RESEARCH REACTORS

AUGUST 1978

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RESEARCH REACTORS

A Reference and Training Text

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DROI, IE

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INTRODUCTION

This publication was developed for use in an introductory training course and as a preliminary guide to the research reactors that are regulated by the NRC. Some of the data may be outdated, and therefore this manual should not be considered as a primary reference. It can, however, enable an individual to gain a basic awareness of and to become familiar with a specified research reactor. It is hoped that this manual will succeed in presenting a general, and individual, perspective of these research reactors.

This information is the best available data as of August 1978.

Any questions or comments concerning this manual are welcome and should be referred to the Assistant Director For Field Coordination, Division of Reactor Operations Inspection, Office of Inspection and Enforcement.

Table of Contents

Univ. of Utah

Reed College

Univ. of California - Irvine

Univ. of Texas

Univ. of Arizona

General Atomic Co.

U. S. Geological Survey

MARK II

Cornell Univ.
Columbia Univ.
Kansas State Univ.
Michigan State Univ.
Oregon State Univ.

MARK III

Pennsylvania State Univ. (Conversion)

Univ. of California - Berkeley

MARK F

Armed Forces Radiobiology Research Institute (AFFRI)

Northrop Corp.

General Atomic Co.

ADVANCED TRIGA

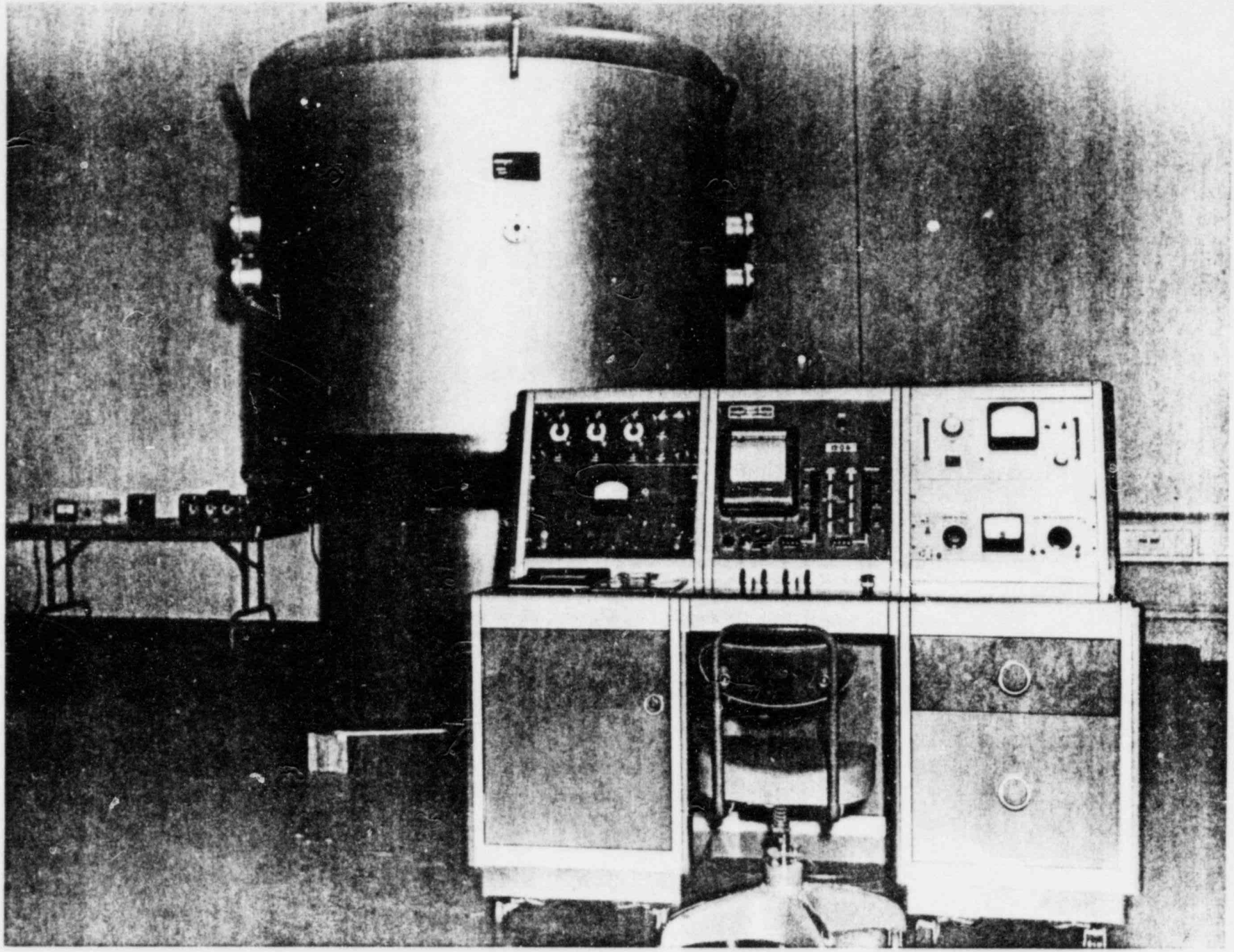
Univ. of Illinois

SOLID HOMOGENEOUS CORE REACTORS

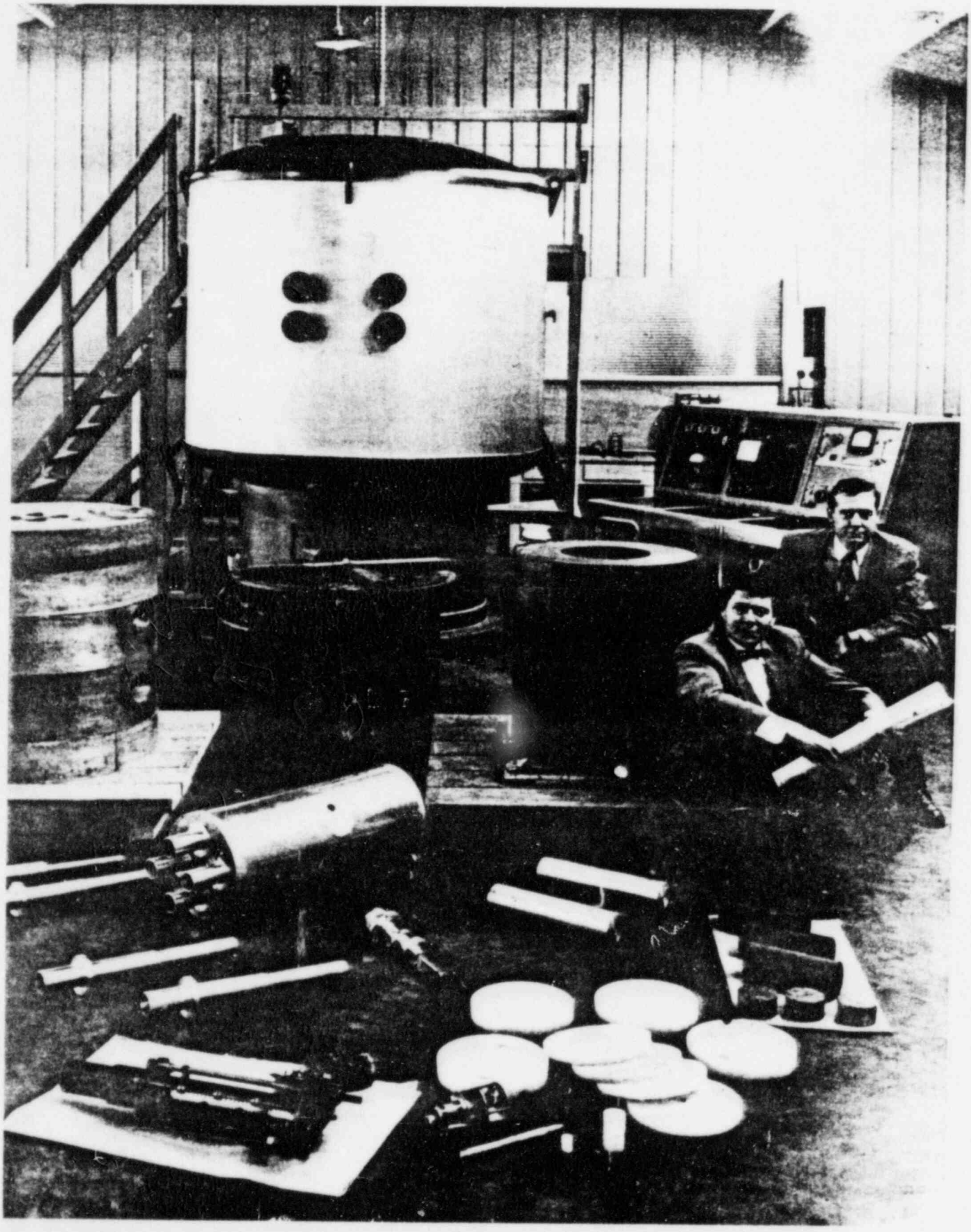
AGN-201
SOLID HOMOGENEOUS REACTOR

The AGN 201 reactor is a compact, portable, self-contained reactor designed to operate at very low power levels. The ten inch diameter core consists of U^{235} embedded in a polyethylene moderator. A graphite, lead and water shield surrounds the core.

The AGN 211 reactor also uses polyethylene to contain the fuel. The core is in a vertical water tank surrounded by a concrete shield.



Name:	Aerojet-General Nucleonics (AGN-201)	
Rated Power:	.1 watt, 5 watt	
Description:	Solid homogeneous core research reactor	
Fuel:	UO_2 alloy dispersed in Polyethylene	
	enrichment	20%
	clad	none
	critical mass	≈ 656 grams
	core loading	≈ 665 grams
	max. excess reactivity	0.5% $\frac{\Delta k}{k}$
	description	10" diameter Polyethylene discs
Max Neutron Flux:	5×10^6 n/cm^2-sec (.1 watt) 2.5×10^8 n/cm^2-sec (5 watt)	
Controls Rods:	2 safety fuel rods	
	composition	UO_2 in Polyethylene
	individual worth	1.25% $\frac{\Delta k}{k}$
	2 control rods	
	composition	UO_2 in Polyethylene
	coarse control rod worth	1.25% $\frac{\Delta k}{k}$
	fine control rod worth	0.15% $\frac{\Delta k}{k}$
Moderator:	Polyethylene	
Coolant:	None	
Reflector:	Graphite	
Shield:	Lead and H_2O	



The following reactors are essentially identical to the Aerojet-General Nucleonics Reactor.

Name: Univ. of Delaware (AGN-201)

Location: Newark, Delaware

Docket Number: 50-98

License Number: R-43

Date of Initial Criticality: 1958

Number of Operators: SRO-1, RO-0

Name: Oregon State Univ. (AGN-201)

Location: Corvallis, Oregon

Docket Number 50-106

License Number: R-51

Date of Initial Criticality: 1959

Number of Operators: SRO-2, RO-2

Name: Calif. State Polytechnic College (AGN-201)

Location: San Luis Obispo, Calif.

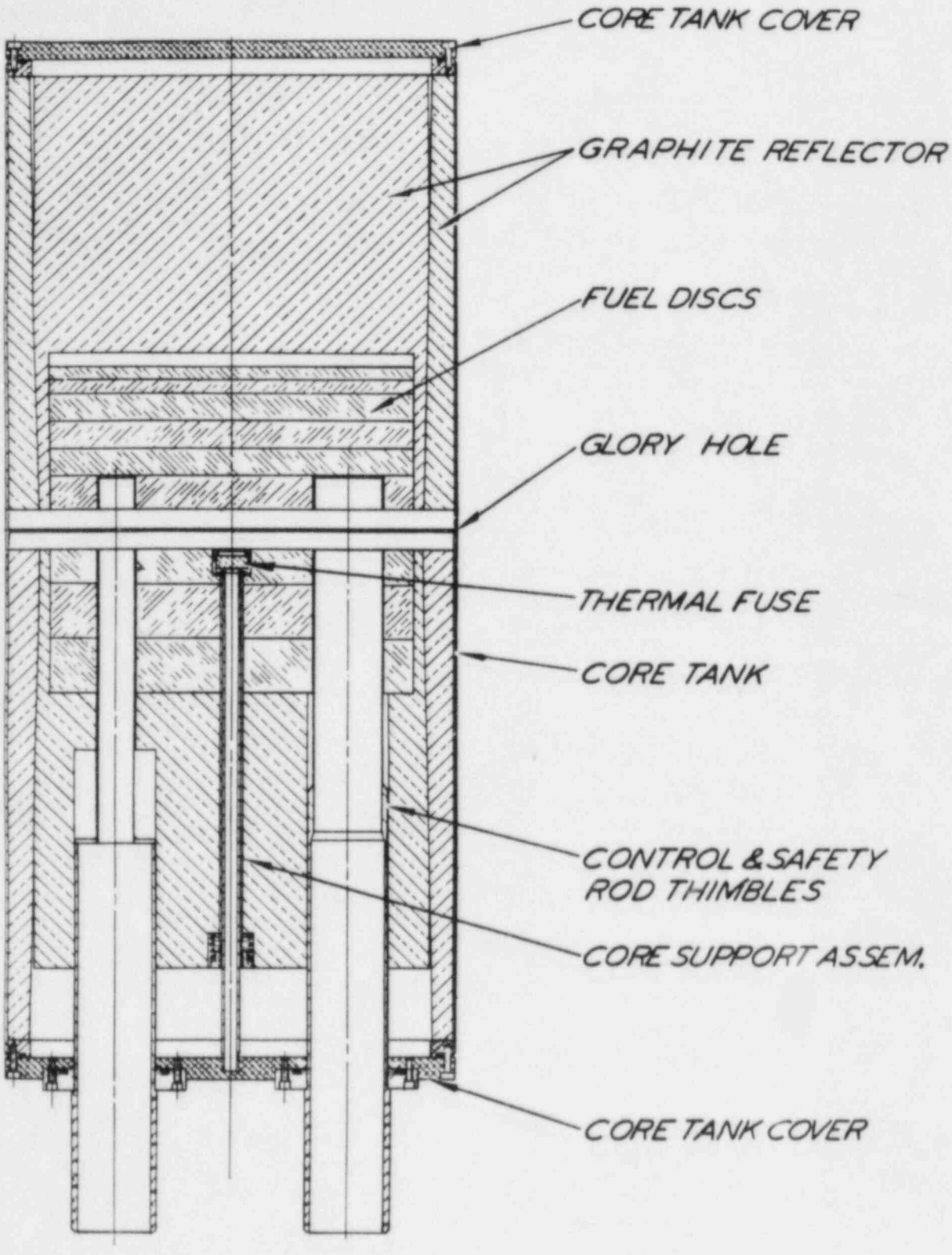
Docket Number: 50-394

License Number: R-121

Date of Initial Criticality: 1957

Utilization: Operated for approximately 5 hours in 1976

Note: Formerly US Naval Post Graduate school reactor transferred to CSPC in 1973


CORE TANK COVER
GRAPHITE REFLECTOR
FUEL DISCS
GLORY HOLE
THERMAL FUSE
CORE TANK
CONTROL & SAFETY ROD THIMBLES
CORE SUPPORT ASSEM.
CORE TANK COVER

Name: Catholic University (AGN-201)

Location: Washington, D.C.

Docket Number: 50-77

License Number: R-31

Date of Initial Criticality: 1957

Number of Operators: SRO - 1, RO - 0

Name: Texas A & M (AGN-201 M)

Location: College Station, Texas

Docket Number: 50-59

License Number: R-23

Rated Power: 5 watts
Increased rated power in 1972

Date of Initial Criticality: 1957

Number of Operators: SRO-3, RO-0

Utilization: Reactor operated approximately 100 hours between 6/77 and 6/78

Startups - 124

Name: Univ. of Utah (AGN-201 M)

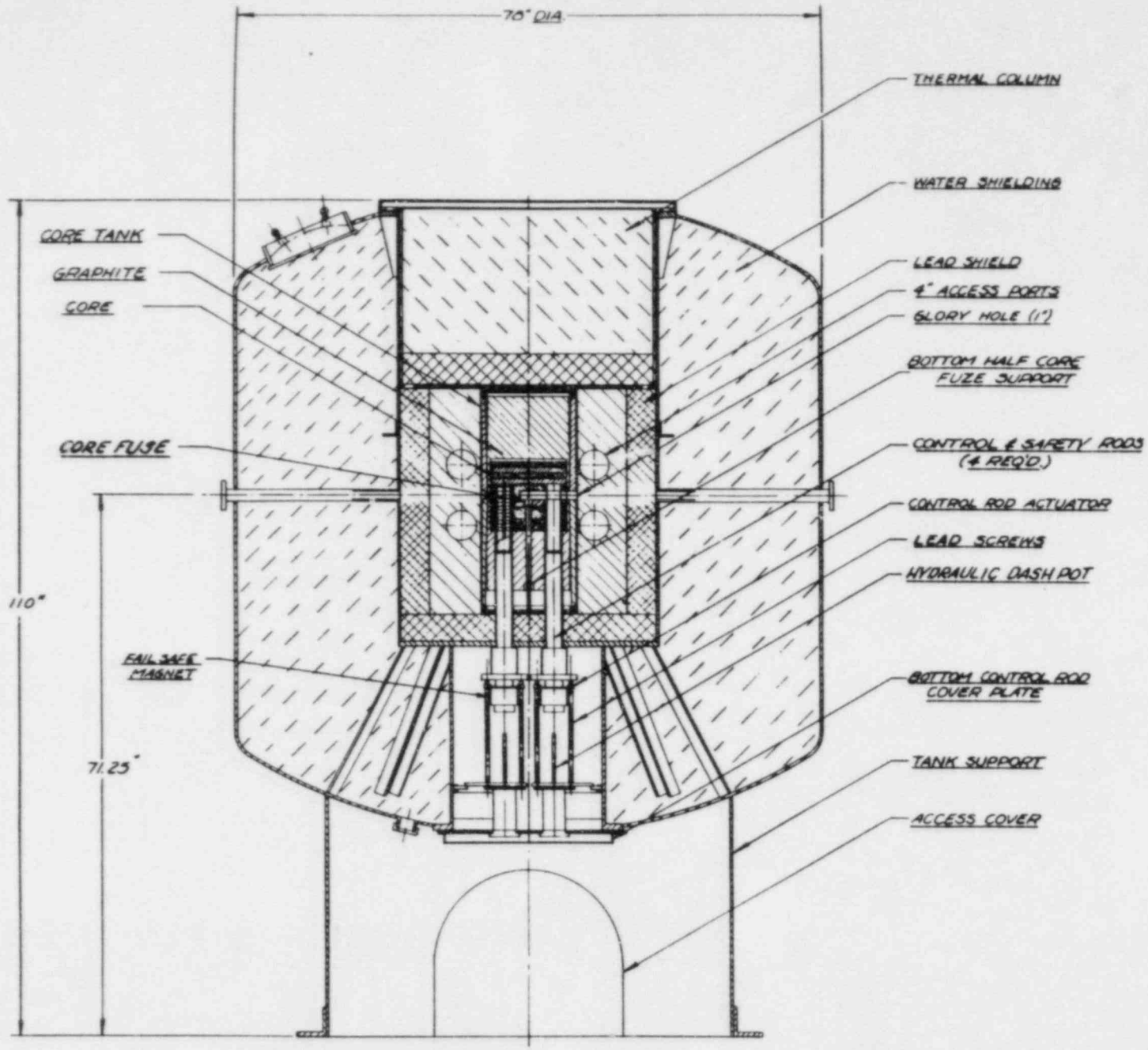
Location: Salt Lake City, Utah

Docket Number: 50-72

Rated Power: 5 watts
Increased rated power in 1975

Date of Initial Criticality: 1959

Number of Operators: SRO-2, RO-3


70" DIA
THERMAL COLUMN
WATER SHIELDING
LEAD SHIELD
4" ACCESS PORTS
GLORY HOLE (1")
BOTTOM HALF CORE FUZE SUPPORT
CONTROL & SAFETY RODS (4 REQ'D.)
CONTROL ROD ACTUATOR
LEAD SCREWS
HYDRAULIC DASH POT
BOTTOM CONTROL ROD COVER PLATE
TANK SUPPORT
ACCESS COVER
CORE TANK
GRAPHITE
CORE
CORE FUSE
FAIL SAFE MAGNET
110"
71.25"

Name: Georgia Institute of Technology (AGN-201)

Location: Atlanta, Georgia

Docket Number: 50-276

License Number: R-111

Date of Initial Criticality: 1968

Number of Operators: SRO-2, RO-4

Name: Idaho State University (AGN-201)

Location: Pocatello, Idaho

Docket Number: 50-284

License Number: R-110

Date of Initial Criticality: 1967

Name: Tuskegee Institute (AGN-201)

Location: Tuskegee, Alabama

Docket Number: 50-406

License Number: R-122

Date of Initial Criticality: 1974

Number of Operators: SRO-1, RO-0

Name: University of New Mexico (AGN-201 M)

Location: Albuquerque, New Mexico

Docket Number: 50-252

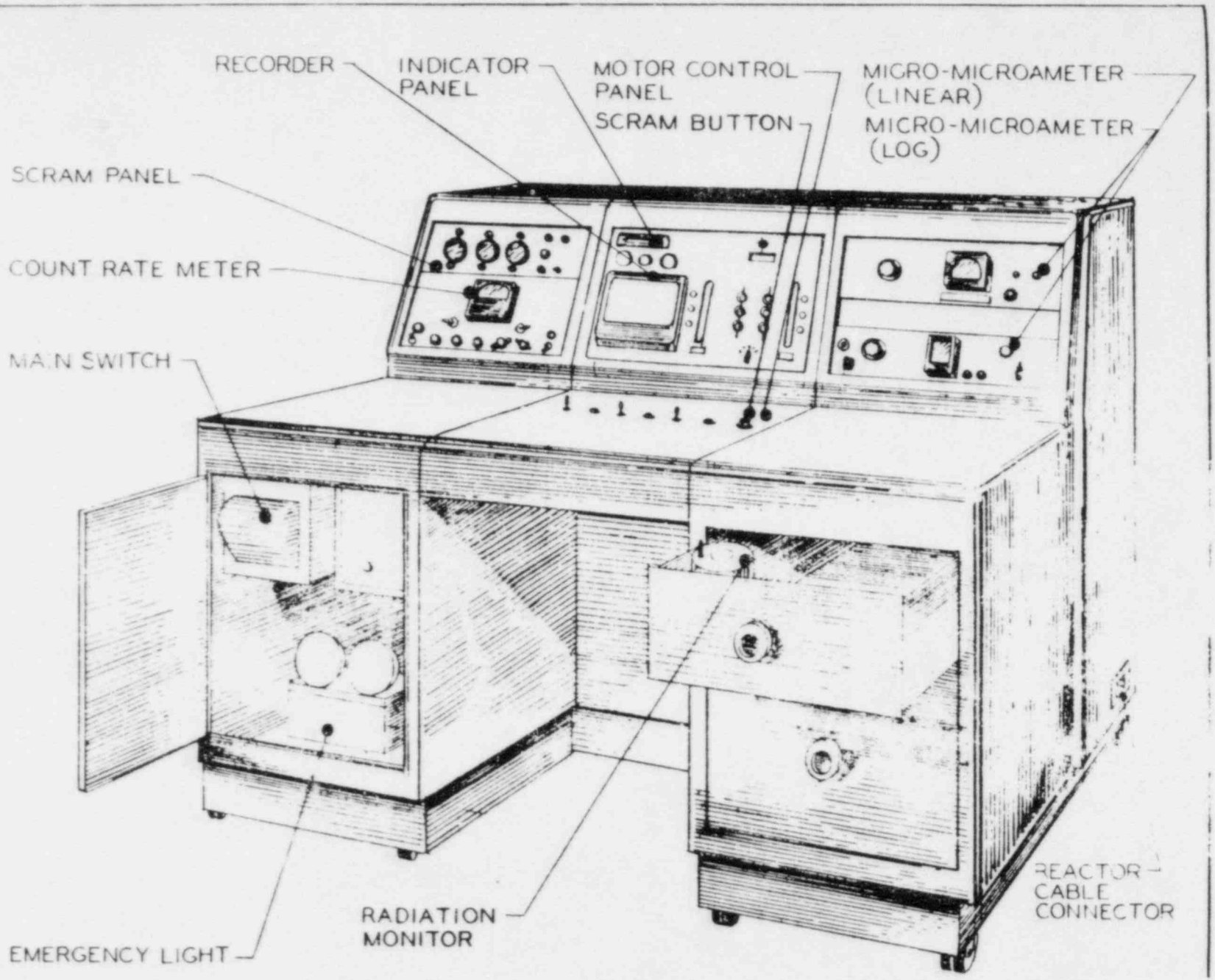
License Number: R-102

Rated Power: 5 watts
Increased rated power from .1 watt to 5 watts in 1969

Date of Initial Criticality: 1966

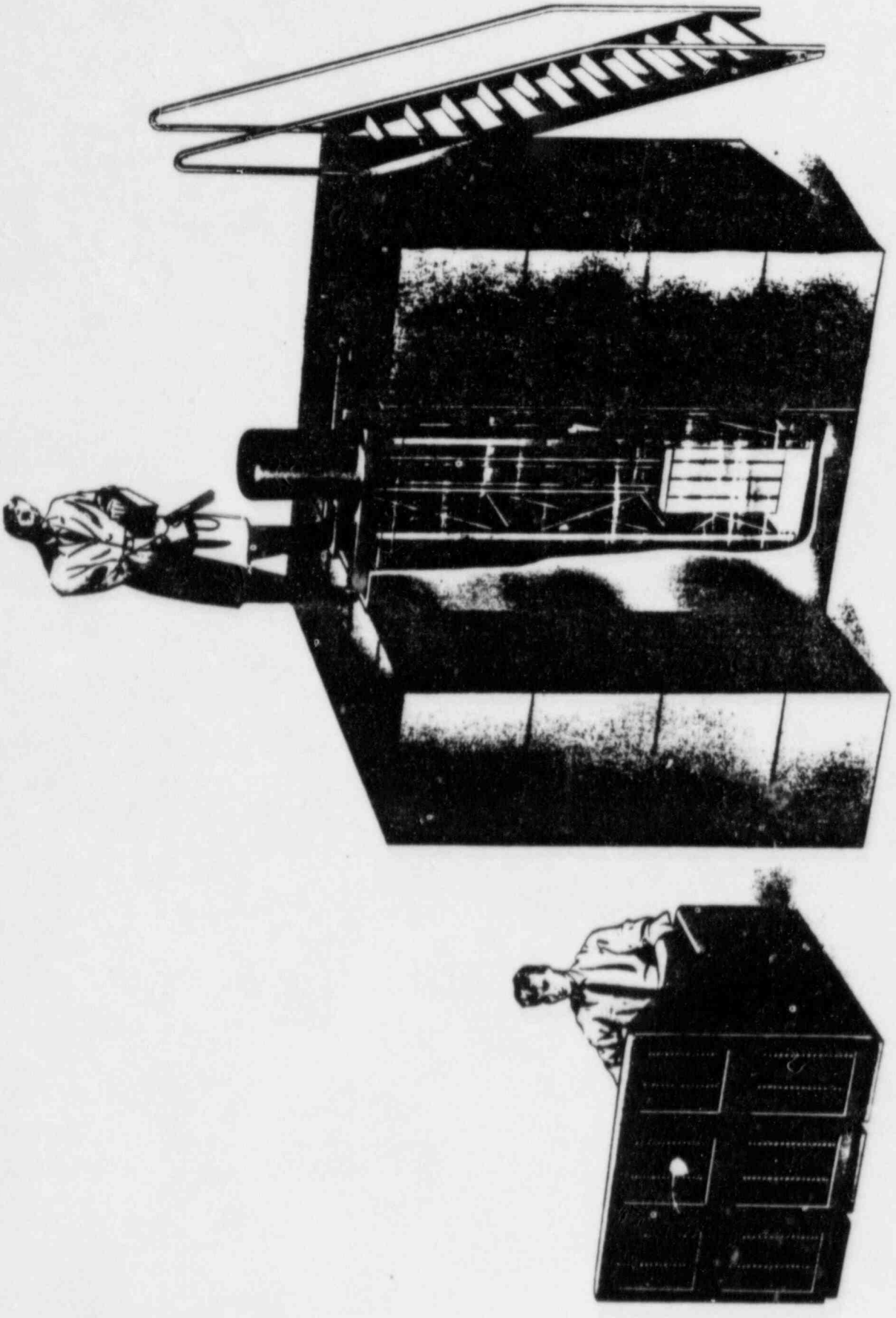
Number of Operators: SRO-3, RO-2

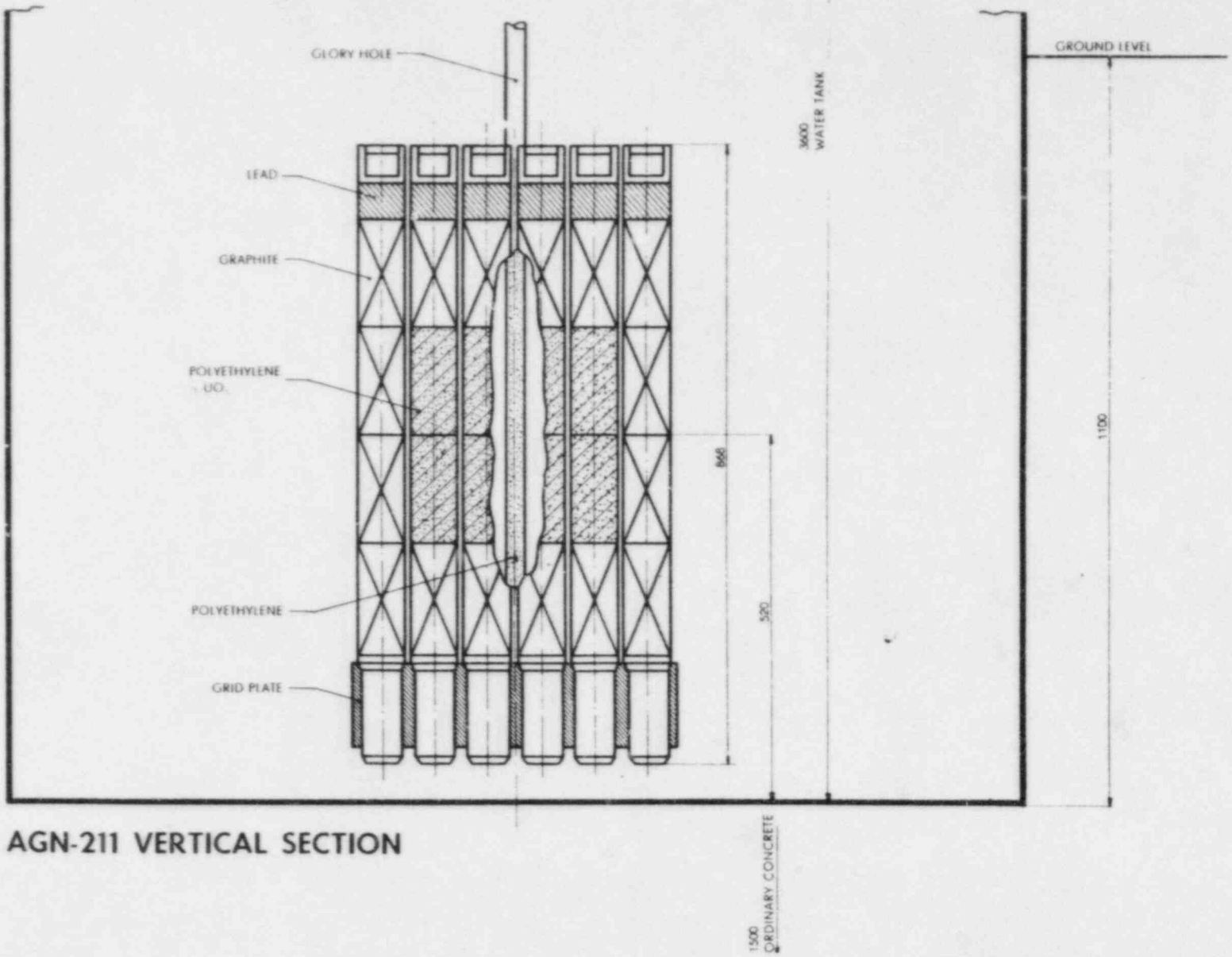
Utilization: Operated approximately 240 hours per year


RECORDER
INDICATOR PANEL
MOTOR CONTROL PANEL
SCRAM BUTTON
MICRO-MICROAMETER (LINEAR)
MICRO-MICROAMETER (LOG)
SCRAM PANEL
COUNT RATE METER
MAIN SWITCH
EMERGENCY LIGHT
RADIATION MONITOR
REACTOR CABLE CONNECTOR

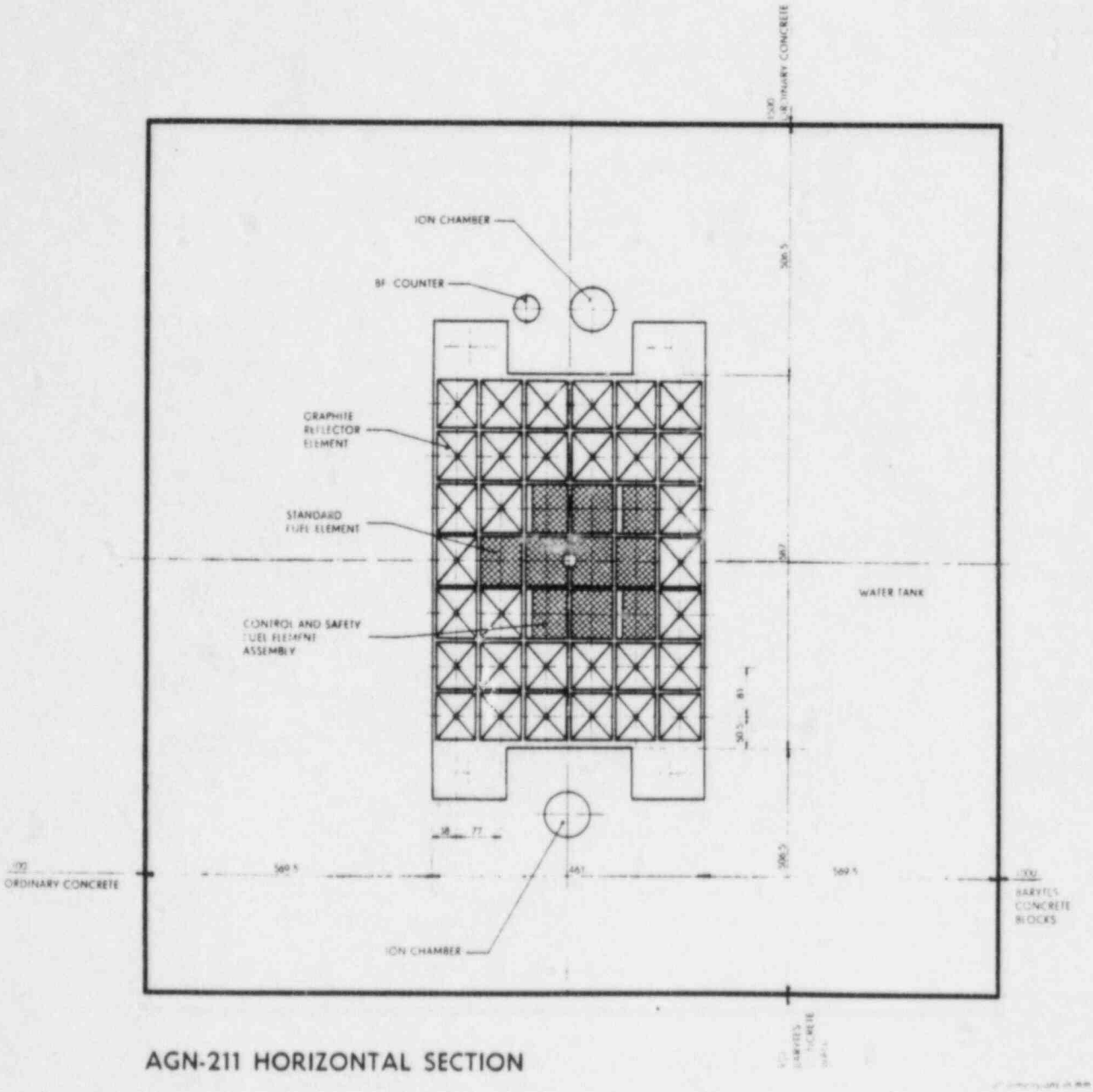
Name:	University of Oklahoma Reactor (AGN-211)	
Location:	Norman, Oklahoma	
Docket Number:	50-112	
License Number:	R-53	
Date of Initial Criticality:	1959	
Rated Power:	15 watts	
Description:	Solid homogeneous core research reactor	
Fuel:	UO_2	
	enrichment	20%
	clad	plastic liner
	critical mass	780 grams
	core loading	785 grams
	max. excess reactivity	0.52% $\frac{\Delta k}{k}$
	description	fuel rods - polyethylene and graphite
Max. Neutron Flux:	3×10^9 n/cm^2-sec	
Control Rods (4):	2 safety rods	
	1 shim rod	
	composition	cadmium
	individual worth	1.1% $\frac{\Delta k}{k}$
	1 regulating rod	
	composition	stainless steel
	worth	0.36% $\frac{\Delta k}{k}$

