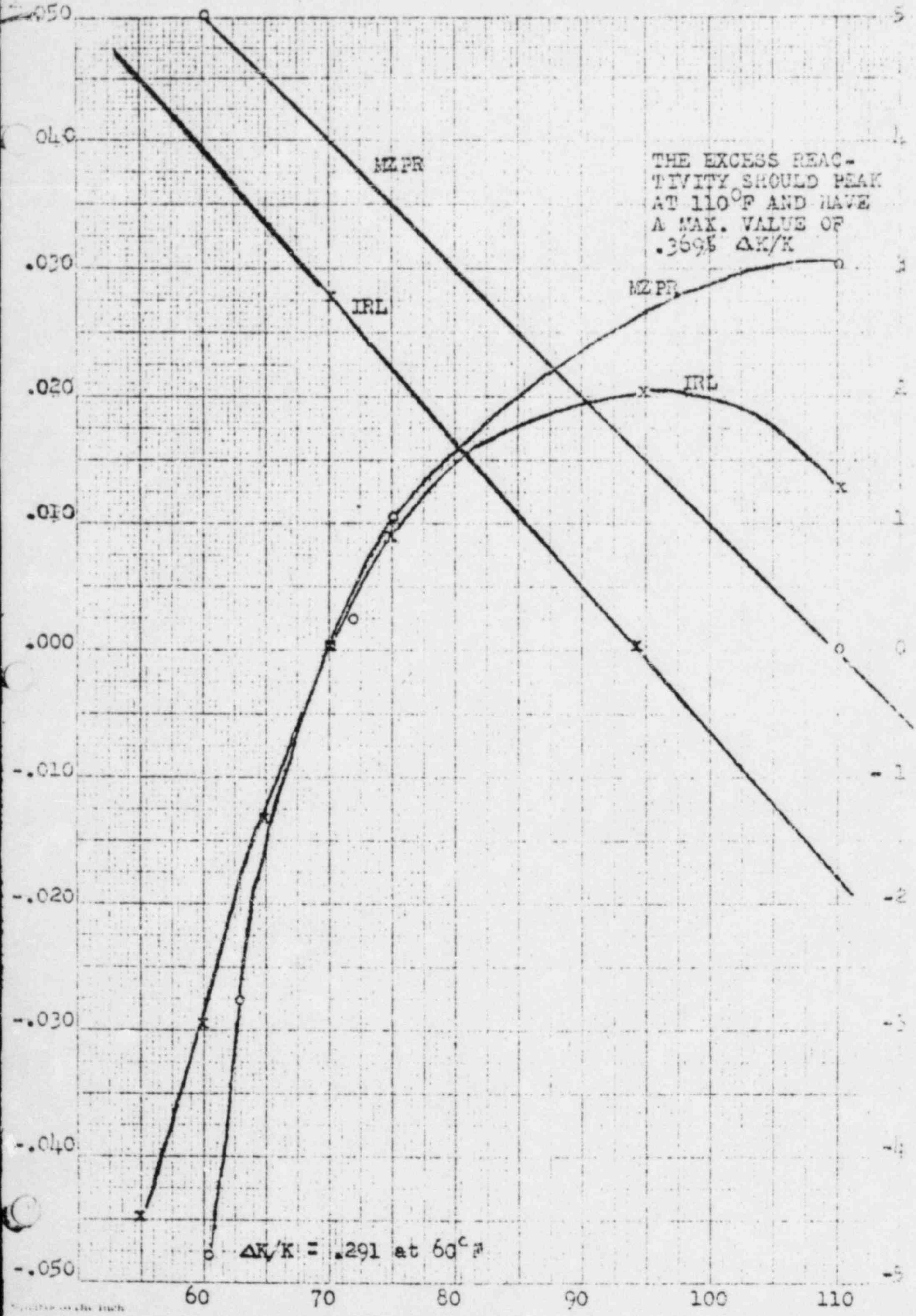
where α_v is the volume expansion coefficient.

The variation in the radius and the height of the core and reflector was unsignificant in the temperature range we were considering. P_1 was held constant since D_{1b} and D_1 were both dependent on the macroscopic cross sections and the variations in these quantities cancelled each other.

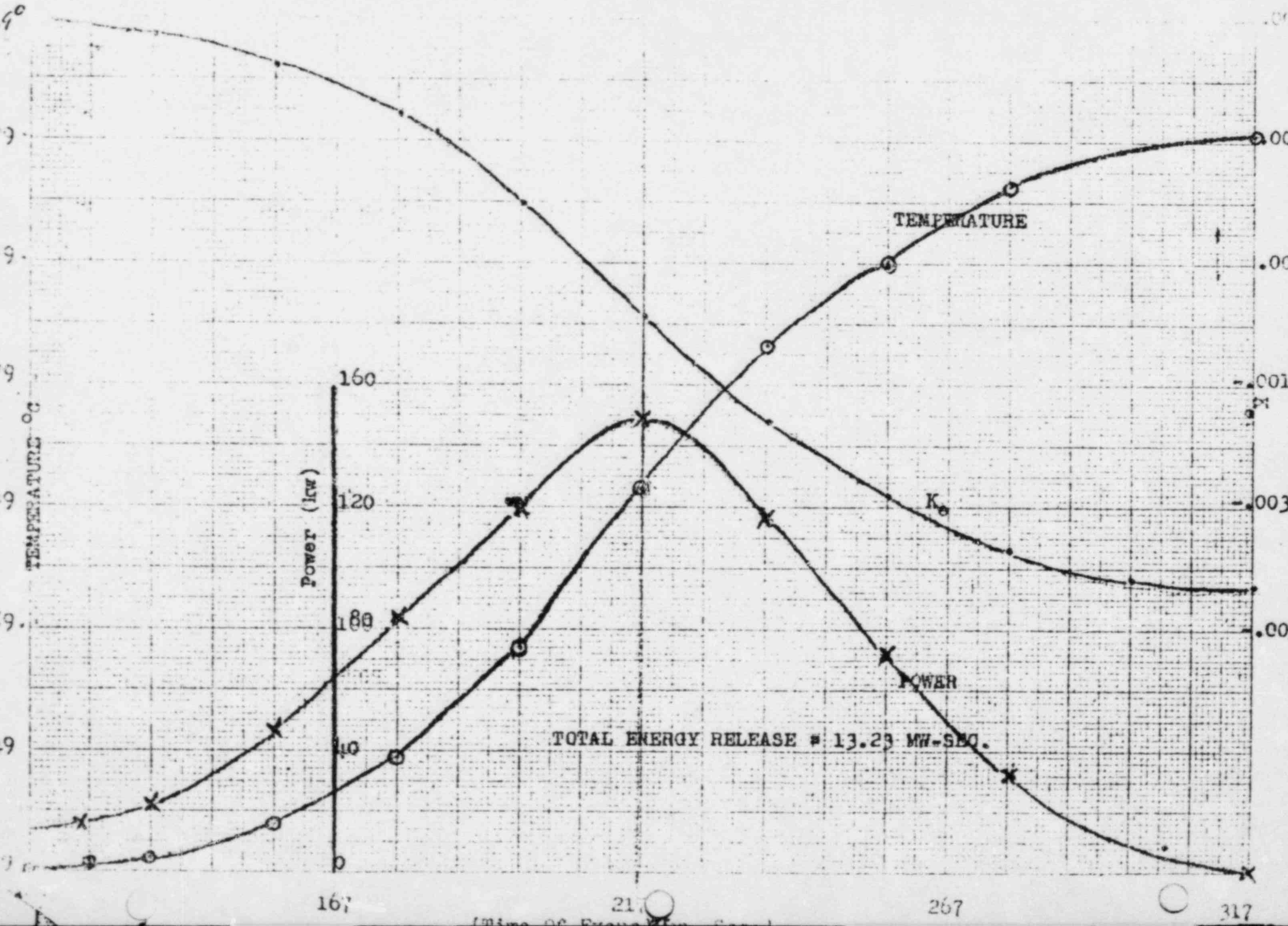
Values for various parameters and k_{eff} at varopis T

		60°F	78°F	90°F
μ^2	=	.0201	.0206	.0204
ν^2	=	.5224	.5259	.5396
$\bar{\mu}^2$	=	.01746	.01796	.01776
$\bar{\nu}^2$	=	.52504	.52854	.54224
L^2	=	2.127	2.107	2.055
τ	=	30.94	31.[illegible]	31.02
$\bar{k}_1^2$	=	.03232	.03227	.03222
P_1	=	.7780	.7780	.7780
k_{eff}	=	1.012	.9820	1.000

The results indicate a temperature coefficient negative in the range 60^{o}F to 78^{o}F and positive in the range from 78^{o}F to 90^{o}F. These results are reported here to demonstrate the sensitivity of the parameters involved in the calculation. Though the calculated temperature coefficient for the bulk water is higher in this temperature range than the measured value there is an indication that by using computer methods it may be possible to show a positive temperature coefficient in the entire range from 60^{o}F to 90^{o}F. This study will be continued.



.050
.040
.030
.020
.010
.000
-.010
-.020
-.030
-.040
-.050
5
4
3
2
1
0
-1
-2
-3
-4
-5
60
70
80
90
100
110
MZPR
IRL
MZPR
IRL
THE EXCESS REACTIVITY SHOULD PEAK AT 110°F AND HAVE A MAX. VALUE OF .369% ΔK/K
ΔK/K = .291 at 60°F


TEMPERATURE °C
Power (kw)
160
120
80
40
0
TEMPERATURE
K_e
POWER
TOTAL ENERGY RELEASE = 13.23 MW-SEC.
.0015
.0035
.005
167
217
267
317

5. TEMPERATURE COEFFICIENT OF REACTIVITY (IRL)

a. Purpose.

This experiment was performed to determine the reactivity effect of uniform temperature changes in the reactor core and surrounding water while the reactor operated at a low power level.

b. Description.

An external heat source was needed to obtain temperature changes with the reactor operating at essentially zero power, that is, a few tenths of a watt. This was done by passing pool water through the primary side of the exchanger where it received heat from saturated steam fed to the secondary side from the plant boilers. To minimize system heat losses, the holdup tank was bypassed by connecting a hose to the tank inlet and outlet flanges. Temperatures were monitored by inserting a thermocouple near the center of the core lattice. Three Alnor resistance thermometers were located at various points around the core. See Figure 24. Core Loading No. 5 was positioned in the stall section of the pool. The gate was placed between the two pool sections.

c. Test and Results.

The temperature ranged from 59°F to 112°F during the three main temperature runs. In the first test the pool water was heated to

a maximum temperature of 112°F and allowed to cool. The pool water circulated through the heat exchanger at a flow rate of 1000 gpm. During the cooling process, critical settings of the regulating rod and temperature readings, at about one degree intervals, were recorded.

In the second test, the pool water temperature was increased over the 76.5 to 100°F range. During the run, the pool water temperature increased at a rate varying from 12°F per hour at 80°F to approximately 3°F per hour near 100°F.

The third test was performed over the temperature range from 59°F to 75°F. In this run, the holdup tank was not bypassed and the two pool sections were not isolated from each other with the pool gate as they were in the two previous runs. Under these conditions, the pool water temperature increased at a constant rate of approximately 2.4°F per hour.

Figure 25 is a plot of the reactivity change due to pool water temperature variations over the range 59°F to 112°F. This curve has been normalized to a nominal room temperature of 70°F. The corresponding temperature coefficients as a function of the pool water temperature are shown in Figure 26. The temperature coefficient for these test conditions varied from a maximum positive value of $+30 \times 10^{-6} \Delta K/°F$ to a maximum negative value of $-14 \times 10^{-6} \Delta K/°F$.

The zero temperature coefficient occurred at approximately 94°F. The net reactivity gain between room temperature and 94°F was 0.02% ΔK.

It should be noted that the uniform temperature effect measured and reported here is due to changes in the density of the water and the core materials. It is not the temperature effect which would occur during normal high power operation or during a transient. During power operation temperature drops exist across the film boundary and over the core length.

In addition, the effect of the reflector on the temperature coefficient during power operation is not included here since the reflector is then at a much lower temperature than the core.[1]

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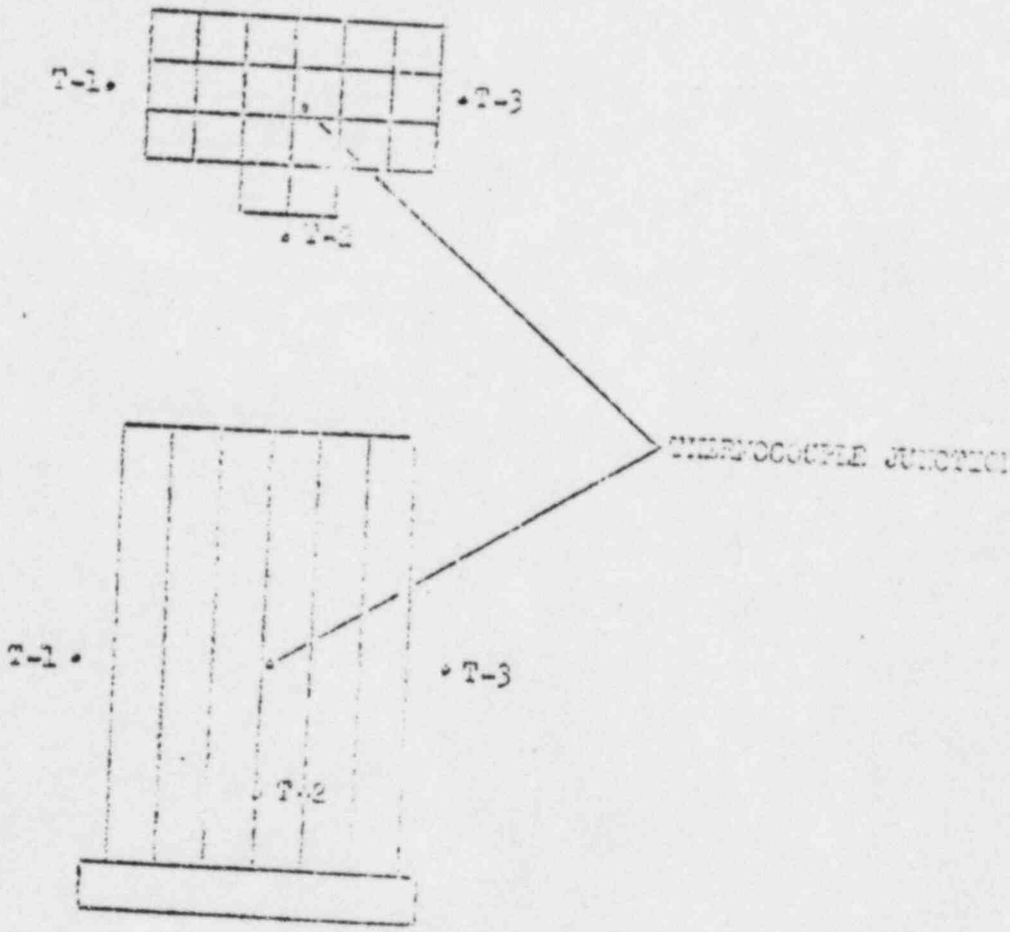
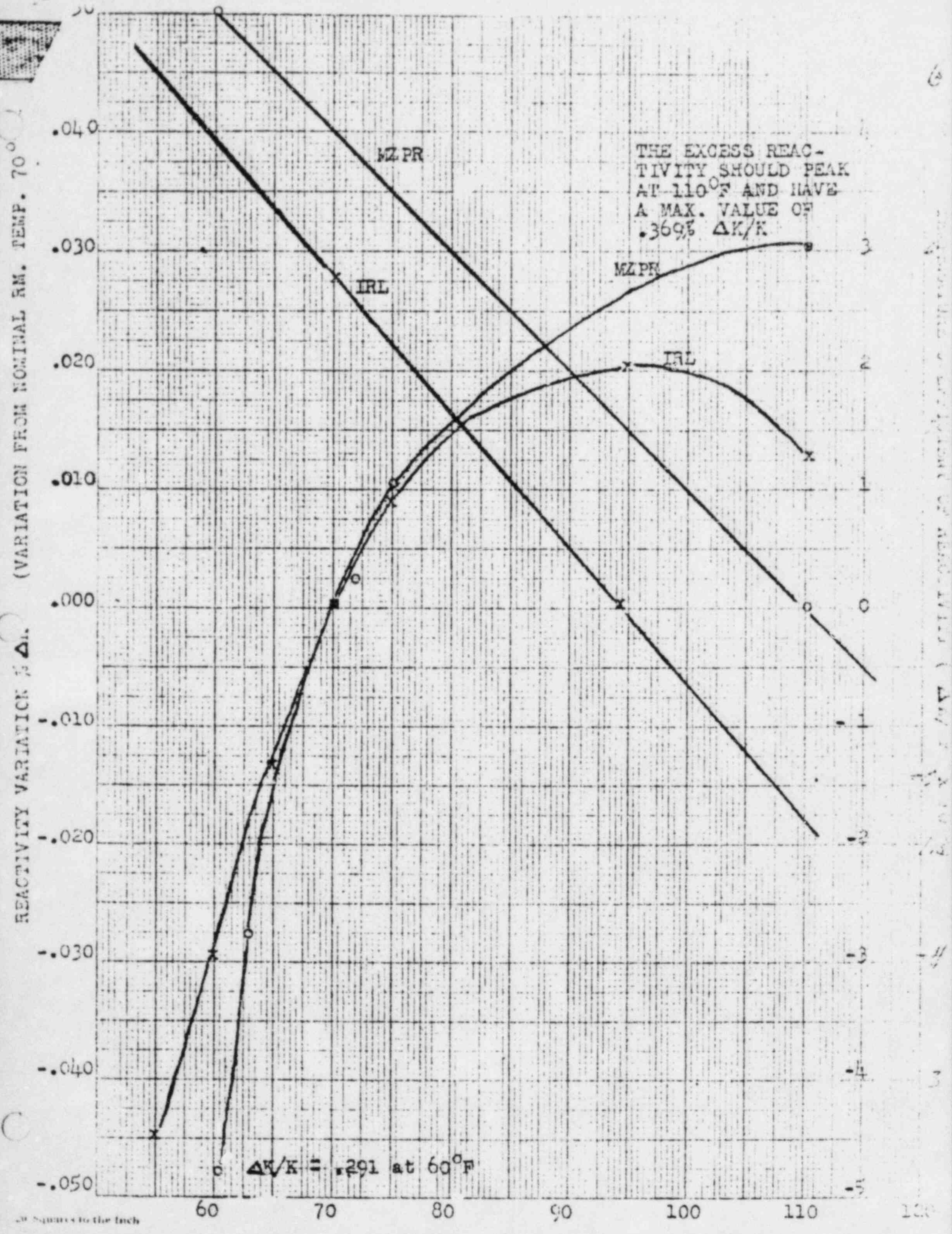
[1] Jacobs, A., Two Group Albedo Theory and Application to Temperature Coefficient Calculations, Research Reactor Facility, The Pennsylvania State University, University Park, Pennsylvania. (Unpublished)



