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INFORMAL REPORT

TMI-2 STANDARD PROBLEM PACKAGE

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ABSTRACT

The TMI-2 accident provides the only full scale integrated facility data for a severe nuclear power reactor data which can at this time be used in bench marking the severe accident computer codes. The TMI-2 Standard Problem Package , including its enclosures, provides the data required to perform the benchmarking calculations. The package is composed of 5 independent but interrelated documents: (1) the plant configuration data base, (2) the sequence of events data base, (3) the initial and boundary conditions data base, (4) the accident scenario and (5) the demonstration calculation.

The TMI-2 accident on March 28, 1979 provides the only full scale integrated facility data upon which to judge the capabilities of the severe accident computer codes such as RELAP/SCDAP. The TMI-2 accident started with a loss of main feedwater to both once-through steam generators (OTSG). This loss of heat sink came about when the main feedwater pumps (MFP) lost suction caused by a loss of both condensate pumps. The main turbine tripped and the auxiliary feedwater pumps (AFWP) started in accordance with plant design. However, the AFW system block valves (EF-V12A and EF-V12B) were in the closed position. Due to the loss of the heat sink, primary system pressure increased rapidly and the pressurizer Electromatic Relief valve (also known as the pilot operated relief valve or PORV) opened. The reactor tripped on high primary system pressure in accordance with plant design and primary pressure system dropped. When primary pressure dropped the PORV should have closed, but remained open. The accident was about 10 seconds old at this point. Without AFW the OTSG's boiled dry in about 1.5 minutes. At 8 minutes the AFW block valves were opened and measurable levels were reestablished in the OTSG's by 25 minutes. By the time that AFW injection was started both primary hot legs had reached saturation temperature. This situation continued until about 74 minutes when the B loop reactor coolant pumps (RCP) were shut down to preclude operation below their net positive suction head. At about 100 minutes the A loop RCP's were shut down for the same reason.

By the time all four RCP's were shut down the primary system had lost a significant portion of its coolant inventory. Shortly after the final pump trip both hot leg temperatures increased above saturation temperature. Thus superheated steam was now being produced in the reactor. At about 139 minutes the PORV block valve was closed and the loss of coolant through this path terminated. At 174 minutes the 2B reactor coolant pump was started and then stopped at 193 minutes due to low motor current. At 200 minutes makeup pumps 1A and 1C were both in operation for a short period of time. At about 260 and 267 minutes make up pumps 1B and 1C were placed into continuous operation. It is generally believed that the reactor was refilled by 300 minutes and the accident was in the recovery phase. This brief sequence of the accident events indicates the severity of the accident in that the core was above the normal subcooled conditions for almost 5 hours and above saturation conditions for about 3 hours.

It is not possible to create from the TMI-2 accident a standard problem in the classic sense. The events on March 28, 1979 were not planned to provide a bench mark data set and the plant instrumentation was intended for normal operations not experiments, and many critical parameters were not recorded. This coupled with the delicate thermal hydraulics of the accident make simulation of the TMI-2 accident a challenge to the severe accident computer codes.

The purpose of this document and it enclosures is to provide sufficient data upon which computer calculations for the first 300 minutes of the accident can be accomplished. The required information is provided in the form of paper documentation, micro computer diskettes and magnetic tape.

The types of information required to perform a computer calculation of the TMI-2 accident are (1) plant configuration data, (2) the sequence of events, far more detailed than the above sequence, during the accident, (3) the initial operating conditions at the time of the turbine trip, (4) the thermal hydraulic boundary conditions during the first 300 minutes of the accident, (5) an accident scenario which provides the best estimate of the events during the accident which are beyond the measurable data, and (6) a demonstration calculation which shows that such a calculation is possible.

The plant configuration data includes the plant geometry and performance parameters and is provided in section 2 of this document. The plant configuration data is provided as a paper data base only. The types of data provided are schematic diagrams of various piping systems, dimensions of pipings systems and components, description of reactor vessel components, data on the reactor core, and performance data for various components.

The sequence of events, initial conditions and boundary conditions data are provided as micro computer data bases. The hardware requirements for these data bases are an IBM PC/AT or XT (or compatible computer) with at least 640K bytes of memory and a math coprocessor. These data bases have been developed in SAGE[1], a scientific, relational data base management system developed at the INEL. The user guides for these data bases are provided in sections 3 and 4. Since not all boundary conditions are available as measured data, missing data are provided on the basis of calculations. The calculated boundary conditions are marked in the data base as estimates. The accident scenario section 5, was not available at the time of publication and will be provided in January, 1987. The remaining section of this document discusses the demonstration calculation performed with the integrated RELAP/SCDAP computer code.

The sequence of events data base (SOE) provides the timing at which various events occurred during the accident (Many of which were operator initiated). The SOE is based on the GPU sequence of events[2], and has been corrected where the plant data taken during the accident indicates the GPU sequence to be in error. Notations have been made in the data base to identify these corrections.

The initial and boundary conditions (ICBC) data base provides the required initial conditions for initiation of the calculation at turbine trip, 100 minutes and 174 minutes into the accident and the boundary conditions. While the initial conditions at turbine trip were readily available, the conditions at 100 and 174 minutes require the use of some estimated parameters. In particular the primary coolant system (PCS) mass inventory is provided as a calculated value. The HPI/makeup and letdown flows and auxiliary feedwater flow were not measured. These flows are significant to primary and secondary system mass inventory. Calculated flows have been provided as the best estimate or bounding set of values. The process by which the quality of the data and the categories of data quality were developed are discussed in the initial and boundary conditions user guide.

The demonstration calculation was performed using the integrated RELAP/SCDAP computer code. Auxiliary feed was calculated by the code based on a steam generator level control system. That is the AFW flow rate was calculated by the code so as to match a specified steam generator level. A discussion of the calculation is provided as the last section of the package. In general the calculation compares well to the data, is consistent with our conceptions of the accident and demonstrates that an integrated calculation of the accident is possible. The calculation indicated that steam generator heat transfer was one of the most dominant influences on the accident along with the mass inventory loss through the pressurizer relief valve. Small changes in AFW flow rates appear to have a significant impact on the primary system. This behavior is still being examined.

REFERENCES

1. H. B. Stewart and K. D. Russell, MODULA2 Tools and Utilities, to be published.

2. T. L. Van Witbeck et. al., THREE MILE ISLAND UNIT II ANNOTATED SEQUENCE OF EVENT MARCH 28, 1979, GPU TDR 044, February 1981.

TABLE OF CONTENTS

NOTE: References for figures and tables are in ( ) following descriptio

CORE DATA

description	value	reference
Fuel Pellets		
Diameter, in.	0.370	2
length, in.	0.70	1
Material	UO_2	2
Density,% of theoretical	92.5	2
Fuel Rods		
Outside diameter, in.	0.430	2
Wall thickness, in.	0.0265	2
Diametral gap, in.	0.007	2
Length, in.	153.125	2
Pitch, in.	0.568	2
Material, cladding & end plugs	zirc 4	2
Fuel Assemblies		
Cross section, in.	8.54 X 8.54	1
Total length, in.	165.6	2
Active length, in.	144	2
Fuel rods	208	2
Guide tubes	16	2
Instrument tubes	1	2
Grid spacers, equally spaced	8	2
Core		
Heated flow area, ft^2.	49.2	2
Core coolant ave. vel, ft/sec.	16.52	2
Heat transfer surface, ft^2.	49,734	2
Ave. temp. rise in core, F.	53.6	1
Hot channel outlet temp., F.	649.5	1
Core coolant vol.(total), ft^3.	722	2
Fuel centerline temp.(max), F.	4170	2
Fuel temperature (ave), F	1200	2

Table 1.0

Volume Data

description	value	reference
Reactor Vessel		
Lower plenum, ft^3.	292	2
Core, ft^3.	722	2
Downcomer, ft^3.	1225	2
Upper plenum, ft^3.	776	2
Upper head, ft^3.	508	2
Steam Generator		
Lower plenum, ft^3.	277	2
Upper plenum, ft^3.	281	2
Secondary side, ft^3.	3412	3
Pressurizer (at 220 in. water level)		
Water volume, ft^3.	800	3
Steam volume, ft^3.	700	3
Cold Leg, each, ft^3.	237.5	3
Hot Leg, each, ft^3.	469	3
Reactor Coolant Pumps, each, ft^3	98	3
Surge Line, ft^3.	20	3
Spray Line, ft^3.	2	3
Core Flood Tank, each, ft^3.	1410	2
Make-up Tank, ft^3.	400	6
Reactor Coolant Drain Tank, ft^3	920	6
Containment		
Free volume, ft^3.	2.116×10^6	4
Sprayed volume, ft^3.	1.629×10^6	4

Table 2.0

CORE DATA

description	value	reference
Fuel Pellets		
Diameter, in.	0.370	2
length, in.	0.70	1
Material	UO_2	2
Density,% of theoretical	92.5	2
Fuel Rods		
Outside diameter, in.	0.430	2
Wall thickness, in.	0.0265	2
Diametral gap, in.	0.007	2
Length, in.	153.125	2
Pitch, in.	0.568	2
Material, cladding & end plugs	zirc 4	2
Fuel Assemblies		
Cross section, in.	8.54 X 8.54	1
Total length, in.	165.6	2
Active length, in.	144	2
Fuel rods	208	2
Guide tubes	16	2
Instrument tubes	1	2
Grid spacers, equally spaced	8	2
Core		
Heated flow area, ft^2.	49.2	2
Core coolant ave. vel, ft/sec.	16.52	2
Heat transfer surface, ft^2.	49,734	2
Ave. temp. rise in core, F.	53.6	1
Hot channel outlet temp., F.	649.5	1
Core coolant vol.(total), ft^3.	722	2
Fuel centerline temp.(max), F.	4170	2
Fuel temperature (ave), F	1200	2

Table 1.0

Volume Data

description	value	reference
Reactor Vessel		
Lower plenum, ft^3.	292	2
Core, ft^3.	722	2
Downcomer, ft^3.	1225	2
Upper plenum, ft^3.	776	2
Upper head, ft^3.	508	2
Steam Generator		
Lower plenum, ft^3.	277	2
Upper plenum, ft^3.	281	2
Secondary side, ft^3.	3412	3
Pressurizer (at 220 in. water level)		
Water volume, ft^3.	800	3
Steam volume, ft^3.	700	3
Cold Leg, each, ft^3.	237.5	3
Hot Leg, each, ft^3.	469	3
Reactor Coolant Pumps, each, ft^3	98	3
Surge Line, ft^3.	20	3
Spray Line, ft^3.	2	3
Core Flood Tank, each, ft^3.	1410	2
Make-up Tank, ft^3.	400	6
Reactor Coolant Drain Tank, ft^3	920	6
Containment		
Free volume, ft^3.	2.116×10^6	4
Sprayed volume, ft^3.	1.629×10^6	4

Table 2.0

FLOW DATA

description	value	reference
Total Reactor Flow, lb/hr.	137.8 E10	2
Average Flow Path Lengths, ft.		
Hot Leg	66	2
Cold Leg	53	2
Steam Generator	70	2
Reactor Vessel	70	2
Reactor Coolant Pump	18	2
Coolant Velocity, ft/sec.		
Cold Leg	48.2	3
Hot Leg	63.8	3
Core	16.52	2
Reactor Coolant System Pressure Drop, psi.	120.4	3
Reactor Coolant Pump Flow, % design		
3 pumps	74.4	2
2 pumps, 1 each loop	48.5	2
Reactor Coolant Pumps		
4 pumps, gpm/pump	92,400	3
Maximum Letdown Flow, gpm.	140	6
High Pressure Injection		
3 pumps, gpm/pump	300	6
Low Pressure Injection		
2 pumps, gpm/pump	3000	4
Emergency Steam Generator Feed (Auxiliary Feedwater)		
2 motor pumps, gpm/pump	470	5
1 turbine pump, gpm/pump	940	5
Reactor Building Spray		
2 pumps, gpm/pump	1500	4

Table 3.0

SAFETY AND RELIEF VALVE DATA

description	value	reference
Pressurizer Code Safety Valves		
Pressure setpoint, psig.	2450	3
Capacity, lb/hr., total	690,000	3
Pressurizer PORV		
Open, psig.	2255	3
Close, psig.	2205	3
Capacity, lb/hr.	112,000	3
Pressurizer Spray Valve		
Open, psig.	2205	3
Close, psig.	2155	3
Secondary Steam Relief Valves/generator		
4 ea. open, psig.	1050	5
2 ea. open, psig.	1065	5
2 ea. open, psig.	1075	5
2 ea. open, psig.	1102	5
Reactor Coolant Drain Tank		
Relief valve setpoint, psig.	150	3
Relief valve capacity, gpm.	2270	3
Burst disc burst pressure, psig.	195	3
Burst disc capacity, lb/sec steam	472	3

NOTE: Secondary steam relief valve capacity, at 1050 psig. and 600 F is 6,340,936 lb/hr. or 120% of a reactor power level of 2772 Mwt. plus the 16 Mwt. contribution of the reactor coolant pumps.

Table 4.0

COMPONENT HEAT LOSS DATA

description	value	reference
Reactor vessel, btu/hr.	356,200	4
Control rod drives, btu/hr.	500,000	4
Steam generators, btu/hr.	418,000	4
Pressurizer, btu/hr.	332,000	4
Reactor coolant pumps, btu/hr.	390,000	4
Reactor coolant piping, btu/hr.	435,000	4
Main steam piping, btu/hr.*	450,000	4
Feedwater piping, btu/hr.*	208,000	4

* inside containment

NOTE: Insulation is all metal reflective insulation fabricated from austinetic stainless steel.

Table 5.0

VALVE LIST FOR TMI-2 STANDARD PROBLEM

Identity[1]	Size	Description	Function/Remarks
REACTOR COOLING SYSTEM			
Pressurizer PORV Line			
{Pressurizer steam dome}			
RC-V2	2.5	MO gate [2]	Block Valve (NO) [3]
RC-R2	2.5	PORV	Pressure relief, opens @ 2255 psig, closes @ 2205
{Reactor Coolant Drain Tank header}			
Pressurizer Spray Line			
{Reactor Coolant Pump RC-P-2A outlet}			
RC-V108	2.5	Manual gate	(NO)
RC-V1	2.5	MO globe	Operator or Auto-control on RCS pressure
RC-V3	2.5	MO gate	(NO)
{Pressurizer Spray Nozzle}			
Pressurizer Vent [4]			
{Pressurizer steam dome}			
RC-V114	1	Manual gate	(NC) [5]
RC=V115	1	Manual globe ???	(NC)
{Reactor Building Vent Header}			
Letdown Line			
{RC-P-1A Inlet Line}			
RC-V121	2.5	Manual globe	Block Valve
MU-V1A	2.5	MO gate	Inlet to Letdown Cooler MU-C-1A
MU-V2A	2.5	MO gate	Outlet from Letdown Cooler MU-C-1A. (ES) [6]
MU-V1B	2.5	MO gate	Inlet to Letdown Cooler MU-C-1B
MU-V2B	2.5	MO gate	Outlet from Letdown Cooler MU-C-1B (ES)
MU-V376	2.5	MO globe	(ES)

NOTE: All data in table 6.0 taken from reference 7.

Table 6.0

VALVE LIST FOR TMI-2 STANDARD PROBLEM

Identity[1]	Size	Description	Function/Remarks
MU-V100	2.5	Manual gate	Letdown Block Orifice (NC)
MU-V4	1.5	AO gate [?]	Let Down Block Orifice flow control.
MU-V102	1.5	Manual gate	Letdown Block Orifice flow block
MU-V101	2.5	Manual gate	Isolate bypass control valve.
MU-V5	2.5	AO gate	Letdown Block Orifice bypass control.
MU-V103	2.5	Manual gate	Isolate bypass control valve.
{MU-4-FE}	2.5	Flow Nozzle	Probably a venturi or calibrated orifice.
{Purification Demineralization complex}			
{Make Up Tank}			
Safety Injection to Cold Leg 1A			
{Make Up Pump and flow distribution network}			
{MU23-FE4}	2.5	Flow Nozzle	Probably a venturi or calibrated orifice.
MU-V16D	2.5	MO Globe	(SE) Safety Injection Control
MU-V402D	2.5	Check	Prevent backflow.
MU-V152D	2.5	Check	Prevent backflow.
{Cold Leg 1A}			
Safety Injection to Cold Leg 2A			
{Make Up Pump and flow distribution network}			
{MU23-FE3}	2.5	Flow Nozzle	Probably a venturi or calibrated orifice.
MU-V16C	2.5	MO Globe	(SE) Safety Injection Control
MU-V402C	2.5	Check	Prevent backflow.
MU-V152C	2.5	Check	Prevent backflow.
{Cold Leg 2A}			
Safety Injection and Normal Make Up to Cold Leg 1B			
{Make Up Pump and flow distribution network}			
{MU23-FE2}	2.5	Flow Nozzle	Probably a venturi or calibrated orifice.
MU-V16B	2.5	MO Globe	(SE) Safety Injection Control
MU-V492B	2.5	Check	Prevent backflow.
MU-V152B	2.5	Check	Prevent backflow.

Table 6.0 (cont)

VALVE LIST FOR TMI-2 STANDARD PROBLEM

Identity[1]	Size	Description	Function/Remarks
{Make Up Pump and flow distribution network}			
{MU24-FE}	2.5	Flow Nozzle	Probably a venturi or calibrated orifice.
MU-V153	2.5	Manual gate	Isolate MU-V17.
MU-V17	2.5	AO globe	Normal make up control.
MU-V154	2.5	Manual gate	Isolate MU-V17.
MU-V155	2.5	Manual globe	Bypass MU-V17.
MU-V18	2.5	AO gate	(ES) Normal make-up block.
MU-V402B	2.5	Check	Prevent backflow.
MU-V152B	2.5	Check	Prevent backflow.
{Cold Leg 1B}			
Safety Injection to Cold Leg 2B			
{Make Up Pump and flow distribution network}			
{MU23-FE1}	2.5	Flow Nozzle	Probably a venturi or calibrated orifice.
MU-V16A	2.5	AO globe	(ES) Safety Injection Control.
MU-402A	2.5	Check	Prevent backflow.
MU-152A	2.5	Check	Prevent backflow.
{Cold Leg 2B}			

Table 6.0 (cont)

VALVE LIST FOR TMI-2 STANDARD PROBLEM

Identity[1]	Size	Description	Function/Remarks

SECONDARY SYSTEM

Main Steam Supply to High Pressure Turbine

{Steam Generator RC-H-1A}

MS-V4A	24	MO globe	Steam generator isolation.
MS-V7A	24	MO globe	Steam generator isolation.

{Steam Chest R. H.}

{Steam Generator RC-H-1B}

MS-V4B	24	MO globe	Steam generator isolation.
MS-V7B	24	MO globe	Steam generator isolation.

{Steam Chest L. H.}

{H. P. Turbine}

Loop A Turbine Bypass

{Main steam trunk lines, connected via individual 8 in. lines to a common 10 in. turbine bypass line.}

MS-V15A	10	MO globe	Steam generator isolation.
MS-V17	4	Manual gate	Gland Steam Seal System steam supply. (NO)
MS-V18	4	Check	Prevent backflow.

{Gland Steam Seal System.}

MS-V21A	4	Manual gate	Steam supply to Feedpump Turbine Drive. (NC)

{FW-11B}

MS-V36A	6	Manual Gate	LP Turbine A heat supply block.
MS-V37A	6	AO gate	LP Turbine A heater control.

{Moisture Separator Reheater MO-T-1A}

MS-V36B	6	Manual Gate	LP Turbine B heat supply block.
MS-V37B	6	AO gate	LP Turbine B heater control.

{Moisture Separator Reheater MO-T-1B}

MS-V23A	10	MO gate	Turbine bypass block. (NO)
MS-V25A	8	AO gate	Turbine bypass control.

{Surface Condenser "H" Hot CO-C-1B}

MS-V24A	10	MO gate	Turbine bypass block. (NO)
MS-V26A	8	AO gate	Turbine bypass control.

{Surface Condenser "H" Hot CO-C-1B}

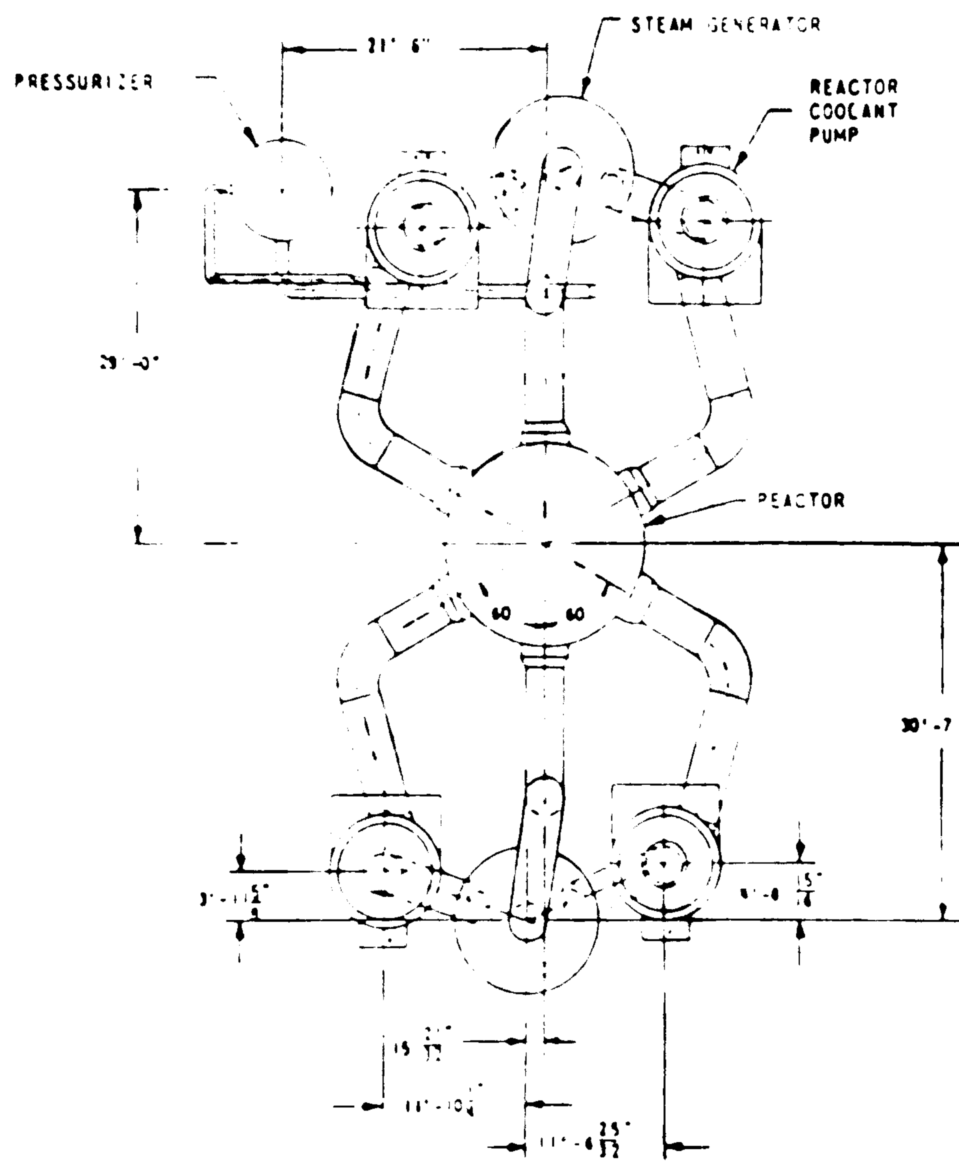
Table 6.0 (cont)

