350
4-29-64

IDO-16871-2
October 1963

FUNDAMENTALS IN THE OPERATION OF
NUCLEAR TEST REACTORS

VOL. 2 MATERIALS TESTING REACTOR DESIGN AND OPERATION

MASTER

PHILLIPS
PETROLEUM
COMPANY

ATOMIC ENERGY DIVISION

NATIONAL REACTOR TESTING STATION
US ATOMIC ENERGY COMMISSION

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency Thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

FUNDAMENTALS IN THE OPERATION OF NUCLEAR TEST REACTORS

Vol. 1	Reactor Science and Technology	IDO-16871-1
Vol. 2	Materials Testing Reactor Design and Operation	IDO-16871-2
Vol. 3	Engineering Test Reactor Design and Operation	IDO-16871-3
Vol. 4	Engineering and Design Considerations for In-Pile Tests	IDO-16871-4

This manual and course of study have been prepared under the direction of the MTR-ETR Operations Training and Qualifications Committee appointed by R. L. Doan, Manager, Atomic Energy Division, Phillips Petroleum Company:

R. J. Nertney, Chairman
W. J. Byron
J. W. Dykes
R. B. Johns
F. R. Keller
E. H. Smith

The Committee finalized the chapter headings, arranged for the authors, and assembled and organized the materials contained as chapters herein.

Editorial work was accomplished by the Committee assisted by M. L. Batt, P. R. Duckworth, R. E. Fearnow, D. P. Halls, L. H. Jones, F. L. McMillan, L. L. Myers, and C. R. Ricks.

LEGAL NOTICE

This report was prepared as an account of Government sponsored work. Neither the United States, nor the Commission, nor any person acting on behalf of the Commission:

A. Makes any warranty or representation, express or implied, with respect to the accuracy, completeness, or usefulness of the information contained in this report, or that the use of any information, apparatus, method, or process disclosed in this report may not infringe privately owned rights; or

B. Assumes any liabilities with respect to the use of, or for damages resulting from the use of any information, apparatus, method, or process disclosed in this report.

As used in the above, "person acting on behalf of the Commission" includes any employee or contractor of the Commission, or employee of such contractor, to the extent that such employee or contractor of the Commission, or employee of such contractor prepares, disseminates, or provides access to, any information pursuant to his employment or contract with the Commission, or his employment with such contractor.

Printed in USA. Price \$2.75. Available from the Office of
Technical Services, U. S. Department of Commerce
Washington 25, D. C.

IDO-16871-2
AEC Research & Development Report
Reactor Technology
TID-4500 (22nd Ed.)
October 1963

FUNDAMENTALS IN THE OPERATION OF NUCLEAR TEST REACTORS

VOL. 2 MATERIALS TESTING REACTOR DESIGN AND OPERATION

PHILLIPS
PETROLEUM
COMPANY

Atomic Energy Division

Contract AT(10-1)-205

Idaho Operations Office

U. S. ATOMIC ENERGY COMMISSION

FUNDAMENTALS IN THE OPERATION OF NUCLEAR TEST REACTORS
VOL. 2 MATERIALS TESTING REACTOR DESIGN AND OPERATION

CHAPTER TITLES AND AUTHORS

I	Engineering Description of the Materials Testing Reactor	R. S. McPherson
II	Reactor Control Components and Instrumentation	T. V. Anderson K. L. Berrett
III	Reactor Control Circuitry	A. D. Hill
IV	Reactor Operation	D. E. Ericson W. R. Cook D. P. Halls C. R. Ricks
V	Reactor Shutdown and Tank Work	W. R. Cook R. T. Dodds K. S. Dawson
VI	Supplemental Facilities at the Materials Testing Reactor	C. R. Ricks

VOLUME 2

TABLE OF CONTENTS

CHAPTER I	ENGINEERING DESCRIPTION OF THE MATERIALS TESTING REACTOR (MTR)	1
	A. PHILOSOPHY AND DESIGN SUMMARY	1
	B. GENERAL DESCRIPTION	9
	C. REACTOR BUILDING	12
	D. REACTOR AND REACTOR STRUCTURE	13
	1. Reactor Tank and Internals	14
	a. Reactor Tanks	14
	b. Reactor Internals	15
	2. Reactor Core and Reflector	16
	a. Fuel Assembly	17
	b. Shim-Safety Rod	17
	c. Regulating Rod	18
	d. Active Lattice and Reflector Pieces	19
	3. Top Plug	20
	a. Shim-Safety Rod Drive	20
	b. Regulating Rod Drive	21
	4. Bottom Plug	22
	5. Graphite Reflector	22
	6. Biological Shield	25
	7. Experimental Facilities	25
	a. Horizontal Beam Holes	34
	(1) Research Facilities	34
	(a) Fast Chopper	34
	(b) Crystal Spectrometer	37
	(c) Neutron Velocity Selector	37
	(d) Cold Neutron Facility	37
	(e) HR-4 Neutron Flux Facility	38
	b. Down Beam Holes	38
	c. VG Holes	39
	d. Other External Hole Facilities	39
	e. Hydraulic Rabbit	40
	f. Pneumatic Rabbit	40
	g. In-Tank Facilities	42

	(1) Active Lattice Facilities	42
	(2) Reflector Facilities	42
	8. Handling Facilities	42
	a. Overhead Cranes	42
	b. Canal	42
	c. Discharge Mechanism	43
	d. Underwater Saw	44
	e. MTR Carrier	44
	f. Universal Coffin	44
	g. Plug Storage Facility	44
	E. TRAINING QUESTIONS AND ANSWERS ON THE MTR	46-47
CHAPTER II	REACTOR CONTROL COMPONENTS AND INSTRUMENTATION	58
	A. INTRODUCTION	58
	B. REACTOR CONTROL INSTRUMENTATION, RODS, AND DRIVES	58
	1. Shim Rod System	58
	a. Shim Rods	58
	b. Shim Rod Control	59
	c. Individual Shim Rod Switches	59
	d. Shim Rod "WITHDRAWAL" Selector Switch	60
	e. Individual "WITHDRAWAL-INSERT" Switch	60
	f. "INTERMITTENT-CONTINUOUS" Group Withdrawal Switch	60
	g. "BYPASS-REVERSE" Switch	61
	h. "RAISE-COCK-SCRAM" Switch	61
	i. "SCRAM" Switch	61
	j. Shim Rod Indicators	61
	k. Shock Absorbers	61
	l. Top Plug Seals	61
	2. Servo System	62
	a. Regulating Rods	62
	b. Limit Swtiches	62
	c. Position Indicators	67
	d. Shock Absorbers	67
	e. Plug Seals	67
	f. Servo System Ion Chambers	67
	g. Servo System Explanation	67
	h. Servo Preamplifiers	67
	i. Servo Amplifiers	67
	j. Amplidynes	67
	k. Tachometers	68
	l. Motor Operated Rheostats	68
	m. Reactor Level Setpoint Switch	68
	n. "SETPOINT VERNIER"	68
	o. "MANUAL-AUTO" Selector Switch	68

C. REACTOR INSTRUMENTS	69
1. Fission Chamber Count Rate System	69
a. Fission Chamber	69
b. Amplifiers	69
c. Log Count Rate Meter and Indicators	69
d. Count Rate Meter Range	69
2. Sigma Bus	71
3. Log N - Period System	71
a. Chamber Power Supply	71
b. Compensated Ion Chambers	71
c. Log N Amplifiers	73
d. Period Amplifiers	73
e. Sigma Amplifiers	73
f. Log N Recorders	73
g. Period Recorders	73
4. Neutron Safety System	74
a. Parallel Circular Plate Ion Chambers	74
b. Safety Preamplifier	74
c. Sigma Amplifiers	74
d. Safety Level Recorders	74
5. Galvanometer Systems	76
6. N ¹⁶ Monitoring System	76
a. Airwall Ion Chambers	76
b. Preamp and Recorder	76
7. Boron Thermopiles	77
8. Water Power Indication	77
9. Main Reactor Water Flow	78
10. Differential Reactor Water Temperature	78
11. Fuel Element Monitoring System	78
a. Monitor Tubes	78
b. Fuel Element ΔT	78
c. Differential Flow	78
d. Activity	78
D. AUXILIARY FACILITIES INSTRUMENTATION	79
1. Reactor Triline Water Flow	79
2. Reactor Inlet and ΔP Pressures	79
3. Inlet-Outlet Water Temperature	79
4. Reactor Air In and Out Temperature	79
5. Pressure-Reactor Air Out	79
6. Temperature, Reactor Structure	79
7. Facilities Temperature	79

8. Instrument Air Pressure	79
9. Overhead Working Reservoir Level	80
10. Demineralized Water Back-up Activity Recorder	80
E. REACTOR CONTROL ROOM ANNUNCIATORS	80
1. Panel 1 - Plant and Reactor Area Trouble Lights	83
1-1 High Temperature Reactor Graphite	83
1-2 High Temperature Reactor Outlet Air	83
1-3 Crossover Bypassed	83
1-4 Low Pressure Water to Beam Holes	83
1-5 Low Flow Water to Beam Holes	83
1-6 High Temperature Water From Beam Holes	83
1-7 High Level HED Tank	83
1-8 High Level Reactor Building Sump	84
1-9 High Level Pipe Tunnel Sump	84
1-10 High Level Reactor Drain Tank	84
1-11 High Level Canal Sump	84
1-12 Vital Circuit Breaker Open	84
1-13 Annunciator Panel Dead	84
1-14 Power Loss to Slave Power Recorders	84
1-15 Trouble Experiment Emergency MG Set	84
1-16 Power Loss to Seismic System	84
1-17 Trouble Reactor Control MG Sets	85
1-18 Low Voltage to Galvanometer Ion Chamber	85
1-19 Control Relay Blocked	85
1-20 Dry Dock Test Block Out	85
1-21 Top Plug Not Connected	85
1-22 Low-High Canal Level	85
1-23 Loss of Suction Vent Scrubber	85
1-24 High Temperature Fuel Element Water	85
1-25 High Temperature Main Water	86
1-26 Trouble MTR Clark Compressor	86
1-27 Low Pressure Instrument Air	86
1-28 Low Pressure Ion Chamber Gas	86
1-29 Through 1-31 are Spare Panels	86
1-32 Fire-Main Floor Shielding	86
1-33 Fire - Wing Basement	86
1-34 Air Conditioner Failure, Lab 120	86
1-35 Air Conditioner Failure Wing Basement Counting Room	87
1-36 Air Conditioner Failure Fuel Scanning Room	87
1-37 Air Conditioner Failure Counting Room Extension	87
1-38 Spare Panel	87
1-39 Spare Panel	87
1-40 Alpha Lab Exhaust Blowers Off	87
1-41 Reactor Building Blowers Off	87
1-42 Spare Panel	87
1-43 Spare Panel	87
1-44 Spare Panel	87
2. Panel 2 - Reactor Trouble Lights	87
2-1 Slow Setback	87
2-2 Fast Setback	87
2-3 Reverse	87

2-4 Jr. Scram	87
2-5 Scram	87
2-6 Experiment Scram	88
2-7 High Activity N-16	88
2-8 Low Reactor Δ P	88
2-9 CRM Off Scale	88
2-10 3N _L In Start	88
2-11 Five Second Period	88
2-12 Seismic Scram	88
2-13 Low Fuel Element Δ P	89
2-14 Low Flow Bypass Water	89
2-15 Low Flow Main Water	89
2-16 Low Level Working Reservoir	89
2-17 Low Flow Reactor Air	89
2-18 Loss of Vacuum Reactor Outlet Air	89
2-19 High Reactor Water Δ T	90
2-20 High Level Boron Thermocouples	90
2-21 High Power Main Recorder	90
2-22 High Servo Demand	90
2-23 Main Valve Closed or 30 Second Power Failure	90
2-24 Loss of Relay Power	90
2-25 Level No. 1 Trouble	91
2-26 Level No. 2 Trouble	91
2-27 Level No. 3 Trouble	91
2-28 Period No. 1 Trouble	91
2-29 Period No. 2 Trouble	91
2-30 Magnet Amplifier Trouble	91
2-31 Level No. 1	91
2-32 Level No. 2	91
2-33 Level No. 3	91
2-34 Period No. 1	92
2-35 Period No. 2	92
2-36 Magnet Amplifier Transfer	92
3. Panel 3 - Experiment Trouble Lights	92
3-1 Trouble KAPL-HB-1	92
3-2 Trouble KAPL-L-42	92
3-3 Trouble WAPD-B-4	92
3-4 Trouble WAPD-VH-3	92
3-5 Trouble GEH-B-3	93
3-6 Through 3-12 are Spare Panels	93
3-13 Trouble PAED-37-HR-4	93
3-14 Trouble PAED-HB-2	93
3-15 Trouble ORNL-HB-3	93
3-16 Trouble VH-4 Experiment Flow	93
3-17 Trouble HB-4 Crystal Spectrometer	93
3-18 Trouble HB-6 Chopper	93
4. Panel 4 - Radiation Trouble Lights	93
4-1 High CAM Activity Basement - Canal	93
4-2 High CAM Activity, Reactor Top	93
4-3 High CAM Activity, Services Building	94
4-4 High CAM Activity, Basement South	94
4-5 High CAM Activity, Basement North	94

4-6	High CAM Activity, First Floor South	94
4-7	High CAM Activity, First Floor North	94
4-8	Spare Panel	94
4-9	Spare Panel	94
4-10	Spare Panel	94
4-11	Spare Panel	94
4-12	Spare Panel	94
4-13	Very High Radiation Reactor Building	94
4-14	High Radiation Reactor Basement	94
4-15	High Radiation Reactor Top or Main Floor	94
4-16	High Radiation Outside Areas or Sub-pile Room	95
4-17	High Radiation at ETR Critical or Lab 111	95
4-18	High Radiation Engineering Research Laboratory	95
4-19	Spare Panel	95
4-20	Spare Panel	95
4-21	Spare Panel	95
4-22	Spare Panel	95
4-23	Spare Panel	95
4-24	Spare Panel	95
4-25	High Activity Iodine Monitor	95
4-26	High Activity Fuel Element	95
4-27	High Activity Stack	96
4-28	High Activity Seal Tank	96
4-29	High Activity Catch Tank	96
4-30	High Activity Demineralized Water	96
4-31	High Activity, Alpha Lab	96
CHAPTER III	REACTOR CONTROL CIRCUITRY WIRING DIAGRAM	97
A.	GENERAL	97
B.	REACTOR CONTROL CIRCUIT ELEMENTARY	98
1.	Startup Limitation Circuits	98
2.	Start Circuit	101
a.	Startup Horn Circuit	101
3.	Timer Circuit	101
4.	Potentiometer Limit Circuit	101
5.	Seven Second Period Trips	102
6.	Trip Circuit	102
7.	Intermittent-Continuous Group Withdrawal	102
8.	Shim Rod Withdrawal Contact	103
9.	Sag and Run Regimes	104
10.	Run Auxiliary	105
11.	Withdraw Permit	105
12.	Shim Rod Drive Withdrawal	105
13.	Shim Rod Insertion	105

14. Motor Operated Rheostat Circuits	106
a. R 91 Circuit	106
b. MOR Limit Switch Circuits	107
15. Regulating Rod Control Circuits	107
16. Fission Chamber Drive Circuit	107
17. N Approximately Equal to N_L Circuit	108
18. Period Restrictions	108
19. Shim Rod Contacts	108
20. Low Speed Circuit	109
21. Loss of Voltage Scram	109
22. Manual "INDICATION" Circuit	109
C. MTR POWER REDUCTION CIRCUITRY	109
1. Preferred Insert	109
2. Reverse	109
a. Regulating Rod Below 5 Inches	109
b. In "START"	109
c. Setbacks to Reverses	110
d. Excess Power Level	110
e. Experiment Reverses	110
3. Slow Setback	110
4. Fast Setback	110
5. Scrams	110
a. Jr. Scram	110
b. Full Scram	111
6. Level and Period Trouble Circuits	111
7. Dial and Other Indicating Lights	111
D. TRAINING QUESTIONS AND ANSWERS ON THE MTR	111-119
CHAPTER IV REACTOR OPERATION	120
A. REACTOR STARTUP	120
1. General	120
2. Startup Check Lists	120
a. Reactor Services Operator Preliminary Checks	120
b. Console Operator Preliminary Checks	120
c. Electronic Technician Preliminary Checks	121
d. Senior Reactor Engineer Responsibilities	121
(1) Lead Experiments	121
(2) High Pressure Loops	121
(3) "W" Switches	121
(4) Cooling Neccessities	122

e. Foreman's Checks	123
f. Supervisor's Responsibilities	123
3. Pulling Rods	124
4. Transition From "START" to "RUN"	126
5. Servo Control to Full Power	126
6. Special Tests	127
a. Flux Runs	127
b. Reverse Reactivity	127
c. Special Experiment Startup Rates	127
B. NORMAL POWER OPERATION	127
1. Duties of Reactor Operators	128
a. Console Operator Duties	128
b. Reactor Basement - North and South	130
c. Roving and Miscellaneous	131
d. Senior Reactor Engineer	131
2. Standard Manipulations	131
a. Calculating and Adjusting Power	132
b. Pulling and Leveling Shim Rods	132
c. Switching Servo Systems	132
C. OPERATIONS UNDER ADVERSE CONDITIONS	133
1. Emergency Scrams and Recoveries	133
a. Full Scram	133
(1) Normal Recovery	133
(2) Recovery Where Time is Limited	135
b. Jr. Scram	135
c. Electronic Scram	136
d. Accidental Shim Rod Drop	136
e. Accidental Regulating Rod Drop	136
2. Other Emergency Power Reductions and Recoveries	136
a. Reverse	136
b. Slow and Fast Setbacks	137
3. Abnormal Reactor Facilities	137
a. Instrument and Control Bus	137
b. Loss of Electrical Power	137
(1) Loss of Commercial Power	137
(2) Amplidyne	138
c. Abnormal Process Water Systems	138
(1) Loss of Vacuum	138
(2) Cold Water Make-up	138
(3) Other Abnormalities	138

d. Abnormal Reactor Component Behavior	140
(1) Operation with Water in VG Hole	140
(2) Horizontal Beam Hole Plug Cooling	140
(3) Fission Break	140
e. Boiling	141
f. Abnormal Cooling of Graphite Region	141
CHAPTER V REACTOR SHUTDOWN AND TANK WORK	146
A. DELIBERATE SHUTDOWN	146
B. REACTOR PRE-SHUTDOWN WORK	147
1. Tool Check	147
2. Miscellaneous Pre-Shutdown Duties	148
3. Control Systems Shutdown	148
4. Reactor Flush	148
C. REACTOR SHUTDOWN WORK	149
1. Top Plug Removal	149
2. Working Platform	149
3. One-Ton Crane	149
4. Tool Handling	149
5. Upper Grid Removal	151
6. Unloader Operation	151
7. Lattice Work	151
a. Fuel Elements	151
b. Shim Rods	151
c. Special "L" Pieces	152
8. Reflector Work	152
a. Capsule Handling	152
b. "A" Piece Handling	152
c. Lead Experiment Handling	152
d. Measurement of Experiments	153
9. Special Shutdown Items	153
a. Man in "A" Tank	153
b. Communciations	153
c. Record Keeping	154
d. Neatness and Trash	154
10. Reassembly	154
a. Upper Grid	154
b. Top Plug	155
c. Vertical Graphite Shielding Plugs	155
D. TRAINING QUESTIONS AND ANSWERS ON THE MTR	156-157

CHAPTER VI	SUPPLEMENTAL FACILITIES AT THE MTR	158
	A. MTR-ETR STEAM PLANT OPERATORS' AREA	158
	B. DEMINERALIZED WATER PLANT OPERATORS' AREA	159
	C. PROCESS WATER BUILDING OPERATORS' AREA	159

FIGURE	LIST OF FIGURES	PAGE
1	Reactor tanks and internals top plan with top plug removed	3
2	Fuel assembly	4
3	Cd-U shim rod assembly	5/6
4	Reactor tank and internals vertical cross section	7/8
5	Reactor structure (vertical section through east-west centerline looking north)	23
6	Reactor structure (vertical section through north-south centerline looking west)	24
7	Reactor air flow schematic	33
8	HB-2 beam hole liner and plug	35/36
9	Reactor structure (top plane)	41
10	Reactor structure (north elevation)	48
11	Reactor structure (east elevation)	49
12	Reactor structure (south elevation)	50
13	Reactor structure (west elevation)	51
14	Reactor structure (horizontal section at reactor centerline)	52
15	Reactor tank section "D" (showing beam hole liners)	53
16	Fuel Element assembly	53
17	Reactor structure (internal construction pictorial)	54
18	Geneva model cutaway	55
19	Geneva model cutaway	55
20	Lower assembly grid (showing corner locking cam)	56
21	Beryllium reflector and lower guide grid	56
22	CPP straddle carrier picking up MTR fuel element cask	57
23	Reactor control circuit elementary wiring diagram	63/64
24	Reactor instrument block schematic diagram	65/66
25	Simple servo system circuit	68
26	Fission chamber assembly	70

FIGURE	LIST OF FIGURES	PAGE
27	Compensated ionization chamber	72
28	Neutron sensitive 3 in. P.C.P. ionization chamber	75
29	Control room annunciator wiring diagram	81/82
30	Power reduction relays and indicating lights wiring diagram	99/100
31	Lead experiment summary	122
32	"W" switch data sheet	123
33	Power level - instrument relationships	125
34	Reverse reactivity curves	128
35	Maximum thermal neutron flux, $10^{14}n/cm^2\text{-sec}$	129
36	Fast neutron flux at reactor midplane (neutron energy > 1 Mev)	129
37	Approximate power vs time for automatic power reductions	134
38	Approximate power vs time for slow scram and jr. scram	134
39	Process water temperature increase with no heat exchanger cooling	139
40	Permissible power vs inlet water temperature	139
41	Control console	142
42	Senior reactor engineer directing increase to 40 Mw	143
43	Excess reactivity change after shutdown	146
44	Top plug removal March 31, 1952	150

TABLE	LIST OF TABLES	PAGE
1	Reactor Core	2
2	Fuel Assemblies	2
3	Shim-Safety Rods	2
4	Regulating Rods	2
5	Reactor Vessel	2
6	Reactor Physics	2
7	Reactor Heat Transfer	3
8	Reactor and Reactor Building Elevations	12
9	MTR Experimental Facilities	26/32
10	Reactor Radiation Instruments	59
11	MTR Operations Branch Startup Check List	144/145

CHAPTER I

ENGINEERING DESCRIPTION OF THE MATERIALS TESTING REACTOR

A. PHILOSOPHY AND DESIGN SUMMARY

The Materials Testing Reactor (MTR) is the result of an evolutionary process in the design of a machine devised for the express purpose of facilitating the conception and design of future reactors. At the time of its inception, it was important that a facility be built which was capable of furnishing physical, chemical, and engineering information at thermal and fast neutron fluxes greater than 10^{14} n/cm²-sec and high gamma ray intensities. On the basis of this information, future test and power reactors could be designed within controllable and permissible limits of uncertainty in operating characteristics.

A reactor which is to be most effective as a radiation source should be designed to maximize both fast- and thermal-neutron fluxes. To obtain these goals, a reactor must have a high specific power per gram of fissionable material and per unit of volume.

The second generation test reactors and first generation power reactors built during the middle 1950's posed many problems which required experimental answers obtained from tests carried on at the MTR. For example, the effect of high fluxes, particularly of fast neutrons, on the properties of structural materials was not well known. Graphite was known to suffer ill effects in a relatively short time, and further information in this field was required. Metals which have desirable structural properties as a result of cold working or of heat treatment may undergo adverse effects under fast-neutron bombardment. The breeding gain of a breeder type reactor and the operating time of a power reactor depend, to a large extent, on the cross sections of the fission products. The effects of second-order reactions and of nuclei of short life were thought to be important in the operation of high-flux reactors. These effects were not apparent in the early low-flux reactors and they can now be studied at the MTR.

Aside from those highly urgent and immediately practical problems, there were many fundamental experimental studies in the high-flux regions that were to be carried out in the MTR. The high density of epithermal neutrons in the MTR permitted the extension of the practical range of the crystal spectrometer to higher neutron energies. The properties of fissionable isotopes in the lower-resonance energy regions could be investigated and their nuclear constants more accurately determined. Reactions of higher order (the capture of two or more neutrons in succession by the same nucleus) could now produce significant quantities of rare isotopes, thereby permitting the study of their nuclear constants.

Production of radioisotopes in amounts and of specific activities heretofore not readily available was initiated. For example, the MTR was used to produce phosphorus compounds of high specific activity which were usable directly, without purification or chemical separation, by clinical institutions. Strong cobalt-60 sources were also easily produced.

The MTR was designed with numerous experimental facilities which permitted the irradiation of materials used for reactor components, fuel assemblies, coolants, moderators, and reflectors. Tests are carried on under simulated operating conditions of temperature, pressure, and other environmental factors.

The state of the art at the time of the MTR design did not permit the experimental facility configurations used in later test reactors. Present knowledge allows the placement of experiments within the core itself, thus utilizing the high fluxes present at that point. Thus, one direct contribution of the MTR to present technology was this major change in test reactor design. The elimination of beam holes and other types of biological shield-penetrating experiment facilities in advanced test reactors has reduced the cost of carrying out testing programs and at the same time has allowed

greater flexibility in sizing test components. The present trend in this field is to provide penetrations in the reactor vessel either through the top or bottom heads or through nozzles in the vessel provided for test installation.

The MTR is a heterogeneous reactor, light-water cooled and moderated, which uses beryllium and graphite as a reflector. The fuel assemblies are plate-type and are fabricated from aluminum. An enriched U-Al mixture is clad with aluminum to form the fuel plates. Design characteristics are listed in tables 1 through 7.

Table 1
Reactor Core (See figure 1)

Design operating power, Mw	30
Operating power Sept. 19, 1955, Mw	40
Operating power design limit, Mw	60
Lattice array	5 N-S x 9 E-W
Fuel assembly array	3 x 9 (north side)
Lattice spacing, in.	3.035 N-S x 3.189 E-W
Fuel assemblies in core	23
Shim-safety rods in core*	7
Beryllium "L" pieces in core	14
Lattice opening, in. (approx)	15.7 (N-S) x 28.8 (E-W)
Beryllium reflector diameter, in.	54
Beryllium reflector height, in.	39-3/8
Regulating rod positions in reflector**	4

*FOUR Cd-U, THREE Cd-BE, ONE SHIM-SAFETY ROD POSITION IN THE CORE IS USED AS AN EXPERIMENTAL FACILITY SPACE, ORIGINAL DESIGN CALLED FOR EIGHT RODS.

**ONLY THE NORTH TWO REGULATING RODS ARE USED DURING REACTOR OPERATION, THE TWO SOUTH LOCATIONS ARE USED AS EXPERIMENTAL FACILITIES.

Table 2
Fuel Assemblies (See figure 2)

Assemblies in core	23
Active core length, in. (approx)	24
Length of assembly, in.	48-11/16
Size of assembly, in.	2.996 x 3.168
Fuel plates per assembly	19
Spacing between fuel plates, in. (nominal)	0.117
Core alloy	Highly enriched U-Al
Fuel plate cladding	Al

Table 3
Shim-Safety Rods (See figure 3)

Rods in core	7
Length of rod, in.	163-9/16
Poison-fuel follower type	4
Poison-beryllium reflector type	3
Weight of fuel-follower rod, lb	110
Fuel plates per rod	14
Spacing between fuel plates, in. (nominal)	0.115
Core alloy	Highly enriched U-Al
Fuel plate cladding	Al

Table 4
Regulating Rods

Rod positions in reflector	4
Rods in use	2
Type of rod	Cd-Al
Weight of rod, lb	10.5

Table 5
Reactor Vessel (See figure 4)

Tanks making up vessel	5
Total height of vessel, ft	30
Maximum ID, in., "A" tank	71
Minimum ID, in., "C", "D", and "E" tanks	54-1/4
Stainless steel tanks "A", "B", and "E"	
Aluminum tanks "C" and "D"	
Design pressure, psig	75
Design temp, °F	125
Tank surrounding core "D" tank	
"D" tank wall thickness, in.	1 and 1-1/4
Diam of water inlet pipes (two in "A" tank), in.	24
Diam of water outlet pipes (two in "E" tank), in.	24

Table 6
Reactor Physics

Active core volume, liters	100
Vertical power ratio in fuel, max/avg	1.5
Horizontal power ratio in fuel, max/avg	1.3
Core power ratio in fuel, max/avg	2
Specific power, kw/kg U, avg	
Design	8330
Jan. 1960	8160
Total U-235 in core, kg	
with 140 g assemblies (design)	4.8
with 200 g assemblies (Jan. 1960)	4.9
Full load core effective excess reactivity, %	
Design (no experiments)	20
January, 1960	13 to 15
Control rod worth, 7 rods, %	40
Regulating rod worth, 1 rod, %	0.5

Table 7
Reactor Heat Transfer

Coolant	Demineralized water	Core pressure, psig	42.5
Flow in one fuel assembly, gpm	440	Heat flux, Btu/hr-ft ² , avg	3.4×10^5
Flow in one control rod, gpm	550	Heat flux, Btu/hr-ft ² , max	8×10^5
Reactor inlet temp, °F	100	Burnout heat flux, Btu/hr-ft ²	15×10^5
Reactor outlet temp, °F	112	Fuel assembly surface temp, max, °F	295

FIGURE 1.
Reactor tanks and internals top plan
with top plug removed

FIGURE 2.
Fuel assembly

FIGURE 3.
Cd-U shim rod assembly

FIGURE 4.
Reactor tank and internal vertical
cross section

B. GENERAL DESCRIPTION

The general description which follows is to allow the reader to become familiar with the over-all picture of this test facility. Details will be given in supplemental sections.

The reactor structure is contained in a large concrete slab building measuring approx 130 ft sq and extending approx 80 ft above grade and 17 ft below grade. Located in the basement is a water-filled canal extending from beneath the reactor structure eastward about 141 ft. The high density concrete biological shield enclosing the reactor vessel is approx square and is positioned in the center of the building. This structure measures 32 ft 6 in. north to south by 34 ft east to west and extends 24 ft vertically above the building's first floor level. Supporting the above structure is a concrete base enclosing the reactor sub-pile room. This base is 35 ft north to south by 36 ft 6 in. east to west. Numerous concrete piers below the basement floor support the reactor and canal structures and building columns; these piers extend down to bedrock. The top tank of the reactor vessel ("A" tank) is installed flush with the top of the concrete biological shield. "B", "C", "D", and "E" tanks are mounted consecutively beneath "A" tank, and the bottom of "E" tank is located in the sub-pile room ceiling. The vessel is closed at each end by lead-filled stainless steel flat heads.

The reactor core, containing the fuel assemblies and beryllium reflector, is located in "D" tank. Several horizontal experimental facility penetrations in the biological shield are located on the core's vertical centerline and the reactor building's first floor is positioned 3-1/2 ft below that elevation for convenient handling of the heavy plugs in these facilities. An arbitrary and convenient method for indicating relative elevations of parts of the reactor was utilized. By choosing elevation 100 ft 0 in. for the core horizontal centerline, the first floor elevation is 96 ft 6 in., the top of the reactor structure is 120 ft 6 in., and the basement floor elevation is 79 ft 10 in. (All elevations may be converted to sea level datum by adding 4828.26 ft.)

Since the primary purpose of the MTR is to produce neutrons and to use these neutrons for various experimental programs, the most efficient generation, energy modification, and utilization of these particles established the

configuration of the reactor core, the surrounding thermalizing graphite, and the biological shield. Numerous penetrations in this shield allow the placement of experiments in zones of varied fluxes, neutron, gamma, or both.

Uranium bearing fuel assemblies form the core of the reactor. The core measures approx 9 in. north to south by 28 in. east to west by 24 in. high. Surrounding the core is a beryllium reflector which is 39-3/8 in. high and extends to the inner surface of "D" tank. This reflector returns a portion of the neutrons generated by the fuel back into the core zone where they are utilized in the fission process. Several beam holes are located in this reflector to allow placement of experiments directly adjacent to the active lattice with the consequent exposure to the very high flux at that point. "D" tank is constructed of aluminum which allows minimum capture of neutrons passing beyond the beryllium reflector into the graphite reflector zone. This increases the flux and the value of the experimental facilities placed in this zone.

A number of experimental holes for irradiation of materials at moderate neutron and gamma levels are located in the large graphite reflector zone which surrounds the reactor vessel "D" tank and extends above and below "D" tank to cover portions of "C" and "E" tanks. This graphite reflector measures 12 ft north to south by about 15 ft east to west by 9 ft 4 in. high. The bottom of the graphite is located 4 ft below the core horizontal centerline, or at elevation 96 ft.

Graphite exposed to a neutron flux rises in temperature with a corresponding volume increase and also "grows" upon capture of neutrons. A solid mass of graphite forming this reflector would therefore pose numerous problems. These problems were alleviated by utilizing graphite balls one inch in diameter in the zone immediately surrounding the tanks. Solid graphite bars were then stacked to form the completed reflector to the required dimensions. The ball or "pebble" zone extends for the full height of the graphite and measures 7 ft 4 in. sq. Two discharge chutes are located at the bottom of the pebble zone and allow the dumping of the balls into bins in the event of damage to the balls or when replacement of any of the three center tanks becomes necessary. A large volume of cooling air from

the reactor building is drawn through the graphite reflector and discharged into the atmosphere through a 250 ft stack located in the yard area.

The graphite reflector forms the boundary of the usable irradiation space around the reactor core. The radiation level at this boundary is too high for direct exposure to personnel and must be reduced. This is accomplished by a high-density concrete biological shield which extends from the top of "A" tank down through the reactor building's first floor to the basement floor. Leakage of neutrons and gamma rays out of the graphite reflector would increase the temperature gradient in the concrete shield. This would result in damage due to expansion stresses. This leakage is absorbed by thermal shields surrounding the graphite reflector. These shields are made of two 4 in. thick steel plates. These plates are placed on all six sides of the reflector and are cooled by the same air used to cool the graphite. Experimental facility penetrations through the biological shield and graphite reflector utilize steel and aluminum liners, respectively. The external surface of the concrete shield is formed by a steel plate. This construction facilitated fabrication of the concrete shield and alignment of the numerous experimental facility liners.

In addition to the experimental facility liners, other reactor supporting equipment is embedded in the biological shield. The ducts which carry air to cool the thermal shields and graphite reflector run from filters located on all four faces of the reactor structure. Four 24 in. process water lines enter the reactor structure under the basement floor, two enter "A" tank to furnish inlet water for cooling the reactor core, and two are connected to "E" tank to carry the heated water back to the process water building for degassing and cooling. Flow through the core is downward and measures approx 24,000 gpm. Structural steel used during construction to support and align "A" and "E" tanks and other components such as piping, the thermal shields, etc, is also embedded in the concrete structure. Due to the complicated and close-packed array of facilities, pipes, etc, in this structure, the conventional method of pouring a plastic concrete mixture inside the steel forms was abandoned in favor of the "prepack" method. Semi-liquid grout was dumped in at the bottom

of the high density aggregate which had been previously placed dry. This forced out all entrapped air and assured a void-free shield. It also allowed maintenance of the correct ratio of grout to aggregate which is important for shielding requirements.

The experimental facility penetrations in the reactor structure may be divided into several groups. There are 17 large experimental holes that lead from the reactor faces either to the "D" tank wall or to the active lattice. In addition to these main experimental holes, there are six more horizontal through holes which penetrate the biological shield and permanent graphite. The MTR also has 66 experimental and instrument holes (VG's and VN's) accessible from the top of the reactor. Some of these penetrate into the graphite pebble zone and some into the permanent graphite. Two are also accessible from the subpile room. In addition, there are four instrument holes (GT's and GM's) and 12 experimental holes (VC's) which penetrate the biological shielding from the top of the reactor structure.

The thermal column is a graphite-filled hole approx 6 ft sq by 8 ft long, extending from the east face of the reactor structure to the outside face of the outer thermal shield plate. It is separated from the permanent graphite by a lead window 4 in. thick mounted in the outer thermal shield plate. Six graphite stringers, 4 in. by 4 in., penetrate the thermal column to the inner lead window. One hole, HG-9, 9 in. by 15 in., penetrates the thermal column, the permanent graphite, and the ball graphite zone to the reactor tank wall. Two horizontal holes, 4 in. by 4 in. at 90 degrees to the column, penetrate from the north face to the south face of the reactor structure. In addition, two 12 in. by 12 in. vertical holes penetrate the thermal column from the top of the reactor. At one time, there was a second thermal column planned for the west face of the reactor. Later it was converted to a facility for testing shielding materials. Subsequently most of the features of this facility were cancelled and at present, the 6-ft-sq hole is filled with barytes concrete blocks.

Two pneumatic shuttle (rabbit) tubes are provided, HR-1 and HR-2. These are horizontal tubes of 1 in. ID which extend completely through the structure and pass within 1 in. of the active lattice.

Hydraulically operated shuttles are also provided. These are for irradiations of small samples which require times up to two weeks. The two hydraulic facilities are vertical tubes of 1 in. ID running through the bottom plug into the beryllium reflector adjacent to and east of the active lattice. In addition, tubes 1.31 in. in diameter are placed in the two south regulating rod positions in the reflector for use as experimental facilities. These hydraulic shuttles are accessible through a short west extension of the main canal in the reactor building basement.

As was previously mentioned, the top and bottom of the reactor vessel are closed by means of flat heads. The top head serves as a base for the shim-safety and regulating rod drives and includes a large viewing port that allows visual inspection of the inside of the reactor vessel during operation. The viewing port is located in the west manhole. The east manhole serves as a mount for an in-tank light.

The shim-safety rods are positioned vertically in the core by drives which are driven by electric motors. Drive rods extend from the motors through seals in the reactor top head and into the vessel. Attached to the drive rods are electromagnets which couple to the tops of the shim-safety rods.

The regulating rod drive rods also extend through seals in the top head and into the vessel and connect to the regulating rods by a conventional threaded drawbolt. Two spiders are positioned below the top head by support tubes and are supported in a lateral manner by a support ring attached to the top flange of "B" tank. These spiders support and align the regulating rod and control rod drive rods and reduce deflection caused by the water flowing against the rods and downward through the core. The reactor core and beryllium reflector components are positioned and supported by the lower support casting together with other grids, supports, etc, which are mounted and positioned by that casting. This casting also withstands the pressure drop across the reactor. It is supported by a mounting ring bolted to the lower flange of "D" tank. The reactor core components are positioned by an upper support casting and the upper grid assembly which is supported and positioned by that casting. The upper support casting is mounted on six internal lugs cast on the inside of "D" tank upper flange.

The fuel elements and core "L" pieces are supported in the core by upper and lower grids which mate with their upper and lower end boxes. The lower end box is rectangular in cross section while the upper end box is circular and incorporates a compression spring. The beryllium reflector is placed on a lower support casting. The close fit between pieces and the downward flow of water eliminates the need for any upper support.

The shim-safety rods are guided by an upper guide grid which is a part of the upper grid assembly. A lower guide grid, which is mounted on a cradle beneath the lower support casting, aligns the lower end of the shim-safety rods. Shock absorbers for these safety rods use the reactor process water for a fluid and are mounted on the vessel bottom head. The regulating rods are guided by bearings mounted in the upper and lower support castings.

Monitor tubes extend through the bottom head upward to a point a short distance inside of each fuel assembly lower end box. These tubes incorporate a thermocouple for temperature monitoring, a sample tube to draw off coolant samples and indicate fission break (if present), and a pitot tube for flow measurement. Leads and tubing from these monitor tubes run from the reactor sub-pile room into a monitoring room located in the reactor building basement.

A discharge chute is positioned under a large beryllium reflector piece on the east side of the core. This chute passes through the bottom head and makes connection to the canal discharge mechanism mounted directly below. Fuel assemblies, control and regulating rods, reflector pieces, and small experiment components are passed into the canal by use of this device.

The bottom of the reactor bottom plug is accessible from the sub-pile room. This room is divided by the canal passing through its center in an east-west direction. The floor of the sub-pile room is at the same elevation as the basement floor and access to this room is through two heavy shielding doors. One door is located on the north side, the other is on the south. Gratings over the canal parapet in the sub-pile room allow personnel to reach either side of the room for maintenance work. During the first few years of reactor operation, personnel could enter the sub-pile room during

periods when the reactor was at power. In later years radiation emanating from the experiments which penetrate the sub-pile room has prohibited access except during shutdowns.

The external appearance of the reactor structure, both on the main floor and in the basement, has altered radically from that which was seen immediately after construction. This change did not stem from alterations to the reactor, but from the installation of semi-permanent basic research tools such as the neutron chopper, crystal spectrometer, etc, and the transient major experiment installations. In addition, various balconies and platforms used for mounting control panels, etc, were installed. A wide deck was fabricated to connect the reactor top area to the third floor balcony. In the basement, a reactivity measurement facility was installed at the east end of the storage canal and several experimental equipment cubicles have been constructed to serve large loop experiments.

For purposes of orientation and quick reference, several key reactor and reactor building elevations are listed in table 8. (All elevations may be converted to sea level datum by adding 4828.26 ft.)

Table 8
Reactor and Reactor Building Elevations

Location	Elevation
Reactor building first floor	96 ft 6 in.
Reactor building basement floor	79 ft 10 in.
First balcony	107 ft 6 in.
Second balcony	120 ft 6 in.
Top of reactor structure	120 ft 6 in.
Top of canal parapet	82 ft 10 in.
Canal water level (avg)	81 ft 10 in.
Canal floor	64 ft 4 in.
Top of "A" tank extension	122 ft 0 in.

Table 8
Reactor and Reactor Building Elevations (Cont)

Location	Elevation
Top of "A" tank	120 ft 6 in.
Top of spider support ring (approx)	110 ft 13/16 in.
Top of shim-safety rod fully withdrawn	108 ft 6-7/16 in.
Top of shim-safety rod fully inserted	105 ft 11-9/16 in.
Top of upper support casting	104 ft 1-3/4 in.
Top of beryllium reflector	101 ft 7-11/16 in.
Top of fuel in fuel plate (approx)	101 ft 0 in.
Core horizontal centerline	100 ft 0 in.
Bottom of fuel in fuel plate (approx)	99 ft 0 in.
Bottom of beryllium reflector	98 ft 4-5/16 in.
Top of lower support casting	98 ft 3-15/16 in.
Top of bottom plug	91 ft 11-19/32 in.
Bottom of "E" tank	90 ft 5-3/8 in.
Bottom of bottom plug	90 ft 2-27/32 in.
Top of discharge tube valve	86 ft 3-3/8 in.

C. REACTOR BUILDING

The reactor building is designed to enclose the reactor structure and canal and to furnish space for experimental facilities on the main floor level and in the basement. In addition, two balconies above the main floor incorporate the control room, a room to house the associated electrical equipment, and operations' personnel offices.

The building was designed to operate at a positive pressure of 1-1/2 in. of water to reduce entrance of dust into the building, but due to building additions and increased usage of ventilating air, atmospheric pressure now prevails.

Building air is drawn through filters into the reactor structure and used to cool the graphite reflector. The building also incorporates precast insulated concrete slabs which are bolted to the concrete-encased structural columns to form the walls. They are designed to be blown outward in the event of a high pressure surge in the building. The flat roof is constructed of precast concrete panels laid on steel purlins covered with foam-glass insulating blocks and built-up roofing.

The main floor of the reactor building is reinforced concrete. The floor area surrounding the reactor structure, measuring 78 ft sq is 3 ft thick, and has a maximum allowable floor loading of 2500 psf. Surrounding this area and extending to the building wall, the floor is one foot thick, and has a maximum allowable floor loading of 1250 psf. The basement floor is also reinforced concrete, one foot thick, and rests on soil which has been tamped to carry a load of 2500 psf. The balcony floors are generally four inches thick reinforced concrete, and can carry a live load of 100 psf.

Each corner of the reactor building contains stairways leading from the basement. Those on the west side are extended to also serve the balconies. At the northwest corner of the building, a passenger elevator serves the basement, main floor, first balcony, and the second balcony. On the west side of the building, a freight elevator serves the reactor building basement, the reactor wing building basement, the main floor of the reactor building, and the reactor wing building.

D. REACTOR AND REACTOR STRUCTURE

The following paragraphs describe in detail the engineering design features to be found in the MTR. The previous general description has allowed the reader to become familiar with the over-all picture of this test facility. Frequent reference to the accompanying figures and photographs and to referenced engineering drawings will facilitate absorption of the material presented. Additional figures (figures 10 through 22) are presented at the end of this chapter for informational purposes.

It should be understood by the reader that the figures show only basic features in most instances. Figures are not to be construed as engineering drawings. The applicable key engineering drawings are referred to in the text or after each general topic heading and these drawings should be used when accurate detailed information is required concerning MTR design features.

Most engineering details dealing with the MTR are shown on drawings prepared by Blaw-Knox Construction Company, Oak Ridge National Laboratory, and Phillips Petroleum Company. An example of a Blaw-Knox drawing number is as follows: BKC-3150-555-1, where BKC identifies the drawing as being prepared by Blaw-Knox; 3150 is their job number assigned to MTR work; 555-1 identifies that particular drawing as covering mechanical components and also constitutes the file or identification number assigned to that individual drawing.

Oak Ridge drawing numbers are of two types: TD-1932 and DRP-392. TD indicates a drawing prepared by the Oak Ridge Technical Division and 1932 constitutes the file or identification number assigned to that particular drawing. DRP indicates a drawing prepared by Development Reactor Project personnel (Oak Ridge personnel assigned to MTR design) and 392 constitutes the drawing file and identification number. In general, Oak Ridge drawings cover only reactor tanks and internals, and Blaw-Knox drawings cover the reactor structure, reactor building, and supporting facilities. Oak Ridge TD series drawings are primarily concerned with the control rod and regulating rod drives and with the control rod and regulating rod assemblies. Most other reactor components are detailed on Oak Ridge DRP - series drawings.

Phillips Petroleum Company drawings are also identified by two drawing numbers as AED-D-1010 and MTR-E-3307. AED stands for Atomic Energy Division; D denotes a particular physical size of drawing paper used, and 1010 constitutes the file or identification number assigned to that drawing. In general, this series was used until early 1954 and may cover work done by Phillips for other areas including the Chemical Processing Plant, Central Facilities Area, and the Idaho Falls Headquarters Building. The MTR series used since that time covers work

situated in the MTR area only and separate drawing series are now used for CPP, CFA, SPERT, and other areas.

All drawings, other than those listed above, which are referred to in the following material will designate the firm which prepared the drawing, as well as the key drawing number.