THERMOCOUPLE AND ALNOR BULB LOCATIONS

CORE LOADING NO. 5



REACTIVITY VARIATION % ΔK (VARIATION FROM NOMINAL RM. TEMP. 70°
THE EXCESS REACTIVITY SHOULD PEAK AT 110°F AND HAVE A MAX. VALUE OF .369% ΔK/K
MZPR
IRL
MZPR
IRL
ΔK/K = .291 at 60°F
.040
.030
.020
.010
.000
-.010
-.020
-.030
-.040
-.050
60
70
80
90
100
110
3
2
1
0
-1
-2
-3
-4
-5

TABLE 36

REACTIVITY EFFECT OF TEMPERATURE

Date	Time	Temperature Readings: Alnor Bulb No. 1	Alnor Bulb No. 2	Alnor Bulb No. 3	Thermocouple	Reg. Rod Setting %	$\Delta K(T) - \Delta K(70°F)$ %	Remarks
2/5/59	10:43 pm	112°F	112°F	112°F	112°F	61.44	--	Shim Rod Settings
	10:54	109	111	111	111	[illegible].31	0.0075	No. 1 86.41%
	11:03	108	111	110	109	62.91	0.0096	No. 2 85.83%
	11:19	106	110	107	107	62.31	0.0123	No. 3 99.99%
	11:36	105	107	104	104	61.67	0.01502	No. 4 70.06%
	11:48	102	105	103	103	61.34	0.01648	No. 5 85.74%
2/6/59	12:11 am	103	101	101	101.5	61.06	0.01725	
	12:28	100	100	100	101	60.88	--	
	12:56	99	99	99	100	60.79	0.01833	
	1:09	98	98	98		60.57	0.0198	
	1:38	92	94	93	[illegible]	61.20	--	
	1:49	87	87.5	87	87	61.74	--	
	2:15	86.5	86.5	86.5	86.5	61.14	0.01754	
	2:30	86.5	86.5	86.5	--	60.91	0.0186[illegible]	
2/7/59	9:43 am	71	71	71	--	67.58	-0.00074	Shim Rod Settings
	10:15	77	77	77	76.5	65.78	0.00555	No. 1 86.47%
	10:31	79	79	79	78.5	63.40	0.0147	No. 2 85.80%
	10:40	81	81.5	81	--	63.23	0.0154	No. 3 99.97%
	10:51	84	84	84	82.6	63.13	0.0153	No. 4 7[illegible].06%
	11:00	85	85	85	85.6	62.65	0.01765	No. 5 85.70%
	11:19	87.5	87.8	87.5	86.4	62.45	0.01845	
	11:29	88	88	88	88.2	62.48	0.01933	
	11:42	89	89	89	89.2	62.05	0.0198	
	12:08 pm	90.5	90	90	90.8	62.40	0.01[illegible]	
	12:18	91.5	91.5	91.5	91.4	62.06	0.02005	
	12:37	92.2	92.2	92.2	92.5	62.00	0.02043	
	12:43	93	93	93	93.4	61.90	0.0208	
	12:57	93.8	93.8	93.8	94.6	62.06	0.02015	
	1:17	94.8	95	94.8	95.6	61.97	0.0205	
	1:33	96	96	96	96.6	62.00	0.01943	
	1:53	97	97	97	97.2	62.02	0.02033	
	2:12	98	98	98	98.4	62.53	0.01895	
	2:32	99	99	99	99.4	62.43	--	
	2:48	99.8	99.8	99.8	100	62.51	0.01905	
2/20/59	12:24 pm	67.5	67.5	67.5		59.81	-0.0052	Shim Rod Settings
	12:35	66.5	66.5	66.5		60.46	-0.0031	No. 1 86.3[illegible]%
	12:43	66.	66	66		60.82	-0.0097	No. 2 85.4[illegible]%
	12:58	65.5	65.5	65.5		61.40	-0.0122	No. 3 99.90%
								No. 4 70.50%
								No. 5 85.63%

TABLE 36 (Cont'd)

REACTIVITY EFFECT OF TEMPERATURE

Date	Time	Temperature Readings: Alnor Bulb No. 1	Alnor Bulb No. 2	Alnor Bulb No. 3	Thermo-couple	Reg. Rod Setting %	$\Delta K(T) - \Delta K(70°F)$ %	Remarks
2/20/59	4:30 pm	55	55	55		61.76	-0.0434	Shim Rod Settings
	4:38	56	56	56		61.87	-0.0439	No. 1 86.25%
	5:13	56	56	56		61.39	-0.0418	No. 2 85.42%
	5:52	56+	56+	56+		61.13	-0.0407	No. 3 99.89%
	6:03	57	57	57		61:47	-0.0422	No. 4 71.55%
	7:12	58	58	58		60.79	-0.0392	No. 5 85.64%
2/21/59	9:43 am	59	59	59		61.11	-0.0349	
	9:59	59.5	59.5	59.5		60.74	-0.0333	
	10:17	60	60	60		60.13	-0.0306	
	10:19	60+	60+	60+		59.85	-0.0294	
	10:33	60.5	60.5	60.5		59.39	-0.0272	
	10:43	61	61	61		59.05	-0.0257	
	10:57	62	62	62		58.66	-0.0239	
2/21/59	11:24	62.5	62.5	62.5		58.01	-0.0207	
	11:33	63	63	63		57.72	-0.0194	
	11:51	63.5	63.5	63.5		56.99	-0.0168	
	12:02 pm	64	64	64		56.86	-0.0151	
	12:23	65	65	65		56.66	-0.0141	
	12:32	65.5	65.5	65.5		56.33	-0.0125	
	12:48	66	66	66		56.14	-0.0115	
	1:04	66.5	66.5	66.5		55.50	-0.0082	
	1:11	67	67	67		55.60	-0.0082	
	1:28	67.5+	67.5+	67.5+		54.95	-0.0056	
	1:32	68	68	68		55.32	-0.0073	
	1:52	68.5	68.5	68.5		54.55	-0.0032	
	2:05	69	69	69		54.61	-0.0036	
	2:22	69.5+	69.5+	69.5+		54.35	-0.0021	
	2:34	70	70	70		54.10	0.0000	
2/21/59	2:54 pm	70.5	70.5	70.5		53.75	+0.0011	
	3:07	71	71	71		53.57	+0.0021	
	3:21	72	72	72		53.26	+0.0038	
	3:34	72.5	72.5	72.5		53.26	+0.0038	
	3:47	73	73	73.5		53.13	+0.0045	
	4:16	74	74	74		52.69	+0.0070	
	4:44	75	75	75		52.37	+0.0088	

TABLE 37

REACTIVITY EFFECT OF VOIDS

(Core Loading No. 5)

Run	Date	Void Element: Element Replaced	Void Element: Core Pos.	Nitrogen or Water Filled	Nitrogen Volume at Pool Surface	Control Rod Setting: % Withdrawn: Reg. Rod	Shim 1	Shim 2	Shim 3	Shim 4	Shim 5	% ΔK	% ΔK / C.C. Void	% ΔK / % Void
1	2/13/59	None	--	--	--	56.78	86.48	85.80	99.99	70.07	85.77	--	[illegible]	--
		17	44	H_2O	--	65.17	86.49	85.80	99.99	70.06	85.78	-	-	--
		17	44	H_2O	--	39.99	86.49	85.80	99.99	75.59	85.78	--	--	--
		17	44	N_2	720 cc	70.26	86.49	85.80	99.99	75.59	85.77	--	--	--
		17	44	H_2O	--	40.02	86.49	85.80	99.99	[illegible]	85.77	0.159	$-3.[illegible] \times 10^{-6}$	-0.238
2	2/13/59	8	43	H_2O	--	40.00	86.47	85.80	99.99	[illegible]	85.77	--	--	--
		8	43	N_2	720 cc	99.99	86.47	85.80	99.99	[illegible]	[illegible]	--	--	--
		8	43	H_2O	--	21.70	86.47	85.80	99.99	[illegible]	[illegible]	0.303	-7.41×10^{-6}	[illegible]
3	2/13/59	19	32	H_2O	--	51.04	85.46	[illegible]	[illegible]	[illegible]	85.70	--	--	--
		19	32	N_2	720 cc	[illegible]	[illegible]	[illegible]	99.91	90.90	85.75	--	--	--
		19	32	H_2O	--	[illegible]	86.47	[illegible]	[illegible]	90.91	85.70	[illegible]	$-8.[illegible] \times [illegible]$	-0.6[illegible]
4	2/14/59	12	13	H_2O	--	8.93	86.49	[illegible]	[illegible]	[illegible]	[illegible]			
		12	13	N_2	720 cc	34.82	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]			
		12	13	H_2O		8.97	86.49	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	$-3.[illegible] \times 10^{-6}$	[illegible]
5	2/14/59	16	23	H_2O		22.40	86.47	[illegible]	[illegible]	[illegible]	[illegible]			
		16	23	N_2	720 cc	55.20	86.47	85.77	[illegible]	[illegible]	[illegible]	0.21[illegible]		
		16	23	H_2O		22.51	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	$-5.[illegible] \times 10^{-6}$	-0.3[illegible]
6	2/14/59	10	12	H_2O		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]			
		10	12	N_2	560 cc	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	85.75			
		10	12	H_2O		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	$-5.[illegible] \times 10^{-6}$	-0.3[illegible]

Core Loading No. 5

Water Height above Center of Fuel Element = 25.75 ft = 10.75 psig = 25.45 psia

Nominal Void Volume in Core = 414 cc

Core Volume = 3750 x [illegible] = 7500 cc

% Void = .55% Void

Average Void Coefficient [illegible] = [illegible]

MANHATTAN COLLEGE
RIVERDALE
BRONX, NEW YORK 10471

OFFICE OF THE PRESIDENT

October 10, 1966

Mr. Eber R. Price, Director
Division of State & Licensee Relations
Atomic Energy Commission
Washington, D. C. 20545

Dear Mr. Price:

In answer to your letter of September 20, 1966, listing four items of apparent noncompliance noted during the compliance inspection conducted on July 28, 1966, I am forwarding herewith a letter prepared by Brother Gabriel Kane, Chairman of the Committee for Nuclear Studies.

Brother Gabriel's letter indicates the corrective steps we have taken or that will be taken with respect to the items listed in your letter. I trust that his explanation regarding the circumstances of the violations and regarding our corrective measures will meet with your approval. The actual date when full compliance will be achieved is contingent upon the Licensing Division of AEC to which we have made application as indicated by Brother Gabriel.

I regret very much that any of our activities may have been in noncompliance with AEC requirements. I trust that this letter, as well as my oral comments to your representatives, will serve to assure you of our utmost cooperation in seeing that all requirements are fulfilled in proper fashion.

Yours sincerely,

BG

Brother Gregory Nugent, F.S.C.
President

BG:mkd

cc: Brother Gabriel Kane ✓
Brother Stephen Sullivan
Brother C. Leonard O'Connor

APPENDIX H

NOVEMBER 15, 1966 CORRESPONDENCE

MANHATTAN COLLEGE BRONX, NEW YORK 10471
PHYSICS DEPARTMENT 212 - 548 - 1400

November 15, 1966

Mr. Roger S. Boyd, Chief
Research & Power Reactor Safety Branch
Division of Reactor Licensing
U.S. Atomic Energy Commission
Washington, D.C. 20545

Dear Mr. Boyd:

Brother Gregory Nugent, President, has referred to me your letter of November 2 relative to the determination of the temperature coefficient of reactivity.

In the second paragraph of your letter you request further information on the following points:

(1) The basis used for predicting the temperature at which the moderator temperature coefficient of reactivity becomes negative.

The graphical estimate of the temperature coefficient of reactivity is shown in the first enclosed graph (Fig. 1). The first point on the line to the left represents the average temperature coefficient of reactivity between 60°F and 75°F. The points off the line represent the values for the temperature coefficient of reactivity taken at intervals between 60°F and 75°F. The second point to the right on the line of this graph represents the turn-around temperature for the temperature coefficient of reactivity. This point was obtained by following the curvature of the graph for the IRL reactor as shown in Fig. 2. This estimate is subject to the errors inherent in taking measurements over a wide period of time, as has been already indicated in the material submitted with our letter of October 6, 1966. It is also subject to limitations because of the comparatively small number of measurements involved and the fact that these measurements were taken with an ordinary thermometer within the tank but outside of the core of the reactor. Finally, there seems to be very little point in pursuing this topic further since we shall repeat all of these measurements with a high degree of accuracy and make a direct experimental determination of the turn-around temperature.