VALVE LIST FOR TMI-2 STANDARD PROBLEM

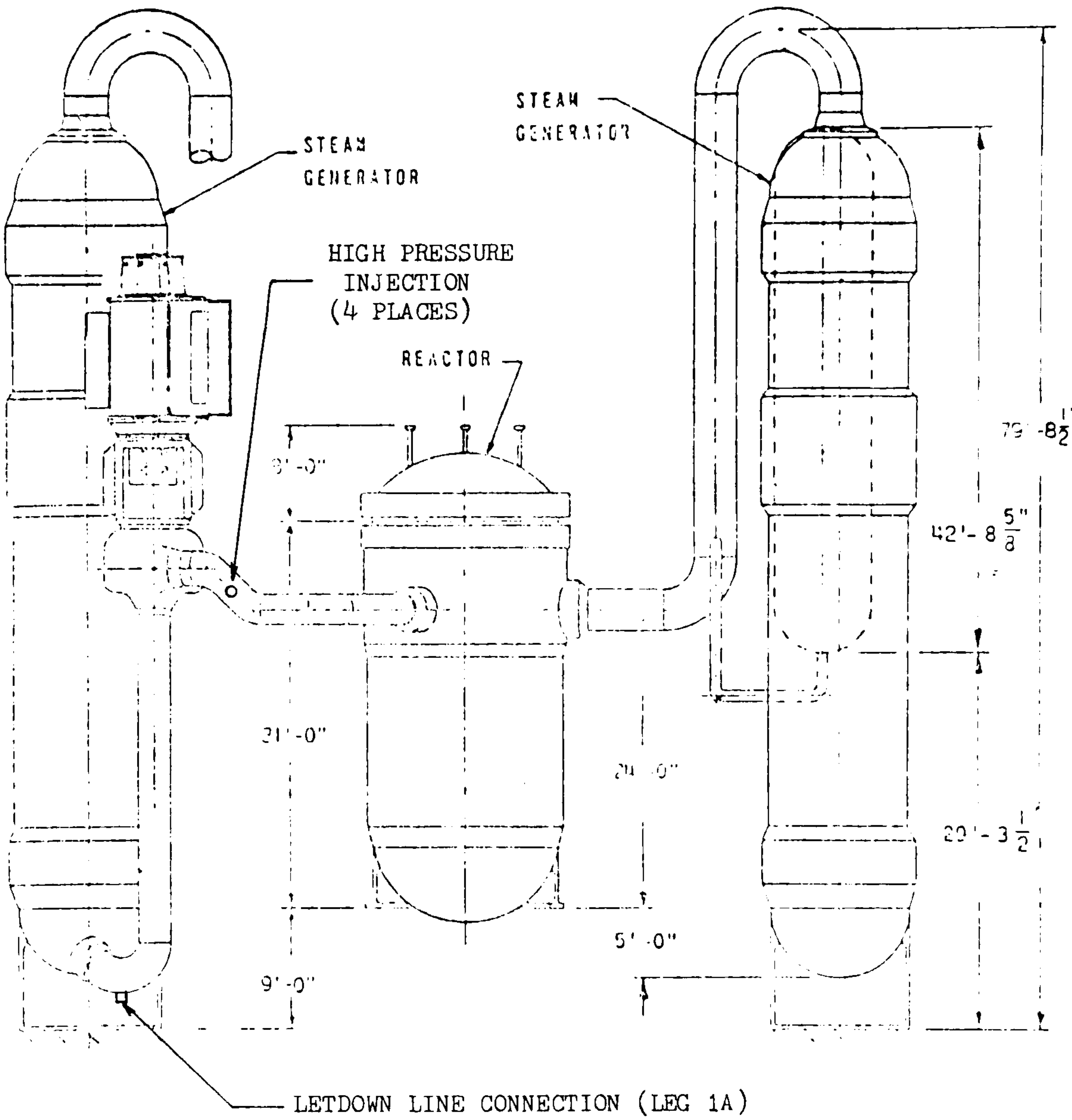
Identity[1]	Size	Description	Function/Remarks
Loop B Turbine Bypass			
{Main steam trunk lines, connected via individual 8 in. lines to a common 10 in. turbine bypass line.}			
MS-V15B	10	MO globe	Steam generator isolation.
MS-V21B	4	Manual gate	Steam supply to Feedpump Turbine Drive. (NC)
{FW-U1A}			
MS-V23B	10	MO gate	Turbine bypass block. (NO)
MS-V25A	8	AO gate	Turbine bypass control.
{Surface Condenser "H" Hot CO-C-1B}			
MS-V24B	10	MO gate	Turbine bypass block. (NO)
MS-V26B	8	AO gate	Turbine bypass control.
{Surface Condenser "H" Hot CO-C-1B}			
Steam Generator A Atmospheric Dump			
{Outlet Steam Generator A}			
MS-V1A	6	Manual gate	Steam dump block valve. (NO)
MS-V3A	6 in/8 out	AO gate	Steam dump to atmosphere.
{MS-U7A}	8 in/10 out		Muffler
Steam Generator B Atmospheric Dump			
{Outlet Steam Generator B}			
MS-V1B	6	Manual gate	Steam dump block valve. (NO)
MS-V3B	6 in/8 out	AO gate	Steam dump to atmosphere.
{MS-U7B}	8 in/10 out		Muffler

[1] Items are ordered according to normal flow direction. When a path branches, elements of each branch are grouped and then parallel groups are indented. Non-valve items, enclosed in braces {}, are included for clarity.
[2] MO = Motor operated.
[3] NO = Normally open.
[4] The pressurizer vent line was not active during the accident.
[5] NC = Normally closed.
[6] ES = controlled by Engineered Safety System.
[7] AO = Air (pneumatic) operated.

Table 6.0 (cont)



REACTOR COOLANT SYSTEM ARRANGEMENT – PLAN



REACTOR COOLANT SYSTEM ARRANGEMENT - ELEV

TABLE 7

REACTOR COOLANT SYSTEM PARAMETERS

Total core power output, MWt	2772
Design system flow, 10^6 lb/h	137.8
Design core flow available for heat transfer, 10^6 lb/h	129.5
Reactor vessel inlet temp, F (at 100% power)	557
Reactor vessel outlet temp, F (at 100% power)	607.7
Core flow area available for heat transfer, ft^2	49.2
Reactor coolant system press. drop, psi	120.4
Unrecoverable core press. drop, psi	18.7
Average core coolant velocity, ft/s	16.5
Cold leg coolant velocity, ft/s	48.2
Hot leg coolant velocity, ft/s	63.8

TABLE 8

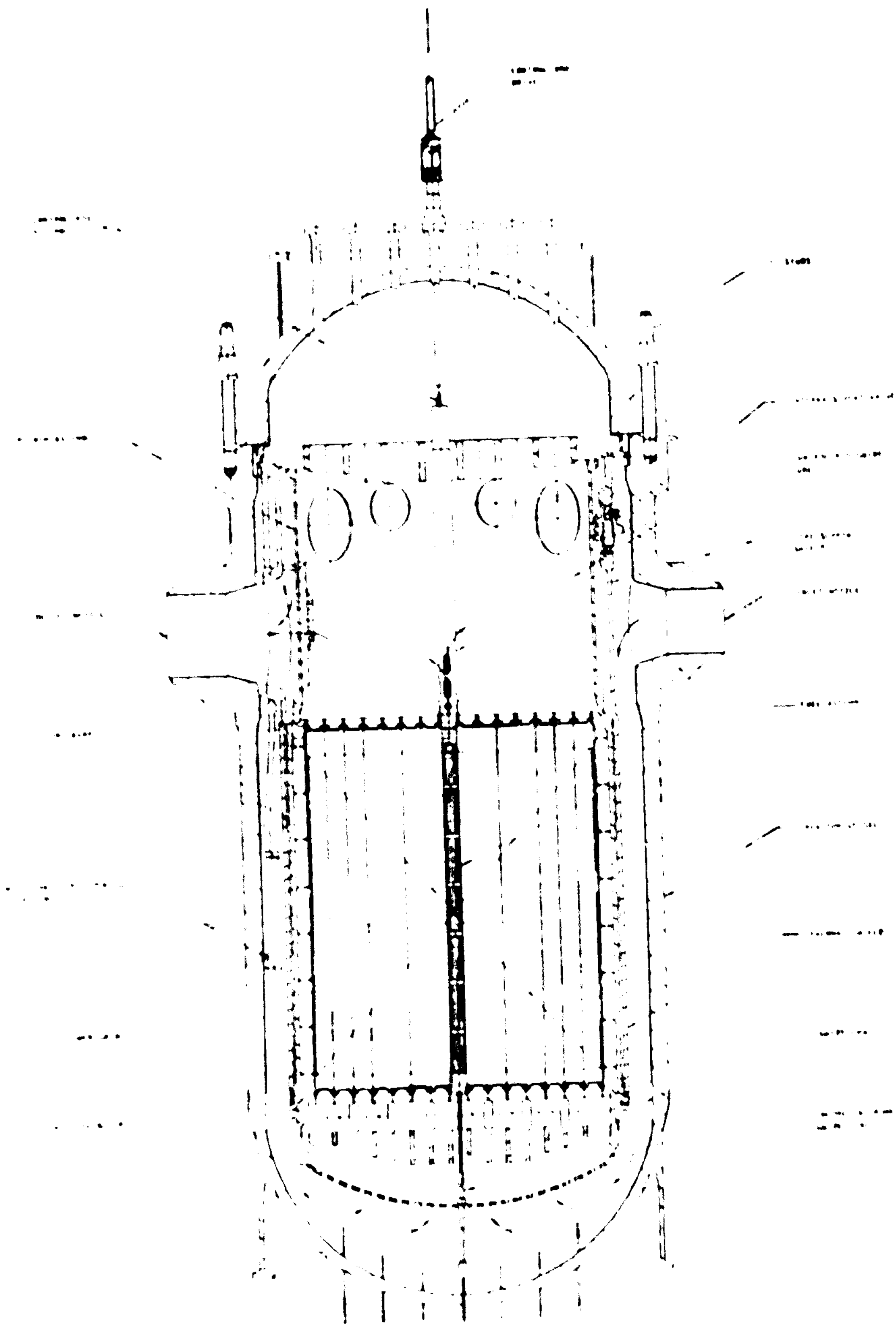
PRIMARY SYSTEM COMPONENT ELEVATIONS

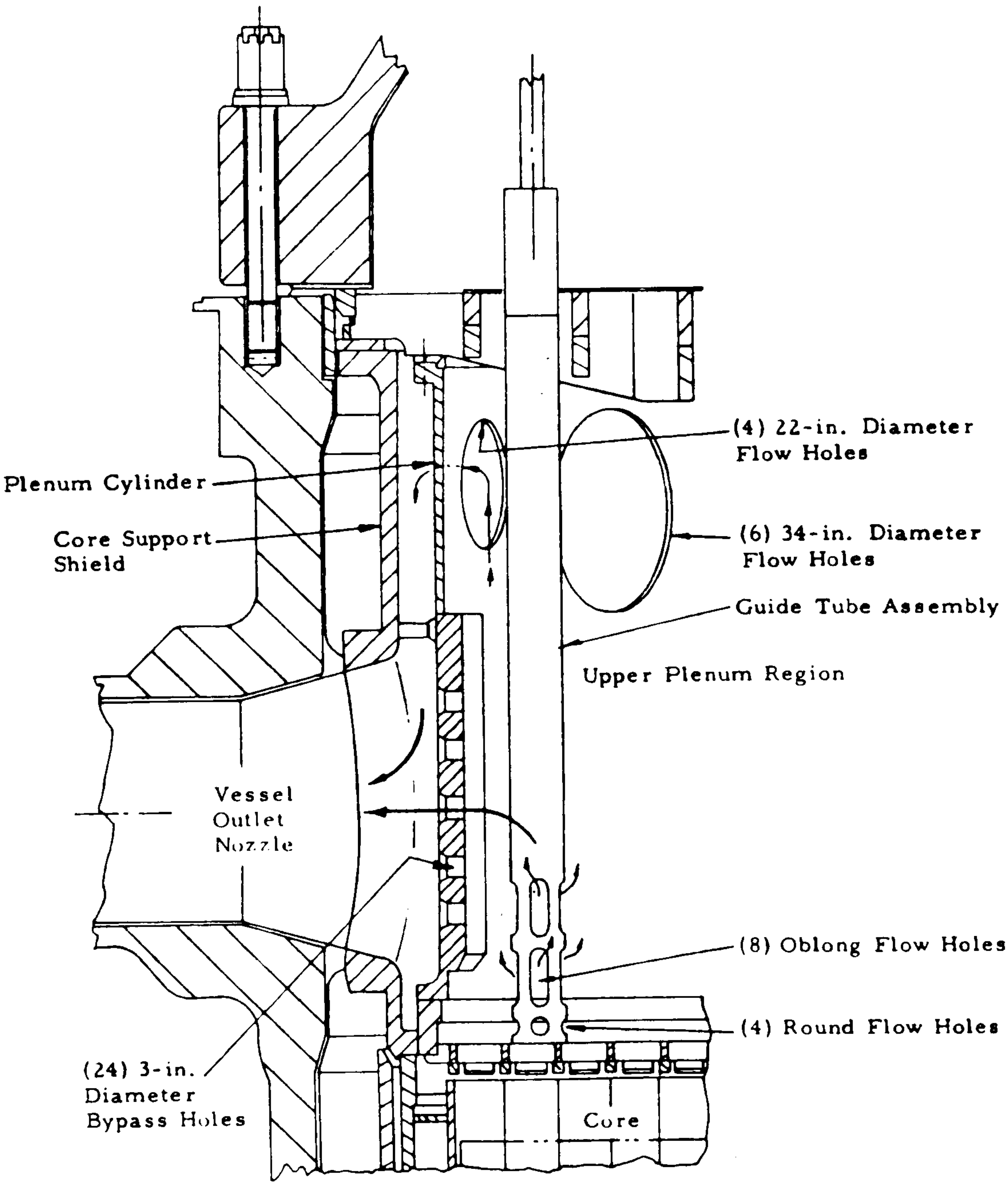
Component	Elevation, ft-in.
Reactor outlet piping	0-0
Reactor vessel lower head	(-)24-0
Steam generator lower head	(-)29-0
Pressurizer lower head	(-) 3-6.5
RC pump discharge piping	(+) 3-0

TABLE 9

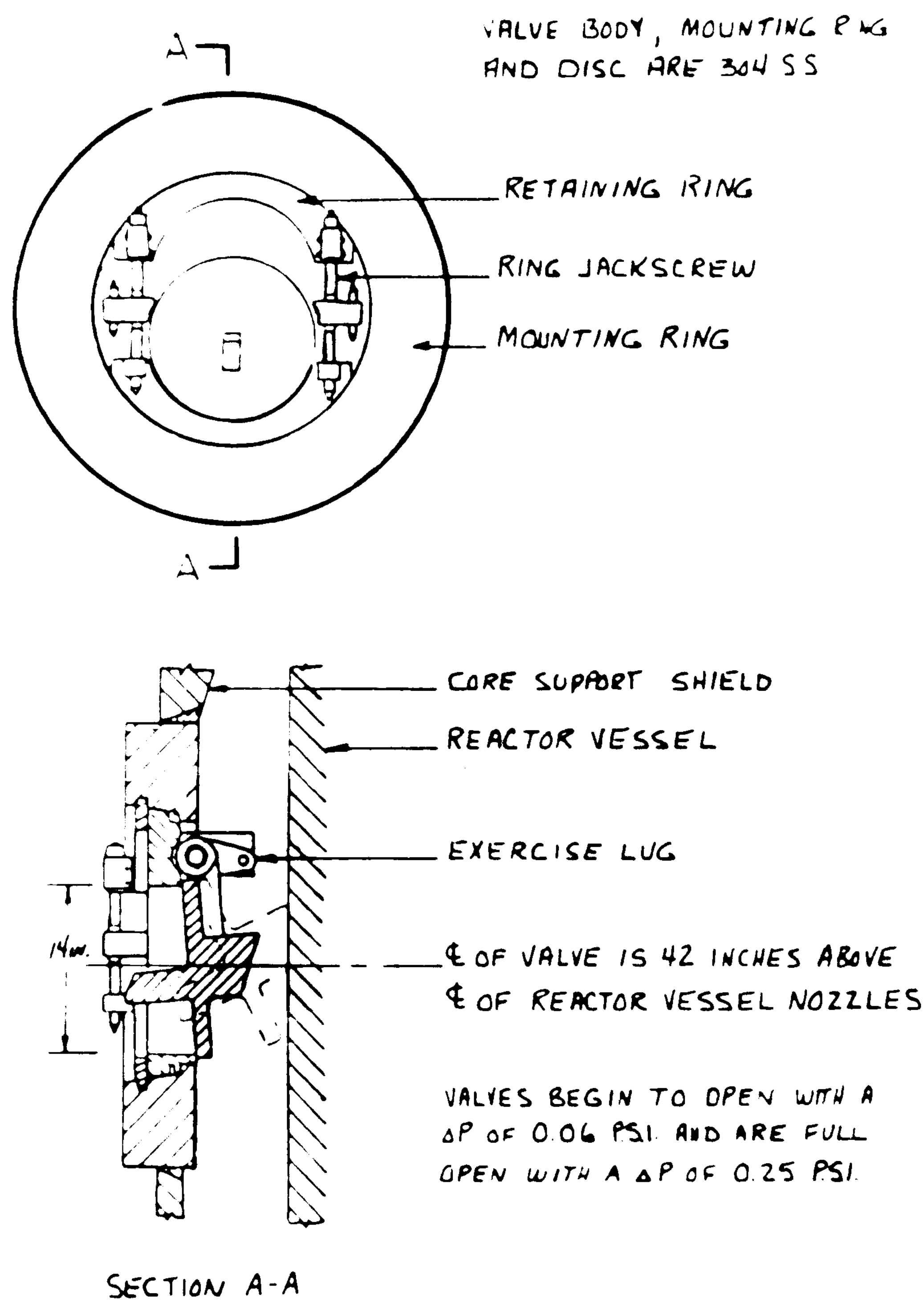
REACTOR VESSEL DESIGN DATA

Item	Data
Design/operating pressure, psig	2500/2185
Hydrotest pressure (cold), psig	3125
Design/operating temperature, F	650/608
Overall height of vessel and closure head, ft/in.	40/8-7/8
Straight shell minimum thickness, in.	8-7/16
Water volume (core and internals in place), ft^3	4010
Thickness of insulation, in.	4
Number of reactor closusure head studs	60
Flange ID, in.	167-1/2
Shell ID, in.	171
Inlet nozzle ID, in.	28
Outlet nozzle ID, in.	36
Core flooding water nozzle ID, in.	11-1/2
Diameter of reactor closure head studs, in.	6-1/2
Coolant operating temperature inlet/outlet, F	557/608
Reactor coolant flow, lb/h	137.90×10^6
Shell cladding minimum thickness, in.	1/8
Shell cladding nominal thickness, in.	3/16
Closure head minimum thickness, in.	6.625
Lower head minimum thickness, in.	5
Control rod drive nozzles ID, in.	2.76
Axial power shaping rod drive nozzles ID, in.	2.76
Incore instrumentation nozzles sched. 160 ID, in.	3/4
Dry weight, lb (estimated)	
Vessel	678,600
Closure head	162,500
Studs, nuts, and washers	40,200





UPPER PLENUM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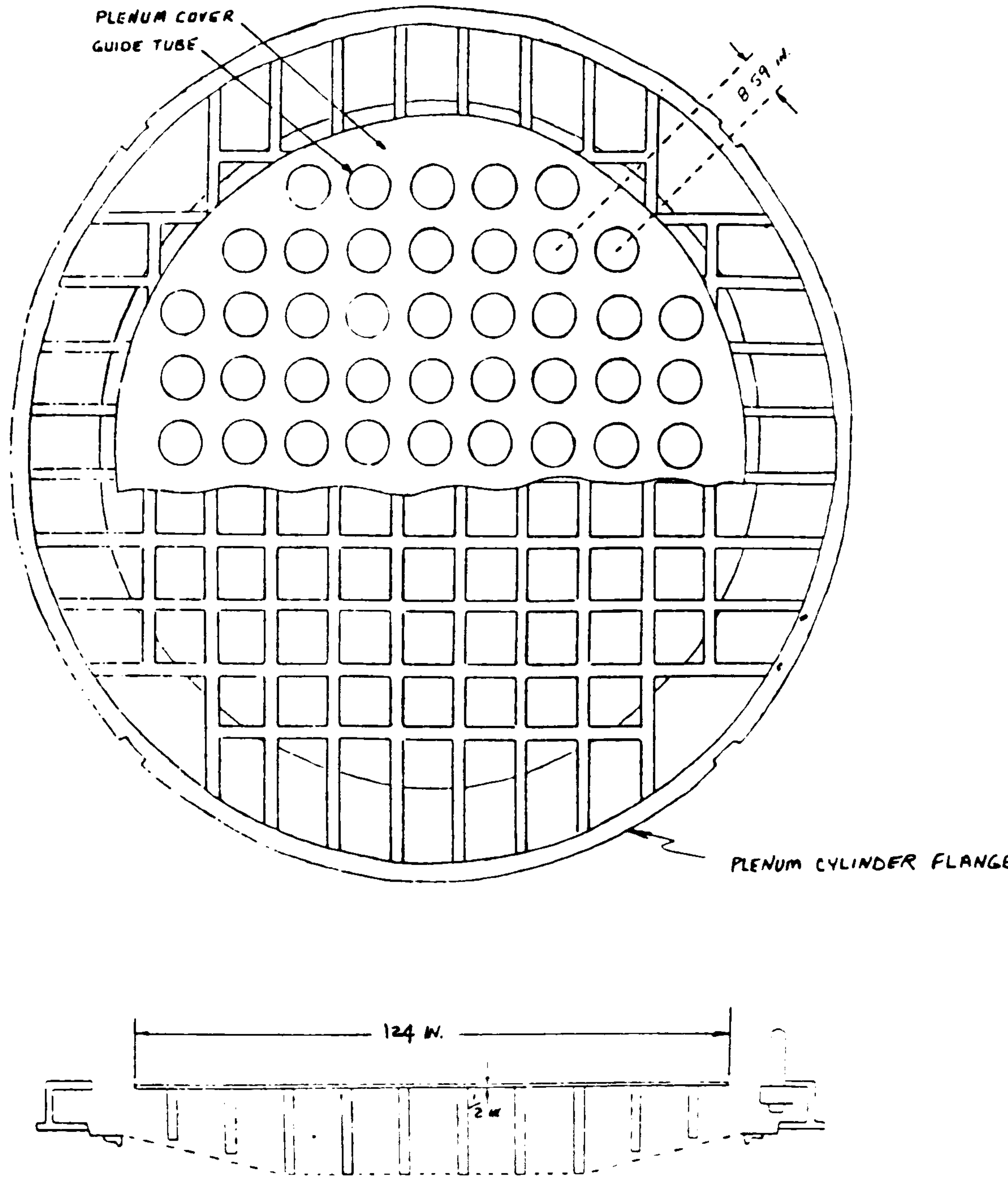
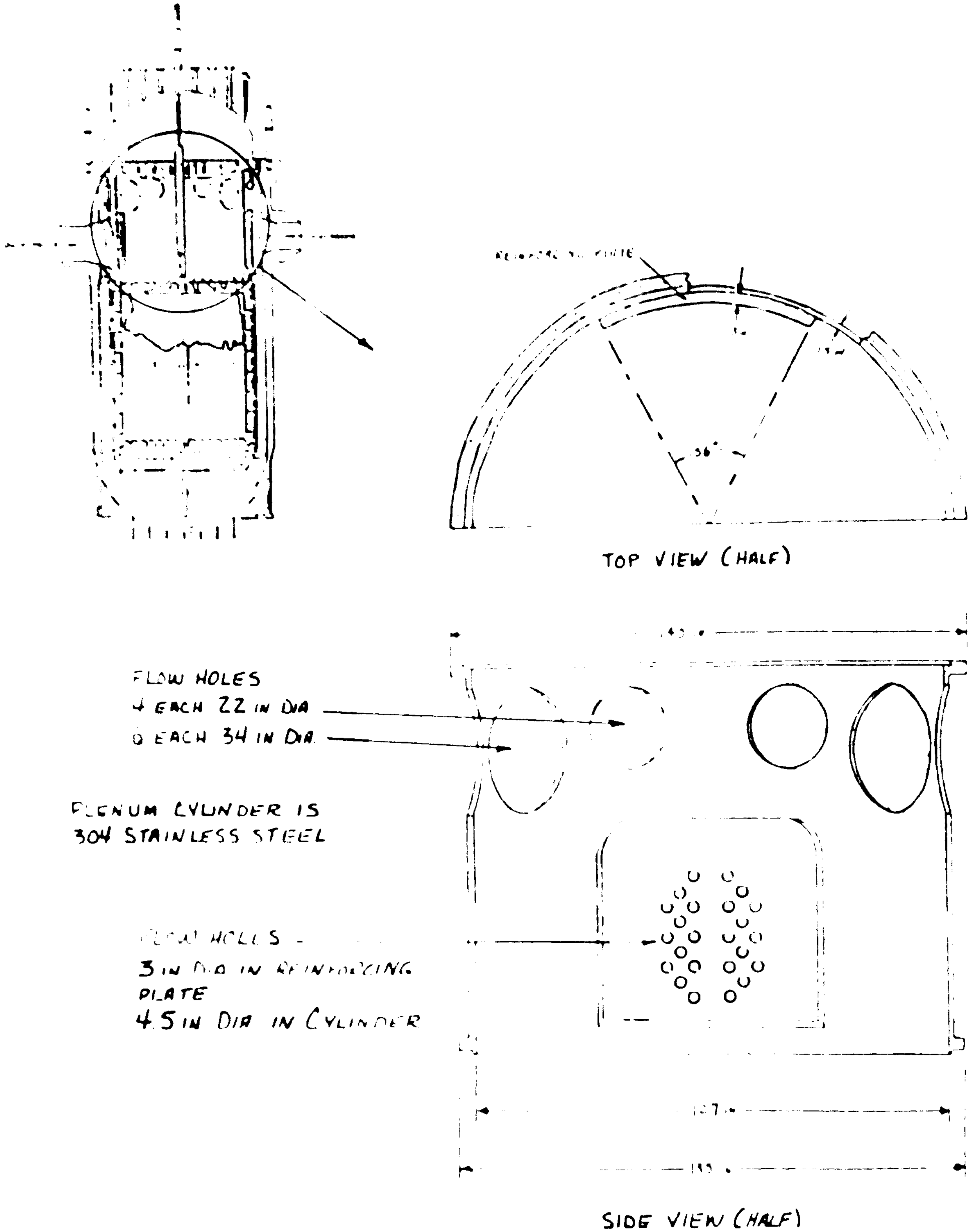
AND DISC ARE 304 SS
A
RETAINING RING
RING JACKSCREW
MOUNTING RING
A
CORE SUPPORT SHIELD
REACTOR VESSEL
EXERCISE LUG
14 in.
℄ OF VALVE IS 42 INCHES ABOVE
℄ OF REACTOR VESSEL NOZZLES
VALVES BEGIN TO OPEN WITH A
ΔP OF 0.06 PSI. AND ARE FULL
OPEN WITH A ΔP OF 0.25 PSI.
SECTION A-A