1. Reactor Tanks and Internals (See figure 4)

The MTR reactor vessel is made up of five individual tanks. Construction requirements, function, and materials choice necessitated this design. The five tanks join together to form the completed vessel about 30 ft in height. The following paragraphs contain a detailed description of the reactor tanks and internals.

a. Reactor Tanks

MTR-E-3301	"A" tank extension
BKC-3150-511-1	"A" tank
DRP-132	"B" tank
DRP-133	"C" tank
DRP-190	"D" tank
BKC-3150-505-1	"E" tank

The "A" tank which is the uppermost tank is fabricated of stainless steel has an ID of 71 in., a height of 11 ft 7-3/4 in., and is permanently set in the concrete biological shield. The top flange is flush with the top of the shield structure and the top flat head, called the top plug, was originally mounted directly on this flange.

Placing reactor experiments directly in the active lattice or beryllium reflector, ie, "in-pile" experiments, called for significant numbers of nozzles opening directly into the vessel. This requirement was met in July, 1956, by the installation of an extension spool piece mounted directly on the top of "A" tank. The top plug is now mounted on this extension.

The "A" tank extension is fabricated of stainless steel and has an ID the same as "A" tank. It is 18 in. in height and incorporates 36 2-1/2 in. ID nozzles inclined 50 degrees from the vertical, equally spaced around its periphery. Blind flanges fitted with tube sealing glands allow installation of instrumentation leads connected to the in-pile experiments.

The two 24 in. inlet process water lines enter into "A" tank from the north and south.

During construction an 8 in. nozzle was attached to the top of each line at an angle of 27 degrees and 23 min from the vertical. This modification to the original design provided additional openings into the vessel and the nozzles were termed "TA-1" (north) and "TA-2" (south). They were later utilized for in-pile lead experiments, but required modification for maximum utility. The 8 in. openings did not provide sufficient area for packing gland assemblies so spool pieces were added with tops which were enlarged to 14 in. pipe size. An elbow was designed into the spool pieces to place the flange top in a horizontal position. Leads entering the vessel through these nozzles were subject to the flow of the inlet water and struts were installed to enclose them. These struts extend a short distance past the tank wall. TA-1 and TA-2 have not seen significant use since "A" tank extension was installed.

Radiation emanating from the core required the top plug to be thick and filled with lead shot. A clearance is required between the outside diameter of this plug and the tank wall for ease of handling. To prevent radiation from streaming through this annulus, a heavy inner shielding ring rests on a stainless steel ring attached to "A" tank wall. A similar ring was installed outside the tank to reduce streaming in that annular zone.

"B" tank is attached to the top face of the bottom flange of "A" tank and serves, by means of a bellows section, as an expansion joint between "A" and "E" tanks which are permanently fixed in the concrete structure. This tank is made of stainless steel, is about 2 ft 2 in. in height, has an ID of 54-1/4 in., and is located in elevation just above the top steel thermal shield plates surrounding the graphite reflector. "B", "C", and "D" tanks were designed to be removable through "A" tank in case of gasket failure, tank failure, or other reasons.

"C" tank is fabricated of aluminum, has an ID of 54-1/4 in. and a height of about 4 ft 3-1/2 in. This tank is in the upper part of the "pebble" zone of the graphite reflector.

"D" tank surrounds the reactor active lattice and beryllium reflector. It is aluminum and has the same ID as "C" and "B" tanks. Its height is about 6 ft. The wall thickness is one inch except for the middle where it is

1-1/4 in. thick in the vicinity of the HB thimble penetrations of the tank. "D" tank was designed to provide the strength required to sustain the coolant water pressure and to support the weight of the core assembly. It was made as thin as possible so that neutron absorption would be minimized.

This tank is pierced by several holes to provide experimental facilities near the active lattice. Six horizontal beam (HB) hole thimbles are at the core horizontal centerline (elevation 100 ft 0 in.) and pierce the 1-1/4 in. thickened section of the tank wall. These thimbles are extruded aluminum tubes 6 in. ID with a 5/16 in. wall thickness and are sealed at the end adjacent to the fuel assemblies by an aluminum plate which is set parallel to the lattice face. These thimbles are welded into the tank wall to receive the ends of the HB plugs. The beryllium reflector is machined to fit around these thimbles with sufficient clearance to permit an adequate flow of cooling water.

In addition to the thimbles, "D" tank is pierced by the aluminum bar containing the HR-1 and HR-2 (pneumatic rabbit) holes and by the HT-1 (horizontal through hole) facility. Sockets are welded to the outer face of "D" tank in order to give support to the inner ends of the down beam (DB), HR-3, HR-4, HG-5, HG-6, and HG-9 (horizontal graphite) liners.

The bottom tank making up the complete reactor vessel is "E" tank. This tank is about 6 ft 4-1/2 in. long and was supported initially by the structural steel which also supported "A" tank. Both "A" and "E" tanks were given a coat of tar and embedded in the concrete biological shield. Alignment of both tanks was maintained within close tolerances to assure proper functioning of the shim-safety rods and correct alignment of the beam holes liners converging on "D" tank.

b. Reactor Internals (See drawings)

DRP-265	Lower Support Casting
DRP-112	Lower Assembly Grid
DRP-116	Lower Guide Grid
DRP-115	Lower Cradle
DRP-104	Upper Support Casting
DRP-107	Upper Assembly Grid
DRP-105	Upper Guide Grid
DRP-106	Grid Spacer
DRP-326	Upper Locking Mechanism Assembly
DRP-563	Spider Guide Ring)

The basic functions of the reactor vessel internals are to furnish support to the fuel assemblies and core reflector pieces and to guide the shim-safety and regulating rods. The cooling water flow downward through the core generates approx 40 psig pressure drop. The fuel assemblies and the reflector are supported by the lower support casting. This component is, in turn, supported by a segmented stainless steel ring which is bolted to the bottom face of "D" tank lower flange. The lower support casting has small buttons and spacer bars bolted to it for the majority of reflector pieces to rest on and has circular holes to serve as receptacles for the lower end boxes of the reflector pieces (commonly called "A" pieces). The active lattice of the core is supported on a lower assembly grid which rests in a recess in the center of the lower support casting. This casting also furnishes support for the lower guide grid which is hung from the casting by the lower cradle. The lower guide grid supports the roller bearing assemblies which align the shim-safety rods. All of these components, except the bearing assemblies, are made of a high strength aluminum alloy. Stainless steel might have been chosen except for its higher neutron-absorption cross section.

As mentioned before, the beryllium reflector pieces are close-fitting and interlocking and do not require a top alignment grid. The only core components requiring top alignment are those in the active lattice. These are the fuel assemblies, the shim-safety rods, and the lattice beryllium pieces called "L" pieces. These latter items are shaped like fuel assemblies, including top and bottom end boxes, and fill the lattice positions not occupied by fuel assemblies. These positions are presently the two southern rows of the 5 by 9 lattice array. The upper grid assembly holding the top end boxes of the lattice components is made easily removable in order that the core may be conveniently refueled from above when the top plug is removed.

A means of supporting the upper grid assembly is necessary since it covers only the area of the 5 by 9 array. Support is furnished by the upper support casting. This item may be pictured as a deep rectangular box, with the top and bottom sides of the box removed, lying on its wide side, with the edges of the box falling just outside of the active lattice. This casting is supported from six lugs projecting

inward from the top flange of "D" tank. The casting also serves as a support for bearing assemblies which guide the regulating rods. The two regulating rods travel in the beryllium reflector on the north side. The two regulating rod positions on the south side of the lattice have been converted to experimental facilities.

Three sub-assemblies form the upper grid assembly located inside the upper support casting "box". The lowest is the upper assembly grid which is positioned just above the lattice fuel assemblies and "L" pieces and contains circular holes to receive the upper end boxes of these components. This grid is fastened to the bottom of the grid spacer which separates the upper assembly and upper guide grids. The top grid of the unit, called the upper guide grid, is also fastened to the grid spacer and supports the bearing assemblies used to guide the seven shim-safety rods. The upper grid assembly (upper assembly grid, the grid spacer, upper guide grid, and locking mechanism) is removed as a unit when work is done in the active lattice. A means of locking this assembly in place is provided by a linkage which is bolted to the bottom face of the upper guide grid and which positions rollers under four locking plates bolted to the north and south inside faces of the upper support casting "box". In removing the unit, a handling tool which attaches to the locking mechanism is lowered into the vessel, and in its first few inches of upward travel moves the rollers from under the locking plates. Further upward travel of the handling tool lifts the upper grid assembly from its position in the upper support casting. Finally, the assembly passes the tops of the shim-safety rods and is then free to be taken over the top of the reactor structure to canal storage.

Since the shim-safety and regulating rods are driven from the top plug, a means is required for connecting them to the drive rods which project into the vessel through the top plug. The top of the shim-safety rod has an iron armature which magnetically couples to an electromagnet attached to the bottom of the drive rod. The regulating rod connection is a simple threaded drawbolt joint. Since the flow of water in the reactor vessel would produce considerable vibration in unsupported drive rods, the rods pass through two supporting spiders. These spiders contain bearing assemblies for the seven shim-safety rods and the two regulating rods. The spiders are hung

from pipe stanchions connected to the bottom face of the top plug. When the top plug is in place, they are also supported laterally by seating on dowels which are mounted on the spider guide ring.

Another internal component installed in the reactor vessel is the discharge chute used to discharge spent fuel assemblies, control rods, experimental components, or irradiated slugs. This chute is installed below the beryllium reflector on the east side of the core and access to it is achieved by removing a large beryllium reflector piece called the "D" piece. The chute is then exposed and is unrestricted except for a shielding plug located at the bottom plug level. This plug serves to shield the hole left in the bottom plug by the discharge chute and is removed and stored in a rack on the spider guide ring prior to use of the discharge mechanism. The discharge chute extends below the bottom plug and is terminated by a hydraulically-operated full-opening valve. The discharge mechanism, described in a later section, connects to the discharge chute at this point and allows the transfer of fuel assemblies, etc., to the canal.

2. Reactor Core and Reflector (See figure 1)

The MTR reactor core and reflector may be visualized as a vertical right cylinder 54 in. in diameter, and 39-3/8 in. high. These are the dimensions of the beryllium reflector, which radially fills "D" tank. Centered in this reflector is the active lattice which is the zone that may contain fuel assemblies, control rods, or reflector pieces. This active lattice is dimensioned approx 15.7 in. north to south (five fuel assembly widths) by 28.8 in. east to west (nine fuel assembly widths).

The position of the fuel assemblies in the active lattice, as presently employed, is in the three northern rows. The seven shim-safety rod positions are in the second and fourth rows of the lattice and are separated by one fuel assembly in all directions in the second row and by beryllium "L" pieces in the fourth row. The three southern shim-safety rods which are surrounded on three sides (the north side excluded) by beryllium reflector pieces are made with a cadmium poison upper section and a beryllium lower section which is drawn into the core during operation. The rods surrounded by fuel have fuel lower sections which are drawn into the core during operation. Thus, in operation,

the reactor core and reflector are composed of the solid beryllium reflector with an off center block of fuel assemblies. This picture is somewhat modified by the addition of experimental holes and regulating rods in the reflector.

a. Fuel Assembly (See figure 2)

The MTR fuel assembly consists basically of 19 equally spaced curved fuel plates roll swaged into aluminum side plates. The fuel section assembly is 2.996 in. (from side plate to side plate) by 3.069 (from the bottom of the concave surface of one outer fuel plate to the top convex surface of the other outer fuel plate) by 24-5/8 in. long. The side plates and outer fuel plates extend 2 in. longer on each end for attachment to the upper and lower adapters or end boxes. The upper end box is a hollow aluminum casting with a circular cross section at the top and with the bottom shaped like the fuel section assembly cross section. The lower end box is also a hollow aluminum casting with the top shaped to adapt to the fuel section assembly, but the bottom is essentially square in cross section. End boxes (adapters) control fuel element positioning in the upper and lower assembly grids. The lower end box incorporates flat pads and beveled lands which are intended to keep the assembly vertical when the upper assembly grid is not in place and to establish the vertical elevation of the assembly in the core. The upper end box is circular in cross section and is fitted with a compression spring and collar. This end box fits into the upper assembly grid. The placement of the grid compresses the spring a small amount, thus holding the assemblies firmly in the lower grid and eliminating vibration that may be caused by the water flow. The end boxes are designed for minimum pressure drop and uniform flow distribution between each fuel plate and between adjacent fuel assemblies.

Cooling water flows down through the inside of the upper end box, between the fuel plates, and exits from the fuel element through the lower end box. This flow through the fuel elements constitutes the bulk of the MTR process water requirements. Water also flows between fuel assemblies to cool the outside surfaces of the outer fuel plates and side plates. The balance of the cooling water is utilized to cool the reflector and reactor experiments.

The fuel plates are fabricated by cladding a core of highly enriched U-235 aluminum alloy with aluminum. The fabrication process is called the "window-frame" technique in which a slug of the U-235 aluminum alloy is placed in a rectangular hole punched out in aluminum bar. A cladding plate is placed on each side of this "frame" and the unit heated and rolled in a controlled atmosphere to produce an elongated plate 0.050 in. thick for the inner fuel plates (17) and 0.065 in. thick for the two outer fuel plates. The alloy core is 0.020 in. thick. After X-raying, to establish the boundaries of the core alloy, the plates are trimmed to center the core and are further inspected. All plates are then rolled to establish the 5-1/2 in. radius of curvature.

The fuel plates are roll swaged into side plates, and the end boxes welded to the side plates and outer fuel plates. The end boxes are then machined to the finished dimension. All material used in the finished assembly is aluminum except for the stainless steel spring and retaining ring on the upper end box. The original 140 g elements had insufficient excess reactivity to keep up with the rapidly increasing experimental load. Therefore, it became necessary early in the operation of the MTR to redesign the fuel elements with a higher gram content. This has been done three times since operation started in 1952; 168 g, 200 g, and 250 g.

b. Shim-Safety Rod (See figure 3 and drawings MTR-D-3804, TD-1925, and MTR-E-4455)

The MTR shim-safety control functions are accomplished by the use of seven shim-safety rods. Eight shim rod positions were included in the original MTR design. One of these, referred to as the L-42 facility, was converted for experimental use in the final phase of MTR construction. The L-42 facility will be described in the section covering experimental facilities.

The three shim-safety rods in the fourth row (fourth row from extreme north side of lattice in positions L-44, L-46, and L-48) are cadmium-beryllium shim rods which are used for reactor startup and shutdown only. The remaining four shim-safety rods are the cadmium-uranium shim rods located in positions L-22, L-24, L-26, and L-28 in the second row of the active lattice. The Cd-U shim rods are

used for reactor startup and shutdown but are also used as power level "coarse" controls during reactor operation. The seven shim-safety rods can overcome an excess reactivity of about 40 percent.

In order to scram the reactor, the current to the shim-safety rods electromagnets is automatically shut off by the scram circuits. This allows the rods to drop due to gravity and the water pressure differential across the core. The rods are stopped at the end of their travel by shock absorbers mounted on the top of the bottom plug. These absorbers are simple cylinders which have small bleed holes in the bottom. They are filled with reactor coolant water. The bottoms of the shim-safety rods are tapered and fit closely with the shock absorbers. The mating parts were designed for uniform deceleration of the dropped rods.

Shim-safety rod functions discussed above do not fully explain the reason for the overall configuration of the assembled rod. The length of the unit is explained by requirements not directly associated with the functioning of the core. Since the shim rod is coupled to and positioned vertically through an electromagnet and drive rod, the position of the armature on the top of the rod was fixed by the radiation level that the magnet could tolerate. This armature is then connected, through a ball-and-socket joint to allow for minor misalignment, to an approx square aluminum tube about 52-1/2 in. long. The bottom of the aluminum tube connects to the poison section.

The poison section is about 31-1/2 in. long, is shaped externally similar to the fuel section assembly, contains cadmium sheets which are used for neutron absorption, and is held in place by rivet-type nuts (Rivnuts). The poison section is hollow, the inside dimensions conforming to those of the upper aluminum tube.

The fuel section of the shim-safety rods is similar to that of a fuel assembly, except only 14 internal fuel plates (no outer fuel plates) are used. Thus, the shim rod fuel section is completely enclosed by an aluminum section shaped like the fuel assembly.

Attached to the bottom of the fuel section is the lower section, about four feet in length,

which includes a shock absorber plunger. It is made of an approx square aluminum tube bolted to a stainless-covered, 16 in. long plunger section filled with lead. The over-all length of the shim rod totals 13 ft 7-9/16 in. While the length of tubing above the poison section was needed to keep the magnet out of the high radiation flux zone, the tubing below the fuel section placed the shock absorber section just above the bottom plug with the rod "full" inserted. The bottom plug was a convenient support for the shock absorbers.

The shim-safety rod cooling water enters slots milled in the tubing just below the magnet armature, flows downward through the poison and fuel sections, and leaves the rod through the slots in the tubing just above the shock absorber plunger section.

The poison-beryllium shim-safety rod differs from the poison-fuel rod in that a beryllium block, shaped similarly to the fuel section, replaces the fuel section. Cooling water requirements for this rod are reduced and the flow is controlled by small longitudinal holes drilled in the beryllium block.

c. Regulating Rod (See drawings AED-C-1141 and MTR-E-4100)

While the original design of the reactor core called for four regulating rods, two in the beryllium reflector directly adjacent to the active lattice on the north and two similarly on the south, only the two rods on the north are used. The two positions on the south are used for hydraulic rabbit or other experimental facility positions. During reactor operation, only one rod is in use, ie, performing the reactor "fine" control function and moving in response to signals from the reactor control circuits. The other is in the full up position with its cadmium poison section above the fuel in the core. The original MTR regulating rod has a diameter of 1-1/2 in. and is 11 ft 7-1/2 in. long. The rod is made of aluminum tubing and the 21-1/4 in. cadmium poison section is located 38-1/2 in. from the rod lower end. The cadmium is in the form of 0.040 in. thick sheets; three sheets, each covering 60 degrees of arc, are equally spaced around the periphery of a tube 1.295 in. in diameter. The cadmium is in turn protected and held in place by a tube 1-1/2 in. in diameter with walls 1/16 in. thick.

Two collars are located on the rod. One, used to lift the rod when making connection to the drive rod, is removable and is located about four feet above the top of the cadmium section. The other collar is permanently welded to the rod and is used as a stop or rod support collar. This collar rests on the top of the upper support casting when the drive rod and regulating rod have been disconnected. In 1957, it became apparent that the northeast regulating rod (RR No. 1) lower bearing, located in the top of the lower support casting, was not functioning properly perhaps due to breakage or loss of the rollers. A new combination bearing assembly and sleeve was fabricated and installed. This unit extends from the top of the upper support casting, through the reflector to the top of the lower support casting where its lower end extends completely through the malfunctioning bearing. The sleeve takes up a portion of the radial space previously used by the regulating rod, therefore a new regulating rod was built with a diameter of 1-1/4 in. The evolution produced 168 g and finally the 200 g assembly currently in use.

When the top plug is to be removed from the reactor, each regulating rod is disconnected from its drive rod by means of a drawbolt which is physically located inside of the drive rod and extends from top to bottom of that rod. The No. 2 rod facility was similarly modified in 1961. The rod in current use is constructed using a swaging technique in the poison section fabrication.

d. Active Lattice and Reflector Pieces (See drawing DRP-366, DRP-358, DRP-323, and DRP-309)

This section describes the beryllium pieces that are placed in either the active lattice or the reflector. This description concerns the pieces as they were originally designed. Modifications made to them for use as experiment component receptacles are described in the section covering experimental facilities.

The beryllium pieces occupying positions in the active lattice not occupied by fuel assemblies and shim-safety rods are termed "L" pieces and have an external shape similar

to a fuel assembly. Since the function of the "L" pieces is to extend the reflector to the south boundary of the fuel assembly group, the center portion of these pieces consists of a beryllium block. End boxes similar to those used on fuel assemblies are riveted to this block. The beryllium block is pierced by a number of longitudinal holes for the flow of cooling water.

The beryllium reflector surrounding the active lattice is 54 in. in diameter and 39-3/8 in. high. Its total weight is about 5750 lb. The reflector is assembled from a large number of individual pieces. The majority of these pieces rest on spacers on the lower support casting. Only the "A" pieces are fitted with circular lower end boxes to fit into mating holes in that casting.

The key reflector pieces are the four containing the vertical holes used by the two regulating rods on the north and the two hydraulic rabbit facilities on the south. These pieces are numbered E-1 through E-4. Large pieces are machined to fit around the HB thimbles projecting inside "D" tank. These are the "N" and "F" series pieces. Forty-three "A" pieces fill a large portion of the remainder of the reflector volume and are about 3 in. sq in cross section. Other wedge-shaped pieces, "B", "C", "J", "K", and other series, are used to complete the cylindrical shape and outline the active lattice. One unit, previously mentioned, is the "D" piece which covers the discharge chute placed below the reflector on the east side of the core. This piece is removed and stored on the reflector when discharging fuel assemblies, shim-safety rods, etc. into the canal.

The close tolerance machining of the reflector pieces allows operation of the reactor without restraining the reflector pieces by clamps, end boxes, etc. Where required, external or internal cooling of the individual pieces is accomplished by means of small diameter holes between outer surfaces or drilled longitudinally throughout individual pieces.

The reflector pieces that may be removed from the top are fitted with lifting pins which match special handling tools designed for that purpose. Those pieces moved with the greatest frequency are the "A", "B", and "D" pieces. The "L" pieces in the active lattice are handled with tools used for the fuel assemblies.

3. Top Plug (See figure 4 and drawings DRP-100 and TD-1339)

The top plug of the reactor vessel serves as a top sealing head and as a base upon which the drive mechanisms for the shim-safety and regulating rods are mounted. The plug is in the shape of a built-up flat head about 10-3/4 in. thick. The top plate, 2-1/4 in. thick, and the bottom plate, 1/2 in. thick, are separated by an exterior cylindrical shell and spacers 1 in. thick as well as by heavy wall tubes through which the drive rods pass. The space enclosed by these plates is filled with lead shot for biological shielding purposes. Except for the shot, the top plug is made of stainless steel. The bottom surface of the top plug flange seats against a square asbestos rope gasket which is recessed partially into the top flange of the "A" tank extension. Fifty-two bolts, 1-1/8 in. in diameter, are used in attaching the plug to the vessel.

In addition to the drive rod penetrations, two large manholes, 18-1/2 in. in diameter, are furnished on the east and west sides. While manhole covers constructed similarly to the top plug were originally used in these holes, one cover has since been fabricated and installed on the west side which incorporates a glass viewing port. The core can thus be viewed during reactor operation. A second manhole cover has been provided with an underwater light to supply additional light inside the reactor during low power operation.

The top plug incorporates two electric cable junction boxes mounted on the drive platform, one on the north and the other on the south. These boxes include multi-contact receptacles, one for each shim-safety and regulating rod. When the top plug is in place on the reactor, the electrical connections and signal connections are brought to the plug on hinged supporting arms called "semaphores". For removal of the top plug to dry dock, the cables are disconnected at the junction boxes and the "semaphores" are dropped to a vertical position on the sides of the north and south reactor instrument cubicles. Here they may be connected to cables which serve the top plug while in dry dock.

Four bases for the pipe stanchions used to support the drive mechanism platform are fabricated on the top surface of the top plug. Similarly, four lugs for connection to the lifting bail are also included. The building

crane lifts the top plug by means of the lifting bail.

Attached to the bottom of the plug are the four stanchions which support the spider assembly. When the "A" tank extension was installed on the reactor vessel, this increased the distance from the top plug to the core. Extensions were added to the shim-safety rod, drive rods, the regulating rods, and to the spider support stanchions. The extension to the stanchions maintained the distance from the bottom spider to the core as originally designed but increased the unsupported length of the drive rods. This length might have resulted in increased vibration in the rods due to the water flow so an intermediate spider similar to the original was fabricated and installed at a point between the top plug and original spider.

a. Shim-Safety Rod Drive (See figure 4 and drawing MTR-E-4573)

The function of the shim-safety rods in reactor operation has been discussed in a preceding section. Since the shim-safety rods in the MTR are made with a poison upper section and a lower fuel section and were designed for vertical travel, a drive was designed to move these rods at a controlled (approx 5 in. per min) rate of speed. The drive rods are magnetically coupled to the top of the shim-safety rods during reactor operation. In the case where the reactor must be shut down quickly, the current to the electromagnet is cut off allowing the shim-safety rods to fall into the core. Only the drive rod and electromagnet operate inside of the reactor vessel. All other components are located above the reactor top plug on the drive platform.

The 1-1/2 in. diameter drive rod extending through the reactor top plug is connected at its upper end to an externally threaded rod. This threaded rod is moved vertically by a rotating worm gear which is held in a fixed vertical position in a cast-iron housing and is internally threaded to match the drive rod. The worm gear is, in turn, rotated by an electric motor-driven worm. The threaded rod thus moves only in a vertical direction carrying with it the electromagnet and the shim-safety rod.

Other features of the drive mechanism include limit switches which are actuated by a projection on the top of the threaded rod and

are mounted in a housing above the worm gear housing. The entire drive rod is hollow and carries a multiconductor cable to transmit current to the electromagnet. These wires terminate at a fixed terminal mounted on top of the drive rod. Since the top of the drive rod moves up and down inside of a fixed housing, coiled cords, similar to those used on telephones, are used to carry the electrical connections from the terminal lug to the outside of the drive housing. This cable emerges at the top of the drive housing and is connected to junction boxes mounted on the top plug platform.

Two methods are used to indicate shim-safety rod position in the core. A direct mechanical connection is accomplished by means of a flexible shaft which is geared to the drive motor and is connected to a decade counter. This counter is similar to those used to indicate mileage on an automobile speedometer and is mounted on the top plug platform. Another method was necessary to indicate to the console operator the rod position. An electric selsyn geared to the drive motor, drives a slave selsyn dial and pointer combination which is mounted on the control console. This indicator is only a rough indication of level and actual leveling of the rods is accomplished by use of the speedometers at the top plug.

A packing gland seals the drive rod housing so as to eliminate contamination of the process water by the lubricating oil in the threaded worm gear housing. This gland is mounted just above the top surface of the top plug, leaving the drive rod exposed below that point. The drive rod in turn passes through a seal in the reactor top plug. Slight leakage of contaminated process water through this seal is eliminated by the addition of an auxiliary upper seal and the introduction of pure demineralized water into the zone between the two seals. This water is at a pressure slightly greater than that of the reactor vessel so any water leakage is into the vessel. The slight leakage out of the upper seal is drained by suitable piping.

The original electromagnet used in reactor operation was a conventional bipolar type designed to lift a 500 lb load with 100 ma current and to drop a 600 lb load held with 140 ma current in 15 milliseconds or less. This quick release time reduced the delay in

scramming the reactor from the initiation of the scram signal. The original magnet design housed the coils in a rectangular stainless steel can which was sealed at the top by numerous small bolts and a polyethylene gasket. Maintenance on this magnet was excessive with work being required on some magnets nearly every normal reactor shutdown. In 1957, the magnet was redesigned utilizing a cylindrical shape. The housing body is made of magnet quality iron as is the central core piece. Filling the annular space is the wire coil. This housing is sealed by a threaded top cap and a single O-ring. This magnet design has been very successful in greatly reducing reactor down time due to magnet maintenance. The magnet housing is insulated from the drive rod and forms a part of an electrical circuit used to indicate contact with the shim-safety rod.

b. Regulating Rod Drive (See figure 4 and drawing TD-1384)

While the shim-safety rod is used to control the reactor power level on a "coarse" scale, a regulating rod is used to provide rapid "fine" control. The drive mechanism for the regulating rods must move a much smaller combined weight of rod and drive rod than that of a shim-safety rod, but at a much higher rate of speed.

The regulating rod is connected to its drive rod by a drawbolt that passes through the drive mechanism and the drive rod. The end of this bolt screws into a 1/2 in. female thread on the top of the regulating rod. The drive rod passes vertically upward through a reactor top plug seal similar to those used on the shim-safety drive rods.

The drive rod makes connection on its top end with a rack which is driven by a gear. The gear is connected in turn, through a single reduction gear, to a one horse-power direct current drive motor. This motor is controlled automatically by the reactor control circuits.

Like the shim-safety rod drives, a regulating rod position indicator is included at the console. A selsyn, geared to the rod drive, transmits to a selsyn mounted on the control console. This is connected to a dial-pointer type position indicator similar to the shim-safety rod indicators.

Two shock absorbers are provided in the drive mechanism to absorb the energy of the moving rod, gears, and motor in the event of failure of the control circuits. One shock absorber is mounted beneath the rackhousing, the other above. Since the drive rod passes through the lower shock absorber, the design of the absorber utilizes a concentric plunger operating in an oil-filled cylinder. The movement of the oil through a tapered annulus effects the shock absorbing action. Springs return the plunger to the original position after the rod is raised. The design of the upper shock absorber is similar to the lower.

4. Bottom Plug (See figure 4 and drawing DRP-120)

The reactor vessel bottom plug is made similar to the top plug. The bottom sheet is 2-1/2 in. stock stainless steel, the top is 1-1/4 in. thick, and the total thickness is 20-1/2 in. The intervening space is filled with lead shot for shielding purposes. The top surface of the plug flange is grooved to fit an aluminum ring gasket and bolts on the lower flange of "E" tank.

The discharge chute placed below the beryllium reflector passes through the bottom plug and is held in place by the discharge chute extension which is bolted on the plug lower face. The top of the discharge chute in the vessel rests in a recess in the bottom of the lower support casting. Thus, the discharge chute might be removed downward through the bottom plug.

As was mentioned before, the shim-safety rod shock absorbers are mounted on the top surface of the bottom plug. Small diameter plugs are installed beneath each shock absorber body in the bottom plug, and include a tube to continuously flow water through the absorber into the vessel. By measuring the individual flow of water into the absorber bodies, the reactor operator can tell if the rods are seated in the absorbers. The piping to these locations originates in the sub-pile room located in the basement.

Thirty-seven monitor tubes are installed in the bottom plug and extend vertically upward to a point inside of the individual fuel assembly lower end boxes. The tubes incorporate: a thermocouple, to measure the fuel assembly coolant temperature; a pitot tube, to

measure the coolant flow; and a sample tube, which is used to draw off samples of the coolant. These samples are measured for radioactivity, for any excess activity might indicate a rupture in that particular fuel assembly fuel plate cladding. Piping for these monitor tubes also runs to the monitor room.

Other penetrations in the bottom plug match the VH-1 through VH-6 holes in the reflector. **The VH-1 through VH-4 positions are used for experimental facilities; the VH-5 and VH-6 are used for the two north regulating rods.**

Located below the bottom plug, and mounted to the ceiling of the sub-pile room, are two barytes shielding doors. These doors were designed to provide the additional shielding required for personnel access into the sub-pile room during reactor operation. During reactor shutdown, the doors may be rolled away, ie, to the north and south, to expose the bottom of the bottom plug and its associated piping. The doors are divided on the east-west centerline and include slots for passage of hydraulic rabbit piping, the discharge chute, etc.

5. Graphite Reflector (See figures 5 and 6)

The function of the graphite reflector surrounding the reactor and vessel is to thermalize and reflect neutrons back into the core active lattice and to contain thermalized neutrons in a zone large enough to allow the placement of numerous experimental facilities. The reflector extends vertically from an elevation near the top of "E" tank, past "D" tank and covers about the lower two-thirds of "C" tank, for a total height of 9 ft 4 in. The horizontal dimensions are 12 ft north to south by 15 ft east to west. Surrounding this graphite are the steel thermal shields which are described in another section.

A graphite pebble zone extends from the reactor tank walls out to the inside edge of the permanent graphite. This zone is 7 ft 4 in. sq and is filled with approx 700,000 1 in. diameter graphite balls. The shape of the graphite in this zone was chosen for several reasons. Thermal heating and radiation effects expand graphite necessitating a design that allowed the graphite to expand vertically. The graphite is exposed to higher radiation fields, since it is nearest the reactor. The small graphite balls provide a relatively free path for air flow and large surface areas for

FIGURE 5.
Reactor structure (vertical section through
east-west centerline looking north)

FIGURE 6.
Reactor structure (vertical section through
north-south centerline looking west)

efficient cooling. Further, these balls may be drained through pipes to storage bins allowing either the replacement of the balls or the replacement of the "B", "C", or "D" tanks. Some experimental facility liners penetrate the ball graphite zone.

Surrounding the graphite ball, or pebble zone, is the solid graphite reflector. This mass is composed primarily of 4 in. by 4 in. graphite bars which extend from the pebble zone outward to the inner face of the steel thermal shield. These bars are supported on steel rails which are in turn precisely leveled by jacks resting on the lower thermal shield plate. This reflector is pierced by numerous experimental facility holes. Precision machining was required to produce a completed assembly that would match all of the liners, etc. The weight of installed graphite balls is 19 tons and that of the bars is 74-1/2 tons.

The cooling air enters the graphite reflector from the space between the lower thermal shield plates, flows vertically upward, and then out exit air ducts embedded in the concrete biological shield.

6. Biological Shield (See figures 5 and 6)

The biological shield surrounding the reactor vessel and the graphite reflector is, as its name implies, a barrier placed between the high radiation flux surrounding the reactor core and the areas to be inhabited by personnel. This high density (approx 3.2 Spec. Gravity) barytes concrete shield extends from the top of "A" tank to a point below the basement floor. The horizontal dimensions above the main floor of the reactor building are 32 ft 6 in. north to south by 34 ft east to west. In the basement, the shield measures 35 ft north to south by 36 ft 6 in. east to west. Concrete piers extending from below the basement floor to bedrock support this structure.

The external surfaces of the biological shield are formed by steel plates 1/2 in. thick above the first floor and 3/4 in. thick in the basement. The cubicles and face plates of the beam holes and other facilities are welded integral with these forms, which supply a convenient and substantial support. The permanent facility liners extend from the

face plates to an inner steel form surrounding the thermal shield. The experimental facility hole liners extending through the thermal shield and the graphite reflector are fabricated of aluminum and could be replaced.

The reactor tanks "A" and "E" were supported by structural steel which also supported the thermal shield plates, the coolant piping, exit air ducts, etc. These tanks became an integral part of the reactor structure when the high density aggregate was placed and the fluid grout piped into the aggregate to form the solid shield.

Heavy steel plates form a thermal shield surrounding the graphite reflector to reduce the heating of the biological shield due to radiation from the core. This shield consists of two 4-in. thick plates placed on all six sides of the reflector. The inner plates are separated from the graphite by a 1/2 in. gap filled with soft asbestos, and from the outer plates by a 3 in. air gap. The outer side plates are separated from the concrete by a steel form. The outer top and bottom plates contact the concrete. Air ducts running from filters located on all four faces of the biological shield near the reactor structure top furnish cooling air to the thermal shield. The air flow enters the space between the side plates, flows downward into the space between the two bottom plates and turns upward to cool the graphite reflector. The air is collected in a space below the top shields and above the graphite and flows into ducts which carry it to an external stack. (See figure 7.)

7. Experimental Facilities

The experimental facilities included in the the MTR are numerous and of a varied nature. These range from relatively large high flux beam holes placed directly adjacent to the reactor active lattice to both large and small facilities placed in the graphite reflector. Specialized facilities include those for pneumatic rabbits, etc. The demand for experimental space in the highest flux available initiated the modification of the active lattice and reflector areas inside the reactor vessel. Each group of these facilities is listed in table 9. Supplemental descriptions are included in the paragraphs following table 9.

Table 9
MTR Experimental Facilities

Facility Designation	Size	Penetration	General Description
HB (horizontal beam holes):			
HB-1	6 in. ID	To active section edge on reactor horizontal centerline	Horizontal approach on line 27 degrees west of north, intersecting edge of active section 10-1/4 in. west of reactor centerline at elevation 100 ft 0 in.
HB-2	6 in. ID (8 in. to tank)	8 in. ID to tank wall, 6 in. ID to active section edge on reactor horizontal centerline	Horizontal approach from north on north-south centerline of reactor at elevation 100 ft 0 in.
HB-3	6 in. ID	To active section edge on reactor horizontal centerline	Horizontal approach on line 27 degrees east of north, intersecting edge of active section 10-1/4 in. east of reactor centerline at elevation 100 ft 0 in.
HB-4	6 in. ID	To active section edge on reactor horizontal centerline	Horizontal approach on line 27 degrees west of south, intersecting edge of active section 10-1/4 in. west of reactor centerline at elevation 100 ft 0 in.
HB-5	6 in. ID (8 in. to tank)	8 in. ID to tank wall, 6 in. ID to active section edge on reactor horizontal centerline	Horizontal approach from south on north-south centerline of reactor at elevation 100 ft 0 in.
HB-6	6 in. ID	To active section edge on reactor horizontal centerline	Horizontal approach on line 27 degrees east of south, intersecting edge of active section 10-1/4 in. east of reactor centerline at elevation 100 ft. 0 in.
DB (down-beam hole):			
DB-1	6 in. ID	Through graphite to reactor tank wall with a 2 in. ID can inside tank from tank wall to active section edge	Approach from northwest
DB-2			Approach from north
DB-3			Approach from northeast
DB-4			Approach from southwest
DB-5			Approach from south
DB-6			Approach from southeast

Table 9

MTR Experimental Facilities (Continued)

Facility Designation	Size	Penetration	General Description
VH (vertical hydraulic rabbit holes): VH-1	1 in. ID	Reflector	Vertical facility running height of reflector at point 16.707 in. east, 6.070 in. south of reactor centerline. Specimens charged in basement for delivery by water to exposure point. Specimen cooled by water discharging past capsule container into reactor tank just above reflector. Specimens returned by reactor water pressure.
VH-2	1 in. ID	Reflector	Same as VH-1, located 16.707 in. east, 6.070 in. north of reactor centerline.
VH-3 and VH-4	approx 1-5/16 in. ID	Reflector	Vertical hydraulics, similar to VH-1 and VH-2, occupying spare regulating rod spaces in reflector. Located 5-1/4 in. east or west and 9-9/16 in. south of reactor centerlines.
HR (horizontal pneumatic rabbit holes): HR-1	1 in. ID	Reflector	North-south horizontal pneumatic tube through reactor structure and tank 1 ft 3-7/16 in. east of reactor centerline. Enters structure at elevation 99 ft 5-5/16 in. and makes a 4 ft radius Z bend to pass through tank at elevation 99 ft 2-5/16 in.
HR-2	1 in. ID	Reflector	North-south horizontal pneumatic tube through reactor structure and tank 1 ft 3-7/16 in. east of reactor centerline. Enters structure at elevation 98 ft 9-5/16 in. and makes a 4 ft radius Z bend to pass through tank at elevation 99 ft 0-5/16 in.
HR-3	4 in. ID	To reactor tank	Horizontal holes for oriented samples approaching reactor radially from west face of structure on line 30 degrees south of west at elevation 100 ft 0 in. extending inward to reactor tank.

Table 9
MTR Experimental Facilities (Continued)

Facility Designation	Size	Penetration	General Description
HR-4	4 in. ID	To reactor tank	Horizontal holes for oriented samples, approaching reactor radially from west face of structure on line 30 degrees north of west at elevation 100 ft 0 in. extending inward to reactor tank.
HT (horizontal through holes): HT-1	4-5/8 in. sq in-side	Reflector	Through hole from side to side of reactor structure, through reactor tank adjacent to west end of active section 1 ft 5-5/8 in. from reactor centerline at elevation 99 ft 3-3/4 in. (dimensions to centerline).
HI (horizontal instrument holes): HI-2	10-3/4 in. ID	Graphite	Horizontal through reactor structure, running east-west, 4 ft 6 in. north of pile centerline at elevation 104 ft 3 in.
HI-3	10-3/4 in. ID	Graphite	Horizontal through reactor structure, running east-west, 4 ft 6 in. south of pile centerline at elevation 104 ft 3 in.
HG (horizontal graphite holes): HG-1	8 in. ID	Graphite	Through reactor structure, running north-south, 5 ft 3 in. west of reactor centerline at elevation 101 ft 6 in.
HG-2	8 in. ID	Graphite	Through reactor structure, running north-south 5 ft 3 in. west of reactor centerline at elevation 98 ft 6 in.
HG-3	4 in. ID	Graphite	Through reactor structure, running north-south 5 ft 1-1/2 in. east of reactor centerline at elevation 101 ft 2 in.
HG-4	4 in. ID	Graphite	Through reactor structure, running north-south 5 ft 1-1/2 in. east of reactor centerline at elevation 98 ft 10 in.

Table 9

MTR Experimental Facilities (Continued)

Facility Designation	Size	Penetration	General Description
HG-5	6 in. ID	Graphite	Horizontal, approaching reactor radially from east face of structure on line 30 degrees north of east at elevation 100 ft 0 in. extending inward to reactor tank.
HG-6	6 in. ID	Graphite	Horizontal, approaching reactor radially from east face of structure on line 30 degrees south of east at elevation 100 ft 0 in. extending inward to reactor tank.
HG-9	10 x 16 in.	Through graphite to tank wall. Rectangular long axis is vertical	Horizontal hole to reactor tank, 1-1/2 in. north of reactor centerline and at elevation 99 ft 9-11/16 in. The centerline of the facility is parallel to the east-west centerline of the reactor. Hole located on east side of reactor.
GT (gamma thimble): GT-1	6 in. ID	Discharge water line	Vertical thimble from top of structure in south-west discharge water line for gamma exposures. Located 7 ft west of north-south centerline and 8 ft 6 in. south of east-west centerline. Extends to elevation 109 ft 3 in.
GT-2	6 in. ID	Discharge water line	Vertical thimble in north east discharge water line. Located 7 ft east of north-south centerline and 8 ft 6 in. north of east-west centerline. Extends to elevation 109 ft 3 in.
T2H (thermal column horizontal): T-2	6 ft sq	To thermal shield	6-ft-sq inner end, expanding to approx 6 ft 4 in. at outer end, east side of reactor on east-west centerline.
T2H-1	4 in. sq	T-2	Horizontal stringer through reactor structure, running north-south 13 ft east of reactor centerline at elevation 101 ft 4 in.

Table 9

MTR Experimental Facilities (Continued)

Facility Designation	Size	Penetration	General Description
T2H-2	4 in. sq	T-2	Horizontal stringer through reactor structure, running north-south 13 ft east of reactor centerline at elevation 98 ft 8 in.
T2H-3	4 in. sq	To thermal shield	Through thermal column horizontally to thermal shield. 1 ft 8 in. south of reactor centerline at elevation 101 ft 10 in.
T2H-4	4 in. sq	To thermal shield	Through thermal column horizontally to thermal shield. 1 ft 11 in. north of reactor centerline at elevation 101 ft 10 in.
T2H-5	4 in. sq	To thermal shield	Through thermal column horizontally to thermal shield. 1 ft 8 in. south of reactor centerline at elevation 100 ft 0 in.
T2H-6	4 in. sq	To thermal shield	Through thermal column horizontally to thermal shield. 1 ft 11 in. north of reactor centerline at elevation 100 ft 0 in.
T2H-7	4 in. sq	To thermal shield	Through thermal column horizontally to thermal shield. 1 ft 8 in. south of reactor centerline at elevation 98 ft 2 in.
T2H-8	4 in. sq	To thermal shield	Through thermal column horizontally to thermal shield. 1 ft 11 in. north of reactor centerline at elevation 98 ft 2 in.
T2V (thermal column vertical): T2V-1	1 ft sq	T-2	Vertical stringer, extending downward through the thermal column from top of structure, located 10 ft 3 in. east of reactor centerline, and 1 ft 1-1/2 in. north of reactor centerline.

Table 9

MTR Experimental Facilities (Continued)

Facility Designation	Size	Penetration	General Description
T2V-2	1 ft sq	T-2	Vertical stringer, extending downward through thermal column from top of structure, located 10 ft 3 in. east of reactor centerline and 10-1/2 in. south of reactor centerline.
VN (vertical instrument holes):			
VN-1	3 in. ID	Graphite pebble zone	Straight slanting holes, the centerlines of which form the frustum of a cone, 8 ft 0 in. in diameter at the top of the reactor structure and 5 ft 4 in. in diameter at elevation 100 ft 5 in. where the holes terminate. Centerline of frustum is coincident with reactor centerline.
VN-2			
VN-3			
VN-4			
VN-5			
VN-6			
VG (vertical graphite holes):			
VG-1	4 in. ID	Graphite pebble zone N-W side	Vertical straight holes from top of reactor structure through pebble zone to bottom of graphite reflector 3 ft 1-1/2 in. from north-south and east-west centerlines.
VG-3		Graphite pebble zone N-E side	
VG-5	4 in. ID	Graphite pebble zone S-E side	
VG-6	4 in. ID	Graphite pebble zone S-W side	
VG-2	4 in. ID	Graphite S-W side	Vertical through hole from top of reactor structure into sub-pile room 4 ft 2 in. from north-south centerline, 1 ft 4 in. from east-west centerline.
VG-4	4 in. ID	Graphite N-E side	Vertical through hole from top of reactor structure into sub-pile room, 4 ft 2 in. from north-south centerline, 1 ft 6 in. from east-west centerline.

Table 9
MTR Experimental Facilities (Continued)

Facility Designation	Size	Penetration	General Description
VG-7 8 10 to 20	2-1/2 in. ID	Graphite pebble zone	Straight slanting holes, the centerlines of which form a frustum of a cone with a vertical axis coincident with the reactor-tank centerline. The holes commence at the top of the structure, the frustum this point being 8 ft 0 in. in diameter, and terminate at elevation 98 ft 4 in. where the frustum is 5 ft 8 in. in diameter.
VG-9	10 in. sq	Graphite to HG-9	Vertical access to HG-9 hole located 4 ft 5 in. east of north-south centerline and 1-1/2 in. north of east-west centerline.
VG-23 to VG-62	2 in. ID	Graphite	Vertical stringers from top of structure through permanent graphite.
VC (vertical holes): VC-1 to VC-13	2 in. ID	Concrete	Vertical exploratory holes from top of structure through concrete to elevation 92 ft 0 in.
SF (shielding facility)	6 ft sq	To thermal shield	Horizontal facility, west side of reactor on east-west centerline.
VT-2 (vertical through holes)	2-1/2 in. ID	Through active section	Vertical through hole occupying any spare shimrod space in active section.

FIGURE 7.
Reactor air flow schematic

a. Horizontal Beam Holes (See figure 8 and drawing BKC-3150-524-1)

Experimental holes 6 in. in diameter placed directly adjacent to the active lattice are furnished by the horizontal beam hole facilities, labeled HB-1 through HB-6. These holes penetrate "D" tank wall and the beryllium reflector and are isolated from the coolant water by aluminum thimbles welded into the vessel. Aluminum liners extend from the vessel wall through the graphite and thermal shields. High temperature cast steel liners (meehanite) extend from the outer face of the inside form plate to the cubicles recessed in the face of the reactor structure. These liners are wound with coolant water tubing to carry off radiation heat induced in these heavy castings.