Moderator:	polyethylene
Coolant:	Light water (H_2O)
Reflector:	Graphite
Shield:	Concrete, lead and H_2O
Number of Operators:	SRO-2, RO-1

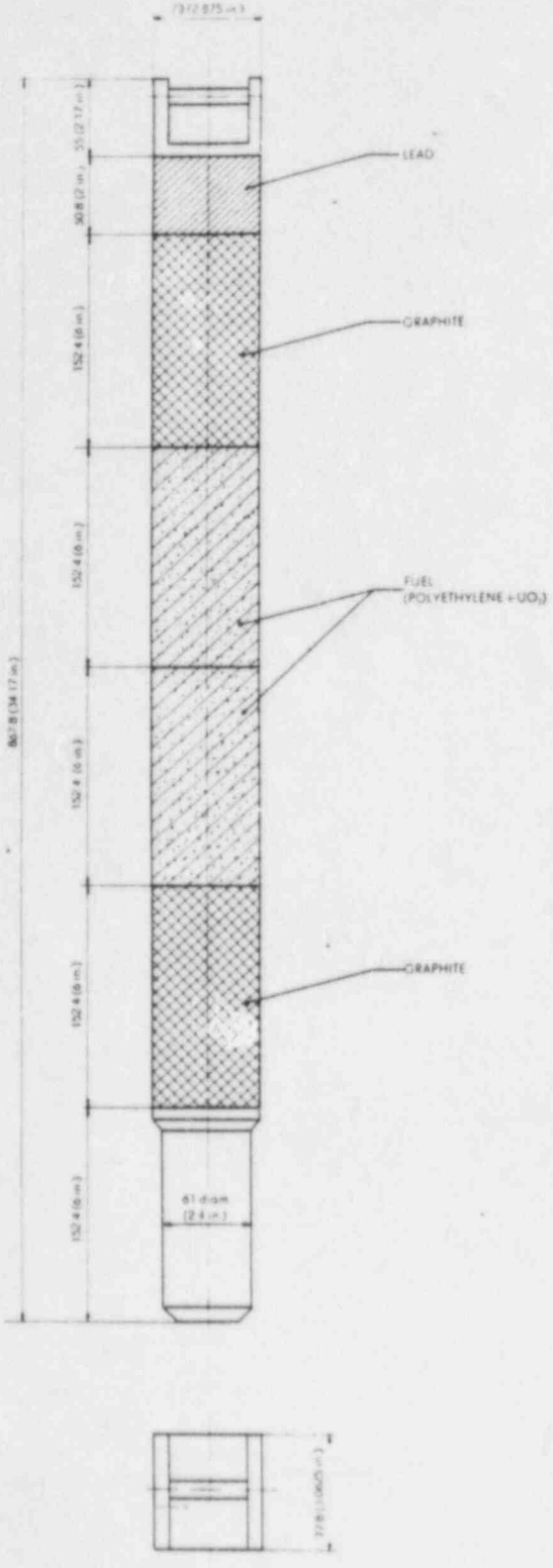




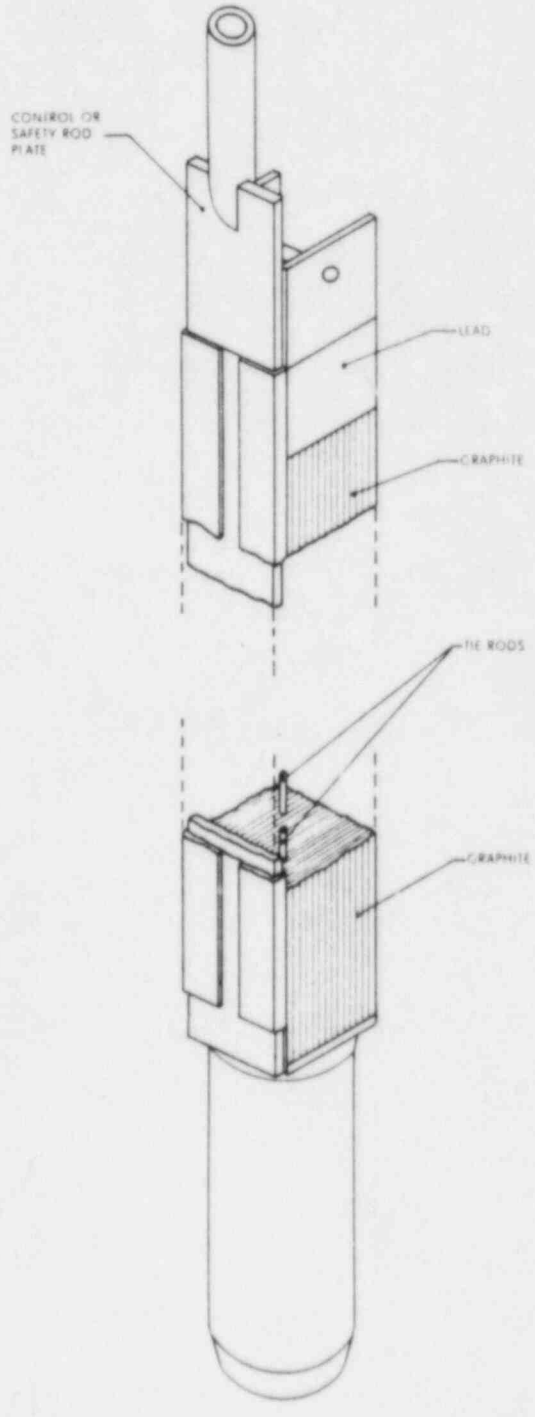
AGN-211 VERTICAL SECTION



AGN-211 HORIZONTAL SECTION



STANDARD FUEL ELEMENT



CONTROL ROD
FUEL ELEMENT

CRITICAL EXPERIMENT FACILITIES

Name:	Babcock and Wilcox Critical Facility
Location:	Lynchburg, Va.
Docket Number:	50-13
License Number:	CX-10
Date of Initial Criticality:	1958
Rated Power:	1 kw
Description:	Tank-type, light water moderated critical reactor
Fuel:	UO_2 pellets or UO_2 - ThO_2 pellets
	enrichment 2.5% or 93%
	clad Aluminum
	max. excess reactivity <2% $\frac{\Delta k}{k}$
Control Rods (4):	3 safety blades
	composition Boron or Cadmium
	clad stainless steel
	total worth 5.1% $\frac{\Delta k}{k}$
	1 regulating rod
	same composition and clad
	worth 0.9% $\frac{\Delta k}{k}$
Moderator:	Mixed moderator in supplemental core tank of D_2O and H_2O
Coolant:	H_2O
Reflector:	Graphite and D_2O-H_2O
Shield:	Concrete
Number of Operators:	SRO-4, RO-0

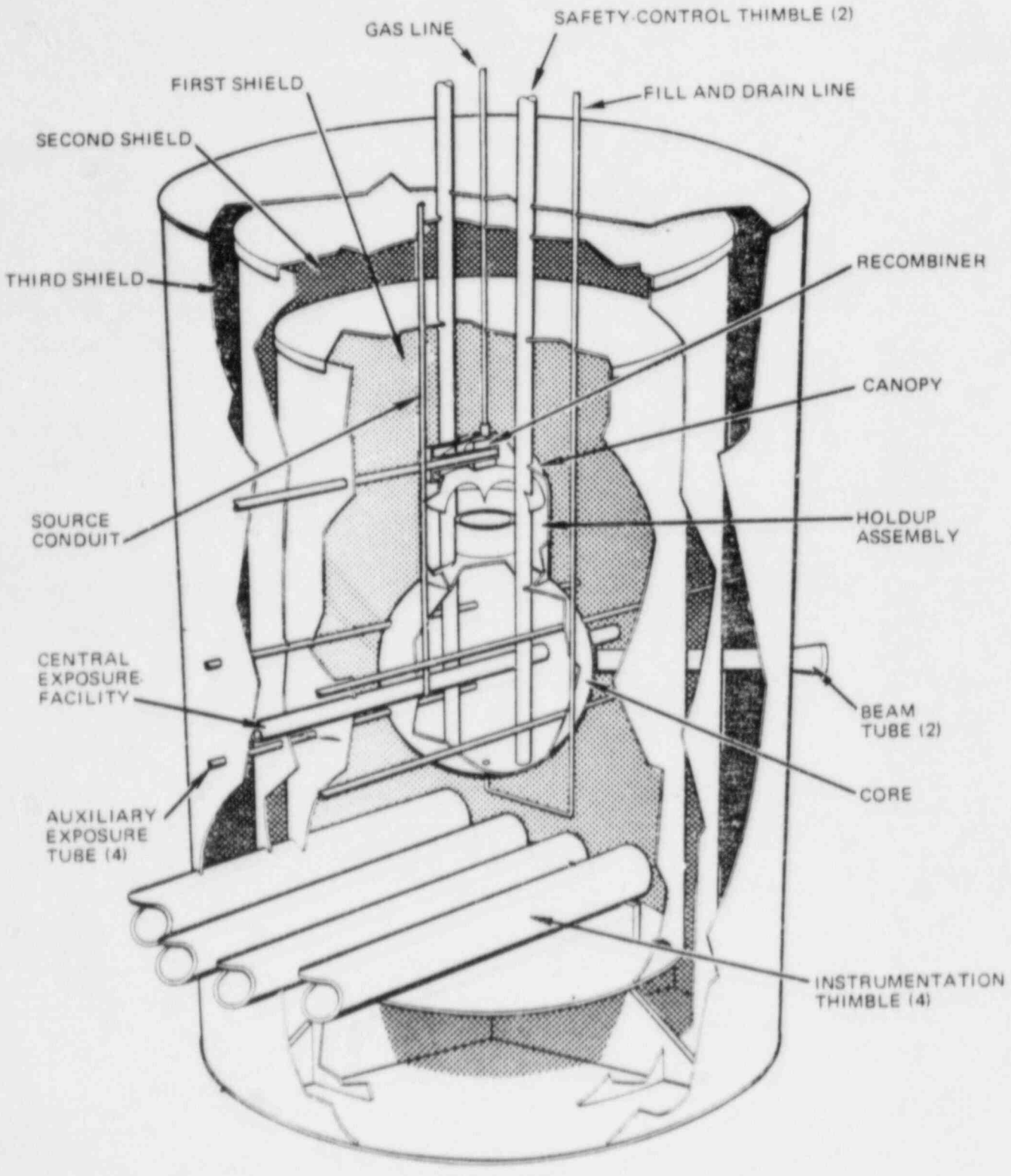
Name:	Rensselaer Polytechnic Institute Critical Experiments Facility	
Location:	Schnectady, New York	
Docket Number:	50-225	
License Number:	CX-22	
Date of Initial Criticality:	1958 (under ALCO Products, transferred to RPI in 1964)	
Rated Power:	100 watts	
Description:	CX-type, light water moderated, critical facility	
Fuel:	UO_2	
	enrichment	93%
	clad	stainless steel cermet
	core loading	6011 grams
	max. excess reactivity	3.9% $\frac{\Delta k}{k}$
	description	standard 38 assemblies with 18 fuel plates per assembly
Control Rods (7):	7 fuel follower control rods	
	composition	Boron, stainless steel
Moderator:	Light water (H_2O)	
Coolant:	H_2O	
Reflector:	Stainless steel and H_2O	
Shield:	Concrete	
Number of Operators:	SRO-5, RO-1	

LIQUID HOMOGENEOUS CORE REACTORS

LIQUID HOMOGENEOUS REACTOR
(L-77 -- L-85)

The liquid homogeneous core reactor utilizes enriched U^{235} which is evenly dispersed in a water solution of uranyl sulfate. This reactor is often referred to as a "water boiler" because during operation there is an evolution of hydrogen and oxygen gases, through the slow decomposition of the water, which causes a bubbling similar to that of boiling. A gas recombiner is provided to prevent the formation of an explosive mixture of the gases.

The reactor consists of a one foot diameter stainless steel sphere containing the aqueous solution. The core is surrounded by a graphite, water or lead reflector and a lead and water shield.



L-77
Homogeneous Liquid Core Reactor (10 W)

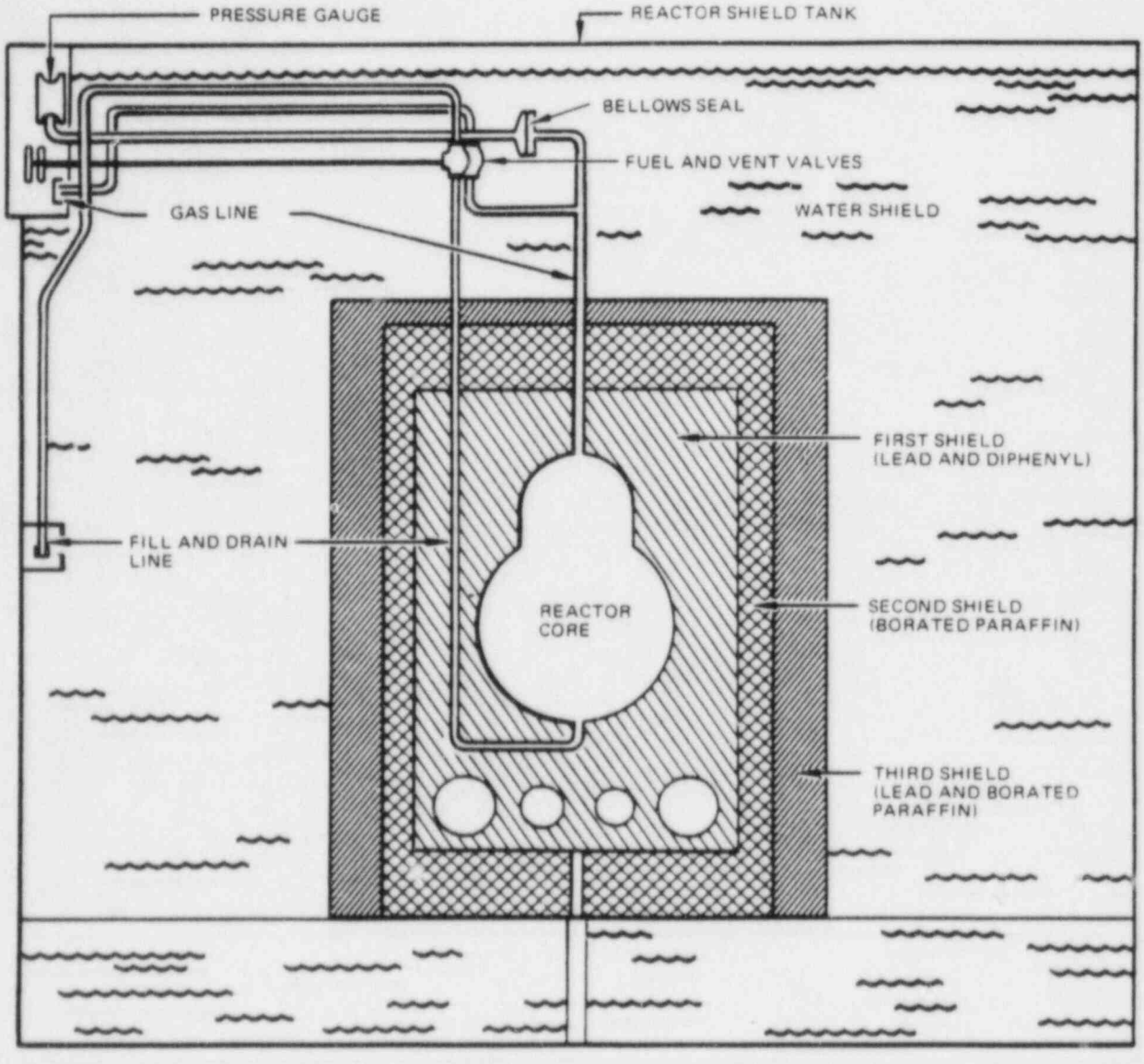
Name:	L-77
Owner:	Rockwell International
Location:	Canoga Park, California
Docket Number:	50-94
License Number:	R-40
Date of Initial Criticality:	1958
Rated Power:	10 watts
Description:	Liquid, homogeneous core research reactor
Core:	15 3/4" diameter stainless steel spherical core gas recombiner
Fuel:	Uranyl Sulfate (UO_2SO_4)

enrichment	20%	90%
critical mass	1.396 kg	1.152 kg
core loading	1.405 kg	1.173 kg
max. excess reactivity	0.5% $\frac{\Delta k}{k}$	

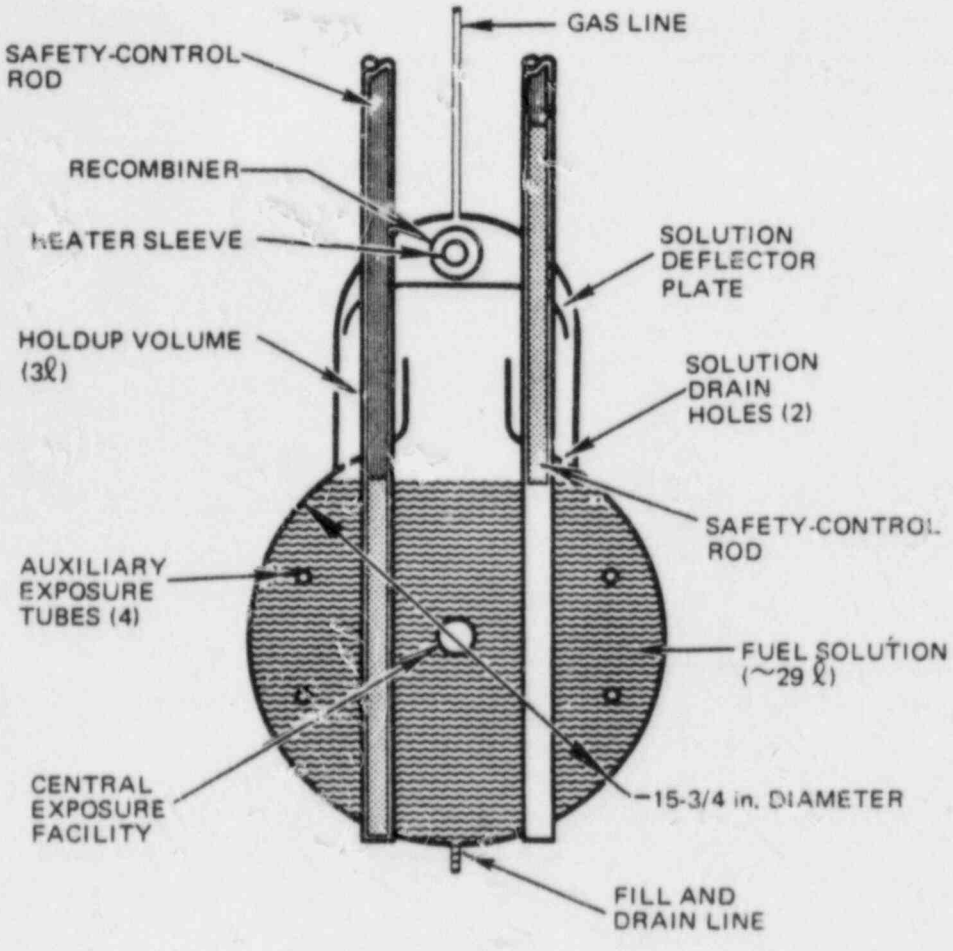
Temp. coefficient:	0.02%/°c
Max. Neutron Flux:	1 x 10^8 n/cm^2-sec
Controls Rods (2):	1 safety rod
	1 regulating rod

composition	stainless steel and cadmuim
clad	Aluminum
individual worth	1.3% $\frac{\Delta k}{k}$

Moderator:	H_2O
Reflector:	Lead and diphenyl
Number of Operators:	SRO-3, RO-0
Utilization:	Operated 62 times, generating 103 watt-hours of energy in 1973.



L-77
Homogeneous Liquid Core Reactor (10 W)



L-77
Homogeneous Liquid Core Reactor (10 W)

The following reactors are identical to the Rockwell International L-77 reactor:

Name: University of California Santa Barbara L-77 Reactor

Location: Santa Barbara, California

Docket Number: 50-433

License Number : R-124

Date of Initial Criticality: 1975
transferred from Univ. f Nevada

Number of Operators: SRO-1, RO

Utilization: Operated approximately 13 hours in 197

Name: Brigham Young University

Location: Provo, Utah

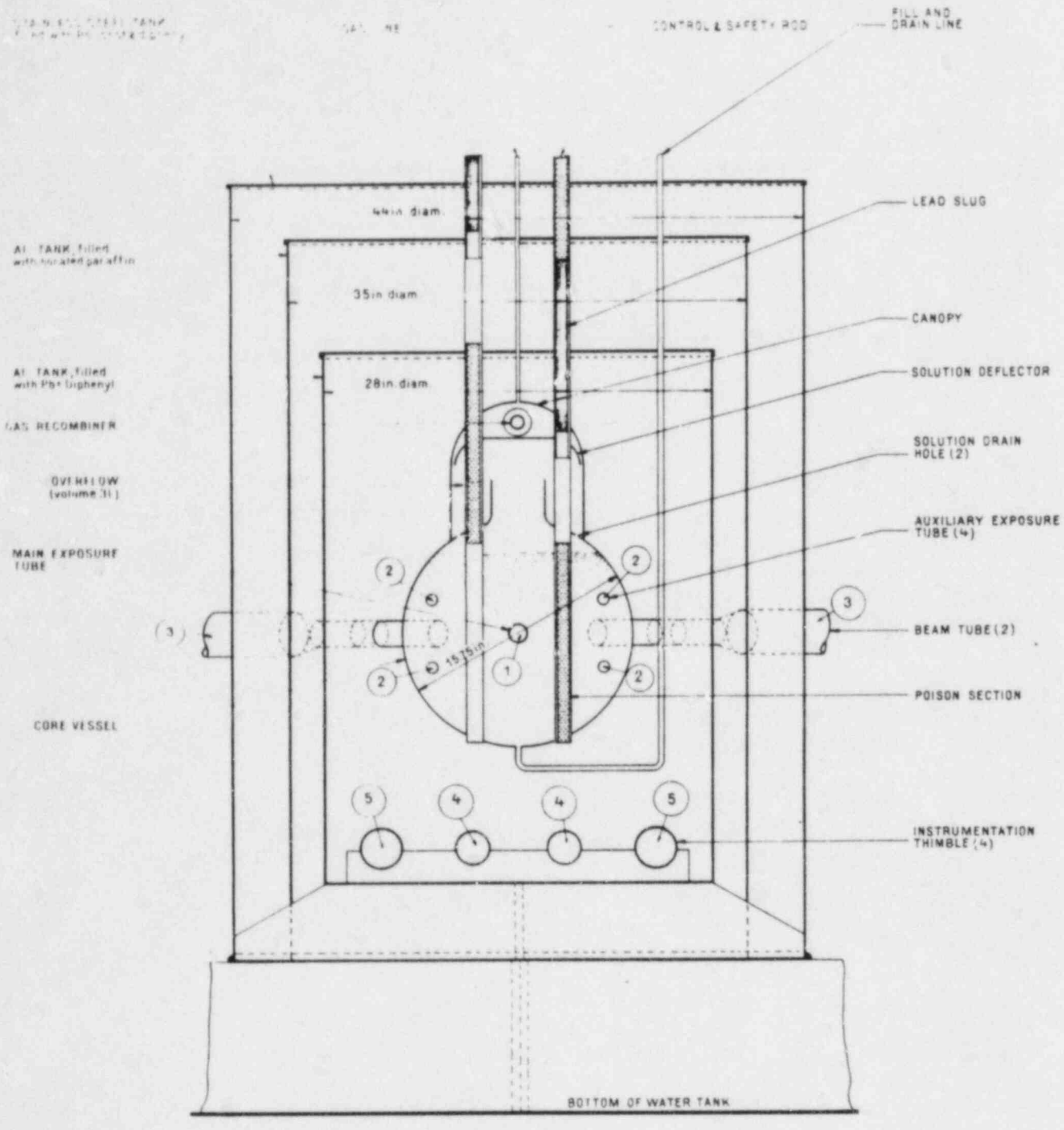
Docket Number: 50-262

License Number: R-109

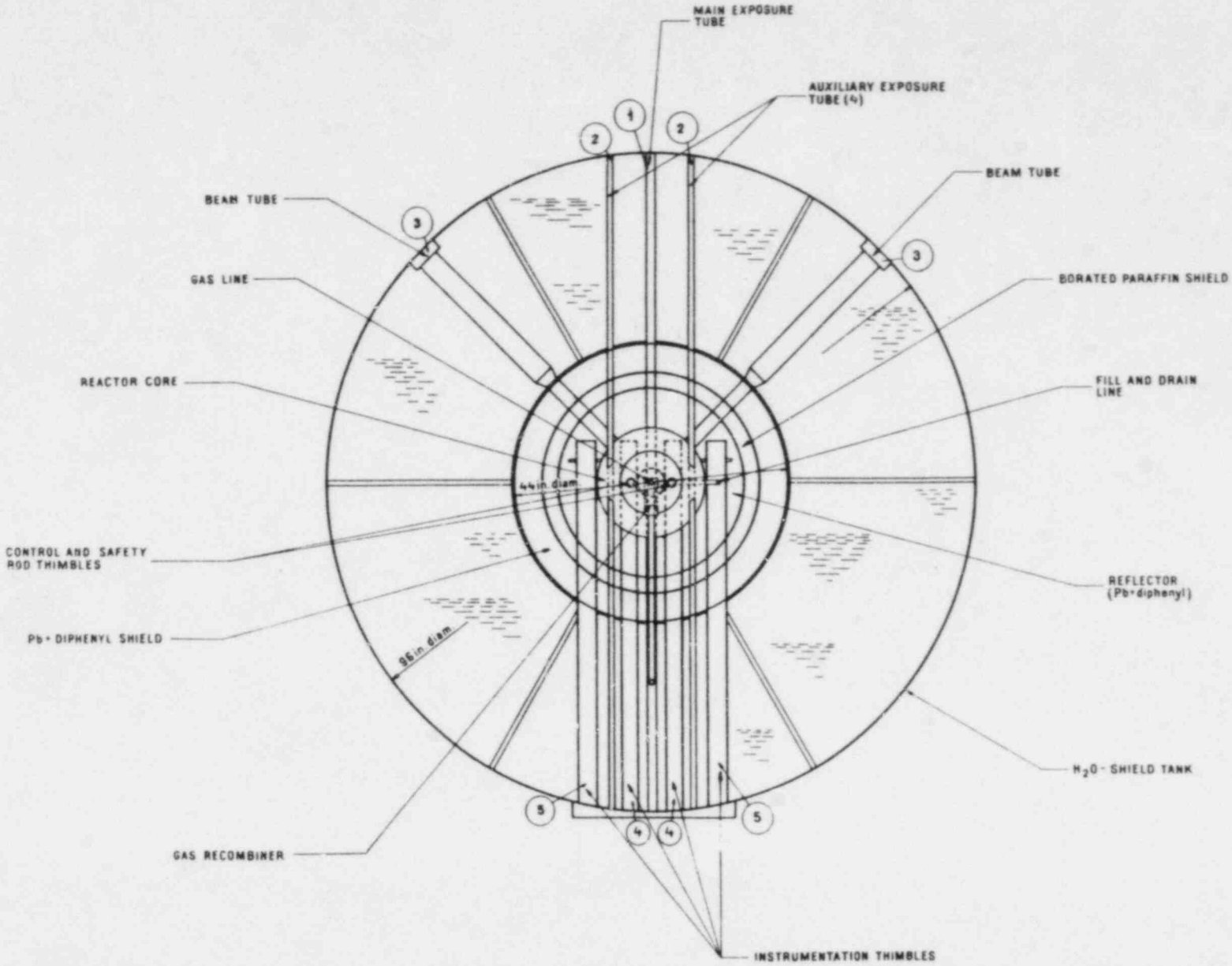
Date of Initial Criticality: 1967

Number of Operators: SRO-2, RO-0

Utilization: Operated 19 times for approximately 15 hours in 1976



VERTICAL SECTION REACTOR L-77



HORIZONTAL SECTION REACTOR L-77

Name:	L-85	
Owner:	Rockwell International Corp.	
Location:	Santa Susanna, California	
Docket Number:	50-375	
License Number:	R-118	
Date of Initial Criticality:	1972	
Rated Power:	3 kw	
Description:	Homogeneous liquid core	
Core:	1 foot diameter stainless steel core	
Fuel:	Uranyl Sulfate (UO_2SO_4)	
	Dissolved in .3 - .4 molar sulfuric acid	
	enrichment	90%
	core loading	800 grams
	max. excess reactivity	0.8% $\frac{\Delta k}{k}$
Max. Neutron Flux:	4×10^{10} n/cm^2-sec	
Control Rods (4):	2 safety rods	
	composition	Cadmium and Cadmium-Silver
	total worth	2.3% $\frac{\Delta k}{k}$
	2 control rods	
	composition	Cd and Cd-Ag

	coarse control rod worth	1.3% $\frac{\Delta k}{k}$
	fine control rod worth	0.4% $\frac{\Delta k}{k}$
Moderator:	Heavy water (D_2O)	
Coolant:	D_2O	
Max. Coolant Temp.:	160°F	
Reflector:	Graphite	
Shield:	Concrete	
Utilization:	Operated approximately 30 hours in 1977	

HETEROGENEOUS CORE REACTORS

Argonaut

An Argonaut is a water and graphite moderated thermal heterogeneous reactor. The core lattice consists of a five foot cube of graphite containing MTR type fuel elements located in aluminum tanks containing water. An internal graphite reflector contains access holes for experimental purposes. The reactor is shielded by concrete and has an integral water tank and graphite thermal column for use in a variety of experiments.

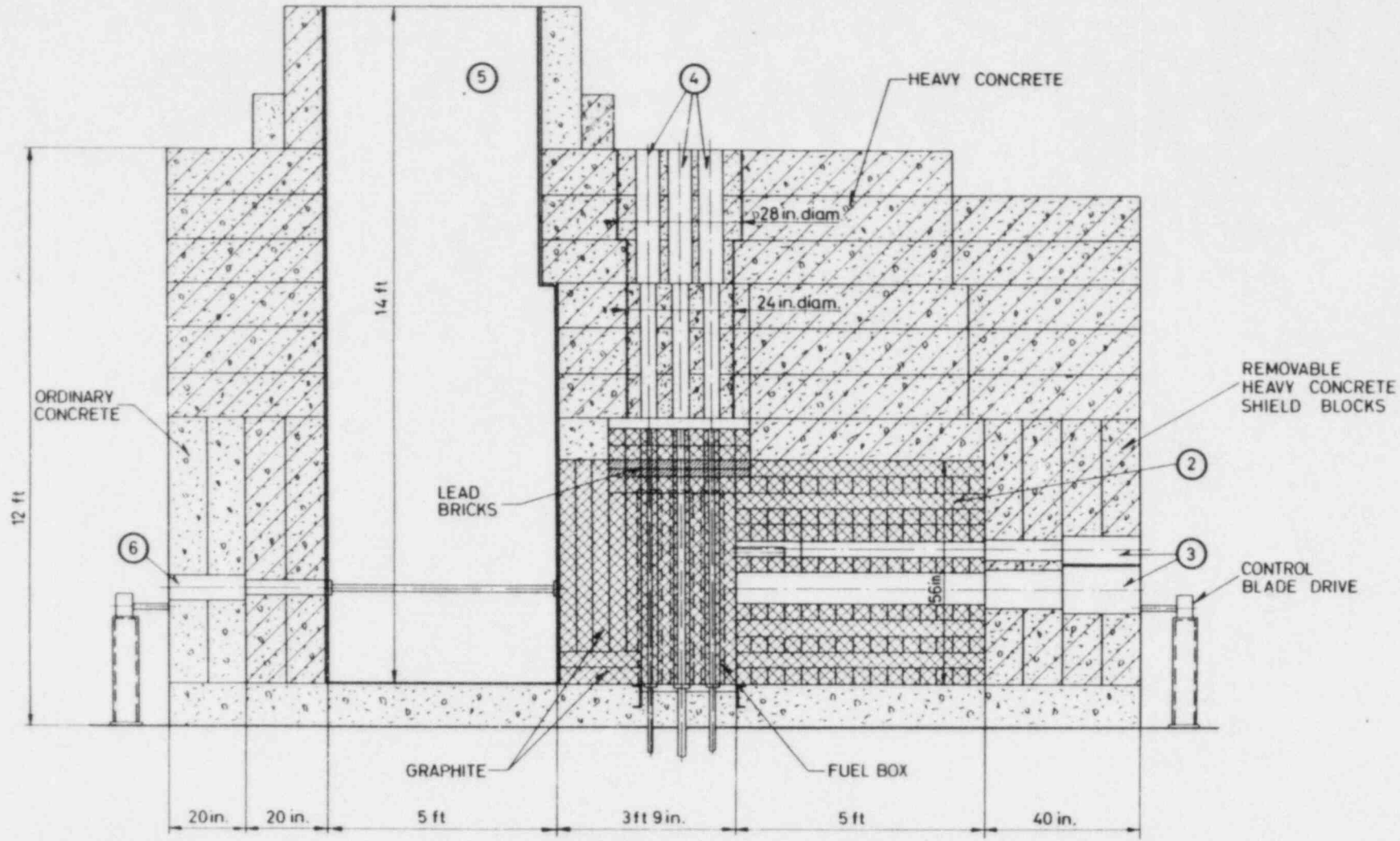
Name:	UCLA Training Reactor	
Location:	Los Angeles, California	
Docket Number:	50-142	
License Number:	R-71	
Date of Initial Criticality:	1960	
Rated Power:	100 kw Rated power increased from 10 kw to 100 kw in 1963	
Description:	Argonaut type, heterogeneous core research reactor	
Fuel:	U-Al alloy	
	enrichment	90%
	clad	Aluminum
	critical mass	3.2 kg
	max. excess reactivity	2.3% $\frac{\Delta k}{k}$
	description	24 elements, 11 MTR type plates per element
Max. Neutron Flux:	1 x 10" $^{n}/_{cm^2}$-sec	
Control Rods (4):	Composition	Cadmium
	clad	Magnesium
	Swinging vane type	
	3 safety rods	
	Total worth	4.5% $\frac{\Delta k}{k}$
	1 regulating rod	
	worth	0.6% $\frac{\Delta k}{k}$

Moderator:	H_2O and graphite
Coolant:	H_2O
Max Coolant Temp.:	110^oF
Reflector:	Graphite
Shield:	Concrete
Number of Operators:	SRO-4, RO-2
Utilization:	Generated approximately 13 Mw-hrs of energy in 1976

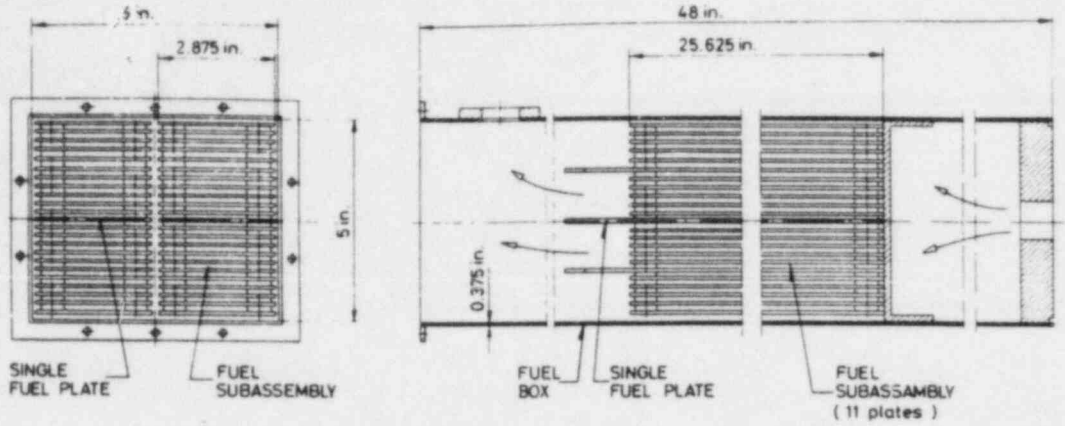
Name:	University of Florida Training Reactor		
Location:	Gainesville, Florida		
Docket Number:	50-83		
License Number:	R-56		
Date of Initial Criticality:	1956		
Rated Power:	100 kw		
Description:	Argonaut type, light water moderated research reactor		
Fuel:	U-Al		
	enrichment	20%	93%
	clad	Aluminum	
	critical mass	3.5 kg	3.1 kg
	core loading	3.6 kg	3.3 kg
	max. excess reactivity	0.6% $\frac{\Delta K}{k}$	2.3% $\frac{\Delta k}{k}$
	description	11 rectangular parallel plates per fuel bundle	
Max. Neutron Flux:	1.8×10^{12} n/cm^2-sec		
	enrichment	20% *	93%
Control Rods (4):	3 shim safety blades total worth	4.24%	4.11%
	1 regulating blade worth	0.78%	1.02%
	composition	Cadmium	
	clad	Magnesium	
Moderator:	Light water (H_2O)		
Coolant:	H_2O		

*Licensee does not currently possess 20% enriched fuel.