FIGURE 1

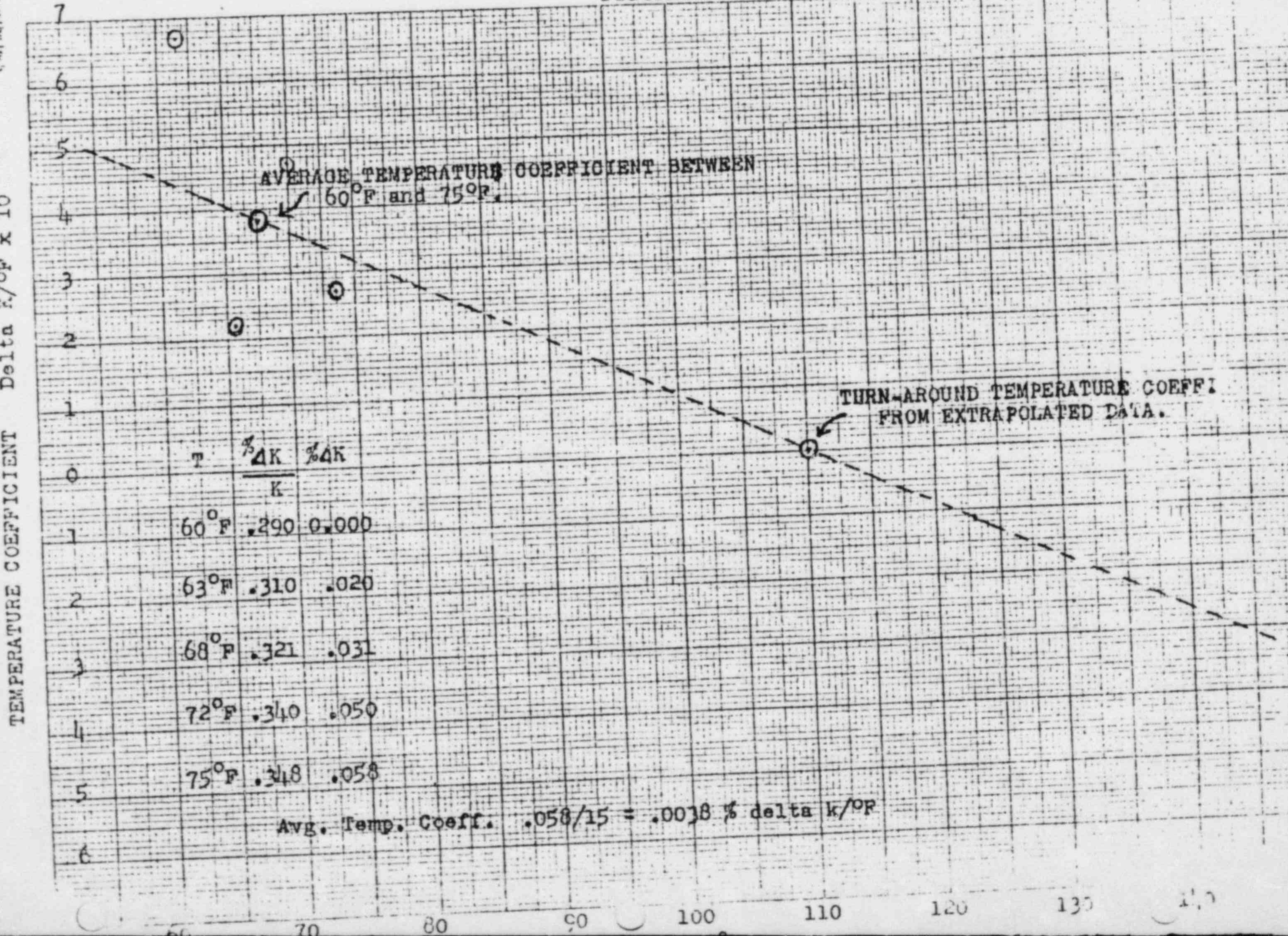
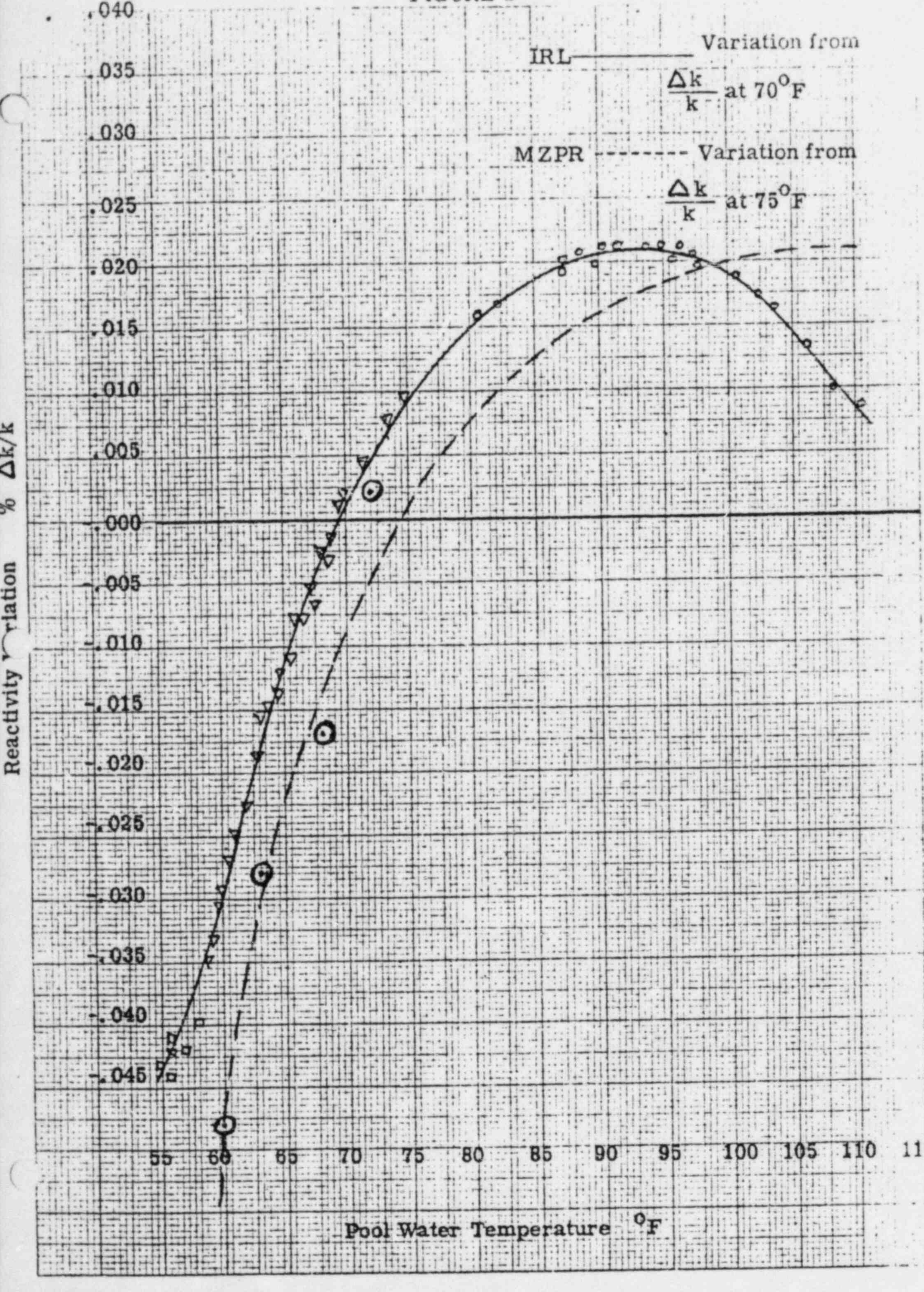

TEMPERATURE COEFFICIENT Delta K/°F x 10^-5
AVERAGE TEMPERATURE COEFFICIENT BETWEEN 60°F and 75°F.
TURN-AROUND TEMPERATURE COEFF. FROM EXTRAPOLATED DATA.
T %ΔK/K %ΔK
60°F .290 0.000
63°F .310 .020
68°F .321 .031
72°F .340 .050
75°F .348 .058
Avg. Temp. Coeff. .058/15 = .0038 % delta k/°F
7 6 5 4 3 2 1 0 1 2 3 4 5 6
70 80 90 100 110 120 130

FIGURE 2


IRL ———— Variation from $\frac{\Delta k}{k}$ at 70°F
MZPR -------- Variation from $\frac{\Delta k}{k}$ at 75°F
.040
.035
.030
.025
.020
.015
.010
.005
.000
-.005
-.010
-.015
-.020
-.025
-.030
-.035
-.040
-.045
Reactivity Variation % Δk/k
55
60
65
70
75
80
85
90
95
100
105
110
115
Pool Water Temperature °F

(2) The integrated dose to the operator during the accident.

The graph and data submitted with our letter of October 6, 1966 represents an excursion with a peak power rise of 147 kilowatts with a release of 13.2 megawatt-seconds of energy. The integrated dose at 150 cm. above the core center line (water surface) will be

$$5 \times 10^{-3} \frac{\text{Roentgen}}{\text{hr-watt}} \times \frac{13.2 \times 10^{6} \text{ watt-sec}}{3600 \frac{\text{sec}}{\text{hr}}} = 18.5 \text{ Roentgens}$$

This calculation is based on "Research Reactors" U.S. AEC, 1955, p. 111 Fig. 2-31. (Cf. Supplementary Hazards Summary Report, p. 5). In comparing this excursion with the one described in Table I and the following graph of the Hazards Summary Report and page 5 of the Supplementary Hazards Summary Report, it should be kept in mind that the earlier calculation of radiation dose is based on an absorption through 129 cm. of water (distance from top of core to water surface), while this more recent calculation for a larger excursion is based upon an absorption through 150 cm. of water (distance from approximate center of core to water surface).

(3) The effect of cold water in the pool reaching the core by natural convection.

The grid plate is a solid aluminum block with aluminum cylinders mounted upon it for receiving the fuel elements and hold-down rods as shown in Figure A-16 of the Hazards Summary Report. Consequently, there will be no free circulation of cold water through the fuel elements by natural convection, even though they are open at the top. The heating due to the excursion should, therefore, remain trapped in these fuel elements for a long period of time. As a result, if a second excursion did occur, it would be after a considerable length of time following the first. It should also be noted that since the excursion was presumed to be initiated at the turn-around temperature, there should be no reason to anticipate a second excursion.

The third paragraph of your letter requests us to: (1) measure the excess reactivity as a function of the temperature up to at least 10°F beyond

the turnover temperature with the partial element removed, (2) re-evaluate the MCA (assuming convection through the core) based on the measured data, and (3) calculate the doses which would be received by the operator during an accidental excursion.

We have taken all the preparatory steps necessary to make a direct determination of the excess reactivity as a function of the temperature up to at least 10° F beyond the turnover temperature:

(a) A heat exchanger will be installed on the Cellar Floor in the area below the Advanced Physics Laboratory. This region is shown in Suppl. Fig. 6 of the Supplementary Hazards Summary Report.

A purchase order for $950.00 to make this installation has been sent to Alex C. Patterson & Sons, Inc., 503 West 57th St., New York, N.Y. 10019.

This unit will be a steam to hot water converter with future capped provisions for chilled water connections. These latter will enable students to perform the experiment on the temperature coefficient of reactivity during the summer months. A steam capacity of 40 #/hr. is required to heat the 5000 gallons in the tank up to 140°F in ten (10) hours. However, the equipment is capable of handling the load in five (5) hours when a steam capacity of 80#/hr. is maintained. Circulation from the Reactor Pool through the heat exchanger will be maintained by a Bell & Gassett high velocity circulator.

When in operation, the water will be withdrawn from the bottom of the tank through the presently existing opening. After passing through the heat exchanger it will be returned to the tank by means of pipes passing over the top rim of the tank. These pipes will enter the water at four points on the circumference and will extend down into the tank and release the water at about one foot above the bottom of the tank.

(b) A portable mixer or agitator will be clamped onto the rim of the tank in order to insure as far as possible a uniform distribution of temperature throughout the tank.

A purchase order for $609.00 for an ND-4B Portable Mixer has been placed with Mixing Equipment Co., Inc., 51 Lincoln St., P.O. Box 3068,

East Orange, New Jersey 07018. This unit has the following specifications according to the vendor:

> "1 - Model ND-4B "LIGHTNIN" Gear Driven Portable Propeller Type Agitator powered by a 3 hp totally enclosed chemical plant type motor wound for operation on a 220/440 volt, 60 cycle, 3 phase current. This 1750 rpm motor will be mounted on a quiet set of MIXCO internal helical reduction gears to provide a propeller output speed of 350 rpm. A shaft 7/8" in diameter x 66" in overall length will be fitted with a single 15.1" diameter SuperPitch adjustable propeller. The shaft and the propeller will be supplied in type 304 SS. The agitator will be furnished complete with an aluminum swivel ball and socket mounting clamp which will attach to either the rim of your tank or a suitable support bracket spanning the top of your tank."

(c) Temperature measurements will be made by thermistors placed at about ten or twelve places within the fuel tubes, in the core between the fuel tubes, and outside the core.

The vendor of the heat exchanger has stated that it can be installed in "two or three days". The delivery time for the portable mixer is about two weeks. We shall try to perform the experiment on the temperature coefficient of reactivity as soon as possible after all these installations have been completed. In your letter you have requested us to state a specific date by which we expect to complete this reactivity measurement. If a specific date is insisted upon, I believe we must be realistic and take into account both the normal and the unexpected delays for such an operation. I would, therefore, specify January 1, 1967 as the ultimate target date for the completion of this measurement.

It is not completely clear to me whether a change in Technical Specifications is necessary in order to introduce the heat exchanger and portable mixer into the reactor system. However, if such a change is necessary, please consider this letter as a formal request for such a change.

I trust that I have treated satisfactorily all of the points which you raised in your letter of November 2, 1966.

Sincerely yours,

Brother Gabriel Kane, Chairman
Committee for Nuclear Studies

APPENDIX I

JANUARY 24, 1967 CORRESPONDENCE - "EXPERIMENTAL DETERMINATION OF THE TEMPERATURE COEFFICIENT OF REACTIVITY OF THE MANHATTAN COLLEGE ZERO POWER REACTOR"

YU 9-1000

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970-2412

MANHATTAN COLLEGE BRONX, NEW YORK 10471
PHYSICS DEPARTMENT

January 24, 1967

Mr. Roger S. Boyd, Chief
Research & Power Reactor Safety Branch
Division of Reactor Licensing
U.S. Atomic Energy Commission
Washington, D.C. 20545

Dear Mr. Boyd:

I am enclosing a report on the determination of the temperature coefficient of reactivity of the MZPR, which you requested in your letter of November 2, 1966 to Brother Gregory Nugent, President. The turnaround temperature is 110.6^{O}F and the excess reactivity at this temperature including the worth of the partial element is 0.440% Δ k/k. In your letter of November 2, 1966 you also requested a re-evaluation of the MCA based on the measured data and the calculated doses which would be received by the operator during the accident. The evaluation of the MCA assuming an excess reactivity of 0.450% Δ k/k has already been presented in our letter of October 6, 1966 to Mr. Marvin K. Woodard. The integrated dose to the operator during the accident was stated in our letter to you dated November 15, 1966.

The information here presented should serve as a basis for the discussion of a change in Technical Specifications which will be acceptable both to the AEC and to Manhattan College.

Sincerely yours,

Brother Gabriel

Brother Gabriel Kane, Chairman
Committee for Nuclear Studies

BGK:mk

EXPERIMENTAL DETERMINATION OF THE TEMPERATURE

COEFFICIENT OF REACTIVITY OF THE

MANHATTAN COLLEGE ZERO POWER REACTOR

Experimental Determination of the Temperature Coefficient of Reactivity of the Manhattan College Zero Power Reactor

This experiment was undertaken to comply with the following directive given by Mr. Roger S. Boyd, Chief of Research and Power Reactor Safety Branch, Division of Reactor Licensing, USAEC in a letter to Brother Gregory Nugent dated November 2, 1966: That "the reactor should not be operated with an excess reactivity exceeding that which exists with the partial fuel element removed (approximately 0.17% delta k/k) until such time that you have: (1) measured the excess reactivity as a function of the tmperature up to at least 10^0F beyond the turnover temperature". The turnover tempeature is defined as that temperature at which the temperature coefficient of reactivity changes from positive to negative.