Dummy plugs are used to fill these holes during reactor operation when the facilities are not used for experiments. Plugs and liners are stepped to eliminate radiation streaming through the necessary clearance annuli between the plugs and liners. Construction materials of the dummy plugs approximate those materials used in the various zones through which the plugs pass. The plug tips are made of beryllium which is aluminum jacketed and water cooled. Located outboard of the tips is a graphite section, a solid steel section to approximate the thermal shields, and finally a barytes concrete-filled section, all of which are penetrated by two concentric tubes. Cooling water enters the inner tube and proceeds to a sealed plenum chamber on the rear end of the beryllium section. From here water is distributed through the beryllium tip in a series of longitudinal holes and emerges at the front end of the beryllium section. Cooling water then sweeps across the face of the beryllium section and returns via an annulus between the beryllium and the aluminum shell to a second plenum which feeds the outer or return tubing. Cooling water is brought to the dummy plug from shielded valve cubicles via a large pipe conduit grouted in the reactor structure between the valve cubicle and the outboard end of the meehanite liner.

The meehanite liner is enlarged in diameter for a distance inside the biological shield outer face. Installed in this section are three plugs or doors. Located just outside the outer end of the plug is an

additional 8 in. thick solid steel outer shielding plug with a diameter to match the enlarged liner. Located inside of this outer shielding plug are two other components, the outer one a concrete-filled shielding plug, fixed in position, with a hole that the beam hole plug passes through. Located inside of it, and filling the remainder of the enlarged section, is a lead-filled steel radiation door. This door also incorporates an off center hole to accommodate the plug, and the door may be rotated when the plug is removed to effectively shut off radiation from the empty beam hole. The reactor is, of necessity, shut down during plug removal or insertion operation.

Air flow in the liner spaces is into the graphite reflector where it is carried along with the main coolant air flow.

HB-2 and HB-5 face the active lattice north and south faces, respectively, on the north-south centerline. Thus, the plug tips are squared off. The other four plugs approach the active lattice at an angle of 27 degrees from the north-south line. These plug tips are slanted a matching amount.

(1) Research Facilities: While the primary use of the horizontal beam holes was for irradiation of components located in the plug tips, these facilities have use as neutron beam sources. These neutrons are used in four basic research tools.

(a) Fast Chopper: The MTR fast chopper was constructed to utilize the high neutron flux available in the MTR for the determination of the various cross sections of numerous isotopes of elements. The source of neutrons is the HB-6 horizontal beam hole.

Two shutters are provided for controlling the reactor beam. The first consists of 3 ft of steel which can be placed in the beam path by a horizontal movement of the tapered steel radiation door section. The second shutter is a 13 ft tank which is filled with helium to allow the beam to emerge or which is filled with water to shut the beam off completely. The steel radiation door offers sufficient protection to allow personnel to work in the vicinity of the chopper for short periods of time.

FIGURE 8.
HB-2 beam hole liner and plug

The chopper rotor, which spins around a vertical axis at a maximum speed of 10,000 rpm, serves as a high-speed shutter to break up the neutron beam into bursts of neutrons. A light pulse timing system is used to indicate the time neutrons leave the chopper and trigger the 1024 channel analyzer. The neutrons stream down the drift tube and are detected with BF_3 counters. The pulses from the BF_3 detectors are recorded in the analyzer during the time T to $T + 1024 \Delta J$ in 1024 equal time channels, where T is the time that has elapsed since the neutron burst occurred until the system starts recording neutron counts, and ΔJ is the width of each information storage channel. The light pulse which accompanies the neutron burst starts the delay circuit which determines T . Knowing the flight time of the neutrons, one can determine their energy, $E = (m/2) (S/t)^2$. By this method of obtaining monoenergetic neutrons, one can measure the effect of neutrons on different samples as a function of neutron energy.

(b) Crystal Spectrometer

The crystal spectrometer is an apparatus for producing a beam of neutrons of one energy. The neutron has wave properties and the atoms in a crystal are arranged in an orderly array thus making such a device possible. When a neutron beam strikes the crystal, the atoms of the crystal act as scattering centers. The scattered waves interfere with one another, reinforcing or cancelling each other according to their relative phases. The specific condition under which these interfering waves add together to form a neutron beam is described by the Bragg Law:

$$\lambda = 2d \sin \theta$$

When a beam of neutrons of wave length λ strikes a set of crystal planes spaced a distance d apart, at an angle θ , the beam will be reflected at an angle θ equal to the angle of incidence. This beam is called the Bragg beam. If the original beam contains neutrons of a great assortment of energies, only those in a narrow range of energies will satisfy the Bragg condition for a particular crystal spacing and angle of incidence. This is the way that the crystal spectrometer produces a monoenergetic neutron beam from the beam of all energies produced by the reactor. The width of this range of energies

depends upon the beam collimation, the orderliness ("mosaic structure") of the crystal, and the crystal spacing. These three factors determine the "resolution" of the instrument.

A complication is introduced by the fact that the Bragg condition is satisfied by neutrons whose wave length is an integral multiple of the desired wave length. One of the biggest difficulties involved in the operation of a crystal spectrometer lies in the effects caused by these "higher order" neutrons.

The production of a monoenergetic beam and the ability to vary this energy makes possible the study of the interactions of neutrons with nuclei at known neutron energies. The energy is varied by changing the angle θ and/or the crystal spacing d . The spectrometer arm is coupled to the crystal holder so that the neutron counters will follow the Bragg beam as the Bragg angle is changed to vary the energy.

(c) Neutron Velocity Selector

The Solid State Section, Nuclear Physics Branch, MTR Technical, uses the HG-6 hole as a source of neutrons in inelastic neutron scattering experiments. The principle of the experiment is to produce bursts of monoenergetic neutrons, scatter these neutrons from samples, and measure, by time-of-flight methods, the neutron energy change produced by the sample. The velocity selector, which consists of 4 thermal neutron choppers spinning in phase at 5000 rpm, is located under the shielding between the reactor and the center of the scattering chamber. The motors are water cooled (controlled by the flow meters near the thermal column) and driven from power supplies located in the racks. The sample and counters are inside the circular shielded scattering room. The time analyzer and other electronics are located in the racks near the east reactor building wall. All power (except for the velocity selector vacuum pump) is distributed from these racks. Several sets of relays located on these panels are used for partial and complete power scrams.

(d) Cold Neutron Facility

The equipment assembled at the HG-5

beam holes is called the MTR cold neutron facility. This equipment is used to make inelastic neutron scattering measurements using an initial beam of beryllium filtered neutrons. The beam of neutrons from the reactor is filtered through two beryllium filters each 16 in. long, which allows 62 percent of the neutrons below the 0.005 eV to pass, while allowing only one in about 10^8 of the neutrons with energies above this value to pass. For the beryllium to act as such an efficient filter, it must be kept at liquid nitrogen temperature (-196°C). Both beryllium filters are contained in triple walled containers such that the beryllium is surrounded by liquid nitrogen and the liquid nitrogen is separated from the outer wall by a vacuum. One filter is located 3 ft inside the reactor shielding and the second filter is located 2 ft outside the reactor shielding. This allows the HG-5 radiation door to be used to stop the beam when experimental changes are needed.

After the beam of "cold" neutrons passes through the filters, it is chopped into bursts by a slow neutron chopper located about 4 ft from the reactor shielding. These bursts of neutrons are scattered by a sample placed immediately after the chopper, and the scattered neutrons are detected by a bank of counters at 90 degrees to the beam and about 1-3/4 meters from the beam. Some of the neutrons that are scattered by the sample gain energy and this energy is measured by the time-of-flight method. A 100 channel time analyzer does this time sorting.

This facility is being used to make survey measurements on possible reactor moderating materials and to measure dispersion curves of single crystals.

(e) HR-4 Neutron Flux Facility

A general purpose neutron beam facility has been installed into the HR-4 beam port of the MTR. The plug which fits into the HR-4 liner has a 3 in. diameter hole leading up to the reactor tank. The radiation door, located at the reactor shielding face, is a revolving, cylindrical, boral clad, lead and steel shield, 1 ft thick, through which are 1/4 in., 1/2 in., 1 in., 2 in. and 3 in. diameter holes. Neutron beams of these sizes may be obtained by revolving the door so that the appropriate hole lines up with the axis of the

3 in. hole through the liner plug. Shielding walls of steel encased borated paraffin enclose a volume about the exit port of about 6 ft along the beam by 10 ft by 7 ft high. The neutron beam exits this shielding cubicle through a 1 ft diameter hole in the back shielding wall and enters a beam catcher containing lead, lithium carbonate, and a cadmium lined water bath of lithium nitrate. A gamma-ray-attenuating plug is placed inside the liner against the reactor tank. This plug is a water cooled cylinder of bismuth metal which affords effective gamma attenuation with a minimum loss of neutron intensity.

The facility is equipped with a "high-intensity, low resolution", crystal spectrometer installed in the shield cubicle. This spectrometer produces a neutron beam of known energy containing little gamma flux for experimental purposes.

The experimental program designed about this facility includes studies of the fission process in heavy nuclei, studies of nuclear structure by measurements of the gamma spectrum emitted following neutron capture in various nuclides, and development of special nuclear particles detectors for reactor control and health physics applications.

b. Down Beam Holes (See drawing BKC-3150-524-1)

Located directly above the HB holes and the reactor first level balconies are six down beam hole facilities designed similar to the HB facilities. DB-2 and 5 are inclined downward at an angle of 30 degrees from horizontal toward a point 9-3/4 in. above the reactor horizontal centerline. In the DB-1,3,4, and 6 facilities, this angle is 27 degrees 13 min. The basic difference is that the DB-plug tips do not penetrate the vessel wall, but stop just short of it. The plug tips are 5-1/2 in. in diameter and are composed of graphite jacketed with aluminum. This tip matches the graphite reflector pebble zone in composition since it is physically located in that zone. Neutrons are directed at the tip from the active lattice by 2 in. diameter sealed tubes which pass through the beryllium reflector.

The liners are designed similar to the HG facilities and include radiation doors and inner and outer shielding plugs.

The relatively large expense of design and fabrication of experiments to be placed in these facilities, coupled with the demand for irradiation space with higher fluxes, has resulted in slight use of the DB holes. In addition, a shielding coffin for use with these holes was not included in the equipment originally supplied with the reactor. The cost of such a coffin would have to be absorbed in the total experiment cost.

c. VG Holes (See drawings BKC-3150-541-1, 555-1, 543-1 and 557-1)

As the term VG implies, these facility holes are positioned vertically in the graphite reflector and extend to the reactor top. The holes pass through the concrete biological shield where they are fitted with stepped steel liners and extend into either the solid graphite reflector or the pebble zone. In the pebble zone, the liner is made of fluted aluminum tubing, perforated to allow flow of cooling air. Liners are not used in the permanent graphite VG facilities. The VG plugs, used to fill the holes in the absence of experiments, are made with a high-density concrete-filled steel upper section and graphite lower sections. Air leakage, if any, flows from the reactor top, between the upper section plug and the steel liner, and into the plenum above the graphite reflector.

d. Other External Hole Facilities (See drawings BKC-3150-524-1, 519-1, 544-1, 546-1, 550-1, 515-1, 554-1, and 514-1)

The HR-3 and HR-4 facilities are horizontal beam holes terminating at "D" tank wall and are located on the west face of the reactor structure at elevation 100 ft. The HR-3 hole is placed at an angle 30 degrees south of west; HR-4 is placed 30 degrees north of west.

The HT-1 facility extends horizontally through the reactor tank at elevation 99 ft 3-3/4 in., and is located 17-5/8 in. west of the reactor north-south centerline. The hole measures about 4-5/8 in. sq and extends in a rectangular tube through "D" tank and the beryllium reflector. The plug center section is aluminum-clad beryllium and is water cooled. Radiation doors and shielding plugs similar to those in the HB facilities are used.

Two holes, used for reactor control instruments are the HI-2 and HI-3 facilities which extend through the permanent graphite at an elevation of 104 ft 3 in. HI-2 is located 4 ft 6 in. north of the east-west centerline and HI-3 the same distance to the south. These holes are used for the compensated ionization chambers which feed the Log-N and galvanometer circuits of the reactor control system. Both holes have a diameter of 10-3/4 in. in the graphite and are plugged only through the thermal and biological shields. The plugs are high-density concrete tipped with hollow graphite plugs cased in aluminum. A hole, 4 in. in diameter, runs through the center of the plug to within 4 in. of the inner end. This allows the tip of the ionization chamber to be inserted to the inner side of the thermal shield. An adjustment rod allows the chamber to be moved back 18 in. from the inner position.

The HG-1 through HG-4 holes extend horizontally through the permanent graphite reflector in a north-south direction. HG-1 and 2 are located west of the HB-2 and 5 cubicles, and HG-3 and 4 are east of these same cubicles. They are not fitted with shielding plugs, radiation doors, etc, due to the low radiation level that would emit from them. The inner plug sections are graphite and the outer plugs are high-density concrete encased in steel and are stepped in size.

HG-5 and 6 are horizontal beam hole facilities on the east face of the reactor on elevation 100 ft and extend to the reactor tank wall. The plugs, liners, radiation doors, etc, are similar to the HB facilities. The liners at the tank wall are 6 in. inside diameter.

Penetrations in the top of the reactor structure extend to 6 in. pipe thimbles welded into the two 24 in. exit water lines. GT-1 serves the southwest exit water line and GT-2 serves the northeast line. It was anticipated that these would be used for experiments requiring a pure gamma field. Liners in the concrete, placed adjacent to the 24 in. pipes and the GT thimbles, are termed GM-1 and GM-2. These facilities are used for the measurement of gamma radiation emitted from the N^{16} in the process water after it leaves the reactor vessel.

A thermal column facility, encompassing a large number of individual holes with neutron

and gamma radiation levels lower than those existing in the permanent graphite reflector, is installed on the east face of the reactor structure. It is composed of a 6 ft sq column of graphite extending from the outer face of the biological shield to the outer face of the outer thermal shield plate.

A 3-in. thick lead plate, placed between the permanent graphite reflector and thermal column, reduces the gamma radiation emanating from the permanent reflector. This plate (called a "neutron window") is positioned in an opening cut in the outer steel thermal shields. Located between the thermal shield plates is a 1/4 in. thick boral curtain which may be raised or lowered into position and which captures neutrons emanating from the graphite reflector. This is the "neutron curtain". Normally, it is left down and out of the way.

The HG-9 facility is a large stepped, rectangular hole, 10 in. horizontally by 16 in. vertically at the inner end extending from the east face of the reactor structure through the thermal column and graphite reflector to the reactor vessel wall. The entire plug is made of graphite. A perforated aluminum liner bridges the pebble zone between the permanent graphite and "D" tank wall on the HG-9 facility.

Other facilities in the thermal column, which extend horizontally to the thermal shield face or downward to the thermal column from the top of the reactor structure, vary in size from 4 in. to 12 in. sq. These are listed in the table at the beginning of this section. (See table 9.)

Instrument holes extending from the top of the reactor structure to the pebble zone are labeled VN-1 through VN-6. These have an inside diameter of 3 in. and may contain an ion chamber used in reactor control. (See figure 9.)

Located on the west side of the reactor is a bulk shielding facility which was intended to duplicate the thermal column located on the east face. Later, this was changed to a facility to study reactor shielding materials. Construction economies eliminated the bulk shielding facility and the steel shell was filled with high density concrete blocks. If the demand warrants, this column could be filled with graphite.

e. Hydraulic Rabbit (See drawing AED-A-1000)

A device for loading, insertion and removal of small samples into and out of the reactor with the reactor operating, is termed the "hydraulic rabbit facility". This facility is located in the rabbit canal, an 8 ft deep extension of the main canal on the west side of the reactor structure in the basement. Four tubes, two of which have a bore of about 1 in. and the other two a bore of about 1-5/16 in. extend from a loading station in the rabbit canal horizontally east, and then turn up and penetrate the bottom plug. VH-1 and VH-2 are the two smaller facilities and are located in the beryllium reflector on the east side of the active lattice. The other two are termed VH-3 and VH-4 and extend into the reflector holes in the south side of the active lattice that were originally intended for the two south regulating rods. The VH-3, or southwest hole, has recently been converted to an in-pile experimental facility.

These facilities utilize process water pressure to force the capsules into the reflector and utilize reactor tank water pressure to eject them back to the rabbit canal. The capsules are termed "rabbits" and are about 3 in. long. A more detailed discussion of this facility is found in IDO-16428, "In-Tank Irradiation Facilities in the MTR and ETR".

f. Pneumatic Rabbit (See drawing BKC-3150-538-4)

A facility similar in intent to the hydraulic rabbit facilities, but operated by compressed air or vacuum, is the pneumatic rabbit facility. There are two tubes which pass through the beryllium reflector in a north-south direction on the east side of the active lattice. The size of the tubes limits the diameter of the capsule to about 1 in. with a length of 3 in. Due to the high flux heating of these samples and the relative inefficiency of air cooling, the sample weights and capsule weights have to be restricted to a total gross weight of 25 g. While it was originally intended that the facility tubes be extended to laboratories located in the reactor wing, the high cost, possibility of contamination, and shielding problems associated with the design and use of these facilities has not allowed this expansion. However, experimenters using push rods, cables, etc. have irradiated capsules in these tubes.

FIGURE 9.
Reactor structure (top plane)

g. In-Tank Facilities (See figure 1)

As was mentioned previously, the high cost of utilizing the beam holes, etc, coupled with their low fluxes, has led to the modification of the active lattice and beryllium reflector for in-pile experiments. These are briefly mentioned below; for a more detailed description with figures, refer to IDO-16428.

(1) Active Lattice Facilities: The "L" beryllium pieces have been modified by the drilling of a single center hole, or four smaller holes, longitudinally in the beryllium body. These holes accommodate slugs, capsules, etc, in a position directly adjacent to the fuel assemblies. These experiments are mainly water cooled using the primary coolant.

The southwest shim-safety rod, termed L-42 position, has been removed and this hole is used for in-pile experiments. These experiments generally are re-entrant type with leads and cooling medium access below the reactor bottom plug.

(2) Reflector Facilities: Beryllium and aluminum "A" pieces have been modified in a manner similar to the "L" pieces. Single hole, two hole, and four-hole pieces, together with special pieces, have been made. These are used primarily for slug and small lead-type capsule experiments and may utilize thin-wall aluminum baskets to contain the capsules during irradiation. The baskets facilitate loading and unloading operations.

Reflector pieces "B" and "D" also have been modified to contain baskets and lead experiments similar to the "A" pieces.

8. HANDLING FACILITIES

Equipment needed to support the function of the reactor core and its experimental facilities is termed handling facilities. Below are listed the primary devices used in this work; specialized components peculiar to a particular experiment are not listed.

a. Overhead Cranes

Two overhead cranes are used in the reactor building. The largest is a compound bridge and trolley type crane of 30 ton and 5 ton capacity. It is used to lift off the top

plug with the drives, and to move the heavy casks used to transport radioactive fuel, etc.

The smaller crane is also a bridge and trolley type but of 800 lb capacity. It is positioned directly over the reactor vessel and is used during reactor shutdown for handling tools, core components, etc.

b. Canal

The use of water as a shielding medium allows direct visual contact with radioactive components and also allows the use of simple tools in the handling of these pieces. It is for this reason that the canal located in the reactor building basement is considered an integral part of the over-all facility design.

The canal contains the equipment for the handling of assemblies discharged from the reactor and provides space for the storage of spent fuel assemblies, irradiated materials and internal parts of the reactor. Water over these materials protects the operating personnel from the hazards of radiation.

The main section of the canal is 8 ft wide and extends eastward from the east face of the reactor. The canal section termed "rabbit canal", that lies partially beneath the reactor west wall, is 6 ft wide. A 7-ft wide canal connects these sections and extends through the reactor sub-pile room. The width of this section provides ample space for the canal unloading mechanism.

The parapet around the canal is 10 in. thick at the bottom and projects outward at the top to a width of 13 in. This projection provides toe space and also gives the operator better stability when working over the parapet. The top of the parapet is 3 ft. above floor level.

The bottom of the hydraulic rabbit canal is 6 ft below the basement floor level and that of the main canal is 16 ft below the basement floor level. The water level in the canal is maintained 2 ft above the basement floor level, providing depths of water in the rabbit canal and main canal of 8 ft and 18 ft respectively.

The depth of water in the canal is sufficient to shield adequately against the fission product

gammas from the stored reactor fuel assemblies. The main canal water depth of 18 ft limits the radiation levels to 0.1 roentgen per 8 hr at the water surface over the fuel storage area.

Outside of the reactor building, the canal has 6 ft wide working space on each side and at the east end. This working space is enclosed by a tunnel or canal envelope 13 ft 8 in high and 21 ft wide. The tunnel extends 87 ft 6 in. beyond the reactor building east wall.

The canal floor in the area inside the reactor building basement is limited to 2000 psf loading which includes the water load and that in the canal extension, 200 psf live load plus the water load. That in the carrier unloading sump will carry the fuel element carrier weight plus the water load. The loading restrictions should be kept in mind during canal operations. The loading should be checked in the event a heavy unit is to be handled.

Although the canal was designed with an access hatch located over the sump in the canal extension for the intended purpose of lifting out or lowering in the fuel carrier, this scheme is not used. The carrier is brought into the reactor building by a lumber-type straddle carrier, set on the floor, and is then handled by means of a bail by the building crane. The carrier is lowered through an open hatch in the first floor into the canal. A structural steel pad distributes the load to the piers supporting the canal floor.

The canal walls were originally covered with 8 by 16 in. white glazed structural tile 4 in. thick, and the bottom was lined with 4 in. of white concrete. Excessive leakage made it necessary to install a stainless steel liner.

A flow of 20 gpm of demineralized water is maintained through the canal to avoid an excessive build-up of radio-activity and turbidity. As originally installed, water from the canal overflowed a weir in the east end of the canal and flowed through a discharge pipe to the canal sump. When the RMF was installed in the east end of the canal, an overflow pipe was installed west of the RMF canal isolation gate and use of the overflow weir was discontinued. The purge water from the canal sump is pumped to the retention basin. A radiation alarm is provided in the sump and a

liquid-level controller governs the operation of the sump pumps.

Provisions are included for the installation of two removable watertight bulkheads which permit isolation of any canal section, except the rabbit canal, for cleaning and maintenance. Each section, except the rabbit canal, is also provided with a drain and a water line connection. The drains are interconnected in such a way that any section can be isolated and flushed. There are three adjustable over-flow stand-pipes in the sub-pile room and rabbit canal section. A continuous overflow to the reactor building sump is maintained through these in order to prevent scum formation.

Good underwater lighting is necessary because the handling of assemblies in the canal is a manual operation carried on under 10 to 18 ft of water. This lighting is supplied primarily by portable watertight light fixtures.

A manually-operated bridge crane with a 2 ton electric hoist and manually operated trolley is provided for the handling of heavy materials in the main canal. The highest hook position is 9 ft 9 in. above the reactor building basement floor. This provides a clearance of more than 6 ft between the hook and the top of the parapet. The maximum lift of the hoist is 25 ft 9 in.

c. Discharge Mechanism (See drawing BKC-3150-571-1)

A device which remotely connects to the discharge tube located on the reactor vessel bottom plug, and transports components from the reactor vessel to the canal, is called the "canal discharge mechanism". This mechanism consists of a long cylinder pivoted at its lower end and contains a piston which is moved by water pressure. The cylinder has a sealing device at its upper end which mates with the lower end of the fixed discharge tube. Radioactive components are lowered from the reactor core into the discharge chute, past a full-opening valve, and into the discharge mechanism cylinder where they rest on the movable piston. The valve is closed, the mechanism breaks connection with the discharge chute and the cylinder then pivots to the east, coming to rest in a horizontal position. The piston then is moved to eject the component onto roller platforms where it may be handled or moved by handling tools.

d. Underwater Saw (See drawing BKC-3150-570-1)

Since the life of a fuel assembly or shim-safety rod in the reactor core is not long enough to burn more than 25 percent of its total uranium content, the unused uranium is reclaimed by a chemical dissolving and separation process. As the end boxes, in the case of the fuel assemblies, or the poison section, etc, in the case of the shim-safety rods, contain no fuel, they are removed before the fuel sections are transported to the chemical processing plant for processing. This removal is done by sawing them off under water in the canal.

This saw is patterned after a conventional power hacksaw with the electric drive motor driving the saw through an extension rod located above water. Fuel assemblies or shim-safety rods are clamped on horizontal tables and the saw is moved through them as cutting proceeds.

e. MTR Carrier (See ORNL drawing 542-21-C-1516-E)

This carrier is used to shield the cut fuel assembly and shim-safety rod fuel sections when they are transported from the MTR canal to the MTR gamma building or the chemical processing plant. It is fabricated of stainless steel and is lead filled. About 14 in. of lead surround the center cavity on the sides and top and about 17 in. is used on the bottom. This carrier weighs approx 25,300 lbs.

The carrier can hold four cut fuel sections. It is loaded underwater in the canal, a plug is inserted in its top, and it is lifted to the main floor using the reactor building 30-ton crane. The straddle carrier picks up the carrier and transports it to its destination.

f. Universal Coffin (See drawing BKC-3150-564-2)

The removal of the various beam hole facility plugs, either startup or experimental, and their transport to a plug storage facility requires the use of a shielded coffin. The coffin used for this purpose consists basically of a steel pipe which is jacketed with about 10 in. of lead and is large enough to contain the largest beam hole plug. Removable inner liners are provided to adapt the coffin for use

with smaller plugs. The lead jacketing is thickest in the area surrounding the plug tip which should be the most radioactive plug section. This coffin is moved horizontally on a dolly and is leveled and adjusted to match the centerlines of a beam hole facility. Horizontal and vertical beam hole centerlines have been painted on the reactor structure and the reactor building first floor to aid in aligning the coffin. The coffin is fitted with a heavy radiation door to close off the end near the plug tip. It must be rotated 180 degrees to match some beam holes. The basic coffin consists of three sections. The tip section is heavily shielded and the motor-operated radiation door is mounted at its outboard end. The second section is heavily shielded at its point of attachment to the first section but tapers to provide approx 4 in. of lead shielding equivalent at the other end. The third section consists of a length of 10 in. pipe with flanges on both ends. These three sections are approx 17-1/2 ft long and weigh approx 32,000 lbs. One additional section is also provided for use with the HT-1 plug which has an extra long radioactive section. This front section bolts on the face of the tip section, is 5 ft 3 in. long, and weighs 9000 lbs.

g. Plug Storage Facility (See Sundberg drawing 866-MTR-765-S1)

The MTR plug storage facility provides a low-cost shielded facility for the dry storage of radioactive beam hole plugs. These plugs may be the dummy plugs which were original equipment installed in the reactor, or plugs incorporating a specific experiment.

The original plug storage facility was located south of the reactor building. The charging face of this facility was later enclosed by the MTR reactor services building. In 1957, a new enclosed facility was constructed on the reactor building north side and the original facility abandoned. The new plug storage facility is connected to the reactor building by an existing truck door and to the plant by a new roll-type truck door.

The plugs are ejected from the universal coffin into pipes or rectangular tubes at elevations approximating those of the beam holes in the reactor structure. The tubes extend 29 ft beyond a concrete facing wall. The tubes are embedded in gravel to obtain

the necessary shielding, and the gravel is retained by concrete walls on the other three sides. The top of the gravel is exposed to the weather; any water entering the top of the fill is drained by perforated drain piping.

Twenty-one tubes are made of 10 in. schedule 40 carbon steel pipe. These may contain the beam hole plugs which are circular in

cross section. In addition, one tube about 15 by 21 in. is used for the HG-9 plug storage and another about 15 in. sq is used for the VG-9, T2V1, or T2V2 plugs. Two tubes, 5 in. sq, may be used for storage of the HT-1 plugs. The tubes are capped by welded plates on the ends embedded in the gravel and by gasketed and bolted plates on the exposed or charging ends.

E. TRAINING QUESTIONS AND ANSWERS ON THE MTR

MTR Construction

1. Q. What is the function of the beryllium in the tank?
A. It reflects the neutrons back into the lattice.
2. Q. What is the function of the graphite?
A. It slows, or thermalizes, the neutrons. This helps reduce further shielding requirements.
3. Q. What is the function of the heavy steel plating?
A. It stops the thermal neutrons and reduces the gamma field. It is called the thermal shield.
4. Q. Why the concrete?
A. To stop the gamma rays.
5. Q. What special concrete is used in the reactor biological shield?
A. Barytes concrete. Barytes aggregate has a high density, thus is a good radiation shield.
6. Q. What and where is the thermal column?
A. An area of graphite where a field of thermal neutrons are available. It is located on the east side of the reactor.
7. Q. What is the neutron curtain? What is its purpose?
A. A 6-ft square of 1/4 in. boral plate used to fill the opening in the east side of the steel thermal shield. Its purpose is to permit turning on and off thermal neutrons to the thermal column.
8. Q. Where are the power winch controls located which raise or lower the neutron curtain?
A. On the east face of the reactor near the lead shielding door.
9. Q. What is the neutron window? What is its purpose?
A. A 3-in. sheet of lead which stops gamma radiation from the lattice, but which allows thermal neutrons to penetrate into the thermal column.
10. Q. Why is the tank composed of five sections?
A. Ease of manufacture, assembly, and for possible disassembly, if necessary.
11. Q. What is the construction of the top and bottom plugs?
A. Stainless steel filled with lead shot.
12. Q. What is the current fuel assembly composition? How much U-235?
A. Nineteen plates, containing 200 g of U-235 total.
13. Q. How "hot" is a fuel element when it is discharged to the canal after a full cycle run?
A. About 10^7 r. For details refer to the MTR Gamma Facility Operating Manual IDO-16423, page 45.
14. Q. What two areas of the tank have "pieces" that fit into them? Where are they?
A. The "L" piece or lattice (fuel) area and the "A" piece or reflector area.
15. Q. What is the "D" piece?
A. The beryllium piece which plugs the discharge chute.
16. Q. Is the "D" piece the only plug in the discharge chute?
A. No, a steel and lead plug blocks the discharge at the bottom plug.
17. Q. What are the two types of control rods and what is their function?
A. Shim-safety rods for coarse neutron control, and regulating rods for fine neutron control.

18. Q. What keeps process water from leaking around the rod drives?

A. Demineralized water pressure seals the leather glands surrounding the rods.

19. Q. What are the lower shock absorbers for the shim rods and where are they located?

A. These are tapered dash-pots mounted on the bottom plugs which cushion the fall of the 110-lb shim rods.

20. Q. Why is the graphite zone composed of two graphite arrangements?

A. The pebble zone graphite is removable, should it be damaged by prolonged neutron bombardment. The permanent graphite zone is not expected to be damaged.

21. Q. Which is at the higher elevation, the seal loop on the reactor tank discharge line or the reactor tank drain valve in the process water building?

A. The seal loop. When the reactor tank is drained via the drain valve in the process water building, the water level will stop at the seal loop elevation, not at the drain valve elevation.

FIGURE 10.
Reactor structure (north elevation)

FIGURE 11.
Reactor structure (east elevation)

FIGURE 12.
Reactor structure (south elevation)

FIGURE 13.
Reactor structure (west elevation)

FIGURE 14.
Reactor structure (horizontal section at
reactor centerline)

FIGURE 15.
Reactor tank section "D" (showing beam
hole liners)

FIGURE 16.
Fuel element assembly

FIGURE 17.
Reactor structure (internal construction
pictorial)

FIGURE 18.
Geneva model cutaway

FIGURE 19.
Geneva model cutaway

FIGURE 20.
Lower assembly grid (showing corner
locking cam)

FIGURE 21.
Beryllium reflector and lower guide grid

FIGURE 22.
CPP Straddle carrier picking up MTR fuel
element cask

CHAPTER II

REACTOR CONTROL COMPONENTS AND INSTRUMENTATION

A. INTRODUCTION

Fossil fuel fired furnaces rely on instrumentation to reveal what is going on inside. Instruments are provided for stack gas analysis, stack gas pressures, fuel oil temperature and pressure, structure temperature, etc. Nuclear reactors, with no means for visual observation, must rely even more on instruments to indicate what is taking place within them. Being totally different from other furnaces, nuclear reactors must use a greater variety of instrument applications to convey internal information to the operators. In the MTR there are three groups of instruments furnishing information to the operator and the control system: (1) the reactor instruments, measuring neutron flux or power level; (2) the rod position and motion indicators; and (3) the instruments for the auxiliary facilities. Reactor instruments will be understood to include: radiation instruments measuring gamma and neutron levels in the reactor and radioactivity in the water; temperature instruments measuring distribution of exit water temperature across the active lattice and temperatures in the thermal and biological shields; and pitot tubes measuring distribution of water flow across the bottom of the active lattice.

Reactor radiation instruments are listed in table 10 for reference purposes.

The purpose of this chapter is to acquaint the reader with those instruments, indicators, and control switches in the reactor control room which he must understand. Items of one system are discussed in sequence in order to present a complete picture of that control system before going on to another. In the case of instruments sensing and recording neutrons, the description begins with the sensing chamber and follows through the stages of amplification to the final recorder.

It is necessary to discuss parts of the control circuit in a general way even though the reader may be unfamiliar with them at the present. A detailed description of the control circuits constitutes the following chapter.

B. REACTOR CONTROL INSTRUMENTATION, RODS, AND DRIVES

The MTR control rods are of two types, the shim-safety rods for coarse neutron level control and the regulating rods for fine control. Both types of control rods lower the reactivity of the reactor when they are inserted, and when all are resting in their lowest position they overcome an excess reactivity of more than 40 percent. Since normal fresh loads contain 13 to 15 percent excess, this provides an adequate margin of safety. For purposes of reactor operation, suffice it to say that reactivity is overcome by means of neutron absorption. This is accomplished by cadmium sheets inserted in the control rods. Cadmium has the high capture cross section of 27,000 barns.

1. Shim Rod System

The shim rod system is the means provided for the operator to control the reactor. With them it is brought to criticality, manual control is exercised, and shutdowns are instituted. Pulling the shim rods upward (withdrawal) gives an increase in reactivity. Conversely, the reactor may be shut down by running the shim rods in (insertion) or by shutting off current to the electromagnets and allowing the rods to drop ("scram") by the force of gravity and water flow. When the rods rest in their lowest position, the cadmium is in the lattice, and as the rods are withdrawn, the cadmium in the lattice is replaced by fuel or beryllium, as the case may be. (Refer again to the drawings in Chapter I.)

a. Shim Rods (See figure 3)

An MTR shim rod is 163-9/16 in. long, including the armature, and weighs about 110 lbs. The rods are composed of six sections: the armature; aluminum section; poison section; fuel section; stainless steel section; and the shock absorber section. The beryllium-cadmium shim rod incorporates a beryllium section rather than a fuel section.

Table 10

Reactor Radiation Instruments

INSTRUMENT	USE
Fission chamber (12 ft travel)	Count rate meter
Compensated ion chambers	2 log N's and period signals, galvanometer signal
Parallel circular plate ion chambers	3 neutron safeties and 2 servo systems
Boron thermopiles	Neutron flux in graphite
Air wall ion chambers	N^{16} in cooling water
Water ion chamber	Water sample monitor

The soft iron armature is connected to a spring mounted swivel that acts as a universal joint, so constructed that it aligns and makes good contact with its magnet. The magnet and armature arrangement is sometimes referred to as the "magnetic clutch".

b. Shim Rod Control

The shim rods are connected to their drive mechanisms by electromagnets (clutches). Two magnet amplifiers in parallel supply the current for each magnet and if one amplifier fails the other automatically takes over the full load. Two ways of stopping magnet current to produce a scram are provided. The first of these, called a fast scram because of its fast response time, is electronic in action. The output current of the magnet amplifiers is controlled by the highest signal from the sigma amplifiers. If the reactor neutron level reaches $1.5 N_F$ or if the period reaches one sec for one sec, the sigma amplifiers affected will raise the voltage of the sigma bus, reducing magnet current by amplifier action, and thus cause one or more shim rods to drop. All this can take place in less than 30 milliseconds.

The second method of producing a scram is through mechanical relays. Either of the two "SCRAM" switches on the console may be thrown or any of the scram contacts in the recorders or experiments may be tripped. All these activate the same relays (R-68 and R-69) producing the mechanical (slow) scram. All rods always drop, as current is interrupted to all magnets, within 100 milliseconds after the initiating scram signal.

For a clear understanding of the operation of the shim rods, it is imperative that the reader distinguish between the shim-safety

control rod and the shim-safety rod drive assembly. The shim rod drive mechanisms are an integral part of the top plug and are driven by 1/6 hp, reversible, three-phase, induction motors with worm gears. The advantage of the induction motor is that no accident can make it run in excess of synchronous speed, therefore the danger of overspeed withdrawal of the shim-safety rods is eliminated. No brake is required since the worm and screw drive is self-locking.

The shim rod motors are remotely controlled from the console by a variety and combination of switches. Shim rods may be withdrawn singly or together in "CONTINUOUS" or "INTERMITTENT". They may be inserted singly or as a group with the "REVERSE" switch, depending on the needs of the operator. The withdraw speed is 30 in. in 6 min. The insert speed is 30 in. in 3 min.

c. Individual Shim Rod Switches

The seven individual shim rod switches are located on panel "N" of the console (operator's left) with a plug for the fifth shim rod not in use.

The purpose of these selector switches is general control of the shim rods. However, with the exception of one position, "JOG", they do not actually activate the rods. There are six selector positions on each switch: (1) "RAISE"; (2) "OFF"; (3) "BLOCK"; (4) "NORMAL"; (5) "PREFERRED"; and (6) "JOG". The switches are not spring loaded and lock in each position.

(1) "RAISE": The "RAISE" position is used for raising the carriers while the shim rods remain in their seats. This position is used in conjunction with the "RAISE-SCRAM" switch located on panel "S" (operator's right), and the carriers are not activated until the "RAISE-SCRAM" switch is put

on the "RAISE" position. (This switch combination is used when the reactor is shut down and the top plug is to be removed.) The carriers then move to their uppermost position (shim rods in the core and disengaged from the magnet) making the top plug removal possible. If the carriers were extended, the magnets would not clear the reactor tank spool piece at the time of removal.

(2) "OFF": The "OFF" position shuts off current to the shim rod motors, and thus prevents either withdrawal or insertion of the shim rods. There is one exception to this, however. The reverse circuit bypasses this switch and in the event of a reverse, the rods will be inserted.

(3) "BLOCK": The "BLOCK" position is essentially the same as "OFF" with one exception. The withdrawal circuits are de-energized completely and the only rod movement permitted is either a reverse or an automatic rundown. "BLOCK" is used more often than "OFF" because automatic rundown is still permitted and it is sometimes used during group withdrawal of the shim rods to prevent one rod from withdrawing faster than the others.

(4) "NORMAL": The "NORMAL" position is the one most generally used. This is the regular operating position, and permits manual withdrawal or automatic insertion of the shim rods. Usually, six of the shim rod switches are on "NORMAL" during operation.

(5) "PREFERRED": The "PREFERRED" position is the same as the "NORMAL" position except a manual or an automatic preferred insertion of that rod is permitted. It will be well to note here that one fuel shim switch must be kept in the "PREFERRED" position and it is usually the shim rod with the most reactivity response. "Preferred" insert initiated by the regulating rod is high speed and will insert any rod which is preferred. A manual insertion of the "preferred" rod is slow speed, i.e. through the inching resistor, and will result in reduced speed or no movement at all if more than one rod is "preferred".

(6) "JOG": The "JOG" position is unique, as it is the only position which actuates a shim rod without the use of another

speed (30 in. in 3 min). If more than two rods need to be inserted simultaneously, a reverse should be initiated.

d. Shim Rod "WITHDRAWAL" Selector Switch

The shim rod "WITHDRAWAL" selector switch, located in front and to the right on the console, is an eight-point switch which selects individual shim rods for low-speed withdrawal. When withdrawing shim rods with the individual switch, usually referred to as the inching circuit, only one will be withdrawn at a time; thus, a selector switch must be used. When withdrawing a particular rod, the rod is selected with this switch and then withdrawn by using the individual "WITHDRAW-INSERT" switch in the "WITHDRAW" position.

e. Individual "WITHDRAW-INSERT" Switch

This is a three-position spring loaded switch located on panel "R" (operator's right), which is used for energizing the inching circuit for individual movement of the shim rod in either direction. The three switch positions are "WITHDRAW", "NEUTRAL", and "INSERT". This switch permits a low-speed withdrawal or insertion for fine control at, or near, full reactor operating power. Use of this switch permits movement of only one rod at a time due to the characteristics of the inching circuit.

The "WITHDRAW" position is used in conjunction with the shim rod withdrawal selector switch.

f. "INTERMITTENT-CONTINUOUS" Group Withdrawal Switch

This is a three-position, no-return switch located in front and to the right of the console and is used for group withdrawal of the shim rods. Unlike the low-speed switch, this is capable of withdrawing all seven shim rods simultaneously. However, this is dependent on the position of the individual shim rod switches. By means of these switches, any combination of shim rods may be withdrawn at any one time with the group withdrawal switch.

Its three positions are "CONTINUOUS", "NEUTRAL", and "INTERMITTENT". In the "INTERMITTENT" position the rods are withdrawn periodically in conjunction with a timer.

In the "CONTINUOUS" group withdrawal position, the shim rods may be withdrawn simultaneously at a high speed but must be used in conjunction with the "BYPASS" switch after the reactor is in "RUN". An individual shim rod switch in the "BLOCK" position will prevent withdrawal of its shim rod.

As a matter of interest, the reason behind the "round-about" procedure for withdrawing shim rods is to force the operator to take an extra step, since withdrawing shim rods is potentially a dangerous move. With an extra step involved, the operator must set his mind to it before making the move, thus minimizing an error.

g. "BYPASS-REVERSE" Switch

The "BYPASS-REVERSE" switch is a spring loaded switch with three positions: "BYPASS", "NORMAL", and "REVERSE".

The "BYPASS" position, in itself, does not initiate any action, but is used in conjunction with the "CONTINUOUS" group withdrawal switch referred to above. In the "START" regime, the "BYPASS" switch will invalidate only the 30-sec period trip, but in the "RUN" regime, the "BYPASS" switch permits continuous group withdrawal. The "BYPASS" switch must be closed before the "CONTINUOUS" switch is used. The opposite sequence will not produce any rod movement.

The "REVERSE" position is a manual method of producing a reactor reverse and is equivalent to that emergency power reduction. Closing this switch inserts all of the shim rods simultaneously at high speed regardless of the position of the individual shim rod switches. Unlike high speed withdrawal, various combinations of rods are not possible since this switch bypasses all other controls and supercedes the other rod actions.

h. "RAISE-COCK-SCRAM" Switch

This switch is used together with the "RAISE" position of the individual shim rod switches to drop the shim rods and raise the rod carriers. The "COCK" position will be discussed with the regulating rod section.

i. "SCRAM" Switch

This manual switch cuts all current to the magnets and drops all shim rods. Two scram relays (R-68 and R-69) are activated

and their response can be checked with the two indicator lights above the switch.

Additional items of equipment connected with the shim-safety rods include the top plug seals, position indicators, shim rod bearings, and lower shock absorbers.

j. Shim Rod Indicators

Position indication of the shim rod carriers is reported to the operator by a selsyn system. The generators (transmitters) are mounted on the rod drive shafts and the motors (receivers) are mounted in the control room console. As the carriers are moved, the generator is rotated and the receiver motor at the console follows the generator movement. The motor moves an indicator on a face plate calibrated in inches.

The shim rod indicators also display four amber lights denoting shim rod conditions. A "NO-CLUTCH" light conveys to the engineer or technician that no contact exists between a carrier magnet and the shim rod armature. An "INSEAT" light indicates the shim rod is in its inner-most position. If a shim rod should drop, the "CLUTCH" and "SEAT" lights should both come on. An upper limit switch ("ULS") light comes on when the shim rod carrier is at the top. A lower limit switch ("LLS") light will turn on when the carrier is at its lower limit.

In addition to the selsyns, direct drive speedometer type indicators are mounted to the top plug and register shim rod carrier position to the thousandth (0.001) of an inch. The selsyns are only accurate to a tenth (0.1) of an inch.

k. Shock Absorbers

The shock absorbers contain a pressure mechanism which indicates to the reactor operator when the shim rod or rods are seated. This is accomplished by introducing high pressure demineralized water through the bottom of the dash pot and forcing the water into the reactor tank. When the shim rod is seated, the water flow is cut off and the pressure rises causing an appropriate signal to be transmitted to the reactor circuitry and console "SEAT" light.

l. Top Plug Seals

Top plug seals are provided to prevent water leakage where the drive rods pass through the top plug. These consist of a

double set of leather chevron packing and packing nuts. As an added precaution a purging system is incorporated to introduce a supply of fresh water between the seals at a pressure slightly greater than the process water in the reactor tank. This water also serves as packing lubrication.

2. Servo System

The servomechanism is the automatic reactor control for the power range N_L to N_F . The operator selects the desired power level by means of the Motor Operated Rheostat (MOR) and if the flux level of the reactor, as seen by the servo ionization chamber, is different from the MOR setpoint, the system will adjust to the correct flux by moving the regulating rod in or out of the core. The servo system will control the MTR within 0.01 Mw (10 kw) of the preset power level. Since the regulating rod reactivity is small, the operator must move the shim rods periodically to keep within the range of the servo system. The servo system is duplicated, with one channel as a standby, and consists of an ion chamber, preamp, amplifier, amplidyne generator, servo motor, regulating rod drive, regulating rod, tachometer, MOR, and "SETPOINT VERNIER". (See block diagrams on figures 23 and 24.)

a. Regulating Rods

The regulating rods are designed to provide continuous fine control of the reactor neutron level. Four possible locations for regulating rods are provided in the beryllium reflector adjacent to the active lattice. Normally, only one regulating rod is used for control of the reactor with one rod available as a standby. The remaining two locations are used as experimental facilities (VH3 and VH4).

Each regulating rod was originally 1-1/2 in. in diameter and consisted of an upper aluminum section, a middle section containing cadmium covered with aluminum, and a lower aluminum section. Guide bearings are provided in the upper and lower support castings. When the regulating rod is disconnected one of its collars rests on top of the bearings in the upper support casting. In this position, the center of the cadmium section is approx

at the same level as the centerline of the active lattice. After the bearings failed, it was necessary to replace them with an undersize unit 1-1/4 in. in diameter. Each regulating rod has a $\Delta k/k$ of about 0.005 and can control a one second period.