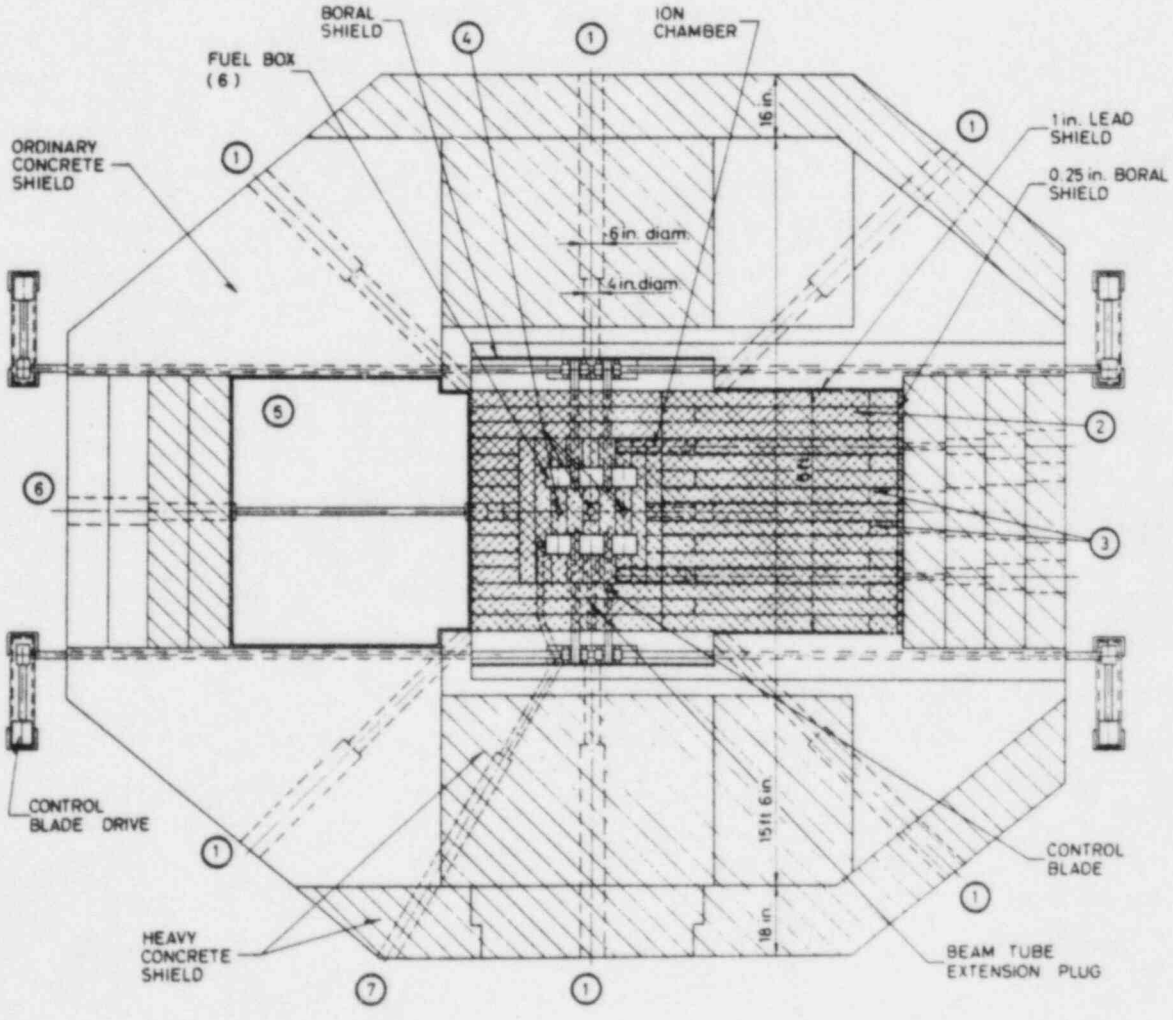
Reflector:	Graphite
Shield:	Concrete
Number of Operators:	SRO-6, RO-2



VERTICAL SECTION REACTOR UFTR



FUEL ELEMENT



HORIZONTAL SECTION REACTOR UFTR

Name:	University of Washington Nuclear Reactor (UWNR)
Location:	Seattle, Washington
Docket Number:	50-139
License Number:	R-73
Date of Initial Criticality:	1961
Rated Power:	100 kw Increased rated power from 10 kw to 100 kw in 1966.
Description:	Heterogeneous, Argonaut-type research reactor.
Core:	Rectangular prism of graphite
Fuel:	U-Al
enrichment	90%
clad	Aluminum
core loading	3.7 kg
max. excess reactivity	2.3% $\frac{\Delta k}{k}$
description	MTR-type plates 24 elements, 11 plates per element
Max. Neutron Flux:	1 x 10" $^{n}/_{cm^2}$-sec
Control Rods (4):	3 safety blades
composition	Cadmium
clad	Magnesium
individual worth	1.5% $\frac{\Delta k}{k}$
	1 regulating rod
	similar composition and clad
worth	0.6% $\frac{\Delta k}{k}$

Moderator:	H_2O and graphite
Coolant:	H_2O
Max. Coolant Temp.:	$160^{o}F$
Reflector:	Graphite
Shield:	Concrete
Number of Operators:	SRO-3, RO-1
Utilization:	Operated 107 times for approximately 180 hours in 1977

Name:	University Training Reactor (UTR-10)
Owner:	Va. Polytechnic Institute and State University
Location:	Blacksburg, Virginia
Docket Number:	50-124
License Number:	R-62
Principle Contractor:	American Radiator and Standard Sanitary Corp.
Date of Initial Criticality:	1960
Rated Power:	100 kw Increased power from 10 kw to 100 kw in 1965
Description:	Argonaut type
Fuel:	$U\text{-}Al_4$
	enrichment: 93%
	clad: Aluminum
	critical mass: 3 kg.
	core loading: 3.4 kg.
	max. excess reactivity: allowed 0.6% $\frac{\Delta k}{k}$
	presently 0.3% $\frac{\Delta k}{k}$
Max. Neutron Flux:	1×10^{14} n/cm^2-sec
Control Rods (4):	3 safety rods
	windowshade type
	composition: Cadmium
	total worth: 0.8% $\frac{\Delta k}{k}$

	1 regulating rod	
	composition	Cadmium
	worth	0.2% $\frac{\Delta k}{k}$
Moderator:	Light water (H_2O)	
Coolant:	H_2O	
Max. Coolant Temp.:	170° F	
Reflector:	Graphite	
Shield:	Concrete	
Number of Operators:	SRO-5, RO-4	
Utilization:	Generated approximately 113,387 kw-hrs of energy in 1976. 235 start ups	

Name:	Iowa State University Reactor
Location:	Ames, Iowa
Docket Number:	50-116
License Number:	R-59
Date of Initial Criticality:	1959
Rated Power:	10 kw
Description:	Argonaut type, light water moderated research reactor
	Similar to UTR reactor at VPISU except:
Max. Neutron Flux:	$1.25 \times 10^{n/cm^2\text{-sec}}$
Control Rods (4):	3 shim safety rods
	composition: Cadmium
	individual worth: 1.86% $\frac{\Delta k}{k}$
	1 regulating rod
	composition: Cadmium
	worth: 0.12% $\frac{\Delta k}{k}$
Operators:	SRO-3, RO-2

TANK REACTORS

Name:	Cornell Zero Power Reactor (ZPR)	
Location:	Ithaca, New York	
Docket Number:	50-97	
License Number:	R-89	
Principle Contractor:	Vitro Engineering Co.	
Date of Initial Criticality:	1963	
Rated Power:	100 watts	
Description:	Low power, light water moderated tank type research reactor	
Fuel:	UO_2 pellets	
	enrichment	2.1%
	clad	Aluminum
	max. excess reactivity	2.8% $\frac{\Delta k}{k}$
	description	228 fuel roads (0.6" diameter, 48" length)
Max. Neutron Flux:	1.45×10^9 n/cm^2-sec	
Control Rods(4):	4 control rods	
	each a cluster of three cylinders	
	composition	Boron-carbide
	clad	Aluminum
	total worth	6% $\frac{\Delta k}{k}$
Moderator:	Light water (H_2O)	
Coolant:	H_2O	

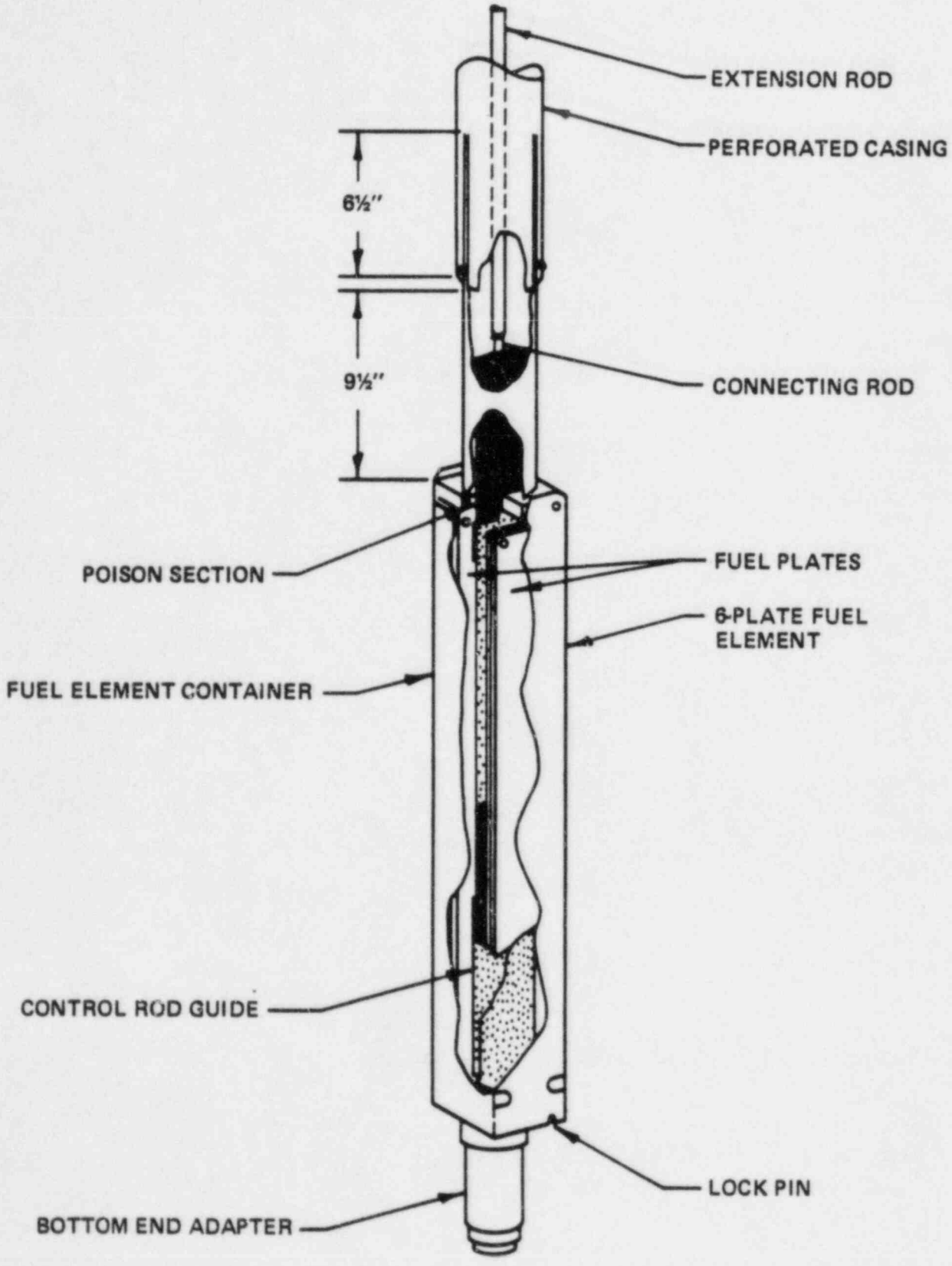
Reflector:	H_2O
Shield:	Concrete
Number of Operators:	SRO-2, RO-0
Note:	The ZPR is located in the same pool as the Cornell TRIGA reactor therefore neutron coupling occurs.

Name:	Westinghouse Nuclear Training Reactor (NTR)	
Location:	Zion, Illinois Transferred from Waltz Mill, Penn. in 1972	
Docket Number:	50-87	
License Number:	R-119	
Date of Initial Criticality:	1972	
Rated Power:	10 kw	
Fuel:	$U\text{-}Al_x$	
	enrichment	93%
	clad	Aluminum
	core loading	7.4 kg
	max. excess reactivity	4.1% $\frac{\Delta k}{k}$
	description	28 elements, 3 tubes per element
Control Rods:	9 fuel follower control rods	
	composition	Cadmium
	clad	stainless steel
	total worth	9.4% $\frac{\Delta k}{k}$
Moderator:	H_2O	
Coolant:	H_2O	
Reflector:	H_2O	
Shield:	Concrete and H_2O	
Number of Operators:	SRO-12, RO-0	
Utilization:	Operated approximately 2000 hours in 1977.	

Name:	General Electric Nuclear Test Reactor (NTR)
Location:	Alameda County, California
Docket Number:	50-73
License Number	R-33
Date of Initial Criticality:	1957
Rated Power:	100 kw Increased rated power from 30 kw to 100 kw in 1969
Description:	Light water moderated research reactor
Fuel:	U-Al alloy
	enrichment: 93%
	clad: Aluminum
	critical mass: 3 kg.
	core loading: 3.7 kg.
	max. excess reactivity: 0.75% $\frac{\Delta k}{k}$
	description: 16 fuel assemblies, 40 disks per assembly
Max. Neutron Flux:	2.5×10^{12} n/cm^2-sec
Control Rods (11):	6 poison sheets
	composition: Cadmium-Aluminum
	individual worth: 1% $\frac{\Delta k}{k}$
	4 safety rods
	composition: Boron carbide powder
	clad: Cadmium steel
	individual worth: 0.5% $\frac{\Delta k}{k}$

	1 fine control rod
	worth 0.12% $\frac{\Delta k}{k}$
Moderator:	Graphite
Coolant:	H_2O
Max. Coolant Temp.:	126° F
Reflector:	Graphite
Shield:	Concrete
Number of Operators:	SRO-5, RO-1
Utilization:	Operated approximately 1820 hours in 1977 with 359 reactor start-ups.

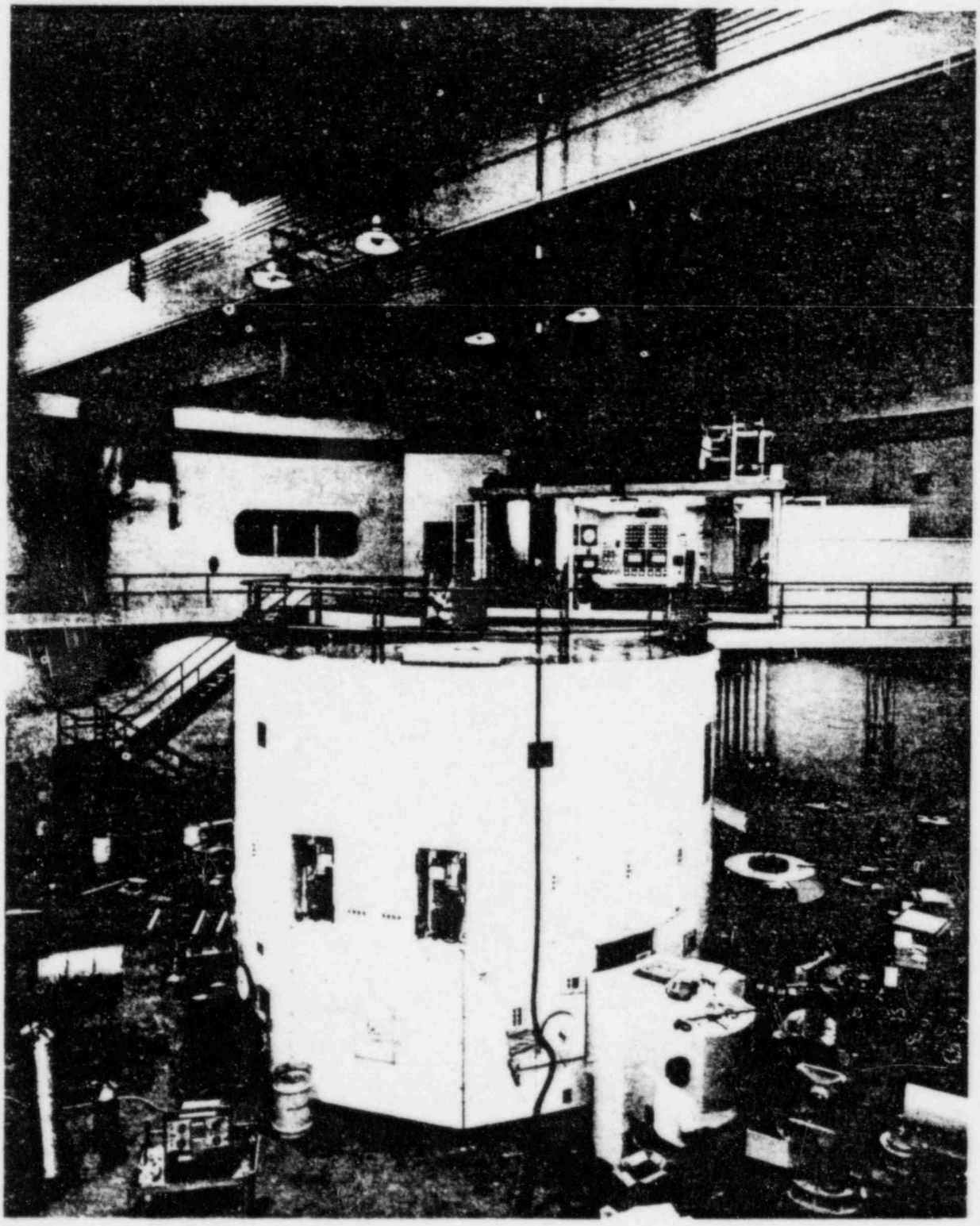
Name:	General Electric Test Reactor (GETR)
Location:	Alameda County, California
Docket Number:	50-70
License Number:	TR-1
Date of Initial Criticality:	1959
Rated Power:	50 Mw increase in power in 1966
Description:	low pressure, low temperature tank test reactor located in a pool.
Fuel:	U-Al alloy, enrichment 93% or $U\text{-}Al_x$ alloy, enrichment 89%
clad	Aluminum
core loading	10.7 kg
max. excess reactivity	11.5% $\frac{\Delta k}{k}$
description	standard 21 elements, 19 fuel plates per element
Max. Neutron Flux:	1.6×10^{14} n/cm^2-sec
Control Rods (6):	6 fuel follower control rods
composition	Boron, steel
total worth	17.5% $\frac{\Delta k}{k}$
	This system contains a liquid emergency shutdown system.
Moderator:	light water (H_2O)
Coolant:	H_2O
Max. Coolant Temp.:	135^oF
Shield:	Concrete
Number of Operators:	SRO - 20, RO - 10



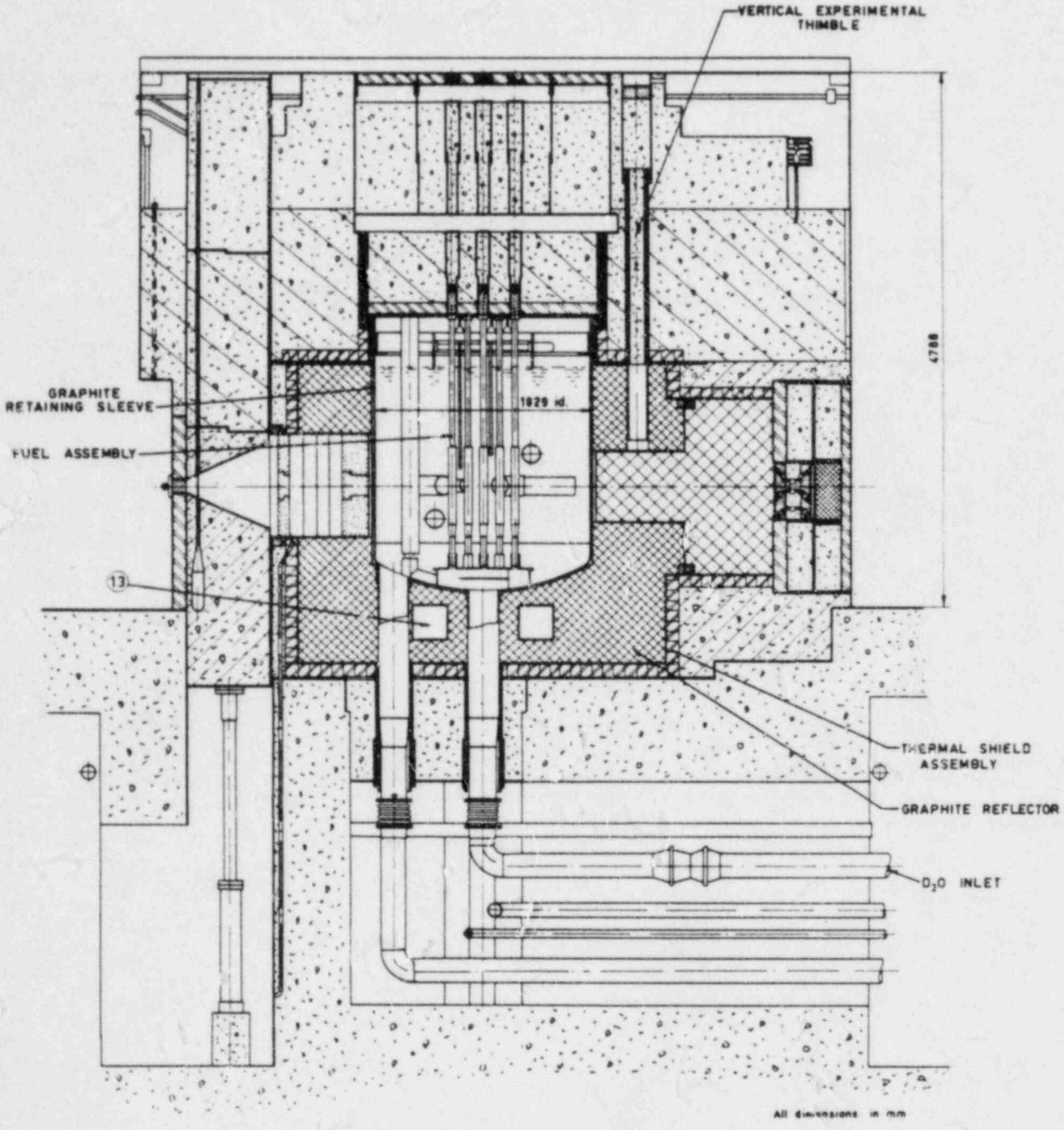
Fuel Follower Control Rods

Name:	Georgia Tech Research Reactor (GTRR)	
Location:	Atlanta, Georgia	
Docket Number:	50-160	
License Number:	R-97	
Date of Initial Criticality:	1964	
Rated Power:	5 Mw Increased rated power to 5 Mw in 1974	
Description:	Tank-type, heavy water moderated research reactor	
Fuel:	U-Al	
	enrichment	93%
	clad	Aluminum
	max. excess reactivity	11.9% $\frac{\Delta k}{k}$
	description	19 fuel assemblies, 16 plates per assembly triangle array
Max. Neutron Flux:	1.5×10^{14} n/cm^2-sec	
Control Rods (5):	4 shim safety blades	
	hollow blades	
	composition	Cadmium filled with Helium
	clad	Aluminum
	individual worth	4% $\frac{\Delta k}{k}$
	1 regulating rod	
	same composition and clad	
	worth	4% $\frac{\Delta k}{k}$

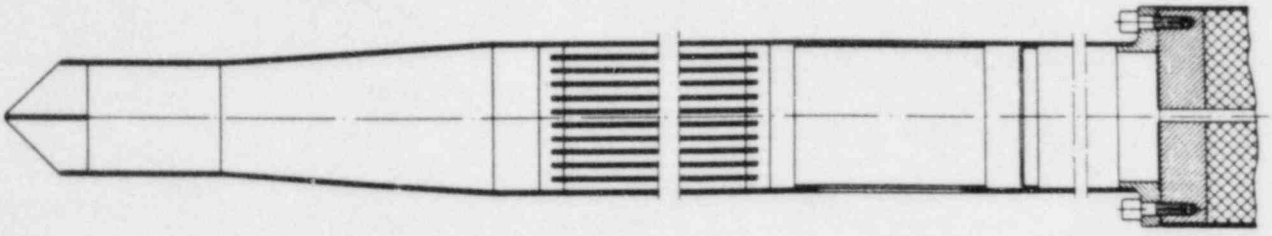
Moderator:	Heavy water (D_2O)
Primary Coolant:	D_2O
Secondary Coolant:	H_2O
Max. Coolant Temp.:	123^oF
Reflector:	D_2O and graphite
Shield:	Concrete
Number of Operators:	SRO-4, RO-6
Utilization:	Operated approximately 420 hours between 6/76 and 6/77



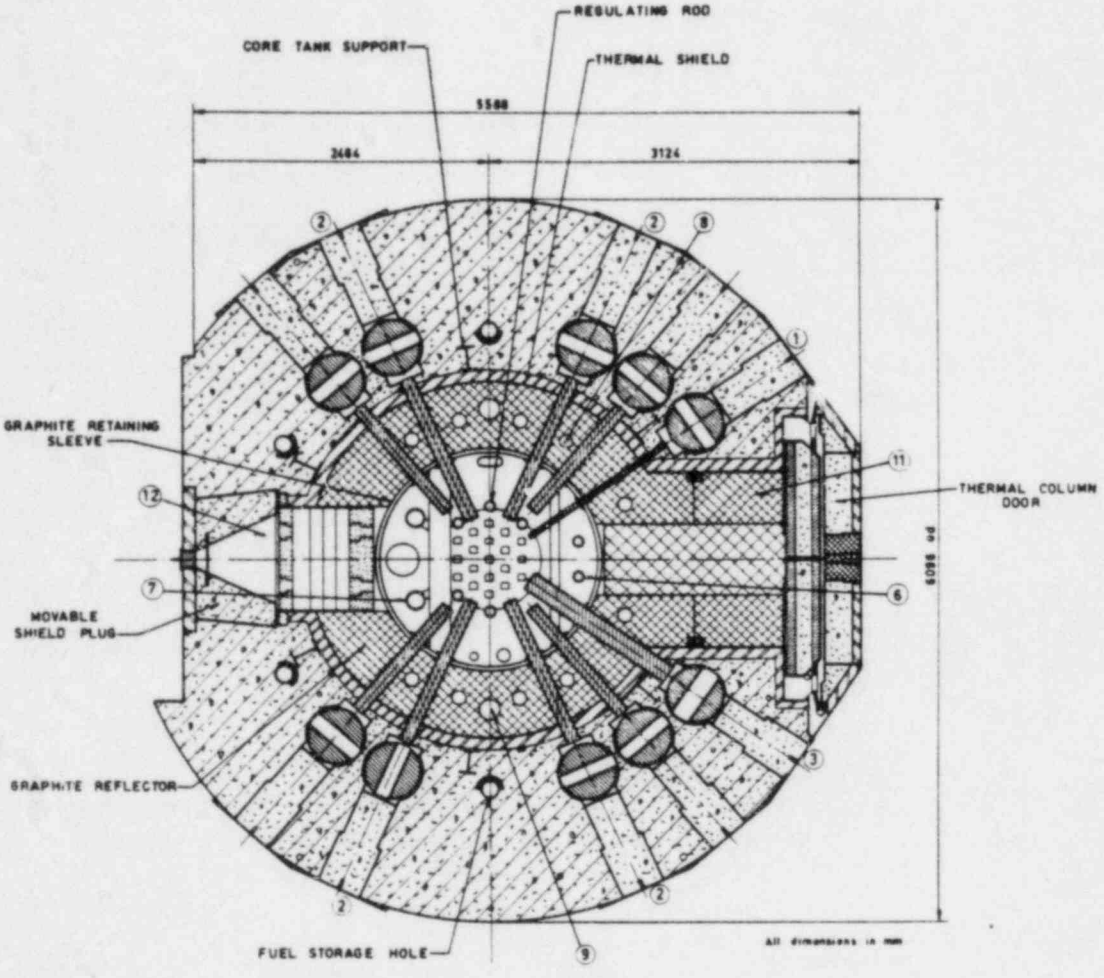
The Georgia Tech Research Reactor.



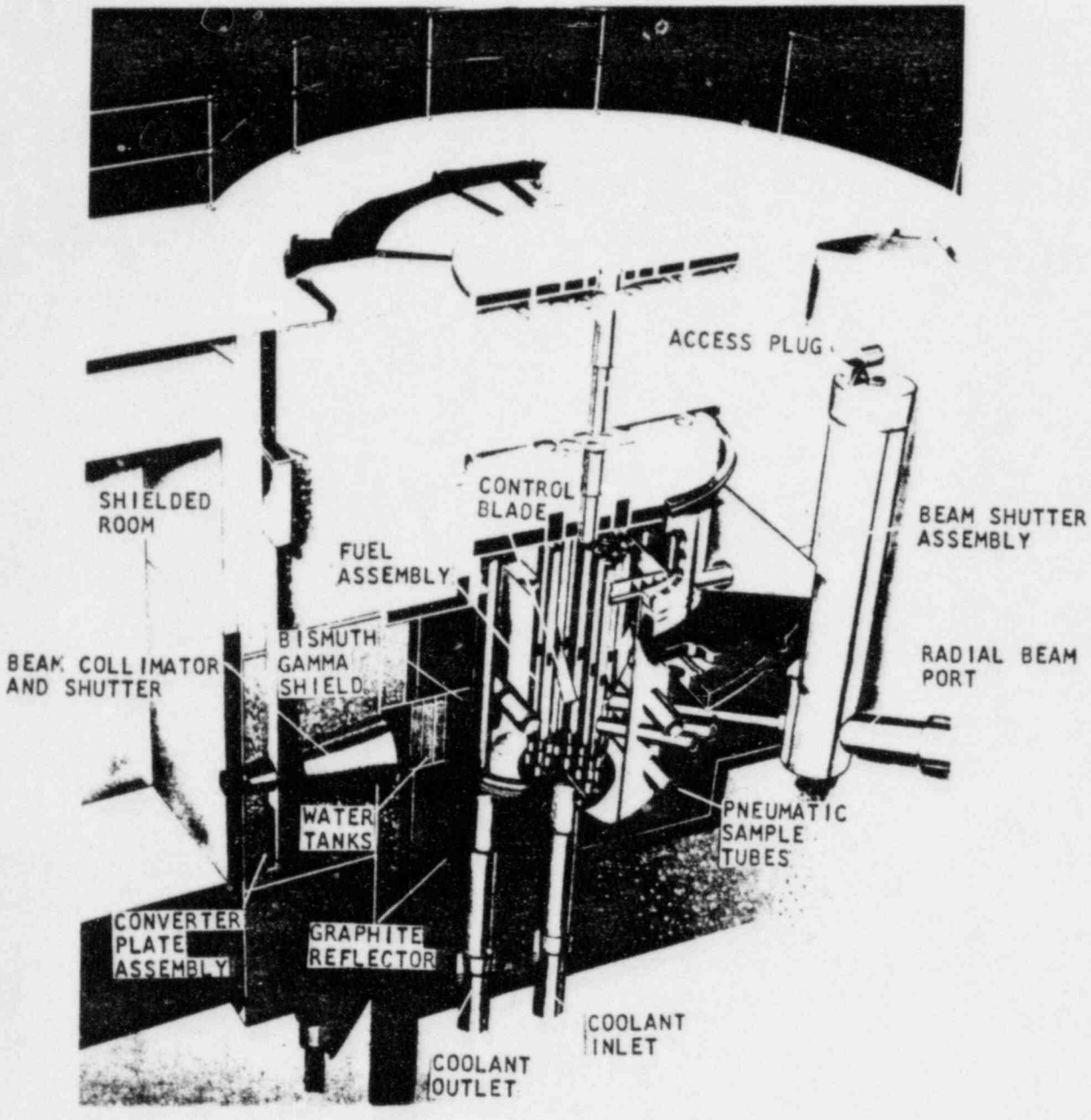
VERTICAL SECTION REACTOR GTRR



FUEL ELEMENT



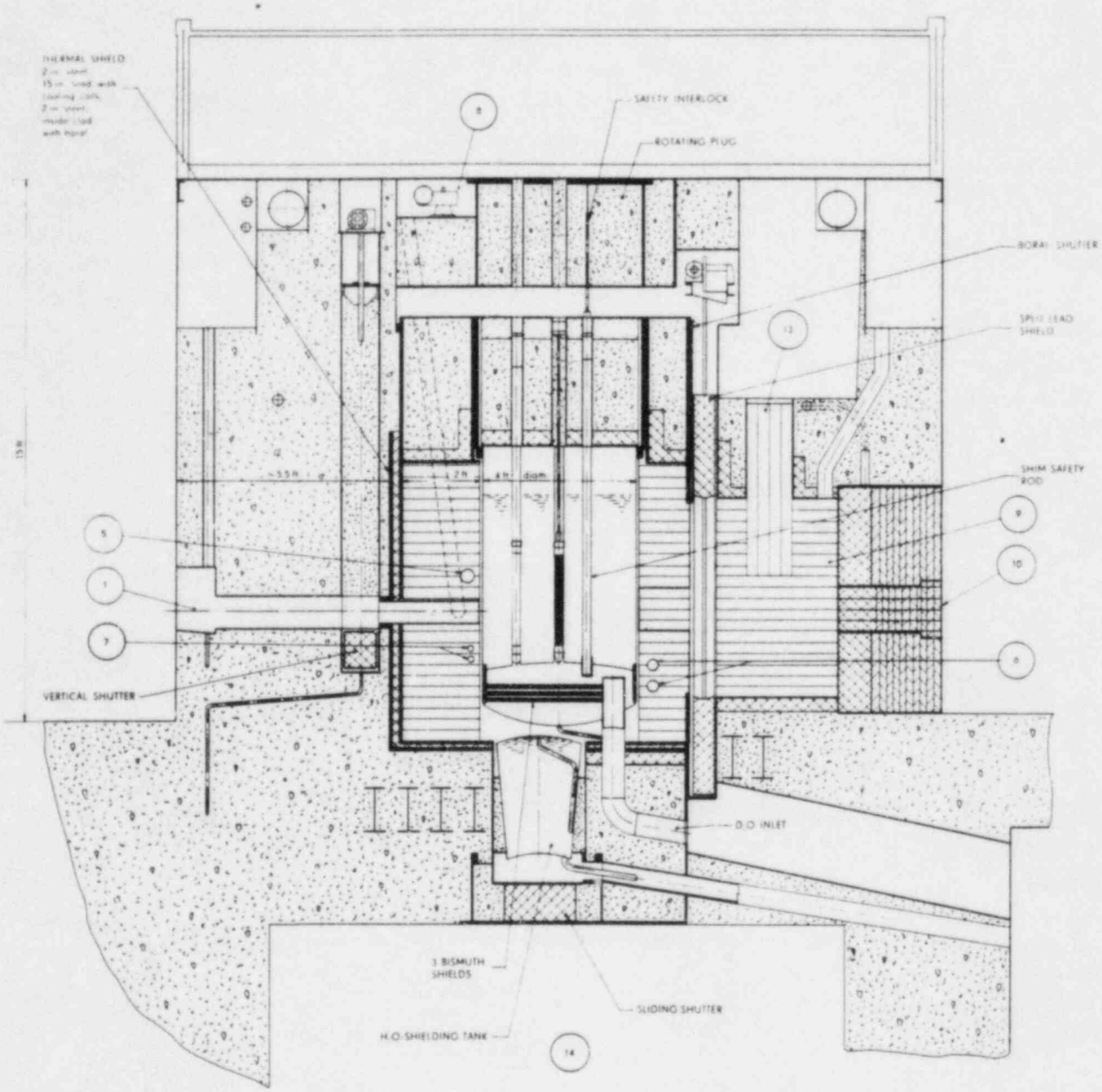
HORIZONTAL SECTION REACTOR GTRR



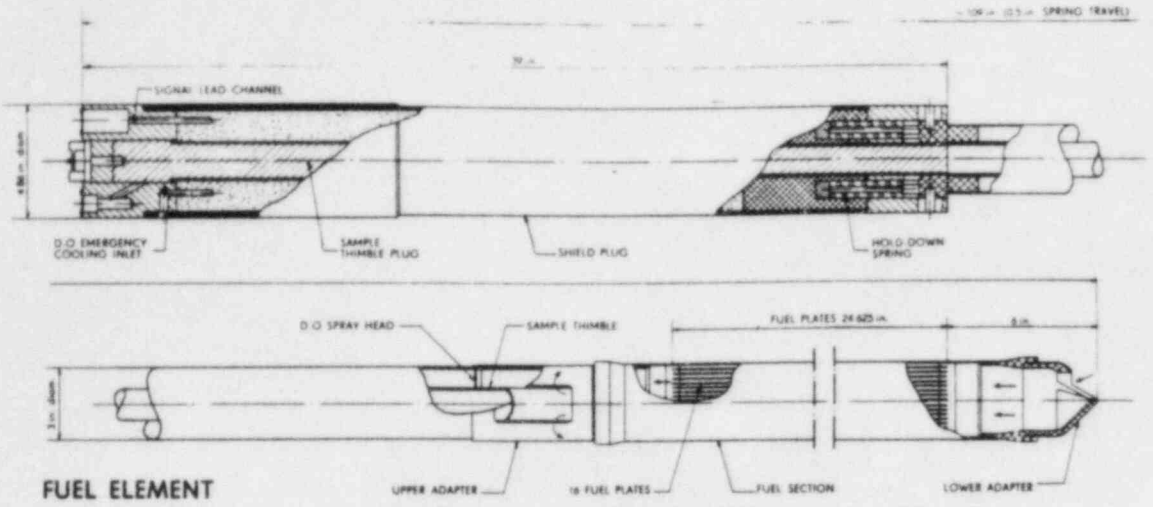
Cutaway Perspective View of the GTRR.