In preparation for this experiment the following three items were purchased and installed:

I. A Heat Exchanger

A heat exchanger was installed in the enclosed Cellar Floor area below the Advanced Physics Laboratory. This region is shown in Suppl. Fig. 6 of the Supplementary Hazards Summary Report. This item was purchased for $950.00 from Alex C. Patterson & Sons, Inc., 503 West 57th St., New York, N.Y. 10019. This unit is a steam-to-hot water converter with capped provisions for chilled water connections. These latter have already been used with temporary fixtures. Permanent connections will be attached later. A steam capacity of 332 lbs. per hour is required to heat the 5000 gallons in the tank up to 140^0F in ten (10) hours. (It should be noted that the figure of 40 lbs. of steam per hour stated in our letter of November 15, 1966 was the figure originally given to us by the vendor.) The steam was sent into the heat exchanger at 5 lbs. gauge pressure. Circulation from the Reactor Pool through the heat exchanger is maintained by a Bell & Gasset high velocity circulator at a rate of 25 gallons per minute.

When in operation, the water is withdrawn from the bottom of the tank through the 3/4" aluminum pipe coupling and gate valve shown in Suppl. Fig. 2 of the Supplementary Hazards Summary Report. The valve leading to the de-ionizer was turned off during this experiment. The water is therefore led through a pipe branching in the opposite direction to the circulation pump and heat exchanger. After passing through the heat exchanger it is returned to the tank by means of pipes passing over the rim at the top of tank. Aluminum pipes enter the water at four points (90 degrees apart) on the circumference and extend down into the tank and release the water about one foot above the bottom of the tank.

II. A Portable Mixer or Agitator

A heavy steel I-beam was hung from the bridge across the opening above the tank which is in the corner of the reactor laboratory nearest to the switch boxes. A portable mixer or agitator was then clamped onto this steel beam in order to insure as far as possible a uniform distribution of temperature throughout the tank. This piece of apparatus is an ND-4B Portable Mixer and was purchased for $609.00 from Mixing Equipment Co., Inc., 51 Lincoln St., P.O. Box 3068 East Orange, New Jersey 07018. The unit has the following specifications according to the vendor:

1 - Model ND-4B "LIGHTNIN" Gear Driven Portable Propeller Type Agitator powered by a 3 hp totally enclosed chemical plant type motor wound for operation on a 220/440 volt, 60 cycle, 3 phase current. This 1750 rpm motor will be mounted on a quiet set of MIXCO internal helical reduction gears to provide a propeller output speed of 350 rpm. A shaft 7/8" in diameter x 66" in overall length will be fitted with a single 15.1" diameter Super Pitch adjustable propeller. The shaft and the propeller will be supplied in type 304 SS. The agitator will be furnished complete with an aluminum swivel ball and socket mounting clamp which will attach to either the rim of your tank or a suitable support bracket spanning the top of your tank".

This mixer was tested before the experiment. The agitation was so violent that it became obvious that this particular model could not be used unless some modification were made. The lights in the tank oscillated back and forth and a vortex was created which was so strong that the core could be seen directly from the bridge with no water intervening. The experiments proceeded satisfactorily without the agitator. The rapid circulation of the pump and the convection currents at high temperature were sufficient to ensure a fairly uniform temperature throughout the core. For the experiment on temperature coefficient of reactivity which will be performed by the students in the future, only a short temperature range of about 60° F to 75° F will be investigated. For this, some stirring action will be necessary. Consequently, we have obtained a smaller impeller from the same vendor. This does not cause any vortex nor serious oscillations of the tank lights. However, the BF_3 counter is moved somewhat by it. Consequently, reactor measurements will be made only while the agitator is turned off.

III. Thermistors for Temperature Measurement

In order to measure the temperature at various positions in the reactor during the experiment, twelve thermistors were purchased from Fenwal Electronics, Inc., 63 Fountain Street, Framingham, Mass. 01702. These thermistors (model #GB35P2) are the glass probe type 1/2 inch long and 0.1 inch in diameter. The nominal resistance at 25°C is

5,000 ohms. Each thermistor was attached to a pair of #22 lead in copper wires. These wires are color coded and tags numbering from 1 through 12 have been fastened to them. The wires were brought to terminal blocks in one of the junction boxes above the reactor. One wire for each thermistor and one common wire were then led through one of the existing conduits under the reactor floor and brought up inside the console. A twelve-pole switch was mounted in back of the console inside the doors. The twelve wires for the thermistors were then attached to the poles. A wire from the wiper of the twelve-pole switch was attached to one of a pair of jacks. The common thermistor lead-in wire was connected to the other jack. This makes it possible to use any one of a number of measuring instruments available such as a Wheatstone bridge or impedance bridge to measure the resistance of the thermistors. The instrument actually used was a Model 355 Ballantine Digital DC-AC Voltmeter. Each thermistor in turn was placed in series with (1) a voltage source provided by a regulated power supply, (2) a 5000 ohm precision resistance and (3) a variable resistance. By means of a double-pole double-throw switch, the digital voltmeter was placed first across the 5000 ohm precision resistance and the variable resistance was adjusted until the digital voltmeter read exactly 5.00 volts. This guaranteed that exactly 1.00 milliamperes was flowing through the thermistor. The digital voltmeter was then switched across the thermistor and its resistance read directly.

All of the thermistors were calibrated using a constant temperature bath and a precision centigrade thermometer which read to 0.2 degrees C. The resistances for each thermistor were determined at twelve different temperatures between 12 degrees centigrade and 65 degrees centigrade. The relationship between resistance and temperature for thermistors is given by the equation

$$R = R_o \, e^{\beta\left(\frac{1}{T_o} - \frac{1}{T}\right)} \tag{1}$$

where T is the absolute temperature, T_o is the reference temperature and R_o is the resistance at the reference temperature. In the logarithmic form this equation becomes

$$\ell n \frac{R}{R_o} = \frac{\beta}{T_o} - \frac{\beta}{T} \tag{2}$$

Our CDC 8090 Digital Computer was used to make a least-square fit for the linear relationship between $\ell n\,(R/R_o)$ and $1/T$ shown in equation (2). The computer then printed out tables for each thermistor of resistances vs. degrees Fahrenheit in steps of one degree F from 50°F to 150°F. The common logarithms of these resistances were also printed out to facilitate interpolation. A copy of these tables is appended to this report.

Thermistor #8 was damaged before the experiment started. Of the remaining eleven thermistors, one was placed near the edge of the tank

and the other ten were placed at various positions in the core either attached to the fuel elements or to lucite rods. The experiment was started with the partial fuel element out. It was then discovered that the copper of the lead-in wires depressed the reactivity so much that the reactor remained sub-critical with both control rods 100% out. Consequently, the control rods were driven in and four thermistors were removed from the core. It was then possible to make the reactor critical. During the experiment there was good agreement among five of the six thermistors in the core. There was an appreciable difference between the temperatures recorded by these five thermistors and that recorded by the sixth. Therefore, only the temperatures recorded by these five thermistors were used in the final calculations. The numbers and locations of these thermistors are indicated below.

Thermistor Number	Location
1	Attached to outside of fuel element #34 6 inches below center.
4	Attached to outside of fuel element #22 at center.
5	Attached to outside of fuel element #54 at center.
6	Attached to outside of fuel element #35 at center.
10	Attached to end of lucite rod which rested on top of fuel plates inside fuel element #34.

Experimental Procedure and Results

On Tuesday, December 13, 1966 thirty-six readings were taken of the excess reactivity of the Manhattan College Zero Power Reactor between 3:00 P.M. and 10:00 P.M. The partial element was out and six thermistors were in the core (readings of five were recorded). The temperature was varied from 65°F to 124°F. Separate records were made of the time of each reactor reading and the reading of each thermistor. Then a quadratic relationship was established and a least square fit made for the temperature (T)-time(t) relationship for each thermistor using the CDC 8090 Digital Computer. This fit had to be made in two steps since $\frac{dT}{dt}$ gradually increased up to about 92.5°F and then gradually decreased. The computer then interpolated so as to obtain the exact value of the temperature of each thermistor when the thirty-six readings of excess reactivity were made by

the reactor operator. The temperatures recorded by thermistors 1, 4, 5 and 10 were in very close agreement throughout the entire experiment. Thermistor #6 recorded about 5°F above the others at the lowest temperatures. This difference was gradually diminished as the temperature rose until all five were in very close agreement at about 102°F. Then thermistor #6 began to record slightly lower temperatures until it was recording about 2°F lower at the end of the experiment. It is believed that these readings represent actual differences of temperature at different places in the core and are not due to any defect in thermistor #6. This thermistor was attached to the outside of fuel element #35, which is at the outer edge of the core. A hot stream of water coming from the return pipes from the heat exchanger would cause the region around this thermistor to be heated more rapidly than the region toward the center of the core. This would account for the fact that thermistor #6 read higher than the others at low temperatures. To account for the fact that it read lower at the higher temperatures, it should be recalled that $\frac{dT}{dt}$ gradually decreases for the entire core above 92.5°F. This can be accounted for by increased radiation losses at these higher temperatures. It is natural to expect, therefore, that the outside of the core should radiate more rapidly than the inside of the core giving a lower temperature reading for this region. The computer took an average of the readings of the five thermistors and determined the deviations from the average for each thermistor. Thermistor #10 was not inserted until after the sixth reading on the other four thermistors.

A quadratic relationship was established and a least square fit was made for the relationship of the excess reactivity to the temperature from 65°F to 120°F. In order to complete the experiment it was necessary to determine the positive reactivity worth of the partial element and the negative reactivity worth of the six pairs of lead in wires to the thermistors. To accomplish this the water was cooled down to 60°F. All the thermistors except #10 were removed. This latter rested on top of the fuel plates of fuel element #34 and it was verified that its effect on the reactivity was negligible. The cooling process was very slow. After six days the temperature of the reactor was down to only 78°F. Every heat source in the laboratory was turned off and the window was left open for 24 hours. This brought the temperature down to slightly above 70°F. Preparations had been made to perform the remainder of the experiment on Tuesday, December 20, 1966. In order to bring the temperature down to 60°F, it was necessary to add three thousand pounds of ice directly to the reactor and run cold water through the heat exchanger. Approval of the use of the partial element at 60°F was sent by telegram from the AEC in Washington. Confirmation of this fact was received verbally from Mr. Roger Boyd of the AEC before the partial element was inserted. The average value of the reactivity before and after the insertion of the partial element was inserted was 0.0707% $\Delta k/k$. The reactivity while the partial element was present was 0.3124% $\Delta k/k$.

This indicates that the worth of the partial element is 0.2417% Δ k/k. This measurement with the partial element in was made at 59.8°F. After the partial element had been removed, the steam was turned on and 13 readings were taken of the excess reactivity of the MZPR between 5:00 P.M. and 7:00 P.M. The temperature varied from 60°F to 75°F. The temperature recorded by the thermistor was checked regularly against the reading on the thermometer suspended in the reactor. Both were found to agree to within 1°F. The computer was again used to make a least square fit for the quadratic relationship between excess reactivity and temperature for the 13 experimental points indicated.

For the remainder of this report, the portion of the experiment performed on December 13, 1966 will be called Run #1 and the portion of the experiment performed on December 20, 1966 will be called Run #2. Run #1 went from 67°F to 124°F with 34 experimental points recorded. Run #2 went from 60°F to 75.5°F with 13 experimental points recorded. In Run #1 there were 6 pairs of copper lead in wires in the core. In Run #2 there was only one pair of copper lead in wires and its contribution to the reactivity was negligible. Between 67°F and 75.5°F there were 8 experimental points in Run #1 and 10 experimental points in Run #2. The following are the values obtained from the computer outputs for the two runs taken separately after the least square fit had been made.

Temperature (Degrees F)	Δ k/k (% x 10^{-2}) Run #1	Δ k/k (% x 10^{-2}) Run #2	Δ k/k (% x 10^{-2}) Difference Run #2 - Run #1
67	0.643	11.069	10.426
68	1.039	11.453	10.414
69	1.426	11.840	10.414
70	1.804	12.232	10.428
71	2.172	12.628	10.456
72	2.531	13.029	10.498
73	2.881	13.434	10.553
74	3.221	13.844	10.623
75	3.553	14.258	10.705
		Average -	10.502

The worth of the copper in the thermistor lead in wires is, therefore, 0.10502% Δ k/k.

This value was added to each of the 34 excess reactivity values determined experimentally during Run #1. The computer then used these corrected values together with the 13 experimental values from Run #2 to make a least square fit for the quadratic relationship between excess reactivity and temperature for the entire 47 experimental values obtained from both Run #1 and Run #2. The relationship established by the computer was

$$(\Delta k/k)\% = -35.83 \times 10^{-2} + 100.67 \times 10^{-4} T - 45.53 \times 10^{-6} T^2$$

The calculated values agreed with the experimental values with a probable error of 2.1×10^{-4} % $\Delta k/k$. The turnaround temperature was 110.6°F. The excess reactivity at this temperature in including the worth of the partial element is 0.440% $\Delta k/k$.