VENT VALVE

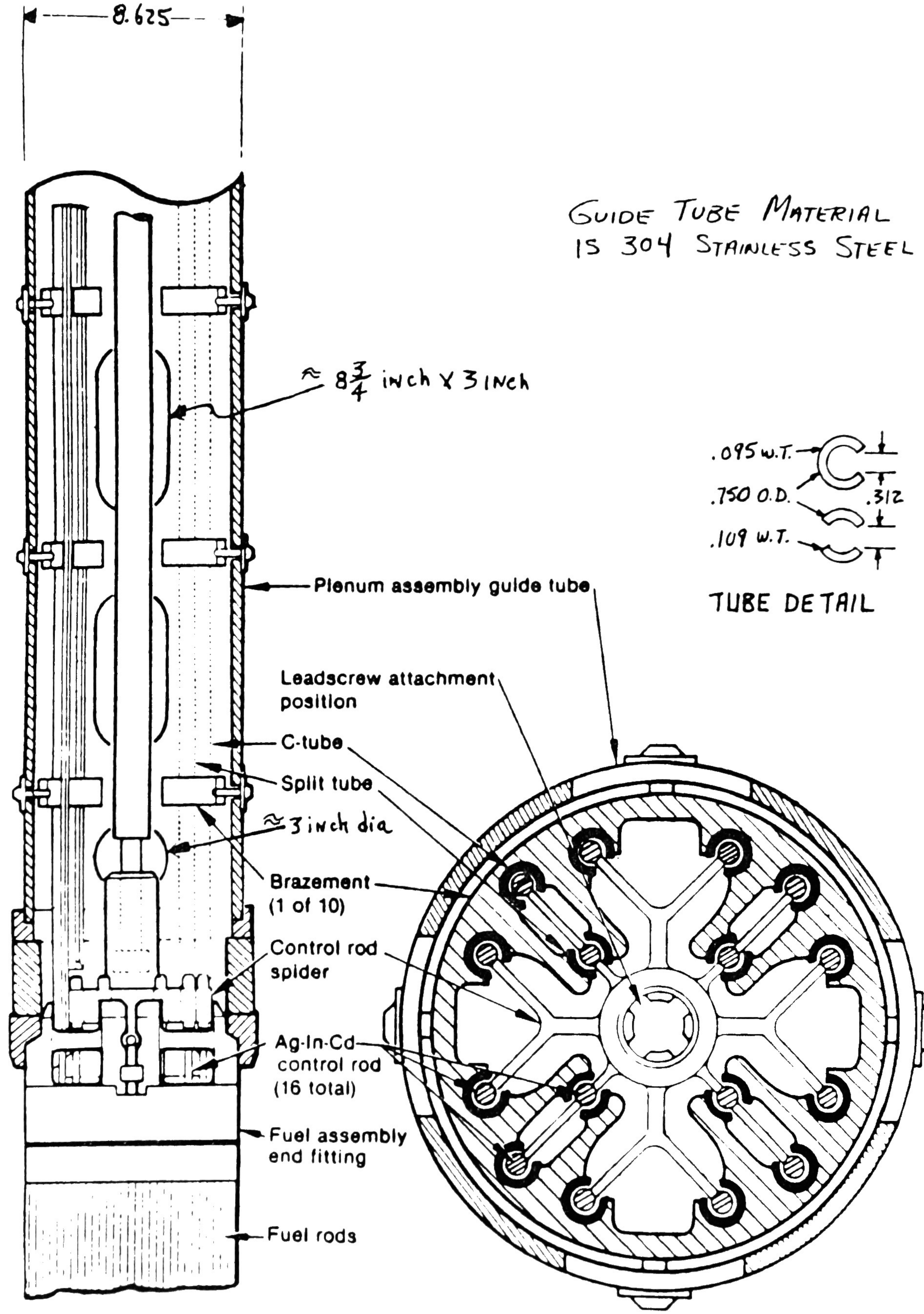
PLENUM COVER MATERIAL IS 304 STAINLESS STEEL



UPPER PLENUM COVER

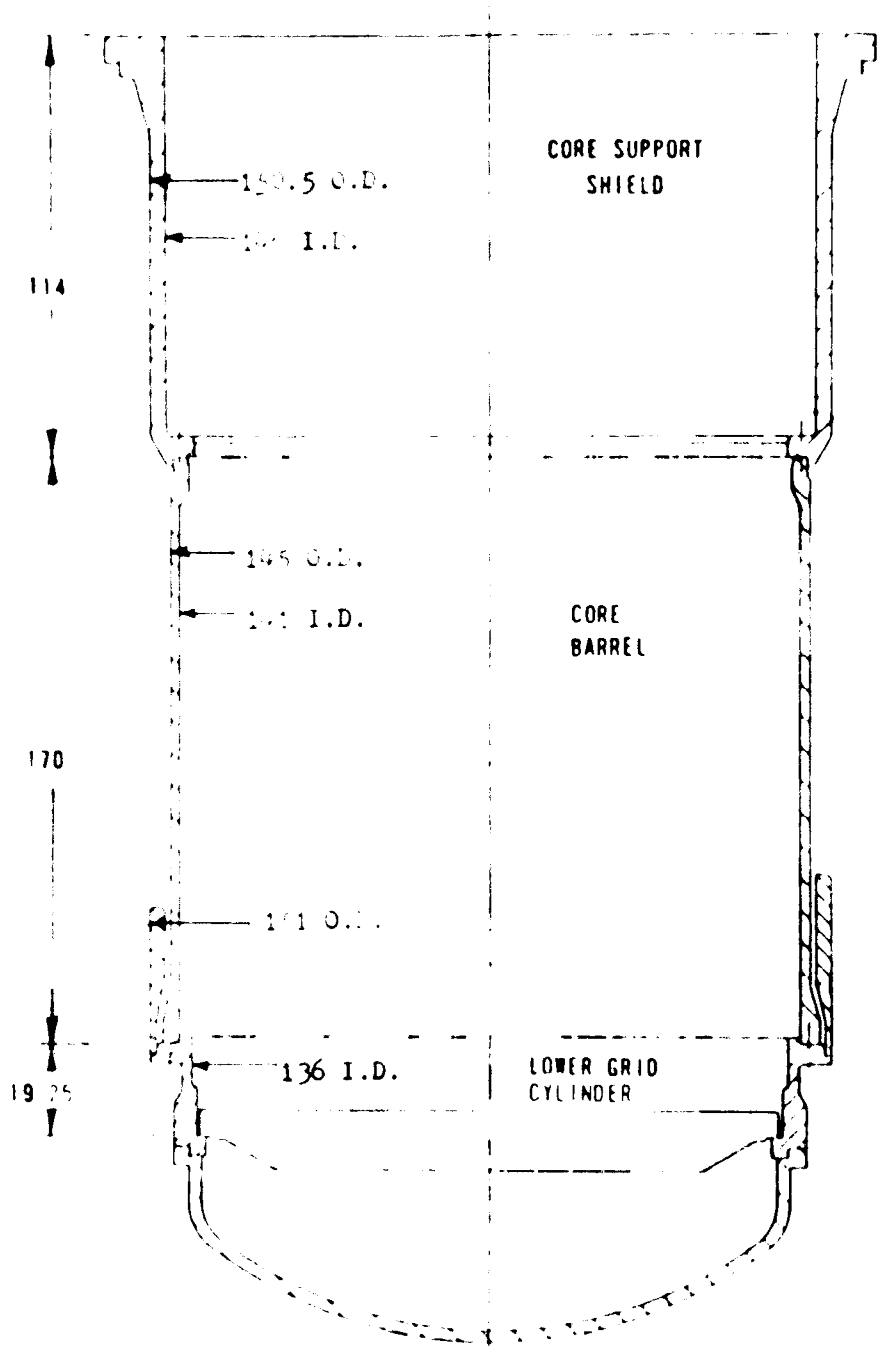


PLENUM CYLINDER



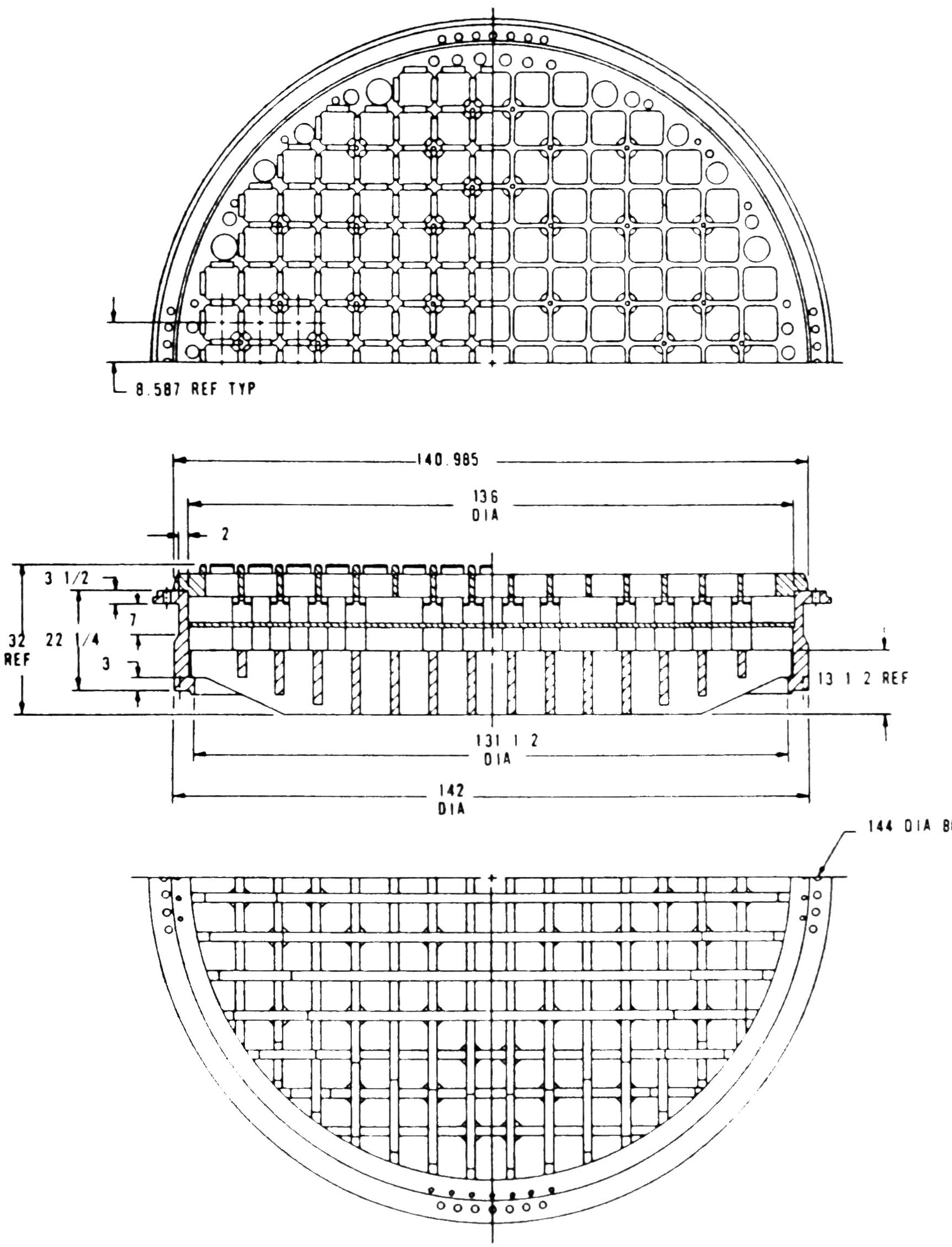
CONTROL ROD GUIDE TUBE

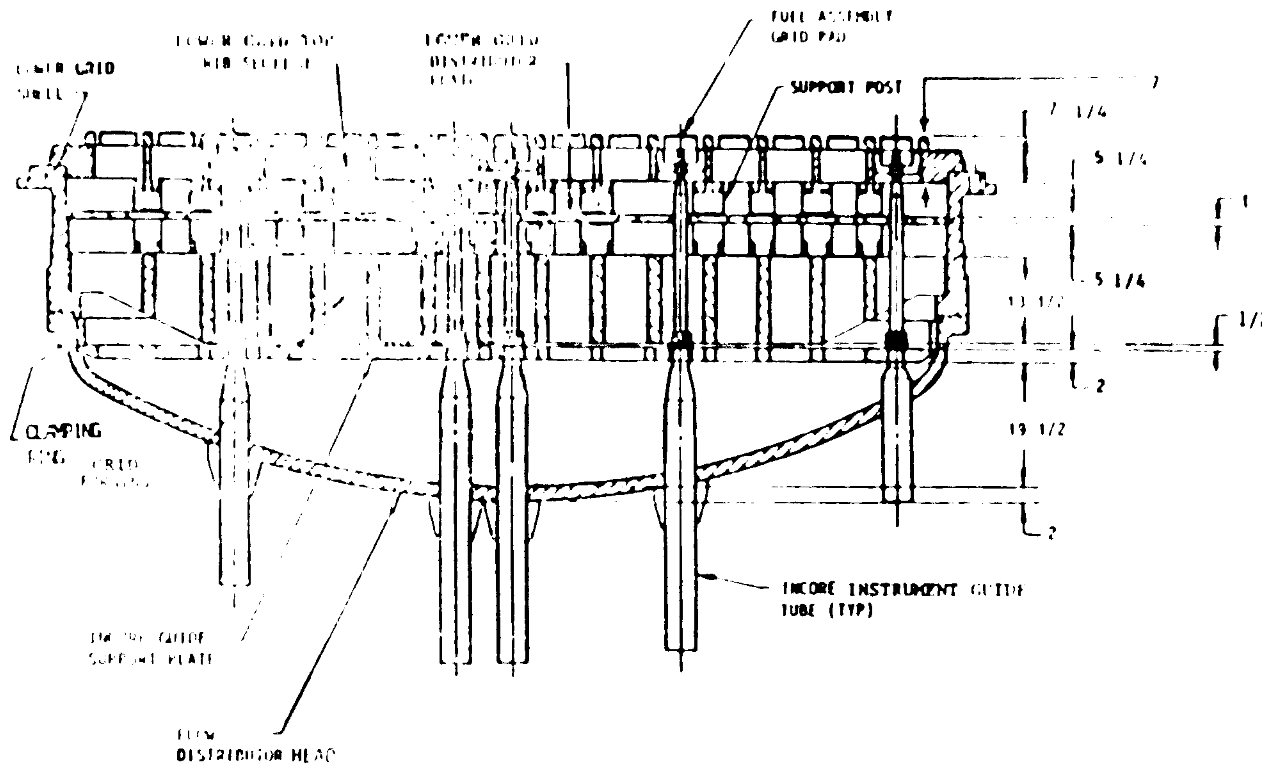
General Arrangement of Core Support Structure



NOTE:
all dimensions are in inches.

Lower Grid Assembly





LOWER PLENUM CROSS SECTION

TABLE 10

REACTOR COOLANT SYSTEM PIPING DESIGN DATA

Reactor Inlet Piping

Pipe, ID, in.	28
Design pressure/temperature, psig/F	2500/650
Operating pressure/temperature, psig/F	2255/556
Hydrotest pressure, psig	3125
Minimum thickness, in.	2-1/4
Coolant volume (hot-system total), ft^3	950
Dry weight, system total, lb (estimated)	225,000

Reactor Outlet Piping

Pipe, ID, in.	36
Design pressure/temperature, psig/F	2500/650
Operating pressure/temperature, psig/F	2192/608
Hydrotest pressure, psig	3125
Minimum thickness, in.	2-7/8
Coolant volume (hot-system total), ft^3	938
Dry weight, system total, lb (estimated)	210,000

Pressurizer Surge Piping

Pipe size, in.	10, Sch 140
Design pressure/temperature, psig/F	2500/670
Operating pressure/temperature, psig/F	2192/650
Hydrotest pressure, psig	3125
Coolant volume, hot, ft^3	20
Dry weight, lb (estimated)	5000

Pressurizer Spray Piping

Pipe size, in.	2-1/2, Sch 160
Design pressure/temperature, psig/F	2500/650
Operating pressure/temperature, psig/F	2255/556
Hydrotest pressure, psig	3125
Coolant volume, hot, ft^3	2
Dry weight, lb (estimated)	650

TABLE 11

MINIMUM FLOW AREAS

Component	Location	Flow area, ft^2
Hot leg	Flowmeter	6.6
Cold leg		4.3
Steam generator	RC inlet nozzle	7.1
Reactor vessel	RC outlet nozzles	14.1
RC pump	Outlet	4.3

TABLE 12

FLOW DISTRIBUTION

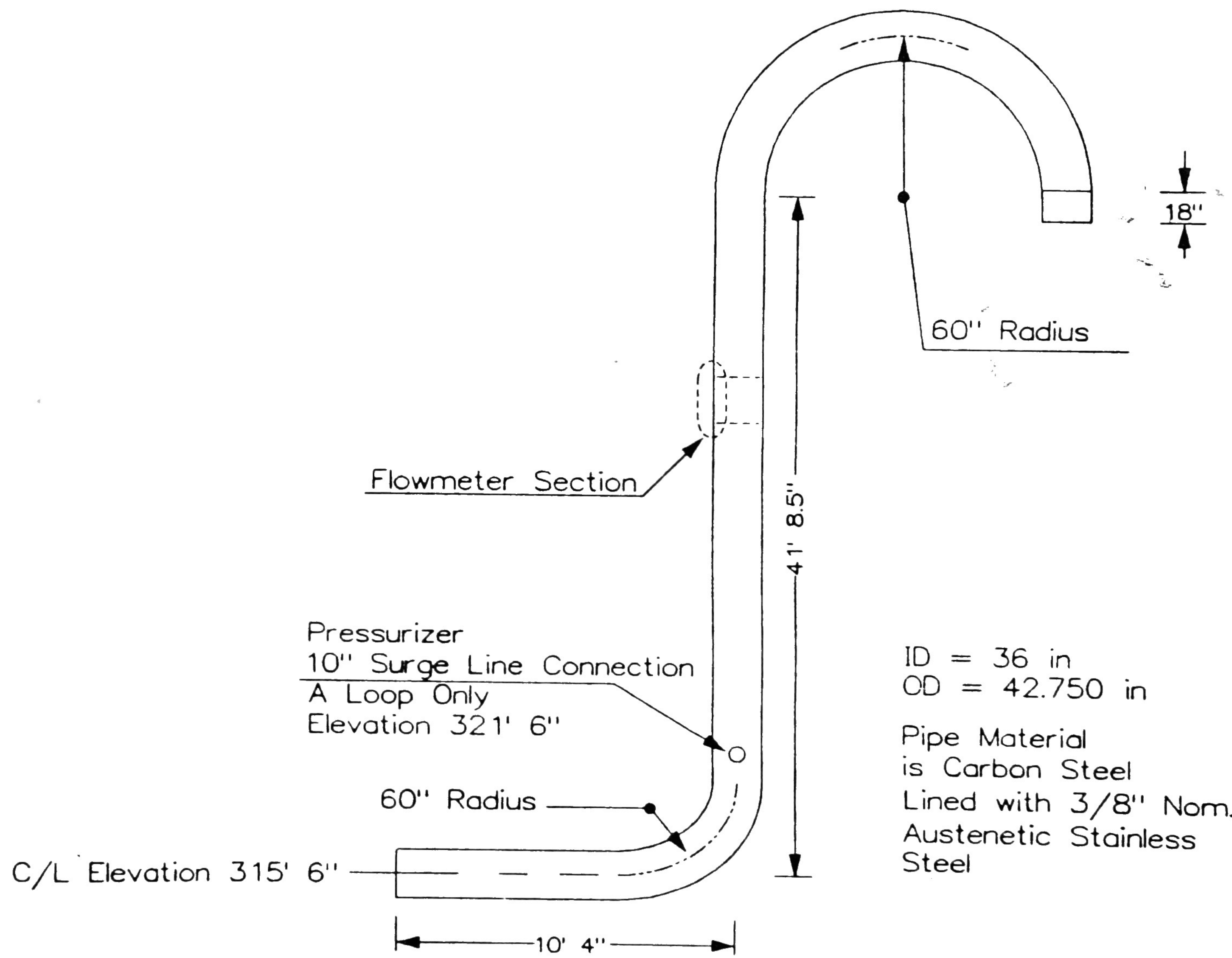
Pump/loop combination (loop A/loop B)	A1 flow	A2 flow	B1 flow	B2 flow
2/2	92,400	92,400	92,400	92,400
2/1	96,600	96,600	119,450	-38,600
1/1	122,500	-32,700	122,500	-32,700

TABLE 13

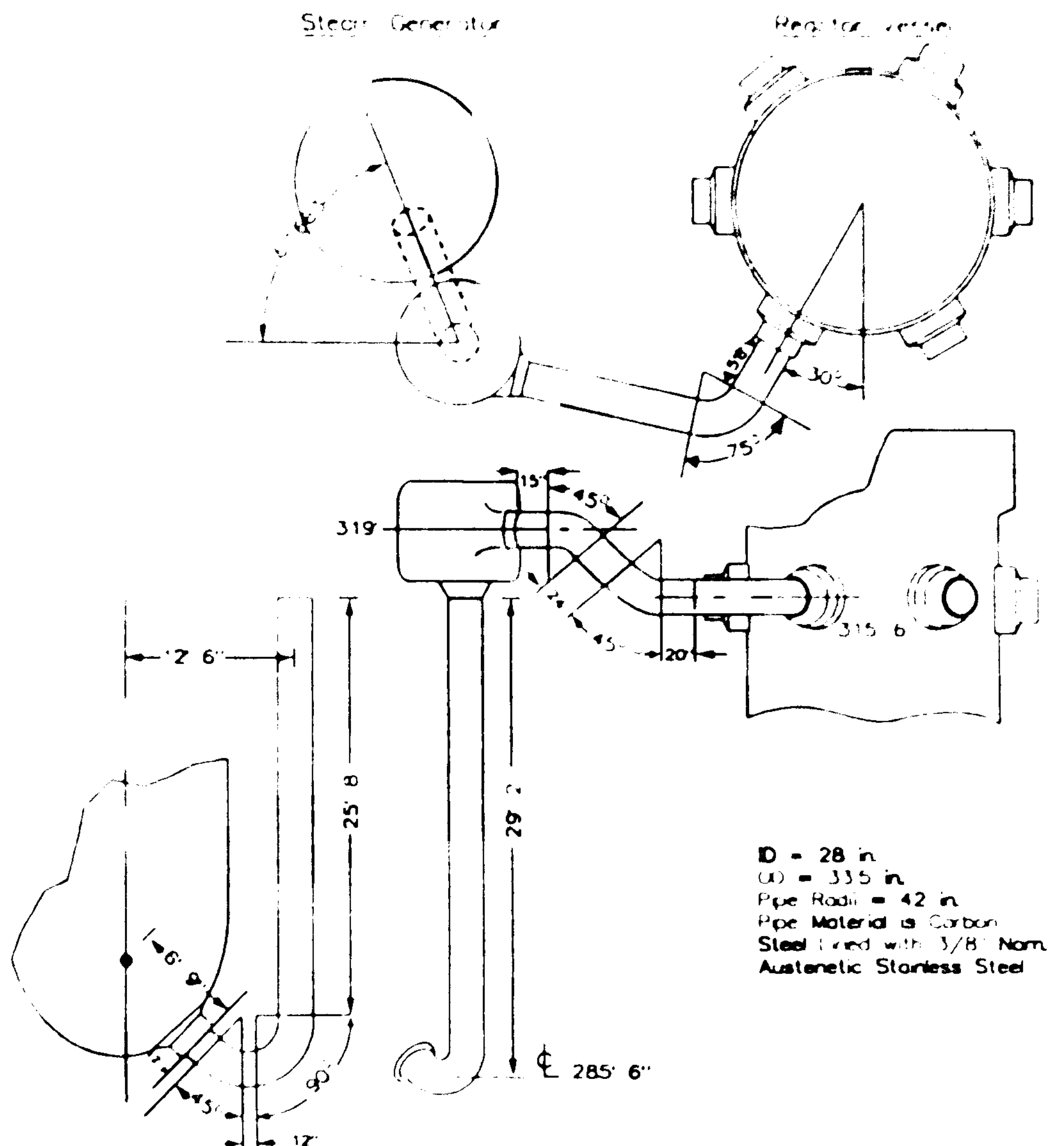
REACTOR COOLANT SYSTEM PRESSURE SETTINGS

	Pressure, psig	Capacity, lb/h, total
Design pressure	2500	
Pressurizer code safety valves	2450	690,000
High pressure reactor trip[a]	2355	
Pressurizer electromatic relief valve[a]		
Open	2255	112,000
Close	2205	
High pressure alarm[a]	2255	
Pressurizer spray valve[a]		
Open	2205	
Close	2155	
Operating pressure[a]	2155	
Low pressure alarm[a]	2055	
Low pressure reactor trip[a]	1900	
Hydrotest pressure	3125	