Name:	Mass. Institute of Technology Reactor (MITR)	
Location:	Cambridge, Mass.	
Docket Number:	50-20	
License Number:	R-37	
Principle Contractor:	ACF Industries	
Date of Initial Criticality:	1958	
Rated Power:	5 Mw	
Description:	Tank-type, heavy water reflected reactor	
Fuel:	$U\text{-}Al_x$	
	enrichment	93%
	clad	Aluminum
	core loading	11.6 kg
	max. excess reactivity	1.8% $\frac{\Delta k}{k}$
	description	Rhomboidal fuel elements, hexagonal distribution
Max. Neutron Flux:	1×10^{14} n/cm^2-sec	
Control Rods:	6 flat plates	
	composition	stainless steel with 1% boron
	total worth	12.6% $\frac{\Delta k}{k}$
Moderator:	H_2O	
Coolant:	Light water (H_2O)	
Absorbers:	Hafnium	

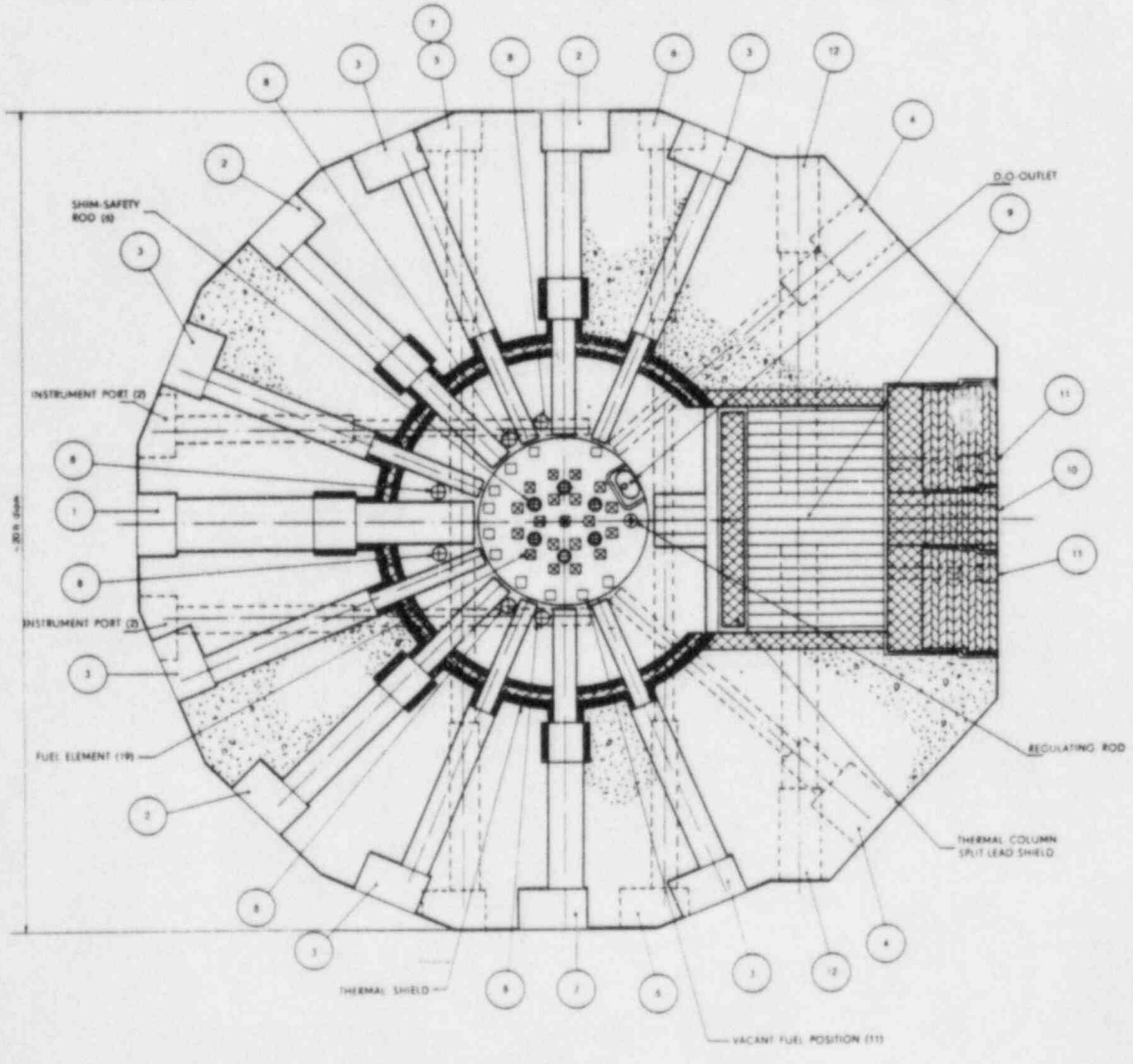
Reflector:	Heavy water (D_2O) and graphite
Shield:	Concrete
Number of Operators:	SRO-11, RO-5
Utilization:	Operated approximately 4500 hours in 1977
Note:	Major change in the core in 1976. Light water relaced heavy water as the coolant and Moderator.



MITR VERTICAL SECTION



FUEL ELEMENT



MITR HORIZONTAL SECTION

Name:	National Bureau of Standards Reactor (NBSR)	
Location:	Gaithersburg, Maryland	
Docket Number:	50-184	
License Number:	TR-5	
Principle Contractor:	Burns and Roe, Inc.	
Date of Initial Criticality:	1967	
Rated Power:	10 Mw	
Description:	Tank-type heavy water moderated test reactor	
Fuel:	U-Al	
	enrichment	93%
	clad	Aluminum
	core loading	6 kg
	max. excess reactivity	10% $\frac{\Delta k}{k}$
	description	24 fuel elements, 17 plates per element MTR-type curved plates, hexagonal distribution
Max. Neutron Flux:	1×10^{14} n/cm^2-sec	
Control Rods (5):	4 shim safety blades	
	semaphore type	
	composition	Cadmium
	clad	Aluminum
	total worth	32% $\frac{\Delta k}{k}$

	1 regulating rod	
	composition	Aluminum
	worth	0.5% $\frac{\Delta k}{k}$
Moderation:	Heavy water (D_2O)	
Coolant:	D_2O	
Reflector:	D_2O	
Shield:	Lead, iron and concrete	
Max. Coolant Temp.:	$50^{o}C$	
Number of Operators:	SRO-16, RO-1	
Utilization:	Operated approximately 6100 hours in 1977	

POOL REACTORS

Name:	Manhattan College Zero Power Reactor (ZPR)	
Location:	Riverdale, New York	
Docket Number:	50-199	
License Number:	R-94	
Principle Contractor:	AMF Atomics	
Date of Initial Criticality:	1964	
Rated Power:	.1 watt	
Description:	Low Power, pool-type reactor	
Fuel:	U-Al alloy	
	enrichment	90%
	clad	Aluminum
	critical mass	3.25 kg.
	core loading	3.74 kg.
	max. excess reactivity	0.44% $\frac{\Delta k}{k}$
	description	16 fuel elements, 18 MTR-type plates per element
Max. Neutron Flux:	1.26 X 10^9 n/cm^2-sec	
Control Rods(2):	Two Y-shaped control rods	
	1 safety rod	
	composition	cadium and stainless steel
	worth	3.4% $\frac{\Delta k}{k}$
	1 regulating rod	
	composition	stainless steel
	worth	0.9% $\frac{\Delta k}{k}$

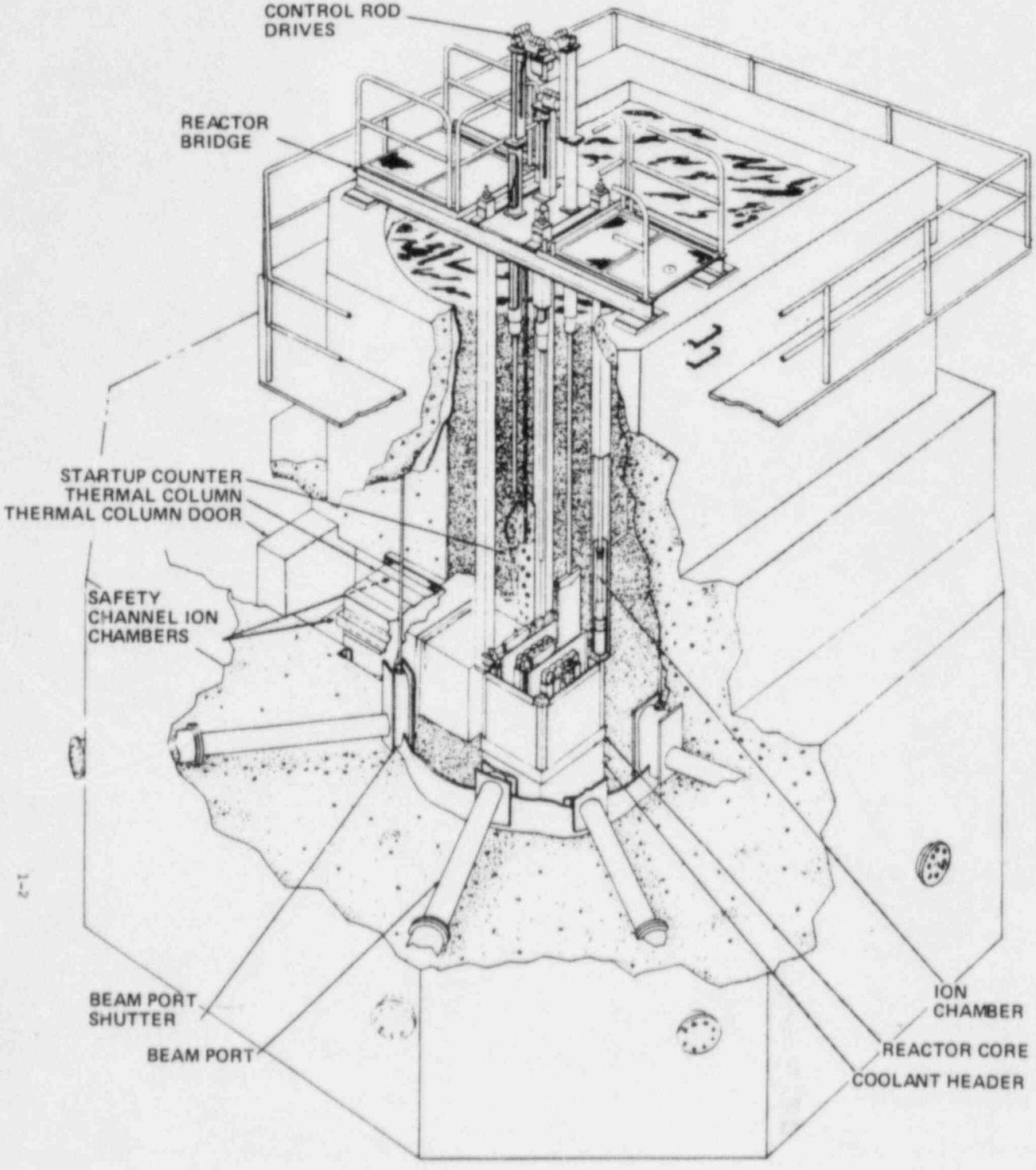
Moderator:	light water (H_2O)
Coolant:	H_2O
Reflector:	graphite
Shield:	concrete
Number of Operators:	SRO - 3, RO - 0

Name:	Cooperatively Assembled Virginia Low-Intensity Educational Reactor (CAVALIER)		
Location:	Charlottesville, Virginia		
Docket Number:	50-396		
License Number:	R-123		
Date of Initial Criticality:	1974		
Rated Power:	100 watts		
Description:	Low power, pool-type training facility. Two types of reflectors are possible, graphite or light water.		
Fuel:	U-Al alloy		
	enrichment	93%	
	clad	Aluminum	
	max. excess reactivity	1.6% $\frac{\Delta k}{k}$	
	description	flat plate, curved MTR elements 12 plates per element	
		light water (H_2O)	Graphite
	core loading	2.31 kg.	2.97 kg.
	elements in core	16	12
Max. Neutron Flux:		8.5×10^7 n/cm^2-sec	1.1×10^8 n/cm^2-sec
Control Rods (4):	4 control blades		
	bayonet type, oval cross section		
	composition	boron stainless steel	
	individual worth	3% $\frac{\Delta k}{k}$	

Moderator:	Light water (H_2O)
Coolant:	H_2O
Reflector:	H_2O or graphite
Shield:	Concrete
Number of Operators:	SRO-1, RO-4
Utilization:	Operated approximately 400 hours in 1977

Name:	Worcester Polytechnic Institute Reactor	
Location:	Worcester, New York	
Docket Number:	50-134	
License Number:	R-61	
Principle Contractor:	General Electric	
Date of Initial Criticality:	1959	
Rated Power:	10 kw	
Description:	Increased rated power from 1 kw to 10 kw in 1967 Light water moderated open pool reactor	
Fuel:	U-Al alloy	
	enrichment	93%
	clad	Aluminum
	critical mass	3.6 kg.
	core loading	3.7 kg.
	max. excess reactivity	0.5% $\frac{\Delta k}{k}$
	description	MTR-type plates 27 elements, 10 plates per element
Max. Neutron Flux:	9×10^9 n/cm^2-sec	
Control Rods(4):	3 safety blades	
	composition	Boral
	individual worth	3.5% $\frac{\Delta k}{k}$
	1 regulating rod	
	composition	stainless steel
	worth	0.7% $\frac{\Delta k}{k}$

Moderator:	Light water (H_2O)
Coolant:	H_2O
Max. Coolant Temp.:	130° F
Reflector:	Graphite and H_2O
Shield:	Concrete and H_2O
Number of Operators:	SRO-3, RO-4



OPEN POOL REACTOR

Name:	Missouri University Research Reactor (MURR)
Location:	Columbia, Missouri
Docket Number:	50-186
License Number:	R-103
Principle Contractor:	Internuclear of St. Louis
Date of Initial Criticality:	1966
Rated Power:	10 Mw
Description:	Increase in rated power from 5Mw to 10 Mw in 1974 Pool-type, light water moderated research reactor
Fuel:	U-Al or U-Alx curved plates
	enrichment: 93%
	clad: Aluminum
	critical mass: 4 kg.
	core loading: 6.2 kg.
	max. excess reactivity: 9.8% $\frac{\Delta k}{k}$
	description: 8 fuel assemblies with 24 plates per assembly
Max. Nuetron Flux:	1.6×10^{12} n/cm^2-sec
Control Rods(4):	3 safety shim blades
	composition: Boron steel
	clad: Aluminum
	individual worth: 3% $\frac{\Delta k}{k}$

	1 regulating blade	
	composition	stainless steel
	worth	0.7% $\frac{\Delta k}{k}$
Moderator:	Light water (H_2O)	
Coolant:	H_2O	
Max. Coolant Temp.:	135° F	
Reflector:	Beryllium-Graphite and H_2O	
Shield:	Concrete and H_2O	
Number of Operators:	SRO-13, RO-11	
Utilization:	Operated approximately 5100 hours in 1977	

Name:	Purdue University Reactor	
Location:	West Lafayette, Indiana	
Docket Number:	50-182	
License Number:	R-87	
Principle Contractor:	Lockheed Nuclear Products	
Date of Initial Criticality:	1962	
Rated Power:	10 kw	
Description:	Pool-type, light water moderated and cooled research reactor	
Fuel:	U-Al	
	enrichment	93%
	clad	Aluminum
	core loading	2.44 kg.
	max. excess reactivity	0.6% $\frac{\Delta k}{k}$
	description	13 MTR-type elements, 10 plates per element
Max. Neutron Flux:	2.1 X 10^{10} n/cm^2-sec	
Control Rods(3):	2 shim safety rods	
	composition	boron stainless steel
	total worth	5.8% $\frac{\Delta k}{k}$
	1 regulating rod	
	composition	H_2O filled stainless steel tube
	worth	0.47% $\frac{\Delta k}{k}$

Moderator:	Light water (H_2O)
Coolant:	H_2O
Reflector:	Graphite waterproofed with a polyester resin
Shield:	Concrete, sand and H_2O
Number of Operators:	SRO-2, RO-3
Utilization:	Generated approximately 200 Mw-hrs of energy between 6/75 and 6/76

Name:	Ohio State University Reactor	
Location:	Columbus, Ohio	
Docket Number:	50-150	
License Number:	R-75	
Date of Initial Criticality:	1961	
Rated Power:	10 kw	
Description:	Light water moderated pool reactor	
Fuel:	U-Al alloy	
	enrichment	93%
	clad	Aluminum
	critical mass	2.84 kg.
	core loading	3.13 kg.
	max. excess reactivity	1.88% $\frac{\Delta k}{k}$
	description	20 elements, 10 MTR-type plates per element
Max. Neutron Flux:	2.2×10^{11} n/cm^2-sec	
Control Rods(4):	3 shim safety rods	
	composition	boron stainless steel
	total worth	8.6% $\frac{\Delta k}{k}$
	1 regulating rod	
	composition	stainless steel
	worth	0.6% $\frac{\Delta k}{k}$

Moderator:	Light water (H_2O)
Coolant:	H_2O
Max. Coolant Temp.:	145° F
Reflector:	Graphite and H_2O
Shield:	Concrete and H_2O
Number of Operators:	SRO-2, RO-2

Name:	University of Missouri Nuclear Reactor Facility	
Location:	Rolla, Missouri	
Docket Number:	50-123	
License Number:	R-79	
Principle Contractor:	Curtiss Wright Corporation	
Date of Initial Criticality:	1962	
Rated Power:	200 kw	
Description:	Light water moderated pool type research reactor	
Fuel:	U_3O_8 - Al	
	enrichment	90%
	clad	Aluminum
	core loading	2.9 kg.
	max. excess reactivity	3.3% $\frac{\Delta k}{k}$
	description	MTR-type fuel elements
Max. Neutron Flux:	2.8×10^{12} n/cm^2-sec	
Control Rods (4):	3 shim safety rods	
	composition	stainless steel and boron
	total worth	8.9%
	1 regulating rod	
	hollow tube	
	composition	stainless steel
	worth	0.65%

Moderator:	H_2O
Coolant:	H_2O
Max. Coolant Temp.:	113° F
Reflector:	Graphite and H_2O
Shield:	Concrete and H_2O
Number of Operators:	SRO-1 , RO-1
Utilization:	Generated approximately 11,800 kw-hrs of energy between 4/77 and 4/78

Name:	University of Kansas Training Reactor	
Location:	Lawrence, Kansas	
Docket Number:	50-148	
License Number:	R-78	
Principle Contractor:	Bendix Aviation Corp.	
Date of Initial Criticality:	1961	
Rated Power:	250 kw, average level 10 kw Power increased from 10 kw to 250 kw in 1971	
Description:	Pool type, light water moderated reactor	
Fuel:	U-Al alloy	
	enrichment	93%
	clad	Aluminum
	critical mass	2.5 kg.
	core loading	2.8 kg.
	max. excess reactivity	1.5% $\frac{\Delta k}{k}$
	description	10 MTR-type plates
Max. Neutron Flux:	3×10^{11} n/cm^2-sec	
Control Rods(3):	3 control plates	
	composition	Boral
	clad	Aluminum
	individual worth	2% $\frac{\Delta k}{k}$
Moderator:	Light water (H_2O)	

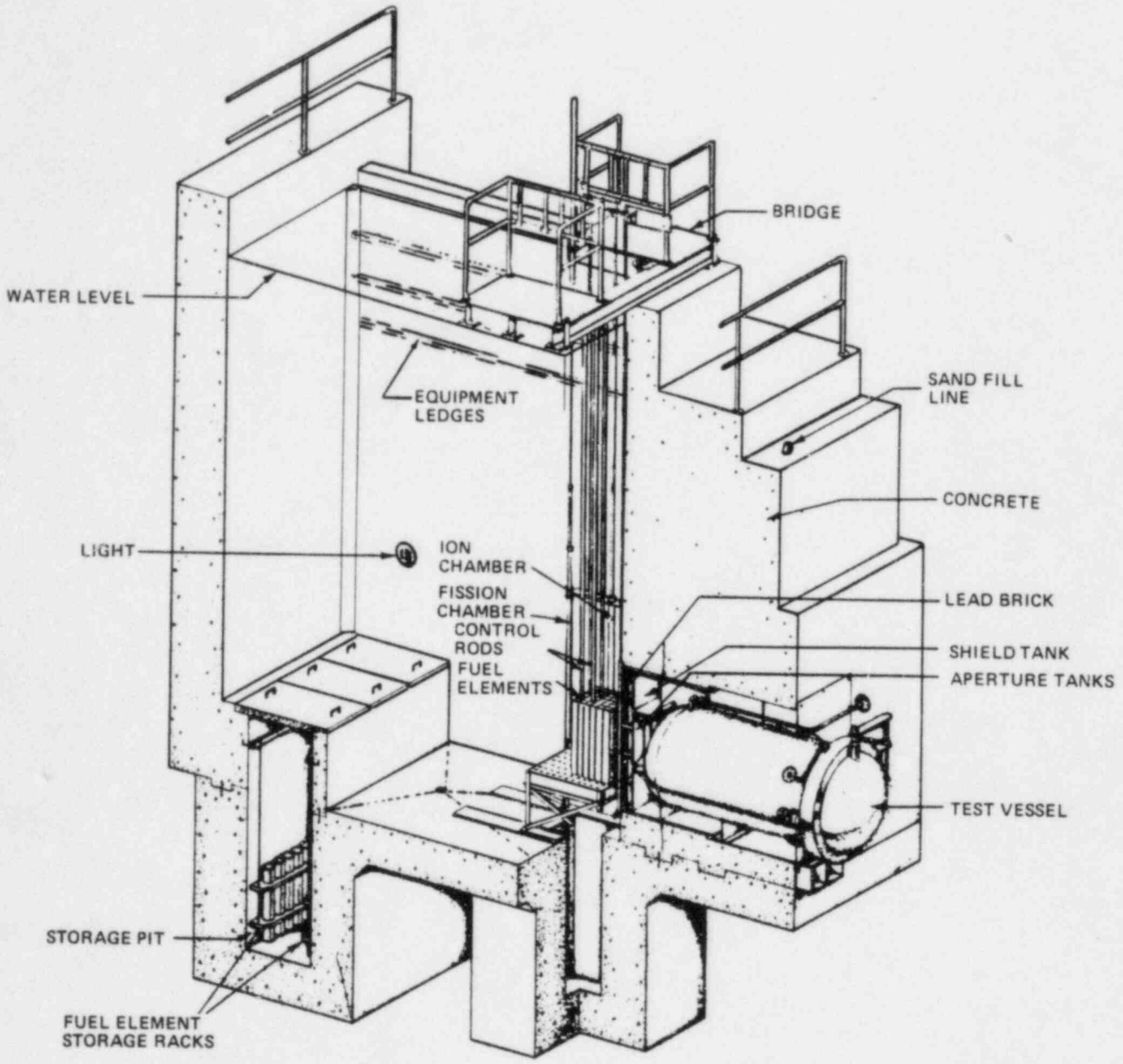
Coolant:	H_2O
Max. Coolant Temp.:	120° F
Reflector:	Graphite and H_2O
Shield:	Concrete
Number of Operators:	SRO-2, RO-2
Utilization:	Generated approximately 2.46 Mw-hrs of energy between 6/75 and 6/76.

Name:	Lowell Technological Institute Reactor	
Location:	Lowell, Massachusetts	
Docket Number:	50-223	
License Number:	R-125	
Date of Initial Criticality:	1975	
Rated Power:	1 Mw	
Description:	Light water moderated and cooled pool reactor	
Fuel:	U-Al alloy	
	enrichment	93%
	clad	Aluminum
	critical mass	2.8 kg.
	core loading	3.5 kg.
	max. excess reactivity	4.5% $\frac{\Delta k}{k}$
	description	26 elements, 18 plates per element
Max. Neutron Flux:	8.6×10^{12} n/cm^2-sec	
Control Rods(5):	4 safety rods	
	composition	Boral
	total worth	15.5% $\frac{\Delta k}{k}$
	1 regulating rod	
	composition	Boral
	worth	0.7% $\frac{\Delta k}{k}$
Moderator:	Light water (H_2O)	

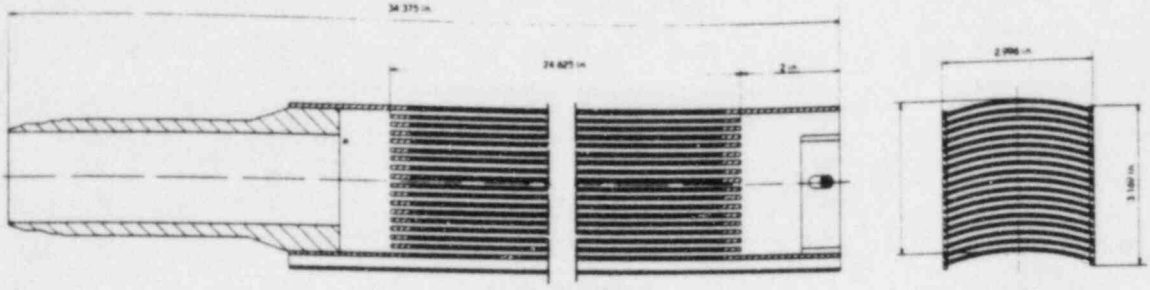
Coolant:	H_2O
Max. Coolant Temp.:	124° F
Reflector:	Graphite and H_2O
Shield:	Concrete and H_2O
Number of Operators:	SRO-5, RO-7
Utilization:	Operated approximately 350 hours between 5/75 and 5/76

Name:	Lynchburg Pool Reactor (LPR)	
Owner:	Babcock and Wilcox	
Location:	Lynchburg, Virginia	
Docket Number:	50-99	
License Number:	R-47	
Date of Initial Criticality:	1959	
Rated Power:	1 Mw increase in rated power in 1962	
Description:	light water moderated pool reactor	
Fuel:	U-Al alloy	
	enrichment	93%
	clad	Aluminum
	core loading	4.1 kg.
	max. excess reactivity	4% $\frac{\Delta k}{k}$
	description	18 elements, 10 plates per element
Control Rods (4):	3 safety shim rods	
	composition	Boron, stainless steel
	individual worth	2.4% $\frac{\Delta k}{k}$
	1 regulating rod (hollow)	
	composition	stainless steel
	worth	0.7% $\frac{\Delta k}{k}$

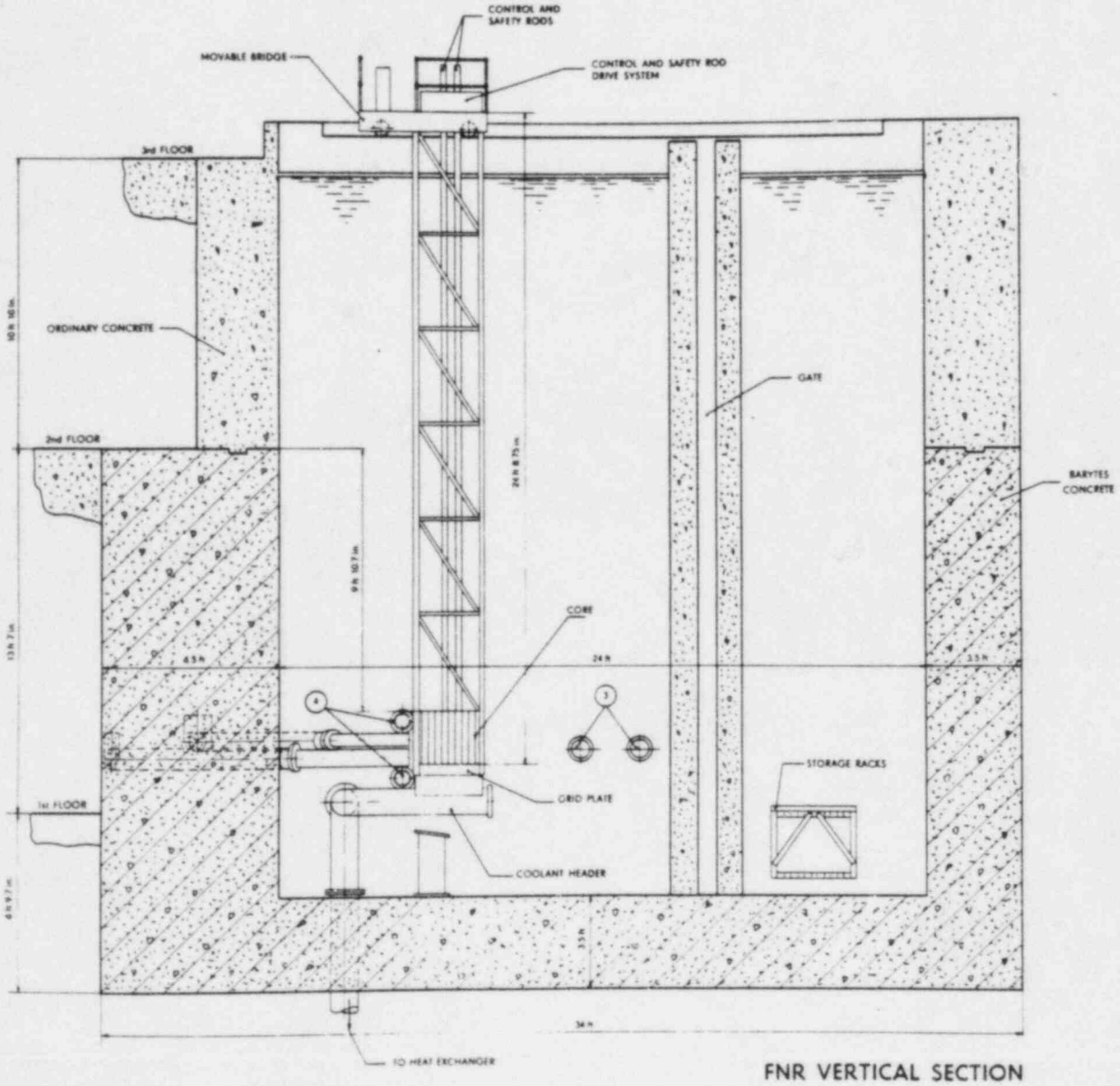
Moderator:	light water (H_2O)
Coolant:	H_2O
Max. Coolant Temp.:	120^oF
Reflector:	Graphite
Shield:	Concrete and H_2O
Number of Operators:	SRO - 2, RO - 2
Utilization:	Reactor was operated approx. 300 hours in 1974



LYNCHBURG POOL REACTOR



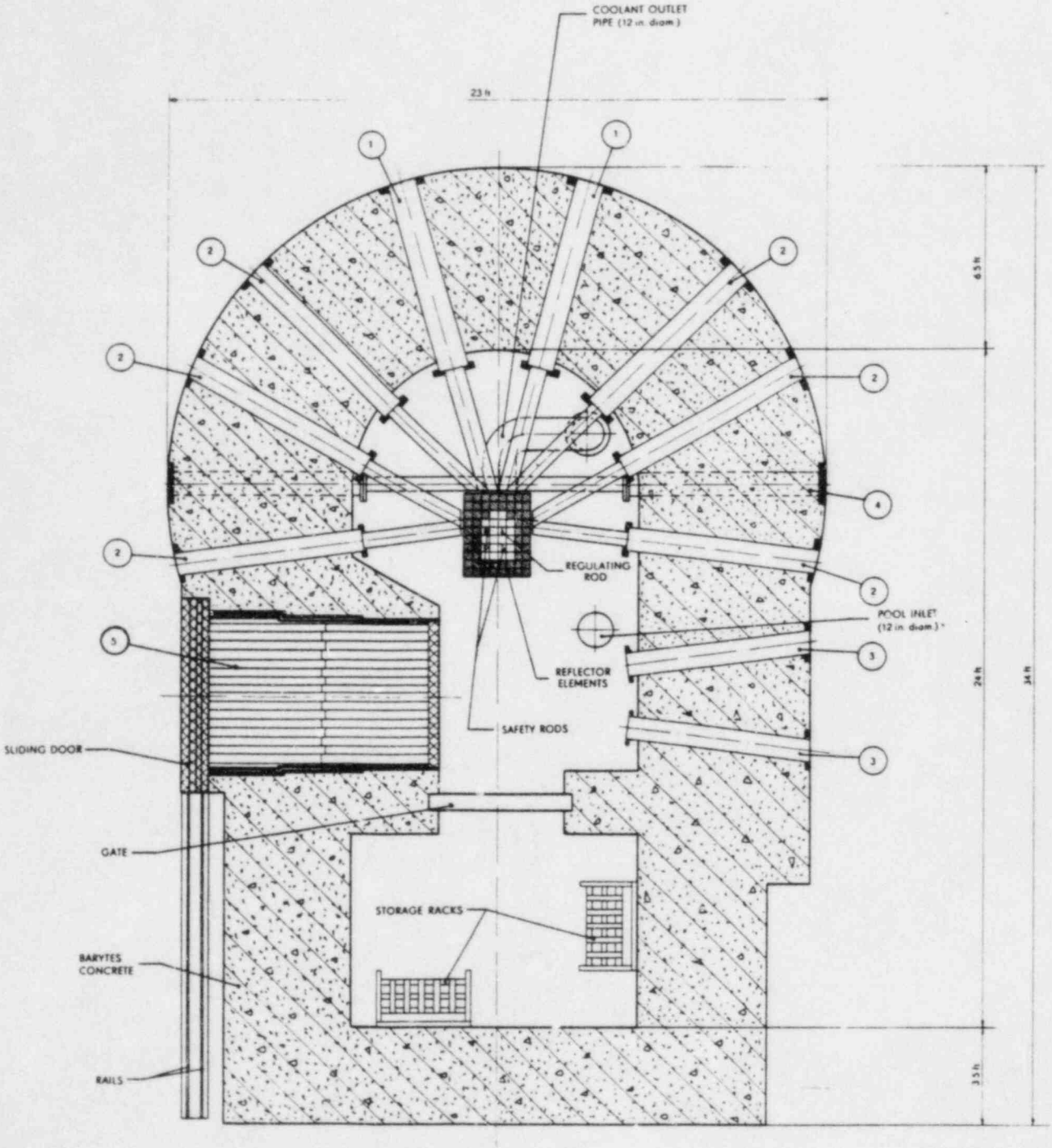
FUEL ELEMENT



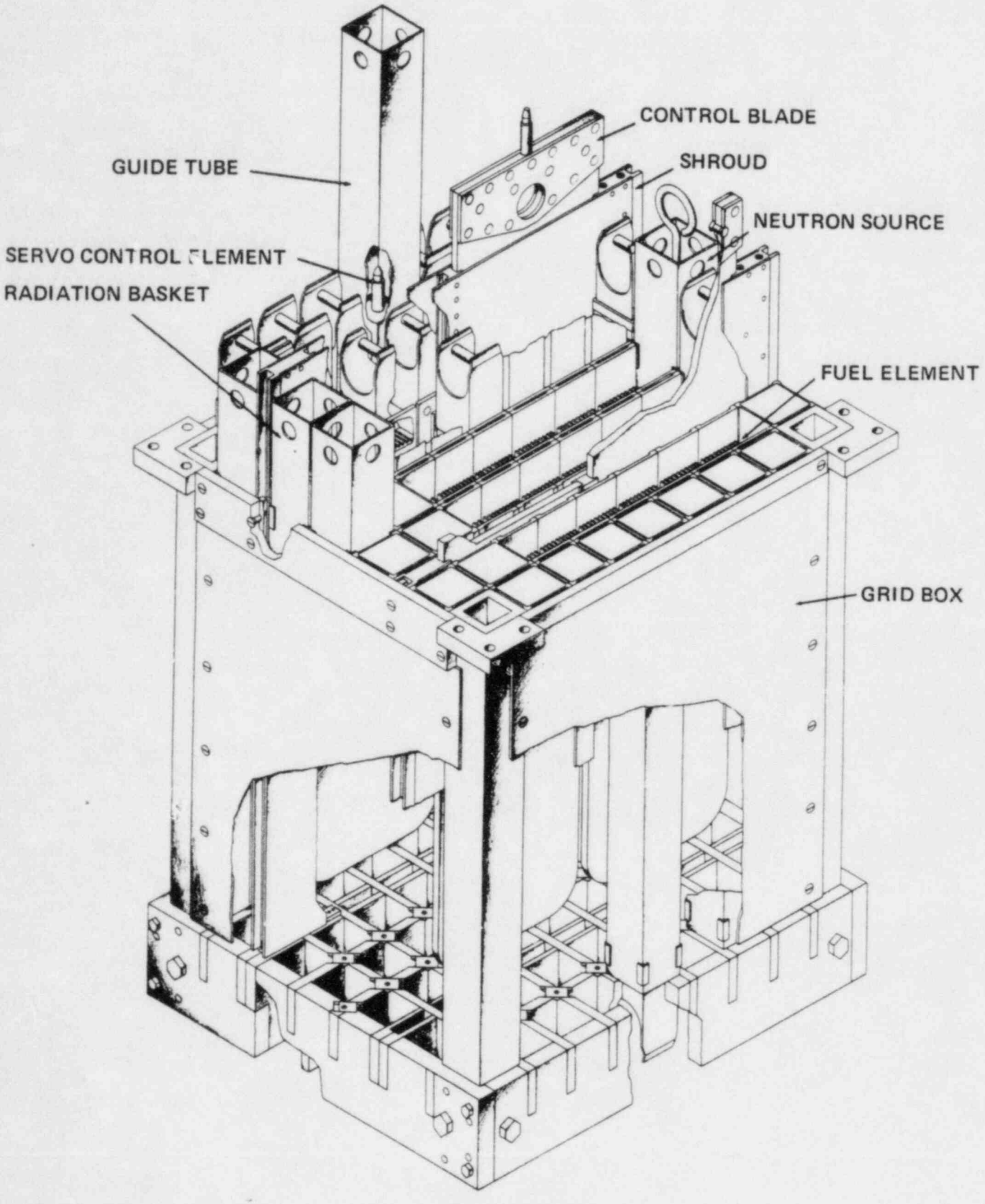
FNR VERTICAL SECTION

Name:	Ford Nuclear Reactor
Location:	University of Michigan Ann Arbor, Michigan
Docket Number:	50-2
License Number:	R-28
Principle Contractor:	Babcock and Wilcox
Date of Initial Criticality:	1957
Rated Power:	2 Mw Increased rated power to 2 Mw in 1963
Description:	Light water moderated, pool type reactor
Fuel:	$U\text{-}Al_x$
enrichment	93%
clad	Aluminum
core loading	4.2 kg.
max. excess reactivity	3.5% $\frac{\Delta k}{k}$
description	25 elements, 10 MTR-curved plates per element
Max. Neutron Flux:	1.4×10^{13} n/cm^2-sec
Control Rods (4):	3 shim safety rods
composition	Boron, stainless steel
individual worth	3% $\frac{\Delta k}{k}$
	1 control rod
composition	stainless steel
worth	0.3% $\frac{\Delta k}{k}$

Moderator:	H_2O
Coolant:	H_2O
Max. Coolant Temp.:	116^oF
Reflector:	D_2O and graphite D_2O reflector is contained in a tank on one side of the pool.
Shield:	Concrete and H_2O
Number of Operators:	SRO - 11, RO - 5
Utilization:	Generated approx. 12,300 Mw-hrs of energy in 1975.