GRAPHS AND TABLES

Fig. 1 - Experimental Results Uncorrected

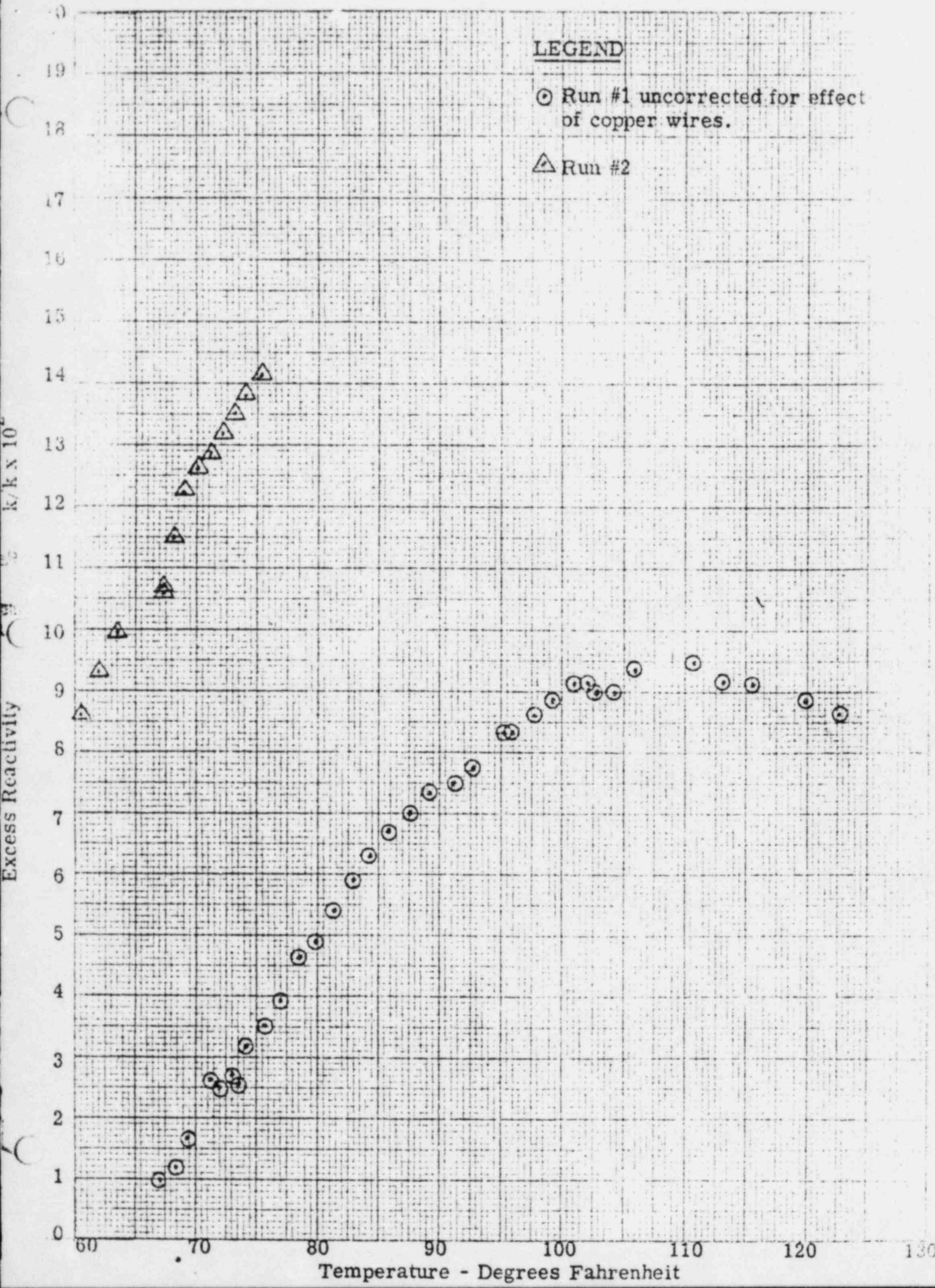

Fig. 2 - Experimental Results Corrected for Effect of Copper Wires

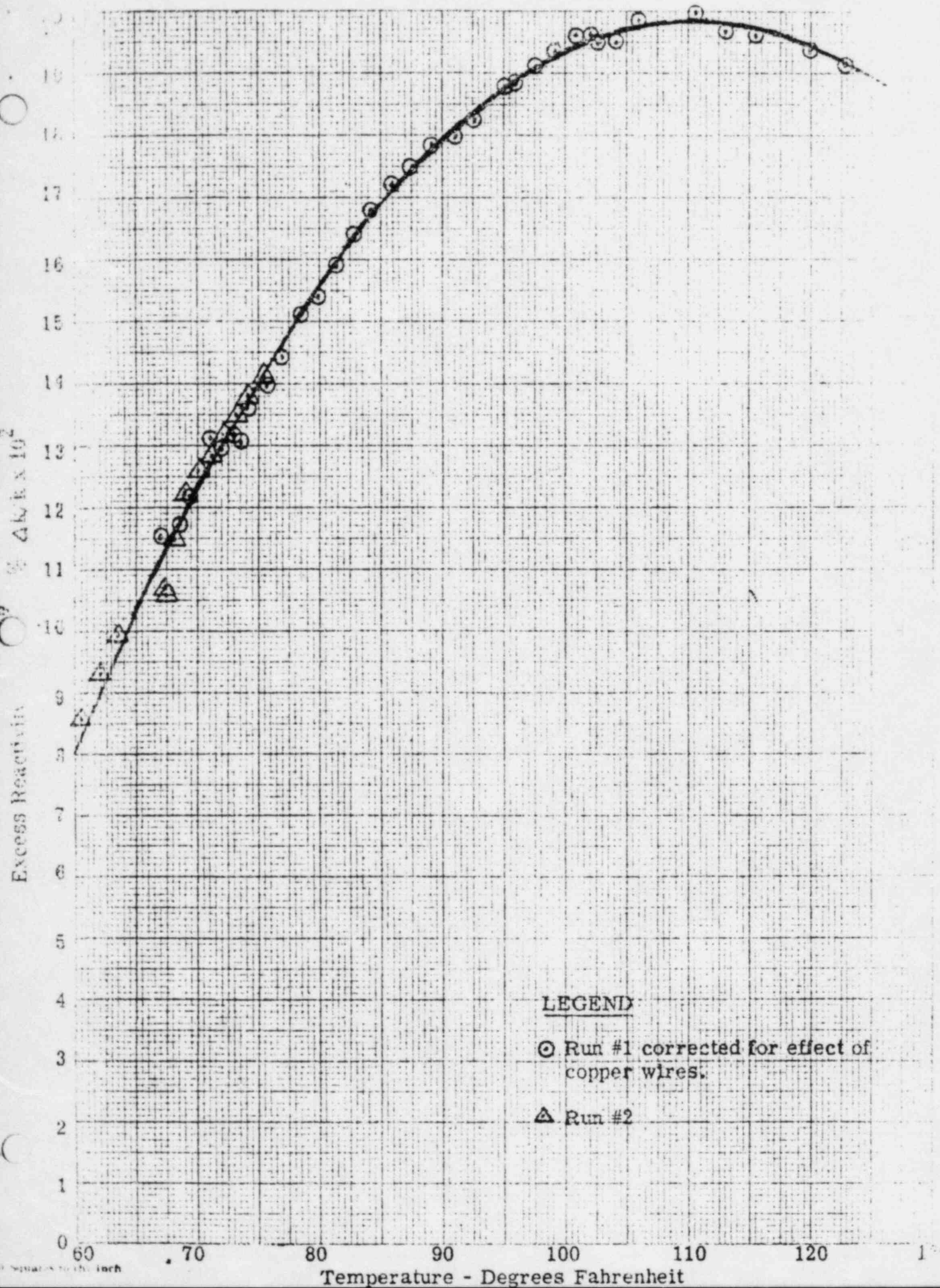

Fig. 3 - Excess Reactivity Including Partial Element and Temperature Coefficient of Reactivity.

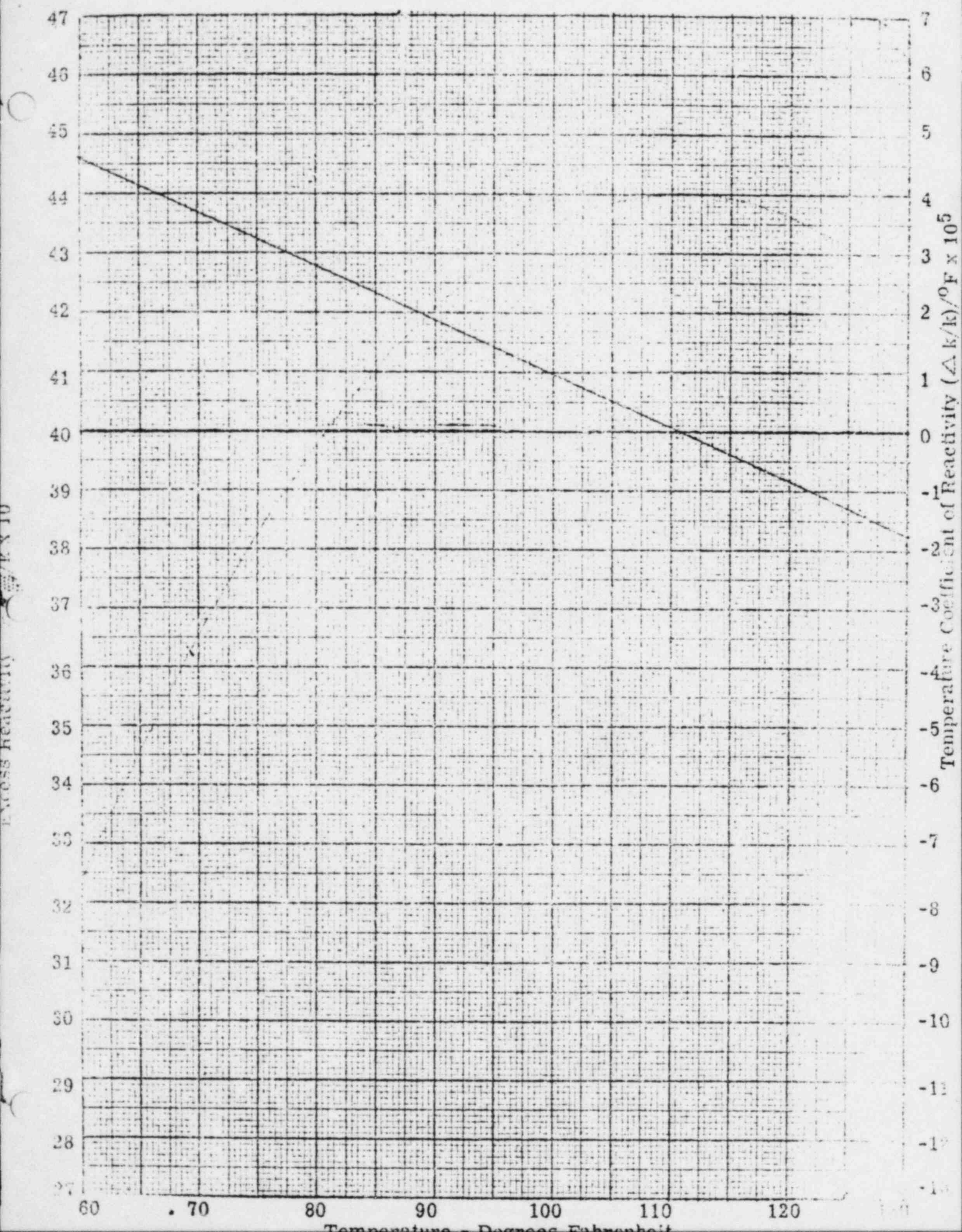

TABLE #1

Reg Rod Calibration

Reg. Rod Pos. %	Δ k/k % (x10^{-2})	Reg. Rod Pos. %	Δ k/k % (x10^{-2})
100.0	0	50.0	51.50
97.5	.06	47.5	55.97
95.0	.31	45.0	60.41
92.5	.79	42.5	64.78
90.0	1.55	40.0	69.06
87.5	2.63	37.5	73.21
85.0	4.02	35.0	77.19
82.5	5.73	32.5	80.92
80.0	7.75	30.0	84.39
77.5	10.03	27.5	87.56
75.0	12.58	25.0	90.42
72.5	15.44	22.5	92.97
70.0	18.61	20.0	95.25
67.5	22.08	17.5	97.27
65.0	25.81	15.0	98.98
62.5	29.79	12.5	100.37
60.0	33.94	10.0	101.45
57.5	38.22	7.5	102.21
55.0	42.59	5.0	102.69
52.5	47.03	2.5	102.94
50.0	51.50	0	103.00

TABLE #2

Control Rod Settings and Excess Reactivity Recorded During Experiment on Tmperature Coefficient of Reactivity, Tuesday, December 13, 1966

Time	Reg. Rod Setting %	$\Delta k/k$ % ($x\ 10^{-2}$)	Time	Reg. Rod Setting %	$\Delta k/k$ % $x\ 10^{-2}$
15:05	94.3	0.415	19:00	79.4	8.340
15:25	95.6	0.230	19:10	79.1	8.620
15:40	91.7	1.000	19:20	78.8	8.870
15:52	91.0	1.215	19:30	78.5	9.140
16:00	89.7	1.660	19:35	78.5	9.140
16:15	87.5	2.625	19:40	78.7	8.975
16:20	87.8	2.480	19:50	78.7	8.975
16:30	87.6	2.580	20:00	78.3	9.330
16:35	87.7	2.535	20:30	78.1	9.500
16:40	86.4	3.198	20:45	78.5	9.140
16:51	85.6	3.640	21:00	78.5	9.140
17:00	85.1	3.965	21:30	78.8	8.870
17:11	84.1	4.625	22:00	79.1	8.620
17:21	83.7	4.900			
17:30	83.0	5.380			
17:40	82.3	5.910			
17:50	81.8	6.310			
18:00	81.3	6.715			
18:10	81.0	6.965			
18:20	80.5	7.340			
18:31	80.3	7.505			
18·40	80.0	7.747			
18:55	79.4	8.340			

TABLE #3

Reactivity Reading during Experiment (December 20, 1966)

Time	Reg. Rod Setting %	$\Delta k/k$ % ($\times 10^{-2}$)
Partial Element Removed		
14:05	80.9	7.040
Partial Element Inserted		
16:05	61.6	31.24
Partial Element Removed		
17:02	80.8	7.110
Steam turned on		
17:15	79.1	8.620
17:22	78.3	9.330
17:30	77.6	9.960
Steam turned off		
17:56	76.9	10.600
18:04	76.8	10.690
Steam turned on		
18:14	76.0	11.520
18:18	75.3	12.250
18:25	75.0	12.580
18:30	74.7	12.860
18:35	74.4	13.180
18:40	74.1	13.520
18:45	73.8	13.850
18:52	73.6	14.120

TABLE 4

Thermistor Temperatures for Each Reactivity Reading of Run #1

REACTIVITY RECORDING TIME	TEMP CALC NO.1	TEMP CALC NO.4	TEMP CALC NO.5	TEMP CALC NO.6	TEMP CALC NO.10	TEMP AV	DELTA TEMP NO.1	DELTA TEMP NO.4	DEL A TEM NO.5	DELTA TEMP NO.6	DELTA TEMP NO.10
15 39	65.68	65.70	65.98	70.78	.00	67.04	1.36	1.33	1.05	-3.74	XXXXX
15 51	67.08	67.11	67.39	72.01	.00	68.40	1.31	1.28	1.01	-3.61	XXXXX
16 0	68.04	68.08	68.34	72.96	.00	69.33	1.28	1.25	.98	-3.52	XXXXX
16 14	69.91	69.95	70.21	74.49	.00	71.14	1.22	1.18	.93	-3.34	XXXXX
16 19	70.56	70.60	70.85	75.04	.00	71.76	1.20	1.16	.91	-3.28	XXXXX
16 29	71.87	71.91	72.15	76.18	.00	73.03	1.15	1.11	.88	-3.15	XXXXX
16 34	72.54	72.58	72.81	76.75	72.83	73.51	.96	.92	.69	-3.25	.67
16 39	73.22	73.26	73.48	77.35	73.51	74.17	.94	.90	.68	-3.18	.65
16 50	74.74	74.79	74.99	78.67	75.05	75.65	.90	.85	.65	-3.02	.60
17 0	76.02	76.07	76.26	79.78	76.34	76.89	.87	.82	.63	-2.88	.55
17 10	77.63	77.68	77.84	81.16	77.96	78.45	.82	.77	.60	-2.70	.49
17 20	79.13	79.17	79.32	82.45	79.47	79.91	.78	.73	.58	-2.54	.44
17 29	80.51	80.55	80.68	83.64	80.86	81.25	.74	.69	.56	-2.38	.38
17 39	82.08	82.12	82.22	84.98	82.45	82.77	.69	.64	.54	-2.21	.32
17 49	83.68	83.72	83.80	86.36	84.07	84.33	.64	.60	.52	-2.02	.25
18 0	85.32	85.36	85.41	87.76	85.73	85.92	.59	.55	.50	-1.84	.18
18 9	87.00	87.04	87.05	89.19	87.43	87.54	.54	.50	.49	-1.64	.10
18 19	88.71	88.75	88.73	90.66	89.17	89.20	.49	.45	.47	-1.45	.03
18 30	90.64	90.67	90.62	92.30	91.13	91.07	.43	.40	.45	-1.22	-.05
18 39	92.27	92.25	92.10	93.64	92.74	92.60	.32	.34	.50	-1.03	-.14
18 54	94.86	94.93	94.76	95.91	95.29	95.15	.28	.21	.39	-.75	-.14
19 0	95.72	95.82	95.63	96.66	96.14	96.00	.27	.17	.36	-.66	-.14
19 9	97.43	97.58	97.37	98.15	97.84	97.67	.24	.09	.30	-.47	-.16
19 19	99.13	99.33	99.00	99.52	99.52	99.34	.20	.05	.25	-.28	-.18
19 29	100.82	101.07	100.79	101.03	101.21	101.00	.17	-.07	.20	-.09	-.21
19 34	101.66	101.93	101.64	101.82	102.05	101.82	.15	-.11	.18	.00	-.23
19 39	102.50	102.79	102.47	102.54	102.89	102.64	.13	-.15	.16	.09	-.24
19 49	104.17	104.50	104.14	103.98	104.56	104.27	.10	-.22	.13	.28	-.29
20 0	105.82	106.19	105.78	105.41	106.23	105.90	.06	-.30	.10	.47	-.34
20 29	110.73	111.20	110.61	109.62	111.22	110.68	-.05	-.52	.05	1.05	-.53
20 44	113.15	113.66	112.96	111.58	113.69	113.03	-.12	-.63	.06	1.35	-.66
21 0	115.55	116.09	115.27	113.71	116.16	115.36	-.19	-.73	.08	1.64	-.80
21 29	120.27	120.86	119.77	117.71	121.06	119.93	-.34	-.92	.16	2.23	-1.12

TABLE #5

<u>Calculated Values of Excess Reactivity and Temperature Coefficient of Reactivity</u>

Temperature	Excess Reactivity without Partial Element $\Delta k/k$ % ($\times 10^{-2}$)	Excess Reactivity with Partial Element $\Delta k/k$ % ($\times 10^{-2}$)	Temperature Coefficient of Reactivity $(\Delta k/k)/^{\circ}F$ % ($\times 10^{-2}$)
60.000	8.187	32.357	.460
61.000	8.643	32.813	.451
62.000	9.089	33.259	.442
63.000	9.527	33.697	.433
64.000	9.956	34.126	.424
65.000	10.375	34.545	.414
66.000	10.795	34.955	.405
67.000	11.187	35.357	.396
68.000	11.579	35.749	.387
69.000	11.962	36.132	.378
70.000	12.336	36.506	.369
71.000	12.701	36.871	.360
72.000	13.056	37.226	.351
73.000	13.403	37.573	.342
74.000	13.740	37.910	.333
75.000	14.069	38.239	.323
76.000	14.388	38.558	.314
77.000	14.698	38.868	.305
78.000	14.999	39.169	.296
79.000	15.291	39.461	.287
80.000	15.574	39.744	.278
81.000	15.848	40.018	.269
82.000	16.113	40.283	.260
83.000	16.368	40.538	.251
84.000	16.615	40.785	.241
85.000	16.852	41.022	.232
86.000	17.080	41.250	.223
87.000	17.300	41.470	.214
88.000	17.510	41.680	.205
89.000	17.711	41.881	.196
90.000	17.902	42.072	.187
91.000	18.085	42.255	.178
92.000	18.259	42.429	.169
93.000	18.423	42.593	.159
94.000	18.579	42.749	.150
95.000	18.725	42.895	.141
96.000	18.862	43.032	.132
97.000	18.990	43.160	.123
98.000	19.109	43.279	.114
99.000	19.219	43.389	.105
100.000	19.320	43.490	.096

Table #5 - (cont'd.)