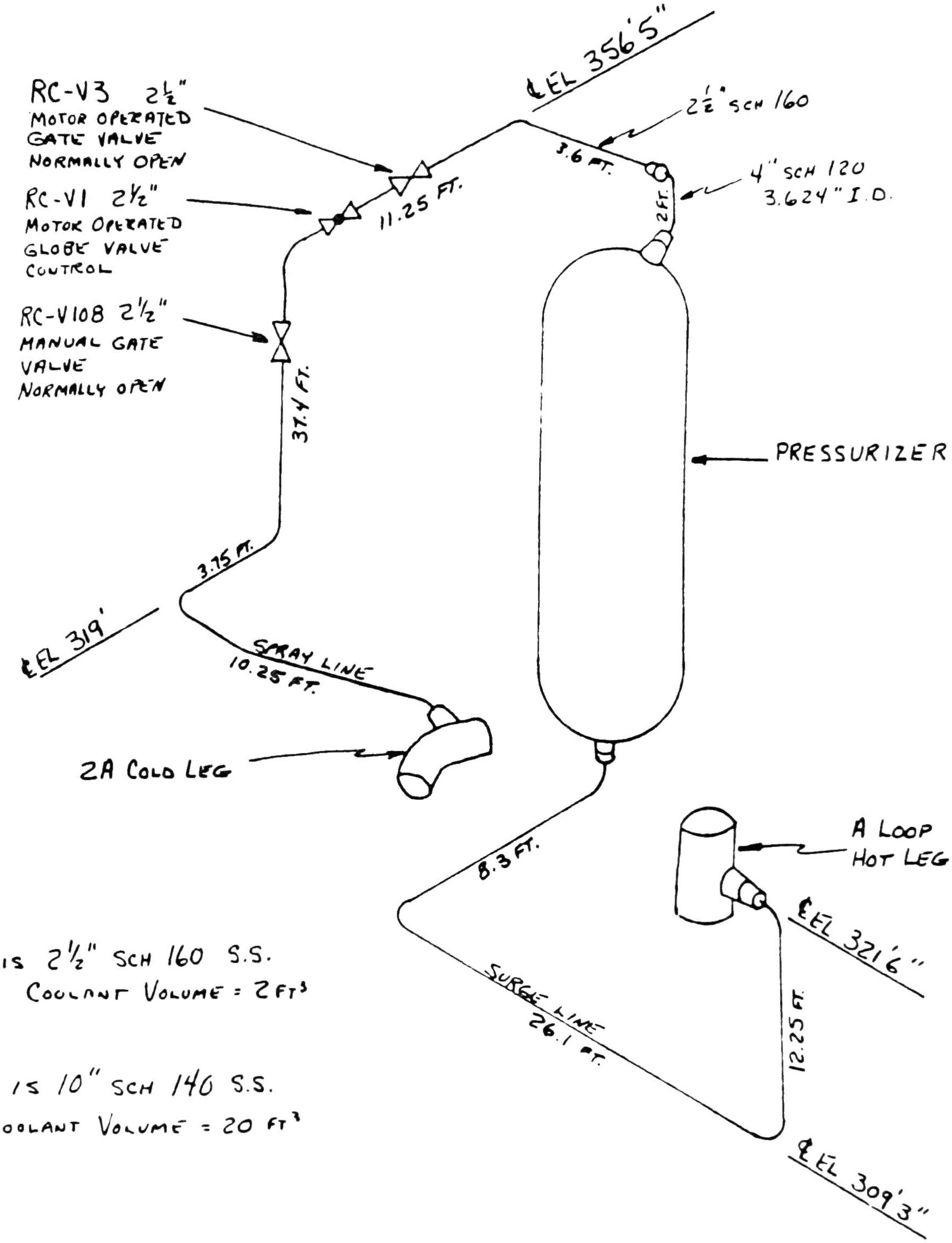
[a] At sensing nozzle on reactor outlet pipe.



A & B LOOP HOT LEG PIPE



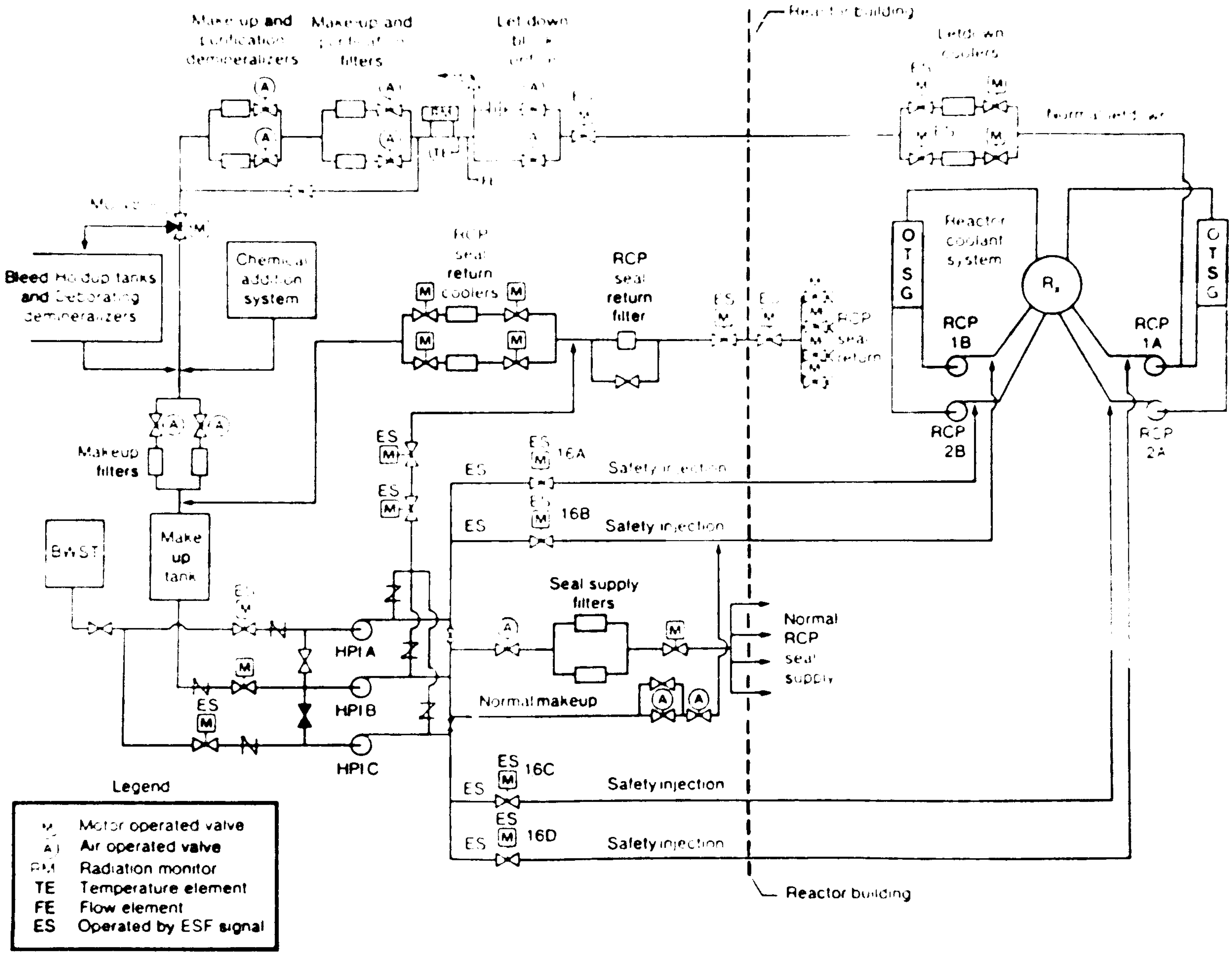
A & B LOOP COLD LEG PIPES



Spray Line is 2½" SCH 160 S.S.
2.125" I.D. Coolant Volume = 2 FT³

Surge Line is 10" SCH 140 S.S.
8.75" I.D. Coolant Volume = 20 FT³

SURGE AND SPRAY LINE DETAILS



HIGH PRESSURE INJECTION AND LETDOWN SCHEMATIC

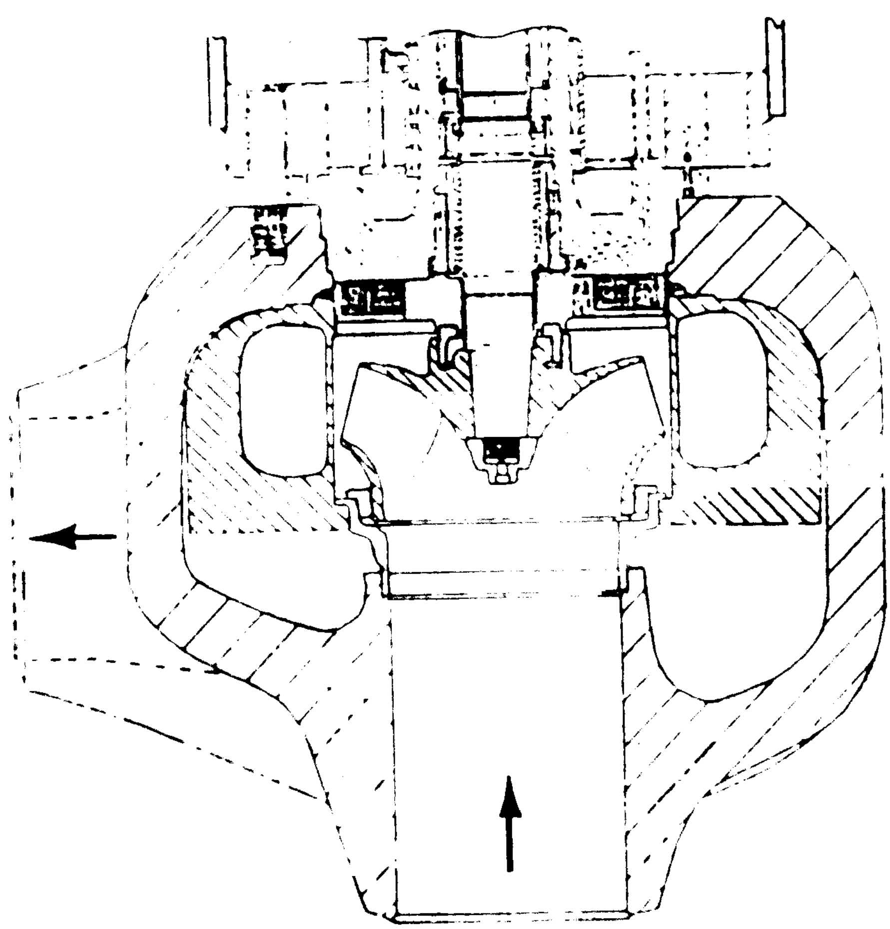
TABLE 14

REACTOR COOLANT PUMP AND MOTOR DESIGN DATA
(Data per pump or motor)

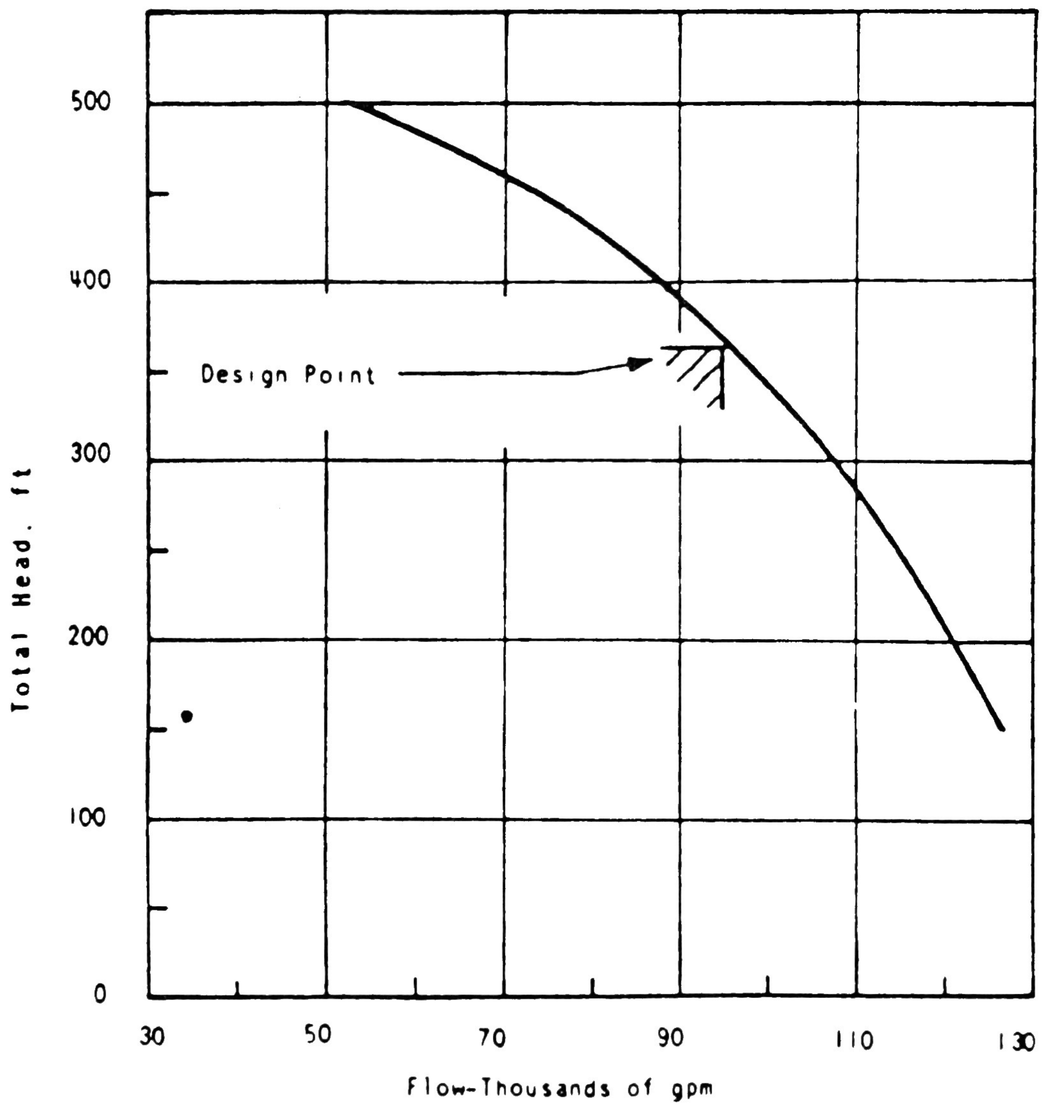
Pump data	
Design pressure/temperature, psig/F	2500/650
Hydrotest pressure	ASME, Section III
rpm at nameplate rating	1190
Developed head, ft	362
Capacity, gpm	92,400
Seal water injection, gpm	8
Controlled bleedoff, gpm	1
Injection water temperature, F	95
Cooling water temperature, F	95
Pump discharge nozzle ID, in.	28
Pump suction nozzle ID, in.	28
Overall height (pump-motor), ft/in.	31/5-15/16
Dry weight without motor, lb	113,000
Coolant volume, ft^3	98
Required net positive suction head, ft	400
Motor data	
Type	Squirrel cage induction single-speed, water-cooled
Voltage	6,600
Phase	3
Frequency, Hz	60
Insulation class	F
Starting current (full voltage), amp	3,600
Power (nameplate), hp	9,000
Rotor moment of inertia, $lb\text{-}ft^2$	70,000
Motor weight, lb	102,850

CASE, DIFFUSER AND IMPELLER ARE 304 STAINLESS STEEL

PUMP INTERNAL FLUID VOLUME IS 98 FT^3



REACTOR COOLANT PUMP



REACTOR COOLANT PUMP ESTIMATE
PERFORMANCE CHARACTERISTICS

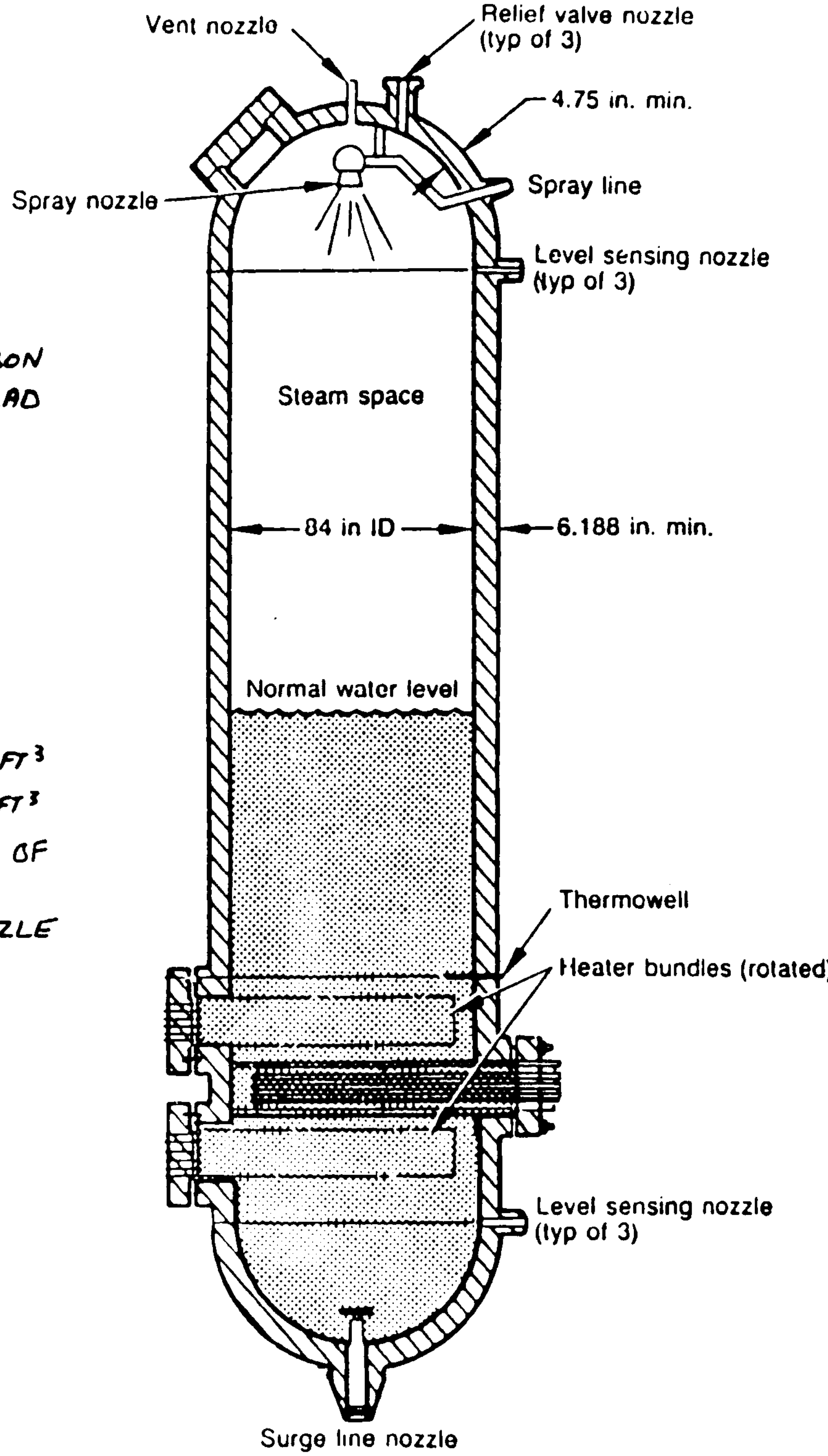
TABLE 15

PRESSURIZER DESIGN DATA

Item	Data
Design/operating pressure, psig	2500/2155
Hydrotest pressure (cold), psig	3125
Design/operating temperature, F	670/648
Normal water volume, ft^3	800
Normal steam volume, ft^3	700
Electric heater capacity, kW	1638
Overall height, ft/in.	44/11-3/4
Shell OD, in.	96-3/8
Shell minimum thickness, in.	6.188
Dry weight, lb. (estimated)	304,700
Surge line nozzle, in.	10, Sch 140
Spray line nozzle, in.	4, Sch 140
Relief valve size, in.	3
Vent nozzle, in.	1, Sch 160
Sample line nozzle, in.	1, Sch 160
Thermowell ID, in.	3/8
Level sensing nozzle, in.	1
Heater bundle dia., in.	80-1/4
Manway opening, dia., ID, in.	16
Electromatic relief valve size, in.	2-1/2