FNR HORIZONTAL SECTION



Rhode Island Open Pool Reactor
Reactor Core

Name:	Rhode Island Open Pool Reactor	
Owner:	Rhode Island Nuclear Science Center	
Location:	Ft. Kearney, Rhode Island	
Docket Number:	50-193	
License Number:	R-95	
Principle Contractor:	General Electric	
Date of Initial Criticality:	1964	
Rated Power:	2 Mw increased the rated power from 1 Mw to 2 Mw in 1970	
Description:	pool type research reactor	
Fuel:	U - Al	
	enrichment	93%
	clad	Aluminum
	core loading	3.7 kg
	max. excess reactivity	4.5% $\frac{\Delta k}{k}$
	description	flat plate MTR-type elements 30 elements, 18 plates per element
Max. Neutron Flux:	5.6×10^{12} n/cm^2-sec	
Control Rods (5):	4 safety blades	
	composition	Boron carbide
	clad	Aluminum
	Total worth	26% $\frac{\Delta k}{k}$
	1 regulating rod	
	square shape	
	composition	Stainless steel

	clad	Aluminum
	worth	$4\% \frac{\Delta k}{k}$
Moderator:	light water (H_2O)	
Coolant:	H_2O	
Max. Coolant Temp.:	125^oF	
Reflector:	Graphite	
Shield:	Concrete	
Number of Operators:	SRO - 2, RO - 4	
Utilization:	Operated approx. 1300 hours between 6/76 and 7/77	

Name:	University of Virginia Reactor (UVAR)
Location:	Charlottesville, Virginia
Docket Number:	50-62
License Number:	R-66
Date of Initial Criticality:	1960
Rated Power:	2 Mw power increased to 2 Mw in 1971
Description:	pool type research reactor capable of either graphite or water reflector
Fuel:	U - Al alloy
	enrichment: 93%
	clad: Aluminum
	critical mass: 2.97 kg (H_2O reflector)
	2.31 kg (graphite reflector)
	description: 16 MTR type fuel elements, 12 plates per element
Max. Neutron Flux:	2.2×10^{13} n/cm^2-sec (H_2O reflector)
	1.7×10^{13} n/cm^2-sec (graphite reflector)
Control Rods (4):	3 control rod fuel elements
	bayonet type
	composition: boron - stainless steel
	individual worth: 3% $\frac{\Delta k}{k}$
	1 regulating rod
	composition: stainless steel
	worth: 0.5% $\frac{\Delta k}{k}$
Moderator:	H_2O

Coolant:	H_2O
Max. Coolant Temp.:	$110^{o}F$
Reflector:	H_2O or graphite
Number of Operators:	SRO - 5, RO - 14
Utilization:	Operated for approximately 408 hours in 1975.

Name:	Union Carbide Nuclear Company Research Reactor (UCNC)	
Location:	Sterling Forest, New York	
Docket Number:	50-54	
License Number:	R-81	
Principle Contractor:	AMF Atomics Inc.	
Date of Initial Criticality:	1961	
Rated Power:	5 Mw	
Description:	Pool type research reactor	
Fuel:	U-Al, U_3O_8 -Al or U-Alx	
	enrichment	93%
	clad	Aluminum
	critical mass	3.8 kg.
	core loading	5.5 kg.
	max. excess reactivity	10.2%
	description	curved MTR fuel plates standard 21 fuel elements
Max. Neutron Flux:	3.1×10^{13} n/cm^2-sec	
Control Rods (6):	5 safety rods	
	thin plates similar to fuel elements	
	composition	Ag-In-Cd
	total worth	16.4%

	1 regulating rod	
	composition	Ag-In-Cd
	worth	0.6%
Moderator:	Light water (H_2O)	
Coolant:	H_2O	
Max. Coolant Temp.:	116° F	
Reflector:	Graphite and H_2O	
Shield:	Lead, concrete and H_2O	
Number of Operators:	SRO-7, RO-12	
Utilization:	Operated approximately 6600 hours in 1977	

Name:	State University of New York PULSTAR Reactor	
Location:	Buffalo, New York	
Docket Number:	50-57	
License Number:	R-77	
Principle Contractor:	AMF Atomics	
Date of Initial Criticality:	1964	
Rated Power:	2 Mw steady state 3000 Mw peak pulse	
Description:	Pulsing research reactor	
Fuel:	UO_2	
	enrichment	6%
	clad	zircaloy
	critical mass	26.65 kg.
	core loading	30 kg.
	max. excess reactivity	allowed 9.3% $\frac{\Delta k}{k}$
		presently 5.55% $\frac{\Delta k}{k}$
	description	25 fuel pins
Max. Neutron Flux:	8×10^{12} n/cm^2-sec	
Control Rods (5):	4 shim safety rods	
	rectangular shape	
	composition	Ag-In-Cd
	individual worth	3% $\frac{\Delta k}{k}$

	1 regulating rod	
	composition	Ag-In-Cd
	worth	$0.6\%\frac{\Delta k}{k}$
Moderator:	Light water (H_2O)	
Coolant:	H_2O	
Reflector:	H_2O	
Shield:	Concrete	
Number of Operators:	SRO-4, RO-12	
Utilization:	Operated approximately 4200 hours in 1977	

Name:	PULSTAR
Owner:	North Carolina State University
Location:	Raleigh, North Carolina
Docket Number:	50-297
License Number:	R-120
Date of Initial Criticality:	1972
Rated Power:	1 Mw steady state 2200 Mw peak power
Description:	Pool type, light water moderated, pulsing research reactor
Fuel:	$U - O_2$ pellets
enrichment	4%
clad	zircaloy
core loading	12.6 kg.
max. excess reactivity	1.035% $\frac{\Delta k}{k}$
description	25 elements, 25 pins per element
Max. Neutron Flux:	6.42×10^{14} n/cm^2-sec
Control Rods(4):	3 shim safety rods
	rectangular shape
composition	Ag-In-Cd
total worth	7.14% $\frac{\Delta k}{k}$

	1 pulse rod	
	composition	Ag-In-Cd
	worth	1.72% $\frac{\Delta k}{k}$
Moderator:	Light water (H_2O)	
Coolant:	H_2O	
Max. Coolant Temp.:	120° F	
Reflector:	H_2O	
Shield:	Concrete	
Number of Operators:	SRO-2, RO-2	
Utilization:	Operated approximately 1600 hours in 1977	

TRIGA REACTORS

A defining feature of the TRIGA reactors is their inherent safety, which results from the large prompt negative temperature coefficient of reactivity of its fuel moderator system. A sudden large increase of reactivity results in an instantaneous increase of the reactor power level to several thousand times the steady state power level. The temperature of the fuel rises with the power level, and as a result of the negative temperature coefficient, the power level returns immediately and automatically to the normal steady state operating range. This large negative temperature effect is a unique feature of Uranium-Zirconium hydride (U-ZrH) fuel. The primary negative effect (90%) is due to the "cell effect" where the neutron scattering, with the bound hydrogen, is temperature dependent. The other 10% is due to doppler broadening.

With a 2.1% $\frac{\Delta k}{k}$ reactivity addition, the resulting power pulse would reach a peak power of approximately 2000 Mw within 2.8 msec and result in a total energy release of approximately 24 Mw-sec. The peak fuel temperatures in this instance approach 450°C. The maximum allowable temperatures for TRIGA and TRIGA-FLIP fuel are 1000°C and 1150°C respectively.

TRIGA reactors are designed by General Atomic.

Name:	University of Illinois Low Power Reactor Assembly (LOPRA)	
Location:	Urbana, Illinois	
Docket Number:	50-356	
License Number:	R-117	
Date of Initial Criticality:	1972	
Rated Power:	10 kw	
Fuel:	U-ZrH	
	enrichment	20%
	clad	stainless steel
	core loading	≈ 2.0 kg
	max. excess reactivity	$0.06
	max. fuel temp.	550°C
	description	TRIGA type fuel; three types of fuel:
		standard U-$ZrH_{1.7}$
		low hydride U-$ZrH_{1.0}$
		Sandia
Control Rods (3):	2 safety rods	
	composition	cadmium
	clad	aluminum
	total worth	$10.00
	poison rod	
	same composition and clad	
	worth	$1.35

Moderator:	Zirconium hydride and H_2O
Coolant:	Light Water (H_2O)
Reflector:	Graphite and H_2O
Shield:	Concrete and H_2O
Number of Operators:	SRO-1, RO-0
Utilization:	Operated approximately 25 hours between 6/76 and 6/77
Note:	The LOPRA is located in the bulk shielding tank of the Illinois Advanced TRIGA reactor and therefore neutron coupling occurs.

TRIGA CONVERSION

Name:	Aerojet-General Nucleonics Industrial Reactor (AGNIR)
Location:	San Ramon, California
Docket Number:	50-228
License Number:	R-98
Date of Initial Criticality:	1965
Rated Power:	250 kw steady state TRIGA conversion with no pulsing capability
Description:	Pool reactor with TRIGA-type fuel
Fuel:	$U\text{-}ZrH_{1.0}$
	enrichment 20%
	clad Aluminum
	critical mass 2265 grams
	core loading 2.3 kg.
	max. excess reactivity 2.25% $\frac{\Delta k}{k}$
	description TRIGA-type fuel elements
Max. Neutron Flux:	6.7×10^{12} n/cm^2-sec
Control Rods (3):	composition boron carbide powder
	clad Aluminum
	worth - shim rod 2.6% $\frac{\Delta k}{k}$
	safety rod 2.6% $\frac{\Delta k}{k}$
	regulating rod 0.75% $\frac{\Delta k}{k}$
Moderator:	Zirconium-Hydride and H_2O

Coolant:	H_2O
Max. Coolant Temp.:	130° F
Reflector:	Graphite and H_2o
Shield:	Concrete and H_2O
Number of Operators:	SRO-4, RO-0
Utilization:	Operated for approximately 880 hours between 6/74 and 6/75

Name:	Maryland University TRIGA Reactor (MUTR)
Location:	College Park, Maryland
Docket Number:	50-166
License Number:	R-70
Date of Initial Criticality:	1960 converted to TRIGA fuel in 1973
Rated Power:	250 kw steady state no pulsing capability
Description:	Pool-type, TRIGA conversion research reactor
Fuel:	U-ZrH
	enrichment 20%
	clad stainless steel
	core loading 3.4 kg
	max. fuel temp. 1000°C
	max. excess reactivity 2.5% $\frac{\Delta k}{k}$
	description 20 standard clusters, 4 fuel rods per cluster
Max. Neutron Flux:	1.2×10^{13} n/cm^2-sec
Control Rods (3):	3 rod clusters
	1 poison rod per cluster
	composition borated graphite
	total worth 8.27% $\frac{\Delta k}{k}$
Moderator:	Zirconium-Hydride and H_2O
Coolant:	H_2O
Max. Coolant Temp.:	110°F

Reflector:	Graphite and H_2O
Shield:	Concrete and H_2O
Number of Operators:	SRO - 7, RO - 2
Utilization:	Operated 101 times generating 2.93 Mw-hrs of energy between 6/76 and 6/77.

Name:	Texas A&M Nuclear Science Center Reactor (NSCR)
Location:	College Station, Texas
Docket Number:	50-128
License Number:	R-83
Date of Initial Criticality:	1968 converted to TRIGA fuel in 1968 added TRIGA-FLIP fuel in 1973
Rated Power:	1 Mw steady state 2000 Mw peak pulse
Description:	Pool-type TRIGA conversion
Fuel:	combination of TRIGA and TRIGA-FLIP fuel
	enrichment 20% 70%
	clad stainless steel
	critical mass 3.3 kg
	core loading 3.8 kg
	max. fuel temp. 525°C
	max. excess reactivity 4.9% $\frac{\Delta k}{k}$
	step insertion \$2.70 (1.89% $\frac{\Delta k}{k}$)
Max. Neutron Flux:	3×10^{13} n/cm^2-sec (steady state) 6×10^{16} n/cm^2-sec (pulse mode)
Control Rods (5):	3 shim safety rods
	1 regulating rod
	composition boron carbide
	clad Aluminum
	total worth 6.9% $\frac{\Delta k}{k}$
	1 transient rod
	composition borated graphite
	clad Aluminum
	worth 2.9% $\frac{\Delta k}{k}$

Moderator:	Zirconium-Hydride and H_2O
Coolant:	H_2O
Reflector:	Graphite
Shield:	Concrete and H_2O
Number of Operators:	SRO - 6, RO - 3
Utilization:	Operated approximately 2000 hours in 1973

Name:	Washington State University TRIGA Reactor		
Location:	Pullman, Wash.		
Docket Number:	50-27		
License Number:	R-76		
Date of Initial Criticality:	1962		
Rated Power:	1 Mw steady state 2000 Mw peak pulse		
Description:	TRIGA Conversion in 1967		
Fuel:	Combination	TRIGA and TRIGA-FLIP $U\text{-}ZrH_{1.7}$ $U\text{-}ZrH_{1.6}$	
	enrichment	20% 70%	
	clad	stainless steel	
	core loading	3.7 kg.	
	max. fuel temp.	861°C	
	max. excess reactivity	4.9% $\frac{\Delta k}{k}$	
	step insertion	1.75% $\frac{\Delta k}{k}$	
	description	modified TRIGA Mark III elements	
Max Neutron Flux:			
Control Rods (5):	3 control blades		
	composition	Boral	
	clad	Aluminum	
	total worth	6.1% $\frac{\Delta k}{k}$	
	1 regulating blade		
	composition	stainless steel	
	worth	0.3% $\frac{\Delta k}{k}$	

	1 transient rod	borated graphite
	worth	2.1% $\frac{\Delta k}{k}$
Moderator:	Zirconium-Hydride and H_2O	
Coolant:	H_2O	
Max. Coolant Temp:	110^oF	
Reflector:	Graphite and H_2O	
Shield:	Concrete and H_2O	
Number of Operators:	SRO-2, RO-4	
Utiiization:	Generated approx. 1000 Mw-hrs. of energy between 6/76 and 6/77	

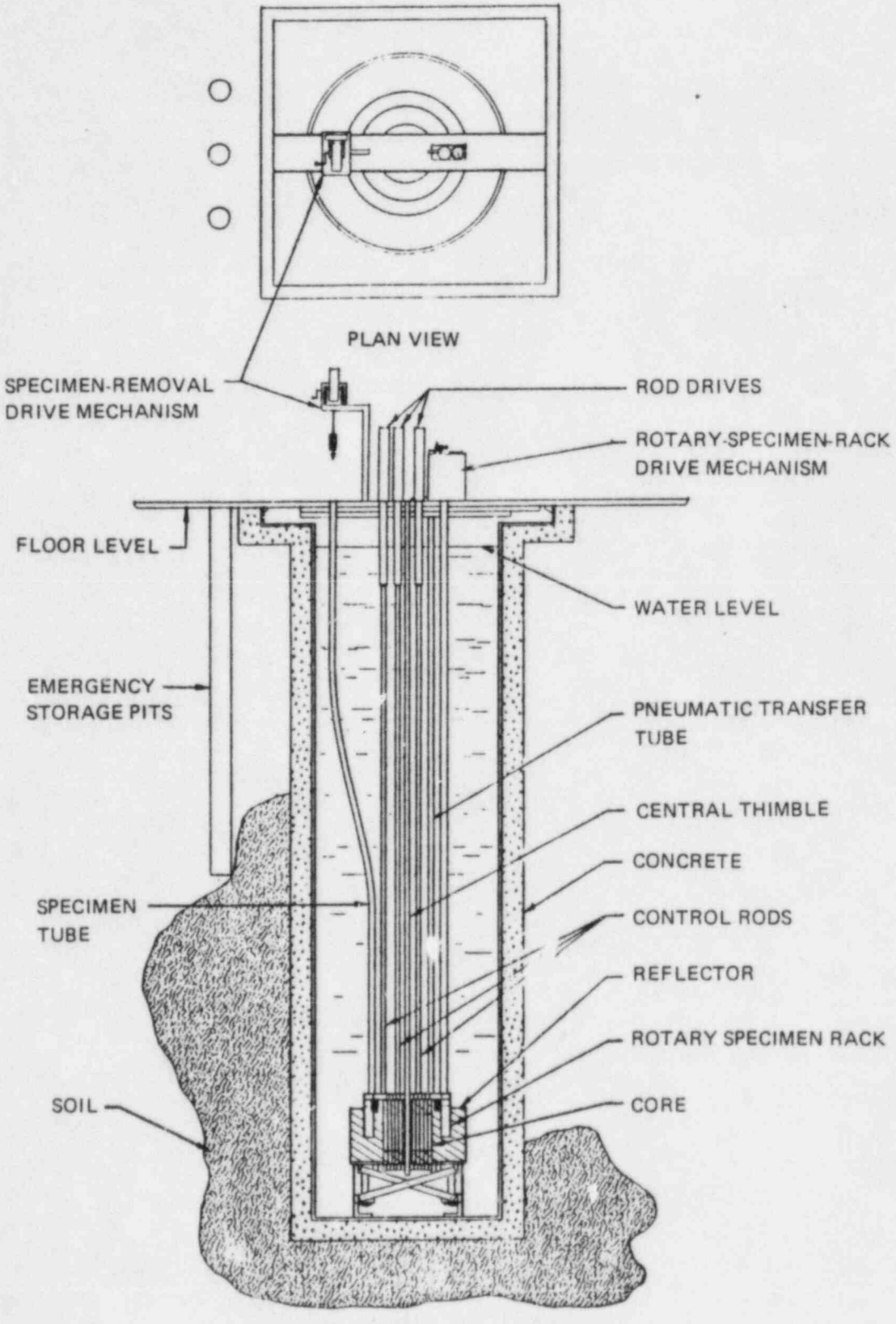
Name:	University of Wisconsin Nuclear Reactor
Location:	Madison, Wisconsin
Docket Number:	50-156
License Number:	R-74
Date of Initial Criticality:	1967
Rated power:	1 Mw steady state 2000 Mw peak pulse square-wave operation
Description:	Converted in 1967 to a TRIGA Reactor with pulsing capability
Fuel:	Combination of TRIGA and TRIGA-FLIP
enrichment	20% 70%
clad	stainless steel
core loading	6.4 kg.
max. excess reactivity	4.9% $\frac{\Delta k}{k}$
description	TRIGA, TRIGA-FLIP or a combination. Four element clusters. 25 clusters in core
Max. Neutron Flux:	3.2×10^{13} n/cm^2-sec steady state 6.5×10^{16} n/cm^2-sec peak pulse
Control Rods (5):	3 safety blades
composition	Boral and stainless steel
1 regulating blade	
composition	stainless steel
Total worth	11% $\frac{\Delta k}{k}$
1 Transient rod	
composition	Borated graphite
worth	2.9% $\frac{\Delta k}{k}$

Moderator:	Zirconium-Hydride and H_2O
Coolant:	H_2O
Max. Coolant Temp:	$130^{o}F$
Reflector:	Graphite and H_2O
Shield:	Concrete and H_2O
Number of Operators:	
Utilization:	Operated 121 times for approx. 470 hours and pulsed 59 times between 6/76 and 6/77

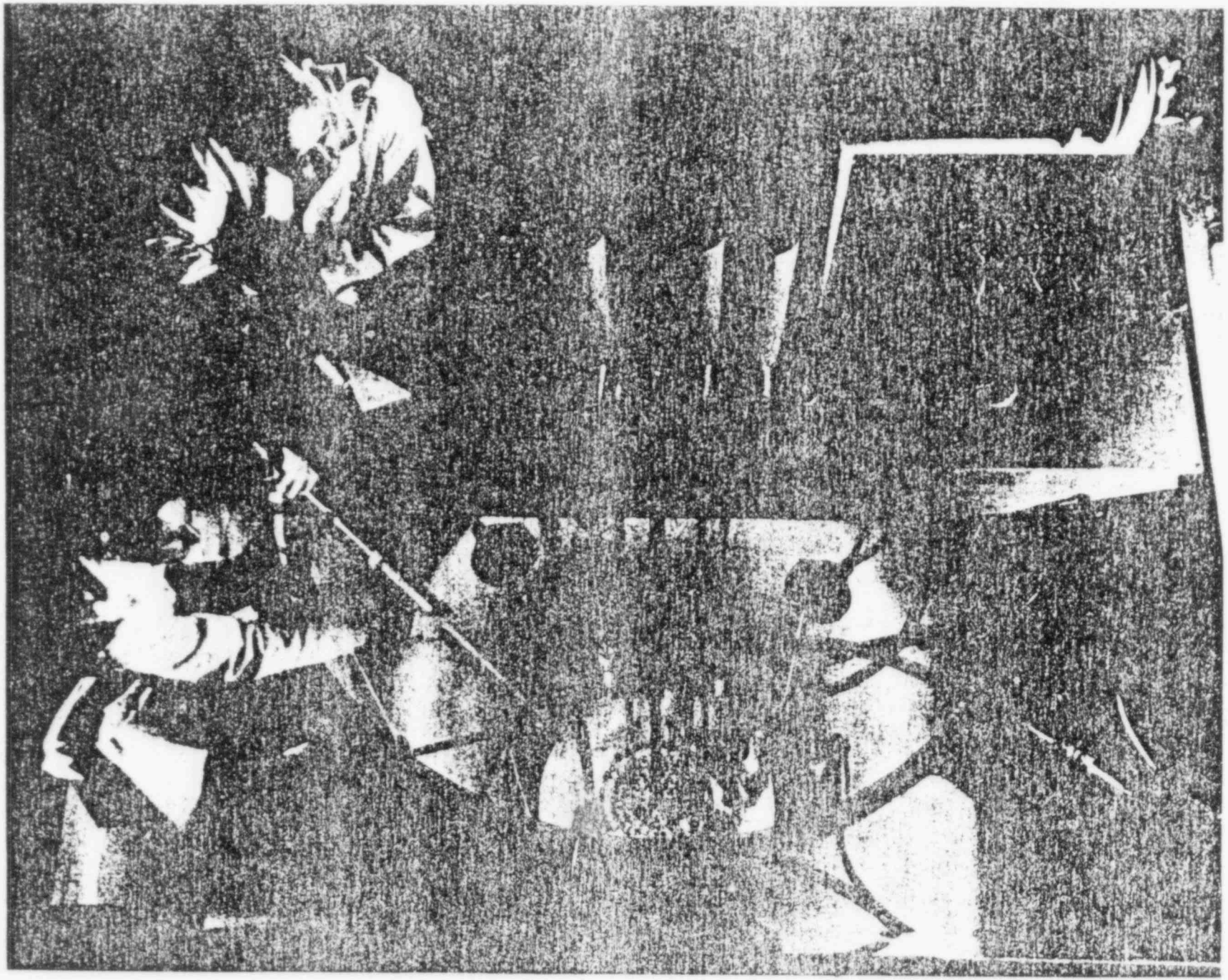
MARK I

Name:	V. A. Hospital TRIGA Reactor	
Location:	Omaha, Nebraska	
Docket Number:	50-131	
License Number:	R-57	
Date of Initial Criticality:	1959	
Rated power:	18 kw steady state no pulsing ability increase in rated power from 10 kw to 18 kw in 1963	
Description:	Tank type reactor TRIGA fuel	
Fuel:	$U\text{-}ZrH_{1.0}$	
	enrichment	20%
	clad	Aluminum
	critical mass	1.9 kg.
	core loading	2 kg.
	max. excess reactivity	0.7% $\frac{\Delta k}{k}$
Max. Neutron Flux:	$4 \times 10^{n/cm^2\text{-sec}}$	
Control Rods (3):	composition	boron carbide powder
	clad	Aluminum
	worth - safety rod	2% $\frac{\Delta k}{k}$
	shim rod	2% $\frac{\Delta k}{k}$
	regulating rod	0.4% $\frac{\Delta k}{k}$

Moderator:	Zirconium-Hydride and H_2O
Coolant:	H_2O
Max. Coolant Temp.:	35^oC
Reflector:	Graphite encased in Aluminum
Shield:	Concrete and H_2O
Number of Operators:	SRO-2, RO-0



TRIGA MARK I Reactor and pit
Va. Hospital (18 kw)



MI-70

View into TRIGA Mark I reactor - Veterans Administration Hospital (Omaha, Nebraska)

Name:	Dow Chemical Co. TRIGA MARK I Nuclear Reactor	
Location:	Midland, Michigan	
Docket Number:	50-264	
License Number:	R-108	
Date of Initial Criticality:	1967	
Rated Power:	100 kw steady state no pulsing capability	
Description:	TRIGA MARK I Research Reactor	
Fuel:	$U\text{-}ZrH_{1.0}$	
	enrichment	20%
	clad	Aluminum and/or Stainless Steel
	critical mass	1.9 kg
	core loading	2.3 kg
	max. excess reactivity	1.5% $\frac{\Delta k}{k}$
Max. Neutron Flux:	4×10^{12} n/cm^2-sec	
Control Rods (3):	2 safety rods	
	composition	boron carbide
	clad	Aluminum
	individual worth	2.6% $\frac{\Delta k}{k}$
	1 regulating rod	
	composition	boron carbide
	clad	Aluminum
	worth	0.8% $\frac{\Delta k}{k}$

Moderator:	Zirconium-Hydride and H_2O
Coolant:	H_2O
Reflector:	Graphite
Shield:	Concrete
Number of Operators:	SRO-6, RO-0

Name:	Dow Chemical Co. TRIGA MARK I Nuclear Reactor	
Location:	Midland, Michigan	
Docket Number:	50-264	
License Number:	R-108	
Date of Initial Criticality:	1967	
Rated Power:	100 kw steady state no pulsing capability	
Description:	TRIGA MARK I Research Reactor	
Fuel:	$U\text{-}ZrH_{1.0}$	
	enrichment	20%
	clad	Aluminum and/or Stainless Steel
	critical mass	1.9 kg
	core loading	2.3 kg
	max. excess reactivity	1.5% $\frac{\Delta k}{k}$
Max. Neutron Flux:	4×10^{12} n/cm^2-sec	
Control Rods (3):	2 safety rods	
	composition	boron carbide
	clad	Aluminum
	individual worth	2.6% $\frac{\Delta k}{k}$
	1 regulating rod	
	composition	boron carbide
	clad	Aluminum
	worth	0.8% $\frac{\Delta k}{k}$

Moderator:	Zirconium-Hydride and H_2O
Coolant:	H_2O
Reflector:	Graphite
Shield:	Concrete
Number of Operators:	SRO-6, RO-0

Name:	University of Utah TRIGA Reactor
Location:	Salt Lake City, Utah
Docket Number:	50-407
License Number:	R-126
Date of Initial Criticality:	1975
Rated Power:	100 kw steady state No pulsing capabilities
Description:	TRIGA MARK I Below ground
Fuel:	$U\text{-}ZrH_{1.0}$ or $U\text{-}ZrH_{1.7}$

enrichment	20%
clad	Aluminum and/or stainless steel
critical mass	2.4 kg.
core loading	2.8 kg.
max. fuel temp.	530° C
max. excess reactivity	2.25% $\frac{\Delta k}{k}$
description	TRIGA MARK I fuel elements

Control Rods (3):

composition	boron carbide
clad	Aluminum
worth - shim	2% $\frac{\Delta k}{k}$
safety	2% $\frac{\Delta k}{k}$
regulating	0.5% $\frac{\Delta k}{k}$

Moderator:	Zirconium-Hydride and H_2O
Coolant:	H_2O
Max. Coolant Temp.:	110° F
Reflector:	H_2O and/or graphite elements and/or D_2O
Shield:	Concrete, sand, and H_2O
Number of Operators:	SRO-1, RO-3
Utilization:	Operated for 40 hours during first year of operation

Name:	The Reed College Reactor Facility	
Location:	Portland, Oregon	
Docket Number:	50-288	
License Number:	R-112	
Date of Initial Criticality:	1968	
Rated Power:	250 kw steady state no pulsing capability	
Description:		
Fuel:	$U\text{-}ZrH_{1.0}$	
	enrichment	20%
	clad	Aluminum and/or stainless steel
	critical mass	≈ 2.1 kg
	max. excess reactivity	2.25% $\frac{\Delta k}{k}$
	description	TRIGA MARK I Fuel-Moderator elements
Max. Neutron Flux:	1×10^{13} n/cm^2-sec	
Control Rods (3):	2 safety rods	
	composition	boron carbide
	clad	Aluminum
	individual worth	2.8% $\frac{\Delta k}{k}$
	1 regulating rod	
	composition	boron carbide
	clad	Aluminum
	worth	1.0% $\frac{\Delta k}{k}$

Moderator:	Zirconium-Hydride and H_2O
Coolant:	H_2O
Reflector:	graphite
Shield:	H_2O and Concrete
Number of Operators:	SRO - 15, RO - 10

Name:	University of California, Irvine Nuclear Reactor Facility
Location:	Irvine, California
Docket Number:	50-326
License Number:	R-116
Date of Initial Criticality:	1969
Rated Power:	250 kw steady state 250 Mw peak pulse
Description:	TRIGA MARK I Nuclear Reactor
Fuel:	$U\text{-}ZrH_{1.7}$
	enrichment 20%
	clad stainless steel
	critical mass 2.3 kg
	core loading 2.7 kg
	max. excess reactivity $2.1\% \frac{\Delta k}{k}$
	step insertion $2.1\% \frac{\Delta k}{k}$
Max. Neutron Flux:	1×10^{13} n/cm^2-sec (steady state)
	1×10^{16} n/cm^2-sec (peak pulse)
Control Rods (4):	2 fuel follower rods
	composition borated graphite
	clad stainless steel
	individual worth $3.40
	2 transient rods
	composition borated graphite
	clad Aluminum
	worth - adjustable rod - $2.30 fast rod - $0.50

Moderator:	Zirconium-Hydride and H_2O
Coolant:	H_2O
Reflector:	Graphite
Shield:	Concrete and H_2O
Number of Operators:	SRO - 5, RO - 2
Utilization:	Operated approximately 663 hours between 6/76 and 6/77.

Name:	University of Texas TRIGA Reactor	
Location:	Austin, Texas	
Docket Number:	50-192	
License Number:	R-92	
Date of Initial Criticality:	1963	
Rated Power:	250 kw steady state 250 Mw peak pulse increase in rated power from 10 kw to 250 kw (steady state) in 1968.	
Description:	TRIGA MARK I type	
Fuel:	U-ZrH	
	enrichment	20%
	clad	Aluminum
	core loading	2.3 kg
	max. fuel temp.	$450^{o}C$
	max. excess reactivity	$2.25\% \frac{\Delta k}{k}$
Max. Neutron Flux:	1.3×10^{13} n/cm^2-sec	
Control Rods (3):	2 safety rods	
	composition	boron carbide powder
	clad	Aluminum
	total worth	$3.5\% \frac{\Delta k}{k}$
	1 transient rod	
	composition	borated graphite
	clad	Aluminum
	worth	$1.5\% \frac{\Delta k}{k}$

Moderator:	Zirconium-Hydride and H_2O
Coolant:	H_2O
Max. Coolant Temp.:	120^oF
Reflector:	Graphite and H_2O
Shield:	Concrete and H_2O
Number of Operators:	SRO - 2, RO - 2
Utilization:	Operated approximately 140 hours in 1977.