The regulating rod is connected to the regulating rod drive assembly by means of a threaded bolt turned from the reactor top. The drive shaft down to this connection is guided by bearings in the spider supports and passes through the top plug to the drive motor assembly. The regulating rod is driven by a one hp low inertia electric motor through a pinion gear and rack. The motor, in turn, receives its power from an amplidyne motor generator. Fastened on the top plug platform is the rack housing and cover. It houses the pinion gear and rack, and locates the regulating rod upper shock absorber and position indicator. The microswitches which control the relative motions and positions of the regulating rods and shim rods are fastened to this housing cover.

b. Limit Switches

Each rod has five limit switches located on the rod drive: the 4.5 in. position; the 5 in. position; the 7 in. position; the 11 in. position; and the 17 in. position. The 4.5 and 17 in. switches are the lower and upper limit switches which reduce power applied to the drive motor in their respective directions. Thus, the rod does not strike the shock absorbers at full speed and power, and it is held there at reduced torque until a signal for motion in the opposite direction is received. If the regulating rod gets below 11 in., the operator is prevented from withdrawing any more shim rods (which would cause the regulating rod to go in still farther). If the regulating rod gets below 7 in., the "PREFERRED" shim rod will insert until the regulating rod backs out beyond 11 in. If for some reason the regulating rod continues on in to 5 in., all shim rods are automatically inserted (a reverse) until the regulating rod travels out beyond 11 in. Obviously then, these switches tend to keep the rod above 11 in., and this is so that ample cadmium length remains for protective purposes. All these switches, except the 4.5 in., operate lights on the console regulating rod position indicator. The 17 in. amber light is on when the

FIGURE 24.
Reactor instrument block schematic diagram

rod is out beyond it; the 11 in. amber light and the 7 and 5 in. red lights are on when the rod is below their switch positions.

c. Position Indicators

Position of the regulating rod drive shafts is indicated at the console by two selsyns identical to the shim rod carrier instruments. The difference is in the display lights previously explained.

d. Shock Absorbers

Shock absorbers are of the hydraulic type. The upper shock absorbers are fastened to the upper surface of the rack housing while the lower shock absorbers are fastened beneath the top plug upper platform. The shock absorbers perform the function of dissipating the energy in the servo motor when the rod is driven to its lowest or highest position.

e. Plug Seals

Regulating rod top plug seals are identical with the double chevron shim rod seals previously described. They also have clean water injected between them.

f. Servo System Ion Chambers

The servo system ion chambers are parallel circular plate (PCP) chambers located in reactor instrument facilities VN-4 and VN-6. They are identical to those in the safety level system (to be discussed later) and are used because of their fast response. An ion chamber is much the same as a resistor whose resistance varies with the magnitude of the flux field in which it is located.

g. Servo System Explanation

A +300 volt potential is applied across the chamber and a -300 volt potential is applied across the vernier network and MOR. With this voltage applied, a current proportional to the resistance, and hence to the flux, will flow through the chamber.

Considering a simple circuit such as that shown in figure 25, the voltage at point A depends on the values of the resistors R_1 and R_2 and battery voltage. If resistance R_1 is increased, the positive voltage at point

A will decrease and if R_2 is increased, the positive voltage at A will rise.

If figure 25 is compared with the "Reactor Control Servo System" diagram on figure 23, it can be seen that the ion chamber is represented by R_1 and the motor operated rheostat by R_2 . The above discussion can then be applied to find the voltage at point A on the servo system diagram. A change in reactor flux level results in a change of flux at the ion chamber. A flux decrease causes an increase of ion chamber resistance and decrease in current flow. This causes the voltage at point A to go more negative which, in turn, signals the servo amplifier to withdraw the regulating rod, and thus, bring the reactor up to its original power level. Point A on the diagram is maintained at -3 volts and represents a balanced system with no signal being transmitted through the servo preamplifier.

h. Servo Preamplifiers

The servo preamplifiers are improperly named in that they are not amplifiers. These units are single stage cathode followers designed as impedance matchers to eliminate outside noise signals from reaching the servo amplifiers. The servo preamps are physically located in the instrument cubicles on the reactor top.

i. Servo Amplifiers

The servo amplifiers, located in the instrument room, provide field current for their respective amplidyne generators which are to be discussed next.

j. Amplidynes

The amplidynes are ac motor - dc generator sets, located in the instrument room under the control room stairs. As their name implies, they are mechanical power amplifiers wherein a small input signal is transformed to a powerful output signal capable of driving a sizeable motor. The amplidyne input signal is from the servo amplifier (whose signal is proportional to flux) and their output drives the 1 hp-dc fast response motors which move the regulating rods to return flux to the "balanced system" level.

With no signal from the servo preamp, the servo amplifier puts out two equal currents (40 ma) to the opposing field coils of the amp-

FIGURE 25.
Simple servo system circuit

lidyne dc generator. The net field current is thus zero and there is no dc current output to the servo motor (regulating rod drive motor). The amplidyne output to the servo motor ranges from 0 to 250 volts dc, depending on the signal to it. With a signal, the servo amplifier increases current in one direction and decreases it in the other, causing a generator output with polarity corresponding to the incoming signal. Polarity of the amplidyne output determines which way the regulating rod motor will turn. Voltmeters are attached to the amplidyne output leads and monitor the amplidyne signals to the regulating rod motors. These are located at the console under the regulating rod selsyns and inform the technician that the selected amplidyne is actually running.

k. Tachometers

A tachometer (generator) with an out-of-phase output proportional to regulating rod velocity is driven by the servo motor. The out-of-phase signal is fed to the input of the servo amplifier and through its dampening effect produces stability in regulating rod movement.

l. Motor Operated Rheostats

The two MOR's, located in the instrument cubicles on the reactor top, have contacts that change resistance in 250 steps rather than continuously. The resistance of each step increases such that its resistance is proportional to the total resistance at that step. This results in a total circuit logarithmic resistance scale ranging from 0.5 megohm to 50 megohms. Selsyn indicators, mounted on the control room panel, inform the engineer or technician at the console of the MOR's positions. Each MOR is driven by two separate motors: one for slow speed that will drive

the rheostat through its operating range in 465 sec; and a fast speed motor that will do the same in 88 sec. Automatic power reductions, termed slow and fast set-backs, are lowering of these rheostats without the operator's volition.

m. Reactor Level Setpoint Switch

A five-position reactor level setpoint switch is located on the console below the procedure panel. This switch activates the motors which operate the rheostat in the selected servo channel. The switch positions "SLOW LOWER" and "SLOW RAISE" engage the MOR slow speed motor. "FAST RAISE" and "FAST LOWER" positions engage the MOR fast speed motor. The "RAISE" switch positions are spring loaded and will return to "NEUTRAL" if released. The "LOWER" switch positions are not spring loaded.

Turning the setpoint switch to "RAISE" causes a decrease in the resistance of the MOR, forcing point A (See figure 23) to go more negative. This signals the servo amplifier to change the field balance in the amplidyne generator. The generator output polarizes the servo motor armature causing the motor to run in such a direction as to withdraw the regulating rod, until the increase in reactor flux results in a "no signal" -3 volts at point A.

n. "SETPOINT VERNIER"

The level vernier is a 5000 ohm potentiometer across which a portion of the negative reference voltage is applied. Its slide contact is connected to one end of the MOR as shown on the diagram in figure 23. This provides a vernier interpolation between the steps of the MOR. The two vernier potentiometers, one for each channel, are mounted on the same shaft behind the console procedure panel.

o. "MANUAL-AUTO" Selector Switch

This three-position selector switch is located on the console below the selsyn position indicators for the regulating rods. It is used to select regulating rod No. 1 or 2 for automatic operation or to bypass them for manual operation. Selecting either rod starts its particular amplidyne. It would be well

to note here that selection of a regulating rod is usually delayed until reactor power is within two decades of N_L . This practice will eliminate unnecessary use of the amplidyne as the servo system is not used below N_L .

C. REACTOR INSTRUMENTS

In this section, the control room instruments will be discussed. Since the fission chamber count rate system is the first to detect reactor activity, it is the first to be covered. Following this are those that see the rising power in the sequence of their activation. In the power range (above N_L), several instruments respond almost simultaneously and these are discussed without regard to their first movement.

1. Fission Chamber Count Rate System

In an early attempt to measure low neutron intensities, a modulated ionization chamber was proposed. This device periodically placed an absorber in front of the ionization chamber which resulted in a modulated signal proportional to neutrons only. This was abandoned in favor of the fission chamber and count rate meter which, by repositioning of the fission chamber, is capable of covering a range of 10^{11} (eleven decades). The fission chamber is designed to give reliable neutron measurements at fluxes as low as 10^{-11} full power flux (N_F).

a. Fission Chamber

The construction of the chamber consists primarily of a brass shell carrying a nickel liner coated with U-235 on the inside surface. (See figure 26.) A central anode rod of aluminum is supported by a coaxial connector. Neutrons absorbed in the U-235 produce fission fragments which cause bursts of ionization in the argon gas purging through the chamber. With the anode at +270 volts, the fission process will produce a pulse height of some 50 microvolts across the 450 micromicrofarad of cable capacitance. The chamber efficiency is one pulse in a flux of 100 n/cm²/sec.

By using an argon gas purge, the pulses are distinguishable up to a limiting rate of nearly a million per second. This pulsating signal is fed from the fission chamber in VG-8 to a preamp located in the north instrument cubicle on the reactor top. Here it is amplified 30 times and leaves as a signal measured in millivolts.

b. Amplifiers

The preamp increases every signal it receives, including both outside electrical noises and pulses from the fission chamber produced by neutrons, alpha, and gamma radiation. By feeding the preamp signal to a linear amplifier (located in the north instrument cubicle), and by proper biasing of that amplifier, the large fission pulses caused by neutrons can be distinguished and counted separately from the lesser pulses caused by outside noises and intense gamma radiation. The discriminator in the linear amplifier puts out a 3-volt pulse for every distinguishable input pulse from the preamp.

c. Log Count Rate Meter and Indicators

The 3-volt pulses are sent to the log count rate meter located in the instrument room below the control room where the signal is changed from a linear to a logarithmic function. This is done by sending the signal from cathode to plate in a log-diode tube. When such a current is small, the voltage across the diode is proportional to the logarithm of the current. The log count rate meter signal is then sent to two separate indicating systems. (See figure 24.) One is the count rate recorder in the control room where the signal is converted to a visual reading and is recorded on a strip chart. The second is the "DEVIATION" and "COUNT RATE GALVANOMETER" (two-in-one instrument), located on the console proper. A manual switch on the console determines which signal the galvanometer receives; the "COUNT RATE METER" signal or the "FLUX LEVEL" deviation signal.

d. Count Rate Meter Range

The useful working range of the count rate meter extends only up to 10^4 counts per sec. To increase the neutron flux range of the instrument, provision is made for moving the chamber over a maximum distance of 12 ft, from above the thermal shield down to a point well inside it. In the innermost position, the fission chamber is in the "source" or "clean startup" region, measuring up to about 3×10^3 n/cm²/sec. In the second position (center), the chamber is withdrawn 6 ft. This position is used during normal reactor startup and is considered the "cold start" region. The outermost location is 12 ft from the innermost location and is considered the "RUN" region.

PPCO - C 2818

FIGURE 26.
Fission chamber assembly

Since the fission chamber will be used at three established positions in its instrument facility (VG-8), motion from one position to the other will give a neutron flux range multiplication of about 3×10^3 each. This is comfortably within the counting rate range of 10^4 , giving about a ten decade counting range. (Each position range overlaps, to some extent, the adjacent position range.)

Means of moving the chamber are semi-automatic and are tied in with the control circuitry which is discussed in Chapter III. Manual movement of the chamber is possible with three control buttons on the console. Three position lights signal its location. The drive motor, positioning micro switches, and linkage for the chamber drive are all located in the north instrument cubicle on the reactor top.

A neutron absorbing segment is connected below the fission chamber and furnishes further means of achieving desired chamber calibration in the three locations. (See figure 26.)

2. Sigma Bus

The sigma bus is part of an elaborate safety system designed to protect the reactor from damaging high fluxes and power excursions and will give an electronic scram under adverse conditions. (See figure 24.)

The magnet amplifiers which supply power to the shim rod magnets are connected to the sigma bus. The sigma bus is a shielded circuit whose voltage controls the output of the magnet amplifiers. With zero voltage on the sigma bus, the magnet amplifiers will have zero output. With 37 volts on the sigma bus, the magnet amplifiers will deliver a nearly maximum output of about 120 milliamps to the magnets. When the sigma bus voltage is increased beyond 37 volts, the magnet amplifiers are biased more and more toward cut off, and the current to the magnet is reduced to a point where the magnet can no longer support the shim rod. One or more rods will drop. This is called an electronic scram and occurs when the sigma bus voltage increases to about 42.5 volts. No scram annunciator is given with an electronic scram and the signal passes through no mechanical relays. This is MTR's fastest scram and takes only 30 milliseconds.

The three neutron level systems and the two log N period systems feed activating signals to the sigma bus in such a way that the highest voltage from any of these five sources will be the controlling voltage, thus the one that senses trouble will cause the scram.

3. Log N - Period System

The two log N - period systems use compensated ionization chambers (CIC) as their sensing elements. The No. 1 log N CIC is located in the east side of the HI-2 instrument facility, and the No. 2 log N CIC is located in the east side of the HI-3 instrument facility. Duplication is deliberate for safety reasons. Should one system fail to function properly, the other is a backup. It is suggested that figure 24 be used to follow the narrative.

a. Chamber Power Supply

Power supplies for the compensated ion chambers are located in the amplifier rack in the monitor room. They supply negative 0 to 350 volts (adjustable) and positive 600 volts to their chambers. A relay which opens at one half normal positive voltage operates an alarm circuit to warn of power supply failure.

b. Compensated Ion Chambers (See figure 27)

The compensated ion chambers are designed to give reliable measurements of neutron flux over a wide range, particularly in the presence of intense gamma radiation. This is accomplished by having two nitrogen gas purged chambers of equal volume built into the CIC. The inside chamber has a volume adjustment for matching the two chamber volumes. The outer chamber is made neutron sensitive by coating its surfaces with boron ten (B^{10}). In a gamma field, both chambers will ionize the same amount of nitrogen gas and their outputs should be equal. In a neutron field, the B^{10} coated chamber will ionize additional gas due to the $B^{10} (n, \alpha) Li^7$ reaction. The outputs of the two chambers within the CIC are connected in opposition so the net result is a signal indicative of neutrons only. The CIC output current ranges from 10^{-4} microamps at low reactor power levels to a maximum of 100 microamps in a flux of 10^{10} n/cm²/sec. (In the MTR, the CIC is repositioned as needed after the reactor reaches 40 Mw, so the chamber will have an output of 45 microamps.)

PP CO - C - 2019

FIGURE 27.
Compensated ionization chamber

c. Log N Amplifiers

The log N amplifiers, located in the amplifier rack in the monitor room, are direct coupled amplifiers with logarithmic characteristics. They receive signals directly from the compensated ion chambers. This signal (0 to 45 microamps) flows from cathode to plate of a log-diode tube in the amplifier. When current is small, the voltage across the diode is proportional to the logarithm of the current. Therefore, the dc signal voltage of the amplifier is proportional to the logarithm of the neutron flux. With no CIC signal, the log N amplifier maintains a potential of 35 v and at 100 percent power the potential increases to 173 v. This potential is applied directly to the period amplifier. The log N amplifier takes a portion of this potential to the 0-10 mv range and drives the log N and period recorders in the control room.

NOTE

Do not confuse the period amplifiers as being connected to and/or driving the period recorders. There is no such connection.

d. Period Amplifiers

The period amplifiers, located in the instrument room below the control room, are part of the safety system associated with the sigma bus. They are coupling devices between the log N amplifiers and the sigma amplifiers. The log N amplifiers supply the period amplifiers with a potential between 35 and 173 volts, depending on the reactor power. The voltage across the period amplifier network is then proportional to the rate of change of the logarithm of the flux. The period amplifier converts the time rate of change signal to a voltage proportional to the period involved and transmits this to the sigma amplifiers. The period amplifiers maintain a normal output of 24 volts to the sigma amplifiers.

e. Sigma Amplifiers

The sigma amplifiers increase the voltage which was received from the period amplifier and transmit it to the sigma bus. The sigma amplifier output is normally maintained at 37.5 volts. An increase to 42.5 volts will represent a one-second period and cause an electronic scram.

f. Log N Recorders

The log N recorders, located in the control room, receive their signals from the log N amplifiers. The recorders are calibrated with a log scale ranging from 0.0001 (10^{-6} N_F) to 300 (3N_F). (10^{-6} N_F corresponds to a neutron flux of 10^8 n/cm²/sec.) Normal recorder reading at 100 percent power is 100 N_F corresponding to a flux of 10^{14} neutrons/cm²/sec. The log N recorders are important instruments in the control system and have six contacts that restrict reactor operation. Below 0.001 N_L, only intermittent withdrawal is allowed because the instruments giving protection against fast periods are not sensitive. Above this, however, switch N-1 closes allowing continuous withdrawal of one or all shim rods. Above 0.1 N_L, switch N-2 closes, energizing the sag relay (R4). This permits the operator to switch the controls into "RUN", and causes the fission chamber to move to its outermost position. R4 also has the function of running the selected MOR to N_L when it drops open; this prepares the reactor for another startup. At about N_L, N-3 closes for a small interval, energizing R70 which permits the run auxiliary relay to become energized. This, in turn, allows movement of the setpoint. The next switch, N-4, is a double pole switch which closes at 3 N_L. One contact gives a reverse if the controls are still in start. The other energizes relay RP-1 and enables certain slow scram circuits, which are necessary only at high power levels, to operate. These features are all explained in detail in the next chapter.

g. Period Recorders

The reactor period recorders indicate and record the period of the reactor. A reactor period has been defined as the time required to increase the reactor flux by a factor of e (2.71). It is also the reciprocal of time rate of change of the logarithm of the flux, ie ,
$$\text{Period} = \frac{d}{dt} (\log \theta).$$
 This is the inverse of the slope of the log N recorder tracing. The slower the power rise, the longer the period.

The relation between the reactor power and the period can be given by $P = P_0 e^{t/T}$ where T is the period, t is the time interval, and P_0 is the power at time = zero. As an example, if reactor power is at 1 Mw and a 5-sec period occurs and is maintained for 16-1/2 sec, power will rise to 27 Mw.

The period indication is obtained by differentiating the output of the log N amplifiers. Auxiliary switches in these recorders also play an important part in reactor operation. Switch T-30, in each recorder, closes whenever the period becomes less than 30 sec. This prevents shim rod withdrawal, unless the "BYPASS" is used. It also requires the reactor period to be greater than 30 sec when changing from "START" to "RUN". Switch T-7 opens if the period becomes less than 7 sec, preventing withdrawal in start. T-5 closes at periods less than 5 sec, and causes a reverse in "START" and a reverse in manual above $3 N_L$.

4. Neutron Safety System

This is the instrumentation which provides the ultimate protection for the reactor. It senses actual neutron density by means of fast response ionization chambers and its electronic circuitry will shut off magnet current without depending on, or waiting for, mechanical relay and recorder response. This is done through the sigma bus, previously discussed. The system is considered so vital that three separate channels are supplied so that even with one being serviced, two will be constantly providing reactor protection. Through the sigma bus, they can initiate a scram in only 30 milliseconds.

a. Parallel Circular Plate Ion Chambers

The three neutron safety systems use parallel circular plate (PCP) ionization chambers as their sensing elements. The PCP chambers are designed, constructed, and located in the reactor so as to give high speed response to changes in neutron flux coming from the core. A cutaway view of a PCP chamber is shown on figure 28. The active section consists of a set of graphite disks, each of which is coated on both sides with B^{10} . This arrangement increases the exposed surface area to neutrons. Alpha particles are emitted by the $B^{10}(n,\alpha)Li^7$ reaction when neutrons bombard these disks. These alpha particles ionize the purging nitrogen gas in the chamber. Under a potential of 300 volts, the maximum ion current produced will be about 50 microamps due to the thickness of the boron coating (0.3 mg/cm^2) on the graphite disks.

The chambers cannot be located as near the reactor tank as would be desirable because

of the extremely high neutron flux. Consequently, they are located in VG holes in the ball graphite a little above the reactor centerline with collimating "boral" sleeves ahead of the chambers to enhance their inherent directional sensitivity to flux directly from the tank. With this arrangement, the major delay is the time, estimated at 5 to 10 milliseconds, for neutrons to leave the core through the tank to the graphite. (No attempt is made to eliminate gamma radiation ionization currents from the system as in the case with the CIC chambers.)

The No. 1, 2, and 3 neutron safety PCP ion chambers are located in VN-1, VN-2, and VN-3, respectively. Triplication is employed for safety reasons and for uniform monitoring of the reactor core.

It is suggested that figure 24 be used to follow the circuit sequence.

b. Safety Preamplifier

The small (0 to 50 microamps) signal from the PCP ion chamber is sent to a one-tube safety preamp located in one of the instrument cubicles on the reactor top. The safety preamp output maintains a voltage of 22 volts to the sigma amplifier with no signal from the chamber. As neutron activity begins and increases, the chamber ionization current increases and the preamp output rises to 32 volts when the reactor reaches 100 percent power.

c. Sigma Amplifier

With no signal, the sigma amplifier maintains 37 volts to the sigma bus. As the safety preamp output increases above 22 volts, the sigma amplifier output increases and will rise to 39 volts when the reactor reaches 100 percent power. If the reactor power continues to increase, the sigma amplifier will increase its voltage output to the sigma bus until the electronic scram point of 42.5 volts is reached. This represents 150 percent of full power. At this time, one or more rods will drop scrambling the reactor.

d. Safety Level Recorders

The three safety level recorders, located in the control room, receive their signals from the sigma amplifiers and record instantaneous flux changes. Contacts set at 110

FIGURE 28
Neutron sensitive 3 inch P.C.P. ionization
chamber

percent on the recorders can give the reactor a slow setback and reverse if the pens drive upscale to that point. (These power reductions are separate from the electronic scram.)

The PCP chambers are usually repositioned, by their mechanical adjustment, after every startup so the recorder pen will read 100 percent power on each recorder. This is because experiment changing and rearranging during the shutdown causes a flux pattern slightly different from the previous cycle. After the reactor stabilizes at full power (calculated by the reactor operator), the chambers are repositioned. This brings the SSB and reverse into proper range. As a matter of interest, the level recorders will indicate a flux shift in the core if the shim rods are not balanced.

5. Galvanometer Systems

Mounted in the console directly in front of the operator are three galvanometer scales. The top scale indicates neutron flux level, and the bottom two (via a split scale on one glass) indicate the neutron count rate and power deviation.

The "FLUX LEVEL" scale can display a signal from either of two galvanometers, both of which receive their signal from a compensated ion chamber in HI-2 (west). The high sensitivity unit is calibrated to 4×10^{-11} amp per millimeter at one meter and is used at low flux levels during startup. The second is 100 times less sensitive and is selected at higher powers.

The control switch for the flux level units is called simply "FLUX LEVEL" and has eight positions. 10^{-4} is the high sensitivity position and either this or the adjacent 10^{-3} position must be selected before rods can be pulled for startup. The third and fourth positions are labeled "HS" and "LS" and mark the separation of the two galvanometer systems. The next three positions are " 10^{-2} ", " 10^{-1} ", and "1" on the lesser sensitive unit. The final position is "OFF".

The upper half of the lower galvanometer glass is divided into four decades of logarithmic scale. This is the count rate indication and when it is switched in through its selector, receives a signal from the log count rate amplifier in the instrument room. The indication is identical to that being recorded by the CRM on the main panel.

The lower scale (25-0-25) of the glass is a useful instrument after power has stabilized and when a drift from the selected setpoint needs to be detected early. When the "DEVIATION GALVANOMETER" is selected, its signal comes from the same CIC used for "FLUX LEVEL" indication. More switches are associated with this unit than the others. The "SELECT CIRCUIT" switch has "CALIBRATE", "LOW", "MEDIUM", and "HIGH" sensitivity positions which refer to it. When in "CALIBRATE", the network is controlled by the "CALIBRATE" rheostat at the left and can be adjusted to zero indication (center of the scale). The other three positions place the galvanometer in progressively more sensitive positions and can be adjusted by the "COARSE" and "FINE" rheostats.

6. N^{16} Monitoring System

Neutron bombardment of the reactor cooling water forms N^{16} in the $O^{16}(n,p)N^{16}$ reaction. The N^{16} decays back into O^{16} with a seven-second half life by emitting a beta particle and a high energy gamma ray. Since the neutrons that are available for N^{16} conversion are proportional to the total reactor neutron flux, monitoring the gamma ray activity of the N^{16} decay indicates approximate power.

a. Air Wall Ion Chambers

Two air wall ionization chambers are used to measure N^{16} gamma radiation. The chambers are located in thimbles placed within the two exit water lines (GM-1 and GM-2). The thimbles are accessible from the reactor top and penetrate the exit water lines at the top of their respective seal loops. The name "air wall" signifies the chambers are made of materials having nearly the same atomic number as air, hence give similar scattering. The chambers are 5 in. in diameter by 19 in. long with cylindrical electrodes. Response of the chambers is 5×10^{-12} amp in a gamma field of 12.5 mr/hr.

b. Preamp and Recorder

The ion chambers send their signal to preamps located in the reactor top instrument cubicles where the signals are amplified and sent to a 0 to 10 mv two-pen recorder in the control room. The recorder is calibrated from 0 to 100 (linear).

The N^{16} indication is one of several checks on the neutron flux within the reactor using a different detection approach.

7. Boron Thermopiles

The boron thermopiles are used for an additional check on neutron flux level. They are located in the solid graphite zone (VG-27, 28, 42, 44, 56) at the same horizontal level. These thermopiles consist of a large number of thermocouple junctions in series, with alternate junctions coated with boron. The thermocouples are so connected that ambient thermal temperature signals from the thermopiles are canceled out. In a field of neutron activity, the boron coated junctions become warmer owing to absorption of neutrons by the $B^{10}(n, \alpha) Li^7$ process, thus yielding a net voltage override which is a measure of neutron flux, since the neutrons available for absorption in the boron are proportional to the total reactor flux.

The thermopiles are 1/2 in. in diameter by 6 in. long. The approx sensitivity is 6 mv in a flux of 10^{12} n/cm²/sec. Internal resistance is of the order of 3 to 4 ohms. By proper mounting and thermal insulation of the thermocouples, the instruments may

be made quite insensitive to ambient temperature (say, 40 microvolt/^oC). For transient conditions, the time constant is about one second. The thermopiles send their signal directly to a 0 to 10 mv recorder in the control room labeled "NEUTRON THERMOMETER".

8. Water Power Indication

Two of the fundamental measurements in the MTR are the flux level and the power generated in the reactor. The one true indication of reactor power is obtained from the heat imparted to the cooling water. The flux level indicators are indications of relative power, but do not necessarily give true power due to variation in chamber position, volume, temperature, poisons, and flux distortion during operation.

The water power recorder, located in the control room, receives a signal of reactor coolant water flow from the main flow recorder and another signal, of the temperature rise through the reactor, from the ΔT recorder. It combines these to give water power.

Water power is derived from the following formula:

$$\text{Power} = \frac{\text{Heat energy added to the water}}{\text{Time}}$$

$$\text{Power} = \frac{(\text{Heat capacity of water})(\Delta T \text{ of water})}{\text{Time}}$$

$$\text{Power} = \frac{(\text{Mass of water})(\text{Specific heat of water})(\Delta T)}{\text{Time}}$$

$$\text{Power} = \frac{(\text{Volume of water})(\text{density})(\text{specific heat})(\Delta T)}{\text{Time}}$$

$$\text{Power} = (\text{Flow of water})(\text{density})(\text{specific heat})(\Delta T)$$

$$\text{Power} = \frac{(\text{gpm})(\Delta T)(8.29 \text{ lb/gal at } 100^{\circ}\text{F})(\text{Btu/lb-}^{\circ}\text{F})}{(5.68 \times 10^{-4} \text{ Btu/Mw-min})}$$

$$\text{Power} = (\text{Mw at } 100^{\circ}\text{F}) = (\text{Flow})(\Delta T)(1.457 \times 10^{-4})$$

$$\text{Power at any temperature} = (\text{Flow})(\Delta T)(\text{Conversion factor})$$

The power recorder incorporates the flow, ΔT and the conversion factor by means of a slide wire bridge and indicates power in megawatts. The recorder is calibrated from 0 to 50. Four slave recorders, two on the first floor and two in the basement, receive a telemetered signal from the master power recorder in the control room.

9. Main Reactor Water Flow

The main reactor water flow is recorded on a "strip chart recorder" located in the control room with a slave recorder in the process water building. The signal to the recorder comes from a venturi and transmitter located in the main pipe tunnel of the process water building. The pressure signal is converted to an electrical signal for transmission to the control room.

10. Differential Reactor Water Temperature

The differential reactor water temperature system measures and records the difference in temperature (ΔT) of the inlet and outlet reactor water and is used in the determination of reactor power. Two resistance bulbs, one located in each of the inlet and outlet water lines, are connected so they provide a signal to the ΔT recorder. The resistance bulbs are located in the reactor main water flow pipe tunnel and are different from the resistance bulbs used for the inlet-outlet water temperature. The recorder is calibrated from -5 through 0°F to + 25°F and will initiate a slow setback at 105 percent full power. Through a slide wire rheostat, the ΔT is transmitted to the water power recorder where it is integrated with the main flow signal to indicate megawatts.

11. Fuel Element Monitoring System

The fuel element monitoring system provides an operating check of the temperature, differential flow and activity of the process water leaving the fuel elements by means of monitor tubes.

a. Monitor Tubes

There are 37 monitor tubes passing through the bottom plug that extend about 100 in. up

into the end boxes of the fuel elements. Only 23 monitor tubes are used with the present slab loading of 23 fuel elements. The extra monitor tubes are part of the design that permits flexibility should another core configuration be desired. Each monitor tube houses four smaller 1/8 in. lines that handle a copper constantan thermocouple and three water lines.

b. Fuel Element ΔT

Two 12 point Leeds and Northrup recorders, located in the monitor room, measure and record the differential temperature (ΔT) between the bulk exit water temperature measured in the reactor pipe tunnel and the temperature of the water leaving the fuel elements as measured by the monitor tube thermocouples. Because of the temperature comparison arrangement, some points on the recorders may read negatively. No point should read greater than +15°F because a high ΔT reading for a fuel element may indicate a blocked cooling channel. Power should not be increased with a high ΔT reading.

c. Differential Flow

The monitor tubes also supply static and dynamic pressure signals to 23 monitor room flow indicators. The ΔP readings are indicative of flow through the fuel elements and can indicate a blockage of flow channels by foreign material or the collapse of fuel plates.

d. Activity

A process water sample is taken from the fuel elements via the monitor tubes. The sample is sent through "100 sec" hold up coils for N^{16} decay and then through a solenoid operated flow switching arrangement. The sample then goes to one of two water activity ion chambers for counting. The ion chambers have a sensitivity of about 3×10^{-13} amp in a 12.5 mr/hr field and their signal is sent to two 0 to 10 mx instruments in the monitor room that record individual fuel element activity. These instruments quickly identify an offending fuel element if one should be the source of fission break activity.

D. AUXILIARY FACILITIES INSTRUMENTATION

1. Reactor Triline Water Flow

The purpose of the 8 in. water system which parallels the main flow lines is to cool the reactor after a scram or shutdown and to flush the reactor prior to taking the top plug off. This is called the bypass or triline system and its flow is recorded on a circular chart in the control room. The originating signal is from an 8 in. venturi located in the main pipe tunnel in the process water building. Loss of triline flow will scram the reactor.

2. Reactor Inlet and ΔP Pressures

The reactor inlet and ΔP water pressures are recorded on a two-point circular chart. The signal inputs for this recorder come from two differential pressure cells which are attached to the inlet and outlet water lines in the main reactor pipe tunnel. Since water cannot be connected directly to the recorder because of contamination problems, the signal is converted to air. A ΔP of 42 psig is maintained across the reactor tank and is the criterion used to determine full water flow.

3. Inlet-Outlet Water Temperature

The inlet and outlet reactor coolant water temperatures are recorded on a two-point recorder in the control room. This instrument receives its signals from resistance bulbs located in the inlet water line and the exit water line. Remember, these are not the same bulbs used in the ΔT system. Due to their placement, their relative temperatures invert when triline flow is being used. Beware of this when taking readings during shutdown periods.

4. Reactor Air In and Out Temperature

The temperatures of the air before entering and after leaving the reactor are sensed by the thermocouples and recorded by a multipoint strip chart instrument. One thermocouple is located in the inlet air duct on the east side of the reactor and the second thermocouple is located in the exit duct plenum chamber just outside the reactor building on the south side. The heat carried off by this air at 40 Mw represents about 1 percent of that being generated.

5. Pressure-Reactor Air Out

The outlet reactor air pressure is indicated by a vacuum gauge. Air is drawn from the reactor building through the reactor air ducts to the fan house and discharged out the stack. A vacuum is then present between the fan house and the reactor. The control room vacuum gauge receives its signal from a re-transmitter located in the reactor basement near the fuel vault. The re-transmitter takes its signal from a sensing element in the exit duct plenum chamber located outside the reactor building under the special services building floor. The re-transmitter and vacuum gauge read pressure below atmospheric in inches of water and will set back the reactor if vacuum approaches within 6.5 in. of atmospheric pressure.

6. Temperature, Reactor Structure

The reactor structure temperatures can be monitored at 47 points. Twelve selected points are recorded on a multipoint strip chart located in the control room. The selected points are within the graphite, thermal, and biological shields of the reactor. An annunciator sounds if any of them exceed 250⁰F.

7. Facilities Temperature

The facilities temperature equipment measures the temperature of out-going water from the six HB liner dummy plugs and both ends of the HT-1 plug which may be in place. These temperatures are indicated on dial faced instruments on the reactor faces near the beam holes and are also recorded on an eight-point strip chart recorder located in the control room. The signals to the temperature indicators and the recorder come from thermocouples located in the exit water lines of the experimental facilities. A high temperature alarm is incorporated into the recorder. Temperatures should be observed carefully for normal response during startup.

8. Instrument Air Pressure

Instrument air pressure at about 125 lbs is supplied to the entire plant by compressors located in the steam plant. This air pressure is monitored at several different places. An indicating gauge is located in the control room.

9. Overhead Working Reservoir Level

The overhead working reservoir level indicator in the control room reveals the water level of the 160,000 gal overhead tank behind the process water building. This gauge receives its air signal from a transmitter in a pit under the overhead tank structure. The air signal is also sent to a level recorder in the process water building. If the reservoir level falls, annunciators, setbacks, and scrams are received in that order.

10. Demineralized Water Back-up Activity Recorder

The demineralized water supply to the reactor building is subject to possible contamination. Due to the piping arrangement in the reactor structure, demineralized water and process (contaminated) water can be used interchangeably for cooling purposes. Such a piping combination is used to take care of emergency situations where vital cooling of one type or the other fails.

At the time of construction, an ion chamber was installed to monitor possible activity in the demineralized water supply. The chamber is located in the wing basement next to the records vault door and is built into the demineralized water piping. The ion chamber sends a doubly amplified signal to an indicator in the control room. On any appreciable reading, the instrument will sound an annunciator.

E. REACTOR CONTROL ROOM ANNUNCIATORS

It is vitally important that the reactor console operator be made aware of abnormal conditions as they develop in systems which could affect the reactor. In order to do this, annunciators are associated with those parts of the plant, reactor, and experiments which fall within this category. At the present time, four separate annunciator panels provide warning information. These are listed in the sequence in which they appear on figure 29, and it is suggested this figure be used to assist in the study of these items. A fully-trained reactor operator should be able to identify the source, meaning, and potential effect on the reactor of all annunciators as they come in.

The annunciators operate like this. When one is tripped, both red and white lights, and the horn come on. To silence the horn, the "ACKNOWLEDGE" button, mounted on the console, is pressed and the white light goes out. The red light remains on until the originating source is cleared, whereupon the white light comes back on and the red light goes out. The white light remains on until the "RESET" button mounted on the console is pressed. The white lights enable the operator to acknowledge a series of annunciators and still maintain a record of the troubles even though correction of the troubles may have already cleared the red lights.

Some experiment trouble lights are red and amber instead of red and white and they function somewhat differently. When trouble occurs at the experiment, both the red light and the amber light are lighted and the horn sounds. When the console operator presses the "ACKNOWLEDGE" button, the amber light goes out and the red light stays on and the horn is silenced. When the annunciator at the experiment control panel is either acknowledged or corrected, the red light on the control room panel board goes out and the amber light comes on. The amber light is then put out by pressing the "RESET" button on the console. In other words, the clearing of the amber light does NOT mean the originating source is necessarily clear. This system enables the console operator to receive additional trouble annunciators from an experiment even though the original trouble may not as yet be corrected.

The four annunciator panels are identified as 1, 2, 3, and 4, and the annunciators are grouped in a general manner according to their function. Panel No. 1 contains plant and reactor area trouble lights. Panel No. 2 concerns reactor controls, power reductions and items directly concerned with the reactor. Panel No. 3 is reserved for specific experiment annunciators, and Panel No. 4 contains area radiation annunciators. The individual annunciators are numbered consecutively. For example, 1-12 is the 12th annunciator on Panel No. 1.

FIGURE 29-A.
Control room annunciator wiring diagram.

FIGURE 29-B.
Control room annunciator wiring diagram.

1. Panel 1 - Plant and Reactor Area Trouble Lights

1-1 - High Temperature Reactor Graphite

This alarm indicates a high temperature in the pebble or permanent graphite zone. The signal is initiated by a control room recorder contact. Thermal shield and concrete temperatures are also monitored but will never be higher than graphite temperatures. This 12 point recorder receives its signal from some of the thermocouples embedded at 47 points throughout the reactor structure so that information may be obtained on the temperature distribution. The alarm set-point is at 225°F.

1-2 - High Temperature Reactor Outlet Air

This alarm indicates high coolant air discharge temperature. The signal is initiated by a contact located in the air temperature recorder. This recorder monitors both inlet and outlet air temperatures by means of thermocouples located in the inlet air duct on the east side of the reactor near the inlet filter, and in the exit plenum chamber outside the south side of the reactor building. The alarm is set to trip at 110 percent of normal inlet temperature.

1-3 - Crossover Bypassed

This alarm should remind the reactor console operator that normal cooling protection to the experimental facilities during full reactor power operation has been bypassed. It indicates that the toggle switch which bypasses the signal circuit to the crossover valve has been placed in the "BYPASS" position. No "low pressure switchover" is possible with the system bypassed.

1-4 - Low Pressure Water to Beam Holes

This alarm indicates low cooling water flow to any of the six horizontal beam

hole dummy plugs. This signal is initiated by one of the seven mercoird switches located in the monitor room which receive their signals from differential pressure transmitters mounted on the reactor face. The mercoird systems are not in use when an experiment is in the hole. HB-3 and HT-1 are using plugs without beryllium tips and need no coolant.

1-5 - Low Flow Water to Beam Holes

Low pressure on either the process water or demineralized water side of the emergency water to the experimental facilities valve will trigger this alarm. The signal is initiated by mercoird switches located on either side of this "crossover" valve at the canal. The valve opens on low pressure (30 psig) and the annunciator sounds. Reset occurs at 50 psig.

1-6 - High Temperature Water From Beam Holes

An alarm here indicates high temperature (175°F) of the discharge cooling water from any of the six horizontal beam holes which do not have experiments in them. The signal is initiated by a contact in the water temperature recorder in the control room. This recorder receives its signals from thermocouples located in the exit water lines of the experimental holes.

1-7 - High Level HED Tank

The high level annunciator comes from the 600 gallon Hot Experiment Drain tank under the southeast stairwell in the reactor basement. Effluent going to this tank is highly contaminated and will be from one of the major experiments, usually following a fission break. There is no continuous flow into the HED tank and any alarm should be investigated. In addition to the control room annunciator, an alarm, a silencing switch and a red light are mounted on the east wall of the monitor room to alert the basement operator of high level. The 37 in. diameter tank is set to annunciate at 25 in. on the level indicator mounted on the north wall in the stairwell.

1-8 - High Level Reactor Building Sump

This alarm is caused by a high water level in the mildly radioactive (warm) building sump located below floor level at the west side of the reactor basement. The signal is initiated by a contact on the sump float switch. High water level in this sump indicates probable failure of both pumps.

1-9 - High Level Pipe Tunnel Sump

This alarm indicates high water level in the contaminated sump located in what is commonly called the "Snake Pit" (Reactor pipe tunnel). The signal is initiated by a contact on the sump float switch. High water level in this sump could indicate failure of the pump.

1-10 - High Level Reactor Drain Tank

This alarm indicates a high water level in the highly radioactive, glass lined reactor drain tank located below floor level at the west side of the reactor basement. The signal is initiated by a contact on the tank float switch. High water level in the drain tank indicates failure of the pump.

1-11 - High Level Canal Sump

The canal sump is located below floor level just south of the canal in the reactor basement. The high level signal is initiated by an electrode sensing system in the sump. It comes on when the second pump starts and also gives an annunciator in the monitor room. High water level in the canal sump could indicate failure of the canal sump pumps.

1-12 - Vital Circuit Breaker Open

Loss of voltage to certain critical reactor instrumentation and control circuit breakers will actuate this annunciator and also may cause the reactor to receive an FSB or reverse. The purpose is to alert the control room anytime a circuit breaker is opened which will affect reactor control. If its opening is particularly

critical, the reactor will be shut down automatically. The instruments involved are: main flow and bypass flow recorders, ΔT , N_{16} , and neutron thermometer recorders. Other control equipment includes the servo amplifiers, shim rod motors, and loss of power to the rheostat drive motors or amplidynes.

1-13 - Annunciator Panel Dead

Loss of power to the annunciator panel gives a light in the "Annunciator Panel Dead" window and a fast setback to the reactor. Power to light the annunciator window is drawn specially from the reactor MG sets.

1-14 - Power Loss to Slave Power Recorders

An alarm here indicates loss of electrical power to the four slave power recorders. Two of these recorders are located in the reactor basement and two on the main floor. The signal is initiated by a switch located in the power supply unit mounted on the back of the main flow recorder in the control room.

1-15 - Trouble Experiment Emergency MG Set

The alarm indicates trouble at the experimentors' failure free MG set. The signal can be initiated by a number of relays and switches which indicate failure of one or more components. Because these motor generator set troubles (open switches, etc) may deprive the experiments of power and result in serious consequences, the reactor will be automatically scrammed.

1-16 - Power Loss to Seismic System

Loss of power to the seismic scram system will actuate this control room annunciator. The annunciator will clear itself when power is restored. Power for the system comes from relay buses 1 and 2.

1-17 - Trouble Reactor Control MG Sets

An abnormal condition existing at one of the reactor control motor generator sets will cause this annunciator. Potential sources are: motor M-3; motor M-4; generator G-3; generator G-4; frequency instrument bus; frequency control bus, phase failure instrument bus; and phase failure, control bus. The motor-generator sets located in the wing basement are equipped with a local alarm panel. Since no acknowledge or reset button is provided at this panel, the condition must be corrected before the control room alarm will clear.

1-18 - Low Voltage to Galvanometer Ion Chamber

Voltage supply to the flux galvanometer ion chamber, located in HI-2 west, has failed when this annunciator occurs. The signal is initiated by a no voltage relay in the power supply unit located in the monitor room.

1-19 - Control Relay Blocked

Five special plastic blocks have been provided for holding reactor control relays open, when necessary, during shutdown. These blocks hang on a bolt on a special pressure switch. Removal of even one of the blocks closes a contact which energizes the annunciator relay. The system warns against startup with any relays blocked with one of these special units. In addition to the control room annunciator, a white light comes on in the relay panel.

1-20 - Dry Dock Test Block Out

If one or more of the dry dock test blocks, (numbers 1 through 4 are located in the electronic instrument room) have been removed, this annunciator will sound. No. 3 dry dock test block is removed during reactor shutdowns to transfer the signal from the annunciator buzzer from the control room to the reactor top.

1-21 - Top Plug Not Connected

If one or more of the eight amphenol plugs in the "semaphore" arms on the reactor top is disconnected from the top plug, this alarm will sound.

1-22 - Low-High Canal Level

If the level in the canal gets 6 in. above or below normal, the alarm will sound. The signal is initiated by a pressure switch which receives its signal from an air bubbler located near the east end of the canal, (south side). An annunciator also is located in the monitor room.

1-23 - Loss of Suction Vent Scrubber

This alarm indicates a loss of vacuum due to failure of vent scrubber blowers in the Fan House. The signal is initiated by a mercoird switch located near the vent scrubber in the wing basement. The set-point is variable and is set so as to detect an early loss of the exhaust blowers. Loss of vacuum will also give an annunciator in the monitor room and in the Alpha Lab. The latter alarm is independent of the vent scrubber mercoird.

1-24 - High Temperature Fuel Element Water

A 15°F differential between the temperature of the cooling water leaving a fuel element and the bulk exit water temperature will cause this annunciator. The signal can originate at two recorders in the monitor room instrument board. Each is a 12 point unit and monitors fuel element ΔT for most of the core positions. Thermocouples located in the tips of the monitor tubes sense fuel element discharge temperatures. These are compared with a common couple located in the discharge line. A plugged or abnormally hot element will show a marked ΔT rise. An annunciator located in the monitor room instrument also sounds when the control room unit is tripped.

1-25 - High Temperature Main Water

An alarm here indicates high reactor coolant water discharge temperature. The signal is initiated by a contact in the water temperature recorder. This recorder monitors both inlet and outlet temperatures of the reactor water by means of resistance bulbs located in the pipe tunnel ("Snake Pit"). Since both inlet and outlet temperatures vary from summer to winter, the alarm is adjusted to trip at 110 percent of normal outlet temperature.

1-26 - Trouble MTR Clark Compressor

The Clark Compressor is provided to supply air for experimental programs at the MTR and as a backup for ETR experiments. Trouble at the compressor will seriously affect these operating experiments. Annunciators are received from high discharge air temperature, high cooling water temperature, high oil temperature, low oil pressure, low water pressure or flow and excessive vibration. There is an annunciator in the process water building control room also.

1-27 - Low Pressure Instrument Air

This alarm indicates low instrument air pressure from the air tanks at the steam plant. The signal is initiated by a pressure switch mounted behind the control room panel and is set to alarm at 90 psig. The normal supply pressure is 115 to 125 psig. There also is an alarm in the steam plant on low instrument pressure.