PRESSURIZER IS CARBON STEEL INTERNALLY CLAD WITH 3/16 INCH THICK STAINLESS STEEL

STEAM VOLUME 700 FT^3
WATER VOLUME 800 FT^3
FOR A WATER LEVEL OF 220 INCHES ABOVE LOWER SENSING NOZZLE

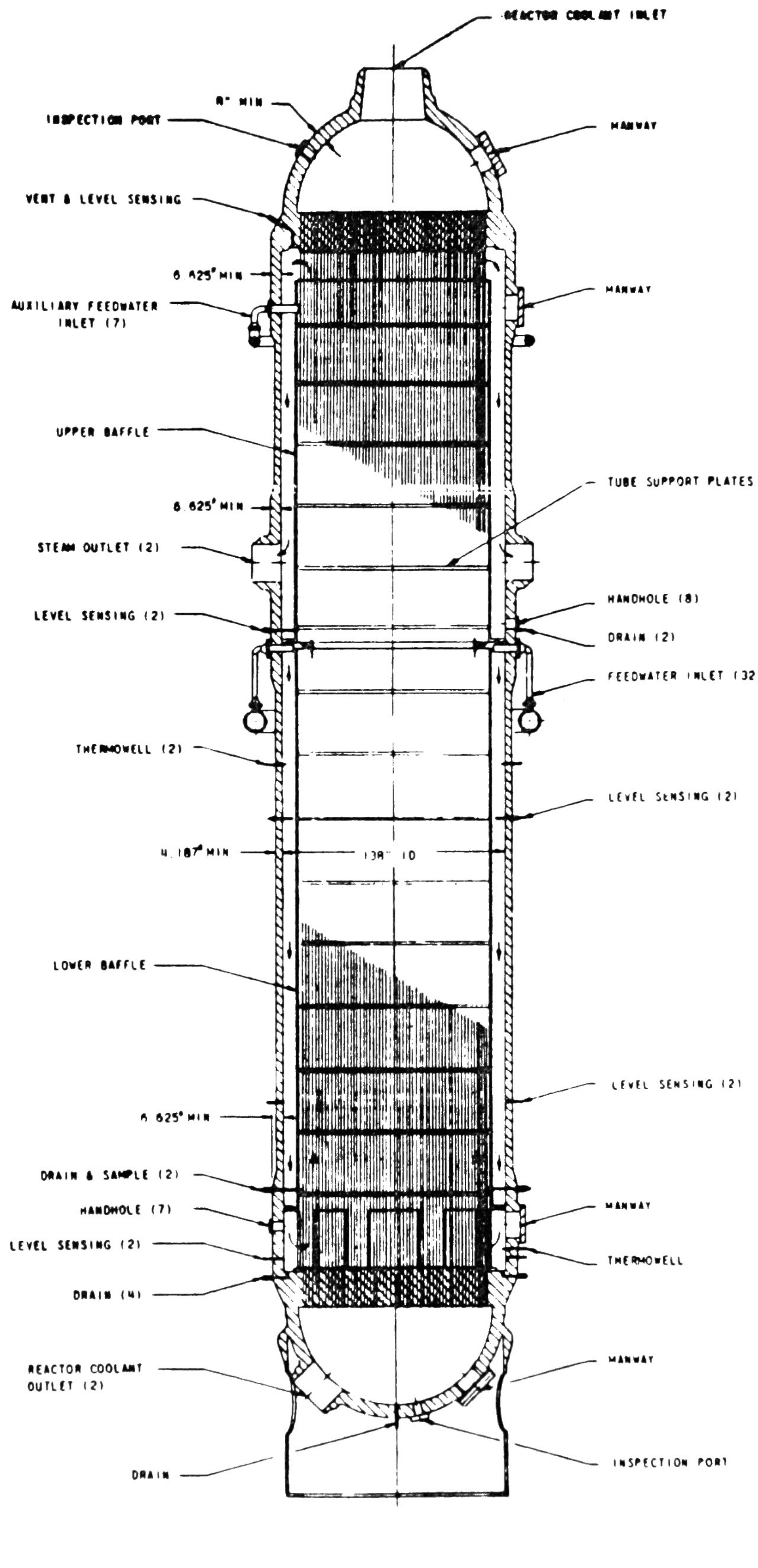


PRESSURIZER

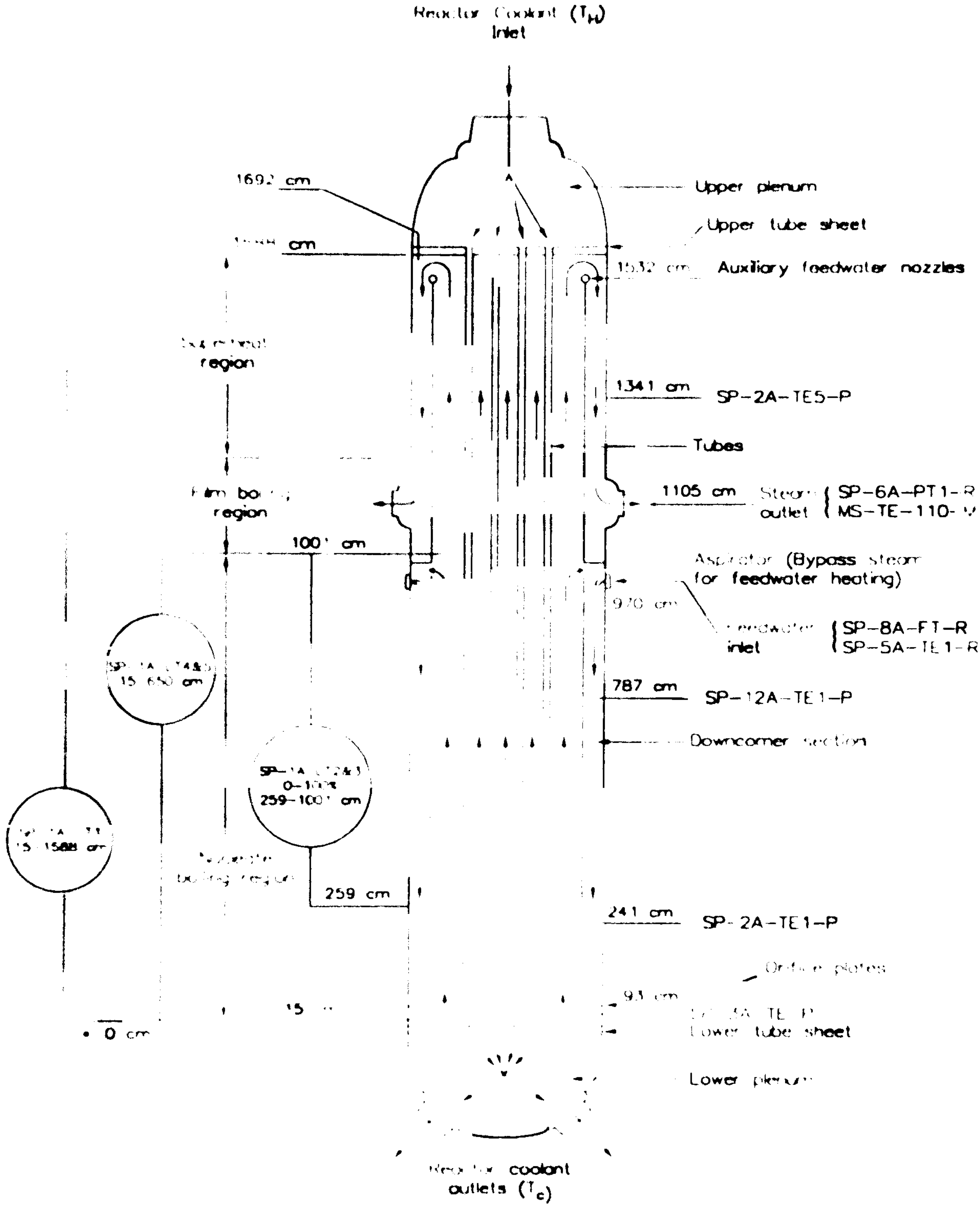
TABLE 10

STEAM GENERATOR DESIGN DATA

Item	Data per steam generator
Steam conditions at full load, outlet nozzles	
Steam flow, lb/h	6.12×10^6
Steam temperature, F	570 (35F superheat)
Steam pressure, psig	910
Feedwater temperature, F	470
Reactor coolant flow, lb/h	68.95×10^6
Reactor coolant side	
Design/operating pressure, psig	2500/2185
Design/operating temperature, F	
Inlet	650/608
Outlet	650/556
Hydrotest pressure, psig	3125
Coolant volume (hot), ft^3	2017
Secondary side	
Design/operating pressure, psig	1050/910
Design temperature, F	600
Hydrotest pressure, psig	1312.5
Net volume, ft^3	3412
Dimensions	
Tubes, OD/min. wall, in.	0.625/0.034
Overall height (including skirt), ft/in.	73/2-1/2
Shell, OD, in.	151-1/8
Shell minimum thickness (at tube sheets & feedwater connect), in.	6.625
Shell minimum thickness, in.	4.1875
Tube sheet, thicknesses, in.	24
Dry weight, lb.	1,144,500
Exposed tube length, ft/in.	52/1-3/8
Nozzles - reactor coolant side	
Inlet nozzle ID, in.	36
Outlet Nozzle, ID, in.	28
Drain nozzle, in.	1, Sch 160
Manway ID, in.	16
Handholes, in.	5
Nozzles - secondary side	
Steam nozzle ID, in.	24-1/4
Vent nozzle, in.	1-1/2, Sch 80
Drain nozzle, in.	1-1/2, Sch 80
Drain nozzle, in.	1, Sch 80
Level sensing nozzle, in.	1, Sch 80
Thermowell ID, in.	3/8
Manway ID, in.	16
Feedwater nozzle, in.	14, Sch 80
Auxiliary feedwater nozzle, in.	6, Sch 80
Handholes dia., in.	5

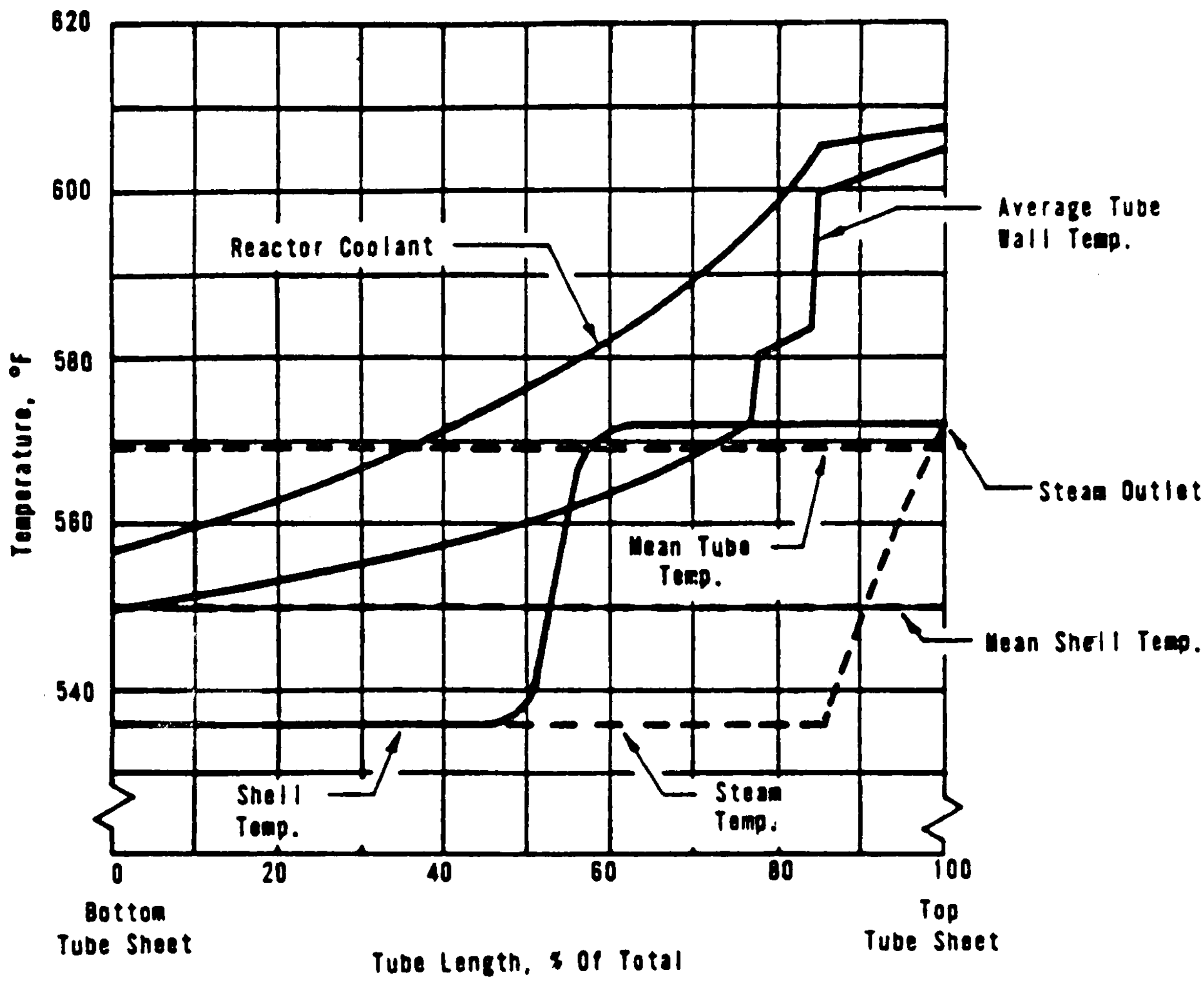


Once-Through Steam Generator

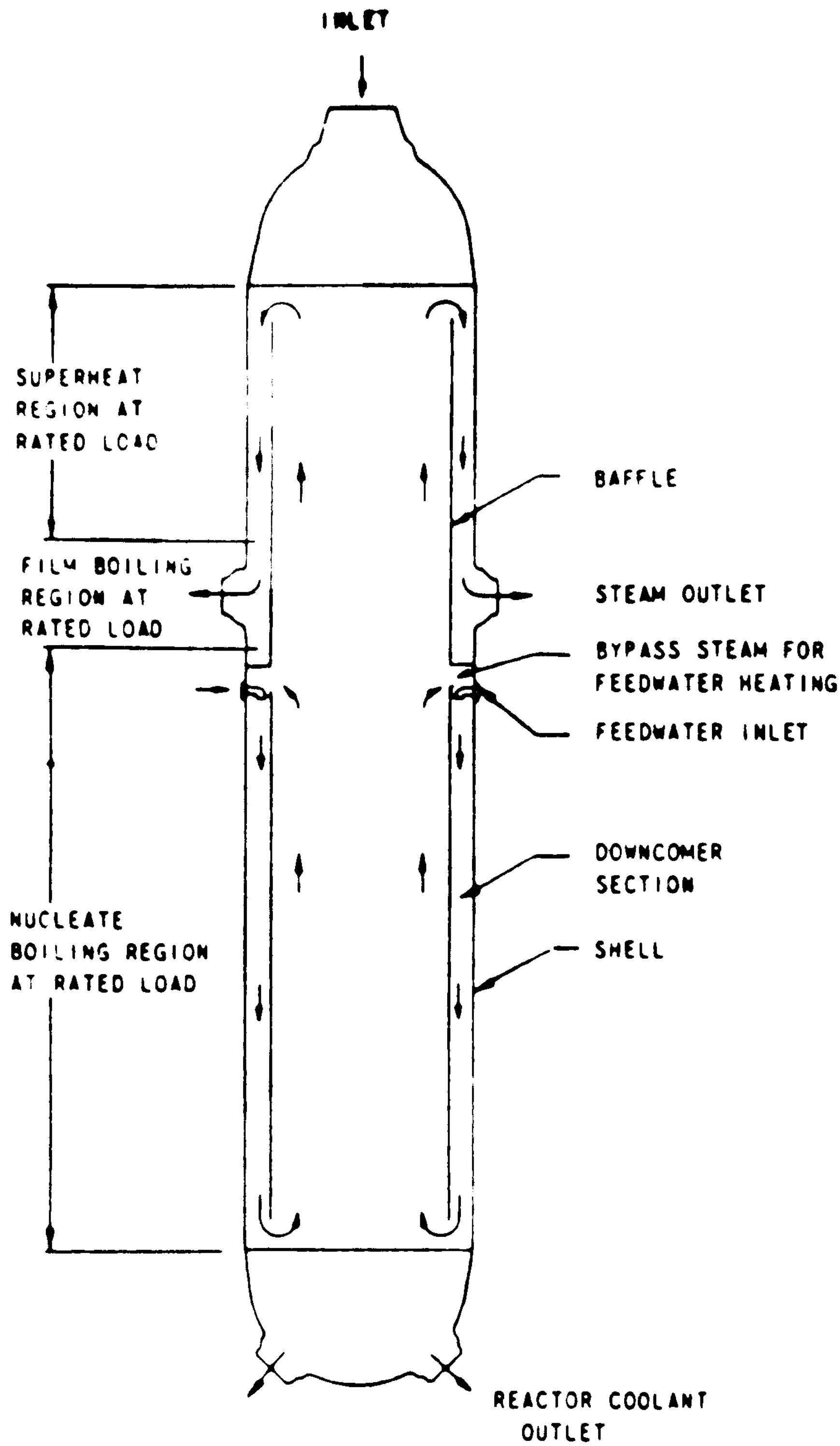


TMI-2 OTSG Measurement Locations

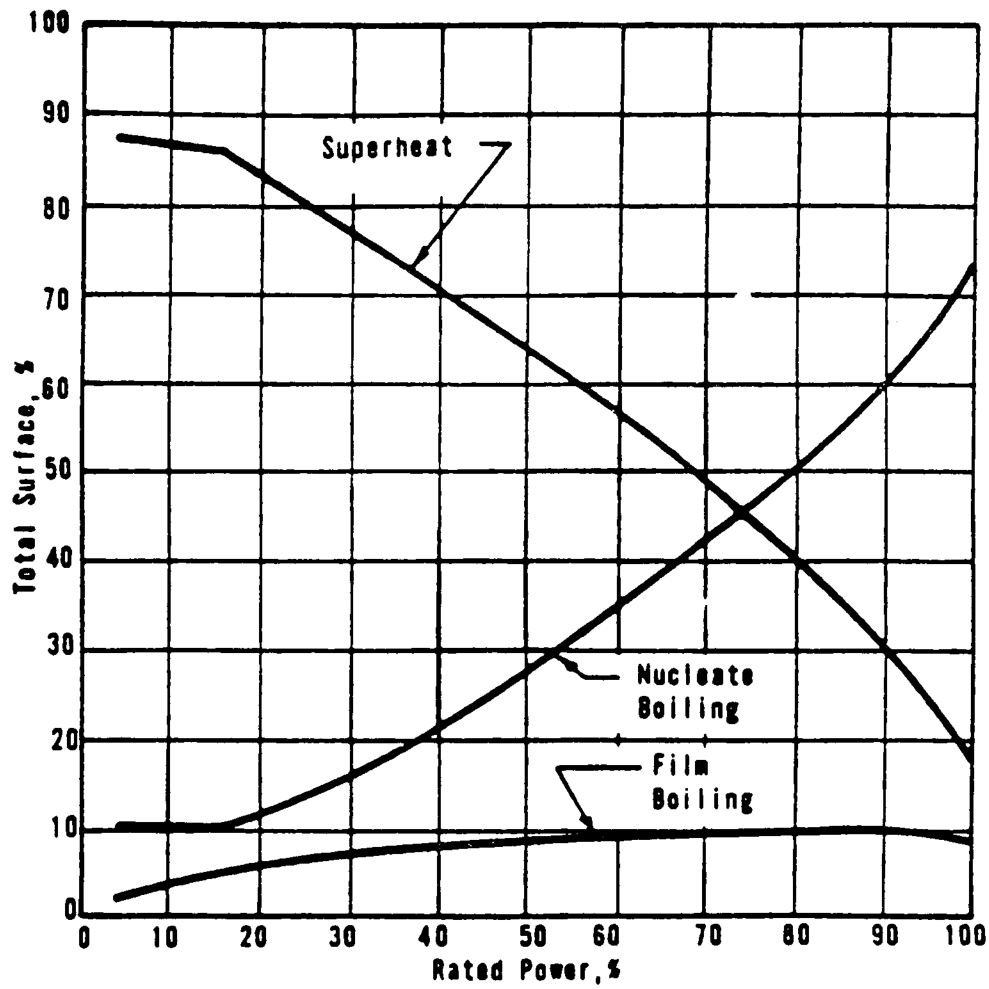
* Corresponds to an elevation of ... m (...) above sea level



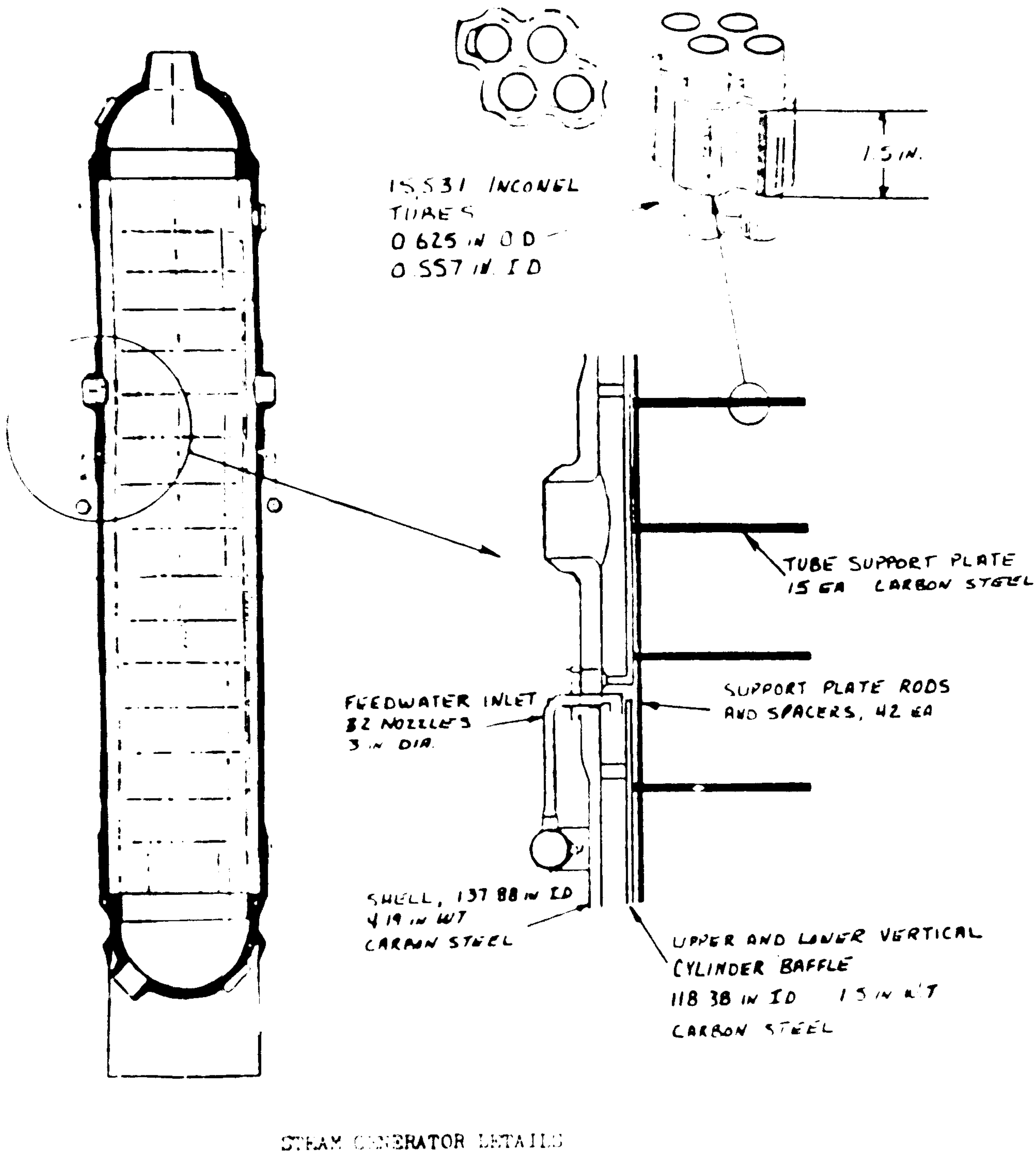
STEAM GENERATOR TEMPERATURE
VERSUS TUBE LENGTH



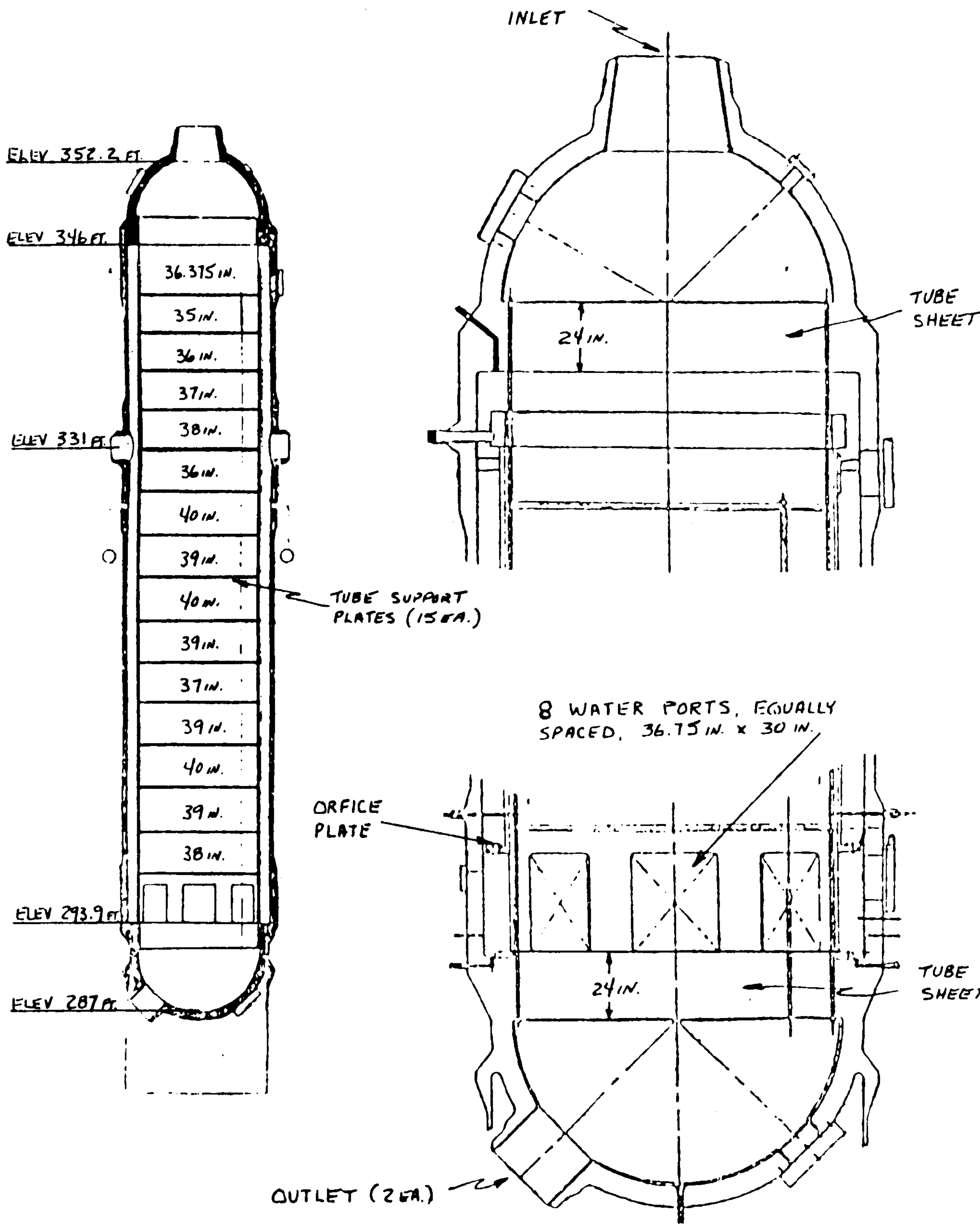
STEAM GENERATOR HEATING REGION

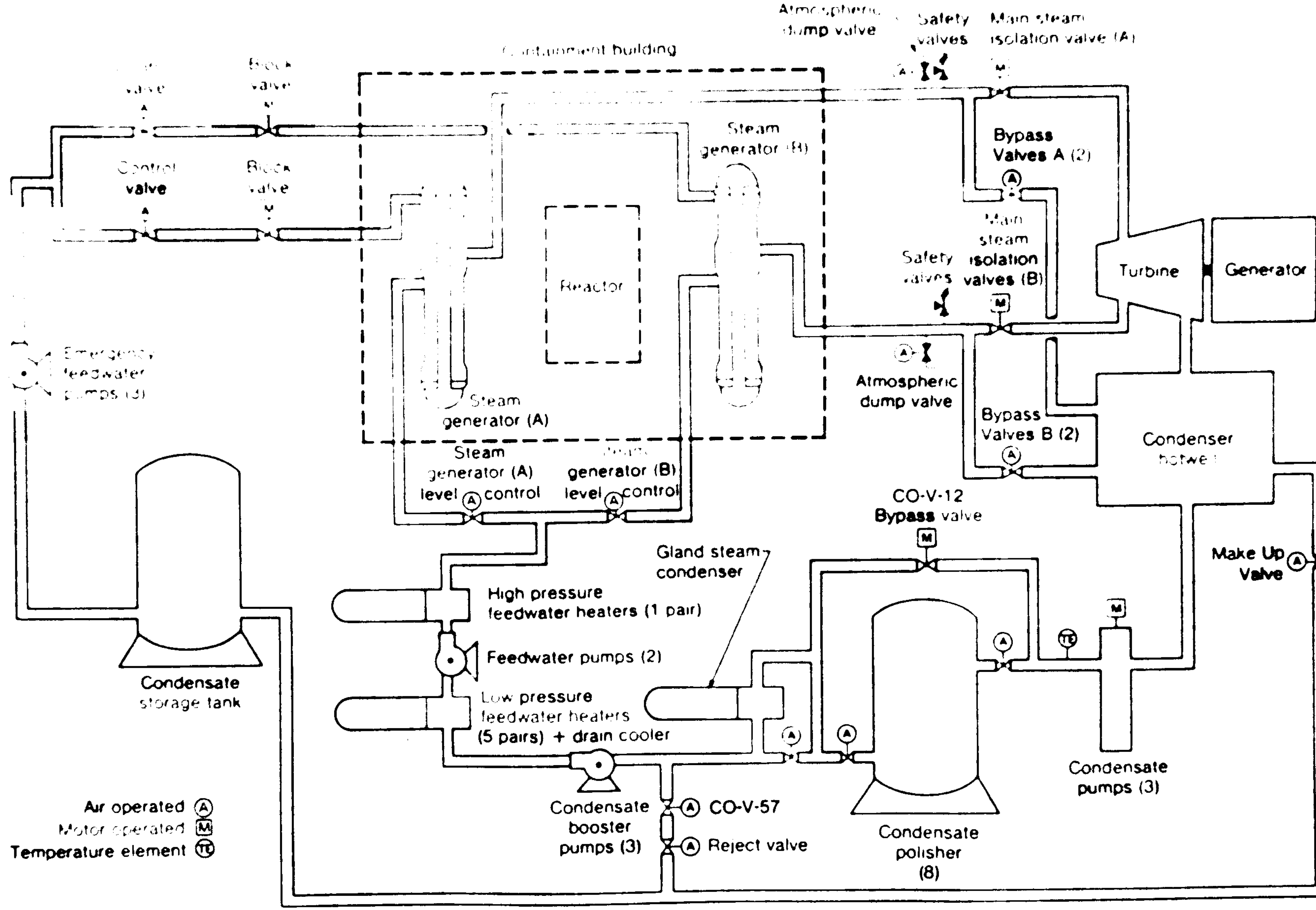


STEAM GENERATOR HEATING SURFACE
VERSUS POWER



STEAM GENERATOR DETAILS


INLET
ELEV 352.2 FT.
ELEV 346 FT.
36.375 IN.
35 IN.
36 IN.
37 IN.
38 IN.
ELEV 331 FT.
36 IN.
40 IN.
39 IN.
40 IN.
39 IN.
37 IN.
39 IN.
40 IN.
39 IN.
38 IN.
ELEV 293.9 FT.
ELEV 287 FT.
TUBE SUPPORT PLATES (15 EA.)
24 IN.
TUBE SHEET
8 WATER PORTS, EQUALLY SPACED, 36.75 IN. x 30 IN.
ORFICE PLATE
24 IN.
TUBE SHEET
OUTLET (2 EA.)