Temperature	Excess Reactivity without Partial Element $\Delta k/k$ % $(x\ 10^{-2})$	Excess Reactivity with Partial Element $\Delta k/k$ % $(x\ 10^{-2})$	Temperature Coefficient of Reactivity $(\Delta k/k)/°F$ % $(x\ 10^{-2})$
101.000	19.412	43.582	.087
102.000	19.494	43.664	.078
103.000	19.568	43.738	.068
104.000	19.632	43.802	.059
105.000	19.687	43.857	.050
106.000	19.734	43.904	.041
107.000	19.771	43.941	.032
108.000	19.799	43.969	.023
109.000	19.817	43.987	.014
110.000	19.827	43.997	.005
111.000	19.828	43.998	-.003
112.000	19.819	43.989	-.013
113.000	19.802	43.972	-.022
114.000	19.775	43.945	-.031
115.000	19.739	43.909	-.040
116.000	19.694	43.864	-.049
117.000	19.640	43.810	-.058
118.000	19.577	43.747	-.067
119.000	19.505	43.675	-.076
120.000	19.424	43.594	-.085
121.000	19.333	43.503	-.094
122.000	19.234	43.404	-.104
123.000	19.125	43.295	-.113
124.000	19.007	43.177	-.122
125.000	18.880	43.050	-.131
126.000	18.745	42.915	-.140
127.000	18.599	42.769	-.149
128.000	18.445	42.615	-.158
129.000	18.282	42.452	-.167
130.000	18.110	42.280	-.176

THE TURN AROUND TEMPERATURE IS 110.509

TABLE #6

CALIBRATION TABLES

FOR

THERMISTORS

Thermistor No. & Position on Switch & on Terminal Block	Color Code in the Cable & on the Terminal Block	Color Code of [illegible] Leading to the Thermistor
1	Red/White	Pink
2	Black/White	Grey
3	Red/Blue	Blue
4	Black	Black
5	Orange	Orange
6	Brown	Brown
7	Yellow	Yellow
8	Black/Blue	Purple
9	Black/Green	Green
10	Black/Red	White-Yellow
11	Red/Yellow	White/Pink
12	Red/Green	Light Brown
Common Wire to Thermistor		
13	Black/Black	Red
Braided Shield		
14		

CALIBRATION CHART FOR THERMISTOR NUMBER 1

TEMPERATURE	RESISTANCE	LOG RES
50.0	3068.6	3.48694
51.0	3145.7	3.49771
52.0	3224.4	3.50844
53.0	3304.7	3.51912
54.0	3386.7	3.52977
55.0	3470.4	3.54037
56.0	3555.8	3.55093
57.0	3643.0	3.56145
58.0	3732.0	3.57193
59.0	3822.8	3.58237
60.0	3915.4	3.59277
61.0	4010.0	3.60313
62.0	4106.4	3.61346
63.0	4204.8	3.62374
64.0	4305.1	3.63398
65.0	4407.5	3.64419
66.0	4511.8	3.65434
67.0	4618.2	3.66447
68.0	4726.8	3.67456
69.0	4837.4	3.68461
70.0	4950.2	3.69462
71.0	5065.2	3.70459
72.0	5182.4	3.71453
73.0	5301.9	3.72442
74.0	5423.7	3.73428
75.0	5547.8	3.74411
76.0	5674.2	3.75390
77.0	5803.1	3.76365
78.0	5934.3	3.77336
79.0	6068.1	3.78304
80.0	6204.3	3.79269
81.0	6343.1	3.80229
82.0	6484.5	3.81187
83.0	6628.5	3.82140
84.0	6775.1	3.83090
85.0	6924.4	3.84037
86.0	7076.4	3.84980
87.0	7231.2	3.85920
88.0	7388.8	3.86856
89.0	7549.3	3.87789
90.0	7712.6	3.88719
91.0	7878.8	3.89645
92.0	8048.0	3.90568
93.0	8220.2	3.91487
94.0	8395.5	3.92404
95.0	8573.8	3.93316
96.0	8755.3	3.94226
97.0	8939.9	3.95132
98.0	9127.8	3.96035
99.0	9318.7	3.96935
100.0	9513.3	3.97832
101.0	9711.0	3.98725
102.0	9912.1	3.99615
103.0	10116.7	4.00503
104.0	10324.7	4.01387
105.0	10536.2	4.02267
106.0	10751.3	4.03145

Thermistor #1 (cont.)

107.0	10970.0	4.04020
108.0	11192.4	4.04891
109.0	11418.4	4.05760
110.0	11648.3	4.06625
111.0	11881.9	4.07487
112.0	12119.3	4.08347
113.0	12360.7	4.09203
114.0	12606.0	4.10056
115.0	12855.2	4.10907
116.0	13108.5	4.11754
117.0	13365.9	4.12599
118.0	13627.5	4.13440
119.0	13893.2	4.14279
120.0	14163.2	4.15115
121.0	14437.4	4.15948
122.0	14716.0	4.16778
123.0	14999.0	4.17605
124.0	15286.4	4.18429
125.0	15578.4	4.19251
126.0	15874.8	4.20070
127.0	16175.9	4.20886
128.0	16481.7	4.21699
129.0	16792.1	4.22509
130.0	17107.3	4.23317
131.0	17427.4	4.24122
132.0	17752.3	4.24924
133.0	18082.1	4.25724
134.0	18416.2	4.26520
135.0	18756.8	4.27315
138.0	19101.8	4.28106
137.0	19451.9	4.28895
138.0	19807.2	4.29681
139.0	20167.9	4.30465
140.0	20533.8	4.31246
141.0	20905.1	4.32024
142.0	21281.9	4.32800
143.0	21664.2	4.33573
144.0	22052.1	4.34344
145.0	22445.6	4.35112
146.0	22844.7	4.35877
147.0	23249.6	4.36640
148.0	23660.4	4.37401
149.0	24077.0	4.38159
150.0	24499.5	4.38914

CALIBRATION CHART FOR THERMISTOR NUMBER 2

TEMPERATURE	RESISTANCE	LOG RES
50.0	3763.7	3.57561
51.0	3835.8	3.58385
52.0	3909.0	3.59206
53.0	3983.3	3.60024
54.0	4058.8	3.60839
55.0	4135.3	3.61650
56.0	4213.0	3.62459
57.0	4291.9	3.63264
58.0	4371.9	3.64066
59.0	4453.1	3.64865
60.0	4535.4	3.65661
61.0	4619.0	3.66454
62.0	4703.8	3.67244
63.0	4789.8	3.68031
64.0	4877.0	3.68814
65.0	4965.5	3.69595
66.0	5055.2	3.70373
67.0	5146.2	3.71148
68.0	5238.5	3.71920
69.0	5332.1	3.72689
70.0	5427.0	3.73455
71.0	5523.3	3.74219
72.0	5620.8	3.74979
73.0	5719.7	3.75737
74.0	5820.0	3.76491
75.0	5921.6	3.77243
76.0	6024.7	3.77992
77.0	6129.1	3.78739
78.0	6234.9	3.79482
79.0	6342.2	3.80223
80.0	6450.9	3.80961
81.0	6561.1	3.81696
82.0	6672.7	3.82429
83.0	6785.8	3.83159
84.0	6900.4	3.83886
85.0	7016.4	3.84611
86.0	7134.0	3.85333
87.0	7253.2	3.86052
88.0	7373.9	3.86768
89.0	7496.1	3.87483
90.0	7619.9	3.88194
91.0	7745.3	3.88903
92.0	7872.3	3.89609
93.0	8000.9	3.90313
94.0	8131.1	3.91014
95.0	8263.0	3.91713
96.0	8396.5	3.92409
97.0	8531.7	3.93102
98.0	8668.5	3.93794
99.0	8807.1	3.94482
100.0	8947.4	3.95168
101.0	9089.4	3.95852
102.0	9233.1	3.96534
103.0	9378.5	3.97212
104.0	9525.8	3.97889
105.0	9674.8	3.98563
106.0	9825.6	3.99235

Thermistor #2 (cont.)

107.0	9978.2	3.99904
108.0	10132.7	4.00571
109.0	10288.9	4.01236
110.0	10447.0	4.01898
111.0	10607.0	4.02558
112.0	10768.9	4.03216
113.0	10932.6	4.03871
114.0	11098.3	4.04524
115.0	11265.9	4.05175
116.0	11435.4	4.05824
117.0	11606.8	4.06470
118.0	11780.3	4.07114
119.0	11955.7	4.07756
120.0	12133.1	4.08396
121.0	12312.5	4.09033
122.0	12493.9	4.09669
123.0	12677.4	4.10302
124.0	12862.9	4.10933
125.0	13050.5	4.11561
126.0	13240.1	4.12188
127.0	13431.9	4.12813
128.0	13625.8	4.13435
129.0	13821.8	4.14055
130.0	14019.9	4.14673
131.0	14220.2	4.15289
132.0	14422.7	4.15903
133.0	14627.3	4.16515
134.0	14834.2	4.17125
135.0	15043.2	4.17733
136.0	15254.5	4.18339
137.0	15468.1	4.18942
138.0	15683.9	4.19544
139.0	15902.0	4.20144
140.0	16122.3	4.20742
141.0	16345.0	4.21337
142.0	16570.0	4.21931
143.0	16797.3	4.22523
144.0	17027.0	4.23113
145.0	17259.0	4.23700
146.0	17493.5	4.24286
147.0	17730.3	4.24870
148.0	17969.5	4.25452
149.0	18211.2	4.26033
150.0	18455.3	4.26611

CALIBRATION CHART FOR THERMISTOR NUMBER 3

TEMPERATURE	RESISTANCE	LOG RES
50.0	3066.1	3.48658
51.0	3142.3	3.49724
52.0	3220.1	3.50786
53.0	3299.5	3.51844
54.0	3380.5	3.52897
55.0	3463.2	3.53947
56.0	3547.6	3.54992
57.0	3633.7	3.56034
58.0	3721.5	3.57071
59.0	3811.1	3.58104
60.0	3902.5	3.59134
61.0	3995.8	3.60159
62.0	4090.9	3.61181
63.0	4187.8	3.62198
64.0	4286.7	3.63212
65.0	4387.6	3.64222
66.0	4490.4	3.65228
67.0	4595.2	3.66230
68.0	4702.1	3.67228
69.0	4811.0	3.68223
70.0	4922.1	3.69214
71.0	5035.2	3.70201
72.0	5150.6	3.71185
73.0	5268.1	3.72164
74.0	5387.8	3.73140
75.0	5509.8	3.74113
76.0	5634.1	3.75082
77.0	5760.7	3.76047
78.0	5889.7	3.77008
79.0	6021.1	3.77966
80.0	6154.9	3.78921
81.0	6291.1	3.79872
82.0	6429.9	3.80819
83.0	6571.2	3.81763
84.0	6715.0	3.82704
85.0	6861.5	3.83641
86.0	7010.6	3.84574
87.0	7162.3	3.85504
88.0	7316.8	3.86431
89.0	7474.1	3.87355
90.0	7634.1	3.88275
91.0	7796.9	3.89191
92.0	7962.7	3.90105
93.0	8131.3	3.91015
94.0	8302.9	3.91922
95.0	8477.4	3.92825
96.0	8655.0	3.93726
97.0	8835.6	3.94623
98.0	9019.3	3.95516
99.0	9206.2	3.96407
100.0	9396.3	3.97295
101.0	9589.6	3.98179
102.0	9786.1	3.99060
103.0	9986.0	3.99938
104.0	10189.2	4.00813
105.0	10395.8	4.01685
106.0	10605.8	4.02553

Thermistor #3 (cont.)

107.0	10819.4	4.03419
108.0	11036.4	4.04282
109.0	11257.0	4.05141
110.0	11481.3	4.05998
111.0	11709.2	4.06851
112.0	11940.7	4.07702
113.0	12176.1	4.08550
114.0	12415.2	4.09394
115.0	12658.2	4.10236
116.0	12905.0	4.11075
117.0	13155.8	4.11911
118.0	13410.6	4.12744
119.0	13669.4	4.13574
120.0	13932.3	4.14401
121.0	14199.3	4.15225
122.0	14470.5	4.16047
123.0	14745.9	4.16866
124.0	15025.5	4.17682
125.0	15309.5	4.18495
126.0	15597.9	4.19305
127.0	15890.6	4.20113
128.0	16187.9	4.20918
129.0	16489.7	4.21720
130.0	16796.0	4.22519
131.0	17107.0	4.23316
132.0	17422.6	4.24110
133.0	17743.0	4.24901
134.0	18068.2	4.25690
135.0	18398.2	4.26476
136.0	18733.1	4.27260
137.0	19072.9	4.28040
138.0	19417.7	4.28819
139.0	19767.6	4.29594
140.0	20122.6	4.30367
141.0	20482.7	4.31138
142.0	20848.1	4.31905
143.0	21218.8	4.32671
144.0	21594.7	4.33433
145.0	21976.1	4.34194
146.0	22362.9	4.34951
147.0	22755.2	4.35707
148.0	23153.0	4.36459
149.0	23556.5	4.37210
150.0	23965.6	4.37958

CALIBRATION CHART FOR THERMISTOR NUMBER 4

TEMPERATURE	RESISTANCE	LOG RES
50.0	3015.2	3.47931
51.0	3091.1	3.49011
52.0	3168.6	3.50087
53.0	3247.8	3.51158
54.0	3328.6	3.52226
55.0	3411.1	3.53289
56.0	3495.4	3.54349
57.0	3581.3	3.55404
58.0	3669.1	3.56455
59.0	3758.6	3.57502
60.0	3849.9	3.58545
61.0	3943.2	3.59584
62.0	4038.3	3.60619
63.0	4135.3	3.61650
64.0	4234.3	3.62677
65.0	4335.2	3.63700
66.0	4438.2	3.64719
67.0	4543.1	3.65735
68.0	4650.2	3.66746
69.0	4759.4	3.67754
70.0	4870.7	3.68758
71.0	4984.2	3.69758
72.0	5099.8	3.70755
73.0	5217.8	3.71747
74.0	5337.9	3.72736
75.0	5460.4	3.73722
76.0	5585.2	3.74703
77.0	5712.4	3.75681
78.0	5842.0	3.76656
79.0	5974.1	3.77626
80.0	6108.6	3.78593
81.0	6245.7	3.79557
82.0	6385.2	3.80517
83.0	6527.4	3.81473
84.0	6672.2	3.82426
85.0	6819.7	3.83376
86.0	6969.9	3.84321
87.0	7122.8	3.85264
88.0	7278.5	3.86203
89.0	7437.0	3.87139
90.0	7598.3	3.88071
91.0	7762.6	3.89000
92.0	7929.8	3.89925
93.0	8100.0	3.90847
94.0	8273.1	3.91766
95.0	8449.4	3.92681
96.0	8628.7	3.93594
97.0	8811.2	3.94503
98.0	8996.9	3.95408
99.0	9185.8	3.96311
100.0	9378.0	3.97210
101.0	9573.5	3.98106
102.0	9772.[illegible]	3.98999
103.0	9974.[illegible]	3.99888
104.0	10180.[illegible]	4.00775
105.0	10389.[illegible]	4.01658
106.0	10602.[illegible]	4.02538

Thermistor #4 (cont.)