1-28 - Low Pressure Ion Chamber Gas

This alarm indicates high or low argon pressure on the fission chamber, or high or low nitrogen pressure on the flux level galvanometer chamber, both log N and Period chambers, both servo chambers, or all three neutron level chambers. The signal is initiated by mercoid switches mounted on the nitrogen

and argon headers located in the monitor room. The alarm will sound in the monitor room and the reactor control room if the pressure exceeds 5.5 psig or drops below 1.5 psig.

1-29 Through 1-31 are Spare Panels

1-32 - Fire-Main Floor Shielding

This annunciator monitors the sprinkler system which protects the paraffin boxes and borated plastic used as shielding around the reactor. The annunciator is actuated by one of four things: 1. Manual water supply valve closed; 2. Water flow, indicating either fire or failure of one of the sprinkler heads; 3. Low water pressure; 4. Low air pressure in the sprinkler lines or reverse tank. The system should be immediately checked when this alarm sounds.

1-33 - Fire - Wing Basement

This alarm indicates a fire somewhere in the wing basement or failure of some component in the existing protection system. When it comes on, it should be assumed a fire exists. The signal is initiated from several sources. Fusible links, located in the electrostatic blower room, will melt at 212°F allowing water to flow through sprinkler heads over the electrostatic filters. A vane-type switch, located in the water header, gives an alarm in the reactor control room. An automatic sprinkler system with fusible plugs that melt at 212°F covers a large portion of the wing basement area. The supply header for these sprinkler heads contains warning devices in case of failure. Loss of pressure punches the ADT system tapes in the steam plant, guard gate, and the central fire station. A closed block valve punches the ADT system tapes. Flow in the line, indicating an open sprinkler head, punches 316 on the ADT system tapes and rings the fire code bells.

1-34 - Air Conditioner Failure, Lab 120

In case of air conditioner failure, such as motor overload, severe voltage

fluctuation, loss of water flow or loss of refrigerant, the unit will shut down and the annunciator will sound. If the unit cannot be restarted, the appropriate technical group should be contacted.

1-35 - Air Conditioner Failure Wing Basement Counting Room (Same as 1-34)

1-36 - Air Conditioner Failure Fuel Scanning Room (Same as 1-34)

1-37 - Air Conditioner Failure Counting Room Extension (Same as 1-34)

1-38 - Spare panel

1-39 - Spare panel

1-40 - Alpha Lab Exhaust Blowers Off

The Alpha Lab blower exhausts air through the laboratory hoods where radioactive materials are handled. It is important that this blower be kept running since radioactive or other troublesome gases could gravitate into the labs. When the blower shuts down, the annunciator will sound. It should be checked immediately.

1-41 - Reactor Building Blowers Off

This annunciator indicates that the reactor building blowers, which keep the building at a slightly positive pressure, are off. An emergency stop button is located at the reactor control console to shut down the blowers in the event of a fission break or other air activity problems. This will minimize spreading contaminated air any more than necessary.

1-42 - Spare panel

1-43 - Spare panel

1-44 - Spare panel

2. Panel 2 - Reactor Trouble Lights

Panel 2 contains annunciators that indicate power reductions and other

important features in the reactor controls and instrumentation. This panel has such vital information that it should be the first one examined when the annunciator horn sounds.

2-1 - Slow Setback

This alarm indicates relay R-6 has been energized causing an "automatic run-down" of the motor operated rheostat. It will go from N_F to N_L in 465 sec. There are many sources of slow setbacks from experiments, as well as the reactor controls.

2-2 - Fast Setback

This alarm indicates relay R-5 has been energized causing an "automatic rundown" of the motor operated rheostat. The reactor will go from N_F to N_L in 88 sec. There are many sources of fast setbacks from experiments, and the reactor controls. These should be learned by study of current setpoint lists.

2-3 - Reverse

When relay R-20 has been energized, this annunciator will sound and an "automatic insertion" of all shim safety rods will occur. There are reverses from experiments, as well as the reactor controls.

2-4 - Jr. Scram

This alarm indicates relays R-68J and R-69J have been energized, shutting off the ac current to No. 6 and No. 7 magnet amplifiers. This causes No. 6 and No. 7 shim rods to fall into their seats. Jr. scram power reductions originate from the experiments and reactor instruments. The reactor console is not equipped with any method for manually initiating the release of No. 6 and No. 7 shim-safety rods.

2-5 - Scram

This is the most complete shutdown provided by the control circuit. The alarm indicates relays R-68 and R-69 have been

energized shutting off ac power to all magnet amplifiers. All seven shim-safety rods fall into their seats. There are many sources of scrams from the experiments, as well as the reactor controls. A scram annunciator is NOT received when an electronic (fast) scram occurs.

2-6 - Experiment Scram

This alarm indicates the reactor has been scrambled by an experiment. It will also indicate to the reactor console operator when the scram conditions at the experiment clear. The experiment signal is supplied to the annunciator and reactor scram relays through the experiment "W" switch circuits.

2-7 - High Activity N-16

This alarm indicates 10 percent higher than normal N-16 activity in the reactor exit cooling water. The signal is initiated by the recorder in the control room which takes advantage of the principle that the number of N-16 atoms in the exit cooling water are proportional to the average reactor core flux. Air wall ion chambers, located near the top of each seal loop, measure the gamma rays emitted from the N-16 atoms. An alarm and fast set-back will occur at $1.1N_F$. A scram will occur at $1.2 N_F$. Loss of voltage to the electrometer power supply will drop out either or both relays, RNP or RNS, and give an alarm. Removal of test block No. 16 also gives an alarm.

2-8 - Low Reactor ΔP

A pressure switch on the pneumatic input to the reactor ΔP instrument is set to annunciate and give a Jr. scram on low ΔP . This system is a backup for the main flow instrument and will trip at a ΔP corresponding to main flow at 80 percent.

2-9 - CRM Off Scale

There are two count rate meters, one in the control room and one on the reactor top. If either one goes above its setpoint this annunciator will sound. During startup

or operation it indicates an upscale drive as power is raised. During shutdown it serves its main function, that of warning plainly that reactivity is rising and should not be. The reactor top unit should have its setpoint just above equilibrium conditions so as to give maximum warning of upward movement.

2-10 - $3N_L$ In Start

If a reactor power level of $3N_L$ is attained while the reactor control system is still in the "START" regime, ie, with relay R-3 (run auxiliary) not picked up, this alarm will sound. The signal is initiated by contacts in either of the log N. recorders. They will give the alarm, pick up relay R-20, and put the reactor into a reverse. At $3N_L$ on either log N recorder, contacts pick up relay RP-1 which in turn picks up the period integrator circuit which allows the reactor to scram only if a period of one second for a duration of one second occurs. When the integrator circuit is picked up, period trouble alarms will "blip".

2-11 - Five Second Period

When the rate of reactor power rise is increasing by a factor of "e" every five seconds this alarm will sound. The signal is initiated by contacts in either period recorder. If the reactor controls are in either the manual or "START" regime, relay R-20 will be energized and a reverse will be given. If the reactor controls are in the "RUN" regime, only the alarm will be received.

2-12 - Seismic Scram

A horizontal shifting of the reactor structure will close the seismic scram switches. The seismic scram may be actuated from either of two oil damped, pendulum switches which are attached to the north face of the reactor on the 2nd floor balcony. There are two white lights at the box to indicate which switch has closed. A reset button is located in the box and the scram must be reset from there.

2-13 - Low Fuel Element ΔP

This alarm indicates low reactor cooling water flow through any of the 23 fuel elements in the lattice. The signal can be initiated by contacts in any of the meletron switches located outside the monitor room. The differential pressure meletrons receive their signals from the monitor tubes which contain static and dynamic pressure taps. This pressure difference is proportional to the flow through the element. A drop of 2 psig will give an alarm, and a drop of 4 psig will give the reactor an automatic scram with accompanying alarms in the monitor room and control room. Normal readings vary slightly from cycle to cycle.

2-14 - Low Flow Bypass Water

Low cooling water flow to the reactor through the 8 in. bypass line will trip this annunciator. The signal is initiated by a contact in the circular recorder located in the control room. It receives its signal from a flow venturi located in the pipe tunnel in the process water building. This reactor recorder is a slave to the one located in the process water building. Normally, with the reactor at 40 Mw, flow through the bypass line is 1000 gpm and an alarm and scram occurs at 800 gpm. Removal of test block No. 21 gives an alarm also. An alarm is located in the process water building control room.

2-15 - Low Flow Main Water

This alarm indicates low main water flow to the reactor through the 30 in. inlet line. The signal is initiated by the recorder in the reactor control room, which receives its signal from a flow venturi located in the pipe tunnel of the process water building. This recorder drives a slave recorder in the process water building. The setpoint is variable because experiment changes in the reactor tank from cycle to cycle change the coolant flow required. Removal of test block No. 22 gives an alarm in the process water building control room. Remember this:

low bypass flow will give an alarm and scram at any reactor power level. Low main flow will give an alarm and scram if reactor power is above 3 N_L. Simultaneous removal of both test block No. 21 and test block No. 22 (bypass and main flow test blocks) will cause a scram at any reactor power level.

2-16 - Low Level Working Reservoir

Water level less than 80 percent in the overhead working reservoir will trip this alarm. The signal is initiated by a relay located in the process water building, which in turn receives its signal from a transmitter located in the pit below the working reservoir. A reactor scram will occur when the working reservoir is less than 50 percent full (contains less than 65,000 gal of water). Removal of test block No. 24 gives an alarm also. High or low level of the working reservoir will give an alarm in process water building control room.

2-17 - Low Flow Reactor Air

This alarm monitors cooling air flow through the reactor thermal shield and graphite regions. The low flow signal is initiated by a recorder contact in the process water building air flow recorder. The recorder receives its signal from a flow tube located in a pit just west of the fan house which measures flow through the reactor air exhaust line. The recorder reading multiplied by 2200 is approximately equal to pounds per hour of air flow. Low air flow will give an alarm in the process water building. Removing test block No. 19 also gives an alarm in the reactor control room.

2-18 - Loss of Vacuum Reactor Outlet Air

This alarm signals loss of vacuum in the reactor air system. The annunciator is initiated by contacts in a meletron relay located behind the panel board in the control room. The meletron relay receives its signal from a transmitter in the reactor basement which is connected

to the exist air duct outside the reactor building. It measures the vacuum between the reactor and the fan house. The alarm is set to trip at a gauge reading of 8.5 and a fast setback will occur at a gauge reading of 6.5. Removal of test block No. 20 will also give an alarm.

2-19 - High Reactor Water ΔT

Anytime a differential temperature greater than 105 percent normal exists between the inlet and outlet reactor cooling water, the alarm will sound. The signal is initiated by the ΔT recorder which receives its signals from two resistance bulbs in the pipe tunnel. One is located in the inlet and the other in the outlet water line. By means of the ΔT indication and cooling water flow, reactor power is calculated. Removing test block No. 18 also gives this alarm.

2-20 - High Level Boron Thermocouples

This alarm indicates the over-all neutron flux level of the reactor has exceeded its normal operating level by 10 percent. The signal is initiated by a contact in the neutron thermometer recorder. This recorder receives its signal from 5 thermopiles placed symmetrically around the reactor core in vertical graphite holes. A thermopile is a large number of TC's hooked in series with alternate TC's inverted. These alternate TC's have their junction coated with boron to make them sensitive to neutrons. The boron coated junctions become warm due to absorption of neutrons and gamma rays while the uncoated junctions are heated by gamma rays only, thus the net voltage is a measure of neutron flux level. Because of its fast response, the neutron thermometer is an important instrument during transient reactor power conditions. Removal of test block No. 17 gives an alarm also.

2-21 - High Power Main Recorder

If the reactor main power recorder goes above 42 Mw the alarm will sound. The signal is initiated by a contact in the

control room power recorder. This instrument drives four other recorders located throughout the reactor building. It receives its signal from a wheatstone bridge circuit with three slidewire resistors which are located in the main flow recorder, the ΔT recorder and the water power recorder. The latter is calibrated directly in megawatts of water power. Removal of test block No. 15 will also give an alarm.

2-22 - High Servo Demand

This alarm indicates an excessive current demand in the field of the servo-amplidyne. The signal is initiated by the de-energizing of relay contact RSD-1 in the servo amplifier and occurs when a current difference of 20 mils, or greater, exists in the field of amplidyne. This alarm occurs frequently while advancing reactor power by raising the motor operated rheostat setpoint.

2-23 - Main Valve Closed or 30 Second Power Failure

This alarm indicates that one of these conditions exists: (1) commercial power has been lost to the sump pumps for 30 sec; (2) the main butterfly valve is less than 40 percent open; or (3) the main downstream block valve is less than 40 percent open. Any of the three conditions will scram the reactor. The signal is initiated by either a time delay relay in the process water building or by microswitches mounted on the main downstream block and butterfly valves. An annunciator is received in the process water building control room also. Removal of test block No. 11 in the instrument room will give the alarm in the reactor control room.

2-24 - Loss of Relay Power

This alarm indicates loss of voltage to the relay bus. The signal is initiated by a contact in relay R-66 which will allow approximately 2 seconds delay before de-energizing, giving the alarm, and scrambling the reactor. Removal of

test block No. 10, located in the instrument room, will also give the alarm.

2-25 - Level No. 1 Trouble

An alarm here indicates abnormal conditions in any of the following: low voltage to the ion chamber, loss of voltage to the preamplifier plate, improper output of the preamp, and sigma amplifier tube failure. Further, if No. 1 level is removed from the sigma bus, relay REL-1-1 drops out and gives an alarm.

2-26 - Level No. 2 Trouble

This alarm indicates abnormal conditions for No. 2 identical to those of No. 1.

2-27 - Level No. 3 Trouble

This alarm indicates abnormal conditions for No. 3 identical to those of No. 1 and No. 2.

2-28 - Period No. 1 Trouble

An alarm indicates abnormal conditions in any of the following: Log N amplifier calibrate switch in any position except "OPERATE", low voltage to the ion chamber, improper output of period amplifier, sigma amplifier tube failure, or malfunction of the No. 1 period integrator circuit. If No. 1 period system is removed from the sigma bus, relay contact REL-2-1 drops out and gives an alarm. Removal of test block No. 5 will light the red instrument "OUT-OF-SERVICE" light on the recorder.

2-29 - Period No. 2 Trouble

The alarm signals abnormal conditions in any of the following: sigma bus amplifier chamber; voltage to the preamp plates; preamp grid off-set, or malfunction of the No. 2 period integrator circuit. If No. 2 period is removed from the sigma bus, relay contact REL-3-1 drops out and gives the alarm. Removal of test block No. 7 will light the red trouble light on the recorder.

2-30 - Magnet Amplifier Trouble

This alarm indicates either high (90 ma) or low (28 ma) current supply to the magnets from any one of the magnet amplifiers. The alarm is initiated by relay contact RM-2-1 which receives its signal from mercooid contacts in the magnet amplifier recorder. This alarm should tell the reactor console operator that one or more of the magnet amplifiers has failed.

2-31 - Level No. 1

Abnormally high neutron flux level in the northwest quadrant of the reactor will cause this alarm. The signal is initiated by a contact in the No. 1 neutron level recorder in the reactor control room. The recorder receives its signal from a parallel circular plate ion chamber located in VN-1. A flux level of 1.1 N_F will give an alarm and put the reactor into a reverse. If the input voltage to the sigma bus, which is normally 32 volts, should exceed 35.5 volts, the thyatron tube in the sigma amplifier will fire and give an alarm. Removal of test block No. 12 will give the red instrument "OUT-OF-SERVICE" light on the recorder.

2-32 - Level No. 2

Level No. 2 recorder receives its signal from a parallel circular plate ion chamber located in VN-2 (NW quadrant of reactor top). In all other respects the annunciator information is identical to No. 1. Removal of test block No. 13 will light the red instrument "OUT-OF-SERVICE" light on the recorder.

2-33 - Level No. 3

Level No. 3 recorder receives its signal from a parallel circular plate ion chamber located in VN-3 (SE quadrant of reactor top). In all other respects the annunciator information is identical to No. 1 and No. 2. Removal of test block No. 14 will light the "OUT-OF-SERVICE" light on the recorder.

2-34 - Period No. 1

This alarm indicates a short reactor period (the time it takes for the reactor power level to increase by a factor of "e"). The alarm is initiated by relay R-75 which receives its signal from contacts in the No. 1 period recorder. This instrument receives its signal from a compensated ion chamber located in HI-2 east, which monitors neutron flux. A 5 sec period will give an alarm and put the reactor in a reverse, provided the reactor controls are in the "START" regime, manual above 3 N_L, or "RUN" without the auxiliary relay energized. If the input voltage to the sigma bus, (which is normally 32 volts) should exceed 35.5 volts, the thyatron tube in the sigma amplifier will fire and actuate an alarm.

2-35 - Period No. 2

This alarm is a duplicate of period No. 1 except that the compensated ion chamber is located in HI-3, east. The reactor period indication is very important to the reactor console operator, especially at low reactor power levels.

2-36 - Magnet Amplifier Transfer

This alarm indicates that one of the magnet amplifiers in the instrument room has been removed from the alarm circuit. This is normally done to allow the electronics technician to work on the selected magnet amplifier without initiating the magnet amplifier trouble alarm.

3. Panel 3 - Experiment Trouble Lights

Panel 3 contains alarms for experiments in the reactor which have power reductions associated with them. These alarms will tell the reactor console operator when an experiment has trouble and which one it is, but, and this must be clearly understood, the alarm will NOT indicate what the trouble is nor how the trouble may affect the reactor. The operator must rely upon the automatic built in safeties in the reactor and experiment controls to take corrective action.

Of course, the advance warning annunciator will allow operators to take action which may eliminate the potential power reduction.

3-1 - Trouble KAPL-HB-1

Abnormal conditions at the HB-1 loop will cause this alarm. This is one of the amber and red annunciators. When the acknowledge button is pushed at the loop, the red light in the reactor control room will go out. It is then possible to receive another alarm if some other loop parameter becomes abnormal. The trouble signal comes from such things as high temperature, low flow, high or low pressure, high radiation, etc.

3-2 - Trouble KAPL-L-42

The L-42 annunciator is another of the amber and red variety. Parameters such as low flow, high or low pressure, and high temperature are the more important causes.

3-3 - Trouble WAPD-B-4

The annunciator for WAPD-B-4 indicates trouble of the same types that the KAPL experiments do. The alarm window has a red/white light and operates differently from the red/amber units. When an alarm signal comes through from the loop, the red and white lights both come on. When the console operator acknowledges the alarm, the white light goes out. The red light stays on. Another abnormal condition at the experiment will only be evidenced by the white light in the control room, since the red light is already lit.

3-4 - Trouble WAPD-VH-3

Abnormal conditions of flow, pressure, radiation, temperature and miscellaneous other parameters actuate this annunciator. The alarm unit is one of the original (red/white) type.

3-5 - Trouble GEH-B-3

This alarm unit is the red/white type. It is actuated from low flow, high/low pressure, high radiation and high temperature.

3-6 Through 3-12 are Spare Panels

3-13 - Trouble PAED-37-HR-4

The annunciator for PAED-37 is the red/white type and alarms from low coolant flow and high plug temperature.

3-14 - Trouble PAED-HB-2

The annunciator is red/white. Conditions which actuate it are: low flow, high/low liquid level, high/low pressure, high radiation and high temperature.

3-15 - Trouble ORNL-HB-3

ORNL-HB-3 has an annunciator of the original (red/white) type. It is actuated by low coolant flow, low coolant pressure, high radiation, high temperature, and several minor parameters.

3-16 - Trouble VH-4 Experiment Flow

Experiments are run in the VH-4 rabbit facility that must have adequate water flow because of their high rate of heat generation. The facility is equipped with a rotometer and two pressure switches; one for an annunciator and the second to provide a full scram on low water flow. These are set to meet the requirements of individual experiments.

3-17 - Trouble HB-4 Crystal Spectrometer

This alarm indicates low demin cooling water pressure to the crystal spectrometer shielding plug. The signal is initiated by a pressure switch located at the face of the reactor near the HB-4 hole. The alarm is set to trip if the pressure gets below 4 psig.

3-18 - Trouble HB-6 Chopper

This alarm indicates low demin cooling water pressure to the neutron chopper columnator and shielding plug. The signal is initiated by a mercooid switch located at the face of the reactor near the HB-6 hole. The alarm is set to trip if the pressure gets below 4 psig.

4. Panel 4 - Radiation Trouble Lights

Panel 4 contains alarms for abnormal radiation fields throughout the areas. Some annunciators indicate gamma fields and some are indicative of air borne activity. All signals which cause the alarms are monitored on 4 multipoint recorders in the Health Physics office. Points 1 through 7 record signals from Constant Air Monitors in the reactor building. The remaining points are concerned with radiation sensing heads throughout the entire MTR area. These "Tracerlab" heads sound a bell and flash a red light when actuated, and at the same time, annunciators sound in the HP office and reactor control room.

4-1 - High CAM Activity Basement - Canal

Constant air monitors have 3 scales, 2X, 10X, and 20X. When sufficient activity accumulates on the filter to cause a shift to the 10X scale, a yellow light comes on and several rings of the local bell occur. The HP office alarm also sounds. When activity causes a change to the 20X scale, a red light and bell come on, another HP alarm occurs and the control room annunciator sounds. The CAM for this alarm is located just north of the main canal.

4-2 - High CAM Activity, Reactor Top

CAM operation is the same as 4-1

The instrument is located on the SW reactor top.

4-3 - High CAM Activity, Services Building

CAM operation is the same as 4-1.

The instrument is located near the center of service building.

4-4 - High CAM Activity, Basement South

CAM operation is the same as 4-1.

4-5 - High CAM Activity, Basement North

CAM operation is the same as 4-1.

4-6 - High CAM Activity, First Floor South

CAM operation is the same as 4-1.

4-7 - High CAM Activity, First Floor North

CAM operation is the same as 4-1.

4-8 - Spare panel

4-9 - Spare panel

4-10 - Spare panel

4-11 - Spare panel

4-12 - Spare panel

4-13 - Very High Radiation Reactor Building

This alarm receives its signal from five Tracerlab monitor heads.

HP Monitor No. 6 The PAED-HB-2 panel in reactor basement

HP Monitor No. 7 The southwest corner of the reactor basement

HP Monitor No. 8 The reactor top near north semaphore arm

HP Monitor No. 9 The south side of reactor under the balcony

HP Monitor No. 10 The north side of reactor under the balcony

These alarms are set to trip if the radiation field exceeds 5 r/hr.

4-14 - High Radiation Reactor Basement

This alarm receives its signal from ten positions in the reactor basement.

HP Monitor No. 21 The PAED-HB-2 sample house

HP Monitor No. 22 The west wall of the reactor basement

HP Monitor No. 23 The PAED-HB-2 cubical entrance

HP Monitor No. 24 The southwest corner of the reactor basement

HP Monitor No. 25 The inside of the decontamination room

HP Monitor No. 26 The south side of the rabbit canal

HP Monitor No. 27 The east end of the canal on the north side

HP Monitor No. 28 The north side of the main canal

HP Monitor No. 29 The south side of the main canal

HP Monitor No. 30 The dry dock area in the reactor basement

These alarms are set to trip if the radiation fields exceeds 200 mr/hr.

4-15 - High Radiation Reactor Top or Main Floor

This alarm receives its signal from eight monitor heads.

HP Monitor No. 11 The north side of reactor under the balcony

HP Monitor No. 12 The south side of reactor under the balcony

HP Monitor No. 13 The north reactor face on the balcony

HP Monitor No. 14 The south reactor face on the balcony

HP Monitor No. 15 The reactor top near north semaphore arm

HP Monitor No. 16 The reactor top near south semaphore arm

HP Monitor No. 17 The east reactor face on the stairway

HP Monitor No. 18 The west reactor face near HR-4

These alarms are set to trip if the radiation field exceeds 100 mr/hr.

4-16 - High Radiation Outside Areas or Sub-pile Room

This alarm receives its signal from four monitor heads.

HP Monitor No. 1 The south side of the hot cell.

HP Monitor No. 3 The process water building basement

HP Monitor No. 4 The north side of the hot cell

HP Monitor No. 5 The sub-pile room

These alarms are set to trip if the radiation field exceeds 100 mr/hr.

4-17 - High Radiation at ETR Critical or Lab 111

This alarm receives its signal from two monitor heads.

HP Monitor No. 19 The ETR critical facility

HP Monitor No. 20 The laboratory numbered 111 in the wing

These alarms are set to trip if the radiation field exceeds 10 mr/hr.

4-18 - High Radiation Engineering Research Laboratory

This alarm receives its signal from No. 2 Tracerlab monitor head located in the engineering research laboratory (northwest corner of wing basement). The alarm is set to trip if the radiation field exceeds 5 mr/hr.

4-19 - Spare panel

4-20 - Spare panel

4-21 - Spare panel

4-22 - Spare panel

4-23 - Spare panel

4-24 - Spare panel

4-25 - High Activity Iodine Monitor

An alarm in this system indicates an increase in the relative concentration of 6.7 hr iodine-135 in cooling water from the reactor. A continuous water sample is drawn from the exit water line in the Snake Pit. It then passes through a cation and anion resin bed located near the main canal. The cation bed removes ions with gamma activity energies which might mask the I-135 which is caught in the anion bed. A scintillator monitors the activity and a discriminator circuit ignores pulses caused by gamma rays of less energy than those of I-135. High iodine is an indication of a fission break somewhere in the reactor core. The control room signal is initiated by a contact in the recorder and also sounds an annunciator in the monitor room.

4-26 - High Activity Fuel Element

This alarm indicates high activity being discharged by one or more of 32 possible lattice fuel positions. The signal is initiated by recorder contacts in either of the two multi-ranged 12 point recorders

located in the monitor room. These recorders receive their signals from water samples taken from the monitor tubes. The fuel element water activity will vary slightly from cycle to cycle, but the alarm should be set to trip at approximately 110 percent of the highest normal reading. High activity will give an alarm at the monitor room also.

4-27 - High Activity Stack

This annunciator indicates high activity gases being exhausted to the atmosphere through the stack. The signal is initiated by a recorder in the fan house which has 3 ranges and a variable setpoint. When operating, it should be on the 2X scale and read less than 10. The annunciator will also sound if the particulate activity pickup tape breaks. There is a high stack activity alarm in the process water building control room, but no alarm if the tape is broken.

4-28 - High Activity Seal Tank

High gamma activity in the process water system will sound this alarm. The signal is initiated by a contact in the activity recorder located in the reactor control room. The recorder receives its signal from an ion chamber located in the tank room near the pipe supplying water to the seal tank. The setpoint is variable. There is also a high seal tank activity annunciator in the process water building control room.

4-29 - High Activity Catch Tank

High activity in the catch tank valve pit is signaled by this annunciator. The alarm is initiated by a Sim-ply-trol indicator located in the health physics office. This indicator receives its signal from a Jordan head mounted near the ladder in the catch tank valve pit. The setpoint is variable depending upon the general background. High activity will give an annunciator in the health physics office also.

4-30 - High Activity Demineralized Water

High activity from the inlet demineralized water line to the reactor building activates this alarm. The signal is initiated by a contact in the control room recorder which receives its signal from an ion chamber located near the record storage vault in the wing basement. The setpoint on the recorder is variable.

4-31 - High Activity, Alpha Lab

Several activity heads are placed in the Alpha Lab (wing) to provide for monitoring of that area. A local alarm is received at each head and is transmitted to the reactor control room and HP office when the annunciator point is reached. The lab should be checked in the company of an HP on off shifts.

CHAPTER III

REACTOR CONTROL CIRCUITRY

A. GENERAL

In order to understand the controls of the MTR, it is necessary to have an appreciation of what the designers had in mind as they worked out the circuits. It is not possible to study the control prints and quickly see the reasons for all the numerous relays and contacts unless their basic philosophy is appreciated.

The reactor will always be maintained in a safe condition whether the operator's attention wanders or whether circumstances are genuinely beyond his control. It is not possible to begin startup until all necessary instruments are available and functioning and all dry dock test blocks are in place. Since these bypass certain important functions and limitations, their proper use is vital. It is not possible to move any control rod (shim or regulating) in the direction which will raise power without the deliberate conscious effort of the operator. In fact, before shim rods can be pulled initially, a long series of safety check conditions must be met. After compliance is once obtained, many limitations drop out or are bypassed but others maintain surveillance continuously while the reactor is operating.

Instruments are duplicated which initiate important power reductions so when one must be taken out of service a second unit will continue to furnish protection. In the case of the "ultimate safety", the neutron level safeties, there are three separate instrument channels so that two will always be available and the probability of simultaneous failure is most remote. These are backed up by instruments that detect power and neutron levels by different means.

If a power reduction is initiated by any of the reactor instruments or experiments there is absolutely no way the operator can block or supersede it. The reduction will continue until the cause "clears". At the

same time, all circuits which could possibly interfere electrically or mechanically are blocked out. These things all guarantee that power will rise only when the operator deliberately requests it and that power will fall (when necessary) in spite of any attempts to block it.

With these things in mind, a study of the MTR control circuitry can begin. In order to obtain a full understanding of the system it is necessary to study figures 23, 29, and 30.

Figure 23 contains the circuitry necessary for starting the reactor and bringing it to power. This includes the circuits for moving the shim rods, the regulating rods, the motor operated rheostats, and the fission chamber. This particular figure must be practically memorized by the operator before he can be allowed to manipulate the controls at the console. The functions of all the relay coils in the top line should be memorized as well as the conditions required to energize them. This is the heart of the MTR control system.

The circuits indicated in the second line of figure 23 are those required to increase or decrease the MOR's (motor operated rheostats) in the servo systems and to move the fission chamber drive system. The bottom line contains power supply circuits for the regulating rod motors and their various limiting relays. These two lines need not be memorized but should be thoroughly understood.

Figure 30 is devoted almost entirely to power reduction and trouble circuits. It contains all circuits having "PREFERRED INSERT", "REVERSE", "FAST SETBACK", "SLOW SETBACK", "Jr. Scram", and "Scram" power reductions. It also shows power supplied to the magnet amplifiers, power for the shim rod and regulating rod position indicators, fission chamber position lights, and shim rod and regulating rod control lights.

Figure 29 contains circuitry which gives control room annunciators. It is self-explanatory once it is realized that an annunciator sounds when its coil is de-energized.

The following descriptive material will detail the study of figures 23 and 30. At first, the method of description will be to call out the name of the circuit, give a brief statement of its purpose and describe the requirements for its activation. At times it will be necessary to skip over certain circuits and return to them later in order to keep the proper train of thought. This need not create any confusion as all circuits on figures 23 and 30 will be covered eventually. Later, as familiarity is gained, a general statement of what takes place will be given and the reader will be expected to work out the details. To limit confusion, it would be well to become familiar with the print legend before studying the figure in detail.

Relay contact points, shown throughout the figures, have always been a source of controversy. A word about them here may simplify this study. A "normally open" contact means the contact point in the relay is open if the relay is de-energized (at rest). Think of "normally open" as the condition of the contact before the relay was installed and hooked up electrically. A "normally closed" contact, by the same reasoning, is closed in its "store-bought" position.

B. REACTOR CONTROL CIRCUIT ELEMENTARY WIRING DIAGRAM (See figure 23)

1. Startup Limitation Circuits

Before the reactor can be started, the top plug circuits must be properly hooked up and test reactor circuits, which can bypass some of the major features, must be invalidated by having their test blocks in place. The top plug circuits feature Amphenol (multi-prong) connectors that facilitate disconnection when the top plug is to be removed and simplify "hook-up" when the plug is returned. The Amphenols are mounted on "connector arms" (sometimes called semaphore arms) that swing down out of the way for shut down work. With the top plug in place, the connector arms are positioned horizontally extending the Amphenols to their matching top plug receptacles. The connector arms actuate switches, when vertical or horizontal, restricting reactor operation.

Test blocks invalidate the normal functions of the instruments or circuits with which they are associated. They consist of two parts: a stationary "built in the wall" section; and a cover plate section that is removable. The wall section contains contacts which open or close when the cover is pulled or removed. The cover plates are in place during normal operations.

Beginning in the upper left hand corner of figure 23, voltage is applied to the upper line (insertion bus) at all times. Next, voltage must be made available to the "ON-OFF" "W" switch. It cannot pass through switch contacts S9-1 or S10-1 because they are open when the semaphore arms are horizontal (in startup position). It therefore passes down through switch contacts S9-2 and S10-2 which are closed when the semaphore cables are in the hookup position. (The dotted line, connecting the S9 and S10 switches, represents a mechanical connection.)

The next safety requirements are the "dry dock" test block contacts, 1F, 2F, 3F, and 4F. In order for current to pass through these contacts, the four test block covers, located in the instrument room, must be in place. These will assure that no startup limitations are inadvertently omitted. The line then divides, feeding the withdrawal bus (bus 8) and the "ON-OFF" "W" switch.

The "W" switch contact (S6-1) closes when the operator turns the "W" switch "ON" at the console. Voltage is then made available to the circuits shown below the "ON-OFF" "W" switch. The circuits will be described in sequence, starting on the left and working toward the right, skipping those which have no effect on the controls until a higher reactor power is reached.

The circuit on the left of R-1 is for procedure panel lights (Q relays operate procedure panel lights). As long as the transfer arms are up, contact S10-3 is closed and coil Q8 energizes, turning on the light at the procedure panel which says "SEMAPHORE AND TEST BLOCK", indicating the semaphore arms are up and the dry dock test block covers are in place. As Q8 is energized, contact Q8-2 opens and de-energizes relay Q6, turning off the light at the procedure panel which says "DRY DOCK", indicating again that the top plug is not in dry dock.

2. Start Circuit

The next step in the startup regime is to push the "START" button (S6-2). Current passing through S6-2 splits and passes through either test block contact 5E or 7E or both, depending on which test block cover is in place. This assures that at least one of the period recorders is operative. The current can then pass through either test block contact 6E or 8E or both. This assures that at least one of the Log N recorders is operative. The current must pass through test block contact 9E guaranteeing the count rate meter is operative for startup. Since this is the first instrument to detect neutrons, the reason for this restriction is clear.

With the above conditions met, start relay R1 energizes. R1 has 5 contacts associated with it. R1-1 closes sealing in R1. R1-2 closes allowing current to flow to the timer circuit. R1-3 closes starting the 10 sec warning horn. R1-4 is not used. R1-5 turns on the green "START" light on the procedure panel and is not shown on the figure.

a. Startup Horn Circuit

The first circuit at the far left is for the startup horn. This circuit gives a 10 sec warning in the Reactor Building signifying the reactor startup regime has begun.

To actuate this circuit, current feeds from bus 1 through switch contact S9-3, which is closed when the semaphore arms on the reactor top are up, and through start relay contact R1-3. At this point the current splits, part of it passing through line 5 where it splits again turning on the "REACTOR ON" light in the control room and energizing relay R90A. R90A is a time delayed relay which allows its only contact R90A-1 to close 10 sec after the coil is energized.

To reach the horn, the current passes through contact R2A-3 which is closed since the reactor is not yet in the "RUN" regime. R90-1 is also closed because R90 is not yet energized. The horn will sound throughout the reactor building. Ten seconds later contact R90A-1 closes, energizing coil R90, thus opening contact R90-1 above the horn and shutting it off. Coil R90 has two contacts; the other contact, R90-2, turns on the "REACTOR ON" lights throughout the area. It is not shown on the figure.

3. Timer Circuit

Since conditions are not yet met for actuating the "RUN" circuit, it should be ignored at this time. Proceed to the timer circuit.

The purpose of the timer circuit is to insure that the shim rods are withdrawn at a controlled rate during the period when reactor power is below $10^{-5}N_F$.

Current passes through contacts R1-2 and R2-2 to reach and energize the timer coil which starts the timer motor rotating. A cam is located on the end of the motor shaft which has two knobs 180 degrees apart. A rider on a microswitch TI-1 rolls on this cam and intermittently rises on either knob closing contact TI-1. The width of each knob is variable and is adjusted so the rider remains on the knob $2/5$ sec out of the 5 required for the cam to rotate 180 degrees. This means that contact TI-1 is closed $2/5$ sec out of every 5 sec while the timer motor is running. Because of the possibility of the timer motor sticking, a mercury switch has been added which is closed by the turning action of the motor. This switch actuates contact TI-2 so the contact will be closed only if the shaft is actually rotating.

With the motor turning, coil 12B is energized $2/5$ sec out of every 5 sec. Contact 12B-1 is located in the R17 circuit to permit the withdrawing of rods intermittently. Contact 12B-2 gives a "TIMER" light on the procedure panel when coil 12B is energized and is not shown on the figure.

4. Potentiometer Limit Circuit

Immediately following the timer circuit on the supply line is a contact combination which guarantees that the MOR's of the servo system will be at opposite limits. This makes sure that the servo channel which is to be used will come into effect at 1 percent of full power and that one will be in the standby position. At this point in the description, both regulating rods are in the "Cocked" or maximum "Up" position.

CAUTION

DO NOT CONFUSE the position of the MOR with the position of the regulating rod in the same servo channel.

If No. 1 MOR is at the lower limit and No. 2 MOR is at the upper limit, then R71-1 and R74-1 are closed permitting current to pass through the lower path. If No. 2 MOR is at the lower limit and No. 1 MOR is at the upper limit, then R72-1 and R73-1 are closed and current will pass through the upper circuit. After passing through the pot limits circuit, the current will energize relay Q1 giving the "POT LIMIT" light on the procedure panel.

5. Seven Second Period Trips

Next encountered are two 7 sec period trip contacts in series. There is a period recorder contact in parallel with a period test block contact. These contacts will stop withdrawal of shim rods in "INTERMITTENT" or "CONTINUOUS" if the period becomes faster (shorter) than 7 sec. Either instrument can be bypassed with its test block pulled to cancel this limitation. At least one must be functioning. Contacts 1T7-1 and 2T7-1 are closed as long as the period on the recorders is greater than 7 sec.

6. Trip Circuit

The next sequence is called the trip circuit. Its function is to make sure that important requirements are maintained before group withdrawal of shim rods is permitted.

Two parallel lines feed line 24 from line 21. Contact R76-2 opens when the period, on either of the period recorders, is less than 30 sec. Contact S1-2, on the "BYPASS-REVERSE" switch, is used to bypass contact R76-2 where shorter periods are necessary yet safe.

Another parallel arrangement connects lines 24 and 28. On the left, contact G-1 is closed when the flux level galvanometer range switch is in one of the sensitive positions. Contact R84-1 is closed as long as the count rate meter fission chamber is stopped in one of its three normal positions. Contact R16-2 is a seal which requires the trip relay (R16) to be reset with switch S2 once it has been tripped out by short periods.

In the other line, contact S2-3, which is closed when the "INTERMITTENT-CONTINUOUS" group withdrawal switch is in the "NEUTRAL" position, acts as the reset for the trip relay. In order to energize coil R16, switch

contacts S2-3 and S8-3 must be closed. This assures the individual "WITHDRAW-INSERT" switch S8 is in the "NEUTRAL" position and switch S2 is ready for the "INTERMITTENT-WITHDRAWAL" position.

When the above conditions are met, coil R16 is energized. R16-1 allows R17 to be energized, R16-2 seals in R16 once it energizes and R16-3 gives a "TRIP" light on the procedure panel when R16 is de-energized. (R16-3 is not shown on this figure.)

7. Intermittent-Continuous Group Withdrawal

The next circuit is intermittent-continuous group withdrawal. Its function is to withdraw several of the shim rods simultaneously, either intermittently by use of the timer, or continuously if reactor power is at a high enough level. At the present stage of this discussion it is assumed the startup regime has just begun and the reactor is not yet critical. Accordingly, continuous group withdrawal will be discussed later.

The first contact in the group withdrawal circuit is the count rate meter contact CR-1 which is closed as long as the CRM(count rate meter) is operating, ie, on scale. In parallel with CR-1 are two test block contacts. 4A is a dry dock test block contact and 9C is a contact on the count rate meter test block. With the block covers in place, both of these contacts are open.

Next is the intermittent group withdrawal switch contact S2-1 which is closed when the switch is in the "INTERMITTENT" position.

Contact 12B-1 is in the timer and is closed 2/5 of a sec out of every 5 sec while the timer motor is running. This means that the shim rod motors pull the rods a very small amount, then pause. This assures the reactor is not brought "critical" too rapidly on a "clean" startup.

Contact R16-1 follows and is closed as the trip relay (R16) is energized. When conditions cause a trip, rod withdrawal is denied until the operator resets the S-2 switch to "NEUTRAL".

Contacts R68J-4 and R69J-4 follow. These open on a jr. scram, if the reactor power is above $3N_L$, and will prevent intermittent or continuous withdrawal of shim rods as long

as the jr. scram signal continues. If these and the other contacts in the line are closed, then relay R17 will energize and close its eight contacts in the separate shim rod withdrawal circuits.

The next four circuits (Q-9, individual withdrawal, sag, and run auxiliary) cannot yet be used because of the reactor power requirements. The next circuit which can be activated is the R15 circuit on the withdrawal bus. However, standard practice is to refrain from selecting a regulating rod until the power is about one decade below N_L . Assume both S4-12 and S4-14 are open so R15 will not be energized at this time.

8. Shim Rod Withdrawal Contact

Continue down the withdrawal bus to the next applicable contact, R20A-2. This contact opens on a reverse and is one of the safety overrides. (Relay R20A is shown on figure 30.) Beyond R20A-2 are two contacts in parallel. Contact R15-2 is open until "WITHDRAW" permit relay R-15 is energized. Contact R49-1 is closed when the regulating rod selector switch is in "MANUAL". Assume R49-1 closed at this time, that is, neither regulating rod has been selected. Continue down to line 54, proceed to the second junction and follow down to contact R17-1. This is closed when coil R17 is energized 2/5 sec out of every 5 sec at this time.

Proceeding on to the MW-1 relay, the next contact is K41-1 which is closed as long as the shim rod magnet and the shim rod armature are in contact. This prevents pulling the rod holders up accidentally without the shim rod attached. At shutdown, this is done deliberately by use of the "RAISE" switch (S-21). More details will be given about this later. The next contact, S21-1, is on the selector switch below the shim rod position indicator for shim rod No. 1. As long as this switch is in the "NORMAL" or "PREFERRED" position, the contact is closed.

Contact R21-1 is closed as long as the shim rod drive is not at the upper limit switch, ie, the shim rod is not fully withdrawn. This is the motor cut-out switch which protects the drive mechanism.

MI1-0 is a mechanical interlock working off relay MI-1 so that it is impossible to

insert and withdraw the same shim rod at the same time. With the appropriate conditions met, MW-1 will energize when R17-1 is closed, and shim rod No. 1 will withdraw. Notice that this shim rod withdrawal circuit is duplicated for each shim rod, although only No. 1 and 8 are shown on the figure. According to the preceding discussion, all shim rods are now being withdrawn 2/5 sec out of every 5 sec.

At this point in the description, it would be well to review the steps performed by the operator in starting the intermittent withdrawal of shim rods:

- (1) Turn reactor "W-Switch" to "ON".
- (2) Push "START" button.
- (3) Put "INTERMITTENT-CONTINUOUS" group withdrawal switch on "INTERMITTENT".

If the shim rods do not begin to withdraw 2/5 sec out of every 5 sec after completing the above steps, check the following:

- (1) Make sure the MOR setpoints indicate the MOR's are at opposite limits.
- (2) Check the galvanometer selector switch and make sure a numbered scale is showing, ie, 10^{-4} , 10^{-3} .
- (3) The count rate meter should be on scale. If it is not, reposition the fission chamber to the "IN", "CENTER", or "OUT" position to bring the CRM on scale. (Usually on a startup the CRM will be on scale when the fission chamber is in the "CENTER" position.)
- (4) Return the "INTERMITTENT-CONTINUOUS" group withdrawal switch to "NEUTRAL" and select the "INTERMITTENT" position again. (This action resets the trip relay, R-16.)

As the shim rods are being withdrawn, more fuel (or reflector) is being pulled into the core and more poison is being withdrawn. The first instrument to detect any change in reactivity is the count rate meter. When the meter reaches the top of its scale, the fission chamber which feeds the signal is withdrawn to the next position and the meter indicator drops back toward the bottom of the scale. As reactor power is increased, positive periods will soon become noticeable on the period

recorders and the log N recorders will begin to climb upscale. After the log N's indicate greater than 10^{-5} N_F (0.001), it is permissible to withdraw shim rods continuously. Even though the reactor circuitry permits it, shim rods are not withdrawn continuously until reactor power has risen above sag, except in the case of scram recovery.

Returning to the figure, look at the top of the Q9 circuit. Two log N instrument contacts are in parallel (1N1-1 and 2N1-1). In parallel with these is dry dock test block contact 4B, and in series with each is a log N test block contact. Contact 4B is open if its cover is in place and the instrument test block contacts are closed while their covers are in place. Contacts 1N1-1 and 2N1-1 close when the log N recorders indicate 10^{-5} N_F and voltage will feed through to the junction of line 36. Contact R2-3 is closed because the reactor is not yet in run and relay R2 is not energized. Contact S8-2 is closed only when the individual "INSERT-WITHDRAW" switch is held in the "WITHDRAW" position. With R18 energized, it is now possible to pull individual rods at slow speeds. To understand how this is done, find contact R18-1 in the No. 1 shim rod withdraw motor circuit. Trace through contact MV-5, which is closed when the individual switch is turned to either "WITHDRAW" or "INSERT" position (except when a reverse signal exists). If No. 1 shim rod has been selected for withdrawal, switch contact S3-1 will be closed. K41-1, S21-1, R21-1, and M11-0 will be closed for the reasons mentioned previously and MW-1 will energize. Shim rod No. 1 will now withdraw until either the withdrawal switch is returned to neutral or one of the above mentioned contacts opens.

Return to the Q9 circuit. As contact 1N1-1 or 2N1-1 closes, Q9 coil energizes and turns on the $N > 10^{-5}$ N_F light on the procedure panel. It is important to notice that after contact 1N1-1 or 2N1-1 closes, all shim rods can be withdrawn continuously by switching the "INTERMITTENT-CONTINUOUS" group withdrawal switch to the "CONTINUOUS" position. This will close contact S2-2 and energize relay R17. However, unless directed by the supervisor, the shim rods should continue to be pulled in "INTERMITTENT" (in the "START" regime) even though "CONTINUOUS" withdrawal is possible.

9. Sag and Run Regimes

The shim rods are pulled until the log N instruments reach 10^{-3} N_F which is called "sag" (0.1 on the recorders). At this reactor power level contacts 1N2-1 and 2N2-1 close in the R4 circuit energizing the sag relay (R-4). The test block contacts in series are for invalidation, as before.