Name:	University of Arizona TRIGA Reactor
Location:	Tucson, Arizona
Docket Number:	50-113
License Number:	R-52
Date of Initial Criticality:	1958
Rated Power:	250 kw steady state 300 Mw peak pulse
Description:	TRIGA MARK I Reactor
Fuel:	$U\text{-}ZrH_{1.0}$
	enrichment 20%
	clad stainless steel
	critical mass 1.9 kg.
	max. fuel temp. 700° C
	step insertion 1.5% $\frac{\Delta k}{k}$
Max. Neutron Flux:	1×10^{13} n/cm^2-sec (steady state)
	1×10^{16} n/cm^2-sec (peak pulse)
Control Rods (3):	composition boron carbide
	worth: safety rod 3% $\frac{\Delta k}{k}$
	shim rod 2% $\frac{\Delta k}{k}$
	transient 2.5% $\frac{\Delta k}{k}$
Moderator:	Zirconium Hydride and H_2O

Coolant:	H_2O
Max. Coolant Temp,:	70° F
Reflector:	Graphite
Shield:	H_2O, graphite, concrete and soil
Number of Operators:	SRO-5, RO-5
Utilization:	Operated approximately 294 hours and generated 17,000 kw-hrs of energy between 6/76 and 6/77

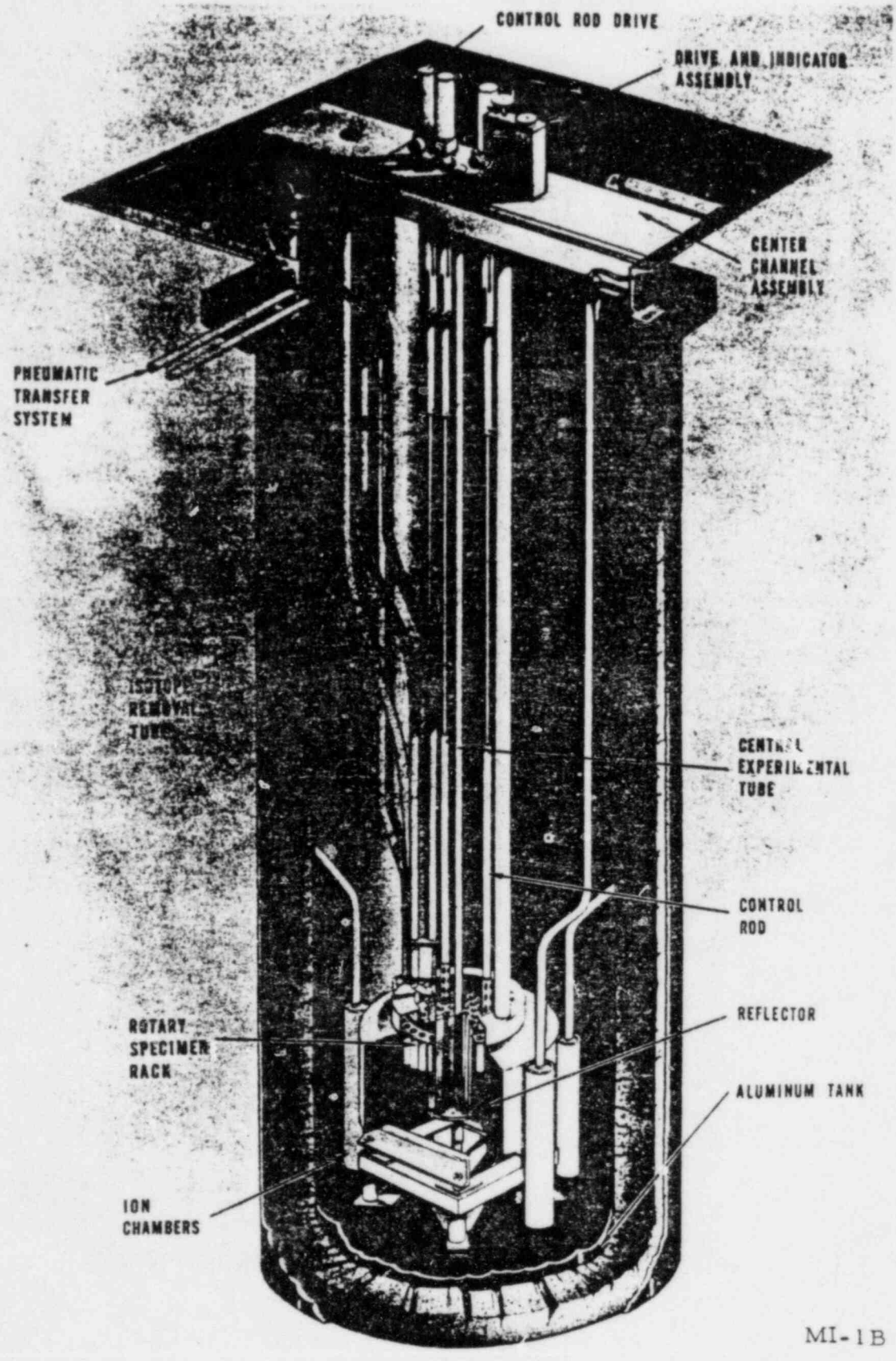
Name:	Torrey Pines TRIGA MARK I Reactor
Location:	San Diego, California
Docket Number:	50-89
License Number:	R-38
Date of Initial Criticality:	1958
Rated Power:	250 kw steady state 800 Mw peak pulse
Description:	Below ground, TRIGA MARK I Reactor
Fuel:	$U\text{-}ZrH_x$
	enrichment 20%
	clad Hastaloy-X or Incaloy-80
	core loading ≈ 2.3 kg
	max. fuel temp. 530°C
	max. excess reactivity 2.25% $\frac{\Delta k}{k}$
	step insertion 1.6% $\frac{\Delta k}{k}$
	description 64 fuel elements
Max. Neutron Flux:	1.2×10^{13} n/cm^2-sec (steady state) 1.2×10^{16} n/cm^2-sec (peak pulse)
Control Rods (4):	3 control rods
	1 transient rod
	composition borated graphite
	total worth $10.73
Moderator:	Zirconium-Hydride and H_2O
Coolant:	H_2O
Max. Coolant Temp.:	65°C

Reflector:	Graphite clad in Aluminum
Shield:	Concrete and H_2O
Number of Operators:	SRO - 2, RO - 2
Utilization:	Generated approximately 28 Mw-hrs. of energy in 1977.

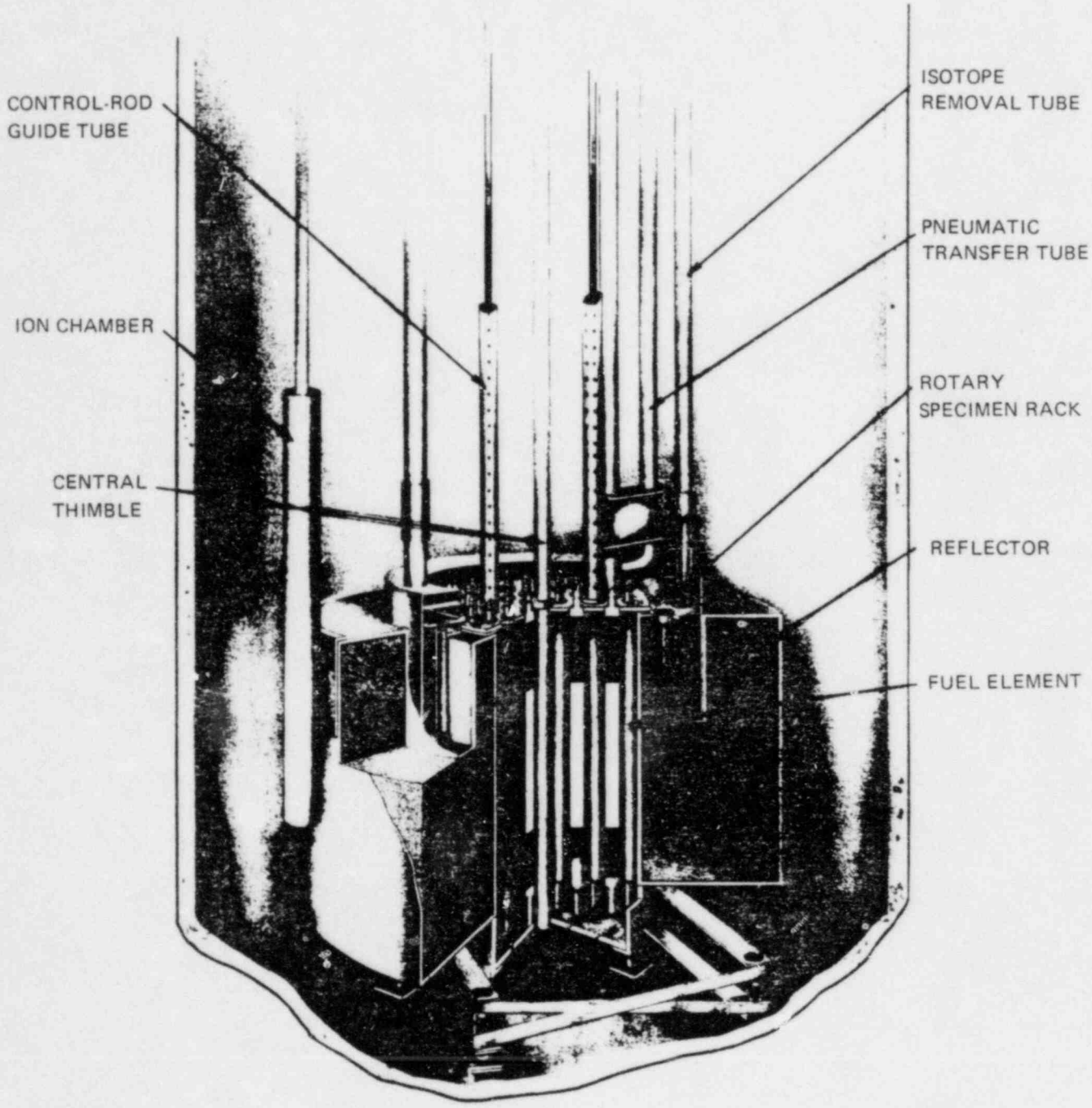
Name:	U. S. Geological Survey TRIGA Reactor
Location:	Jefferson County, Colorado
Docket Number:	50-274
License Number:	R-113
Date of Initial Criticality:	1969
Rated Power:	1 Mw steady state 1200 Mw peak pulse square-wave operation
Description:	TRIGA MARK I Nuclear Research Reactor
Fuel:	$U\text{-}ZrH_{1.7}$
	enrichment 20%
	clad stainless steel
	critical mass 2.86 kg
	max. excess reactivity 4.9% $\frac{\Delta k}{k}$
	reactivity insertion 2.1% $\frac{\Delta k}{k}$
	description TRIGA MARK III fuel-moderator elements
Max. Neutron Flux:	3×10^{13} n/cm^2-sec (steady state)
	6×10^{16} n/cm^2-sec (peak pulse)
Control Rods (7):	3 fuel follower rods
	composition borated graphite
	clad stainless steel
	2 safety rods
	individual worth 1.8% $\frac{\Delta k}{k}$
	1 regulating rod
	worth 2.7% $\frac{\Delta k}{k}$

Control Rods (continued):	1 transient rod	
	composition	borated graphite
	clad	Aluminum
	worth	2.1% $\frac{\Delta k}{k}$
Moderator:	Zirconium-Hydride and H_2O	
Coolant:	H_2O	
Max. Coolant Temp:	60^oC	
Reflector:	H_2O and graphite	
Shield:	H_2O and concrete	
Number of Operators:	SRO - 3, RO - 0	
Utilization:	Operated for approximately 1300 hours in 1976.	

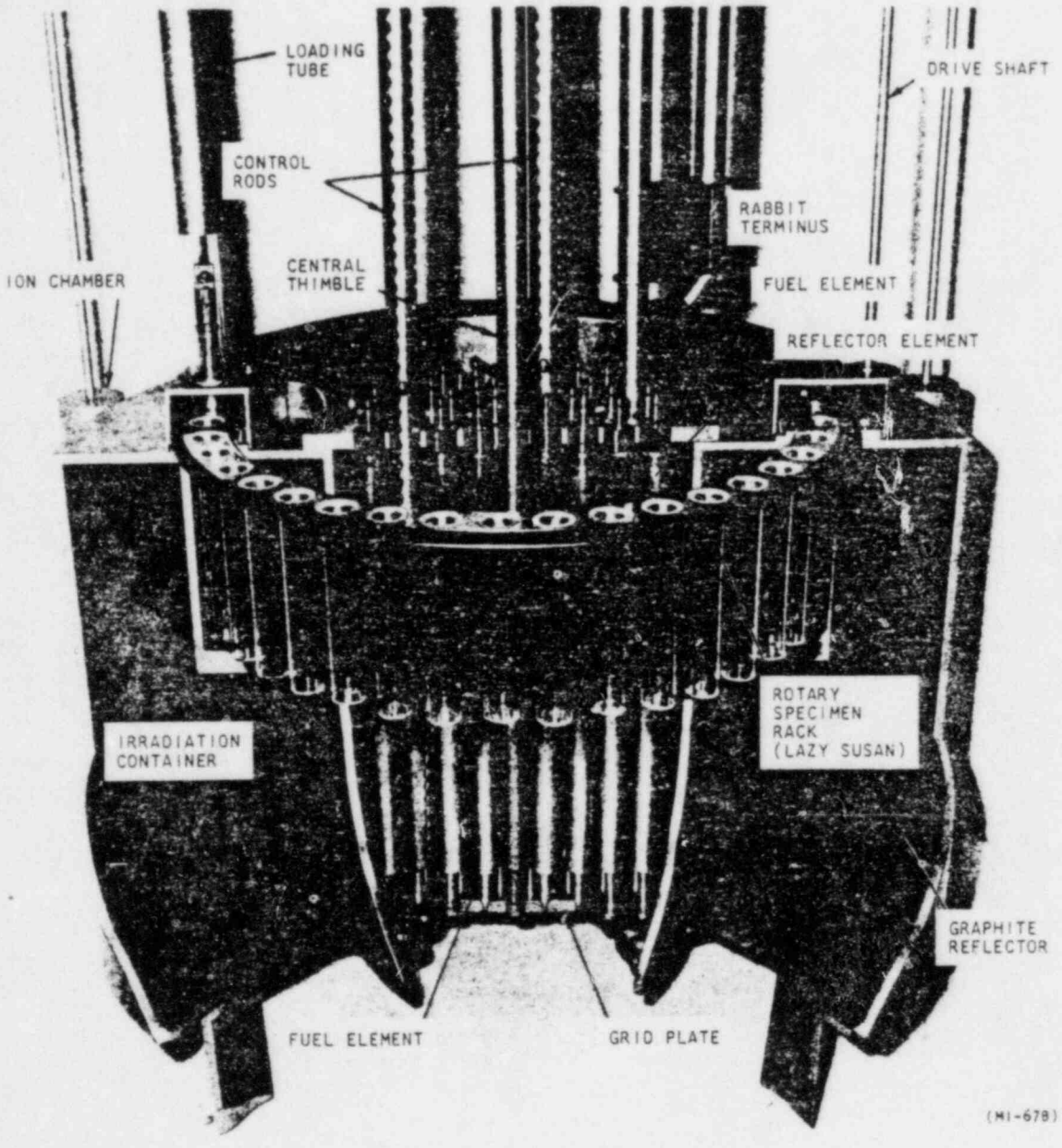
MARK II



Cutaway of TRIGA Mark I reactor installation

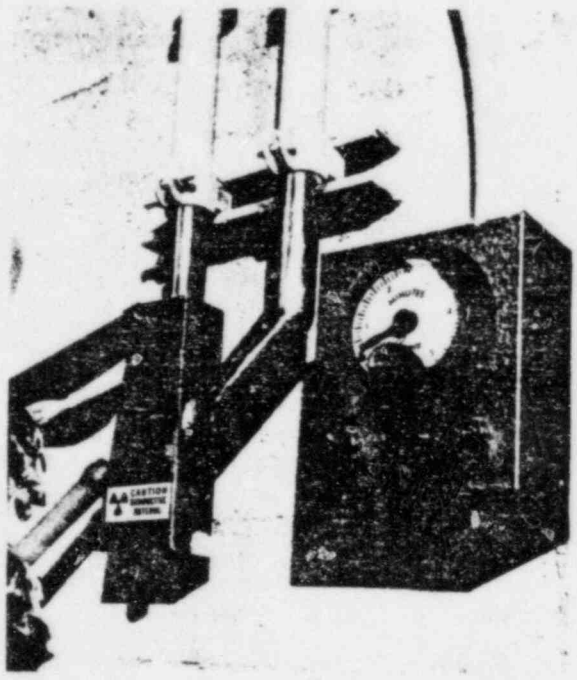


TRIGA MARK I Core and Reflector Assembly

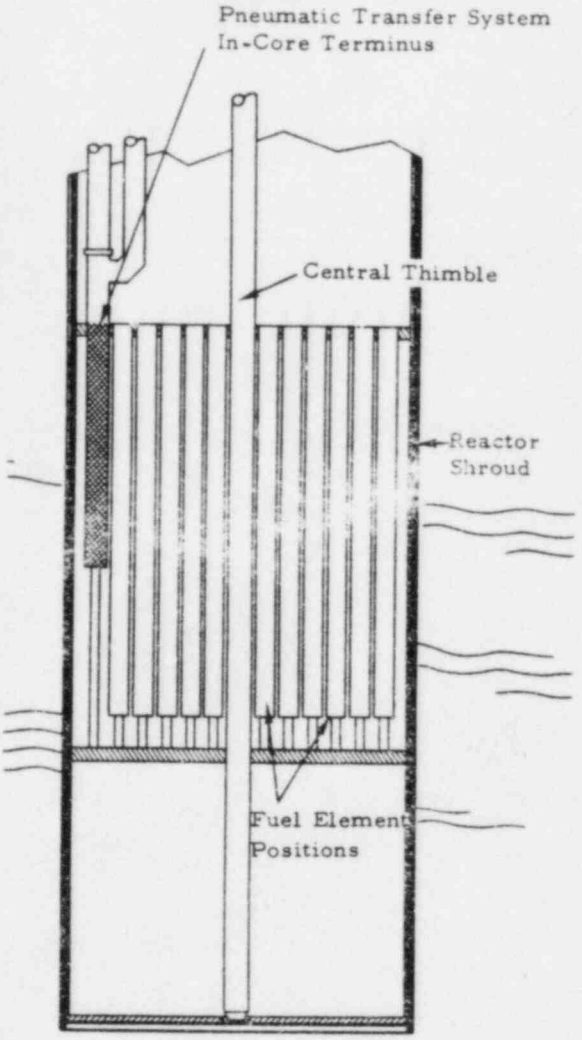


Cutaway view of reflector and rotary specimen rack surrounding TRIGA Mark I or Mark II core

"Rabbit" can accommodate samples up to 3.8 in. and 0.5 in. in diameter



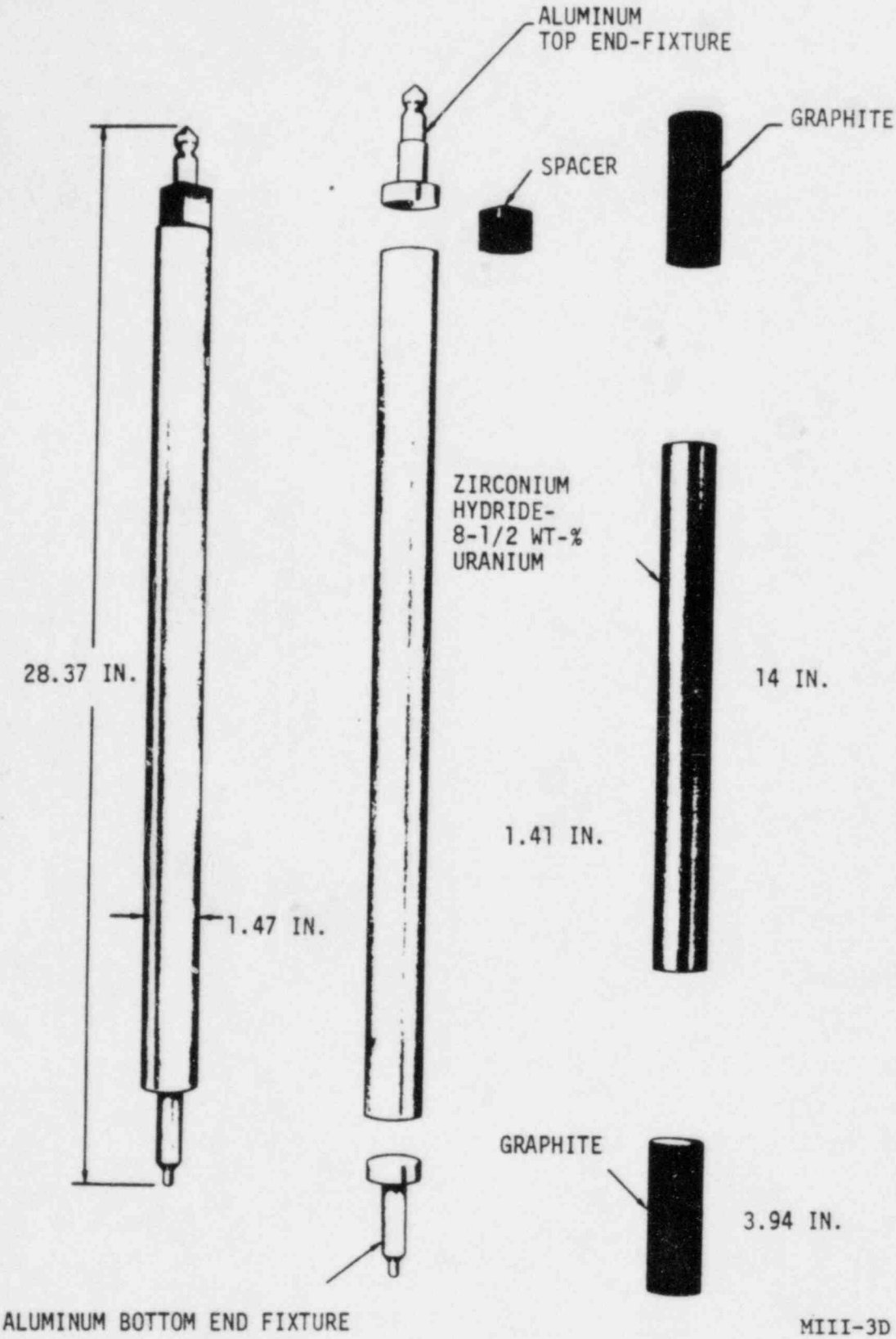
Wall-mounted laboratory terminus and convenient control assembly



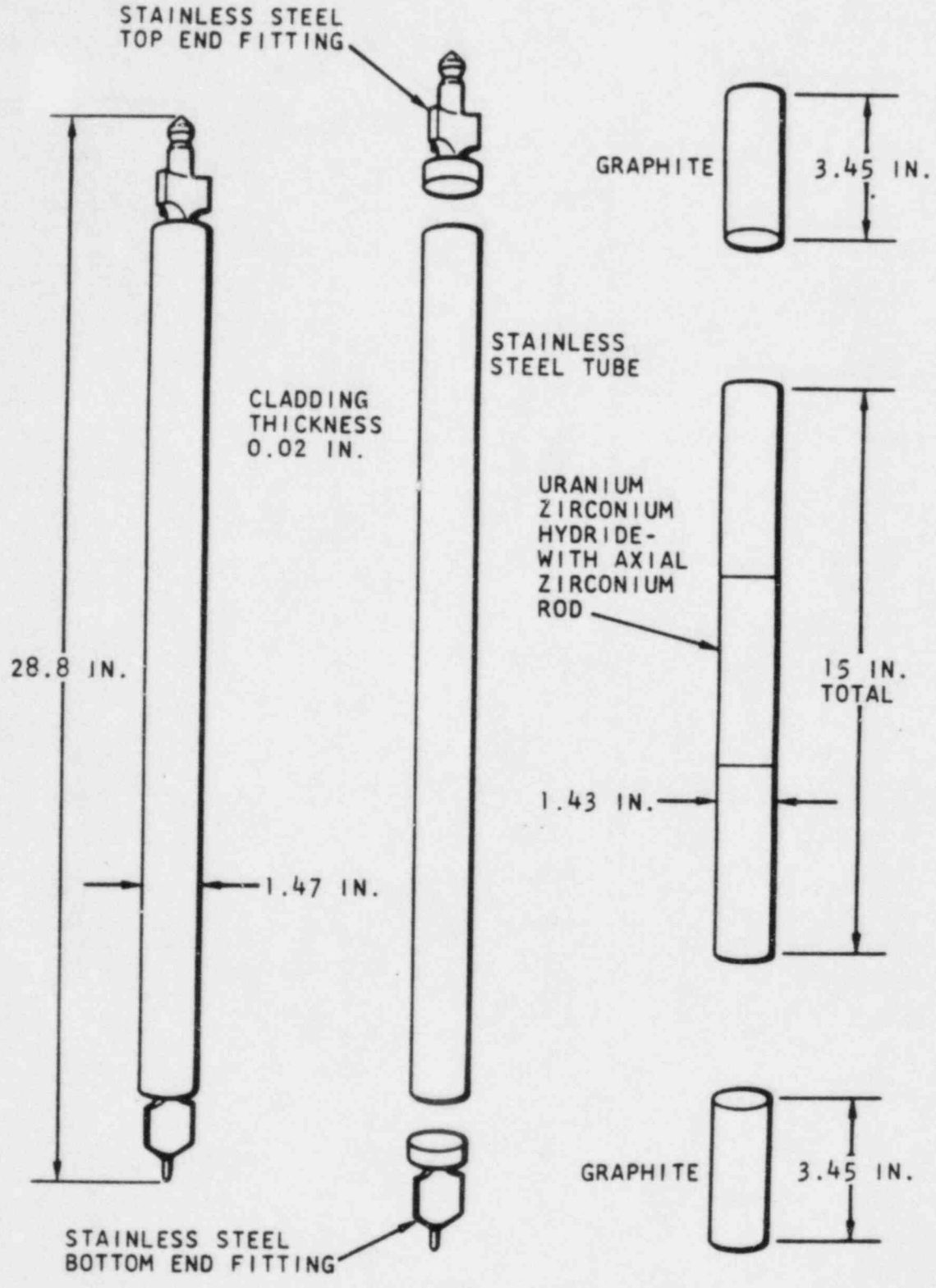
Reactor core and shroud showing in-core terminus

MIS-48

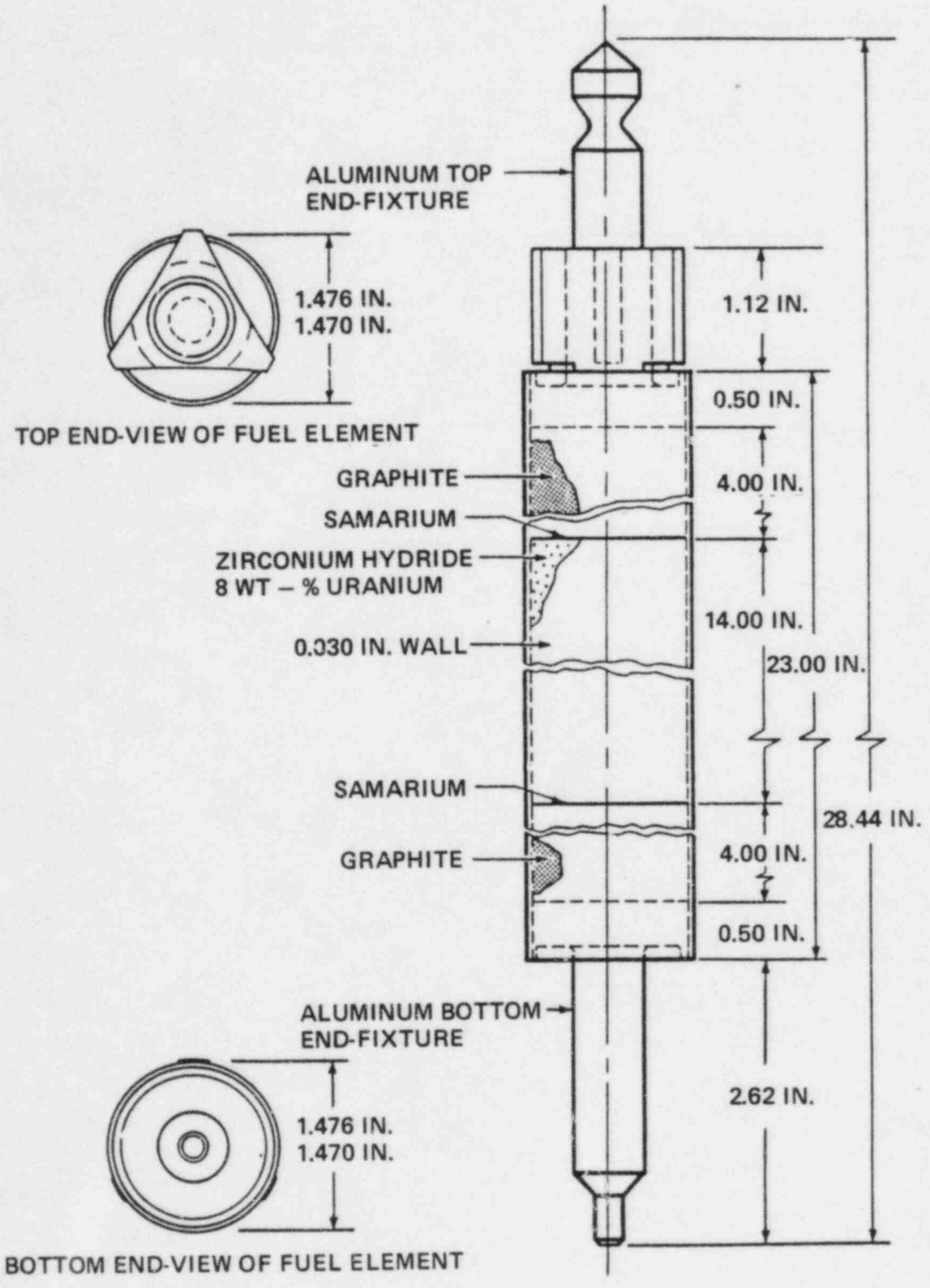
Pneumatic Transfer System



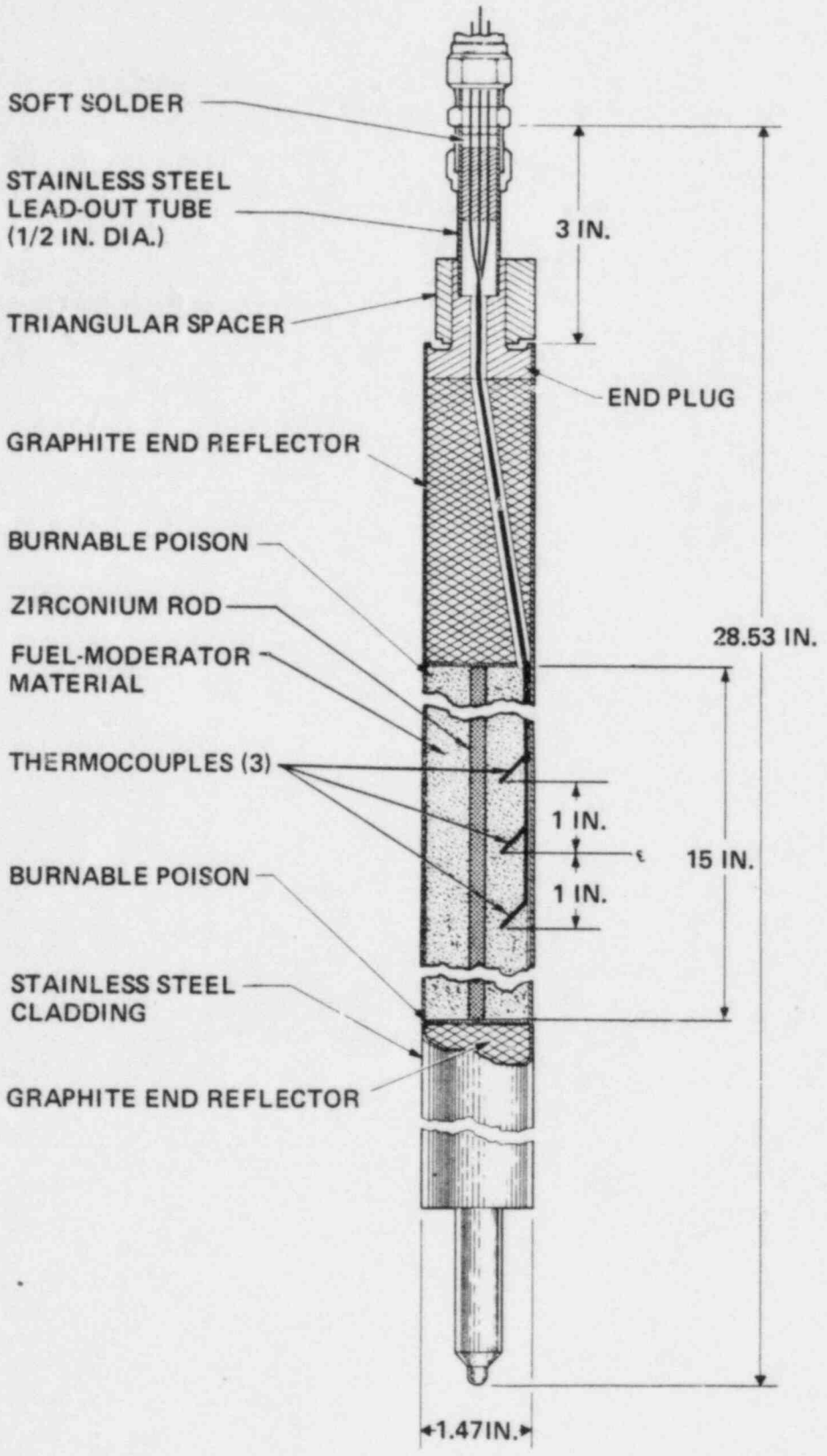
$U\text{-}ZrH_{1.0}$ fuel element. Can be used up to 250 kW steady state



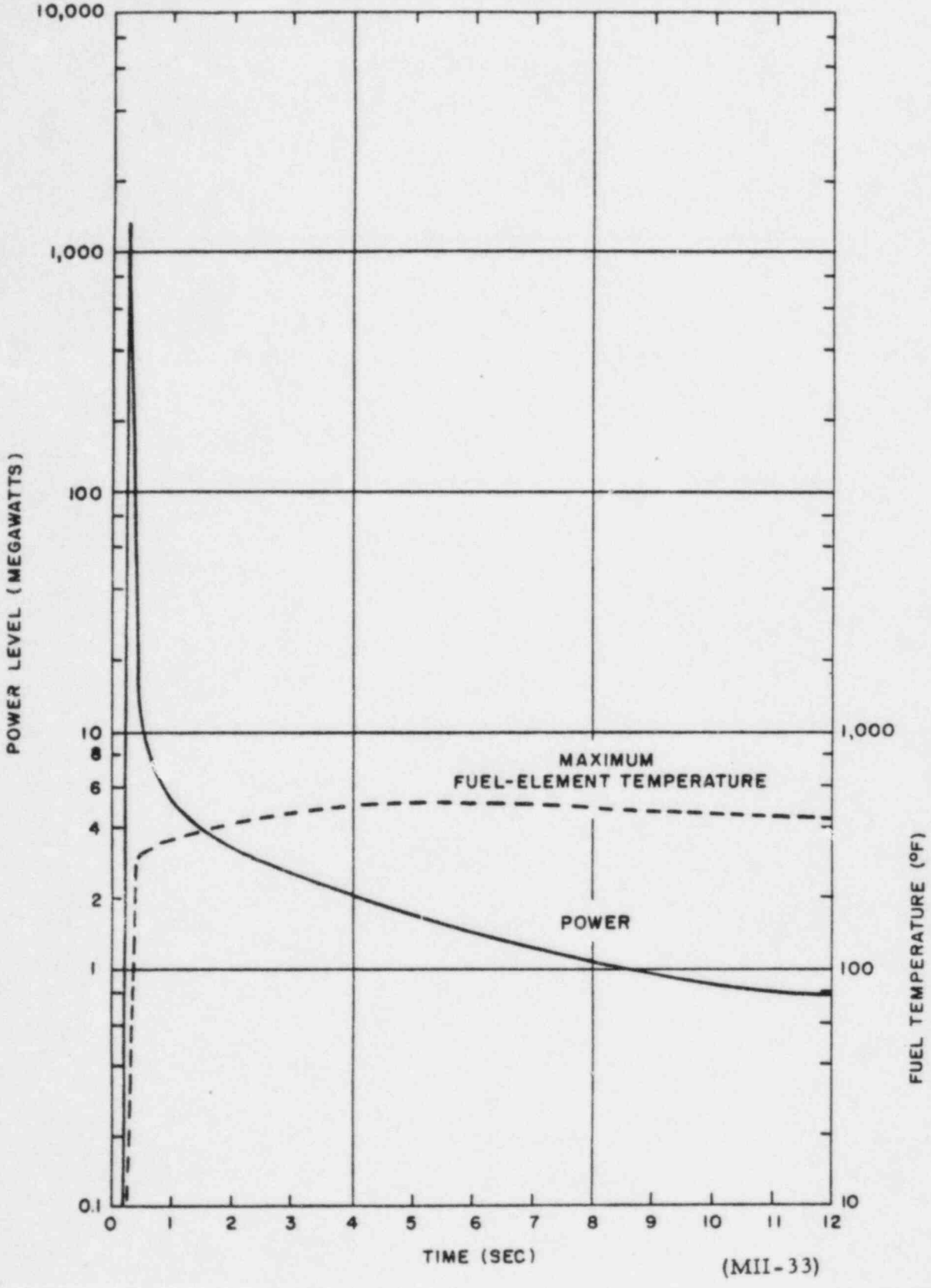
U-$ZrH_{1.6}$ fuel element. Can be used up to 2000 kW steady state and pulsing up to 2,000,000 kW (natural convection cooling); higher pulsing is optional. With forced convection cooling-steady state operation can be increased to 3000 kW with pulsing



TRIGA Mark I Fuel Moderator Element



Instrumented TRIGA Fuel Element



Transient power and fuel temperature as functions of time after 2.25% δk/k ($3.00) reactivity insertion

Name:	Cornell TRIGA Reactor
Location:	Ithaca, New York
Docket Number:	50-157
License Number:	R-80
Date of Initial Criticality:	1962
Rated Power:	100 kw steady state 250 Mw peak pulse
Description:	TRIGA MARK II Reactor, above ground

Fuel:

	$U\text{-}ZrH_{1.0}$	$U\text{-}ZrH_{1.7}$
enrichment	20%	20%
clad	Aluminum	stainless steel
critical mass	1.9 kg.	
core loading	2.9 kg.	
max. fuel temp.	550°C	1000°C
max. excess reactivity	2.6% $\frac{\Delta k}{k}$	
step insertion	1.5% $\frac{\Delta k}{k}$	

Max Neutron Flux: 5×10^{12} steady state
1×10^{16} peak pulse

Control Rods (4): 3 safety rods

composition	boron carbide
clad	aluminum
worth - shim rod	1.7% $\frac{\Delta k}{k}$
safety	1.7% $\frac{\Delta k}{k}$
regulating	0.9% $\frac{\Delta k}{k}$