107.0	10818.4	4.03415
108.0	11038.4	4.04289
109.0	11262.0	4.05160
110.0	11489.3	4.06028
111.0	11720.4	4.06893
112.0	11955.3	4.07755
113.0	12194.1	4.08614
114.0	12436.7	4.09469
115.0	12683.4	4.10322
116.0	12934.0	4.11172
117.0	13188.7	4.12019
118.0	13447.6	4.12863
119.0	13710.5	4.13704
120.0	13977.7	4.14542
121.0	14249.2	4.15378
122.0	14524.9	4.16210
123.0	14805.0	4.17040
124.0	15089.6	4.17866
125.0	15378.6	4.18690
126.0	15672.1	4.19511
127.0	15970.2	4.20330
128.0	16272.9	4.21145
129.0	16580.3	4.21958
130.0	16892.5	4.22768
131.0	17209.4	4.23575
132.0	17531.2	4.24380
133.0	17857.9	4.25182
134.0	18189.5	4.25981
135.0	18526.1	4.26777
136.0	18867.8	4.27571
137.0	19214.7	4.28362
138.0	19566.7	4.29150
139.0	19924.0	4.29936
140.0	20286.5	4.30719
141.0	20654.5	4.31500
142.0	21027.8	4.32278
143.0	21406.6	4.33054
144.0	21791.0	4.33826
145.0	22180.9	4.34597
146.0	22576.5	4.35364
147.0	22977.9	4.36130
148.0	23385.0	4.36892
149.0	23797.9	4.37653
150.0	24216.7	4.38410

CALIBRATION CHART FOR THERMISTOR NUMBER 5

TEMPERATURE	RESISTANCE	LOG RES
50.0	2986.2	3.47512
51.0	3061.6	3.48594
52.0	3138.5	3.49672
53.0	3217.0	3.50745
54.0	3297.2	3.51814
55.0	3379.1	3.52880
56.0	3462.7	3.53941
57.0	3548.0	3.54997
58.0	3635.0	3.56050
59.0	3723.9	3.57099
60.0	3814.6	3.58144
61.0	3907.1	3.59185
62.0	4001.5	3.60221
63.0	4097.8	3.61254
64.0	4196.0	3.62283
65.0	4296.2	3.63308
66.0	4398.4	3.64329
67.0	4502.6	3.65346
68.0	4608.9	3.66359
69.0	4717.3	3.67369
70.0	4827.8	3.68374
71.0	4940.5	3.69376
72.0	5055.3	3.70374
73.0	5172.4	3.71369
74.0	5291.8	3.72359
75.0	5413.4	3.73346
76.0	5537.4	3.74329
77.0	5663.7	3.75309
78.0	5792.4	3.76285
79.0	5923.5	3.77257
80.0	6057.2	3.78226
81.0	6193.3	3.79191
82.0	6331.9	3.80153
83.0	6473.2	3.81111
84.0	6617.0	3.82065
85.0	6763.5	3.83016
86.0	6912.7	3.83964
87.0	7064.6	3.84908
88.0	7219.3	3.85848
89.0	7376.8	3.86786
90.0	7537.1	3.87719
91.0	7700.3	3.88650
92.0	7866.4	3.89577
93.0	8035.5	3.90500
94.0	8207.6	3.91421
95.0	8382.8	3.92338
96.0	8561.0	3.93251
97.0	8742.4	3.94162
98.0	8926.9	3.95069
99.0	9114.7	3.95973
100.0	9305.7	3.96874
101.0	9500.0	3.97771
102.0	9697.6	3.98665
103.0	9898.7	3.99556
104.0	10103.1	4.00444
105.0	10311.1	4.01329
106.0	10522.5	4.02211

Thermistor #5 (cont.)

107.0	10737.6	4.03090
108.0	10956.2	4.03965
109.0	11178.5	4.04837
110.0	11404.6	4.05707
111.0	11634.3	4.06573
112.0	11867.9	4.07436
113.0	12105.3	4.08297
114.0	12346.7	4.09154
115.0	12591.9	4.10008
116.0	12841.2	4.10859
117.0	13094.5	4.11708
118.0	13351.9	4.12553
119.0	13613.5	4.13396
120.0	13879.2	4.14235
121.0	14149.2	4.15072
122.0	14423.5	4.15906
123.0	14702.1	4.16737
124.0	14985.2	4.17565
125.0	15272.6	4.18390
126.0	15564.6	4.19213
127.0	15861.2	4.20032
128.0	16162.4	4.20849
129.0	16468.2	4.21663
130.0	16778.7	4.22475
131.0	17094.1	4.23283
132.0	17414.2	4.24089
134.0	18069.3	4.25693
135.0	18404.3	4.26491
136.0	18744.3	4.27286
137.0	19089.4	4.28078
138.0	19439.8	4.28868
139.0	19795.3	4.29655
140.0	20156.1	4.30439
141.0	20522.3	4.31221
142.0	20893.9	4.32001
143.0	21270.9	4.32777
144.0	21653.5	4.33552
145.0	22041.7	4.34323
146.0	22435.4	4.35092
147.0	22834.9	4.35859
148.0	23240.2	4.36623
149.0	23651.3	4.37384
150.0	24068.2	4.38143

CALIBRATION CHART FOR THERMISTOR NUMBER 6

TEMPERATURE	RESISTANCE	LOG RES
50.0	2211.7	3.34472
51.0	2276.8	3.35732
52.0	2343.5	3.36986
53.0	2411.9	3.38237
54.0	2482.1	3.39482
55.0	2554.0	3.40722
56.0	2627.7	3.41958
57.0	2703.3	3.43188
58.0	2780.7	3.44414
59.0	2860.0	3.45636
60.0	2941.2	3.46852
61.0	3024.4	3.48064
62.0	3109.7	3.49271
63.0	3197.0	3.50474
64.0	3286.4	3.51672
65.0	3378.0	3.52865
66.0	3471.8	3.54054
67.0	3567.7	3.55239
68.0	3666.0	3.56419
69.0	3766.6	3.57594
70.0	3869.5	3.58765
71.0	3974.9	3.59932
72.0	4082.7	3.61094
73.0	4193.0	3.62252
74.0	4305.9	3.63406
75.0	4421.4	3.64555
76.0	4539.5	3.65700
77.0	4660.3	3.66841
78.0	4783.9	3.67977
79.0	4910.2	3.69109
80.0	5039.4	3.70237
81.0	5171.5	3.71361
82.0	5306.6	3.72481
83.0	5444.7	3.73596
84.0	5585.8	3.74708
85.0	5730.1	3.75815
86.0	5877.6	3.76919
87.0	6028.3	3.78018
88.0	6182.2	3.79113
89.0	6339.5	3.80205
90.0	6500.3	3.81292
91.0	6664.5	3.82375
92.0	6832.2	3.83455
93.0	7003.5	3.84531
94.0	7178.5	3.85602
95.0	7357.2	3.86670
96.0	7539.6	3.87734
97.0	7726.0	3.88794
98.0	7916.2	3.89851
99.0	8110.4	3.90903
100.0	8308.7	3.91952
101.0	8511.0	3.92997
102.0	8717.6	3.94039
103.0	8928.4	3.95076
104.0	9143.5	3.96110
105.0	9363.0	3.97141
106.0	9587.0	3.98167

Thermistor #6 (cont.)

107.0	9815.5	3.99190
108.0	10048.7	4.00210
109.0	10285.5	4.01226
110.0	10529.1	4.02238
111.0	10776.5	4.03247
112.0	11028.9	4.04252
113.0	11286.2	4.05254
114.0	11548.7	4.06252
115.0	11816.2	4.07247
116.0	12089.1	4.08238
117.0	12367.2	4.09226
118.0	12650.8	4.10210
119.0	12939.8	4.11192
120.0	13234.4	4.12169
121.0	13534.7	4.13144
122.0	13840.7	4.14115
123.0	14152.5	4.15082
124.0	14470.3	4.16047
125.0	14794.1	4.17008
126.0	15124.0	4.17965
127.0	15460.0	4.18920
128.0	15802.4	4.19871
129.0	16151.1	4.20819
130.0	16506.4	4.21764
131.0	16868.1	4.22705
132.0	17236.6	4.23644
133.0	17611.8	4.24579
134.0	17993.9	4.25511
135.0	18382.9	4.26440
136.0	18779.0	4.27366
137.0	19182.3	4.28289
138.0	19592.9	4.29209
139.0	20010.8	4.30125
140.0	20436.2	4.31039
141.0	20869.1	4.31949
142.0	21309.8	4.32857
143.0	21758.3	4.33761
144.0	22214.6	4.34663
145.0	22679.0	4.35561
146.0	23151.5	4.36457
147.0	23632.2	4.37349
148.0	24121.3	4.38239
149.0	24618.9	4.39126
150.0	25125.0	4.40009

CALIBRATION CHART FOR THERMISTOR NUMBER 7

TEMPERATURE	RESISTANCE	LOG RES
50.0	3167.1	3.50065
51.0	3246.8	3.51145
52.0	3328.2	3.52220
53.0	3411.3	3.53291
54.0	3496.1	3.54358
55.0	3582.7	3.55421
56.0	3671.2	3.56480
57.0	3761.4	3.57534
58.0	3853.5	3.58585
59.0	3947.5	3.59631
60.0	4043.4	3.60674
61.0	4141.3	3.61713
62.0	4241.1	3.62747
63.0	4342.9	3.63778
64.0	4446.8	3.64804
65.0	4552.8	3.65827
66.0	4660.9	3.66846
67.0	4771.1	3.67861
68.0	4883.5	3.68872
69.0	4998.0	3.69879
70.0	5114.9	3.70883
71.0	5234.0	3.71882
72.0	5355.4	3.72878
73.0	5479.2	3.73871
74.0	5605.3	3.74859
75.0	5733.9	3.75844
76.0	5864.9	3.76825
77.0	5998.4	3.77802
78.0	6134.4	3.78776
79.0	6273.0	3.79747
80.0	6414.2	3.80713
81.0	6558.0	3.81676
82.0	6704.5	3.82636
83.0	6853.7	3.83592
84.0	7005.7	3.84544
85.0	7160.5	3.85493
86.0	7318.1	3.86439
87.0	7478.5	3.87381
88.0	7641.9	3.88319
89.0	7808.3	3.89254
90.0	7977.6	3.90186
91.0	8150.0	3.91115
92.0	8325.4	3.92040
93.0	8504.0	3.92961
94.0	8685.8	3.93880
95.0	8870.7	3.94795
96.0	9058.9	3.95707
97.0	9250.4	3.96615
98.0	9445.2	3.97520
99.0	9643.5	3.98422
100.0	9845.1	3.99321
101.0	10050.2	4.00217
102.0	10258.9	4.01109
103.0	10471.1	4.01998
104.0	10686.9	4.02884
105.0	10906.4	4.03767
106.0	11129.6	4.04647

Thermistor #7 (cont.)

107.0	11356.6	4.05524
108.0	11587.3	4.06397
109.0	11822.0	4.07268
110.0	12060.5	4.08135
111.0	12302.9	4.09000
112.0	12549.4	4.09861
113.0	12799.9	4.10719
114.0	13054.5	4.11575
115.0	13313.3	4.12427
116.0	13576.3	4.13277
117.0	13843.5	4.14123
118.0	14115.0	4.14967
119.0	14390.9	4.15808
120.0	14671.3	4.16646
121.0	14956.0	4.17480
122.0	15245.3	4.18312
123.0	15539.2	4.19142
124.0	15837.7	4.19968
125.0	16140.9	4.20792
126.0	16448.8	4.21612
127.0	16761.6	4.22430
128.0	17079.1	4.23245
129.0	17401.6	4.24058
130.0	17729.1	4.24867
131.0	18061.5	4.25674
132.0	18399.1	4.26478
133.0	18741.8	4.27280
134.0	19089.7	4.28079
135.0	19442.8	4.28875
136.0	19801.2	4.29668
137.0	20165.1	4.30459
138.0	20534.3	4.31247
139.0	20909.1	4.32032
140.0	21289.4	4.32815
141.0	21675.3	4.33595
142.0	22067.0	4.34373
143.0	22464.3	4.35148
144.0	22867.5	4.35920
145.0	23276.5	4.36690
146.0	23691.4	4.37458
147.0	24112.4	4.38223
148.0	24539.4	4.38985
149.0	24972.5	4.39745
150.0	25411.8	4.40502

CALIBRATION CHART FOR THERMISTOR NUMBER 8

TEMPERATURE	RESISTANCE	LOG RES
50.0	3043.8	3.48341
51.0	3119.9	3.49413
52.0	3197.5	3.50481
53.0	3276.8	3.51544
54.0	3357.7	3.52603
55.0	3440.2	3.53658
56.0	3524.5	3.54709
57.0	3610.5	3.55756
58.0	3698.3	3.56799
59.0	3787.8	3.57838
60.0	3879.2	3.58873
61.0	3972.3	3.59904
62.0	4067.4	3.60931
63.0	4164.4	3.61954
64.0	4263.2	3.62973
65.0	4364.1	3.63989
66.0	4466.9	3.65000
67.0	4571.8	3.66008
68.0	4678.7	3.67011
69.0	4787.6	3.68011
70.0	4898.7	3.69007
71.0	5012.0	3.70000
72.0	5127.4	3.70989
73.0	5245.0	3.71974
74.0	5364.9	3.72955
75.0	5487.0	3.73933
76.0	5611.4	3.74907
77.0	5738.2	3.75877
78.0	5867.4	3.76844
79.0	5999.0	3.77807
80.0	6133.0	3.78766
81.0	6269.5	3.79723
82.0	6408.6	3.80675
83.0	6550.1	3.81624
84.0	6694.3	3.82570
85.0	6841.1	3.83512
86.0	6990.6	3.84450
87.0	7142.7	3.85385
88.0	7297.6	3.86317
89.0	7455.3	3.87246
90.0	7615.8	3.88171
91.0	7779.2	3.89092
92.0	7945.4	3.90011
93.0	8114.6	3.90926
94.0	8286.7	3.91837
95.0	8461.9	3.92746
96.0	8640.1	3.93651
97.0	8821.4	3.94553
98.0	9005.8	3.95451
99.0	9193.4	3.96347
100.0	9384.3	3.97239
101.0	9578.3	3.98128
102.0	9775.7	3.99014
103.0	9976.5	3.99897
104.0	10180.6	4.00776
105.0	10388.1	4.01653
106.0	10599.2	4.02526

Thermistor #8 (cont.)