Once coil R4 is energized, its four contacts do the following: R4-1 opens allowing the selected motor operated rheostat to be raised; R4-2 closes in the run circuit, but R2 must wait for one more contact to close before the run button is pushed; R4-3 closes, withdrawing the fission chamber to the outermost position, if it is not already in that position; R4-4 opens, preventing insertion of the fission chamber unless the reactor power again drops below sag.

Once the fission chamber is in the "OUT" position, contact R80-1 in the R2 circuit closes and the "RUN" button may be pushed putting the reactor into the "RUN" regime. This energizes relays R2, R2-A, and R2-B. R2-B merely acts as a mechanical latch for coil R2, holding it in for two seconds if voltage is lost to the coil.

The "RUN" or power regime releases the reactor control from some of the limitations it had been subject to and imposes others. R2-1 seals in coil R2 so that releasing the "RUN" button will not drop it back out. R2-2 opens dropping out the timer and group withdraw circuit. R2-3 opens isolating the individual withdraw (R18) circuit from the group withdraw (R17) circuit. R2-4 closes permitting individual rod movement only (R18) through switch contact S8-2. R2-5 closes giving a double seal on R1 to insure its being energized at all times. R2-6 closes in the run auxiliary circuit (R3), which will be discussed later. R2-7 closes allowing emergency group withdrawal, R17, by means of the "BYPASS-REVERSE" switch (Contact S1-3). R2-8 turns on the "RUN" light at the procedure panel. (R2-8 is not shown on the figure.)

Coil R2A has four contacts. R2A-1 turns out the "START" light on the procedure panel (not shown on figure). R2A-2 and R2A-4 bypass regulating rod limit contacts in the withdraw permit, R-15, circuit which will be discussed later. Contact R2A-3 opens in the startup warning horn circuit to prevent its

sounding if R90-1 malfunctions. At, or near, this same time one of the regulating rods should be selected. The log N recorders should continue to climb and one decade later will reach N_L (1 on the scale). At this point the regulating rod should activate and insert into the operating range and another relay, R3, called run auxiliary, should energize.

10. Run Auxiliary

This circuit can be thought of as the "safe rate of approach" system because it assures that the operator has slowed down the rate of power rise to at least a 30 sec period as he crossed N_L into the high reactor power range. Not only this, but a regulating rod must have moved into its operating range between 11 and 17 in., or the controls must be deliberately in manual. The R70-2 contact is closed only in a narrow band near N_L . This contact must close before the regulating rod comes in or reactor power cannot be raised. Occasionally this happens, due to a slight misadjustment of the servo chamber, and it is then necessary for the instrument technician to pick up R3 by hand. The chamber position is readjusted after the startup.

When R3 energizes it seals itself in, bypassing the above limiting conditions with R3-5. Two other contacts (R3-6 and R3-7) will now permit the raising of a MOR with the attendant rise of reactor power. If the above conditions are not properly met, R3-3 will cause a reverse at 3 N_L . (See figure 30.) The time delay relay (R3-A) is used for the purpose of holding R3 in the energized position for two seconds after a voltage dip. This gives stability to the controls during minor electrical fluctuations.

11. Withdraw Permit

This circuit, with R15 as its relay, is another check on the operator. It assures that the regulating rod is cocked (above 17 in.) and ready at the time one is selected. If the regulating rod goes below its normal lower operating limit of 11 in., then permission to pull shim rods is denied. The run relay (R2) contacts are necessary to allow shim rod withdrawal during normal 11 in. to 17 in. regulating rod operation. The R15 circuit does not enter the picture if manual operation is deliberately selected.

The withdraw permit relay has four contacts. R15-2, in the shim rod motor circuit, is the one that prevents any rod withdrawal with the regulating rod below 11 in. The three other contacts are not shown on this print. R15-1 gives the regulating rod permit light on the procedure panel in the run regime. R15-3 gives the regulating rod permit light in the start regime, and R15-4 allows the light in the group withdrawal section below the regulating rod permit light to come on if the "BY-PASS-REVERSE" switch is placed in "BY-PASS".

12. Shim Rod Drive Withdrawal

Up to this point, two ways of raising the shim rod magnets (with shims attached) have been considered, namely, group withdrawal and individual withdrawal. A third method exists of raising the magnets, but without the rods, so they will be in their fully "up" positions when the top plug is removed by the 30-ton crane. Obviously, since the magnets are to move up continuously in high speed, a guarantee must exist that the rods are not attached or the reactor power would rise out of control, perhaps even to the "prompt-critical" level. Control switch S5 is called the "RAISE-SCRAM" switch because of its dual function. In the counter clockwise position it closes S5-1 in the shim rod withdraw circuit. In the clockwise direction the switch cocks the inservice regulating rod; any departure from the normal central position scrams the reactor. These last two functions will be discussed later. With S5-1 closed, current is still not available to the MW relays until the shim rods actually drop into their seats and the individual rod switches are turned to "RAISE". Occasionally, a seat switch will fail to function. Under these circumstances magnet current or magnet to shim resistance should be checked to confirm a released rod before temporarily invalidating the faulty switch. The shim rod carrier should now withdraw to their upper limits.

13. Shim Rod Insertion

There are several ways to cause a shim rod holder (with or without its rod) to insert. The top line on the wiring drawing is called the insertion bus and supplies current only to the relays which cause the 8 shim rod motors to insert the rod carriers.

Switch contact S8-1 will cause an insertion of the "PREFERRED" rod only. The MV-4 contact is closed if the individual switch is in the "INSERT" or "WITHDRAW" position, unless a reverse is being called for. R19-2 closes and gives a "PREFERRED" insert when the regulating rod inserts to the dangerously low position of 7 in. (Refer to the regulating rod switch drawing at the bottom of figure 23.)

One of the shim rod selector switch positions is "JOG". This function is a manual insertion available to any rod at any time. In parallel with the "JOG" switch contact, S21-2, is the reverse contact R20-1. Notice that nothing will interfere with the incoming signal as long as the shim rod is not in its seat. Relay M1-1 will energize and the rod drive will insert. Contact R31-1 is a lower limit switch to protect the drive system. The motor withdraw (MW) and motor insert (MI) mechanical interlocks have been discussed previously. The separate side circuit, containing S21-4 and K41-3, is called the "auto-rundown" system. When the shim rod selector switches are in "OFF" or "RAISE" position the circuit will be invalidated. Otherwise when clutch contact is broken (rod off) the holder automatically runs down until the magnet touches the armature of the shim rod. This will save the operator from having to remember in the excitement of a scram.

14. Motor Operated Rheostat Circuits

The two MOR's are each driven by two separate motors, a high speed and a low speed unit. In order to operate at either speed, four relays are needed for each MOR. Becoming familiar with one serves for both since the two systems are identical. When manual fast lowering of reactor power is desired, control switch S7 (contact S7-1) is closed and the selected MOR will rotate around at high speed until switch S7 is opened or the lower limit is reached. Full travel in fast takes 88 sec (1-1/2 min). A fast setback through R5 (contact R5-2) will do the same. Contact R4-1 is in the circuit to assist the operator by automatically decreasing the rheostat to N_L in case reactor power is reduced to sag (0.1 on the log N recorders). This positions the rheostat for a normal reactor power recovery without the operator's effort.

Slow lowering of the MOR takes about 465 sec (7-3/4 min) and is accomplished

through switch contact S7-2 or through an automatic slow setback. Only the selected servo system is affected and, as before, the drive is cut off at the lower limit. Since damage would result if both drive motors to one MOR were to operate at the same time, blocking contacts M060-1 and M061-1 prevent low speed movement if the fast motors are driving. Contacts M066-1 and M067-1 are interlocks which prevent circuit malfunction from attempting to drive the slow motors in both directions at the same time.

The MOR raise motors are subject to restrictions also. The first is that they may not be raised until the run auxiliary (R3) relay energizes at N_L . Second, the rate of speed must be manually selected on the MOR setpoint switch (S7). Third, R72 will stop the drive at the upper limit switch (N_F). Fourth, the normal interlock prevents the energizing of the raise relays when its lower motor is running. The most important cutout to recognize is R91-1 which will open on either a fast or slow setback. This and M060-1 and M061-1 are overrides that give precedence to movement in the safe (reduced reactor power) direction.

A small side circuit is set up to automatically position the MOR's before one assumes control of the power level. During the reactor startup check, the MOR's are observed and one is temporarily selected; pretend it is No. 1. Assume there is no reactor power at this time. MOR No. 1 will run down. On MOR No. 2, S4-7 and S4-11 will be closed (No. 1 selected) and this rheostat will rotate to its upper limit. A seal-in contact, M065-1 will continue to energize the MOR relay M065 even if the selector switch is returned to normal. In other words, when a regulating rod is selected its MOR rotates down to the lower limit and the opposite one rotates to the upper limit. The reason for this becomes apparent when switching from one servo system to the other and will be discussed in a later section.

a R91 Circuit

R91 relay contacts were previously encountered as limits in the MOR circuitry. If either a fast or slow setback occurs, R91 will de-energize and its two contacts will prevent any attempt to raise the MOR's while the setback is in progress.

b. MOR Limit Switch Circuits

The next four relays (R71 through R74) are the upper and lower limit switches for the motor operated rheostats. The contacts for these relays were encountered in the previous MOR drive control circuits. Their functions are self-evident.

15. Regulating Rod Control Circuits

The regulating rod is driven by a 1 hp dc motor which receives its current from an amplidyne generator. The amplidyne supplies positive or negative current, as required, to withdraw or insert the regulating rod. The control circuits for these amplidynes are next. When the regulating rod selector switch (S4) is turned to the No. 1 position and that rod is cocked (above 17 in.), relay AM1 picks up. Contact AM1-4 seals in AM1 around the 17 in. restriction (contact R7-3). A procedure panel light, "AMPLIDYNE RUNNING", comes on and AM1-5, in the amplifier circuit, permits voltage to feed the controls, providing other requirements are met. Study the regulating rod switch drawing at the bottom of the page. As the trip block moves past any of the switch positions it changes their aspect. 1RR-1 is closed after the regulating rod inserts below 17 in. 1RR-6 is closed all the time the regulating rod is above 4-1/2 in. These two lines affect the amplifier allowing the amplidyne to drive the rod at full power only when both are energized. This is the braking circuit that reduces the rod drive to half power as the rod approaches its shock absorbers, ie, above 17 in. or below 4-1/2 in. Above the 17 in. mark 1RR-2 is closed, energizing R7. R7-1 was previously observed in the withdraw permit (R15) circuit. R7-3 was the "cocked" contact that allowed the amplidyne to start in the AM1 circuit just covered. R7-4 imposed the "cocked" limitation in the run auxiliary (R3) circuit and R7-2 lights the 17 in. indicator light on the console.

Relays R8, R9, and R10 are associated with the three remaining position switches on the regulating rod. At 11 in., R8 de-energizes and blocks shim withdraw permit through R15. Two R8 contacts are shown on parts 2 and 3 of the control circuit. R8-2 stops a reverse or "PREFERRED" insert above 11 in. if regulating rod position was responsible for the signal. R8-3 actuates the 11 in. light on the sel-syn dial. Relay R9 is the "7 in. relay" and

through its contacts gives a "PREFERRED" insert and a red light on the dial. Relay R10 gives a reverse and red light at 5 in. Obviously, any time the regulating rod is in this far the operator is not alert or conditions are changing radically.

16. Fission Chamber Drive Circuit

This circuit moves the fission chamber up or down in VG-8. From startup power to full power the chamber must be moved to keep the count rate meter on scale.

The chamber has three normal positions, an "IN", "CENTER", and "OUT" position but it can be stopped as necessary anywhere within its 12 ft travel range. The chamber drive circuitry is set up to prevent shim rod withdrawal unless the chamber is in one of its normal positions, yet it can be stopped anywhere within its travel range if desired. One automatic feature is the withdrawal of the chamber to its full "OUT" position at sag, if the operator neglects to do so.

Assume the chamber is fully inserted, as it is on a "clean" startup. 1FC-2 is closed and R84 is energized. Its one contact R84-1 is in the trip circuit. R83 will be energized because the chamber is not yet in the "CENTER" position. Two of its contacts will be encountered in the remainder of the fission chamber drive circuit, and its third contact operates the small "IN" position light on the console. R80 is energized through 3FC-1. Its contact R80-1, in the run (R-2) circuit prevents going into the "RUN" regime until the chamber is fully withdrawn. Through this same 3FC-1, current can flow through the "IN" button to the "OUT" contact. When the "OUT" button is pushed, current will flow and energize relay MF-2. The motor drive will pull the chamber. As before, a mechanical interlock (MF2-0) prevents the "INSERT" relay from energizing.

MF2-4 seals in around the button through R83-2, previously closed. When the "CENTER" position is reached, R83-2 opens and stops the drive motor.

To pull the chamber to the "OUT" position, the button is pushed once more. Since R83-2 must close before the circuit can seal in, the button must be held until the chamber leaves the "CENTER" position. As before, the chamber moves out until current is cut off at its next

position. When fully out, 3FC-1 opens the circuit. Contact R4-3 withdraws the chamber at sag and will keep it fully retracted while reactor power is above this level.

Insertion is very similar. When the "IN" button is pushed, current seals in through MF-4 and R83-1. R4-4 prevents any attempt to insert the chamber above sag.

17. N Approximately Equal to N_L Circuit

It will be recalled that the run auxiliary (R3) relay could not be energized unless the reactor power level passed through a narrow band very near N_L . R70 is the relay which closed within that band and imposes the restriction. The contacts 1N3-1 and 2N3-1 are microswitches within the log N instruments. Test blocks invalidate them if an instrument must be temporarily removed from service. An indicator light on the procedure panel lights when R70 is energized.

18. Period Restrictions

The next two relays impose restrictions on the controls if the period gets too short. R76 relay contact R76-2 opens the trip (R16) circuit unless deliberately bypassed and guarantees a period longer than 30 sec before run auxiliary (R-3) can energize. On relay R-75, contact R75-1 will give a "REVERSE" any time an operator raises reactor power at a rate less than a 5 sec period. R75-2 gives a reverse above 3 N_L in "START" and R75-3 trips the 5 sec period annunciator.

19. Shim Rod Contacts

The circuits which control the shim rod carriers (drive rods and magnets) are comparatively simple. Upper and lower limit switches prevent damaging overtravel and other contacts allow the magnets to energize only after clutch contact is made. R92 was placed in the circuitry after operating experience showed that seat switch and clutch switch (ISR-3, etc) troubles often combined to prevent holder rundown. When the "EMERGENCY CLUTCH RELEASE" button is pushed, the holder of a shim rod which has fallen will run down.

The arrangement to the right of the K41 circuit will now be explained. Line 137A and 137B contains a transformer that reduces the 115 volt supply to 24 volts. Parallel to relay

P41 are two circuits connected to ground. As long as these ground circuits are closed all current will travel through them. P41 is a coil and does have a resistance through which the current does not try to pass. The clutch switch (ISR-3) represents the magnetic clutch arrangement and will open should No. 1 shim rod become disengaged from its carrier. (Current will continue to pass through the ground line to the left of P41). Number 1 shim rod (disengaged) will fall into its seat closing seat switch ISR-4 which will energize relay R51. Contact R51-4 will open forcing current to flow through the P41 coil, thus energizing that relay. Contact P41-4 (seal) opens, P41-3 closes, energizing relay K41. The K41 relay contacts are found in the number 1 shim rod motor circuits. Contact K41-1 prevents the withdrawal relay from energizing. Contact K41-3 inserts the shim rod carrier for recovery of the fallen shim rod. When the carrier magnet and shim rod armature touch, ISR-3 (clutch switch) closes and P41 is bypassed and de-energizes. P41-4 and R92-1 are closed, but R51-4 is open because the rod is still in its seat. As soon as rod withdrawal begins, R51-4 closes and buildup of "crud" on the surface of the magnet will not cause a spurious pickup of P41.

Presume now that a rod falls off, deliberately or otherwise. After the rod falls into its seat, P41 picks up and so does K41. K41-3 starts the automatic rundown. K41-1 blocks any attempt at withdrawal. K41-4 cuts off power to the magnets so they won't attract stray particles while running down. K41-2 lights the "NO CLUTCH" indicator. (The variable resistance in the circuit limits the short circuit current that can flow and is adjusted so as to permit sufficient voltage to pick up P41.) If the seat switch fails to open or stay open, pushing the "EMERGENCY CLUTCH RELEASE" button will energize R92, contact R92-1 will open that circuit, allowing rundown.

Of the four contacts on seat relay R51, two are in the shim rod motor circuit, one energized the "SEAT" light, and the fourth is in the P41 bypass just discussed.

Notice that six sets of circuits for shim rod controls are omitted. This becomes important in the jr. scram circuits where rods 6 and 7 are involved. If this omission is not remembered some of the actuating relays will not be found. The next two circuits are an example.

Any time both of the jr. scram rods (6 or 7) are not at their upper limits, R93-A coil de-energizes, but a time delay prevents its contact R93-A-1 from opening for one minute. R93 de-energizing will cause a full scram. In other words a jr. scram signal, which does not clear within 60 sec and the reactor power is above $3 N_L$, converts to a full scram. Also, if a second jr. scram signal is received before at least one of the two rods are returned to its upper limit and reactor power the second jr. scram will be converted to a full scram. This will be more fully explained on figure 30.

20. Low Speed Circuit

At the time the reactor controls permit individual shim rod movement, it is felt undesirable to have the drive motors start at full power. Accordingly, fine control of the rod movement is obtained by placing limiting resistors in the motor supply line. The MV relay does this. Individual movement is obtained through switch S8 which energized MV. Three of its contacts (not shown on this figure) open around the line resistors and compel starting current to flow through them, thus reducing starting voltage. The two others, in the withdraw and insert circuits, assure that the MV relay has indeed picked up when it is required. Contact R20A-4 is the reverse override so safety insertion can proceed at full speed.

21. Loss of Voltage Scram

An electrical power failure of longer duration than one second will drop all rods through R66 and R66A. The scram relays themselves (R68 and 69) are shown on the next figure to be studied, figure 30.

22. Manual "INDICATION" Circuit

The final relay of any consequence is the manual indicator relay (R49). While the regulating rod selector switch remains in "MANUAL" this relay is energized, permitting shim rod withdrawal via R49-1. The Q relays associated with it operate indicating light on the procedure panel.

C. MTR POWER REDUCTION CIRCUITRY

All items causing power reductions through the control relay system are shown on figure 30. The material shown there is vital to the

understanding of the reactor operation and should be understood just as thoroughly as the items on figure 23. The circuitry is considerably less involved however, and it is assumed that the reader now has a "feel" for reading electrical drawings. Accordingly, only a general description will be made.

1. Preferred Insert

A preferred inset is the automatic insertion of one shim rod that has its selector switch in the "PREFERRED" position. In the strictest sense, a preferred insert is not a power reduction but it is so closely associated with these circuits that it is appropriate to explain here. It is actually an automatic attempt by the servo system to stay within a "safe" control band. This band is the regulating rod travel which extends from 11 in. to 17 in. If the regulating rod should insert below 11 in. due to operator negligence or factors beyond his control, there is an ever decreasing amount of regulating rod remaining which can insert and overcome an undesired power rise. If the rod should insert as far as the 7 in. position, the situation is obviously undesirable and contacts close which will energize R-19 and insert the "PREFERRED" shim rod until the regulating rod withdraws to greater than 11 in. There has been no power loss, as such, since the servo system has maintained control. Obviously, this circuit will be invalid when operating in manual.

2. Reverse

a. Regulating Rod Below 5 in.

If the regulating rod should insert to the 5 in. level, the operator has lost control, and it is imperative the servo system have more regulating rod available. Since the preferred insert has not remedied the situation, an insertion of all shim rods is initiated through R20 and R20-A. This is a reverse and it will continue until the regulating rod withdraws above 11 in. In actual practice a reverse will cause the regulating rod to cock and a shim rod or two will need to be pulled to return the regulating rod to control.

b. In "START"

If the operator attempts to go above $3 N_L$ while in the "START" regime, he is either unaware of his power level or is in mild trouble. In either case, he needs automatic help in the form of a reverse. The same is true if the period shortens down to 5 sec or less. If

the $3 N_L$ signal is spurious, the log N instrument can be invalidated with its test block.

c. Setbacks to Reverses

If the reactor is being operated in manual, the servo system and its regulating rod are not being used. In this case, there is no such thing as a power reduction by the servomechanism. If a setback is called for, a reverse is substituted as the first alternative. A short period (5 sec or less) is considered dangerous in manual above $3 N_L$ so a reverse remedies this also.

d. Excess Power Level

If power rises above 100 percent, the first instruments likely to detect it are the neutron level recorders. Since a slight power rise is not serious, a scram is not warranted. A reverse is therefore initiated at 10 percent above full power.

e. Experiment Reverses

Power reductions are called for when any of the parameters at the experiments deviate sufficiently from normal. If a scram is not necessary, but a rapid lowering of power is, then a reverse is caused. (In order to guarantee against component failure, a backup power reduction is used.)

3. Slow Setback

A slow setback is the logarithmic reduction of the servo demand by lowering the motor operated rheostat, over the reactor power range from N_F to N_L , in the time interval of 465 sec. A SSB can be caused by a number of plant and experiment instruments. An examination of the circuits quickly discloses that seven control room recorders will initiate a SSB if their parameters go a little into the unsafe zone. In the case of the neutron levels, the SSB backs up the reverse at $1.1 N_F$, as previously discussed. The others are the first power reductions incurred by excursions (real or spurious) of the indicated instrument recorders.

Two SSB signals originate in the process water building. Low working reservoir level and low main water flow are conditions both justifying a lowering of reactor power if it is above $3 N_L$.

4. Fast Setback

A FSB (fast setback) is the same as a slow

setback but requires only 88 sec to reduce reactor power from N_F to N_L . The fast set-back will lower power from N_F to N_L about 5 times as rapidly as a SSB. A quick check of the first three instruments indicated discloses the same ones which initiate SSB's and at the same points. Since a slow and fast setback cannot proceed simultaneously, the FSB governs and the SSB is a backup.

Since loss of cooling air at full power would allow rapid heating of the graphite zone, a FSB is mandatory when either air flow or air pressure (suction) drops below normal. This protection is so vital that the test block in each of these systems may not be out at the same time.

Experiments can also give fast setbacks and scrams, as indicated by typical circuits.

5. Scrams

A scram is the cut-out of current to the shim rod magnets resulting in the shim rods dropping by gravity to their seats. The next circuits (indicated on figure 30) are those of greatest importance. They include the jr. and full scram systems. Notice first, that the main busses are double wired so that an accidental open circuit in one will not prevent a scram. This signal must come through when called for. The mechanical scram is actually caused by cutting off power to the magnet amplifiers either by opening a relay contact or a switch contact. The electronic scram is the biasing of the magnet amplifier output by the sigma bus and does not depend on mechanical movement response.

a. Jr. Scram

Jr. Scrams (SR's 6 and 7) cannot occur below $3 N_L$ as voltage is not available to R68-J and R69-J until reactor power is above that point. The log N contacts 1N4-2 and 2N4-2, when closed, will energize RP-1 whose contacts have been seen in the setback and reverse circuits. Notice also that jr. scrams are caused only by experiments through RXJ and RBXJ relays which energize the jr. scram relays. The jr. scram relay contacts perform such important functions that they should be thoroughly understood. Contacts numbered "1" drop shim rod No. 6; those numbered "2" drop shim rod No. 7. In other words, either relay will drop both rods with duplicated contacts to back up the action. Contacts numbered "3" open one leg of the power line feeding all magnet amplifiers and work in conjunction with R93 to cause a full scram if the jr. scram signal does

not clear within 60 sec. This relay, it will be recalled, was encountered on the previous circuit drawing (figure 23) and is operated by the upper limit switches of shim rods No. 6 and 7. It will also be seen that if a second jr. scram comes through before one of the two rods gets back to its upper limit, and if reactor power is above $3 N_L$, a full scram will result. Contacts numbered "4" prevent withdrawal of other shim rods (through R17) while a jr. scram signal is in effect.

b. Full Scram

This can be caused by items in the process water system as well as in the reactor or experimental systems. Some need not be effective until reactor power is above $3 N_L$, others should always be available. In the first category are low mainflow and low working reservoir level. If the SSB at 70 percent has not lowered power below $3 N_L$ by the time the water level drops to 50 percent, a full scram is warranted because of the rapid loss of water and the necessary removal of "after heat". Experiments also fall within this category; they need not scram the reactor if its power level is less than $3 N_L$. The remainder of the scram signals are not dependent on power level. Any time their contacts close, all shim rods drop. Main water flow, bypass flow, main pumps, vital electrical power failure, and control room recorders all have their place. Most of their signals can be temporarily invalidated by test blocks.

The four contacts of relays R68 and R69 should be understood in detail. Contacts numbered "1" turn on the red indicating lights above the console manual "SCRAM" switch. These should always be checked after a scram to verify the response of both scram relays. Contact "2" seals in the scram signal. "3" and "4" are in parallel in the power lines to the magnet amplifiers and cut off all power to all shim magnets.

Three mechanical switch contacts are in the magnet amplifier power lines. One is from the "RAISE-SCRAM, COCK-SCRAM" switch and drops all rods before permitting fast raise of the magnet drives or cocking of a regulating rod. SX-1 and SX-2 are contacts on the console manual "SCRAM" switch. A slight turn of the switch closes SX-3 and

energizes R68 and R69. If these fail to do the job, turning the switch a little farther opens "1" and "2". Normally, of course, all three function and back each other up.

One last item can cut magnet power, and this is the K41 through K48 series of relays. These do not scram the reactor but cut off magnet current to their individual rods if clutch contact is not made. This is to prevent the attraction of any magnetic "crud" to the face of the magnets during rundown of the rod holders.

6. Level and Period Trouble Circuits

If internal trouble develops in the amplifier or if the connections are improperly made, a relay (REL) is energized which in turn will light the "Level Trouble" annunciator. If the scram level is approached, a thyatron will fire, which energizes another relay (RY-1), which then lights the "Level" annunciator.

Circuits with almost identical characteristics, including the thyatron, are in the period amplifiers. These give control room annunciators in the same manner.

7. Dial and Other Indicating Lights

The remaining circuits on this figure have to do with position indicating lights for the shim rod drives, regulating rod drives, and the fission chamber. It will be recalled that there are four lights each associated with the shim and regulating rod selsyn indicators. These are self-evident from an examination of the print.

The final circuit shows the fission chamber drive 3-position lights. Associated with the same circuit breaker are the selsyn indicators for all shim and regulating rods.

D. TRAINING QUESTIONS AND ANSWERS ON THE MTR

MTR Control

1. Q. Basically, there are five methods of reactor power reduction. Name each and describe briefly.

- A. (1) Slow Setback: A logarithmic reduction of servo demand by a lowering of the motor-operated rheostat (MOR) over the power range N_F to N_L during a period of 465 seconds.
- (2) Fast Setback: The same as a slow setback, but requiring only 88 sec rather than 465 sec.
- (3) Preferred Insert: Insertion of one shim rod that has its selector switch in the "PREFERRED" position.
- (4) Reverse: A simultaneous insertion of all shim rods.
- (5) Scram: A reduction or complete cut-out of current to the shim rod magnets with the result that one or more shim rods drop, depending upon specific circumstances.
2. Q. Within the scram system there is the slow scram, the fast (or electronic) scram, and the jr. scram. Identify each.
- A. (1) Slow Scram: An electrical-mechanical cut-out of magnet current and release of all shim rods by action of scram relays R68 and R69.
- (2) Fast Scram: A reduction of current to the shim rod magnets by electronic means only, with the subsequent release of one or more shim rods.
- (3) Jr. Scram: An electrical-mechanical cut-out of magnet current to two beryllium-cadmium shim rods by action of junior scram relays R68-J and R69-J.
3. Q. What is the Servo System?
- A. An automatic control system for the primary purpose of maintaining reactor power at an adjustable, preset level.
4. Q. Within what range of reactor power does the servo system control?
- A. Between 1 percent (N_L) and 100 percent (N_F) of full power (two logarithmic decades).
5. Q. Name the principal components of the servo system.
- A. PCP ion chamber, amplifier system, amplidyne, regulating rod drive motor (with tachometer), regulating rod motor operated rheostat, and the level vernier.
6. Q. What is an amplidyne?
- A. An electrical-mechanical amplifier for dc current. More specifically, a motor-generator set which precisely controls a large output whenever a small power input is varied in the field winding of the generator.
7. Q. Make an elementary sketch of the reactor servo control system and describe how it works.
- A. Refer to figure 23 or 24.
8. Q. What is meant by reactor "period"?
- A. The time required for reactor power to increase by a factor of "e" (2.718). Example: A reactor at 10 Mw on a steady period of 30 sec will be at power of approx 27 Mw within 30 sec.
9. Q. Why should the regulating rod selector switch be placed in the "MANUAL" position following a deliberate scram for shutdown?
- A. To stop the amplidyne during shutdown.
10. Q. What console manipulation starts the amplidyne?
- A. (1) The selection of a regulating rod, providing the rod selected is in the cocked position (above 17 in.)
- (2) The selection of a regulating rod together with actuation of the "COCK-SCRAM" switch. This action automatically cocks the selected regulating rod and gives simultaneous reactor scram. Such action would obviously be dangerous during periods of reactor operation.
11. Q. How short a period was the servo system designed to control?

- A. 1 sec
12. Q. Why is the regulating rod motor a full horsepower while the motors on the larger shim rods are only 1/6 hp?
- A. The greater power overcomes the regulating rod inertia, permitting fast response.
13. Q. Describe the functions of the positions of the shim rod selector switches: "RAISE", "OFF", "BLOCK", "NORMAL", "PREFERRED" and "JOG"
- A. (1) "RAISE": Raises the shim rod holders only, used in conjunction with the "RAISE-SCRAM" switch.
- (2) "OFF": Blocks all shim rod motion except reverse.
- (3) "BLOCK": Blocks withdrawal, but allows automatic rundown.
- (4) "NORMAL": Allows all normal motion except preferred insertion.
- (5) "PREFERRED": Same as normal plus preferred insertion.
- (6) "JOG": Gives insertion of its shim rod.
14. Q. What is meant by the term cold, clean reactor?
- A. A reactor with a freshly fuelled core and no xenon or other poisons to lessen its reactivity.
15. Q. What is the purpose of the timer?
- A. To limit the reactor to "INTERMITTENT" withdrawal of shim rods during reactor startup and low power ranges, thus assuring rod withdrawal sufficiently slow to protect against dangerously short periods in a cold, clean reactor.
16. Q. Describe the purpose of the dry dock test blocks.
- A. Removal of the dry dock test blocks circumvents certain operating requirements and energizes several relays necessary for control rod movement. This permits operation of the control rod drives with the top plug in dry dock.
17. Q. Can these operating requirements be by-passed during reactor operating by removal of the dry dock test blocks?
- A. Removal of any dry dock test block during reactor operation will kill power to the withdrawal bus preventing further withdrawal of all rods.
18. Q. What circuit requirements must be satisfied in so far as instruments are concerned, before the start relay (R1) can be energized?
- A. Test blocks for at least 1 period recorder, at least 1 log N recorder, and the count rate motor (CRM) must be in place.
19. Q. Can reactor operation be continued if both log N test blocks are removed after R1 is energized?
- A. Yes, Intermittent withdrawal up to full power in "START" and in "MANUAL".
20. Q. Why must the motor-operated rheostats be at opposite limits before withdrawal of any kind is permitted?
- A. This assures that the selected MOR is at its lower limit (permitting servo operation at N_L) and that the stand-by MOR is at its upper limit, it becomes necessary to switch regulating rods, once in servo.
21. Q. Continuous shim rod withdrawal at low or high speeds is permissible at what minimum power level?
- A. At $10^{-5} N_F$, or approx 400 watts (0.001 on the log N recorders).
22. Q. Why is continuous shim rod withdrawal prohibited below $10^{-5} N_F$?
- A. At power levels below $10^{-5} N_F$ the reliability of information is relatively poor coming primarily from only one instrument, the CRM. At higher levels, the instrumentation furnishes more

varied and reliable signals, making continuous rod withdrawal less hazardous.

23. Q. What is the inching circuit?

A. The inching circuit is used in conjunction with the individual switch. Use of this switch for both withdraw and insert provides low acceleration action to shim rod movement due to resistors in series with the shim rod motors. This permits finer adjustment of rod position, and, at the same time, limits the use of low speed to one rod at a time.

24. Q. What must be true of the count rate meter (CRM) before "INTERMITTENT" withdrawal is permitted? Why is this necessary in "START" and not in "RUN"?

A. It must be on scale. The CRM is the only instrument which gives a reliable signal at low power. When at high power (run condition) other instruments give adequate protection.

25. Q. The withdrawal permit relay, R15, must be energized at all times (except in manual) in order to withdraw shim rods. Under what conditions is this relay energized?

A. The selected regulating rod must be cocked (above 17 in.) in "START" and above 11 in. in "RUN".

26. Q. What conditions will drop out the trip relay, R-16, preventing group withdrawal of shim rods?

A. (1) A period less than 30 sec (unless using "BYPASS" switch).

(2) A period less than 7 sec.

(3) The fission chamber between stations.

(4) The flux level galvanometer sensitivity selector switch on "OFF", "HS", or "LS" position.

27. Q. How may such a trip be reset?

A. By putting the "INTERMITTENT" control switch in "NEUTRAL" position.

28. Q. What does the "BYPASS" switch do?

A. It bypasses the 30 sec period trip in "START" and permits continuous shim rod withdrawal (with 30 sec period trip bypassed) in "RUN".

29. Q. What is the shortest period permitted by use of the "BYPASS" switch?

A. 7 sec.

30. Q. What is sag? At what point is it on the Log N recorder and what does it do?

A. The sag point might be thought of as the dividing line between the startup ("START") regime and the operating ("RUN") regime. It is at 0.1 on the Log N recorders ($10^{-3} N_F$). Below sag, the MOR for the selected servo channel is automatically lowered to N_L . Above sag, the fission chamber is automatically run to its outermost position and cannot be inserted. Pickup of the sag relay (R4) also permits pickup of the run relay (R2).

31. Q. What is the next manipulation after reaching sag?

A. Push the "RUN" button.

32. Q. What control changes are made after going from "START" to "RUN"?

A. (1) The "BYPASS" switch must always be used for group rod withdrawal when using the "CONTINUOUS" switch.

(2) Individual withdrawal of the selected shim rod is not restricted by the 7 sec period trip.

(3) The 30 sec period trip is always bypassed except during pickup of run auxiliary (relay R3) at N_L .

(4) The withdrawal permit relay (R15) will not drop out unless the selected regulating rod is inserted below the 11 in. limit switch.

33. Q. Conditions imposed upon energizing the run auxiliary relay (R3) are as follows: (1) must be in run; (2) unless in manual, the selected regulating rod must be uncocked, ie, inserted below the 17 in. limit switch; (3) the reactor must be at about N_L ; and (4) the reactor period must not be less than 30 sec. Give reasons for these restrictions.
- A. (1) In automatic, it insures that the regulating rod becomes sensitive at N_L and indicates that the servo system is functioning properly, prior to increasing power, by means of the servo demand setpoint (MOR). The period restriction encourages a reasonably slow rate of power rise during the time that the servo system takes over. Otherwise, the regulating rod might drive in with sufficient velocity at N_L to cause insertion below the 7 in. or 5 in. limit switches, causing a preferred insert or reverse.
- (2) In "MANUAL" it restricts the operator from entering the power range at N_L at an unsafe rate.
34. Q. Suppose the run auxiliary relay is not energized?
- A. (1) In automatic, it will prevent raising the MOR setpoint and will automatically cause a reactor reverse at $3 N_L$.
- (2) In "MANUAL", the reactor will be reversed at $3 N_L$.
35. Q. What control changes are incurred after getting into run auxiliary?
- A. (1) The servo demand setpoint may be raised by use of the MOR.
- (2) The reverse at $3 N_L$ is invalidated.
- (3) A reverse caused by a reactor period of 5 sec or less is invalidated when in automatic.
36. Q. A reverse is automatically initiated under certain conditions from a reactor period of 5 sec or less. Specify these conditions.
- A. (1) In automatic, the reverse is effective until the run auxiliary relay (R3) is energized.
- (2) In "MANUAL", the reverse is effective until run auxiliary relay (R3) is energized and at all times above $3 N_L$.
37. Q. What period protection, if any, is available when in automatic and in run auxiliary?
- A. Electronic scram only, for a reactor period of 1 sec (or less) lasting for a duration of 1 sec. Note, however, that at this point power is being raised with the MOR and this normally limits a period to a minimum of 20 sec.
38. Q. At $3 N_L$ and above, in "MANUAL" certain changes become effective in the power reduction circuits. What are these?
- A. (1) A period of 5 sec or less causes a reverse even with the run auxiliary relay (R3) energized.
- (2) Slow and fast setbacks become reverses.
39. Q. Describe the purposes of the lower (at 4.5 in.) and two upper (at 17 in.) limit switches in the regulating rod drive system.
- A. The lower limit switch and one upper limit switch are, in reality, "servo speed switches" which serve to reduce power applied to the drive motor in their respective directions. Thus, the rod will not strike the lower or upper shock absorbers at full speed and power. The second upper limit switch assures desired rod position during pickup of the run auxiliary and withdraw permit relays, and during start-up of the amplidyne.
40. Q. Describe the purposes of the 11 in., 7 in., and 5 in. limit switches.

- A. When the selected regulating rod is inserted below the 11 in. limit switch, shim rod withdrawal is not permitted. Insertion of "PREFERRED" shim rods occurs if the regulating rod goes below 7 in., and a reverse is initiated if it goes below 5 in. In either case, the action continues until the rod moves above the 11 in. switch. These switches maintain the regulating rod within a useful and safe operating range.
41. Q. What will happen if you are pulling rods and a signal for a reverse is received?
- A. The withdraw circuit is over-ridden and a reverse will be initiated.
42. Q. Are there any circuits that will override a call for reduction in power?
- A. Normally, the safety motion will always override any other action. Test blocks keep some power reduction signals from being recognized.
43. Q. What is automatic rundown?
- A. When a shim rod has dropped from its magnet, the drive rod holder will automatically run down until contact is made with the shim rod armature, or until the lower limit switch is reached.
44. Q. What two types of shim rods are used?
- A. One contains a cadmium section above a beryllium section; the other contains cadmium above a fuel section. (With the reactor scrammed, the cadmium sections are in the lattice.)
45. Q. Of what material is the regulating rod made?
- A. Cadmium sheathed in an aluminum jacket.
46. Q. How do the control rods control reactor power?
- A. Cadmium is a poison to the reactivity of a pile because of its ability to absorb neutrons. Insertion or withdrawal of the cadmium sections of the rods permits control of the chain reaction.
47. Q. In what direction will the control rods move as fuel is burned and with the reactor maintaining constant power?
- A. Out. The cadmium sections of the rods must be gradually moved out of the lattice in order to compensate for fuel burnup.
48. Q. Discuss briefly the shim rod switches, seat switch, clutch switch, upper and lower limit switches.
- A. (1) The seat switch is a mercoide switch activated by a change in demineralized water pressure flowing into the shim rod seat to give indication of the shim rod being in the seat. The clutch switch is actually the contact between the shim rod and the magnet. It is activated by the loss of the contact. Upon activation of the clutch the rod drive automatically runs down.
- (2) The upper and lower limit switches are activated by the rod drives to prevent extreme up or down movement.
49. Q. What is the significance of an "ON CLUTCH" light?
- A. That the shim rod has probably dropped.
50. Q. If the rod has, in fact, dropped, what other lights will normally be on?
- A. (1) The green rundown light indicating that the shim rod holder is going down (automatic rundown circuit).
- (2) The "SEAT" light indicating that the rod is seated in its shock absorber.
51. Q. What is a compensated ionization chamber?
- A. An ion chamber so constructed so as to cancel out the effect of gamma irradiation, hence a monitor of neutron flux.
52. Q. In what parts of the MTR control system are compensated ionization chambers used?

- A. One each in two Log N and period channels and one for the flux level galvanometer.
53. Q. What is the relationship of the Log N and period recorders?
- A. The period meter indicates the rate of change of the Log N, hence, the rate of change in the neutron flux level, as indicated by the Log N recorders. Both receive their signals from the same ion chamber.
54. Q. What is a parallel circular plate (PCP) chamber?
- A. Ionization chambers having parallel graphite plates coated with boron-10 to make them neutron sensitive.
55. Q. PCP Chambers are valuable as a neutron sensing device because of their rapid response to changes in neutron flux levels. In what control systems are these chambers used at the MTR?
- A. (1) One each in the two servo channels.
(2) One each in the three level safety channels.
56. Q. What is the sigma bus?
- A. The bus which receives the individual output signals from the sigma amplifiers of the three level safety channels and the two period channels. The magnet amplifiers are in turn tied into this bus. The output current of the magnet amplifiers (to the shim rod magnets) is controlled by the highest signal from the sigma amplifiers. Hence, an increasing voltage on the sigma bus reduces magnet current and may cause one or more shim rods to drop. (This is the electronic scram.)
57. Q. What will give a fast (or electronic) scram?
- A. (1) A signal from the level sigma amplifiers indicating a power level of $1.5 N_F$.
(2) A signal from the period sigma amplifiers indicating a reactor period of 1 sec or less. (When above $3 N_L$ this signal must have a duration of at least 1 sec.)
58. Q. Where are the PCP chambers for the three level safety channels located?
- A. In VN-1, 2, and 3, located roughly in the northwest, northeast, and southeast quadrants of the pile.
59. Q. Other than the electronic scram from the level safety sigma amplifiers, what safety features do the three level safety recorders supply?
- A. Slow setback, reverse, and alarm at $1.1 N_F$.
60. Q. The count rate meter receives its signal from what source?
- A. The fission chamber.
61. Q. Why is the fission chamber moved during startup?
- A. The fission chamber, movable over a linear distance of 12 ft, is moved to one of three positions, thus giving it a maximum range of flux variations.
62. Q. What instrument first indicates a rise in activity when coming up from zero power?
- A. The count rate meter.
63. Q. What system of instruments gives the truest indication of reactor power level?
- A. The water power system, measuring heat power output in terms of gallons of cooling water flowing, and temperature rise (across the lattice) of this water.
64. Q. From what source does the water power recorder get its signal?
- A. The main water flow recorder and the ΔT recorder.

65. Q. What other instruments are indicative of power level?
- A. CRM, boron thermopiles, N16 activity, flux galvanometer, level safeties, Log N's.
66. Q. What three safety contacts are in the water power recorder?
- A. Slow setback, fast setback, and slow scram.
67. Q. What are the two small red lights near the manual scram switch?
- A. These are signal lights on each of scram relays R68 and R69, indicating that they are energized and the reactor is scrammed.
68. Q. What does it mean if one of these lights fails to come on after a slow scram?
- A. It may mean that one of the scram relays failed to pick up. This should be reported.
69. Q. If a power reduction annunciator lights up and there is no power reduction as indicated, what should the console operator do?
- A. Manually reduce power at the indicated rate.
70. Q. If one of the reactor control room instruments starts to rise and there is doubt as to whether it is real, should the appropriate test block be pulled?
- A. A test block should never be pulled until absolutely certain that the signal is spurious. To do so would invalidate protection to the reactor.
71. Q. What features concerning the control room are located in the monitor room?
- A. Gas distribution for the ion chambers, galvanometer power supply, Log N amplifiers, and power supplies.
72. Q. The control console is divided into five sections. Describe each.
- A. From the operator's position, running from left to right, the sections are:
- (1) Panel "N", containing indicators and controls for the eight shim rods
 - (2) Panel "P", containing the 2 regulating rod position indicators and the regulating rod selector switch.
 - (3) Panel "Q", containing the flux level, count rate, deviation galvanometers, and the fission chamber drive control.
 - (4) Panel "R", containing manual scram switch, period indicator, and shim rod drive motor controls.
 - (5) Panel "S", containing reactor procedure panel, reactor set level point, and the "OFF", "START", and "RUN" switches.
73. Q. What major control components are located in the instrument room?
- A. Cabinets containing major amplifiers, relay, power distribution equipment, and the amplidyne generators.
74. Q. What provisions are made for quick replacement of faulty amplifiers?
- A. A standby rack holds spares which are kept in a standby conditions.
75. Q. What do the top reactor cubicles contain?
- A. (1) The north cubicle contains the No. 1 servo, N16 chamber head, neutron level preamplifiers, power supply for N16, fission chamber drive motor, the transfer plug for dry dock operation, and the No. 1 motor operated rheostat (MOR).
- (2) The south cubicle contains the No. 2 servo, N16 chamber head, the neutron level preamplifiers, the No. 2 motor operated rheostat (MOR), and the master "W" switches.

76. Q. Where are the limit switches and accurate rod position indicators for the shim rods located.
- A. On the top plug.
77. Q. Describe the procedure for switching from one operating servo channel to another.
- A. (1) There are several methods used for switching servo channels, and the exact procedure to be used should be outlined by the immediate supervisor. In general, the procedure is as follows.
- (2) Check the regulating rod not in use and make sure it is out as far as possible. Cock the regulating rod in use by inserting one of the shim rods enough to cause the regulating rod to go above 17 in. With the rod cocked, switch to the lower servo system and lower the MOR until the regulating rod is back in normal operating range.
78. Q. If a rod is dropped with the reactor at power and the Log N's do not drop below sag, describe the accepted method for recovering power.
- A. Lower the MOR with fast speed and pull the remaining shim rods by use of the "BYPASS" switch and the "CONTINUOUS" withdrawal switch until the regulating rod uncocks. Then, by withdrawing the dropped shim rods, and inserting the other shim rods, bring the shim rods into an approx level condition. The return to full power can then be made at the direction of supervisor by use of the MOR.
79. Q. What procedure should be followed when lowering main flow if a scram is not desirable?
- A. (1) Pull the cover on test block 11. "Main water shut off valve less than 40 percent open."
- (2) Pull the cover on test block 21. "bypass flow". This will prevent a scram from oscillation in bypass flow as main flow is lowered. (Bypass flow setpoint should remain at 800.)
- (3) Lower reactor power below 3 N_L and have the shift electronic technician check contact 1N4-2 and 2N4-2 in the Log N instruments to make sure they are open.
- (4) After completing the above items, lower the flow to the desired value.
80. Q. While the reactor is at power, why is it inadvisable to pull the covers on both test block 21 (bypass flow) and 22 (main flow) at the same time?
- A. Because a full scram will result.
81. Q. Low reactor cooling air flow and loss of reactor cooling air pressure have a common power reduction. What is the power reduction and how are test blocks 19 and 20 involved in this circuit?
- A. The power reduction is a fast setback. Test block 19 will invalidate the fast setback from low cooling air flow and test block 20 will invalidate the fast setback from low cooling air pressure; but, pulling both test block covers at the same time will result in a fast setback regardless of the air flow or pressure.