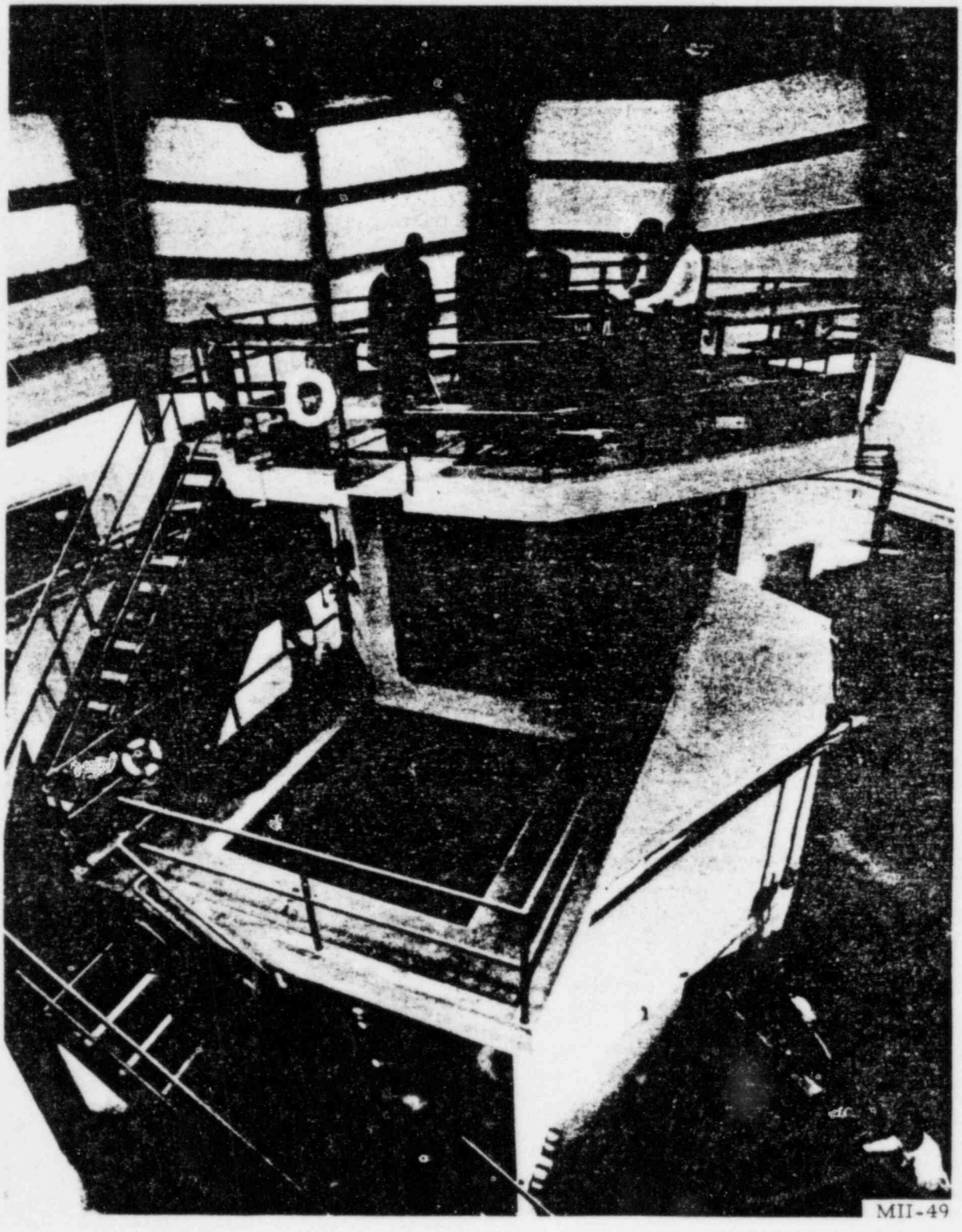
	1 transient rod
	same composition and clad
	worth 1.7% $\frac{\Delta k}{k}$
Moderator:	Zirconium-Hydride and H_2O
Coolant:	H_2O
Max. Coolant Temp.:	130^oF
Reflector:	Graphite
Shield:	Concrete and H_2O
Number of Operators:	SRO-3, RO-0

Name:	Columbia University Research Reactor
Location:	New York, New York
Docket Number:	50-208
License Number:	R-128
Date of Initial Criticality:	License issued in 1977. Reactor operation is currently suspended pending the outcome of court cases.
Rated power:	250 kw steady state 250 Mw peak pulse
Description:	TRIGA MARK II research reactor
Fuel:	$U\text{-}ZrH_{1.7}$
enrichment	20%
clad	stainless steel
core loading	2.3 kg.
max. fuel temp.	$500^{o}C$
max. excess reactivity	$2.45\% \frac{\Delta k}{k}$
step insertion	$1.5\% \frac{\Delta k}{k}$
description	TRIGA MARK III elements
Max Neutron Flux:	4.0×10^{12} n/cm^2-sec steady state
Control Rods (3):	2 safety rods
composition	borated graphite
clad	stainless steel
total worth	$3.5\% \frac{\Delta k}{k}$
	1 pulse rod
	similar composition and clad
worth	$1.8\% \frac{\Delta k}{k}$

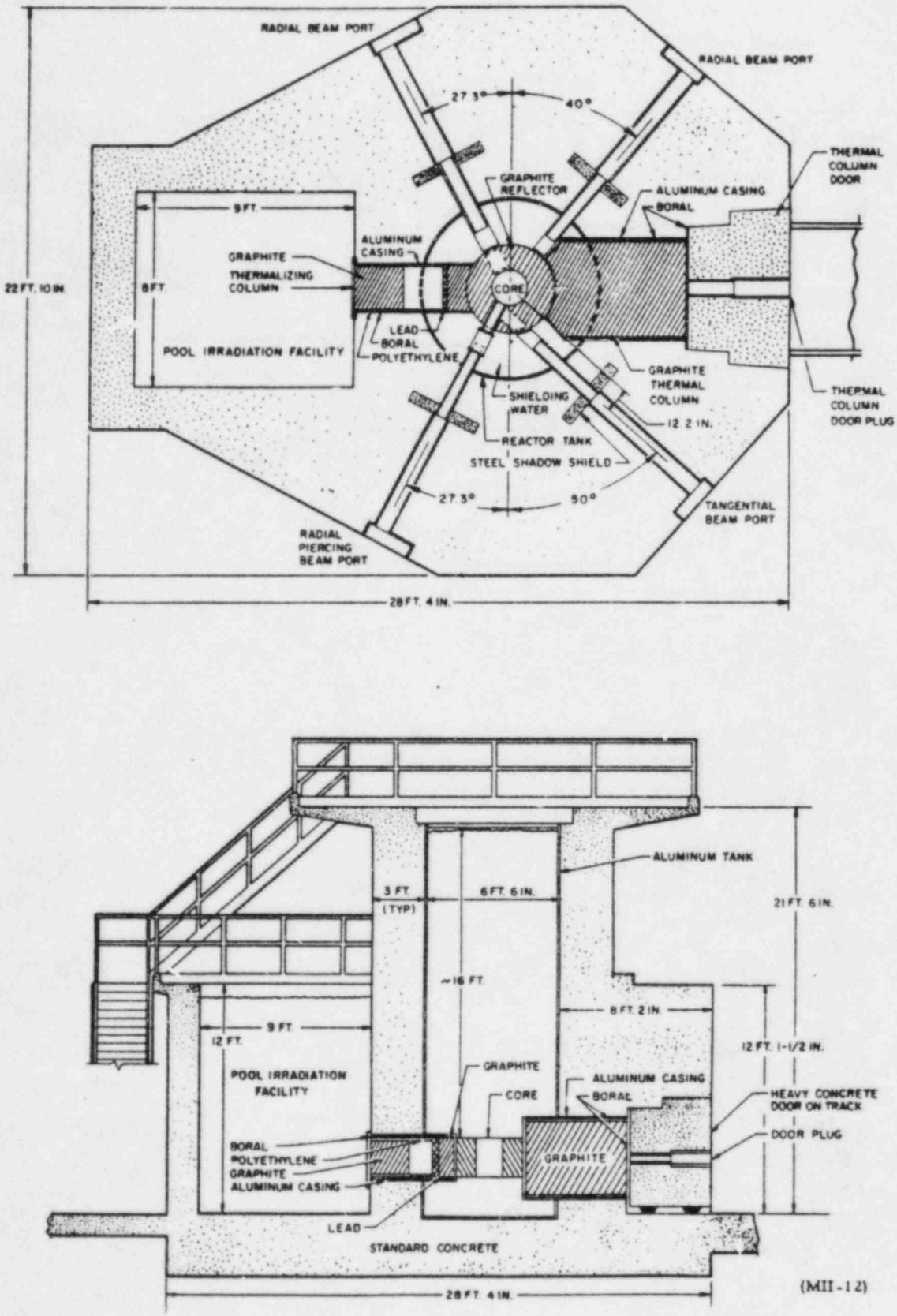
Moderator:	Zirconium-Hydride and H_2O
Coolant:	H_2O
Max. Coolant Temp.:	$41^{o}C$
Reflector:	Graphite and H_2O
Shield:	Concrete and H_2O
Number of Operators:	SRO-2, RO-0

Name:	Kansas State University TRIGA MARK II Reactor (KSUTM II)
Location:	Manhattan, Kansas
Docket Number:	50-188
License Number:	R-88
Date of Initial Criticality:	1962
Rated Power:	250 kw steady state 250 Mw peak pulse Increase in rated power from 10 kw to 250 kw (steady state) in 1968
Description:	TRIGA MARK II Reactor with pulsing abilities
Fuel:	U-ZrH
	enrichment: 20%
	clad: stainless steel
	core loading: 2.1 kg.
	max. fuel temp.: 450° C
	max. excess reactivity: \$1.92 (1.3% $\frac{\Delta k}{k}$)
Max. Neutron Flux:	4×10^{12} n/cm^2-sec
Control Rods (3):	2 safety rods
	composition: boron carbide
	clad: Aluminum
	total worth: \$6.00

	1 regulating rod	
	composition	Cadmium
	clad	Aluminum
	worth	$1.60
Moderator:	Zirconium-Hydride and H_2O	
Coolant:	H_2O	
Max. Coolant Temp.:	60° C	
Reflector:	Graphite	
Shield:	Concrete	
Number of Operators:	SRO-3, RO-4	



Kansas State University TRIGA Mark II reactor



250 kW TRIGA Mark II with pool irradiation facility, thermal column, and three radial and one tangential beam ports

Name:	Michigan State University TRIGA Reactor
Location:	East Lansing, Michigan
Docket Number:	50-294
License Number:	R-114
Rated Power:	250 kw steady state 250 Mw peak pulse
Description:	TRIGA MARK II Reactor. Transferred from University of Illinois in 1969
Fuel:	$U\text{-}ZrH_{1.0}$
enrichment	20%
clad	stainless steel
core loading	2.3 kg.
max. fuel temp.	500° C
max. excess reactivity	1.9% $\frac{\Delta k}{k}$
step insertion	1.5% $\frac{\Delta k}{k}$
Max. Neutron Flux:	8×10^{12} n/cm^2-sec
Control Rods (3):	2 safety rods
composition	boron carbide
clad	Aluminum
total worth	3.8% $\frac{\Delta k}{k}$
	1 transient rod
composition	solid boron carbide
clad	Aluminum
worth	1.5% $\frac{\Delta k}{k}$

Moderator:	Zirconium-Hydride and H_2O
Coolant:	H_2O
Max. Coolant Temp.:	100° F
Reflector:	Graphite and H_2O
Shield:	Concrete and H_2O
Number of Operators:	SRO-3, RO-3

Name:	Oregon State TRIGA Reactor (OSTR)
Location:	Corvallis, Oregon
Docket Number:	50-243
License Number:	R-106
Date of Initial Criticality:	1967
Rated Power:	1 Mw steady state 3200 Mw peak pulse square wave mode
Description:	TRIGA MARK II Research Reactor, above ground

Fuel:

combination of	TRIGA $U\text{-}ZrH_{1.7}$	and	TRIGA-FLIP fuel $U\text{-}ZrH_{1.6}$
enrichment	20%		70%
clad	stainless steel		
max. excess reactivity	4.9% $\frac{\Delta k}{k}$		
step insertion	2.1%		
description	TRIGA-FLIP fuel was added in 1976. Core may be completely TRIGA or TRIGA-FLIP or a combination.		

Control Rods (4): 3 FLIP fuel follower rods

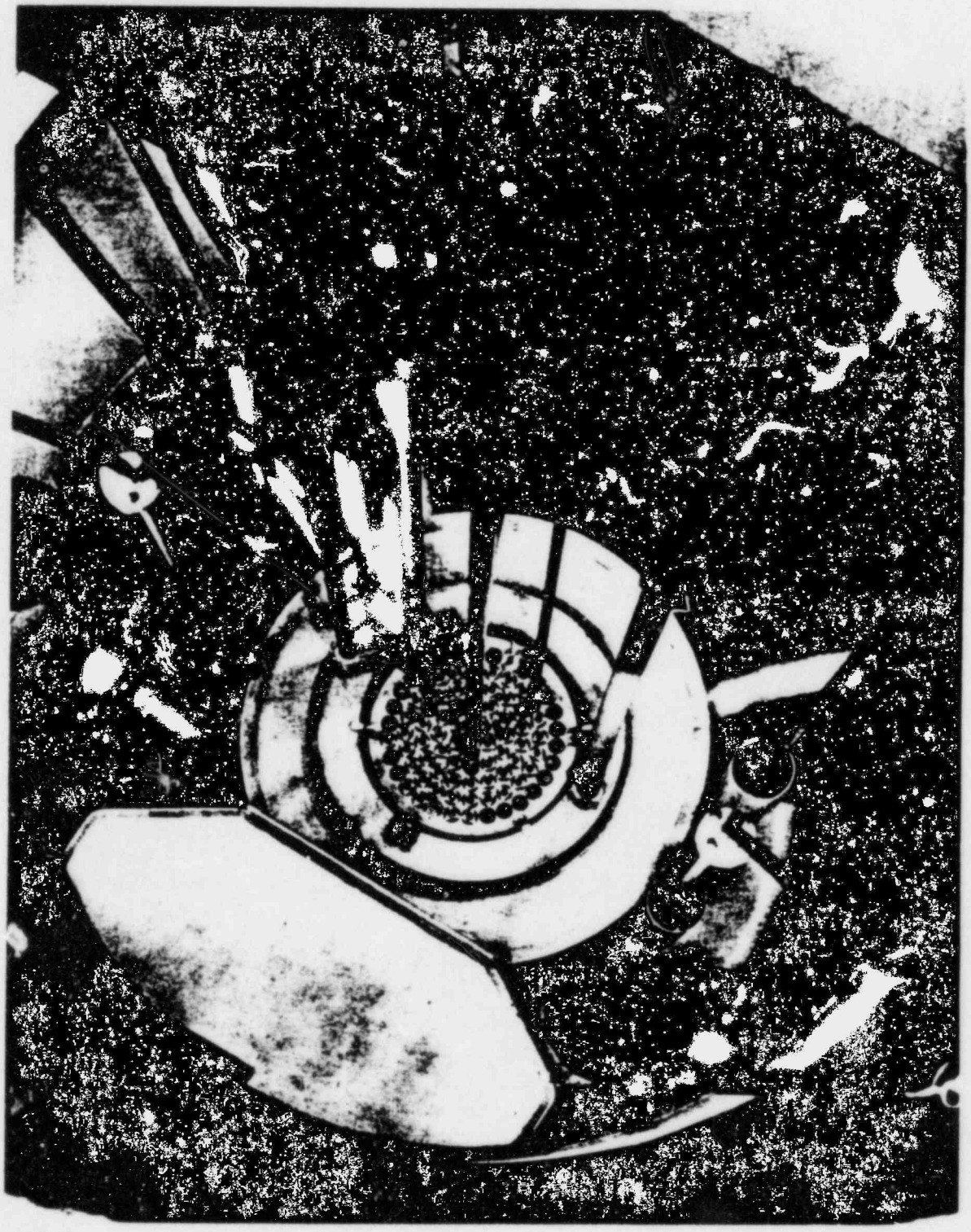
composition	graphite and boron carbide
clad	stainless steel
total worth	7.0% $\frac{\Delta k}{k}$

1 safety-transient rod

similar composition and clad worth

2.45% $\frac{\Delta k}{k}$

Moderator:	Zirconium-Hydride and H_2O
Coolant:	H_2O
Reflector:	Graphite
Shield:	Concrete and H_2O
Number of Operators:	SRO - 8, RO - 4



K15409 M11-19

Core view of the TRIGA Mark II pulsing reactor, FiR-I,
at Institute of Technology, Otaniemi

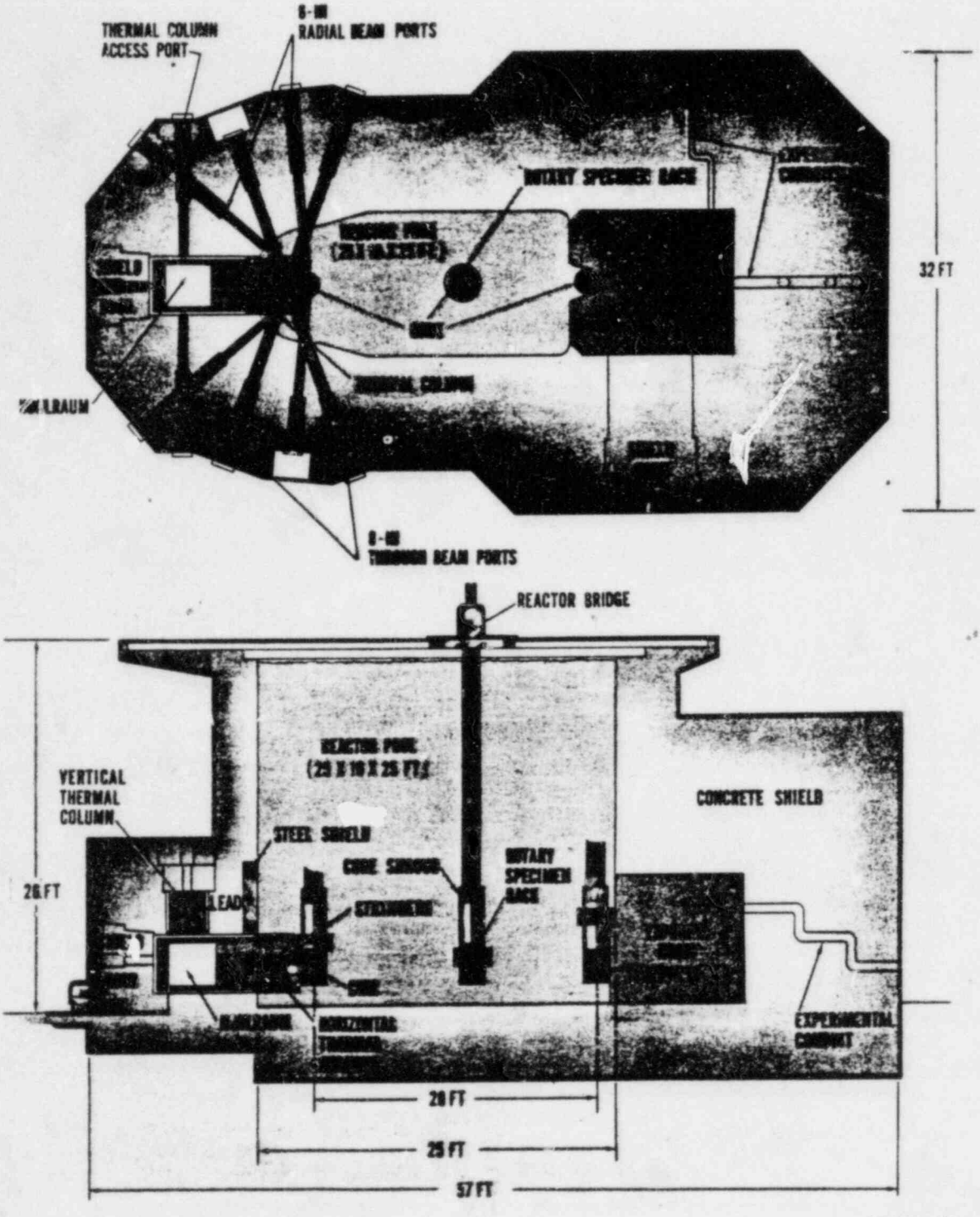
MARK III

Name:	Penn State Reactor (PSR)	
Location:	University Park, Pennsylvania	
Docket Number:	50-5	
License Number:	R-2	
Date of Initial Criticality:	1955, converted to TRIGA MARK III in 1965	
Rated Power:	1 Mw steady state 2 Mw peak pulse	
Description:	TRIGA MARK III conversion, below ground	
Fuel:	$U\text{-}ZrH_{1.7}$	
	enrichment	20%
	clad	stainless steel
	core loading	3.2 kg
	max. excess reactivity	4.9% $\frac{\Delta k}{k}$
	step insertion	2.38% $\frac{\Delta k}{k}$
	description	TRIGA MARK III fuel elements
Max. Neutron Flux:	3.26×10^{13} n/cm^2-sec (steady state)	
	6.52×10^{16} n/cm^2-sec (peak pulse)	
Control Rods (4):	3 fuel follower rods	
	composition	Silver - Indium - Cadmium
	total worth	6.3% $\frac{\Delta k}{k}$
	1 transient rod	
	composition	Ag - In - Cd
	worth	2.1% $\frac{\Delta k}{k}$
Moderator:	Zirconium-Hydride and H_2O	
Coolant:	H_2O	

Max. Coolant Temp.:	110°F
Reflector:	H_2O
Shield:	Concrete and H_2O
Number of Operators:	SRO - 8, RO - 3

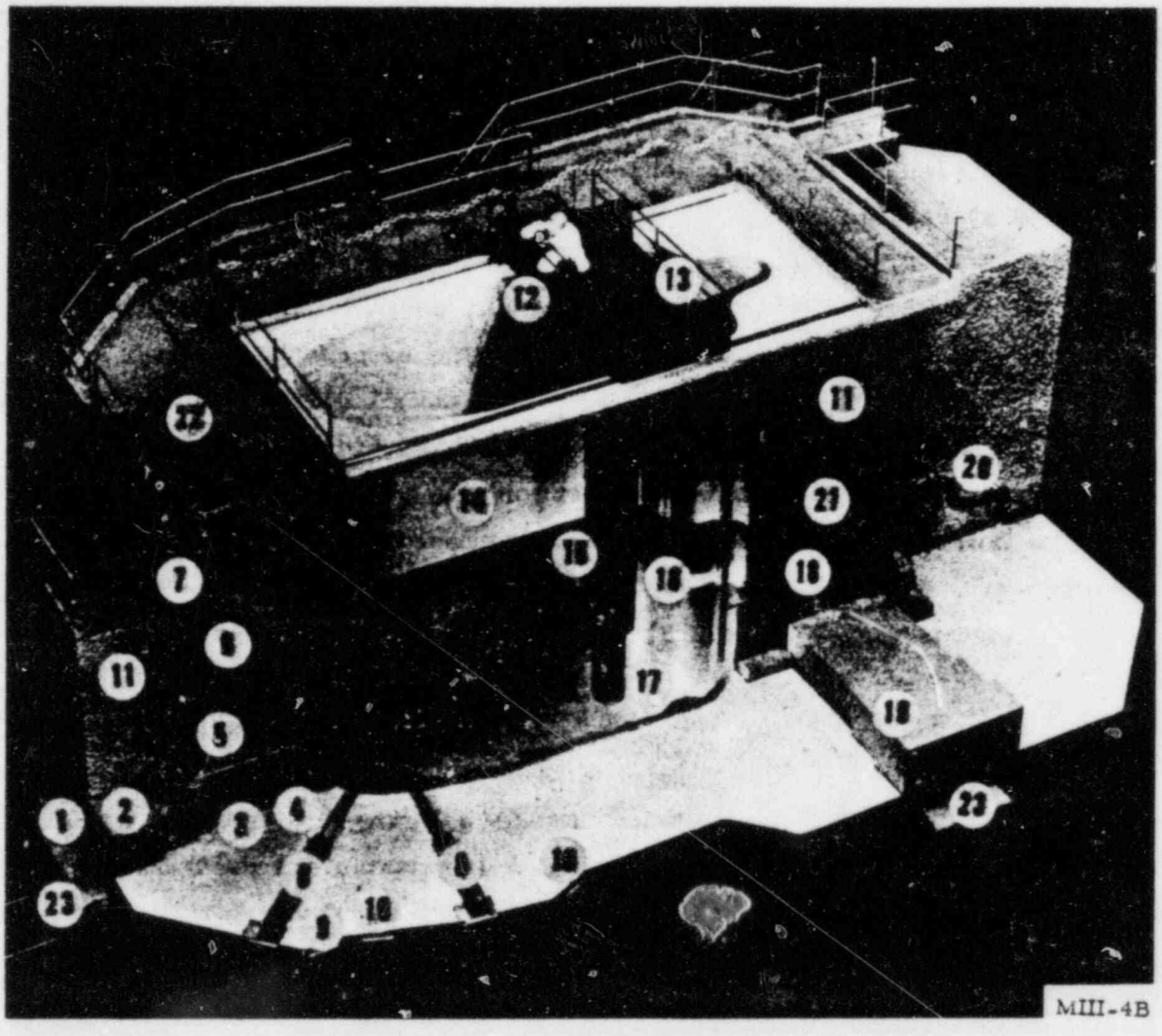
Name:	Berkeley Research Reactor
Location:	University of California Berkeley, California
Docket Number:	50-224
License Number:	R-101
Date of Initial Criticality:	1966
Rated Power:	1 Mw steady state 2000 Mw peak pulse
Description:	movable-core TRIGA MARK III Reactor, above ground
Fuel:	$U\text{-}ZrH_{1.7}$
	enrichment 20%
	clad stainless steel
	critical mass 2.86 kg
	max. excess reactivity 4.9% $\frac{\Delta k}{k}$
	step insertion 2.1% $\frac{\Delta k}{k}$
Max. Neutron Flux:	3.3×10^{13} n/cm^2-sec (steady state)
	6.5×10^{16} n/cm^2-sec (peak pulse)
Control Rods (4):	3 fuel follower control rods
	composition borated graphite
	clad stainless steel
	total worth 4.5% $\frac{\Delta k}{k}$
	1 transient rod
	composition borated graphite
	worth 2.1%
Moderator:	Zirconium-Hydride and H_2O

Coolant:	H_2O
Reflector:	H_2O
Shield:	Concrete and H_2O
Number of Operators:	SRO - 8, RO - 3



MIII-23

Plan view and side elevation of Mark III reactor



1. Stringer Access Port
2. Thermal Column Shield Door
3. Hohlraum
4. Horizontal Thermal Column
5. Vertical Thermal Column
6. Vertical Thermal Column Shield Plug
7. Vertical Access Port
8. Radial Beam Ports
9. Thermal Column Access Port
10. Intersecting Through Ports
11. Concrete Shielding
12. Movable Bridge
13. Control Rod Drives
14. Full Height Aluminum Reactor Tank
15. Pneumatic Transfer System (Rabbit)
16. Isotope-Production Facility (Lazy Susan)
17. Reactor Core
18. Exposure Room
19. Exposure Room Shield Door
20. Experimental Access Conduits
21. Borated Concrete Exposure Room Liner
22. Removable Plate for Access to Vertical Thermal Column
23. Enclosed Door Drive

MARK F

Name:	Defense Nuclear Agency - TRIGA MARK F
Owner:	Armed Forces Radiobiology Research Institute (AFRRI)
Docket Number:	50-170
License Number:	R-84
Date of Initial Criticality:	1962
Rated Power	1 Mw steady state 2000 Mw peak pulse increased rated power from 100 kw to 1 Mw in 1968
Description:	TRIGA MARK F, tank in a pool reactor
Fuel:	$U\text{-}ZrH_{1.7}$
	enrichment 20%
	clad stainless steel
	core loading ≈ 3.5 kg
	max. fuel temp. 600°C
	max. excess reactivity 3.5% $\frac{\Delta k}{k}$
	step insertion 2.3% $\frac{\Delta k}{k}$
	description TRIGA MARK F fuel elements
Max. Neutron Flux:	1.1×10^{12} n/cm^2-sec (at 100 kw)
Control Rods (4):	3 control rods
	composition boron carbide
	clad stainless steel
	total worth 3.9% $\frac{\Delta k}{k}$

	1 transient rod	
	composition	borated graphite
	clad	stainless steel
	worth	2.1% $\frac{\Delta k}{k}$
Moderator:	Zirconium-Hydride and H_2O	
Coolant:	H_2O	
Max. Coolant Temp.:	60^oC	
Reflector:	lead and/or water	
Shield:	concrete and H_2O	
Number of Operators:	SRO - 4, RO - 3	
Utilization:	generated approximately 9,800 kw-hrs of energy between 10/75 and 10/76	

Name:	Northrop Reactor (NOR)	
Location:	Hawthorne, California	
Docket Number:	50-187	
License Number:	R-90	
Date of Initial Criticality:	1963	
Rated Power:	1 Mw steady state 2000 Mw peak pulse	
Description:	below ground, moveable core TRIGA MARK F Reactor	
Fuel:	$U\text{-}ZrH_{1.7}$	
	enrichment	20%
	clad	stainless steel
	core loading	3.6 kg
	max. fuel temp.	$600^{o}C$
	max. excess reactivity	$3.8\% \frac{\Delta k}{k}$
	description	87 fuel elements
Max. Neutron Flux:	1.1×10^{12} n/cm^2-sec	
Control Rods (4):	3 safety rods	
	composition	borated graphite
	individual worth	$1.4\% \frac{\Delta k}{k}$
	1 pulse rod	
	composition	borated graphite
	worth	$3.4\% \frac{\Delta k}{k}$
Moderator:	Zirconium-Hydride and H_2O	
Coolant:	H_2O	

Max. Coolant Temp.:	$90^{o}C$
Reflector:	Graphite and H_2O
Shield:	Concrete and H_2O
Number of Operators:	SRO - 4, RO - 1

Name:	General Atomics TRIGA MARK F Reactor
Location:	San Diego, California
Docket Number:	50-163
License Number:	R-67
Date of Initial Criticality:	1960
Rated Power:	1.5 Mw steady state 8400 Mw peak pulse
Description:	TRIGA MARK F
Fuel:	$U\text{-}ZrH_{1.0}$ or $U\text{-}ZrH_{1.7}$ and special test fuel elements
enrichment	20%
clad	Hastalloy X or Incalloy 800
critical mass	≈ 2.5 kg
core loading	≈ 2.9 kg
max. fuel temp.	570°C
max. excess reactivity	3.5% $\frac{\Delta k}{k}$
step insertion	2.8% $\frac{\Delta k}{k}$
description	TRIGA fuel elements
Max. Neutron Flux:	
Control Rods (4):	3 fuel follower control tubes
composition	boron carbide
clad	Aluminum
individual worth	1.8% $\frac{\Delta k}{k}$
	1 transient rod
	same composition and clad
worth	2.6% $\frac{\Delta k}{k}$

Moderator:	Zirconium-Hydride and H_2O
Coolant:	H_2O
Max. Coolant Temp.:	90^oC
Reflector:	H_2O, lead or graphite Reflector can be modified for any of these materials.
Shield:	Concrete and H_2O
Number of Operators:	SRO - 2, RO - 2
Utilization:	Generated approximately 530 Mw-hrs of energy in 1977.

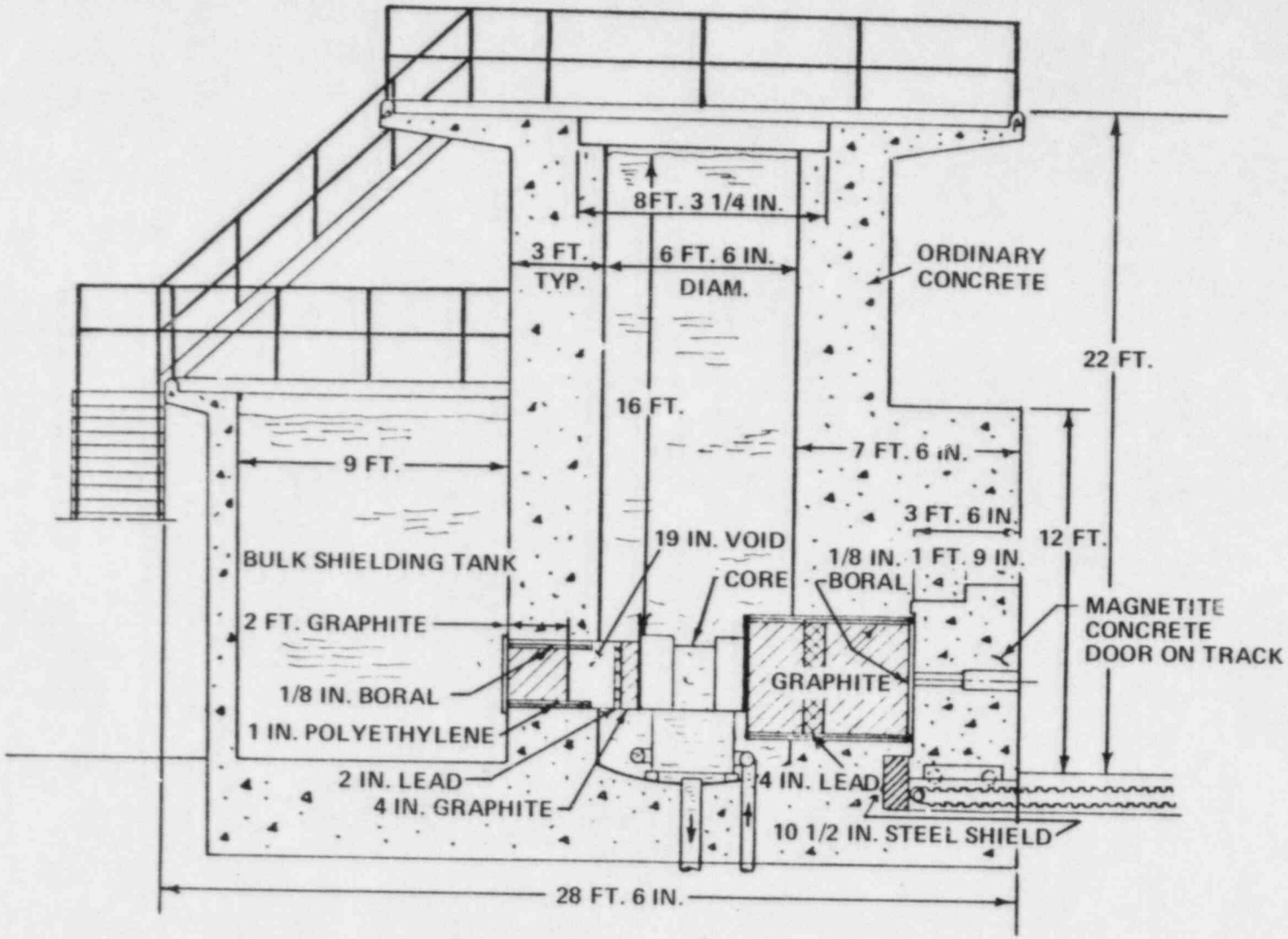
Note: The TRIGA MARK F reactor was originally designated as the FLAIR Reactor (FLashing Advanced Irradiation Reactor).