107.0	10813.7	4.03396
108.0	11031.8	4.04264
109.0	11253.5	4.05128
110.0	11478.9	4.05989
111.0	11708.0	4.06847
112.0	11940.8	4.07702
113.0	12177.4	4.08554
114.0	12417.9	4.09404
115.0	12662.2	4.10250
116.0	12910.5	4.11093
117.0	13162.8	4.11934
118.0	13419.1	4.12771
119.0	13679.4	4.13606
120.0	13943.9	4.14437
121.0	14212.6	4.15266
122.0	14485.5	4.16092
123.0	14762.7	4.16915
124.0	15044.2	4.17736
125.0	15330.1	4.18553
126.0	15620.4	4.19368
127.0	15915.2	4.20180
128.0	16214.5	4.20989
129.0	16518.4	4.21796
130.0	16826.9	4.22599
131.0	17140.2	4.23400
132.0	17458.2	4.24199
133.0	17780.9	4.24994
134.0	18108.6	4.25787
135.0	18441.1	4.26577
136.0	18778.6	4.27365
137.0	19121.1	4.28150
138.0	19468.7	4.28932
139.0	19821.4	4.29712
140.0	20179.2	4.30489
141.0	20542.4	4.31264
142.0	20910.8	4.32036
143.0	21284.5	4.32805
144.0	21663.7	4.33572
145.0	22048.4	4.34336
146.0	22438.5	4.35098
147.0	22834.3	4.35857
148.0	23235.7	4.36614
149.0	23642.8	4.37369
150.0	24055.7	4.38120

CALIBRATION CHART FOR THERMISTOR NUMBER 9

TEMPERATURE	RESISTANCE	LOG RES
50.0	3141.6	3.49714
51.0	3220.9	3.50797
52.0	3301.9	3.51876
53.0	3384.7	3.52951
54.0	3469.2	3.54022
55.0	3555.4	3.55088
56.0	3643.4	3.56151
57.0	3733.3	3.57209
58.0	3825.0	3.58263
59.0	3918.7	3.59313
60.0	4014.2	3.60359
61.0	4111.7	3.61401
62.0	4211.1	3.62439
63.0	4312.6	3.63473
64.0	4416.1	3.64503
65.0	4521.7	3.65529
66.0	4629.4	3.66552
67.0	4739.2	3.67570
68.0	4851.3	3.68585
69.0	4965.5	3.69595
70.0	5082.0	3.70602
71.0	5200.7	3.71605
72.0	5321.8	3.72605
73.0	5445.2	3.73600
74.0	5571.0	3.74592
75.0	5699.2	3.75580
76.0	5829.8	3.76565
77.0	5963.0	3.77546
78.0	6098.7	3.78523
79.0	6236.9	3.79496
80.0	6377.8	3.80466
81.0	6521.3	3.81432
82.0	6667.5	3.82395
83.0	6816.4	3.83354
84.0	6968.0	3.84310
85.0	7122.5	3.85262
86.0	7279.8	3.86211
87.0	7440.0	3.87156
88.0	7603.1	3.88098
89.0	7769.2	3.89036
90.0	7938.2	3.89971
91.0	8110.3	3.90903
92.0	8285.5	3.91831
93.0	8463.9	3.92756
94.0	8645.4	3.93677
95.0	8830.1	3.94595
96.0	9018.1	3.95510
97.0	9209.4	3.96422
98.0	9404.0	3.97330
99.0	9602.0	3.98235
100.0	9803.5	3.99137
101.0	10008.5	4.00036
102.0	10217.0	4.00931
103.0	10429.0	4.01823
104.0	10644.7	4.02712
105.0	10864.1	4.03598
106.0	11087.2	4.04481

Thermistor # 9 (cont.)

107.0	11314.0	4.05361
108.0	11544.7	4.06237
109.0	11779.3	4.07111
110.0	12017.7	4.07981
111.0	12260.2	4.08848
112.0	12506.6	4.09713
113.0	12757.1	4.10574
114.0	13011.8	4.11432
115.0	13270.6	4.12288
116.0	13533.6	4.13140
117.0	13800.9	4.13990
118.0	14072.6	4.14836
119.0	14348.6	4.15680
120.0	14629.0	4.16520
121.0	14913.9	4.17358
122.0	15203.4	4.18193
123.0	15497.5	4.19025
124.0	15796.2	4.19854
125.0	16099.6	4.20680
126.0	16407.8	4.21504
127.0	16720.8	4.22325
128.0	17038.7	4.23142
129.0	17361.5	4.23958
130.0	17689.4	4.24770
131.0	18022.2	4.25580
132.0	18360.2	4.26386
133.0	18703.3	4.27191
134.0	19051.7	4.27992
135.0	19405.3	4.28791
136.0	19764.3	4.29587
137.0	20128.7	4.30380
138.0	20498.6	4.31171
139.0	20873.9	4.31959
140.0	21254.9	4.32745
141.0	21641.5	4.33528
142.0	22033.9	4.34308
143.0	22432.0	4.35085
144.0	22835.9	4.35861
145.0	23245.8	4.36633
146.0	23661.6	4.37403
147.0	24083.5	4.38171
148.0	24511.4	4.38936
149.0	24945.5	4.39698
150.0	25385.9	4.40458

CALIBRATION CHART FOR THERMISTOR NUMBER 10

TEMPERATURE	RESISTANCE	LOG RES
50.0	2704.4	3.43207
51.0	2772.2	3.44282
52.0	2841.5	3.45354
53.0	2912.2	3.46421
54.0	2984.3	3.47484
55.0	3058.0	3.48544
56.0	3133.2	3.49598
57.0	3210.0	3.50649
58.0	3288.3	3.51696
59.0	3368.2	3.52739
60.0	3449.7	3.53778
61.0	3532.9	3.54812
62.0	3617.8	3.55843
63.0	3704.3	3.56870
64.0	3792.6	3.57893
65.0	3882.6	3.58912
66.0	3974.5	3.59927
67.0	4068.1	3.60939
68.0	4163.6	3.61946
69.0	4260.9	3.62950
70.0	4360.2	3.63950
71.0	4461.3	3.64946
72.0	4564.5	3.65938
73.0	4669.6	3.66927
74.0	4776.7	3.67912
75.0	4885.8	3.68893
76.0	4997.1	3.69871
77.0	5110.4	3.70845
78.0	5225.9	3.71815
79.0	5343.5	3.72782
80.0	5463.3	3.73745
81.0	5585.4	3.74704
82.0	5709.7	3.75661
83.0	5835.3	3.76613
84.0	5965.3	3.77562
85.0	6096.6	3.78508
86.0	6230.3	3.79450
87.0	6366.4	3.80388
88.0	6505.0	3.81324
89.0	6646.1	3.82256
90.0	6789.7	3.83184
91.0	6935.9	3.84109
92.0	7084.6	3.85031
93.0	7236.0	3.85949
94.0	7390.1	3.86864
95.0	7546.9	3.87776
96.0	7706.5	3.88684
97.0	7868.8	3.89590
98.0	8033.9	3.90492
99.0	8201.9	3.91390
100.0	8372.8	3.92286
101.0	8546.6	3.93178
102.0	8723.4	3.94067
103.0	8903.2	3.94953
104.0	9086.0	3.95836
105.0	9272.0	3.96716
[illegible]	[illegible]	[illegible]

Thermistor #10 (cont.)

107.0	9653.2	3.98466
108.0	9848.7	3.99337
109.0	10047.4	4.00204
110.0	10249.3	4.01068
111.0	10454.7	4.01930
112.0	10663.3	4.02788
113.0	10875.4	4.03643
114.0	11091.0	4.04496
115.0	11310.0	4.05345
116.0	11532.6	4.06192
117.0	11758.8	4.07035
118.0	11988.6	4.07876
119.0	12222.1	4.08713
120.0	12459.3	4.09548
121.0	12700.3	4.10380
122.0	12945.1	4.11209
123.0	13193.7	4.12035
124.0	13446.2	4.12859
125.0	13702.7	4.13679
126.0	13963.2	4.14497
127.0	14227.7	4.15312
128.0	14496.2	4.16124
129.0	14769.0	4.16934
130.0	15045.9	4.17740
131.0	15327.0	4.18544
132.0	15612.4	4.19346
133.0	15902.1	4.20144
134.0	16196.2	4.20940
135.0	16494.8	4.21733
136.0	16797.8	4.22524
137.0	17105.3	4.23312
138.0	17417.4	4.24097
139.0	17734.1	4.24880
140.0	18055.5	4.25660
141.0	18381.6	4.26437
142.0	18712.5	4.27212
143.0	19048.3	4.27984
144.0	19388.9	4.28754
145.0	19734.4	4.29521
146.0	20084.9	4.30285
147.0	20440.5	4.31048
148.0	20801.2	4.31809
149.0	21167.0	4.32565
150.0	21538.0	4.33319

CALIBRATION CHART FOR THERMISTOR NUMBER 11

TEMPERATURE	RESISTANCE	LOG RES
50.0	2685.2	3.42897
51.0	2752.1	3.43966
52.0	2820.4	3.45030
53.0	2890.1	3.46091
54.0	2961.2	3.47147
55.0	3033.8	3.48199
56.0	3107.9	3.49247
57.0	3183.5	3.50291
58.0	3260.7	3.51330
59.0	3339.4	3.52366
60.0	3419.7	3.53398
61.0	3501.6	3.54426
62.0	3585.1	3.55450
63.0	3670.3	3.56470
64.0	3757.2	3.57486
65.0	3845.5	3.58499
66.0	3936.2	3.59507
67.0	4028.3	3.60512
68.0	4122.2	3.61512
69.0	4217.9	3.62509
70.0	4315.5	3.63503
71.0	4415.0	3.64492
72.0	4516.3	3.65478
73.0	4619.6	3.66460
74.0	4724.9	3.67438
75.0	4832.2	3.68413
76.0	4941.4	3.69384
77.0	5052.7	3.70352
78.0	5166.1	3.71316
79.0	5281.7	3.72276
80.0	5399.3	3.73233
81.0	5519.1	3.74186
82.0	5641.1	3.75136
83.0	5765.4	3.76082
84.0	5891.9	3.77025
85.0	6020.7	3.77964
86.0	6151.9	3.78900
87.0	6285.4	3.79832
88.0	6421.3	3.80761
89.0	6559.6	3.81687
90.0	6700.4	3.82609
91.0	6843.7	3.83528
92.0	6989.5	3.84444
93.0	7137.9	3.85356
94.0	7288.9	3.86265
95.0	7442.5	3.87171
96.0	7598.8	3.88073
97.0	7757.7	3.88972
98.0	7919.5	3.89868
99.0	8083.9	3.90761
100.0	8251.2	3.91651
101.0	8421.4	3.92537
102.0	8594.4	3.93421
103.0	8770.4	3.94301
104.0	8949.3	3.95178
105.0	9131.2	3.96052
106.0	9316.1	3.96922

Thermistor #11 (cont.)

107.0	9504.1	3.97790
108.0	9695.3	3.98655
109.0	9889.5	3.99517
110.0	10087.0	4.00375
111.0	10287.7	4.01231
112.0	10491.7	4.02083
113.0	10699.0	4.02933
114.0	10909.6	4.03780
115.0	11123.6	4.04624
116.0	11341.1	4.05464
117.0	11562.0	4.06302
118.0	11786.5	4.07137
119.0	12014.5	4.07969
120.0	12246.1	4.08792
121.0	12481.4	4.09625
122.0	12720.3	4.10449
123.0	12963.0	4.11269
124.0	13209.4	4.12087
125.0	13459.7	4.12902
126.0	13713.8	4.13715
127.0	13971.9	4.14524
128.0	14233.9	4.15331
129.0	14499.9	4.16135
130.0	14769.9	4.16937
131.0	15044.0	4.17735
132.0	15322.3	4.18531
133.0	15604.7	4.19324
134.0	15891.4	4.20115
135.0	16182.3	4.20903
136.0	16477.6	4.21688
137.0	16777.3	4.22471
138.0	17081.3	4.23251
139.0	17389.9	4.24028
140.0	17702.9	4.24803
141.0	18020.5	4.25575
142.0	18342.7	4.26345
143.0	18669.6	4.27112
144.0	19001.2	4.27877
145.0	19337.6	4.28639
146.0	19678.8	4.29399
147.0	20024.8	4.30156
148.0	20375.8	4.30910
149.0	20731.7	4.31662
150.0	21092.7	4.32412

CALIBRATION CHART FOR THERMISTOR NUMBER 12

TEMPERATURE	RESISTANCE	LOG RES
50.0	2979.0	3.47407
51.0	3053.9	3.48485
52.0	3130.4	3.49559
53.0	3208.4	3.50629
54.0	3288.1	3.51694
55.0	3369.5	3.52755
56.0	3452.5	3.53813
57.0	3537.2	3.54866
58.0	3623.7	3.55915
59.0	3712.0	3.56960
60.0	3802.0	3.58001
61.0	3893.9	3.59038
62.0	3987.6	3.60071
63.0	4083.2	3.61100
64.0	4180.8	3.62125
65.0	4280.3	3.63146
66.0	4381.7	3.64164
67.0	4485.2	3.65177
68.0	4590.7	3.66187
69.0	4698.2	3.67192
70.0	4807.9	3.68195
71.0	4919.7	3.69193
72.0	5033.6	3.70187
73.0	5149.8	3.71178
74.0	5268.2	3.72165
75.0	5388.8	3.73149
76.0	5511.8	3.74128
77.0	5637.0	3.75104
78.0	5764.7	3.76077
79.0	5894.7	3.77046
80.0	6027.2	3.78011
81.0	6162.2	3.78972
82.0	6299.6	3.79931
83.0	6439.6	3.80885
84.0	6582.2	3.81836
85.0	6727.4	3.82784
86.0	6875.3	3.83728
87.0	7025.8	3.84669
88.0	7179.1	3.85606
89.0	7335.1	3.86540
90.0	7493.9	3.87470
91.0	7655.6	3.88397
92.0	7820.2	3.89321
93.0	7987.7	3.90241
94.0	8158.2	3.91158
95.0	8331.6	3.92072
96.0	8508.1	3.92982
97.0	8687.7	3.93889
98.0	8870.4	3.94793
99.0	9056.3	3.95694
100.0	9245.4	3.96591
101.0	9437.8	3.97486
102.0	9633.4	3.98377
103.0	9832.4	3.99265
104.0	10034.7	4.00150
105.0	10240.5	4.01031
106.0	10449.8	4.01910

Thermistor #12 (cont.)

107.0	10662.6	4.02785
108.0	10878.9	4.03657
109.0	11098.9	4.04527
110.0	11322.5	4.05393
111.0	11549.7	4.06256
112.0	11780.8	4.07116
113.0	12015.6	4.07973
114.0	12254.3	4.08828
115.0	12496.8	4.09679
116.0	12743.3	4.10527
117.0	12993.8	4.11372
118.0	13248.3	4.12215
119.0	13506.9	4.13054
120.0	13769.6	4.13891
121.0	14036.4	4.14725
122.0	14307.6	4.15555
123.0	14583.0	4.16383
124.0	14862.7	4.17208
125.0	15146.8	4.18031
126.0	15435.3	4.18850
127.0	15728.3	4.19667
128.0	16025.9	4.20481
129.0	16328.1	4.21292
130.0	16634.9	4.22101
131.0	16946.3	4.22906
132.0	17262.6	4.23709
133.0	17583.6	4.24510
134.0	17909.5	4.25307
135.0	18240.4	4.26102
136.0	18576.2	4.26894
137.0	18917.0	4.27684
138.0	19262.9	4.28471
139.0	19613.9	4.29255
140.0	19970.1	4.30037
141.0	20331.6	4.30816
142.0	20698.4	4.31592
143.0	21070.6	4.32366
144.0	21448.2	4.33138
145.0	21831.2	4.33907
146.0	22219.8	4.34673
147.0	22614.1	4.35437
148.0	23013.9	4.36198
149.0	23419.5	4.36957
150.0	23830.9	4.37713