FEEDWATER AND CONDENSATE SCHEMATIC

REFERENCES

1. Three Mile Island Nuclear Power Station, Unit Number Two, License Application, Final Safety Analysis Report, Docket-50320-73, April 1974, Section 1.

2. Ibid; Section 4.

3. Ibid; Section 5.

4. Ibid; Section 6.

5. Ibid; Section 10.

6. Analysis of Three Mile Island-Unit 2 Accident, NSAC 80-1, March 1980.

7. Three Mile Island Nuclear Station-Unit No. 2, Mechanical Flow Diagrams, Burns & Roe, Inc., April 1979.

8. Reactor Internals Stress And Deflection Due To Loss-Of-Coolant Accident And Maximum Hypothetical Earthquake, BAW-10008, Part 1, Rev.1, Topical Report, Babcock and Wilcox, June, 1970.

9. Once-Through Steam Generator Research And Development Report, BAW-10027, Topical Report, Babcock and Wilcox, April, 1971.

10. TMI-2 Technical Bulletin, TB 86-35 Rev.3, August, 1986.

PART III

As-Built Design and Material Characteristics of the TMI-2 Core

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PART III
NSAC PERSPECTIVE

PROJECT DESCRIPTION

A detailed analysis of core conditions for the TMI-2 accident requires detailed information about the geometry and materials properties of the core and adjacent regions. This information is provided here so that different core transient analyses can start from the same description of the TMI-2 core in its original, intact condition.

PROJECT OBJECTIVE

The objective is to minimize discrepancies between individual analysis of TMI-2 by providing a consistent input description of the core and its materials.

The analysis of the TMI-2 core is complicated by a need to couple together separate analyses of various time intervals and plant events. There is also a need to compare detailed calculations with a generalized analysis of core conditions in order to bench-mark the generalized analysis approach. A good set of boundary conditions and materials properties is the logical beginning point.

PROJECT RESULTS

The TMI-2 as-built core information has been organized in a handbook format to facilitate its use in any TMI-2 core analysis. The TMI-2 experience has shown that the availability of a well-documented set of basic plant design and materials information can be a tremendous asset in core-event analyses. In general, it appears that plant safety analyses reports and related licensing information are neither complete enough nor in sufficient detail to permit such analyses. This report or a logical extension of it might serve as a model in preparing similar handbooks for other plants.

ABSTRACT

The nominal design and material characteristics of the TMI-2 reactor core and adjacent regions have been surveyed. The dimensions, functions, and basic thermal properties of reactor components are organized and discussed for reference purposes.

TABLE OF CONTENTS

TABLE OF CONTENTS (Continued)

LIST OF FIGURES

LIST OF TABLES

1.0 SUMMARY

A survey was made of publicly available documentation for the purpose of characterizing the nominal geometry and material configuration of the TMI-2 reactor core and immediately adjacent regions. Information about the design, material inventory, and related thermal properties was identified and organized in a consistent format for each of the components considered. The results of this survey were documented to support the generation and interpretation of NSAC-sponsored analyses of the March 28, 1979 incident at TMI. The report format allows further details to be added, if the need arises.

2.0 INTRODUCTION

In an upcoming technical report, NSAC plans to assess the core damage consequences of the 3/28/79 TMI-2 accident. Current analytical results and small-break modeling requirements will also be addressed. For these reasons, it is necessary to organize and document the pre-accident configuration of the TMI-2 core. Such documentation will provide: 1) a physical perspective by which to evaluate the post-accident core condition, and 2) consistency of input among the various component and system codes which may be involved in subsequent analytical efforts.

The following report consolidates much of the publicly available data on the design and material configuration of the TMI-2 core region. The reporting of nominal data implies an assumption that the core was built as designed. Section 3 addresses the functional aspects of the core as part of the overall nuclear steam supply system. Section 4 describes the basic configuration of the reactor core and immediately adjacent regions. Section 5 summarizes the core material inventory and thermal properties. References are identified in Section 6.

3.0 NUCLEAR STEAM SUPPLY SYSTEM

The basic function of the reactor core as an integral part of the nuclear steam supply system is outlined in this section.

Figure 1[17] illustrates the main components of the nuclear steam supply system at TMI-2. For simplicity, only one of the two primary and secondary loops connected to the reactor vessel is shown. Also, only one of the two cold legs in the primary loop is shown.

In summary[1,16], the highly pressurized circulating fluid in the primary loop is continually being heated in the reactor core. The primary loop is housed in the containment building. Heat is transferred from the primary to the secondary loop fluid in the steam generator. The resulting steam passes through the turbine, condenses, and is returned to the steam generator for another heating cycle. Subsequent discussion will focus on the primary loop portion of the nuclear steam supply system.

3.1 Primary System

As previously indicated in Figure 1, the main primary loop components are the reactor vessel, pressurizer, steam generators, reactor coolant pumps and interconnected piping. Figure 2[2] shows a top view of how the primary loop components are arranged in two heat transfer loops, each incorporating two reactor coolant pumps and one steam generator. Figure 3[2] gives a side view and the relative elevation of the primary loop components.

The primary loop coolant is heated in the core region of the reactor vessel and transported by the hot leg piping to the steam generator. Heat is transferred to the cooler fluid in the secondary system as the primary fluid flows downward through the steam generator. The pumps return the primary coolant to the reactor vessel through the two cold legs on each heat transfer

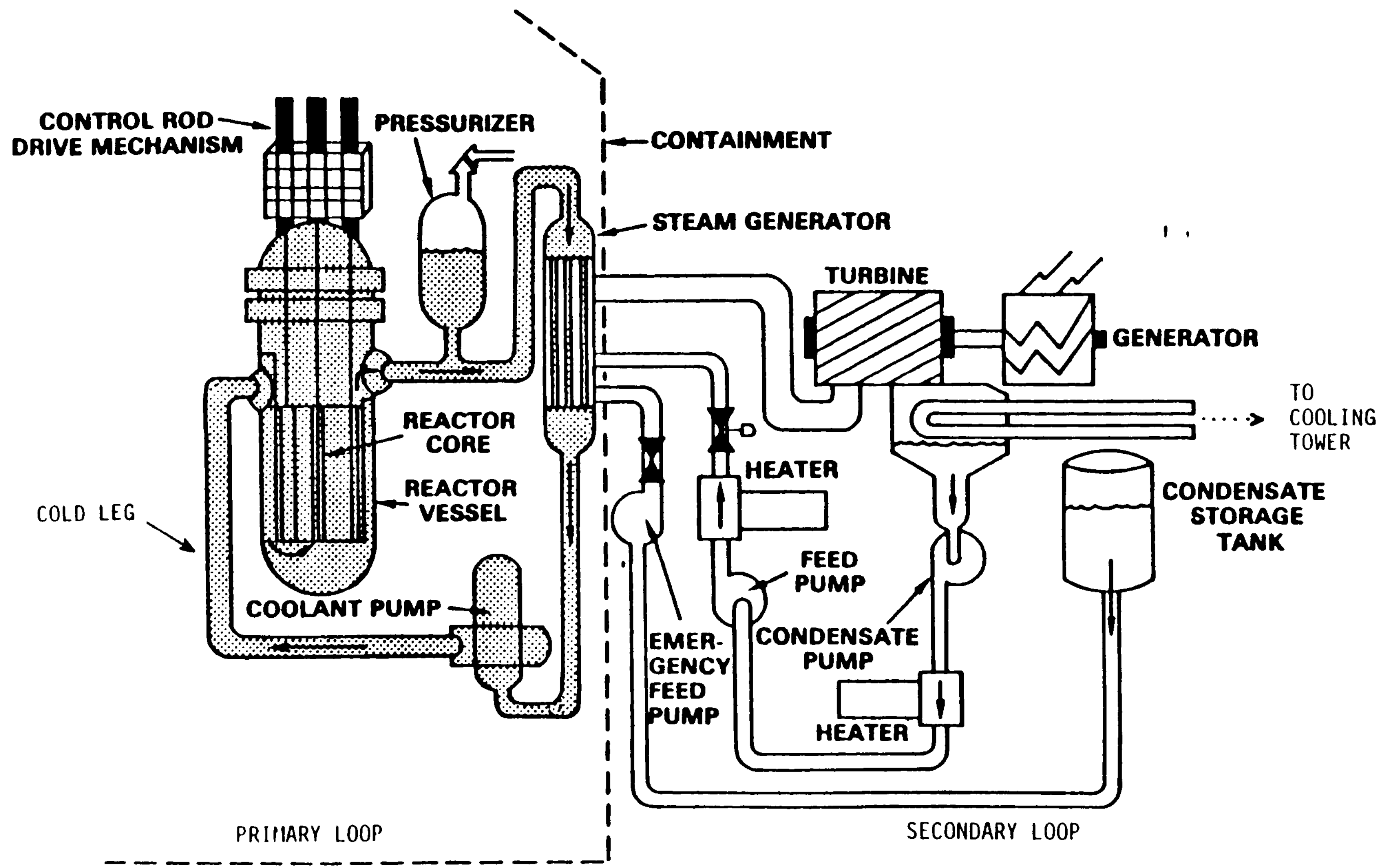


FIGURE 1 - Basic Components of TMI-2 Nuclear Steam Supply System

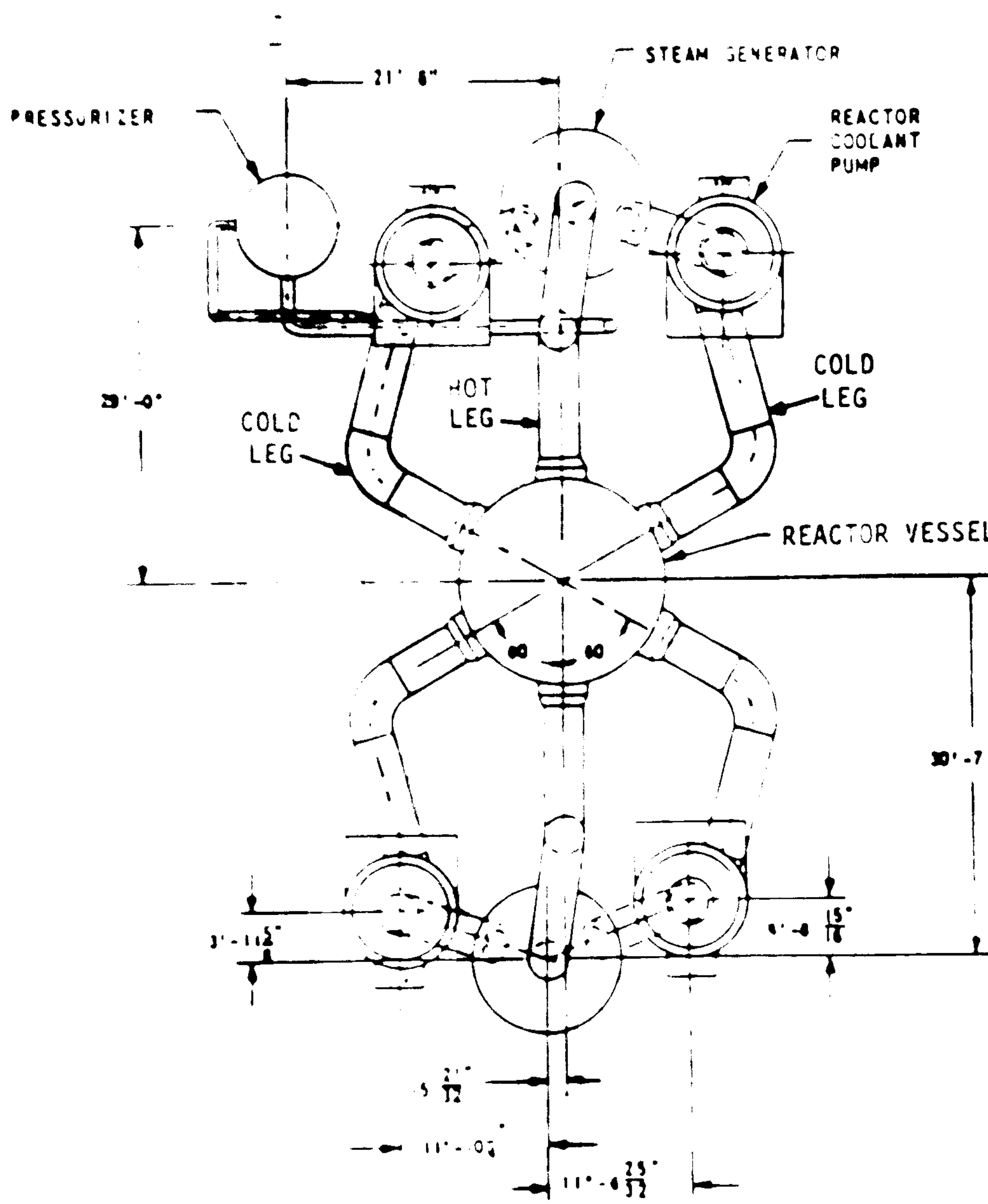


FIGURE 2 - Top View of TMI-2 Primary System Layout

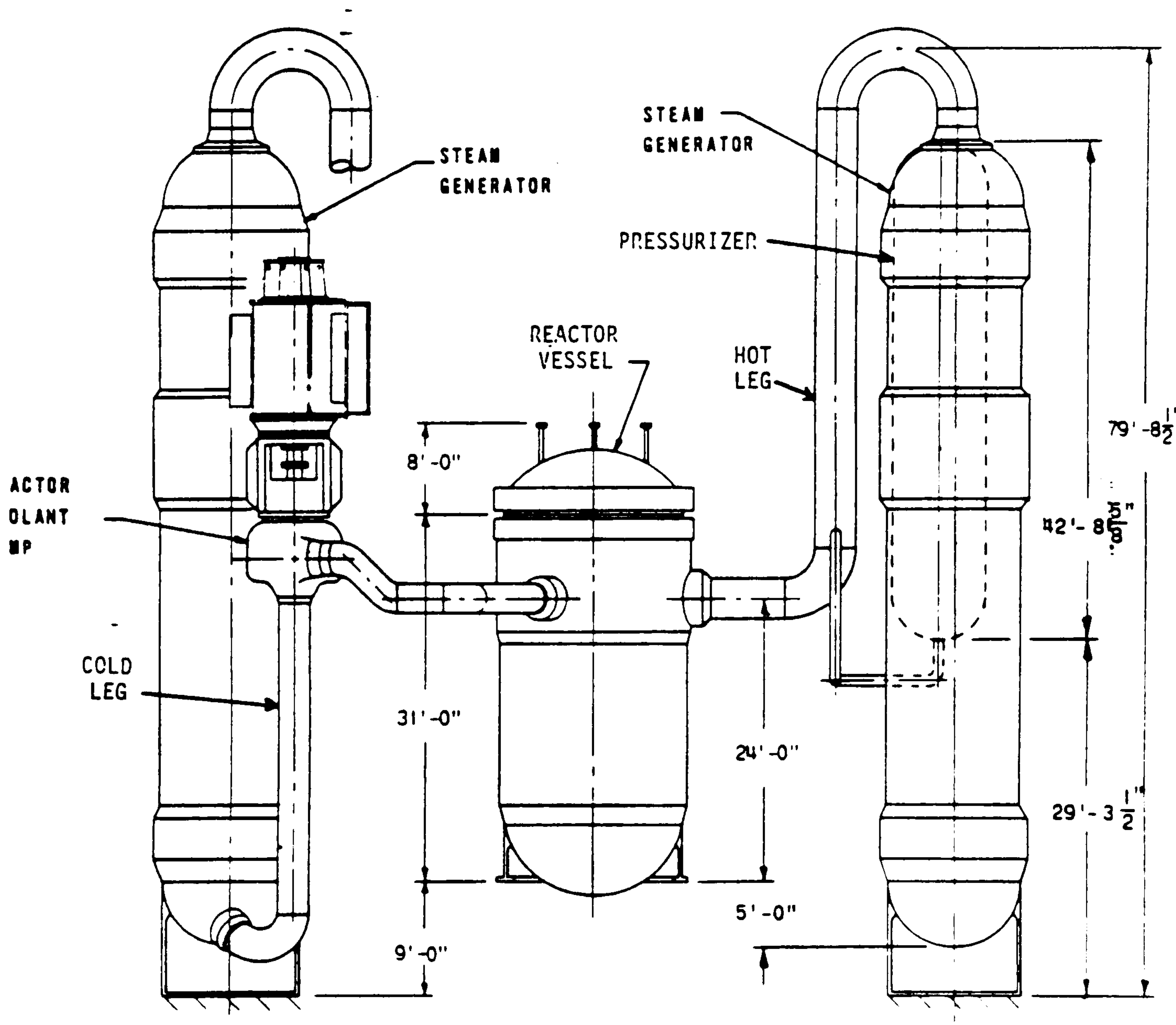


FIGURE 3 - Side View of TMI-2 Primary System Components

loop. During normal operation, primary coolant temperatures are maintained in a sub-cooled state by varying the amount of electrical heat input to the pressurizer. The reactor components of the primary system will be emphasized below.

3.1.1 Reactor Vessel

The reactor vessel is a large steel tank some 41 feet high and 16 feet in diameter. The reactor vessel encloses and supports the nuclear core and associated structures. As shown in Figure 3, the overall vessel geometry is cylindrical with spherical upper and lower plenums at the ends of the cylinder. The upper head piece is removable for refueling and material surveillance. The minimum wall thickness of the vessel shell (sides), upper head, and lower head are respectively 8.4, 6.6 and 5.0 inches. The shell incorporates coolant inlet and outlet nozzles as previously seen in Figures 2 and 3. The top and bottom heads are penetrated by flanged nozzles. The top penetrations are mainly for reactivity control hardware. The bottom penetrations are for core instrumentation hardware. All internal surfaces of the vessel are clad with a stainless steel layer about 0.2 inches thick to minimize corrosion by the primary coolant. The vessel, upper head, and closure pieces together have a dry weight of some 440 tons. The reactor vessel internals are described below.

3.1.1.1 Reactor Vessel Internals

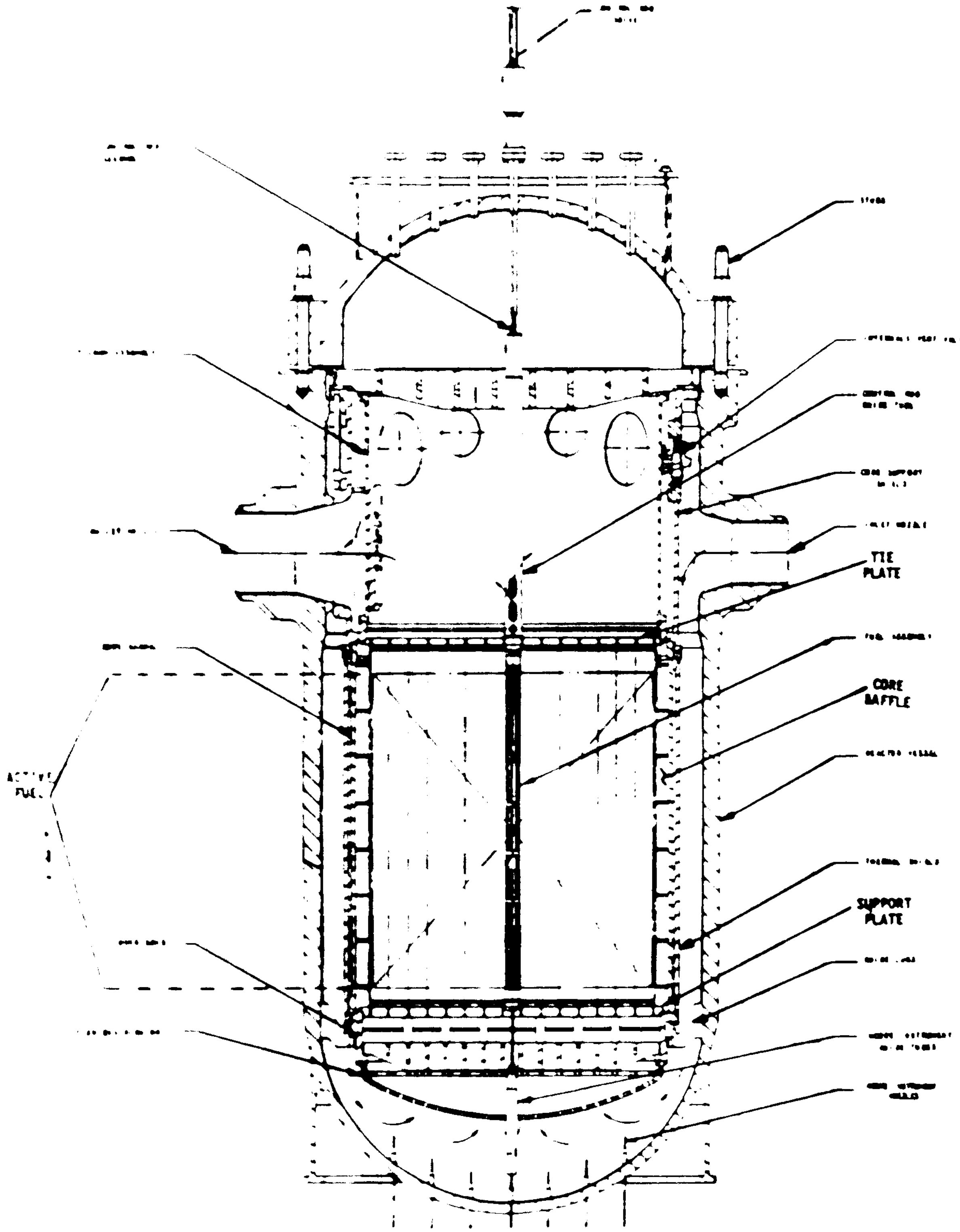
The reactor vessel internals include the active core, plenum assembly and core support assembly. The active core is an array of nuclear fuel rod bundles and their associated control element assemblies. The plenum assembly consists of a plenum cover, upper grid, control rod assembly guide tubes, and a flanged plenum cylinder. The core support assembly is comprised of a support shield, vent valves, core barrel, lower grid, flow distributor, instrument guide tubes, thermal shield, and surveillance tubes. The reactor vessel internals are all removable.

Figure 4[2] shows an axial cross section of the reactor vessel with the internals in place. Figure 5[13] shows a radial cross section of the vessel internals in the active core region.

The active core and directly adjacent regions will be described in detail in Section 4.