CHAPTER IV

REACTOR OPERATION

A. REACTOR STARTUP

1. General

A major shutdown ends when the reactor top is bolted into place. During the shutdown, the reactor fuel has been changed, control rods have probably been changed and moved, and a multitude of experiments have been replaced. There may also have been some major changes at the reactor faces involving piping and shielding. Each startup is considered on its own merits, and conditions and checks which were valid for other runs are not automatically assumed to be acceptable for the startup at hand. Important items are individually rechecked before each and every start.

Since there is rarely a specified time for the actual startup of the reactor, there is no "count down" that controls MTR startup activities; however, the bolting down of the top plug does signal the beginning of intense activity throughout the reactor building and the supporting facilities.

2. Startup Check Lists

Wherever possible, this activity is controlled by check lists and procedures. The most important of these checks is the "Startup Check List", which funnels a report of the actions of the foreman, senior reactor engineer, reactor engineer, instrument technician, and reactor services operator to the Supervisor. The information contained on these sheets is combined into list form which is shown in table 11. (See page 144.)

a. Reactor Services Operator Preliminary Checks

The reactor services operator must first assure that the reactor unloading mechanism is down, turned "OFF", and that the unloader keys are removed from the interlocks and placed in the RSO's desk. This makes it impossible for anyone to open the gate valve during reactor operation.

He checks the monitor room instruments which record individual fuel element temperatures, activities and ΔP 's. The fuel element ΔP 's are especially important, as an abnormally low reading could indicate blocked flow element channels. This could lead to a fission break after the reactor becomes critical. He also checks the operation of the iodine monitor equipment. He assures that there is proper purge gas flow to the ion chambers which feed signals to reactor instruments.

The RSO is also required to check the electrical equipment in the wing basement. The motor generator units, backed up by batteries that provide reactor instrument power and emergency experimental power, receive close attention and their operating voltages and currents are adjusted to prescribed values.

As soon as the RSO has completed the formal check list and made a thorough tour of his area, he gives his check list to the senior reactor engineer.

b. Console Operator Preliminary Checks

The console operator has the very important job of assuring the proper functioning of the various safety features of the reactor control circuit. Working in conjunction with the instrument technician, he makes trial scrams (both electronic and mechanical) with the shim rods withdrawn a few inches. These guarantee that the circuits and relays of this ultimate safety action are functioning properly. Since the reactor control circuit has previously been covered in another chapter of this manual, let it suffice to say that the console operator makes sure that all the requirements for safe rod withdrawal and operation have been met. The "check list" indicates necessary settings of console switches and confirms that necessary instruments are turned on and operating.

The first move of the operator assigned to operate at the console is a complete survey

of the instruments to see that they are turned on and showing normal response. The most important instrument at the beginning of start-up is the count rate meter. The operator moves the count rate chamber up and down while he watches for proper response on the recorder.

c. Electronic Technician Preliminary Checks

Some hours prior to the console checks, the electronic technician has completed a check list of his own which consists of a comprehensive review of all the control circuitry. This demands a calibration of amplifiers and instruments, inspection of relays and wiring, and simulation of reactor periods as a check on the sigma bus voltage response.

The electronic technician is also responsible for the radiation instrumentation on all experiments. In preparation for reactor start-up, he calibrates these instruments and checks them for correct response to activity.

d. Senior Reactor Engineer Responsibilities

The senior reactor engineer follows the progress of startup preparatory operations and delegates many responsibilities to reactor engineers for completion. There are a number of "reactor top" jobs preliminary to the securing of the top plug, such as checking shim rods for freedom of movement and cleaning the armature faces. These jobs are usually completed in a short time.

(1) Lead Experiments

A project usually started in advance of top plug placement is the preparation of lead experiments for power operation. The large number of leads and the operating information concerning them is summarized, for convenience, in a "Lead Experiment Summary". This letter is a digest of essential information gleaned from the Safeguard letters, the Lead Information letters, the thermocouple wiring instruction schedule and the appropriate lead set-point lists. Using it, the engineer can start up the appropriate recorders and heaters. He can also tell at a glance what the various lead experiments are composed of, what their operating limits are,

and what special care or readings are required. A sample page from this letter is shown in figure 31.

(2) High Pressure Loops

The high pressure water loops and other large experiments usually receive close attention hours before startup to insure adequate flows and to give the components of these complex experiments some operating time before neutrons actually are available. Usually they are brought to normal pressure but only partial temperature. Some sponsors request that their loops not be brought above 200° F until the water chemistry has been brought within desired limits of pH, dissolved oxygen, etc. It is important that these restrictions be observed.

(3) "W" Switches

The "W" switches on the various experiments are checked with the aid of a check sheet. (See figure 32.) All the Amphenol plugs from the experiments to the reactor control system are inspected to see that they are firmly plugged into their proper outlets, and that the "W" switches at operating experiments are turned to "ON". Because there are two "W" switches in each circuit, the master switches in the south reactor top instrument cubicle should also be checked. They are numbered the same as their corresponding units at the experiments and both switches for each experiment are operated by a single numbered key which cannot be removed if the switch is in the wrong position. At the experiment, the key cannot be withdrawn in the "ON" position. The opposite is true at the master switch. This means the experiment switch must be deliberately "OFF" before the key can be brought and used in the master. Since a control room annunciator is given when an experiment "W" switch is opened ("OFF"), this action can be detected by the reactor console operator, but if the master switch is open ("OFF"), this signal is blocked. Examination of the master switches will disclose all open ("OFF") switches to have keys and all closed ones to be without keys. The importance of the "W" switch check cannot be overemphasized, as a great share of the protection of many of the experiments and the reactor itself depends on

1. ANL-46-4 in A-29-SW, Flange 29, Cycle 7:

Proj. Engineer: Martin

43.87 grams U-238. EBR-II plutonium fission fuel pin in a tantalum cup enclosed in a nickel can. This is enclosed in an outer SS shell.

Temperature Recorder: TR-1W (N) In service_____

Temperature Recorder: TR-2W (N) In service_____

ANL-46-4 may be operated with one functional TC.

	<u>Normal Temp.</u>	<u>Hi Alarm</u>	<u>Low Alarm</u>	<u>Max. Permiss.</u>
TR-1W	610°C	688°C		
TR-2W	1130°F	1155°F	1105°F	1280°F

This lead is a single pass, continuous gas flow experiment, utilizing a mixture of He and N₂ for temperature control. Prior to startup, set the He and N₂ regulators at the bottles for 25 psig. Place switches T1 and T2 in the No. 1 position and set the panel regulators at 10 psig. Maximum cooling is desired, but do not exceed 0.7 on the flowmeter. Use He, only.

At shutdown close valves 1-VH and 2-VH.

Readings are required once/day on midnight shift.

2. BMI-43-4 in A-29-SE, Flange 28, Cycle 6:

Proj. Engineer: Bergstad

3.74 grams U-235. The capsule contains two UO₂-CeO specimens and three UO₂-CaO-ZrO₂ specimens which are immersed in NaK and double contained in SS.

Temperature Recorder: TR-2T (N) In service_____

BMI-43-4 may be left in the Reactor with no TC's.

<u>Normal Temp.</u>	<u>Alarm</u>	<u>Max. Permiss.</u>
580°F	640°F	660°F

This experiment has no heaters.

No readings are required.

FIGURE 31.
Sample sheet from experiment summary letter.

correct "W" switch procedures. Only those who thoroughly understand the significance of the circuitry are to make this safety check.

(4) Cooling Necessities

The cooling necessities of the beam holes and the shielding are also checked. During shutdown, if any dummy plugs have been inserted into the HB holes, it is of paramount importance that these plugs receive water cooling. If this is overlooked, the plug tip will be damaged as reactor power increases.

After these and other items are done, the senior reactor engineer must assure himself that others under this direction have properly concluded their pre-startup work. He must make a brief personnel review of all console and experimental conditions and then combine the RSO's, the console operator's and the senior reactor engineer's startup check lists with the "W" switch check sheet and give them to the foreman. The Control Room copy of the "Lead Experiment Summary" letter should be verified as completed, then kept in

"W" SWITCH DATA SHEET							
				CHECKED BY _____	DATE _____		
REACTOR TOP SWITCH NO	OUTLET NO	OUTLET LOCATION	EXPERIMENT	SWITCH NO	AMPHENOL IN-OUT	EXPERIMENT "W" SWITCH ON-OFF	REACTOR TOP "W" SWITCH ON-OFF
1	1	First Floor, N Face					
2	2	First Floor, N Face					
3	3	First Floor, N Face					
4	4	First Floor, S Face					
5	5	First Floor, S Face					
6	6	First Floor, S Face					
7	7	First Floor, N Face					
8	8	Behind GE Panel					
9	9	Behind ORNL Panel					
10	10	South Balcony					
11	11	Basement, E Face					
12	12	BWC - 301 Panel					
13	13	South Balcony					
14	14	South Balcony					
15	15	South Balcony					
16	16	Basement, E Face					
17	17	Basement, E Face					
18	18	Basement, W Face					
19	19	North Balcony					
20	20	North Balcony					
21	21	North Balcony					
22	22	North Basement					
23	23	North Basement					
24	24	Basement, W Face					

PP CO C-2822

FIGURE 32.
"W" switch data sheet

the Control Room for reference during the cycle.

e. Foreman's Checks

The foreman calls the process water operator at about the time the top plug goes into place and asks for vacuum to be established in the evaporative heat exchangers. This takes about 1/2 to 3/4 hour. As soon as the top plug is secured, main flow is established by the foreman in communication with the process water operator. Experiment changes cause differences in flow required each cycle. Flow is increased until the pressure drop across the lattice is 42 psig. This assures proper flow rates through the fuel elements. The foreman can then have instrument maintenance zero the main flow and reactor ΔP instruments to be sure their calibration is correct. Slight flow adjustments can again be made, if necessary. The process water operator checks the reactor blowers, the experimen-

tal compressors, and his minor equipment, then reports he is prepared for startup.

The foreman makes his own tour of the reactor building, watching for any factor that may inhibit successful startup. If he sees nothing out of order, he takes the check sheets he has gathered, adds his own, and passes them on to the supervisor.

f. Supervisor's Responsibilities

The supervisor follows as many details of the startup preparation as he can, but his primary concern is maintaining safety of personnel and of the reactor.

He reviews the safe work permits and safety tags for any indication of unfinished projects or unsafe equipment, and he checks sub-pile room and beam hole shielding.

After he has personally toured the reactor building and has reviewed the check lists given him, he will signal approval for reactor start-up.

3. Pulling Rods

When the reactor was first brought critical, fuel elements were added one at a time until enough were present to make criticality possible. Caution was necessary because the reactor core contained only one neutron source, (polonium-beryllium), and the only poisons present were those inherent in the construction materials. During this first startup, there were five decades of neutron population increase indicated on the count rate meter before it showed on any control room instrument. Soon the beryllium reflector, and the many high energy gamma emitting sources it contained, provided a high level of neutrons which is now available as a startup source. The neutron flux during shutdown is approx 10^6 n/cm² sec. This starts the reactor within two decades of Log N recorder response. The count rate meter is of paramount importance during the early stages of an MTR startup and must be on scale and operative before a startup is begun. Refer to figure 33 for a relationship between reactor power level and the control room instruments.

For a number of years, this high neutron background and the great amount of residual poison the core carried gave a highly safe reactor to start. In 1960, high concentration cores were approved for routine loading which made 700 Mwd (17-1/2 day) operation possible. In order to verify that no calculating or loading error had been made, the rod pulling was programmed so as to detect an error while still in a safe condition. After experience and further checking verified no problems were present in using 700 Mwd charges; normal startup routines were resumed.

Assuming that the check list and control circuit requirements have been met, the first moves needed for actual rod withdrawal are to unlock the console switch and press the "START" button. The timer will begin operating and rods can be withdrawn 2/5 sec out of every 5.

Normally, all 7 shim rods are pulled intermittently until the fuel shims reach 10 in.

They are then blocked until the reflector rods are nearly fully withdrawn so final fuel withdrawal to criticality can be made with full reflector efficiency.

As a critical assembly is formed, the count rate meter will begin to indicate continuously increasing activity. Soon the period recorders will begin to kick in a positive direction, indicating that each upward movement of the rods is giving a transient measurable increase in neutron population. If all four fuel rods are being pulled together, it will be necessary to block one or more towards the last to reduce the rate of power increase.

If, by chance, the period recorders drive up to a period of 30 sec or less, "withdraw permit" will trip out and the shim rods will cease to withdraw even though the timer switch is engaging. The console operator must then reset the trip relay by returning the "INTERMITTENT" switch momentarily to the neutral position.

Eventually, criticality will be reached which is of no operational significance unless some technical measurement is to be made. It can be recognized as the point at which the power is self-sustaining without further rod withdrawal. N_L , on either log N recorder, has arbitrarily been chosen to represent criticality at the MTR. The difference in rod level is negligible and N_L is easily reproduced with a minimum of time.

Once the neutron level increases to where it shows on the log N recorders, the count rate meter loses its vital importance but should still be kept on scale for supplementary power indication.

At the low end of the log N recorder (0.0001), the reactor is producing 40 watts. The reactor controls are physically restricted to intermittent until power rises one more decade (to 0.001, $10^{-5}N_F$). At this point, a lesser restriction designed for use during power recoveries becomes possible. Continuous, full speed withdrawal of any or all rods is permitted by the circuitry, but during a

FIGURE 33.
Power level - instrument relationships

"clean" startup its use is forbidden. Intermittent rod movement must be used until the reactor controls are switched to the "RUN" regime.

4. Transition from "START" to "RUN"

Until the reactor reaches 40,000 watts or "SAG", as it is called (0.1 on the log N), the console operator is involved in raising the shim rods while maintaining a reasonable period. At "SAG", the count rate chamber will automatically retract to its outermost position.

A regulating rod should be selected at this time by placing the regulating rod selector switch to the desired channel, eg, No. 1 regulating rod or No. 2 regulating rod position. It should be remembered by the console operator that the decade above "SAG" is the transition zone from the "START" to the "RUN" regime. After one of the log N recorders crosses the (0.1) SAG point, the "RUN" button may be pushed. (If the "RUN AUX" relay, R-3 fails to operate due to minor missetting of R-70, the instrument technician will have to close it manually.) The timer motor stops and the intermittent withdrawal is invalidated as the "RUN" system seals in. On normal startup from this point, shim rods are withdrawn individually. The shim rod withdrawal selector switch is used to choose the rod to be used, then the individual switch is placed in the "WITHDRAW" position. The rods pulled should be alternated so they will remain within 1/4 in. of each other. The long N's, including most power monitors, will continue to increase.

5. Servo Control to Full Power

At 400,000 watts (1 on the log N), the regulating rod will activate and come into range, as shown by the selsyn position indicator. An announcement should be made that "the reactor is at N_L ". The regulating rod will maintain the power level at N_L until the technician calls for a power rise through the MOR system. At N_L , another check of the experiments and the shielding around the reactor is made. Enough power is now being produced so that many experiments will begin to show temperature increases, and shielding weaknesses will be detected by roving health physicists.

At about the time the reactor reaches N_L , the demineralizer operator should start the cooling tower coolant pumps and valve the water flow through the cooling tower. As reactor power increases, the process water operator will maintain a predetermined reactor inlet water temperature by controlling secondary coolant flow through the heat exchangers. The demineralizer operator will add more secondary coolant pumps and more cooling tower fans as reactor power increases to keep the process water temperature within the control range of the vacuum evaporative system.

The last two decades of power, from 0.4 Mw to 40 Mw (1 to 100 on the log N's), are controlled by the servo system. The motor operated rheostat switch is placed on "RAISE" and the cadmium regulating rod's stepwise outward movement will increase the reactor power.

Theoretically, the regulating rod should withdraw until the neutron level rises to that called for by the MOR circuit in the servo system, and then return to its point of beginning. Because some residual neutron "poisons" are present in the shim rod fuel sections, experiments, and some fuel elements, the actual response is not this way. As power is increased these poisons are transmuted by neutron bombardment and become less effective. This causes the regulating rod to insert to compensate for the gain in reactivity. The over-all effect then is for the regulating rod to withdraw quickly until power rises, then insert part way; this is true for each step. As the poisons are burned out, the rod will continue to slowly insert to maintain stable power until equilibrium is reached.

Power is raised upon instruction from the senior reactor engineer (who has been delegated this authority by the supervisor) in 5 Mw steps up to 30 Mw, and in 2-1/2 Mw steps from 30 Mw to 40 Mw. These increments provide many opportunities for operations people to check and double check the reactor, the experiments, and the radiation fields as power increases and the radiation fields as power increases. Quite often, some experimenters are on hand to record the parameters of their experiments at these different power levels. The smaller power increments between 30 Mw and 40 Mw were established

to prevent any rapid entrance into nucleate boiling conditions. A very sensitive "Brush" recorder is attached to the servo channel that is not in use and records any aberrations that might indicate boiling in the core. If boiling occurs, it is due to a "hot spot" or a loading error. Since this could lead rapidly to a fission break, the power must be reduced 10 percent until two more inches of shim rod burnup occurs.

When 40 Mw is reached, the experiments are brought to normal control conditions, one more radiation survey is made, and the process water inlet temperature is stabilized at its normal operating temperature (100°F to 105°F).

On the average, some five hours have elapsed between the bolting down of the top plug and the attainment of full power. They are the most critical ones for operations personnel, since a great share of experimental fission breaks and equipment malfunctions occur during the startup. If all has gone smoothly, the reactor is considered to be operating "on the line" at full power.

6. Special Tests

At this time, it is appropriate to mention special tests that are sometimes conducted during the startup processes of the reactor. Three of these are: Flux Runs; Reverse Reactivity; and Special Experiment Startup Rates.

a. Flux Runs

These are most often conducted at N_L just after the servo system (regulating rod) has taken over control and are made to determine the true neutron flux present in particular locations. For example, a new experimental loading may be known to have a heavy "poisoning" or neutron shading effect in its area. Since its neighboring experiments are affected, their sponsors need to know exactly what the flux is to interpret their own data. For this reason, measurements must be made for what cannot be calculated with certainty.

Generally, the flux monitors are cobalt wires or gold foils, and they are irradiated for a specified time at 1 percent of full power. If they are in an internal position, the reactor must be shut down so they can be removed and

counted after irradiation. The counts are then extrapolated to full power operation. Two standards are always run at N_L and N_F in VG-33 and VG-23. These serve as checks on each other and on the main flux monitors.

b. Reverse Reactivity

A phenomenon associated with depleted shim rods causes their cadmium sections not only to cease absorbing neutrons, but to actually increase reactivity by a small amount. (This appears to be a reflective effect in highly transmuted cadmium.) The influence is small and localized, but it is a potential danger and so must be detected and removed. If this were not done and the effect became pronounced, dropping that shim rod could raise power. Accordingly, tests are made on a Be-Cd rod each cycle startup to see if reverse reactivity is present. (Refer to the curves of figure 34.) Since the effect develops slowly, once per cycle is often enough. Fuel shims are changed so often that they do not require this check.

c. Special Experiment Startup Rates

Occasionally, an experiment may require a slower startup rate than normal due perhaps to the necessity of melting an experimental sodium heat conductor or by some other limitation. Sometimes it is important that data be obtained every few megawatts until the equipment fails as anticipated. The reason may be that transient data, observable only during startup, may be of particular value. For these, or any number of other reasons, special slow or segmented power rises may be requested. After coordination office approval is granted, the requests are complied with as closely as possible. These also constitute special tests.

B. NORMAL POWER OPERATION

After the reactor has been brought to full power, it passes through a transition stage while water temperatures, xenon and other parameters come to equilibrium. The shim rods must be inserted for a short period as residual xenon and other poisons are "burned out" (transmuted) from the partially used shim fuel and possibly some experiments. After this, the shim rods are withdrawn somewhat as xenon and other poisons build up slowly to equilibrium at full power. Then, after about a day and a half, rod

FIGURE 34.
Reverse reactivity curves

movement due to burnup assumes a near uniform rate and console operation becomes routine until burnup is complete or a power reduction occurs. Figure 35 and 36 are full power neutron flux maps.

In the rest of this section, the reactor is considered to be operating at a stable power level and no abnormal circumstances prevail

in any of the systems. The normal jobs that must be done by operators are both numerous and varied.

1. Duties of Reactor Operators

There are four normal duty stations manned by operators around the clock and a fifth position which is periodically required. These are: (a) Reactor Console; (b) Reactor Basement North; (c) Reactor Basement South; and (d) Roving Readings and Miscellaneous Experiments. Since there is a man at each of these stations who must be relieved at shift change, there is a schedule made up in advance so the men will be able to go directly to their first work station. This scheme is not a mandatory policy, but each duty man should be relieved as quickly as possible so as to have maximum time for information exchange before he must leave. Under normal circumstances, a tour of duty at any one station is two hours so as to alleviate the tendency to tire. In a little more detail, these are the duties of the various stations.

a. Console Operator Duties

At the first of each shift, the duty operator should make a visual check of his instrument readings to verify all are behaving normally. Then, he should open the duty log for the shift, recording by name all who are present. During his two hour duty, all information concerning items of consequence which may be useful to oncoming crews should be entered. This is true concerning power reductions, operational problems, experiment troubles, etc. It is good policy to indicate annunciators received each time they come through unless they are repetitious from some understood source (such as instrument work). Every operator should take pride in having the reputation of writing an adequate log. There is no excuse for inadequate log information. What seems of little consequence is often of great importance.

Normal routine control room instrument readings are also the duty operator's responsibility. These should be taken every hour on the half hour to avoid undue rush at shift relief time when other information must be exchanged.

FIGURE 35
Maximum thermal neutron flux,
 10^{14} n/cm²/sec

FIGURE 36
Fast neutron flux at reactor midplane
(neutron energy >1 Mev)

Circular charts should be changed at 0100 each graveyard and turned over to the foreman. New ones should be made out early on swing shift so that they will be ready for the oncoming graveyard crew.

One of the items required by the hourly log sheet is a calculation of reactor power based on ΔT , main flow, and inlet water temperature. The derivation of the equation is found in the chapter covering the reactor instrumentation and on page 132. The result is:

$$\text{Power (Mw)} = \text{Flow (gpm)} \times \Delta T(^{\circ}\text{F}) \times 1.457 \\ \times 10^{-4} \text{ (at } 100^{\circ}\text{F)}$$

Of course, the correct factor for the existing inlet water temperature should be used.

Special power readings, taken at 0830 and 2030, are used to plot points on the shim rod burnup curve. At this time, the regulating rod should be between 11 and 11-1/2 in. and the fuel shim rods should be level to 0.001 in.

On the back of the control room log sheet is a tabulation of power data accumulated during each day. Any item required, which can be supplied by the operator, should be entered during his console duty. The items are simple enough in themselves but mixups sometimes occur. For this reason, **SP-2.07** spells out in detail what is required in each space. Every operator should understand this **SP**.

b. Reactor Basement - North and South

These two duty spots have the same responsibilities, but they concern different experiments. At the beginning of each shift, after relief information is received, a quick check of the operating experiments should be made. This should concern parameters which may be drifting from normal levels. For example: Surge tank levels and loop coolant temperatures and flow rates should all be closely checked.

The next important item should be a review of the experimental logs. These should contain all that was given orally at shift change and more. They should contain details on all abnormal conditions, information on all valve

changes and why they were made, and information on other manipulations performed even though they are routine. These logs must be complete since sponsors interpret much of their data in the light of log entries. Changes made in valves should also be indicated on the pin-board so that these are up to date at all times. The pin boards should be kept as accurately as humanly possible. Valve changes which have not been indicated can mislead other operators and lead to serious incidents. It is as important to change pins in the boards as it is to make log entries.

The next routine job is the timing and dating of all strip charts. These should be marked where the pen is indicating, and timing should be to the nearest minute so that prior or subsequent events can be identified accurately in time on all the recorders of that experiment. It is not important when the strip charts are marked, but they must be marked once each shift. It is preferable to do this job early. Of course, the circular charts should be checked for synchronization each time they are read. The graveyard operators are responsible for changing all the circular charts on their experiments, and this should be done between 0030 and 0100. In order that this may be accomplished within the time specified, they should have been made out during the previous swing shift by those on duty.

Readings are to be taken according to the log sheet of the particular experiment. Most are taken every two hours on the even half hour. Others are on the odd hour. Since this varies from cycle to cycle, specific instructions are issued by the coordinator's office. Checks of experiment conditions are to be made between readings also.

Many of the experiments require routine sampling, and the samples are drawn by the duty operator on the off-shifts. The sponsor's chemist is permitted to draw these samples on day shift in order to minimize unnecessary radioactive exposure to operations personnel. The frequency of these, and other specific instructions concerning them, are issued through the coordinator's office. Normally, these and other chemical tests (conductivity, pH, etc) are conducted within the first two hours of the shift.

Most of the high pressure water loops require routine make-up to cover minor losses. The techniques vary a little from experiment to experiment and the details need not be given here. Suffice it to say, make-up of a loop is considered a routine duty and the operator is expected to perform it, as necessary, without upsetting loop conditions.

Near the close of each shift, the duty operators are to report to their senior reactor engineer a summary of the experiments' conditions and other pertinent information. This should be written onto the special form provided and given to the shift supervisor.

c. Roving and Miscellaneous

The operator who performs this duty is responsible for all experiments which do not require an operator in full time attendance. These include the lead experiments entering the reactor top and those on the reactor balconies and main floor.

His first duty is to time and date all the strip charts and to check the operating conditions of the experiments. The log from the previous shifts is to be read and an opening for his shift entered.

Pressure readings are to be made on lead experiments every even half hour to assure that dissociation gasses are not building up to unsafe levels. If the pressure goes to 90 psig, they should be bled off and reported to the senior reactor engineer. Slow build-up is normal; rapid build-up is potential trouble. If pressure falls due to leakage, inert gas (He or N₂) should be used to restore them to 80 psig. A manifold is provided for this purpose.

Periodically, the gas bottles supplying this manifold and other experiments around the area need to be replaced. They are obtained from the supply near the RSO's desk. The log should be signed indicating what was taken, how much, where it was used, and who obtained it. Empty bottles should be tagged as such and returned to the empty bottle rack.

Data readings are made as requested by the sponsor. Those that require only one set per shift are read on the third hour. At this same time, a regulating rod check is made to assure that neither of the rods is vibrating loose. Take care that the bolt is snug but not

overtight. It is possible to strip the threads by continued overtightening.

As in other duty positions, the swing shift man should make out the required circular charts and the graveyard operator should change them at 0100.

There is experimental apparatus belonging to technical groups located on the reactor main floor. Much of this is left running without attendance and it is not operations' direct responsibility. These should be checked periodically to see that obvious trouble is not developing.

Other duties of the roving operator include assisting the console operator in the leveling of shim rods and the reading of their reactor top position indicators. Other miscellaneous details which may arise during shift also fall to him.

d. Senior Reactor Engineer

During normal operation, the senior reactor engineer does not man a duty position with his operators but moves about keeping track of all of them. What they do is his responsibility, and his job is to keep himself fully informed of their activities. The operation of the reactor and its experiments are his prime interest. His next most important responsibility is records including those of the reactor and the experiments. In the control room, he should personally check the correctness of the log book, log sheet, and the daily power summary figures. He should also check and sort the experiment charts and data sheets before they are turned over to the foreman. A third record responsibility is the miscellaneous irradiation facility log. Long term irradiations must be removed after prescribed doses, so all reactor power changes and accumulated megawatt days should be entered here.

2. Standard Manipulations

With the reactor operating steadily at full power, there are a few console manipulations that are routine. Adjusting and calculating power is one, pulling and leveling shim rods is another, and switching from one servo-system to the other is still another.

a. Calculating and Adjusting Power

It is not unusual for power to drift slightly due to progressive shading of the servo chamber or other causes. The best way to be certain of true power level is to calculate it from the heat added to the coolant flow per unit of time. As mentioned previously, this is entered on the log sheet and should be done every hour, or oftener, if power levels are being changed. This is the derivation:

$$\text{Power} = \frac{\text{Heat energy added to water}}{\text{Time}}$$

$$\text{Power} = \frac{(\text{Heat capacity of water})(\text{Temp change of water})}{\text{Time}}$$

$$\text{Power} = \frac{(\text{Mass of water})(\text{Specific heat of water})(\text{Temp change})}{\text{Time}}$$

$$\text{Power} = \left(\frac{\text{Volume of water}}{\text{Time}} \right) (\text{Density})(\text{Specific heat})(\Delta T)$$

$$\text{Power} = (\text{Flow rate})(\text{Density})(\text{Sp Ht})(\Delta T)$$

$$\text{Power in Mw} = \frac{(\text{gpm})(\Delta T)(8.29 \text{ lb/gal at } 100^{\circ}\text{F})(\text{Btu/lb } ^{\circ}\text{F})}{5.688 \times 10^4 \text{ Btu/min at 1 Mw}}$$

$$\text{Power in Mw} = (\text{gpm})(\Delta T)(1.457 \times 10^{-4}) \text{ for } 100^{\circ}\text{F inlet water}$$

Minor power adjustments are easily made with the vernier rheostat. Large adjustments (a megawatt or more) must be made with a full step on the MOR. Often a combination of the two is necessary.

Since there is an inherent time delay in the power recorder of approx 1/2 min, due to transport time of heated water to the resistance bulbs, power changes of specific size must be gauged by other instruments. The level instruments are good for this (their response is rapid) as long as no flux distortion is present. The neutron thermometer (boron thermopiles) is also good and has special advantages since it averages the flux in several locations. A little experience makes it easy to determine which to use.

b. Pulling and Leveling Shim Rods

As fuel is consumed, the regulating rod slowly withdraws to compensate and hold power level. As it reaches its upper control limit

at 17 in., the fuel shims are pulled to compensate for burnup and to cause the regulating rod to return to near the lower limit of its normal control range, at 11 in. It is standard operating practice to keep the fuel shim rods level with each other to prevent unnecessary flux distortion. Accordingly, two men are necessary for the job. The console operator pulls each rod an equal amount guided by phoned information from the second who is reading the position integrators on the top

plug. When the operator is alone at the console, he pulls an estimated equal amount and the rods are leveled later.

c. Switching Servo Systems

A manipulation which isn't performed too often is the switching of servo systems while the reactor is at power. It is such a straightforward operation, however, that every operator should be well acquainted with it so he will feel at ease making it. There are one or two items of technique which will make it a smooth transition with a minimum loss of power.

The principle involved is to cock the regulating rod of the servo system being abandoned, then switch through manual into the other servo channel. First, put the deviation galvanometer on zero, so drift from level power can be detected. Next cock the regulating rod by inserting a shim rod. It is important that the regulating rod be made to cock very gently or the reactor

will go into a negative period and power will be unnecessarily lost. The rod is cocked so it will be possible to return to this channel, if desired. As soon as the rod is above 17 inches, switch the servo selector through manual into the new channel and bring the deviation galvanometer back to zero by pulling one of the "weak" shim rods. Since the new reg. rod is fully cocked, it cannot respond because its MOR is set above existing reactor power. It is now necessary to lower the MOR down to true power level. This should be done as quickly as possible (fast lower) so that any power drift will be quickly overtaken. Good technique is to slow down with the MOR drive just before the system takes over, so as to prevent a large overshoot with its attendant rapid regulating rod insertion. Properly done, only a little power recovery compensation should be necessary.

C. OPERATIONS UNDER ADVERSE CONDITIONS

The MTR and its many experiments constitute so complex an assembly that equipment failure and component malfunction can be expected periodically. Some of these could jeopardize the reactor or a potentially dangerous experiment, so safety circuits are incorporated to shut the reactor down. The severity of the situation determines what reduction system is used and whether an immediate power recovery is appropriate.

Occasionally, some unusual circumstance develops in the supplemental facilities which supply the reactor. It may be in the electrical, water, or air system, and may be difficult to analyze.

In this section, an attempt is made to give the reader the benefit of many years of operating experience in both diagnostic and recovery techniques.

1. Emergency Scrams and Recoveries

Three types of scrams can be initiated through the MTR safety circuits and each requires a slightly different recovery procedure.

a. Full Scram

The full scram, sometimes called the slow or relay scram, is the most severe power reduction, as it is a positive drop of all seven shim rods. (See the power drop versus time curves on figures 37 and 38.) A full scram will be accompanied by the scram annunciator and a trouble annunciator which will give an indication of what caused it. All reactor power level recorders will drift down scale and the shim rod position selsyns should show the carriers inserting automatically. The selsyns will also display "NO CLUTCH" and "INSEAT" lights. If the lights are not on and a selsyn does not show carrier movement, call the instrument technician. The operator should announce over the communication system that the reactor is scrambled, then dial 40-444 which is the code used to inform everyone the reactor has scrambled.

The shim rod carriers travel 30 in. in six minutes giving the operator time to consider his next steps. Nothing can be done to recover reactor power until the rod carriers insert to the point of shim rod contact. Because of friction and rod carrier drive motor characteristics, all carriers do not insert (or withdraw) at the same rate. Carriers insert twice as fast as they withdraw due to double speed motor drivers.

Scram signals from experiments will clear as reactor power decreases below 3 N_L . However, scram signals from reactor components will continue to restrict the reactor until the trouble is rectified. The console operator must remember to push the "SCRAM RESET" button after the scram signal clears.

In some cases, reactor power will drift below "SAG" before, or shortly after, the carriers reach the shim rods. Below "SAG", the reactor controls will regress to the start-up regime and the selected servo MOR will automatically return to the N_L position.

(1) Normal Recovery

Assume that at the time of the scram ample rod remains so there is plenty of time available for recovery. Remember, no power increases may be made without approval from supervisor (S.P. 2.201).

FIGURE 37.
Approximate power vs. time for automatic
power reductions

FIGURE 38.
Approximate power vs. time for slow scram and
jr. scram

After the rod carriers reach their shim rods, withdrawal should be delayed for a moment to let the magnet currents buildup. With the "CONTINUOUS" and "BYPASS" switches, withdraw the shim rods. (If the reactor has regressed to the startup regime, the "BYPASS" switch need not be used.)

Eventually, positive periods will be shown and the Log N recorders will stop falling and start rising. Shim rod withdrawal will have to be discontinued from time to time to reduce short periods. Blocking a few shim rods, or using individual withdrawal will help hold short periods down. The rods should be kept level within 1/4 in.

As the Log N recorders pass "SAG" the "RUN" button may be pushed. The servo system will come in near N_L and normal power increases can then be made using the MOR switch.

(2) Recovery Where Time is Limited

Assume that after the scram, very little time remains before the reactor will be overcome by xenon and power will have to be resumed in as short a time as possible.

After the scram signal has cleared and the rod carriers have made contact with the shim rods, the shim rods should be pulled by use of the "CONTINUOUS" and "BYPASS" switches. If the reactor has regressed to the startup regime, the "BYPASS" switch need not be used until periods less than 30 sec begin to appear.

The foreman should call the process water building and request the cooling water temperature be lowered so as to increase the reactivity of the reactor through its negative temperature coefficient. The console operator should put the regulating rod selector switch in the "MANUAL" position sometime before the reactor reaches N_L . If the reactor is not put into "MANUAL", the servo system will come into operation at N_L , stopping the reactor power rise. This momentary delay may be crucial where time is limited. Also, power increases in servo cannot be made rapidly. With the reactor in "MANUAL", power may be increased rapidly enough to stay ahead of xenon buildup. It might be well to note here that occasionally the shim rods are withdrawn to the upper limit switches before power has increased

sufficiently to overcome xenon. The shim rods can be manually withdrawn another inch when necessary, and this has, at times, been enough to override the xenon buildup. Operators should be standing by, on the reactor top, ready to "belt up" the rods should supervision call for it. Care must be taken not to go beyond 31 in., as it is possible to damage the limits switches with the trip-blocks.

When the Log N recorders reach "SAG" the "RUN" button must be pushed, and since the MOR automatically set itself back to N_L previously, the operator will now momentarily select the No. 2 servo system (if No. 1 rod is to be used). It can then be returned to MANUAL. The MOR will raise continuously since the reactor is in "MANUAL". (See figure 23.) (The shim rods are still being withdrawn as needed to sustain a strong positive period.) Supervision will direct the console operator to level off power (manually) at 26 Mw or below, depending on the needs. This limit is set because there is no need to go higher, since 26 Mw will burn out 40 Mw xenon as fast as it forms. In the meantime, the MOR will still be rising. Rather than have the MOR go fully to the upper limit, it can be stopped at a point above the existing power level by "switching-in" the original servo channel. Since the servo system is calling for a reactor power level greater than the existing level, the regulating rod remains cocked. The MOR can now be lowered to the existing power level where the regulating rod will uncock and move into range. The reactor is now in servo and power can be increased normally, as directed.

NOTE

With this type of scram recovery, the MOR must be raised above the existing power level before selecting the regulating rod. If the MOR is stopped at a point below the existing power level by prematurely selecting a servo channel, the regulating rod will drive in fast and hard. This will probably result in a reverse from the 5-in. regulating rod limit switch.

b. Jr. Scram

A jr. scram can only be initiated from an experiment, and the annunciator system will indicate which experiments are in trouble

A check of No. 6 and No. 7 shim rod selsyns should be made, and if the carriers are not running down automatically, or the "IN SEAT" and "NO CLUTCH" lights are not on, call the instrument electronic technician. Then, lower the MOR below 50 percent of full power (SP 2.322). The announcement should be made of the scram over the intercom and the code 40-444 dialed.

Only after reactor power drifts below $3N_L$ can the fuel shim rods be safely withdrawn to hold power from falling further. Above $3N_L$, the jr. scram will convert to a full scram after 60 sec. Reactor power should be held at N_L or below until an investigation of the jr. scram has been made, then, with supervisions' approval, shim rods may be withdrawn to increase the reactor power. The servo system will come into operation somewhere around 50 percent of full power. Reactor power must not be raised above 26 megawatts until rods No. 6 and No. 7 are withdrawn above 25 in. (SP 2.322), otherwise boiling may occur due to flux distortion. Normal power increases may now be made using the MOR.

c. Electronic Scram

An electronic scram will drop one or more shim rods. Recovery will be identical to the jr. or full scram, depending on the number of shim rods dropped. The relay scram annunciator is not given with an electronic scram. However, other annunciators would be given which would identify the source.

d. Accidental Shim Rod Drop

The first indication of an accidental shim rod drop will be the power recorder drifting down scale for no apparent reason. The regulating rod will be cocked and one shim rod selsyn will show "NO CLUTCH" and "IN SEAT" lights with the carrier inserting.

A scram announcement should be made in the usual way. The electronic technician should then be called and informed which rod dropped. He will check the voltages across the P-relays. Normal is 0 to 2.5 volts with the magnetic clutch in contact and 12 to 13 volts when the shim rod has dropped.

Proceed with the recovery in the same manner as for a jr. scram. If trouble is experienced in picking up the rod, the magnet current can be increased, but the new current must not exceed $1\frac{1}{2}$ times the drop off current (see SP 2.103). Power should not exceed 26 Mw until the faulty shim rod is withdrawn above 25 inches.

e. Accidental Regulating Rod Drop

This condition should never occur as long as regulating rod tightness checks are made as scheduled once each day. It has happened once or twice, however, so should be understood. The indications of an accidental regulating rod drop will be identical to the shim rod drop except the selsyns will not show a clutch disconnect and carrier run down. The power may drift down more slowly than with a shim rod drop.

Checks should be made on the shim rod P-relays to discount a shim rod drop. An operator dispatched to the reactor top can visually check for regulating rod disconnect through the glass covered manhole. With confirmation that a regulating rod did drop from the carrier, the reactor power may be held at N_L with shim rod manipulation, the main water flow decreased, a manhole cover removed from the top plug, and the regulating rod reconnected, unless it failed mechanically.

After main flow has been re-established, power can be increased as specified by supervision.

The $\Delta K/K$ of a regulating rod is only 0.005, and from the standpoint of reactivity, the reactor could operate easily with a regulating rod inserted (disconnected). However, from the standpoint of flux distribution, the reactor cannot operate at power with a regulating rod down, as hot spots and boiling might occur due to the flux distortion.

2. Other Emergency Power Reductions and Recoveries

a. Reverse

When given a reverse, all shim rods will insert at high speed and the regulating rod will cock.

Assuming the reverse continues for some

seconds, lower the MOR to a point designated by the senior reactor engineer. He may wish to keep the MOR around the 50 percent power position for a fast recovery if time is limited. This allows a little power leeway and brings the servo system into play before the last top megawatts are approached. After the reverse clears, the negative period produced can be checked by pulling shim rods. Power may be restored at the direction of the senior reactor engineer after investigation of the reverse.

Occasionally, reverse blips occur and clear immediately. In these cases leave the MOR as it is and withdraw No. 6 and No. 7 shim rods back to their upper limits. This will prevent a jr. scram from becoming a scram through the interlock system. Withdraw the remaining rods carefully until the servo system comes back into operation.

b. Slow and Fast Setbacks

The slow and fast setbacks are identical except for the rate of decrease.

Upon a setback, the operator should insert shim rods at a rate necessary to keep (try to keep) the regulating rod selsyn indicator between the 17 and 11 in. lights. A setback will stop at N_L unless the initiating trouble clears before MOR rundown is complete. If no action is taken on the part of the console operator, a setback will insert the regulating rod to the lower part of its scale and a preferred insert will be given at the 7 in. light and a reverse at 5 in.

The negative period can be checked, after the setback clears, by pulling shim rods. If the setback clears before the MOR is reduced to its lower limit, shim rods will have to be withdrawn in order to keep the regulating rod within range.

After an investigation of the cause, power may be increased in the normal way.

3. Abnormal Reactor Facilities

a. Instrument and Control Bus

The reactor controls and their instrumentation are supplied by the "Uninterrupted Power System". This is composed of 4 motor generator sets (MG sets) which feed the instrument bus and control bus. The instrument bus serves the reactor instruments and the control

bus serves the top plug motors, amplidynes, control relays and electric main flow butterfly valve in the process water building. Both busses must be energized at all times or the reactor will scram.

Normally, each bus is fed independently by separate ac generators. (See drawing MTR-E-4658.) Further information can be found in the RSO manual (IDO-16372-IV). Each generator is rated at double its normal capacity so it is capable of carrying both loads if one unit fails for any reason. If both unit dc motors stop, there is a battery bank floating on the line which can supply normal power to these motors for approx 4 hours.

These MG sets have 3 distinct power supplies: commercial power; diesel generated power (emergency); and the battery bank. When commercial power fails, the units will automatically operate from the batteries, and M-3 and M-4 will stop. The automatic switch will transfer to diesel generated power, but the reactor service operator will have to manually restart M-3 and M-4 and transfer the power from the batteries before they are operating on emergency diesel power. When commercial power is restored, the MG sets are manually switched from emergency back to commercial power. (See IDO-16372-IV, pages 58, 59, and 61 for detailed switching procedures.)

There are 8 trouble sources indicated by the annunciators at the MG sets: trouble with M3-G3 or M4-G4 (one may have dropped off the line); frequency trouble, or phase trouble on either bus. If trouble develops, the "REACTOR AC POWER SUPPLY" annunciator will sound in the control room and it cannot be reset until the trouble is cleared. When this annunciator is received, the reactor service operator should be notified immediately since he is responsible for the operation of these machines.

b. Loss of Electrical Power

(1) Loss of Commercial Power

The partial or total loss of commercial power is indicated by "AC POWER SUPPLY ANNUNCIATOR" and a scram. This annunciator and the "EXPERIMENTERS AC POWER SUPPLY" may be the indication of a very serious situation, therefore, it is imperative that the console operator notify the reactor service operator and supervision immediately

so a visual check may be made of the system. The experimenters failure free power supply, on a power failure, will scram the reactor and operate from its battery supply for 30 min, after which the failure free battery bank will be exhausted. Since experiment main flow pumps are on failure free power, its loss will stop flow on all loop experiments and possibly damage an experimental element from after heat. The emergency diesel power should take over the load from the failure free battery bank approx 20 sec after a commercial power failure.

The reactor is generally not brought back into operation until commercial power is restored. The reactor could be operated at N_L or below with emergency diesel power available, but a scram would almost certainly result when switching back to commercial power.

(2) Amplidyne

When power is lost to the selected servo channel amplidyne, the regulating rod will cease to operate and remain in its uncocked state. The first indication of servo control loss will be the zero indication of the amplidyne output voltmeter located below the regulating rod selsyn indicator. Reactor power will be unstable, drifting either up or down. Reactor negative periods can be checked by cautiously moving a shim rod to hold power. If reactor power drifts upward and is not stopped by the console operator, the safety level recorders will give a reverse at 1.1 N_F . The water power recorder, N^{16} recorder, and neutron thermometer recorder will give relay scrams at 1.2 N_F .

Should an amplidyne failure occur, switch into the other servo channel, then lower its MOR until it takes control. This should be done before power drifts very far. Positive or negative drifting can, of course, be controlled with a shim rod before the servo system activates.

c. Abnormal Process Water Systems

(1) Loss of Vacuum

Loss of vacuum to the evaporators will result in a loss of cooling for the main process water system. Water will not be drawn up into the heat exchangers, but will overflow from

the seal tank into the sump tank without passing through the heat exchangers.

Upon loss of vacuum, supervision will probably reduce reactor power to N_L . During the time lapse while trying to restore vacuum, supervision may call for temporary reactor power to burn out xenon build-up. This can be done only as long as the maximum reactor inlet water temperature, 115°F, is not exceeded. In calling for power to reduce the xenon level, supervision will follow figures 39 and 40. For example, if the inlet water temperature is 100°F, the reactor may be operated approximately 29 min at 26 Mw before reaching the 115°F maximum.

(2) Cold Water Make-up

Lowering of the cooling water temperature will increase the reactivity of the reactor by a pronounced amount due to its inherent negative coefficient of reactivity.

If cold make-up water, in large volume, is introduced into the reactor to "buy" a little more operating time, certain effects will be evident to the console operator. A false (high) ΔT will be registered driving the ΔT recorder upscale. Since the water power recorder receives part of its signal from the ΔT , it will also show a false power increase.

The ΔT recorder will initiate a slow setback at 105 percent of full power, unless test block No. 18 is pulled. This test block will also invalidate the power reductions (SSB and scram) from the power recorder by action of relay RP-2.

In addition to the false power and ΔT rises, the reduced temperature will cause an increase in reactivity, driving the regulating rod in. Shim rod compensation will have to be made if the temperature drop is severe. Test block No. 18 may be replaced after system temperatures line out.