ADVANCED

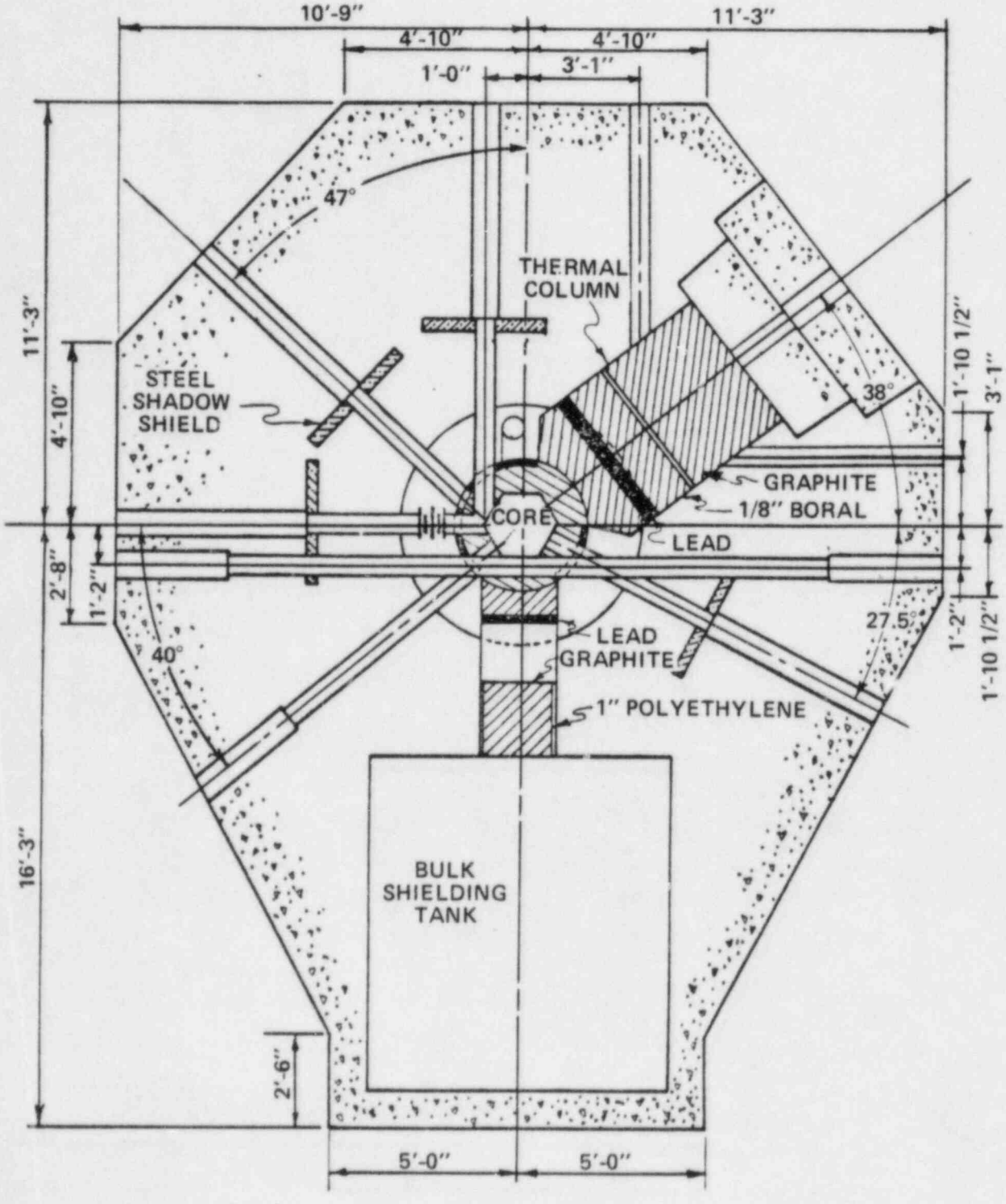
Name:	Illinois Advanced TRIGA Reactor
Location:	Urbana, Illinois
Docket Number:	50-151
License Number:	R-115
Date of Initial Criticality:	1969 Originally a TRIGA MARK II but changed in 1969 to an advanced TRIGA
Rated Power:	1.5 Mw steady state 6500 Mw peak pulse Square wave operation
Description:	Advanced TRIGA
Fuel:	$U\text{-}ZrH_{1.0}$ or $U\text{-}ZrH_{1.7}$
	enrichment 20%
	clad stainless steel
	critical mass 2.6 kg.
	core loading 3.8 kg.
	max. fuel temp. 850° C
	max. excess reactivity $8.08
	step insertion $4.60
	description fuel elements in hexagonal array
Control Rods (5):	composition borated graphite
	3 fuel follower rods
	individual worth $3.00
	1 adjustable transient rod
	worth $2.30
	1 fast transient rod
	worth $2.30

Moderator:	Zirconium-Hydride and H_2O
Coolant:	H_2O
Max. Coolant Temp.:	50° C
Reflector:	Lead and graphite
Shield:	Concrete and H_2O
Number of Operators:	SRO-2, RO-2
Utilization:	Reactor was operated approximately 1000 hours and pulsed 436 times between 6/76 and 6/77

VERTICAL SECTION
ILLINOIS ADVANCED TRIGA

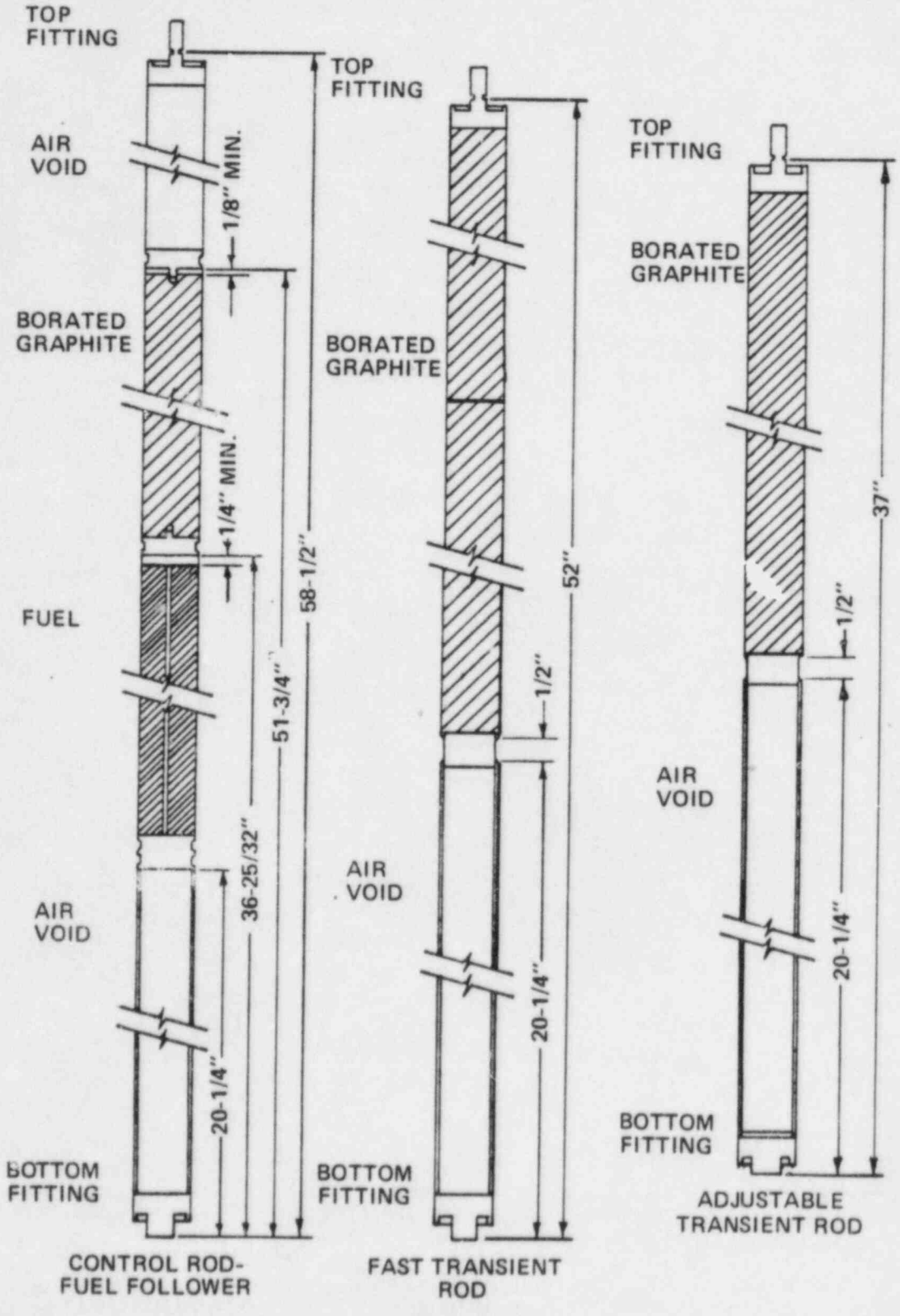


SECTION THROUGH BULK SHIELDING TANK AND THERMAL COLUMN.



SECTION AT BEAM PORT LEVEL.

ILLINOIS ADVANCED TRIGA



CONTROL RODS

ILLINOIS ADVANCED TRIGA

TRIGA® Reactors

INSTALLATIONS AND CONVERSIONS

GENERAL ATOMIC

GEN 10
Jan 1977

		LOCATION	TYPE	MAXIMUM RATING STEADY STATE	MAXIMUM RATING PULSING	INITIAL CRITICALITY
Arizona	1	University of Arizona Tucson	TRIGA Mark I	250 kW	300 000 kW	12 7 58
California	2	General Atomic San Diego	TRIGA Mark I	250 kW	800 000 kW	5 3 58
	3	General Atomic San Diego	TRIGA Mark F	1 500 kW	8 400 000 kW	7 2 60
	4	General Atomic San Diego	TRIGA Mark III	Decommissioned		1 17 66
	5	Norair Division of Northrop Corporation Hawthorne	TRIGA Mark F	1 000 kW	1 500 000 kW	3 5 63
	6	University of California Berkeley	TRIGA Mark III	1 000 kW	2 000 000 kW	8 10 66
	7	University of California Irvine	TRIGA Mark I	250 kW	250 000 kW	11 25 69
	8	Aerotest Operations San Ramon	TRIGA Conversion	250 kW		7 9 65
Colorado	9	U S Geological Survey Denver	TRIGA Mark I	1 000 kW	1 200 000 kW	2 26 69
Illinois	10	University of Illinois Urbana	TRIGA Mark II	1 500 kW	6 500 000 kW	8 16 60
Kansas	11	Kansas State University Manhattan	TRIGA Mark II	250 kW	250 000 kW	10 16 62
Maryland	12	Harry Diamond Laboratories (U S Army) Forest Glen	TRIGA Mark F	250 kW	2 000 000 kW	9 18 61
	13	Nuclear Agency (AFRRI) Bethesda	TRIGA Mark F	1 000 kW	2 000 000 kW	6 28 62
	14	University of Maryland College Park	TRIGA Conversion	250 kW		6 13 74
Michigan	15	The Dow Chemical Company Midland	TRIGA Mark I	100 kW		7 6 67
	16	Michigan State University East Lansing	TRIGA Mark I	250 kW	250 000 kW	3 21 69
Missouri	17	University of Missouri Rolla	TRIGA Conversion	200 kW		Under Construction
Nebraska	18	Veterans Administration Hospital Omaha	TRIGA Mark I	18 kW		6 26 59
New Mexico	19	Sandia Corporation (USAEC) Albuquerque	TRIGA-ACPR	600 kW	12 000 000 kW	6 2 67
New York	20	Columbia University New York	TRIGA Mark II	250 kW	250 000 kW	Licensed
	21	Cornell University Ithaca	TRIGA Mark II	100 kW	250 000 kW	1 12 62
Oregon	22	Oregon State University Corvallis	TRIGA Mark II	1 000 kW	3 200 000 kW	3 8 67
	23	Reed College Portland	TRIGA Mark I	250 kW		7 2 68
Pennsylvania	24	Pennsylvania State University University Park	TRIGA Mark III Conversion	1 000 kW	2 000 000 kW	12 31 65
Puerto Rico	25	Puerto Rico Nuclear Center Mayaguez	TRIGA Conversion	Decommissioned		1 19 72
Texas	26	Texas A & M University College Station	TRIGA Conversion	1 000 kW	2 000 000 kW	8 1 68
	27	University of Texas Austin	TRIGA Mark I	250 kW	250 000 kW	8 2 63
Utah	28	University of Utah Salt Lake City	TRIGA Mark I	250 kW		10 23 75
Wisconsin	29	University of Wisconsin Madison	TRIGA Conversion	1 000 kW	2 000 000 kW	11 14 67
Washington	30	Washington State University Pullman	TRIGA Conversion	1 000 kW	2 000 000 kW	7 14 67
	31	Westinghouse-Hanford Richland	TRIGA Mark I	250 kW		Under Construction

P O BOX 81608, SAN DIEGO, CALIFORNIA 92138 (714) 455-3574 TWX 910-335-1260

TRIGA® REACTORS Research, Training, and Isotope Production

		LOCATION	TYPE	MAXIMUM RATING STEADY STATE	MAXIMUM RATING PULSING	INITIAL CRITICALITY
Austria	1	Federal Ministry of Education Vienna	TRIGA Mark II	250 kW	250,000 kW	3.7.62
Bangladesh	51	Institute of Nuclear Technology Savar	TRIGA Mark II	1,000 kW	1,250,000 kW	Under Construction
Brazil	54	University of Minas Gerais Belo Horizonte	TRIGA Mark I	250 kW		11.6.60
England	50	Imperial Chemical Industries Brringham, Teesside	TRIGA Mark I	250 kW		8.14.71
Finland	12	The State Institute for Technical Research Helsinki	TRIGA Mark II	250 kW	250,000 kW	3.27.62
Germany	17	German Cancer Research Center Heidelberg	TRIGA Mark I	250 kW		8.25.66
	18	Johannes Gutenberg University Mainz	TRIGA Mark II	100 kW	250,000 kW	8.3.65
	19	Association for Radiation Research Garching	TRIGA Mark III	1,000 kW	2,000,000 kW	8.23.72
	20	Medical College of Hannover Hannover	TRIGA Mark I	250 kW		1.31.73
	21	University of Frankfurt Frankfurt	TRIGA Conversion	1,000 kW		Under Construction
Jugoslavia	22	Institute of Atomic Energy Handring	TRIGA Mark II	1,000 kW		10.16.64
Iran	43	Nuclear Research Center Tehran	TRIGA Conversion	5,000/10,000 kW		Under Construction
Italy	23	National Committee for Nuclear Energy Rome	TRIGA Mark II	1,000 kW		6-10-60
	24	University of Pavia Pavia	TRIGA Mark	250 kW	250,000	11.15.65
Japan	25	Japan Atomic Energy Research Institute Tokai-Mura	TRIGA ACPR	300 kW	22,000,000	6.30.75
	45	Musashi College of Technology Tokyo	TRIGA Mark II	100 kW		1.29.63
	26	Rikkyo University Tokyo-Ikebukuro	TRIGA Mark II	100 kW		2.8.61
Korea	44	National Atomic Energy Institute Seoul	TRIGA Mark II	250 kW		3.19.62
	27	National Atomic Energy Institute Seoul	TRIGA Mark III	2,000 kW	2,900,000 kW	4.10.72
Malaysia	31	Tun Ismail Atomic Research Centre Kuala Lumpur	TRIGA Mark II	1000 kW	1,250,000 kW	Under Construction
Mexico	52	National Commission for Nuclear Energy Mexico City	TRIGA Mark III	1,000 kW	2,000,000 kW	1.8.68
Romania	53	Institute for Nuclear Technologies Bucharest	TRIGA-ACPR	500 kW	15,000,000 kW	Under Construction
	54	Institute for Nuclear Technologies Bucharest	TRIGA	14,000 kW		Under Construction
Thailand	55	Office of Atomic Energy for Peace Bangkok	TRIGA Mark III Conversion	2,000 kW	2,000,000 kW	Under Construction
Turkey	56	Technical University of Istanbul Istanbul	TRIGA Mark II	250 kW	250,000 kW	Under Construction
Viet Nam	57	Institute of Nuclear Research Dalat	TRIGA Mark II	Decommissioned		2.26.63
Yugoslavia	58	Jozef Stefan Nuclear Institute Ljubljana	TRIGA Mark II	250 kW		5.31.66
Zaire (Congo)	59	Nuclear Science Commission Kinshasa, Zaire	TRIGA Mark II	1,000 kW	1,000,000 kW	5.27.59

REACTOR TERMS

Reactor Terms

fission — The splitting of an atom. The opposite process is fusion, which is combining two smaller atoms to make a larger one. Both processes release neutrons. gamma rays and heat.

fissile material — Fissionable nuclear fuel such as Uranium-235, Uranium-233 or Plutonium-239. Uranium-235 is the most common fuel. Plutonium-239 and Uranium-233 generally are not used in research reactors. Due to low power levels very little U-238 is converted to PU-239. (50 mega watt days produce about 6 grams of PU-239).

fertile material — Material that may be made fissile by absorbing a neutron and decaying, such as Uranium-238, which can be made into Plutonium-239 and Thorium-232 which can be converted to Uranium-233.

critical — That combination of fuel and poison where the chain reaction is constant. That is the number of neutrons available for fission is constant and the power level is not changing. A term called K-effective is 1 in this condition. Keff is also called the neutron balance equation.

nuclear reactor — A combination of fuel and control systems capable of attaining a self-sustaining chain reaction.

critical facility — A type of nuclear reactor that generally operates at very low power levels such as 0.1 watts, which is below the point where heat is generated. Compare, for example, to the heat generated by a 100 watt bulb.

fast reactor	A reactor capable of sustaining a chain reaction using high energy neutrons. There are very few of this type; none regulated by NRC. They require about 10X more fuel than a so-called thermal reactor. These reactors do not use a moderator.
thermal reactor	The chain reaction is maintained by thermalized (low energy) neutrons. These reactors require much less fuel than fast reactors because the fuel more readily absorbs thermal neutrons.
core	The fuel area of the reactor.
reflector	Material placed around a core to reflect some of the escaping neutrons back into the core.
moderator	Material in a reactor used to slow down (thermalize) neutrons. Usually water or graphite or polyethylene.
poison	Anything that absorbs neutrons such as boron, hafnium, cadmium, xenon, etc.
barn	Unit of measure originated in manhattan project that describes how readily a neutron is absorbed in a material.
control rods	Usually a poison used to control the chain reaction. In the case of the AGN reactors, fuel rods are used for control in a manner similar to but inverse to the manner poison rods are used.
excess reactivity	Nuclear term that is related to the amount of fuel in the core in excess of that needed to achieve a critical mass. Excess reactivity is increased by adding fuel and is normally expressed as $\frac{\Delta k}{k}$.

shutdown margins	A measure of the ability of the control rods to compensate for excess reactivity. Usually the term is a measure of how much a reactor is below being critical assuming one rod is stuck in the out position.
scram	Term used to describe the automatic rapid insertion of control rods in the core to shutdown the reactor. PWRs generally use the word trip, which means the same thing.
prompt critical	A condition created by rapidly adding positive reactivity to the core (sudden movement of a control rod) such that power rises in a rapid and uncontrolled manner. Enough positive reactivity must be added to over come the time delay effect on power rise of the delayed neutrons. This is usually about .7% $\frac{\Delta k}{k}$. An example of prompt criticality is a pulse where power rises from 1 watt to 4000 megawatts in a fraction of a second. Prompt criticality can occur any time and in any location where sufficient fuel is consentrated in a small area under optimum conditions of moderation.
delayed neutrons	99.3% of the neutrons that result from fission occur immediately (within 10^{-14} sec). The other 0.7% of the neutrons (delayed nuetrons) appear over the next minute or two. These neutrons are very important to the safety of a nuclear reactor because they slow down the chain reaction. Normal changes to power level are controlled to a maximum of one power of 10 (e.g., going from 1 watt to 10 watts to 100 watts) per minute. If the delayed neutrons were not present to slow down the chain reaction, the power level would change several thousand powers of ten per minute. This is a prompt critical condition.

reactivity ($\Delta k/k$)

Term used to describe the ability of the reactor to respond. Changes in reactivity are normally made by changing the position of control rods; however, changing to position of an experiment or the amount of fuel will also cause changes in reactivity.

Reactivity is frequently expressed in $ and ¢ of reactivity where a $1 addition of reactivity to a critical reactor would cause the reactor to go prompt critical.

K-effective (Keff)

This term represents the neutron balance equation. When the reactor is critical Keff = 1 which means that as many neutrons are being born as are being lost. When the reactor is shutdown Keff equals about 0.8.

Note: If a reactor's reactivity is said to be Keff = 1.02, this means that if the rods were removed the reactor is capable of attaining a Keff of 1.02. Another way of stating this is that the reactor has either $.02\frac{\Delta k}{k}$, $2\%\ \frac{\Delta k}{k}$ or $2.85 of excess reactivity.

Radiation and Shielding

Alpha particles (α) short range, very high energy particles. Relatively rare except around heavy elements. Frequently found in small amounts in concrete or rocks that contain natural uranium. Alpha emitting particles are considered dangerous if inhaled or injested, however, externally skin or a piece of paper are sufficient to stop them. Alpha particles travel about an inch in air.

Beta particles - (β) Very common form of radiation. Beta particles (or rays) are actually high energy electrons. They can cause the skin to turn red similar to sunburn. Beta particles are fairly easy to stop and will travel about 4-5 inches in air.

Gamma Rays - (γ) The most common form of radiation found around a shutdown reactor. Usual sources are activated experimental apparatus. Gamma rays are a highly penetrating form of radiation. For all practical purposes they are not stopped by air. Usually when one speaks of a radiation field or a radiation dose rate they are referring to gamma radiation. To reduce gamma radiation by a factor of 10 requires approximately 2 inches of lead or 4 inches of steel or 24 inches of ordinary concrete or water. If the source of gamma rays can be approximated as a point source then the radiation level decreases with the square of the distance. This means that if you double your distance from the source the radiation field is reduced to 1/4 of the original value. Example: If a self protecting fuel rod reads 100 Rem/hr at 3 feet it should read approximately 25 Rem/hr at 6 feet. Conversely at 1-1/2 feet from the fuel rod the dose rate would be about 400 Rem/hr.

Neutron Radiation - Neutrons are produced in the reactor core by the fission process. When the reactor is shutdown this radiation is insignificant. During operation neutron leakage out of the reactor if all shielding is in place will equal approximately 25% of the radiation level due to gamma rays from the same source. In the core or with a beam port plug removed the neutron radiation would be about 300 times the radiation level of the gamma rays. Fast (high energy) neutrons are about 3 times more damaging than thermal (low energy) neutrons. Neutrons are slowed down by water, polyethelene and to some extent iron. When thermalized they are readily absorbed by boron cadmium and many other materials.

Cerenkov Radiation - The blue glow around water moderated reactor fuel is caused by the rapid deceleration of electrons. These electrons are produced by fission product gamma rays.

Radiation Levels (Approximate)

(milli = 1/1000)

200 milli Rem/year	Normal Background Radiation
2 milli Rem/hr	Maximum radiation level allowable in an unrestricted area
10 milli Rem/hr	A normal area radiation monitor set point
100 milli Rem/hr	Upper limit of Radiation Area - Lower limit of High Radiation Area
125 milli Rem/quarter	Exposure limit for non radiation workers
1.25 Rem/quarter (5 Rem/yr)	Exposure limit for radiation workers
25 Rem/2 hr period	Part 100 design limit in event of accident
25 - 100 Rem	Emergency life saving dose (slight blood changes)
100 R at 3 feet	Self protecting defination
200 Rem (whole body)	Moderate blood changes
300 Rem (whole body)	Vomiting within 2 hours, loss of hair after 2 weeks
400 Rem (whole body)	50% fatalities - hemorrhage, infection
800 Rem (whole body)	80-100% fatalities within 2 months
2500 Rem (localized)	Given to cancer patients
1 million Rem/hr	Radiation level in core of 100kw Research Reactor

PRINCIPLE NAMES AND ADDRESSES

Name: AGNIR
Docket No.: 50-228
Address: Aerotest Operations, Inc.
3455 Fostoria Way
San Ramon, CA 94583

Supervisor: R. L. Newacheck Telephone No.: 837-4248
Correct as of 9/76

Name: AFRRI
Docket No.: 50-170
Address: Defense Nuclear Agency - Armed Forces
Radiobiology Institute
Bethesda, MD 20014

Supervisor: Capt. J. Casady Telephone No.: 301-295-0411
Correct as of 9/76

Name: Lynchburg Pool Reactor / Babcock & Wilcox Critical Facility
Docket No.: 50-99, 50-13
Address: Babcock & Wilcox Company
ATTN: Dr. T. C. Engelder
Director, Lynchburg Research Center
P. O. Box 1260
Lynchburg, VA 24505

Supervisor: Dr. T. C. Engelder Telephone No.: 804-384-5111
Correct as of 9/76

Name: Brigham Young University, L-77 Reactor
Docket No.: 50-262
Address: BYU Reactor Facility
c/o D. R. Dixon
166 Eyring Science Center
Brigham Young University
Provo, UT

Supervisor: D. R. Dixon Telephone No.: 374-1211
X4216
Correct as of 9/77

Name: California Polytectnic AGN-201
Docket No.: 50-394
Address: Bldg. 40, Room 103, Mechanical Engineering Department
California Polytechnic State University
San Luis Obispo, CA 93407

Supervisor: R. W. Adamson Telephone No.: 805-546-2405

Correct as of 9/77

Name: Catholic University Reactor
Docket No.: 50-77
Address: 620 Michigan Avenue, N.E.
Washington, D. C. 20064

Supervisor: Dr. Paul Thiess Telephone No.: 202-635-5184

Correct as of 9/77

Name: Cornell TRIGA Reactor / Cornell ZPR Reactor
Docket No.: 50-97, 50-157
Address: Cornell University
Ithaca, NY 14850

Supervisor: Dr. H. Aderhold Telephone No.: 607-256-3480

Correct as of 9/77

Name: Dow Chemical Co, TRIGA I Reactor
Docket No.: 50-264
Address: Dow Chemical Company
1602 Building
Midland, MI

Supervisor: O. Anders Telephone No.: 636-0304

Correct as of 9/76

Name: Torrey Pines TRIGA MARK I / General Atomic TRIGA MARK F
Docket No.: 50-89, 50-163
Address: General Atomic Company
P. O. Box 81608
San Diego, CA 92138

Supervisor: W. L. Wittemore Telephone No.: 714-455-3277

Correct as of 9/77

Name: General Electric / GETR, NTR
Docket No.: 50-70, 50-73
Address: General Electric Company
Vallecitos Nuclear Center
P. O. Drawer B
Pleasanton, CA 94566

Supervisor: R. W. Darmitzel Telephone No.: 415-862-2211 X4344

Correct as of 9/76

Name: GTRR
Docket No.: 50-160
Address: Georgia Institute of Technology
ATTN: Dr. M. V. Davis, Director
Nuclear Research Center
Atlanta, GA 30332

Supervisor: Dr. Lynn Weaver Telephone No.: 404-894-3724

Correct as of 9/77

Name: Georgia Tech AGN-201
Docket No.: 50-276
Address: Georgia Institute of Technology
School of Nuclear Engineering
Atlanta, GA 30332

Supervisor: Dr. Lynn Weaver Telephone No.: 404-894-3724

Correct as of 9/77

Name: Idaho State AGN-201
Docket No.: 50-284
Address: School of Engineering
Idaho State University
Box 8060
Pocatello, ID 83201

Supervisor: A. E. Wilson Telephone No.: 208-236-0211
X2281

Correct as of 9/77

Name: Iowa State University
Docket No.: 50-116
Address: Nuclear Engineering Laboratory
Iowa State University
Ames, IO 50011

Supervisor: Dr. Adolf F. Voligt Telephone No.: 515-294-2500

Correct as of 9/77

Name: Kansas State University TRIGA MARK II Reactor
Docket No.: 50-188
Address: Ward Hall
Kansas State University
Manhatten, KS 66506

Supervisor: Michael McEwan Telephone No.: 913-532-5624

Correct as of 9/77

Name: Manhatten College ZPR
Docket No.: 50-199
Address: Manhatten College
Bronx, NY 10471

Supervisor: Bro. G. Kane Telephone No.: 212-548-1400
X295

Correct as of 9/77

Name: MITR
Docket No.: 50-20
Address: Mass. Institute of Technology
138 Albany St.
Cambrige, MA 02139

Supervisor: OttoK. Harling Telephone No.: 617-253-4211

Correct as of 9/77

Name: Michigan State University TRIGA Reactor
Docket No.: 50-294
Address: Division of Engineering Research
Michigan State University
East Lansing, MI 48824

Supervisor: Jim Carrick Telephone No.: 517-353-9097

Correct as of 9/77

Name: NSBS
Docket No.: 50-184
Address: U.S. Department of Commerce
National Bureau of Standards
Washington, D. C. 20234

Supervisor: T. Raby Telephone No.: 301-948-0083

Correct as of 9/76

Name: Rockwell International / L-77, L-85
Docket No.: 50-94, 50-375
Address: 8900 DeSoto Avenue
Canoga Park, CA 91304

Supervisor: M. E. Remley Telephone No.: 213-341-1000
X2238

Correct as of 9/76

Name: PULSTAR - N.C. State
Docket No.: 50-297
Address: N.C. State University
Department of Nuclear Engineering
Raleigh, NC 27607

Supervisor: J. R. Bohannon Telephone No.: 919-737-2322

Correct as of 9/76

Name: Northrop Reactor
Docket No.: 50-187
Address: Northrop Research & Technology Center
3401 W. Broadway
Hawthorne, CA 90250

Supervisor: D. H. Rusling Telephone No.: 213-970-2297

Correct as of 9/76

Name: Ohio State University Reactor
Docket No.: 50-150
Address: 1298 Kinnear Road
Columbus, OH 43212

Supervisor: B. K. Hajek Telephone No.: 422-6755

Correct as of 9/77

Name: Oregon State TRIGA Reactor / Oregon State AGN Reactor
Docket No.: 50-243, 50-106
Address: Radiation Center, OSU
Corvallis, OR 97331

Supervisor: C. H. Wang Telephone No.: 503-754-2344

Correct as of 9/77

Name: Penn State Reactor
Docket No.: 50-5
Address: Pennsylvania State University
University Park, PA 16802

Supervisor: Robert Totenbier Telephone No.: 814-865-6351

Correct as of 9/77

Name: Purdue University Reactor
Docket No.: 50-152
Address: Purdue University
Nuclear Engineering Department
West Lafayette, IN 17907

Supervisor: Eldon R. Stansberry Telephone No.: 317-749-2920

Correct as of 9/77

Name: Reed College Reactor Facility
Docket No.: 50-288
Address: Reed Reactor Facility
Reed College
Portland, OR 97207

Supervisor: K. Higley Telephone No.: 503-771-1112

Correct as of 9/76

Name: RPI Critical Experiments Facility
Docket No.: 50-255
Address: Rensselaer Polytechnic Institute
Troy, NY 12181

Supervisor: Telephone No.: 518-393-4281

Correct as of 9/76

Name: Rhode Island Open Pool Reactor
Docket No.: 50-193
Address: Rhode Island AEC
South Ferry Road
Narragansett, RI 02882

Supervisor: A. F. DiMeglio Telephone No.: 407-789-9391

Correct as of 9/76

Name: PULSTAR - State University of New York
Docket No.: 50-57
Address: Nuclear Science & Technology Center
State University of New York at Buffalo
Rotary Road
Buffalo, NY 14214

Supervisor: P. Orlosky Telephone No.: 716-831-2826

Correct as of 9/77

Name: Texas A&M AGN-201
Docket No.: 50-59
Address: Department of Nuclear Engineering
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Supervisor: J. B. Zgliczynski Telephone No.: 713-845-4161

Correct as of 9/77

Name: Texas A&M Nuclear Science Center Reactor
Docket No.: 50-128
Address: Nuclear Science Center
Texas A&M University
F. E. Box 89
College Station, TX 77843

Supervisor: J. D. Randall Telephone No.: 713-845-7551

Correct as of 9/76

Name: Tuskegee AGN-201
Docket No.: 50-406
Address: Tuskegee Institute
School of Engineering
Tuskegee, AL

Supervisor: Z. W. Dybczak Telephone No.: 205-727-8354

Correct as of 9/76

Name: Union Carbide Nuclear Company Research Reactor
Docket No.: 50-54
Address: Union Carbide Corp.
P. O. Box 324
Tuxedo, NY 10987

Supervisor: W. Fecych Telephone No.: 914-351-2131

Correct as of 9/76

Name: U.S.G.S. TRIGA Reactor
Docket No.: 50-274
Address: U.S. Geological Survey
Mail Stop 424
Box 25046, Federal Center
Denver, CO 80225

Supervisor: Pat Kraker Telephone No.: 303-234-2608

Correct as of 9/76

Name: University of Arizona TRIGA Reactor
Docket No.: 50-113
Address: Room 122, Engineering Building
The University of Arizona
Tucson, AR 85721

Supervisor: Dr. George Nelson Telephone No.: 602-884-2565

Correct as of 9/77

Name: UCLA Training Reactor
Docket No.: 50-142
Address: UCLA School of Engineering
2567 Boelter Hall - N.E.L.
Los Angeles, CA 90024

Supervisor: Mr. Anthony Zane Telephone No.: 213-825-2040

Correct as of 9/76

Name: Berkeley Research Reactor
Docket No.: 50-224
Address: Department of Nuclear Engineering
University of California
Berkeley, CA 94720

Supervisor: Ted H. Lim Telephone No.: 415-642-5213

Correct as of 9/77

Name: Irvine Nuclear Reactor Facility
Docket No.: 50-326
Address: Department of Chemistry
University of California, Irvine
Irvine, CA 92717

Supervisor: G. E. Miller Telephone No.: 714-833-6083

Correct as of 9/77

Name: Santa Barbara L-77 Reactor
Docket No.: 50-443
Address: Regents of the University of California
c/o University of California, Santa Barbara
Santa Barbara, CA 93106

Supervisor: A. E. Profio Telephone No.: 850-961-3788

Correct as of 9/77

Name: University of Florida Training Reactor
Docket No.: 50-83
Address: University of Florida
202 Nuclear Science Building
Gainesville, FL 32601

Supervisor: Dr. N. Diaz Telephone No.: 904-392-1429

Correct as of 9/77

Name: Illinois Advanced TRIGA and LOPRA Reactors
Docket No.: 50-151, 50-356
Address: Nuclear Reactor Lab., University of Illinois
Urbana, IL 61801

Supervisor: Gerald P. Beck Telephone No.: 217-333-0866

Correct as of 9/76

Name: Lowell Technology Institute Reactor
Docket No.: 50-223
Address: University of Lowell
One University Avenue
Lowell, MA 01854

Supervisor: Tom Wallace Telephone No.: 617-458-9081

Correct as of 9/77

Name: University of Kansas Training Reactor
Docket No.: 50-148
Address: Nuclear Reactor Center
University of Kansas
Lawrence, KS 66045

Supervisor: Russel Mesler Telephone No.: 913-864-3938

Correct as of 9/76

Name: Maryland University TRIGA Reactor
Docket No.: 50-166
Address: University of Maryland
College Park, MD 20742

Supervisor: Dr. Jim Sheaks Telephone No.: 301-454-2436

Correct as of 9/77

Name: Ford Nuclear Reactor
Docket No.: 50-2
Address: 2301 Bonistell Blvd.
North Campus
University of Michigan
Ann Arbor, MI 48109

Supervisor: R. Burn Telephone No.: 313-764-6223

Correct as of 9/77

Name: MURR
Docket No.: 50-186
Address: University of Missouri
Columbia, MO

Supervisor: Charles McKibben Telephone No.: 314-882-4012

Correct as of 9/77

Name: University of Missouri Nuclear Reactor Facility
Docket No.: 50-123
Address: University of Missouri, Rolla
Rolla, MO 65401

Supervisor: Alva Elliott Telephone No.: 314-341-4236

Correct as of 9/77

Name: University of New Mexico AGN-201
Docket No.: Nuclear Engineering Laboratory
Address: Department of Chemical & Nuclear Engineering
University of New Mexico
Albuquerque, NM

Supervisor: Dr. Robert Long Telephone No.: 505-277-5431

Correct as of 9/77

Name: University of Oklahoma Reactor
Docket No.: 50-112
Address: Nuclear Reactor Laboratory
NEL Building
University of Oklahoma
Norman, OK 73019

Supervisor: Johnny James Telephone No.: 405-325-5084

Correct as of 9/77

Name: University of Texas TRIGA Reactor
Docket No.: 50-192
Address: Nuclear Reactor Laboratory
University of Texas at Austin
Austin, TX 78772

Supervisor: Dr. Lynn Draper Telephone No.: 512-471-5136

Correct as of 9/77

Name: University of Utah AGN-201 / TRIGA Nuclear Reactor
Docket No.: 50-72, 50-407
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Nuclear Reactor Laboratory
Salt Lake City, UT 84112

Supervisor: G. M. Sandquist Telephone No.: 801-581-7109

Correct as of 9/77

Name: University of Virginia / UVAR, CAVALIER
Docket No.: 50-62, 50-396
Address: University of Virginia
Department of Nuclear Engineering
Charlottesville, VA

Supervisor: Dr. Meem Telephone No.: 804-924-7136

Correct as of 9/77

Name: University of Washington Nuclear Reactor
Docket No.: R-73
Address: Nuclear Reactor
FD-10
University of Washington
Seattle, WA 98105

Supervisor: Dr. A. L. Babb Telephone No.: 206-543-2754

Correct as of 9/77

Name: University of Wisconsin Nuclear Reactor
Docket No.: 50-156
Address: Reactor Laboratory
Mechanical Engineering Building
University of Wisconsin
Madison, WI

Supervisor: R. J. Cashwell Telephone No.: 608-262-3392

Correct as of 9/77

Name: V.A. Hospital TRIGA Teactor
Docket No.: 50-131
Address: 4101 Woolworth Avenue
Omaha, NB 68105

Supervisor: A. J. Blotcky Telephone No.: 346-8800
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Correct as of 9/76

Name: VPISU University Training Reactor
Docket No.: 50-124
Address: Virginia Polytechnic Institute and State University
Nuclear Engineering Group
Blacksburg, VA 24061

Supervisor: Robert Stone Telephone No.: 703-951-6510

Correct as of 9/77

Name: Washington State University TRIGA Reactor
Docket No.: 50-27
Address: Nuclear Radiation Center
Washington State University

Supervisor: Dr. W. E. Wilson Telephone No.: 509-335-8641

Correct as of 9/77

Name: Westinghouse NTR
Docket No.: 50-87
Address: Westinghouse Training Center
505 Shiloh Blvd.
Zion, IL 60099

Supervisor: John M. Roth Telephone No.: 312-872-4585

Correct as of 9/76

Name: WPI Reactor
Docket No.: 50-134
Address: Worcester Polytechnic Institute
Worcester, MA 01609

Supervisor: L. C. Wilbur Telephone No.: 617-753-1411

Correct as of 9/77

INDEX