In summary, the active core fills the inside of an approximate right circular cylinder having a height of 12 feet and an equivalent diameter of 10.7 feet. The active core consists of a closely packed array of axially oriented nuclear fuel bundles. The bundles contain equal numbers of nominally identical fuel rods. Space is provided between the fuel rods to allow the passage of coolant flow and the placement of in-core instrument tubes and various types of reactivity control rods.

The adjacent core regions include the upper and lower end fittings on each fuel bundle, the upper and lower core support plates, and the concentric cylindrical hardware that occupies the annular region between the peripheral fuel bundles and the inside wall of the reactor vessel. In summary, the components of the adjacent core region structurally support the core, maintain alignment between the fuel, control, and instrumentation assemblies, direct the flow of primary system coolant between the vessel and core inlets, and limit neutron flux levels at the vessel wall.



NOTE: Surveillance Specimen
Holder Tube Not Shown

FIGURE 4 - Longitudinal Cross Section of TMI-2 Reactor Vessel
and Internals

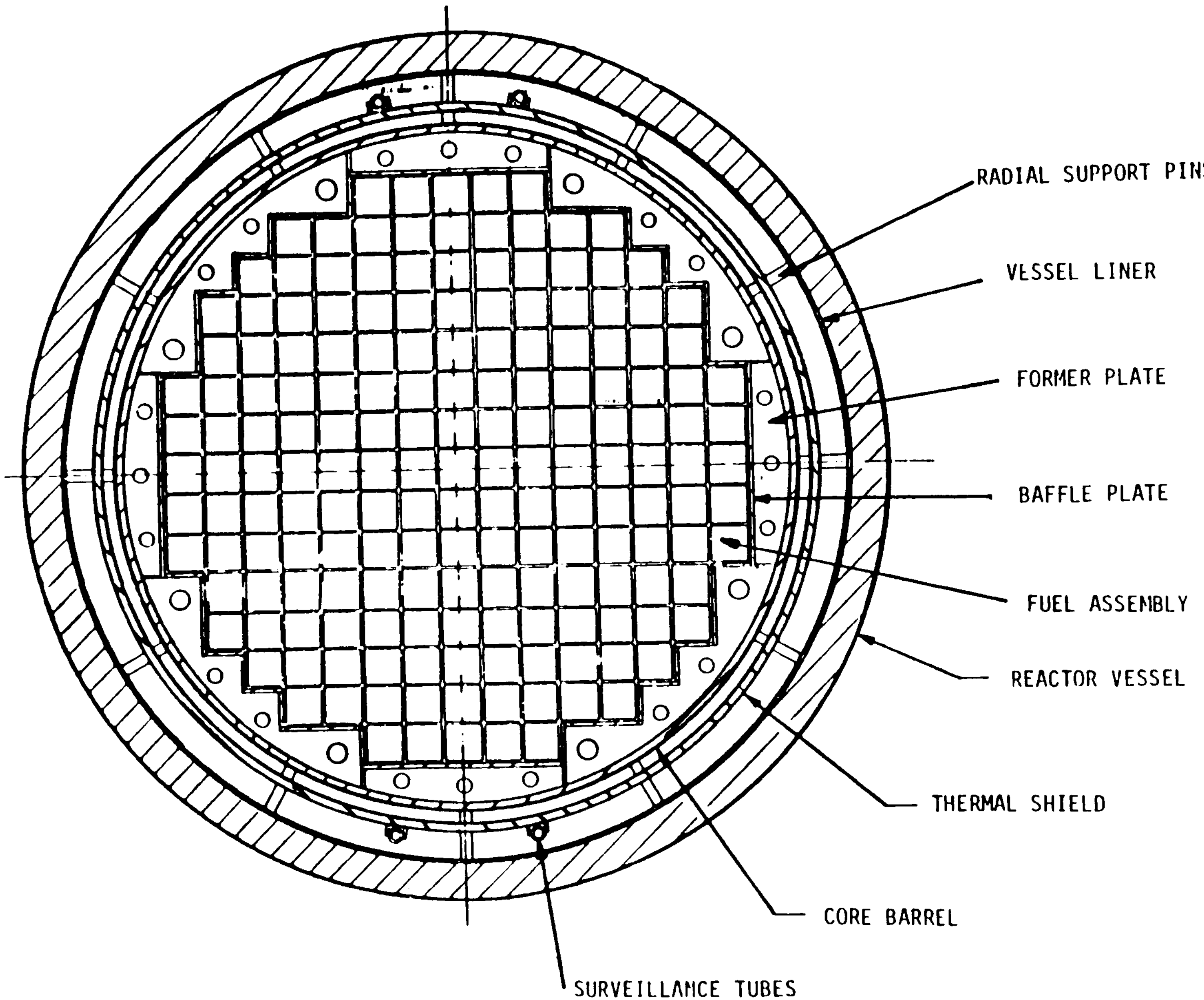


FIGURE 5 - Transverse Cross Section of TMI-2 Reactor Vessel and Active Region Internals

4.0 CORE CONFIGURATION

This section presents geometry and material data which characterize the nominal design configuration of both active and immediately adjacent regions of the TMI-2 core. Most of the discussion which follows is based on the review and consolidation of information contained in safety analysis reports for TMI-2[2] and other plants of the same or comparable vendor product line[26,27]. The summary tables in this section indicate when significant uncertainty exists in the available dimensional or material data for a given component. Unless otherwise stated then, all of the data presented below are thought to represent the actual core design conditions to within a few percent.

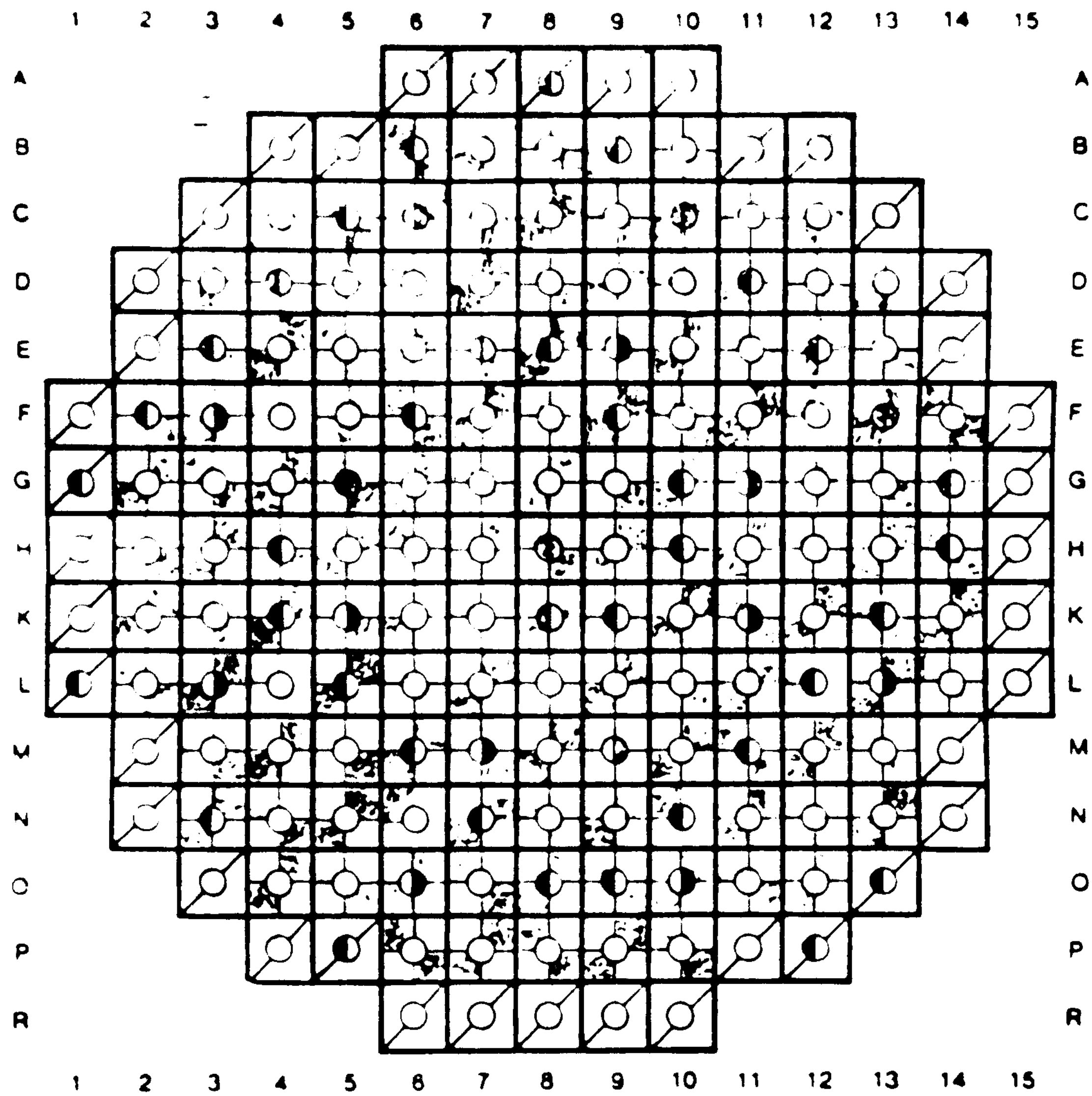
4.1 Active Core Region

The active core region consists of 177 individual fuel assemblies arranged in a square lattice to approximate the shape of a cylinder. In the discussion which follows, the core will be described in its shutdown configuration. Shutdown configuration means that the control rod assemblies, normally withdrawn from the core during operation, are assumed to be fully inserted and thus part of the active core region. The axial and radial locations of the active core region within the reactor vessel were previously seen in Figures 4 and 5. The overall dimensions and configuration of the active core are summarized in Table 1.

All of the fuel assemblies that constitute the core are of identical construction and materials. The fuel assemblies differ only in the contents of the guide tubes and instrument tubes that are part of each assembly. The core cross section shown in Figure 5 differentiates the fuel assemblies in this respect[2,6,15,32].

TABLE 1 - ACTIVE CORE REGION DATA SUMMARY

Parameter	Units	Value	Comment
geometry	-	-	open lattice
total length	in	155.2±1	between assy end fittings
active length	in	144	pellet stack length
maximum core diameter	in	133.8	diagonally across 11 assys.
minimum core diameter	in	129.0	perpendicular across 15 assys.
total flow area	ft^2	52.3±1	based on total/effective flow
heated flow area	ft^2	49.2	without core bypass flow
total surface area	ft^2	57979	without grids
heated surface area	ft^2	49734	active surfaces
fuel rod assemblies	-	177	-
full length control rod assemblies	-	61	-
part length control rod assemblies	-	8	-
burnable poison assemblies	-	68	-
orifice rod assemblies	-	40	-
zircaloy	lbs	50770	-
304 stainless	lbs	3550	without assy end fittings
inconel	lbs	2670	-
Ag-In-Cd	lbs	6060	-
Al_2O_3-B_4C	lbs	1380	-
Gd_2O_3-UO_2	lbs	290	-
ZrO_2	lbs	730	-
UO_2	lbs	205140	-
trace materials	lbs	250±100	instrument thimbles, instruments, insulation, neutron sources
total material	lbs	270840±5%	between assy end fittings and baffle plates



INSTRUMENTATION

- NONE
- TOTAL CORE MONITOR POSITION, T/C
- SYMMETRY MONITOR POSITION, T/C
- COMBINED MONITOR POSITION, T/C

FUEL ASSEMBLY

CONTROL ASSEMBLY:

- BURNABLE POISON ROD, FIXED
- FULL LENGTH CONTROL ROD
- PART LENGTH CONTROL ROD
- ORIFICE ROD, FIXED

FIGURE 6 - Symmetric Distribution of Instrumented Components in TMI-2 Active Core Region

The nuclear reactivity of the core is controlled by fixed or movable bundles of unfueled rods that are symetrically spaced among the fuel rods in each assembly. The movable control bundles contain a neutron absorber along their full length or part of their length. The fixed control bundles contain either burnable poison rods or empty orifice rods.

Each assembly in the core contains an instrument tube at its center. Fifty-two of the fuel assemblies have an instrumented thimble within the instrument tube to measure the assembly neutron flux distribution and coolant temperature. The balance of the instrument tubes contain empty thimbles. Fuel assembly details are described in the following section.

4.1.1 Fuel Assembly

Each of the TMI-2 fuel assemblies is a 15x15 array of 208 fuel rods, 16 guide tubes, and 1 instrument tube. The fuel assembly is about 14 feet long, including end fittings, and is 8.54 inches square. An axial view and a radial cross section of the fuel assembly are shown in Figures 7[2] and 8[12], respectively.

In the lateral direction the fuel assembly elements are held together by eight "egg-crate" type grids, equally spaced along the assembly length. Axial structure is provided by the guide tubes which run the length of the assembly and are attached to the upper and lower end fittings, shown in Figure 7. Figure 8 shows the symmetrical arrangement of the components within the fuel assembly. The space provided between these components allows the passage of coolant flow. Table 2 summarizes the main assembly geometric parameters. Fuel assembly components are further described below.

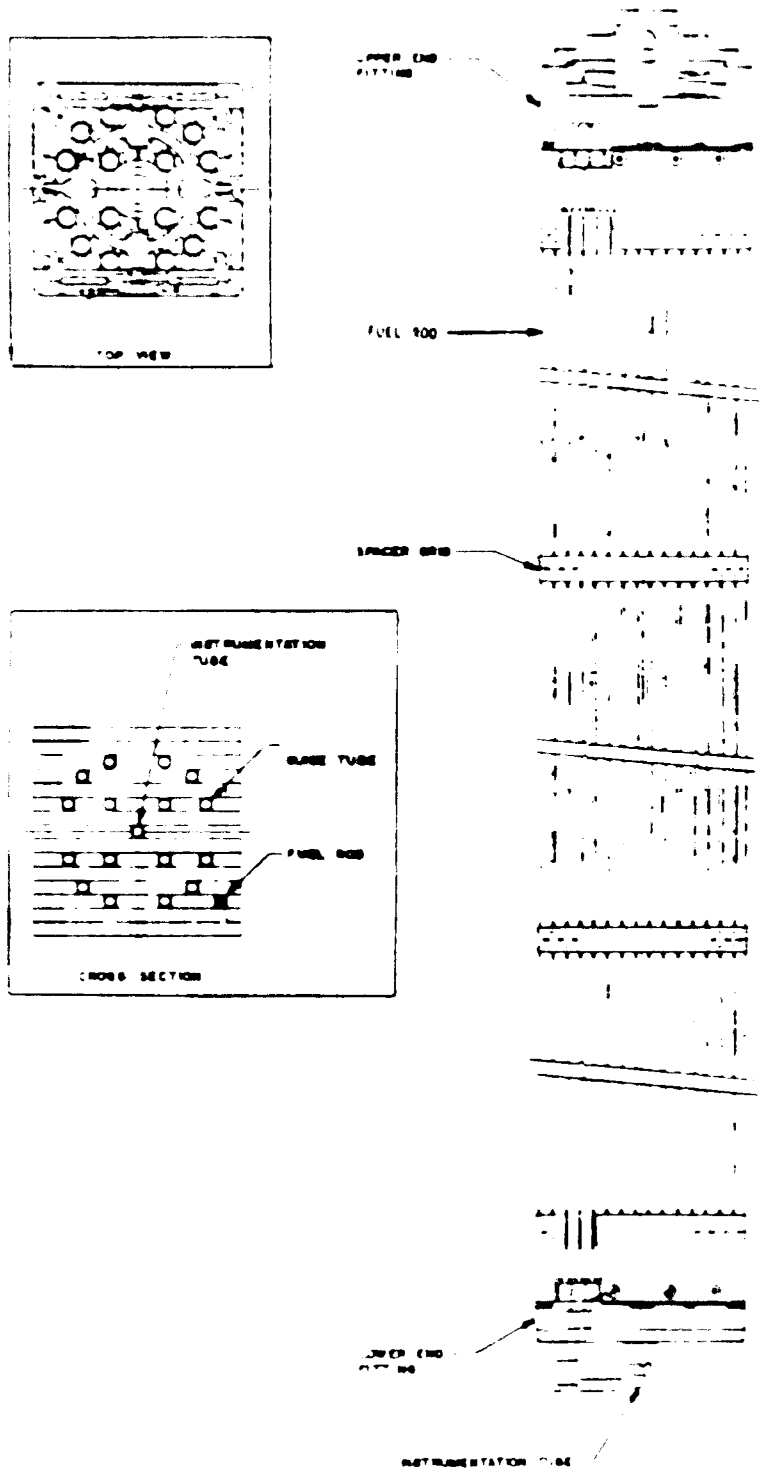
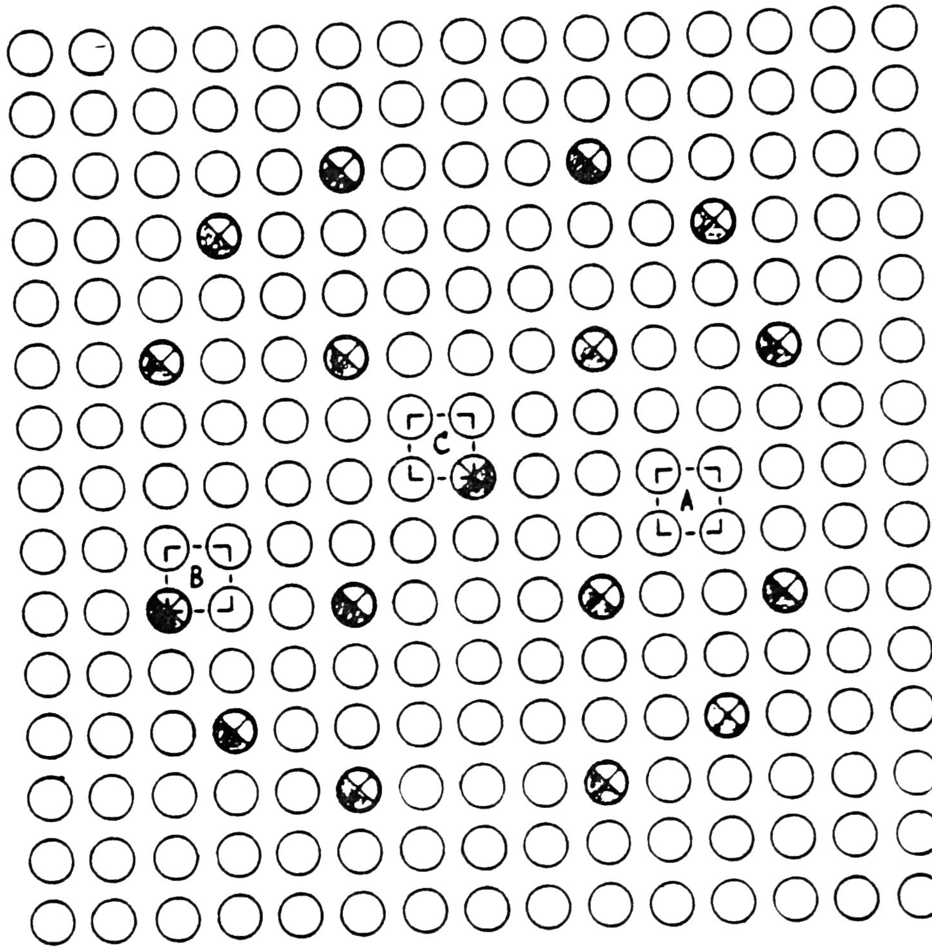


FIGURE 7 - Side, Top, and Cross Sectional Views of TMI-2 Fuel Rod Assembly



SYMBOL	COMPONENT	SUBCHANNEL TYPE
	FUEL ROD	A
	GUIDE TUBE	B
	INSTRUMENT TUBE	C

FIGURE 8 - Transverse Cross Section of TMI-2 Fuel Rod Assembly and Subchannel Types

TABLE 2 - FUEL ASSEMBLY DATA SUMMARY

Parameter	Units	Value				Comment
geometry	-	15x15				square array
total length	in	165.6				with end fittings
bundle length	in	155.2±1				between end fittings
active length	in	144.0±.5				pellet stack length
cross section	in	8.54 x 8.54				-
rod pitch	in	0.568				-
flow area	in^2	39.6				between grid elevations
total surface area	ft^2	327.6				without grids
heated surface area	ft^2	281.0				active surfaces
equivalent hydraulic diameter	in	0.521				-
equivalent heated diameter	in	0.575				-
fuel rods	-	204				-
guide tubes	-	16				-
instrument tube	-	1				-
grids	-	8				-
assembly type*	-	A	B	C	D	-
zircaloy	lb	276	276	300	276	-
304 stainless	lb	37	31	9	11	without end fittings
inconel	lb	15	15	15	15	-
Ag-Cd-In	lb	96	26	0	0	-
Al_2O_3-B_4C/Gd_2O_3-UO_2	lb	0	0	22/72	0	-
ZrO_2	lb	4	4	4	4	-
UO_2	lb	1159	1159	1159	1159	-
total materials	lb	1588	1513	1510/ 1560	1466	between end fittings

*A: fuel assembly with full length control assembly inserted
B: fuel assembly with part length control assembly inserted
C: fuel assembly with burnable poison assembly in place
D: fuel assembly with orifice assembly in place

4.1.1.1 Fuel Rods

An axial and radial fuel rod cross section is shown in Figure 9a[2]. Fuel rod design and coolant channel data is summarized in Table 3. The fuel is UO_2 powder, pressed, sintered, and centerless ground to form cylindrical pellets. The pellets are stacked end to end inside zircaloy cladding tubes which incorporate upper and lower plenum voids and support springs. The tubes are pressurized with helium and welded shut with zircaloy end plugs.

The ends of each fuel pellet have a slight dish-shaped depression to allow space for fuel volume changes during operation[1,2]. Also, the upper and lower edge of each pellet is ground down to help minimize cladding stress concentration when the fuel to cladding gap is closed. A ceramic insulator disc prevents physical contact between the plenum springs and the hot fuel stack.

4.1.1.2 Guide Tubes

Each fuel assembly incorporates 16 zircaloy guide tubes which are permanently attached to the upper and lower assembly end fittings. Axial and radial cross sections of a single guide tube are shown in Figure 9b. Geometric data are given in Table 4.