(3) Other Abnormalities

It should be mentioned here that most of the other process water abnormalities, such as flow stoppages, low overhead working reservoir levels, pump stoppages, premature closing of flow valves, etc., are monitored by the reactor safety circuits and will shut the reactor down if any of them should occur.

FIGURE 39.
Process water temperature increase with no
heat exchanger cooling

FIGURE 40.
Permissible power vs. inlet water
temperature

d. Abnormal Reactor Component Behavior

(1) Operation with Water in a VG Hole

Sometimes, leaks will develop in the many lines or leads which penetrate the reactor top. It is also possible for leakage to occur around the shim rod or regulating rod drives and tank water can leak from under the flange on the top plug due to a worn or deformed gasket in the spool piece. A more likely source of leakage is from one of the 36 access ports, or flanges, which are present around the periphery of the spool piece.

If leakage from one of these sources is not quickly detected, water may enter some of the instrument holes which penetrate the reactor from the top. Those that are vulnerable are the 3 safety levels, both servo chambers, and the 5 holes which contain the boron thermopiles.

When water enters the connectors in the instrument lead cables to the above ion chambers, the resistance of the leads and the current output varies considerably. The affected recording instrument wanders aimlessly and it is possible for it to go upscale giving a power reduction.

The first corrective action an operator should take under these circumstances, after recognizing the symptoms, is to notify the Sr. Engineer. The reactor will be shut down at the discretion of the supervisor if it becomes necessary. The moisture source must then be sealed off. It is possible for this type of failure to take place very slowly, therefore, abnormal instrument behavior can be diagnosed early and the cause of the trouble removed before it gets serious.

If the moisture enters the operating servo-chamber instrument, the regulating rod will oscillate and may vary from mild to wildly erratic. If the oscillation is very pronounced, the other regulating rod system should be used. If both are erratic, the reactor should be operated in "MANUAL" until the condition can be rectified.

(2) Horizontal Beam Hole Plug Cooling

Horizontal Beam holes (HB Holes) have facilities for supplying air or water cooling for their respective dummy plugs. Plug coolant flow is monitored by a gauge on the

reactor face adjacent to the HB hole. The temperature of the cooling medium is also monitored by an indicator at the beam holes and is recorded in the control room.

If there is not effective cooling, permanent damage may occur to the plug and possibly to the reactor. The aluminum and beryllium plug tip may oxidize to a fine powder rendering the expensive plug useless and presenting a serious contamination problem.

Before reactor startup, adequate cooling for the beam hole dummy plugs must be verified. It is a check list item.

In the case of inadequate cooling to an experimental plug, the boiling of plug coolant may cause erratic servo control, usually in the form of a continuous power cycling. The reactor power should be reduced a little and an investigation started. The temperature recorder in the control room will usually reveal the hot plug.

(3) Fission Break

A fission break is the result of cladding failure of a fuel element or rupture of an experimental fuel capsule which introduces fission products into the cooling water system.

In any operating reactor, the possibility of a fission break is always present. It can be the result of mishandling fuel bearing pieces or damaging the thin cladding over the fuel. Overheating (hot spots) can also end in a fission break by melting or causing a rupture of the cladding. Improper metal-to-metal bonding of fuel bearing pieces, at the time of manufacture, will sometimes result in fission breaks.

With an inherent likelihood of fission breaks, the MTR has built into it a routine monitoring system that is ready to detect any such break. Regularly scheduled water samples are taken to the health physicists for counting. Normal cooling water activity is around 20 to 40 thousand counts per minute per milliliter. This will be about 2 to 4 mr per milliliter. The reactor is shutdown when the activity of the water reaches approx 100 thousand counts (approx 10 mr) per milliliter.

As cooling water activity rises, the "VENT SEAL" annunciator in the process

water building will sound. This informs the operator that radioactive gases are being released at the evaporators. The control room "STACK ACTIVITY" annunciator will probably sound next and alert the console operator that radioactive gases are being discharged from the stack. A "FUEL ELEMENT ACTIVITY" annunciator will sound and an activity recorder will indicate which fuel element has the break, if a fuel element is involved, otherwise all points on the recorder will rise with the activity level of the water system. The "FISSION BREAK" annunciator in the control room will sound as the process water activity increases in the seal tank. Finally, the iodine monitor will show an increase confirming fission product release into the cooling water.

At the direction of supervision, the reactor will be shut down, flushed, and the offending piece discharged.

e. Boiling

Nucleate boiling in a reactor is the result of too high a temperature at the fuel plates. A number of conditions can bring this about. Low reactor water flow, high inlet water temperature, flow restrictions to individual fuel elements, warped fuel plates, mechanical defects in fuel elements and shim rods, uneven fuel loadings with high gram content toward the core center, abnormal shim rod position, and raising reactor power too fast are all potential causes. Boiling is detected by the erratic behavior of the servo system and period recorders. When it is suspected, the console operator should notify supervision and request the electronic technician to connect the brush recorder to the standby servo system. The brush recorder tracing will verify, or disprove, boiling. If boiling is present, the reactor power must be reduced 10 percent or more until stable operation returns. An investigation should then be conducted to determine the cause. For limitations and operation of the reactor with boiling conditions, refer to SP No. 2.313.

f. Abnormal Cooling of the Graphite Region

The reactor air system is primarily designed to cool the graphite section within

the thermal shield and the many experimental holes in it. Gamma ray and neutron collision generated heat is removed with a high air flow through channels provided in this region. The air discharge system is also used as a means of removing radioactive gasses from some experiments, for cooling other experiments, and for reducing contamination hazards by purging experiment cubicles.

Any change in graphite temperatures, as indicated by the reactor structure data logging system in the control room, should be investigated. Temperature rises can be caused by a number of things. One of these is the partial plugging of reactor air intake filters by normal dirt and lint. Detection of plugged filters is accomplished by ΔP meters calibrated in inches of water, located in the reactor top instrument cubicles. When these meters read nearly 5 in. of water pressure drop, the filters should be cleaned or replaced.

Operating graphite temperatures should be kept as low as possible due to the "Wigner Effect Energy Release" probability. Under neutron bombardment, graphite atoms are displaced from their normal equilibrium positions in the solid lattice structure. If several atoms in close proximity are displaced in this manner, some will merely be transferred from one equilibrium position to another in the lattice. However, if a displaced atom is unable to find a vacant equilibrium site, its final location will be a non-equilibrium position. When the temperature rises, the increased atomic movement within the lattice structure will let the displaced atoms slip back into their original equilibrium positions and release their energy in the form of heat. Once this "Wigner Effect Energy Release" starts, a chain reaction type sequence follows where more energy releases are triggered by the increased temperature. The graphite temperatures will rise rapidly to the point of oxidation where ignition can take place. (Combustion temperatures for graphite occur between 800-2000°F.)

Graphite temperature decreases may mean water leakage into the ball zone. All temperature changes should be accounted for. Report all temperature decreases to supervision.

FIGURE 41.
Control console

FIGURE 42.
Senior reactor engineer directing
increase to 40 Mw

TABLE 11
MTR OPERATIONS BRANCH STARTUP CHECK LISTS

CYCLE _____ DATE _____

REACTOR SERVICE OPERATOR

1. Unloading mechanism down and off.
2. Experimental cooling loop on. Pressure at snake pit _____ lb.
3. Crossover valve and bypass switch positioned for run.
4. Monitor room instruments on and readings normal.
5. Argon flow normal.
6. Nitrogen flow normal.
7. Reactor uninterrupted power system checked.
8. Experimenter's uninterrupted power systems checked.
9. Observe fuel element ΔT and ΔP 's while approaching power.

CONSOLE OPERATOR

1. Control room instruments on.
2. Flux level galvanometer on 10^{-4} .
3. Count rate galvanometer on count.
4. Three level recorders read zero.
5. Water power recorder reads zero.
6. N^{16} recorder reads zero.
7. Neutron thermometer recorder reads zero.
8. Both period recorders read infinity.
9. Count rate meter system checked for proper response and on scale.
10. Bypass water flow above 900 gpm.
11. Air discharge pressure above 10 in. water.
12. Instrument air pressure above 110 psig.
13. Working reservoir level at _____.
14. One shim rod switch on "PREFERRED".
15. Both regulating rods above 17 in.
16. Desired MOR No. _____ at N_L .
17. Standby MOR No. _____ at N_F .
18. Setpoint vernier in midrange.
19. Manual scram checked.
20. Electronic scrams completed.

ELECTRONIC TECHNICIAN

1. Power distribution breakers closed.
Exceptions:
2. Test block covers in place.
Exceptions:
3. Inspect amplifier and control cabinets for test wiring, tagged components, and other

abnormal conditions. Advise operator of any new changes.

4. Experiment equipment turned on.
Exceptions:
5. All recorders in control room, monitor room, and instrument room turned on.
6. Log N amplifiers calibrated.
7. Sigma amplifiers lights normal.
8. Magnet amplifiers currents normal.
9. Magnet amplifier monitor switches on "RESET".
10. Count rate amplifier calibrated.
Remarks:
11. Instrument log book checked.
12. Balance servo amplifier currents.
13. Remove water monitor chambers from purge.
14. Period simulator test.
Results:
15. Electronic scram check completed.

SENIOR REACTOR ENGINEER

1. All fuel elements seated.
2. Shim rod armatures wiped off.
3. All shim rods checked for freeness after upper grid in place. (DANGER!)
4. Abnormalities noted in log book approved for startup.
5. Top plug in place.
6. Both regulating rod drives connected.
7. Top plug bolted down.
8. Man hole covers bolted down.
9. Top plug seal water hoses connected.
10. Top plug seal water flowing.
11. Control room test block covers on proper blocks.
12. All possible annunciators cleared. Others approved for startup.
13. Lead experiment instruments turned on.
14. Startup regimes begun on lead and loop experiments.
15. "W" switch check list completed.
16. Seat switch pressure checks completed. (Cycle "A" only.)
17. Instrument technician's check list completed.
18. Reactor services operator's check list completed.
19. Beam hole cooling water turned on and low flow annunciator mercoids properly set.

FOREMAN

1. Upper grids switched.
2. Call power dispatcher one hour before starting sump tank pumps.
3. Magnets meggered in dry dock and after top plug is in place.
4. Vacuum requested.
5. Air flow requested (two main blowers).
6. Main process water flow requested.
7. Instrument section notified to zero ΔP instrument and main flow instrument, and set seat switches. (Seat switches set cycle "A" only.)

8. ΔP and main flow instruments checked and zeroed.

SUPERVISOR

1. Interested persons notified for startup.
2. Beam hole shielding satisfactory.
3. Both concrete sub-pile room doors closed.
4. Safe work permits cleared.
5. Safety tags checked.
6. Hot drain covers on.
7. All other check lists completed.
8. Experiments normal.

REACTOR SHUTDOWN AND TANK WORK

Abnormal and emergency reactor power reductions have been considered in a previous chapter. There are times, however, when the reactor is deliberately shut down, either for experimental reloading or for other circumstances which demand it.

itself in an unusual manner. After the last shim rod withdrawal, the regulating rod will slowly withdraw until it cocks. In the act it will have given the reactor a slight positive period. As power rises above the MOR setpoint, the regulating rod will again come down into range, then the sequence will be repeated. This hunting of the control system may continue for as long as one-half hour. Finally, the period will remain negative when the rod cocks and xenon will begin to grow as power sags. The effect is a logarithmically accelerating power dive and the reactor is irrevocably down. A xenon growth curve is shown in Figure 43.

Oftimes it will be necessary to shut the reactor down while there is still fuel remaining. Whenever these deliberate shutdown occur, an opportunity exists for a live check of one of the reactor safety circuits. In order that these may all receive periodic checks, in addition to their setpoint checks, a sequence list is used.

In general, the shutdown is accomplished in two steps, (1) a reverse or setback, and (2) a scram via the relays. The scram is initiated as soon as it is obvious that the setback or reverse has functioned properly. The appropriate annunciators, scram lights, and power reduction response are also verified.

A few of the more typical shutdown sequences included in SP 2.301 are given below:

No. 1 Manual Switch Check

Reverse: Move the Reverse Bypass Switch to Reverse. All shim rods insert.

Scram: Release the Reverse Bypass Switch and move the Raise-Cock Scram Switch off normal. All rods drop.

No. 4. N₁₆ Recorder Check

Setback: Turn off the N₁₆ Recorder and move the pointer above 1.1 N_F.

Scram: Move the pointer above 1.2 N_F.

No. 8. Low Air Flow and Main Flow Valve Position Check.

Slow Setback: Cut off one main fan in the Fan House. Allow power to decrease below 3 N_L.

Scram: Pull Test Block 22 (main Flow Recorder) and then close the Downstream Block Valve.

B. REACTOR PRE-SHUTDOWN WORK

It would seem that reactor shutdown work should begin after the reactor has scrammed for the last time on a fuel charge. Actually, it begins sometime prior to that. When a shutdown is scheduled in advance (as cycle shutdowns are), there is time to prepare in advance.

1. Tool Check

Part of the preparation is a tool check. Many of the complex tools used in the reactor get worn or damaged or otherwise fail and need repair. The following list helps assure that many of those which receive much use will be operable when they are needed.

TOOL CHECK LIST FOR SHUTDOWN

- (1) 22 ft pliers
- (2) 22 ft extension handle
- (3) Extension handle release tool
- (4) Upper grid tool
- (5) Long modified "A" tools (crow's foot and standard)
- (6) Short regular "A" tools
- (7) Long fuel element tool
- (8) Shim rod tool
- (9) Bucket tool
- (10) X-basket tool (Vorhies tool)
- (11) L-tool
- (12) Bumper tool
- (13) Wedge tool
- (14) Snare tool
- (15) Lead bending tool
- (16) 20 ft and 10 ft finger tools
- (17) Three hook tools
- (18) Depth measuring tool
- (19) Underwater cutters
- (20) Keys, hooks, and crow's feet (spares)
- (21) Lead clamps
- (22) Sight glass and binoculars
- (23) Steering rod
- (24) Lifting cables
- (25) Three discharge buckets
- (26) Bucket extension and two dividers
- (27) Working platform with stairs, cables, etc
- (28) Air wrench, socket, and hose
- (29) Two underwater lights
- (30) Two pulleys and nylon rope
- (31) Loose rope
- (32) Rags, masking tape, blotting paper
- (33) Check one-ton crane

If bent, worn, or broken parts require tool repair, the maintenance department personnel, at the request of the coordinator's office, will repair them.

It should be pointed out here, that many of the tools used in the reactor tank and canal are precision devices and, as such, should receive the same care as other good machine tools. Special care should be taken to avoid bending or undue rough treatment of tools with center drive rods or complicated operating heads. It is desirable and somewhat important that operations personnel become familiar with the mechanical details of their tools so they may appreciate their (the tools) purposes and limitations. Complete details in this regard are available from the division engineering branch. This knowledge, coupled with good judgment, planning, and careful handling techniques, can improve handling operations and shorten shutdown periods. Misuse can result in physical damage to the tool, or reactor, and can interrupt and extend shutdown duties.

2. Miscellaneous Pre-shutdown Duties

Other items of pre-shutdown preparation are the unloader check-out, miscellaneous experiment duties, and preparation of the reactor top. In order to be sure all components of the reactor discharge mechanism are functioning properly, the reactor service operator runs it through its cycle. When maintenance work is required, there is time for repairs.

At the experiments, last minute data, such as heat balance tests and water samples, are often routinely taken. A reactor process water sample (1 liter) is also drawn for chemical and radio-analysis. Often, there are other tests made by special request.

A final pre-shutdown job is the papering of the reactor top. Blotter paper is taped to the top to absorb water which may drip on the reactor due to moving tools out of the tank. Health physics then isolates the area as potentially contaminated and it becomes a shoe-cover area for the duration of the shutdown. Shoe covers, gloves, and coveralls should be in the supply boxes and bins in adequate supply before the reactor is scrammed.

3. Control Systems Shutdown

The console operator locks the reactor controls after the scram, turns off the ampli-

dyne, and places the "RAISE-SCRAM" switch in the "RAISE" position. The individual shim rod selector switches are turned to "RAISE" and the carriers withdraw to their upper limit; then the magnets can clear the reactor as the top is removed. Of course, the rods must be indicated as in their "SEATS" before carrier movement will occur.

The instrument technician may turn off some of the Control Room instruments to service them, but at least one Log N, one Neutron Level, and one Count Rate meter must be on at all times. Generally no instruments are turned off until the neutron level has dropped four or more decades. The instrument technician also transfers the annunciator signal and acknowledgment button circuit to the reactor top where the men will be working. This is done by pulling test block No. 3. Next, the power to the top plug is disconnected and the semaphore connector arms are lowered. This completes his preparations.

The instrument maintenance group makes a check on the magnets by meggering them in the tank at 1000 volts while main flow is still on. An indication of 2 K to 10 K megohms from windings to ground is considered normal. If it is below 50 megohms, it must be checked again at 500 v. If the resistance is still below 50 megohms, the magnet must be changed. They are meggered again in dry dock to see if water flow was a factor in the reading. The same standards apply to the dry-dock readings. All magnets are given a holding current test at each major shutdown. The magnet current holding tests are performed in the dry dock area and are a measure of the ability of the magnet to hold 600 pounds while the carrier is being raised.

Main flow is continued for a short time after shutdown to give radiolytic decomposition or other gasses time to be removed in the flash evaporation system. The time reserved for this is dependent upon whether or not gas trouble is expected and other previous indications.

4. Reactor Flush

After main flow is stopped and the 50,000 gal fresh water flush begins, seal gland flow can

be stopped and the supply hoses removed. The normal flush rate is 1000 gpm for 30 min, then 500 gpm for 40 min. As soon as flush flow begins, the manhole and top plug can be unbolted but it is not general practice to remove either manhole until flow is reduced below 1000 gpm.

Because there may be a small accumulation of gas trapped below the top plug, the large air hose tied to reactor suction should be standing by to draw in these gasses as the first manhole is pulled. A health physicist must be present at this time. The regulating rod tool and a light will then be inserted and both rods disconnected from their drives. These should be lowered carefully. Never let them drop as their upper bearings may be damaged by the support collar. The top plug is now ready for removal.

C. REACTOR SHUTDOWN WORK

1. Top Plug Removal (See figure 44)

The 30-ton crane is used to remove the 11-1/2 ton top plug. Since the hook is not centered perfectly below the block centerline, it is necessary to place the back of the hook against the lifting bail to obtain a straight lift. The north-south alignment must also be accurate to prevent swinging when the shielding plug clears the tank.

The large number of lead experiments in the tank make it impossible to raise the top plug directly out of the tank. It must be rotated and moved horizontally a little as it is withdrawn to clear the leads and avoid damaging them. The operation is difficult and must be carefully done. The man who directs the operation is approved by the supervisor and may be the foreman or the senior reactor engineer. This man is the only one who is to signal the crane operator. Since it is impossible for him to observe all parts of the tank at once, at least two other engineers or technicians should watch and advise of clearance in parts of the tank to which they are assigned.

After the restricted sections are cleared, rinse water is washed over the drive rods

and magnets as they are pulled from the tank. A drip pan is then installed and an engineer or technician follows the plug to dry-dock to assist in the removal of the crane hook.

2. Working Platform

Working down in the open tank would be dangerous and awkward so a working platform is provided. It is stored in the dry-dock area during operating periods and is brought to the top when work is to be done in the reactor tank. The platform has 1/4" of lead beneath the working deck to strengthen its shielding ability. Care must be used in setting it into place as it can crush experimental leads.

3. One-Ton Crane

A one-ton capacity crane is located above the reactor for handling heavy tools and other awkward items. The trolley and bridge are limited by mechanical stops, but the block travel is limited by electric cutouts. The crane should not be operated so as to cause it to ram the stops or pass the electric limits at high speed. Raising the block at high speed near the limit switch will cause it to coast past and trip a second switch which must be cleared at the drum itself. Slow and high speed are provided for each direction movement. The crane should never be operated unless the operator can see the load or the man who is watching it. Care should be exercised if the block is raised while it is swinging as the cables will leave the grooves and run off the side of the drum. If it is necessary to use the small crane while the large crane is overhead, it may be done only after the circuit breaker to the main crane is open. (Refer to SP 2.333).

4. Tool Handling

Heavy tools are generally handled by means of a nylon rope and pulley combination which gives a 2 to 1 mechanical advantage. The crane block is raised to a spot just short of the upper limit switch. Then tools can easily be inserted or removed by manual manipulation of the rope. This arrangement gives more "feel" and control than if the system were motorized.

FIGURE 44
Top plug removal March 31, 1952

Tools which could possibly reach the 30-ton crane bridge must not be inserted nor removed while the crane is near the reactor as they could touch its power lines. Further, no tool should be placed in the tank unless the engineer or technician can see where it is going as leads to experiments can be easily damaged. No tool should be stored in the tank in such a position that bumping it could cause it to fall farther down and damage the reflector or fuel elements. Keep all tools not in immediate use in the tool rack and out of the way.

5. Upper Grid Removal

Before the fuel can be exposed, the upper grid must be removed from its operating position. The special tool, with a locking device, is attached to the grid, and, while the operator keeps one hand on the tool (to feel for binding), the one-ton crane pulls it slowly. While this is in progress, a man should be watching the count rate meter and seat switches. These will indicate whether a shim rod is stuck in the upper grid and is being pulled unintentionally. After clearing the shim rod tops, the grid should be checked as it approaches the water surface to see that no fuel is hanging from beneath it. All elements should be in the core. The grid can then be transferred to the five-ton crane and removal to the canal begun. A health physicist must be present before it breaks the water surface to verify capsules are not riding the grid. The canal operator must be given 5 minutes notice of the impending transfer. After the reactor top is cleared of personnel, the transfer to the canal can be made.

6. Unloader Operation

The mechanism used for discharging radioactive material from the reactor tank has its "ON-OFF" switch and position indicator lights on the reactor top, but it is operated from the canal. If the remotely operated valve in the sub-pile room were to malfunction and stay open when the discharge tube was not in place, the water level in the tank could fall to a dangerous level in a few minutes. Interlocks are provided to insure safety, but good practice is to assume malfunction could occur. Always have a clear understanding with the canal

operator as to what manipulation is about to be performed.

Before the unloader can be used, the discharge chute must be cleared by the removal of the "D" piece and the steel plug. The latter is in the bottom plug. This has a special storage holder on the tank side. The beryllium "D" piece, however, is stored on the reflector so as to keep it deep under water during "man in tank" operations. Care must be used in handling and setting this down to prevent damage to X-basket tops and lead experiments.

The handling of buckets and the long extension tools, which are used in conjunction with discharges, is best learned by actual experience so will not be described here. It should be pointed out that there are different length buckets, and those of adequate length must be used for long items to prevent damage when the handling tool head is inserted.

7. Lattice Work

Work in the lattice begins as soon as the upper grid is removed. The first item is to map the foreign material visible in the fuel elements and to locate bent or damaged combs.

a. Fuel Elements

Depending on scheduling, the fuel elements can be discharged and new ones loaded. There are two tools available. One has two horizontal pins which extend to mate with holes in the upper end box. This exerts an even pull on the element if it is stuck. If it is not stuck, an ordinary hook tool is more convenient. The element must be placed in a handling bucket to protect it while it is discharged.

When fuel is inserted, it must be properly oriented and fully seated. If difficulty is experienced, it is sometimes helpful to raise adjoining elements and seat them together. Never force an element into the lattice.

b. Shim Rods

Movement of these rods requires special care. First, they are heavy and are best handled by the special tool which has fingers that fit into the milled upper cooling openings. Second, they may present a hazard due to the

large amount of reactivity poison (cadmium) which is removed when one is withdrawn. When two shims must be switched, it is obvious that the danger potential is very high. With present loadings (5000 grams), the reactor can go critical with two shim rods removed and low xenon concentration. When the transfer of shim rods is to take place, it should either be accomplished soon after shutdown to take advantage of the xenon buildup, or it should be done after the majority of old fuel has been discharged but before the new fuel has been inserted. In order to increase the safety factor, a cylindrical tube filled with cadmium sheet is provided. Before a shim rod is removed, the cadmium bucket should be inserted into a fuel element space and nearer to the core center than the shim rods being handled.

Periodically, it is necessary to replace the armature on one or more rods in the tank. This is a "hot" job and all necessary equipment should be ready to go when the armature is raised out of the water. The rod is supported by a bar through the cooling holes, then the set screw is loosened and the armature screwed off and replaced. Care should be taken to get the proper spacing (13/32 in.) between the bottom of the armature and the top of the shim rod as this compresses the spring sufficiently, yet allows adequate armature movement.

c. Special "L" Pieces

The beryllium reflector pieces that occupy lattice positions in the "4" and "5" rows are sometimes modified to hold experiments. Others have been replaced with aluminum pieces that are drilled to hold capsules. There are three types. One has a single 5/8-in. center hole, one has an X-basket hole in each quadrant, and the third holds a single X-basket in a center hole. If these can be loaded while in position, it should be done. Where difficulty is experienced, it must be done in the canal.

When work in the lattice has been completed or when extensive work is underway in other parts of the tank, the "lattice protector" screen should be put in place to keep foreign material from falling into the fuel element tops or down through empty lattice holes.

8. Reflector Work

A large percentage of intank reactor shutdown work takes place in the beryllium reflector surrounding the lattice.

a. Capsule Handling

Capsules are placed in aluminum tubes known as X-baskets, D-baskets, L-baskets, etc, to designate their type and size. They can be handled with a hook tool if the probability of dropping them is small or would not be serious. A positive connection tool ("Vorhies" tool) is available when necessary. The rule is: never handle a basket in such a way it could drop off the handling tool and fall through an opening and become inaccessible on the bottom plug. Either have potential loss openings filled or use positive handling methods. After a tool is attached for pulling a basket, it should be raised straight up to avoid bending the basket.

After irradiation, these baskets sometimes become stuck in their piece. After a reasonable effort has been made to remove it, or in the process the top of the basket has pulled off, the piece must be sent to the canal for dumping. This can add many complications to the shutdown. Try to avoid it.

b. "A" Piece Handling

Handling of "A" pieces is most easily done using a "crow's foot" tool on their lifting pins. This is not a positive connection and care should be taken not to drop the piece as damage will surely result. A special "ball connector" tool which provides positive grip is available when necessary.

Removing an "A" piece which is partially under the lower tank ring requires the removal of an adjoining piece. The piece under the ring can then be raised until its bottom clears its seat, then it is moved through the adjacent opening. If an "A" piece binds while being inserted, a "wedge tool" must be used to force the adjoining pieces into proper alignment. If this fails, it is helpful to raise the nearby pieces a few inches, then lower all of them together.

c. Lead Experiment Handling

This type of experiment is an instrumented capsule with thermocouples, heater leads, and

possibly, gas pressure supplied. A lead damaged during insertion ruins the experiment and cancels all previous work done, so extreme care is demanded. A lead experiment should normally be inserted into the tank through a spool piece port and fed slowly to a man guiding it into position in the tank. Its lower end can be guided into its piece with a large "crow's foot", then lowered until it "bottoms" in the hole. Excess lead outside the tank should then be cut off to the proper length and final instrument connections made.

Some leads are too stiff or too large to be inserted this way; therefore, it becomes necessary to run the capsule down into the discharge chute, then back the lead out the access port.

Special care should be taken with all lead experiments to avoid kinking. These spots become breaks after vibrating in the turbulence of main flow for a short time.

In order to reduce vibration, all leads should be clamped at the lower and top rings of the tank. Securing the lead in the upper clamp is more difficult due to the bend as the lead enters the spool piece. A constant pressure should be kept on the lower end of the lead with a large "crow's foot" while the upper portion is forced into the clamp with the "lead bending tool". The downward pressure is necessary to keep the capsule seated during this maneuver.

d. Measurement of Experiments

Near the end of the shutdown and prior to replacing the upper grid, all new experiments must be measured to see that they are at the proper depth in the reflector. This is done with a long slender measuring tool which is inserted into the X-baskets. The top of the beryllium reflector is used as a zero reference and the measurement is taken off a rule attached to the top of the tool. All measurements are then checked against previously prepared information to see that they coincide with what is desired by the experimenter. If the two measurements differ, a second check is made to see that the experiment is fully seated in the reflector. Occasionally, loading errors are discovered by this check.

9. Special Shutdown Items

There are a number of miscellaneous jobs and work items which are often done during

shutdown and it is appropriate to consider them here.

a. Man in "A" Tank

The first is the occasional requirement that a man be lowered via Bosun's chair into the top tank section to tighten bolts, assist in experiment removal or insertion, or perhaps to do some welding. Before entry he should have removed all personal clothing, put on the necessary protective clothing, and a pair of fisherman's waders. In addition, a lineman's safety harness must be worn with a rope attached. While the man is in the tank, the rope must be held by someone capable of supporting the man manually should the chair become disconnected from the crane or should the man otherwise get into trouble while in the tank (See SP 2.336). The constant attendance of a health physicist is required to monitor the man while in the tank.

The water level is lowered for the entry by opening the remotely air-operated valve located in the process water discharge line to the seal tank. The valve bypasses the level limits imposed by the seal tank weir and permits a maximum lowering of 9 ft. The air control regulator for the bypass valve is located on the south reactor instrument cubicle and its key is kept in the supervisor's safe. It may not be used without his authorization.

b. Communications

During periods of reactor shutdown, good communication between the different operating areas such as the canal and the reactor top, crane operator and reactor top, supervisor and top plug, supervisor and canal, etc., are vital to smooth, safe operation. Telephones and an intercommunication system are available on the reactor top, so there is no reason for lack of information or contact with any necessary area.

In special instances, such as operation in the sub-pile room or operation of the large crane through the canal hatch, it is necessary for uninterrupted communication. A special, dual sound power phone system and battery operated two-way radios are available. These systems should always be handled with bare, clean hands to keep contamination away from the face. Good communication cannot be stressed too heavily, and it should be one of

the first jobs of new operations personnel to familiarize themselves with the various communications systems.

c. Record Keeping

It is the responsibility of the past shift to present the on-coming shift with a complete and accurate record of what has taken place, what remains to be done, and any irregularities that have taken place during the shutdown shift. Emphasis on shutdown items that need immediate attention should be made. This is so the work in progress at the time of shift change may be continued with a minimum interruption.

Not only is it necessary to keep a record for the on-coming shift, but a running log should be kept so that as on-shift personnel are relieved on the top plug, they can, without delay and confusion, continue with the work in progress.

Frequently, it is necessary for experiments or lattice pieces in the reactor to be removed temporarily while other experiments are inserted. As the work progresses, it has been found helpful to keep a map showing the location of these until they are reinserted into their proper position.

A reactor shutdown schedule, itemizing all work to be done, is prepared and issued to operations before each scheduled shutdown. It is the obligation of all reactor personnel actively involved in the shutdown to read this schedule before the shutdown and visualize the operating procedure required to accomplish each item. When this is done, operations' work proceeds with a minimum of confusion and delay.

d. Neatness and Trash

Working conditions are not ideal on the reactor top during shutdown due to the necessary presence of experiment leads, instrumentation, shielding, and tools. A great deal can be gained in orderly, smooth, safe operation by keeping the reactor top as neat as possible. Keep the pulley rope coiled, tools in their places, leave no material on the floor which can be a tripping hazard, and keep shielding neatly stacked.

Neatness in the reactor tank is an absolute must. When any foreign material is dropped in or noticed in the tank, it should be removed

as soon as is practical. Nothing of this sort should remain in the tank until every reasonable effort to remove it has been made. If it is not retrieved, the supervisor should be notified so that pertinent information can be entered in the logs and passed on to the relieving crew. The reactor must be kept as free from foreign material as possible at all times.

It should be kept in mind that anything that has been in the reactor an unknown length of time is potentially very radioactive. With the exception of tools, nothing should be removed without a health physicist monitoring it.

10. Reassembly

Eventually, the in-tank and other shutdown work is completed and reassembly for startup can begin.

a. Upper Grid

One of the most difficult shutdown operations is the replacing of the upper grid. To bring it back from the canal, the area must be cleared of personnel and health physicists must be present. With the working platform extension doors open, the crane operator will lower the grid part way into the tank without undue exposure to engineers or technicians. It can then be transferred to the one-ton crane and lowered slowly into place. A check should be made to verify that it is properly oriented with respect to fuel plate curvature. Using a "tamper tool", the armatures can be straightened, if they bind, and care should be exercised to prevent the weight of the grid being borne by bound shim rods. Shaking the grid as it slips over the rods is sometimes helpful. If the grid is seated properly, the lifting arm will go down fully and the locking pins on each corner will slip under their holding blocks on the support casing.

With the grid in place, raise each shim rod a few inches with a hook tool and allow it to drop back into its seat to see that it falls freely.

NOTE

Each shim rod should only be pulled a maximum of 6 in., and only one rod at a time may be checked. Any deviation from this procedure will require prior approval.

The armature top faces should then be wiped clean with a rag attached to the "tamper tool" to insure good contact with the magnets.

b. Top Plug

Replacing the top plug should be done with extreme caution. As the plug is lowered, all experiment leads should be watched closely to insure that the magnets or guide supports do not touch them. Remember that different leads may be present than were there at the time of removal. As the plug seats, see that the spider support sockets slip over their positioning pins and force out the trapped air bubble. This confirms proper positioning.

After the regulating rods are connected and the manhole covers replaced, the top is ready for bolt-down. Following this, the seal water and electrical connections can be made and startup checks can begin.

c. Vertical Graphite Shielding Plugs

Whenever the reactor goes to power, all plugs for the VG holes should be in place. Before a plug is removed, a health physicist must be present to monitor the beam being emitted. If the plug must remain out for a time, the area should be ribboned off and properly tagged. A plug should never remain out longer than necessary.

D. TRAINING QUESTIONS AND ANSWERS ON THE MTR

MTR - General

1. Q. Why is the reactor flushed before the top plug is removed?
 - A. This removes much of the contaminated water from the tank, and thus lowers radiation in the working area.
2. Q. How much demineralized water is used?
 - A. 50,000 gal (1000 gpm for 30 min, and 500 gpm for 40 min).
3. Q. What general rule governs the removal of anything from the reactor to the canal?
 - A. Never remove or bring to the surface anything from the reactor tank or canal without monitoring it for activity.
4. Q. What items should be checked before the crane begins lifting the plug?
 - A. Shim rods seated, rod holders at upper limits, regulating rods disconnected, electrical plugs disconnected and semaphores down, seal water hoses removed, all hold down bolts removed, crane centered overhead, and no loose material nearby which may fall into the tank. Notify health physics for monitoring.
5. Q. Is it permissible to unscrew the regulating rods without the tool holding the rod?
 - A. No. Lower the rod with the tool.
6. Q. What precautions should be observed when removing the upper grid? Why?
 - A. Make sure both hooks of the tool are engaged and that the tool is locked. See that the locking pins have been withdrawn, and have a man watching the seat lights and CRM. If a seat light goes off, a shim rod is being pulled and may allow the reactor to go critical.
7. Q. What precautions should be taken whenever a shim rod is to be discharged?
 - A. Remove the fuel around the shim rod first, then insert the cadmium bucket. Watch the count rate meter as the shim rod is pulled. Shim rods should be discharged as soon as possible after shut-down.
8. Q. When discharging pieces to the canal, what check is made with the unloading mechanism?
 - A. Have the reactor services operator lower the piston after the piece has been lowered to confirm contact with the piston. (There is the possibility of the piece resting on a shoulder rather than on the piston.)
9. Q. What confirmation is there that the upper grid is correctly and fully seated?
 - A. The four locking pins can be seen to be under the casting lugs, and the lifting handle will be full down.
10. Q. When replacing the top plug, what is watched for in the tank as it goes in place?
 - A. Clearance of experiments and a bubble from each alignment pin and socket on the spider ring.
11. Q. What are the types of radiation encountered at the MTR? What is most dangerous if taken internally?
 - A. Alpha, beta, gamma, and neutrons. Alpha.
12. Q. Where are the microswitches for the regulating rods lights located?
 - A. On the regulating rod housing cover on the top plug.
13. Q. What information do the monitor tubes supply the console operator?
 - A. (1) Measure relative flow through each fuel element.
 - (2) Measure the temperature of the water leaving each fuel element.
 - (3) Measure the activity of the water leaving each fuel element.

14. Q. What is the purpose of the hold-up coils in the monitor room?

A. To allow time for the N^{16} gamma activity to die off from the monitor tube water sample that will be measured for radioactivity.

15. Q. What control room annunciators are associated with the monitor tubes?

A. (1) High water temperature.

(2) High water activity.

(3) Fuel element flow.

16. Q. What does the air do that is drawn into the reactor by the main blowers?

A. It flows through the graphite and thermal shield and cools them.

CHAPTER VI

SUPPLEMENTAL FACILITIES AT THE MTR

In order for the MTR and ETR reactors to run, they must be supplied with facilities and services not directly involved in the nuclear reactions. Steam must be supplied to heat the buildings; water of various refinements must be supplied for a multitude of services including reactor cooling; air must be supplied for instrument and experiment use; and electricity must be supplied for light, power, and electronic devices. Some of these facilities at the MTR serve both reactor sites.

In order that a basic understanding of these services (and in what way they can affect reactor operations) can be had, this chapter will describe them to that degree. More detailed information is available in the operating manuals for the respective areas.

A. MTR-ETR STEAM PLANT OPERATORS' AREA

The steam plant operator and helper are responsible for four separate services common to the entire MTR-ETR Site: fuel oil; steam; air; and emergency power.

Fuel oil (No. 6 Bunker oil) for the boilers and diesel oil for various diesel engines and burners are stored in tanks at the northern edge of the site. A small pumphouse located there can transfer these fuels to the areas where their greatest usage occurs. Diesel oil, for the emergency power generators at the MTR and ETR and for the oil fired airheaters at the ETR, is pumped automatically on demand by float operated switches in the "day-tanks" at the use locations.

Steam has its greatest use in the heating of buildings, although considerable quantity is used in the MTR process water building for drawing a vacuum in the flash evaporators. Still other usage is for water heating and at some experiments. The steam is generated in three 17,500 lb/hr boilers which automatically adjust to the load and hold steam line pressures

near 135 psig. If this pressure should fall to less than 100 psig, the drop in vacuum in the MTR process evaporators would result in rapid overheating of the reactor coolant, and this, in turn, would necessitate a reactor shutdown.

Air for the plant complex is supplied at 125 psig from a bank of four compressors located in a portion of the steam plant building. All together, they can furnish 1100 cubic ft per min. Normal usage, however, requires only 2-3 compressors and the remaining 300 cfm unit serves as standby. The smallest compressor (200 cfm) can be driven by the emergency power generator in case of total failure of incoming voltage. The air is eventually used in precision pneumatic instruments so is passed through silica gel driers to reduce its dewpoint to 40°F below zero. From the storage tanks, the air system divides into two parts. One, the plant air line at 135 psig, goes to almost every building for what might be called industrial use; air motors, blowdown, etc. The second line is called instrument air and is the preferential system. If the compressors should fail and air pressure in the receivers drops to 115 psig, a control valve will close reserving all remaining air in the system for the instrument line. This is done so that pneumatic instruments in the plant building, reactor control rooms, and experimental complexes will have signal air for proper indication and response during the initial part of an emergency period. Failure of the air system could quickly jeopardize the operation of both reactors due to instrument malfunction.

Also located in the compressor room at the steam plant is a 750 KVA, 2400 volt emergency generator driven by an 880 hp diesel engine (mentioned previously). Associated with this automatic device is the necessary switchgear for distributing its power to locations in the MTR plant where emergency electricity is required during commercial outages. Lights in the buildings and along the fences are on this system. So are vital pumps such as fuel oil, condensate, and important waters, elevators, and parts of some experiments such as heaters,

pumps, and some relay power. Other more vital parts are supplied from uninterrupted power sources. Since it takes the diesel about 15 sec to come up to speed, power is interrupted to these loads for that time interval whenever commercial power fails. Commercial power failure for one second will scram the reactor

B. DEMINERALIZED WATER PLANT OPERATORS' AREA

The demineralizer operator and helper have three areas of responsibility, two of which are common to both reactor sites. The first is the raw water production and pumping facilities. Raw water may be drawn from the subterranean water table (450-500 ft down) by any of three wells having a combined capacity of 8900 gpm. It is then stored in three 500,000 gal, ground level storage tanks where pumps can draw from them for site usage. Some distribution pumps supply the 12 in. fire mains, others send water to the demineralizer building via an overhead storage tank. Still others supply the ETR cooling water evaporative losses. Temporary loss of raw water pressure can jeopardize the reactors through experiments that use it for cooling.

The second important area of responsibility is the demineralizer where ion-exchange resin beds purify the water destined for canals, reactor cooling, and experimental usage. Raw water contains far too many foreign atoms to permit its indiscriminate use in nuclear cores. The impurities would become radioactive and make work on the system unnecessarily difficult or impossible. Accordingly, both cations and anions are removed in separate resin beds so that water of purity approaching 1 part per million is produced. Maximum continuous production at 325 gpm is possible, although short periods of 400 gpm can be attained. Associated with this production facility are the necessary chemicals for regenerating the depleted beds and controlling the pH of the 200,000 gal of stored demineralized water. Pumps send the water to both reactors and canals as necessary and to numerous experiments for both make-up and cooling. Temporary loss of demineralized water pressure could cause an MTR power reduction (GEH-4) and prolonged loss would seriously affect operations.

The third area of responsibility is the MTR cooling tower. Here the 40 million watts of heat generated in the reactor is dumped to the atmosphere. Since reactor water itself must not leave the "exclusion area", nor be exposed to contaminating wind-born dust, it cannot be cycled directly through the cooling tower. Heat exchangers in the process building transfer reactor heat to the secondary cooling water which then circulates over spray baffles for evaporative cooling in a redwood tower. The water is treated with corrosion inhibitor which gives it an identifying yellowish cast. Loss or malfunction of the cooling tower and equipment would quickly necessitate an MTR power reduction.

The demineralizer operator and helper are also responsible for the potable water production and distribution throughout the two plants, and also the chemical distribution. Acid is pumped to the ETR, whereas caustic is normally shipped over in tank lots.

C. PROCESS WATER BUILDING OPERATORS' AREA

The process water operator and helper have three areas of responsibility, only one of which has a common tie with the ETR. Their primary operating area is the process water system which furnishes coolant for the reactor core itself. Pumps, tank levels, flow rates, and proper heat exchange in the flash evaporators are their constant concern.

If the pumps fail, dropping main flow, or if tank levels fluctuate severely, or if flow rates drop below preset levels, power reductions will immediately take place in the reactor. Loss of control of the flash evaporators due to abnormally low steam pressure or cooling tower water flow will, as previously mentioned, make it necessary to reduce reactor power due to overtemperature.

Supplemental responsibilities within the building are the clean-up resin bed and the experiment cooling loop (ECL) pumps. The reactor resin bed (cation) can have a 300 gpm stream flowing through it which will remove most of the radioactive fission products from the process water. Because of the nature of ion exchange, this tends to lower the water pH below acceptable limits if operated continuously. The ECL system provides process

water to the reactor basement at 200 psig where experiments draw from it for heat exchange and pump cooling. If pressure falls in this system, the experiments soon leave their control limits and a reactor shutdown will follow.

Obviously, the process water building is a sensitive area so far as reactor operation is concerned. Full scrams can be caused by six separate parameters ranging from loss of power to loss of main flow, while slow setbacks can be given the reactor in five different ways. Refer to Process Water Relay and Contact Schematic, MTR-E-4226 (not in this manual).

The second area of PW operator responsibility is the fan house. Positive displacement blowers are located here which draw cooling air through the reactor graphite and discharge it up the stack at 1800 lb per min. When these shut down, small units (400 lb/min) start automatically to maintain a minimum flow and prevent reverse air flow out of the reactor. Loss of the main blowers (air flow or reactor vacuum) would initiate a reactor setback. Also, within this fan house are exhaust blowers for laboratory hoods in the MTR wing and radiation monitor recorders for exhaust air and plant waste waters.

These plant waste waters are part of the third area of operator responsibility which might be termed "outside areas". They include waste radioactive liquids from the reactors into three different tank systems. The first tank system is referred to as catch tanks. These 1500 gal units (4) receive water from the reactor wing laboratory contaminated sinks and from "hot drains" in the reactor building. It is important that only water which needs to be placed in this system be discharged to it. After water is received in the underground catch tanks, it is sampled and tested for radioactivity. If the type of radioactivity is unsatisfactory (alpha emitters or strontium-90, etc), the water cannot be discharged to the ground and must be retained. It is therefore sent to the second underground tank area which is known as hot waste storage. Here it is held with other unsatisfactory waters in one of four 10,000 gal tanks until its radioactivity has decayed sufficiently or until it can be sent to the chemical processing plant for disposal with other extremely radioactive waste. Incidentally, it is here at the hot waste storage that the MTR and ETR waste systems

first tie together. ETR wastes can also be stored here, and, if circumstances warrant, the wastes can be recirculated through ETR cation-anion, resin exchange beds for cleanup. If dilution or radioactive decay permit dumping, then hot storage water is sent to the final of three tanks system. This is known as the retention basin. Here in two large (350,000 gal) concrete pools, radioactive water is directed through a serpentine path which should, at normal flows, take it 96 hours to pass through. This gives short half-lived isotopes a chance to decay before they overflow the outlet weir and go to the leaching pond where they pass into the ground.

Three other waters enter the retention basins, none of which pass through previously mentioned tanks. One is water from MTR "warm drains". This is water known to be less contaminated than ordinary reactor cooling water and known to be free of serious contaminants. Normally, most of the waste water from MTR experiments is of this type. So are MTR canal effluent and "building sump" discharge waters.

A second source of retention basin water is from the reactor flushes of both MTR and ETR. These are by far the largest short period quantities of water and push much of the previously stored water out. If flush water is excessively contaminated, it is dumped to the standby basin and held until it can be disposed of within the standards set by the AEC. This is true of all plant wastes. The final water involved in the retention basin disposal system is that which comes from uncontaminated sources such as the MTR or ETR cooling towers, or demineralizer building.

A constant monitoring of discharge of plant liquid radioactivity is performed where water leaves the retention basin. A sample, typical of, and proportional to the total plant effluent is counted and the signal recorded in the fan house, as previously mentioned. Stack effluent activity is also counted and recorded in the fan house and in the MTR control room. Excessive radioactive discharge will sound annunciators and will limit reactor operations as will be discussed in the health physics control section of this manual.

The final unit of responsibility in the "outside area" is the compressor complex. Compressors which feed air to several

experiments are started, operated, and shut down by PW operators and helpers. Normally, the foreman passes operating requests to these men, but because of their intimate association

with experiments which can shut down the reactor, reactor engineers and technicians often contact them with emergency requests regarding the compressors.