The guide tubes provide an envelope which either directs the movement of control rods or positions the fixed burnable poison and orifice rods when they are first inserted. The guide tubes also hold the upper and lower end fittings together. The tubes are secured by lock welded nuts threaded to sleeves welded on each end. The

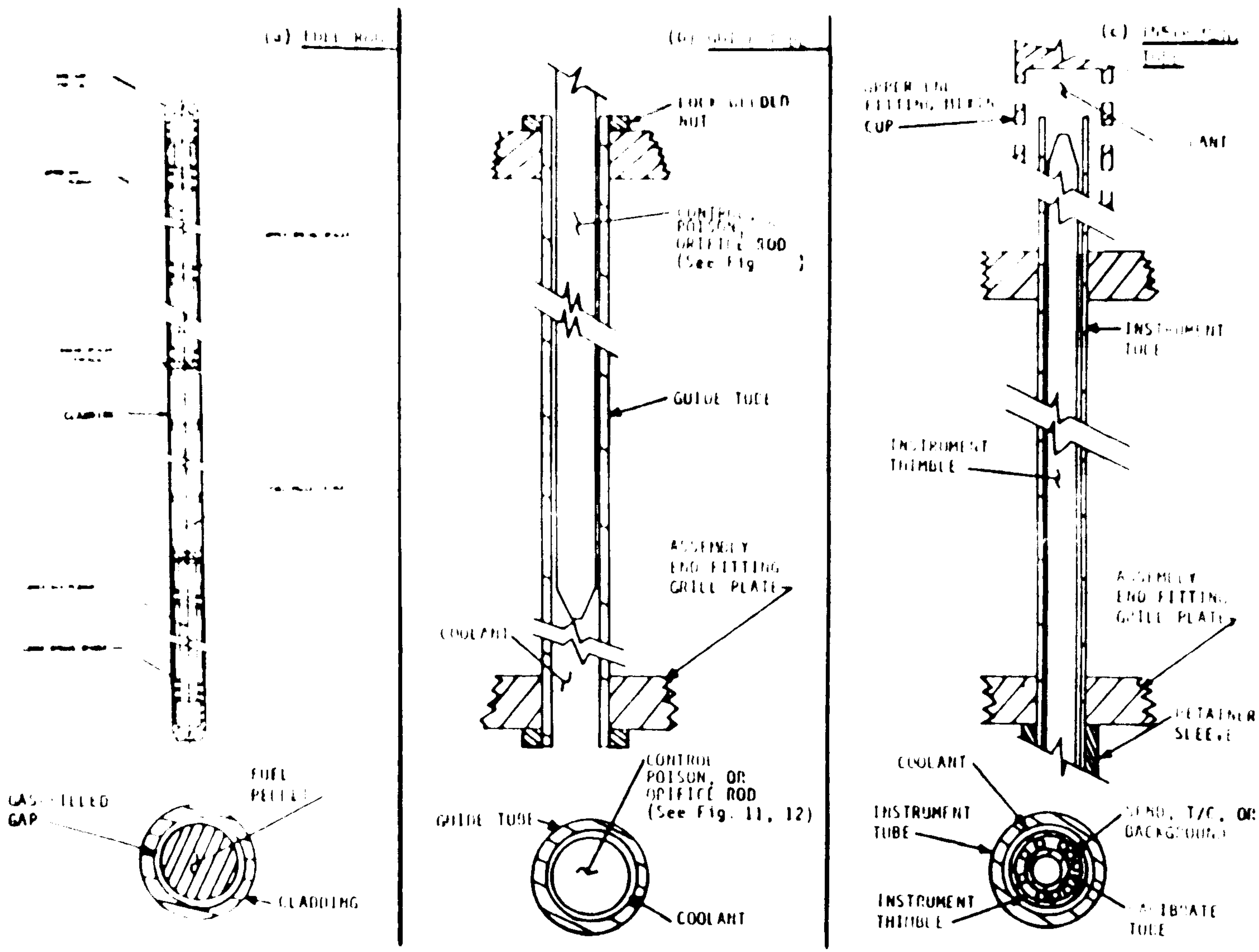


FIGURE 9 - Longitudinal and Traverse Cross Section of TMI-2 Fuel Rod, Guide Tube, and Instrument Tube

TABLE 3 - FUEL ROD DATA SUMMARY

Parameter	Units	Value			Comment
geometry	-	-			cylindrical
total length	in	153.2			-
active length	in	144			-
subchannel types*	-	A	B	C	-
flow area	in^2	.177	.159	.166	-
total surface area	in^2	207	220	215	-
heated surface area	in^2	194	146	146	-
equivalent hydraulic diameter	in	.525	.444	.474	-
equivalent heated diameter	in	.525	.626	.655	-
cladding O.D.	in	0.430			-
cladding ID	in	0.377			-
pellet diameter	in	0.370			-
pellet density	% T.D	92.5±1.5			-
pellet avg. enrichment	wt%	2.57			-
pellet length	in	0.7			-
pellet dish	vol %	1.7±.5			assumed
upper plenum length	in	8±1			assumed
lower plenum length	in	3±1			assumed
fill gas pressure	psia	465±50,He			assumed
plenum spring volume	in^3/in	0.012±.004			assumed
spacer diameter	in	0.366			-
spacer length	in	0.440			assumed
fuel material	-	sintered UO_2			-
cladding material	-	cold work Zirc-4			-
end plug material	-	zirc-4			-
spring material	-	304SS			assumed
spacer material	-	ZrO_2			-
zirc-4	lbs	1.24			-
UO_2	lbs	5.57			-
304 stainless	lbs	0.04			assumed
ZrO_2	lbs	0.02			-
total material	lbs	6.87			-

*A fuel rods
B fuel rods & guide tube
C fuel rods & instrument tube

TABLE 4 - CONTROL ROD GUIDE TUBE DATA SUMMARY

Parameter	Units	Value	Comment
geometry	-	-	cylindrical
total length	in	157±2	-
total surface area	in^2	261±5	-
tube OD	in	0.530	-
tube ID	in	0.498	-
tube material	-	zircaloy	-
zircaloy	lb	1.0±.1	-

TABLE 5 - INSTRUMENT TUBE DATA SUMMARY

Parameter	Units	Value	Comment
geometry	-	-	cylindrical
total length	in	159^{+2}_{-1}	-
total surface area	in^2	246±5	-
tube OD	in	0.493	-
tube ID	in	0.441	-
tube material	-	zircaloy	-
zircaloy	lb	1.4±.1	-

TABLE 6 - SPACER GRID DATA SUMMARY

Parameter	Units	Value	Comment
geometry	-	-	egg crate, no mixing vanes assumed
# strips per grid	-	32	-
strip length (horizontal)	in	8.54	-
strip width (vertical)	in	1.30±.2	-
strip thickness	in	$0.020^{+.02}_{-.01}$	-
strip porosity	%	10	stamped out volume, assumed
grid surface area	in^2	639±100	both sides
strip material	-	inconel	-
inconel	lb	1.[illegible]	-

tubes ends are open to coolant flow at the top and bottom, but the amount of flow is small compared to a fuel rod channel since the guide tubes each contain a control, poison, or orifice rod.

4.1.1.3 Instrument Tube

A Zircaloy instrument tube occupies the central position of each fuel assembly. The instrument tube is attached to a retainer sleeve which is part of the lower end fitting.

The instrument tube extends the length of the active core and terminates in a coolant mixing cup in the fuel assembly upper end fitting. Zircaloy sleeves are fitted around the instrument tube between the spacer grids to prevent their axial motion.

In 52 selected fuel assemblies, the instrument tube contains a full length instrument thimble. This thimble is inserted from the bottom of the active core and connected to a fixture at the bottom end of the instrument tube retainer sleeve. The thimble is clad with inconel and houses various in-core measurement devices that are positioned around a central calibration tube. These devices include 7 self powered neutron detectors (SPND), axially spaced at equal intervals through the active core. Also included are a background or symmetry monitor and a coolant thermocouple. The thermocouple junction is located at the top of the instrument tube. The instrument tube and thimble configuration is shown in Figure 9c and summarized in Table 5. Since the instrument thimble mass is only about 1 pound[32], its characteristics will not be discussed further.

4.1.1.4 Spacer Grids

Each fuel assembly has eight spacer grids uniformly distributed along its length. The grids are each made from 32 slotted strips of inconel which are fit together in an "egg-crate" fashion. The inconel strips thus constitute a 15x15 lattice as shown in Figure 10. The overall grid geometry is summarized in Table 6. Physical contact exists between the outside grid faces of adjacent fuel assemblies. The grids maintain the square array and spacing of the fuel rods, guide tubes and instrument tube within each assembly. These components are supported within the grid by contact points on each grid face. A load is imposed on the fuel rods by the contact points which is sufficient to minimize fretting wear, but not enough to interfere with cladding elongation. The outside strips of the top and bottom grids are axially extended a few inches to allow mechanical attachment to the end fitting located a few inches above and below the active fuel region. The small amount of material represented by this extension will be neglected here.

4.1.2 Unfueled Assemblies

As previously stated, core reactivity is controlled by four types of unfueled assemblies; namely, full and part-length control rod assemblies, burnable poison rod assemblies, and orifice rod assemblies. Following shutdown, all of the unfueled rods reside within the active core region, symmetrically positioned inside the guide tubes in each fuel assembly. The threaded upper ends of the 16 unfueled rods in each fuel assembly are attached by a nut to a stainless steel spider-like structure. The

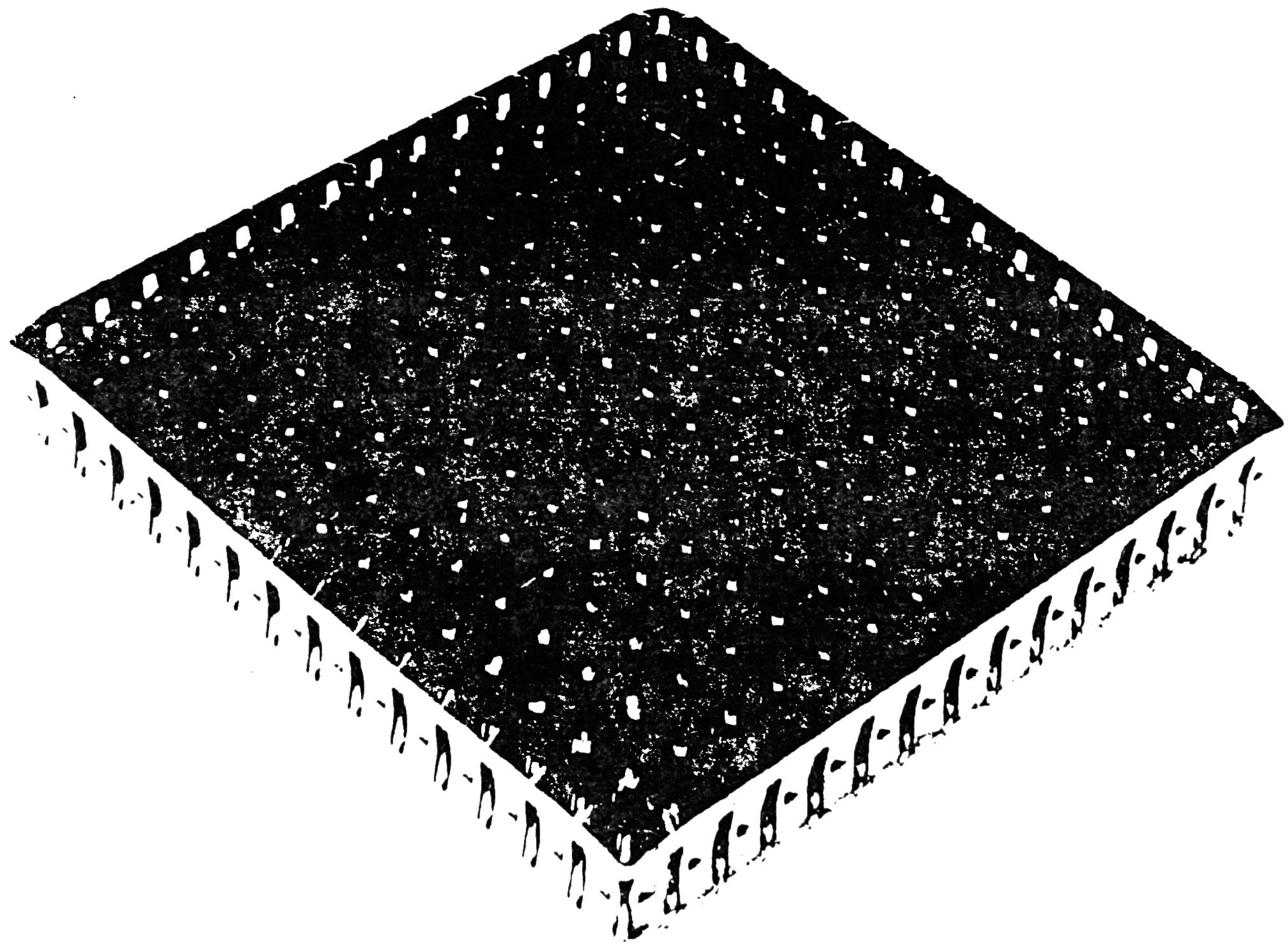


FIGURE 10 - TMI-2 Spacer Grid and Sleeve Components
(Courtesy of Babcock and Wilcox Co.)

spider hub is positioned by a fixture in the upper part of the end fitting and is not considered part of the core region for the present purpose. The following discussion will summarize the characteristics of the unfueled rods.

4.1.2.1 Full Length Control Rods

Sixty-one of the unfueled assemblies consist of full-length control rods. These rods contain a strong neutron absorber over a length that spans most of the active core region. Full-length control rods provide the primary safe shutdown and power regulation functions in the core.

The absorber material itself is in the form of a solid metal alloy rod containing by weight 80% silver, 15% indium, and 5% cadmium. The absorber rod is axially positioned within the control rod cladding by internal spacers and restrained by a hold-down spring. The cladding material is cold-worked stainless steel. The cladding is mechanically stronger than the absorber material and so maintains a fixed control rod geometry. Since primary system coolant is present in the control rod guide tube, use of stainless cladding prevents corrosion as well. The control rod has a chemically inert internal atmosphere. The end plugs are annealed stainless steel. A cross-section of a full length control rod is shown in Figure 11a[2]. The geometry and material data have been summarized in Table 7.

4.1.2.2 Part Length Control Rods

Eight of the unfueled assemblies in the active core region consist of part-length control rods. These rods have a similar geometry and incorporate the same materials as the full length control rods. The absorber section, however, spans a relatively short region near the bottom

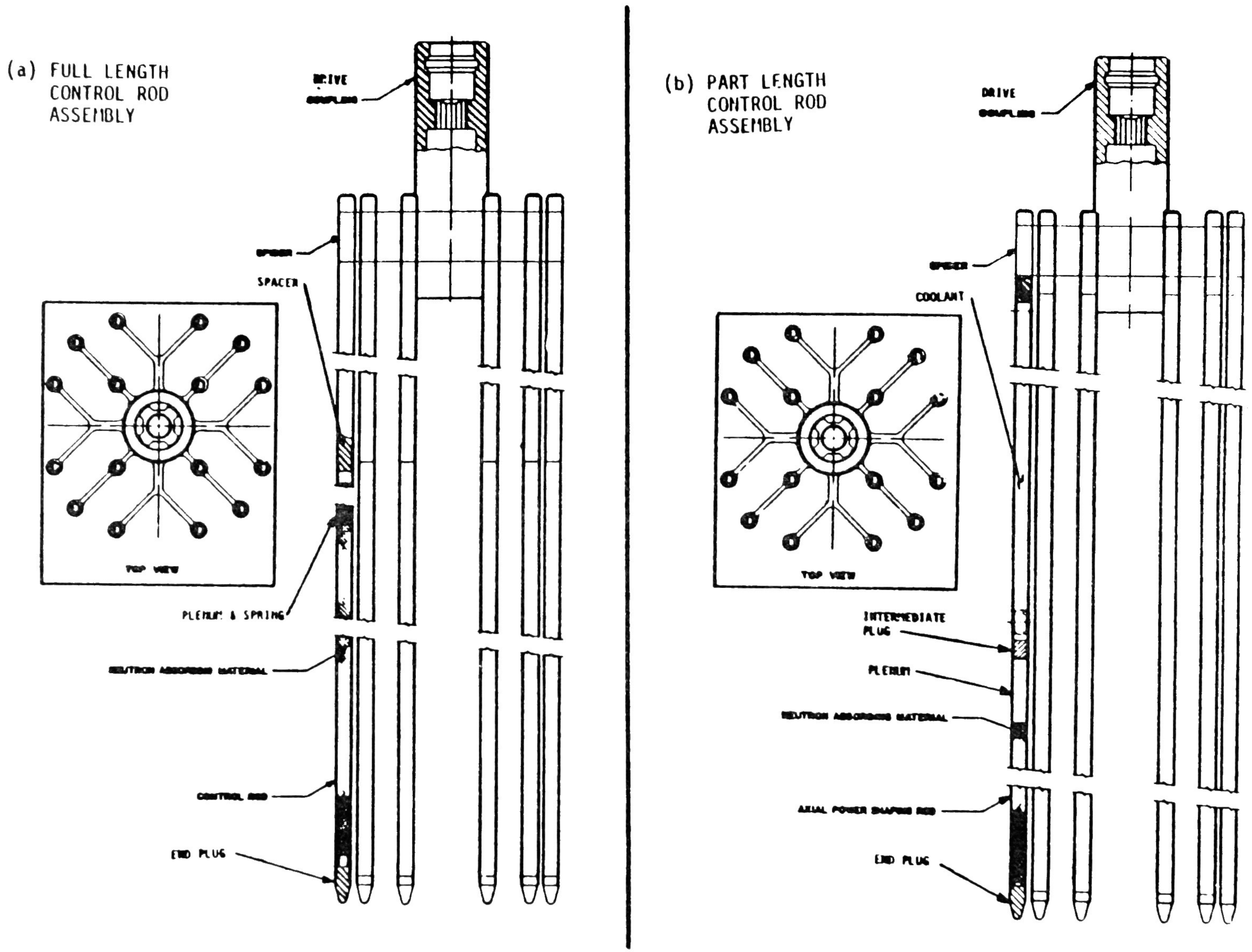


FIGURE 11 - Side, Top, and Cross-Sectional Views of Movable TMI-2 Full and Part Length Control Rod Assemblies

TABLE 7 - FULL LENGTH CONTROL ROD DATA SUMMARY

Parameter	Units	Value	Comment
geometry	-	-	cylindrical
# rods per assembly	-	16	-
total length	in	152±2	-
absorber length	in	134	-
clad OD	in	0.440	-
clad ID	in	0.398	-
absorber diameter	in	0.394	1% gap assumed
clad material	-	304 SS,CW	-
absorber material	-	80Ag+15In+5Cd	wt %
spacer material	-	stainless	assumed
spring material	-	stainless	assumed
end plug material	-	304SS,Ann	-
304 stainless	lb	1.8±.2	-
Ag-Cd-In	lb	6.0±1	-
ZrO_2	lb	0.02	-
total material	lb	7.8 ±1.2	-

TABLE 8 - PART LENGTH CONTROL ROD DATA SUMMARY

Parameter	Units	Value	Comment
geometry	-	-	cylindrical
# rods per assembly	-	16	-
total length	in	152	-
absorber length	in	36	-
clad OD	in	0.440	-
clad ID	in	0.398	-
absorber diameter	in	0.394	1% gap assumed
absorber material	-	80Ag+15In+5Cd	wt %
clad material	-	304SS,CW	-
end plug material	-	304SS,Ann	-
304 stainless	lb	1.4±.4	-
Ag-Cd-In	lb	1.6	-
total material	lb	3.0±.4	-

of the active core. Part-length control rods are designed to damp out the effect of xenon oscillations on the axial flux distribution during power changes. Coolant occupies the vented region above the isolated absorber section of a part-length control rod. The cross section and dimensions of a part-length control rod are shown in Figure 11b[2] and summarized in Table 8.

4.1.2.3 Burnable Poison Rods

Sixty-eight unfueled assemblies contain zircaloy clad burnable poison rods. The position of these rods is fixed inside the fuel assembly guide tubes, since the spider element is latched to an upper end fitting fixture. The burnable poison rods incorporate ceramic pellets containing a neutron absorbing material. The absorber is gradually depleted during exposure to the core neutron flux. The burnable poison reduces the positive moderator temperature coefficient that exists at the beginning of the initial fuel cycle. The poison also flattens the core interior power distribution and balances the effect of slowly occurring negative reactivity changes due to fuel burnup and fission product accumulation.

The burnable poison material is B_4C suspended in cylindrical alumina (Al_2O_3) pellets. The pellets are loaded into Zircaloy cladding tubes and axially positioned with internal spacers. A small gap exists between the pellets and the cladding. Motion of the pellet stack is restrained by a holddown spring. The ends of the cladding tubes are closed by welded Zircaloy plugs. A cross section of a burnable poison rod is shown in Figure 12a[2]. The dimensions and material data are summarized in Table 9.

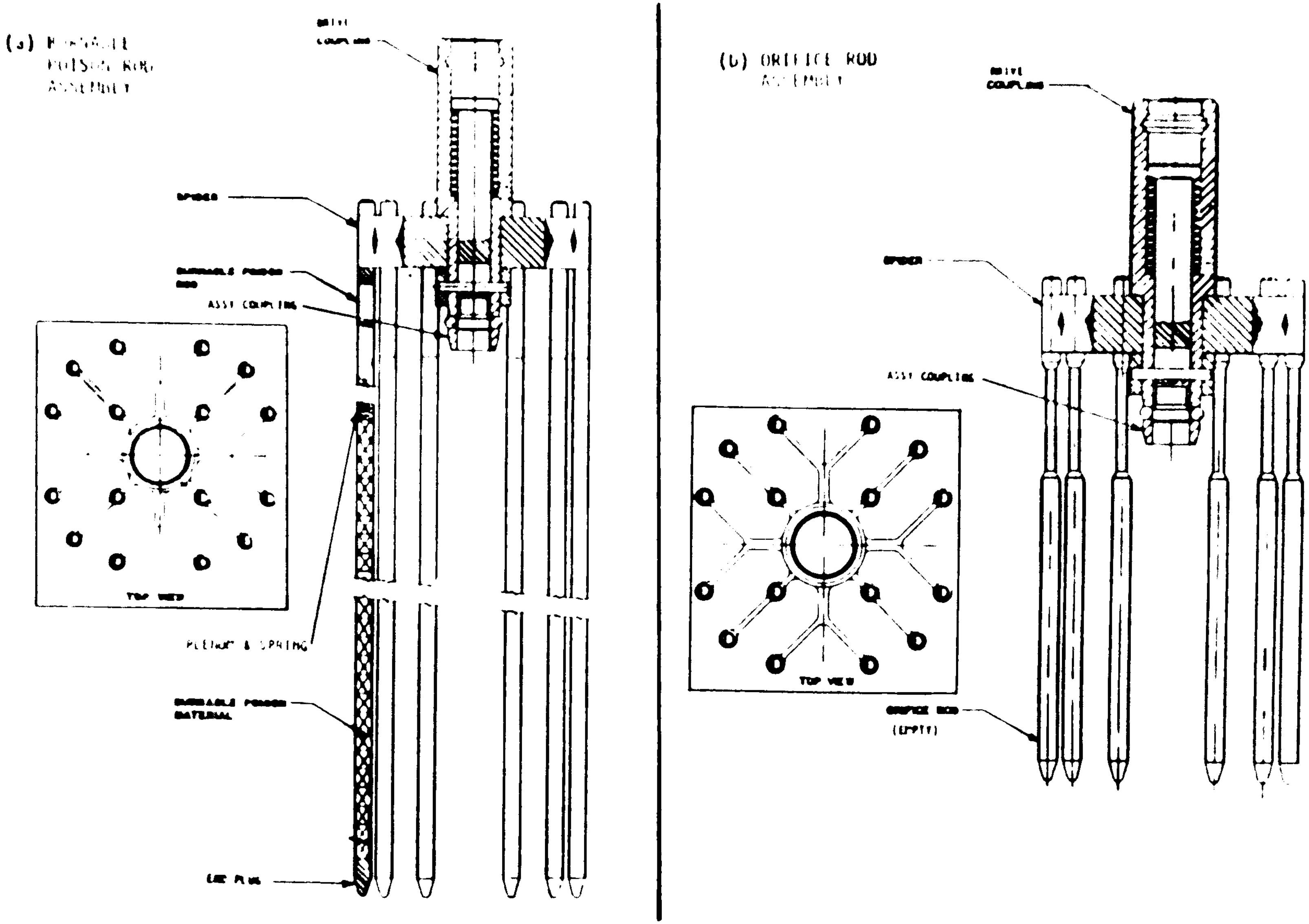


FIGURE 12 - Side, Top, and Cross-Sectional Views of Fixed TMI-2 Burnable Poison and Orifice Rod Assemblies

TABLE 9 - BURNABLE POISON ROD DATA SUMMARY

Parameter	Units	Value	Comment
geometry	-	-	cylindrical
# rods per assembly	-	16	-
total length	in	148±2	-
poison length	in	126	-
clad OD	in	0.430	-
clad ID	in	0.360	-
poison diameter	in	0.353	2% gap assumed
clad material	-	zirc-4,C.W.	-
poison material	-	$Al_2O_3+B_4C/Gd_2O_3+UO_2$	-
spring material	-	stainless	assumed
end plug material	-	zirc-4,Ann	-
zircaloy	lb	1.6	-
$Al_2O_3+B_4C/Gd_2O_3+UO_2$	lb	1.4/4.5	-
stainless	lb	0.06 ±.03	-
total material	lb	3.1/6.2	-

TABLE 10 - ORIFICE ROD DATA SUMMARY

Parameter	Units	Value	Comment
geometry	-	-	cylindrical
# rods per assembly	-	16	-
total length	in	12±4	assumed
clad OD	in	0.480	-
clad ID	in	0.440	assumed
clad material	-	304SS,Ann	-
end plug material	-	304SS,Ann	-
stainless	lb	0.19	-

4.1.2.4 Orifice Rods

Forty of the unfueled assemblies consist of empty Zircaloy orifice rods. These rods are inserted a short distance into the upper portions of the guide tubes in the peripheral fuel assemblies. The peripheral fuel assemblies do not require supplemental reactivity control rods because the neutron flux is relatively low at the edge of the active core. The presence of orifice rods is necessary however, to limit the amount of coolant flow that would otherwise pass through the empty guide tubes and avoid the fuel rod channels. Like the burnable poison rods, the axial position of the orifice rods is fixed by the mechanical coupling that exists between the spider element and the fuel assembly upper end fitting. An orifice rod is illustrated in Figure 12b[2]. The geometric parameters are listed in Table 10.

4.2 Adjacent Core Region

The configuration of the reactor vessel internals that are immediately adjacent to the active core region are described in this section. The components of the adjacent core region are distinguished here on the basis of their axial or radial orientation relative to the effective cylindrical shape of the active core region. This approach is taken, because the coolant flow path through the active core region is through the ends of the effective core cylinder. Flow can enter or leave the active core region only by passing through the annular region surrounding the effective core cylinder.

4.2.1 Radial Orientation

Figure 5 previously showed a radial cross section of the vessel internals in the active core region. The space between the outer edge of the peripheral fuel assemblies and the inside of the reactor vessel wall forms an annulus around the core. The main components of this annulus are the core baffle, the core barrel, and the vessel thermal shield. The dimensions of the radially adjacent core region are illustrated in Figure 13 and summarized in Table 11.

4.2.1.1 Core Baffle

The core baffle consists of horizontal former plates and a series of vertical baffle plates. These plates are forged from stainless steel and together form an inner wall of structural material that laterally encloses the active core region. The eight horizontal former plates are axially spaced between the bottom and top of the active core region and are bolted to the core barrel. The vertical baffle plates are bolted to the inner surface of the former plates and lie flat against the outside grid faces of the peripheral fuel assemblies. Symmetric holes in the horizontal former plates allow a small portion of the primary coolant to flow upward in the 5 inch space between the baffle plates and the inside wall of the core barrel. Relative to core conditions, slightly lower coolant pressure exists in the core baffle region to avoid tensile stress on the plate attachment bolts.

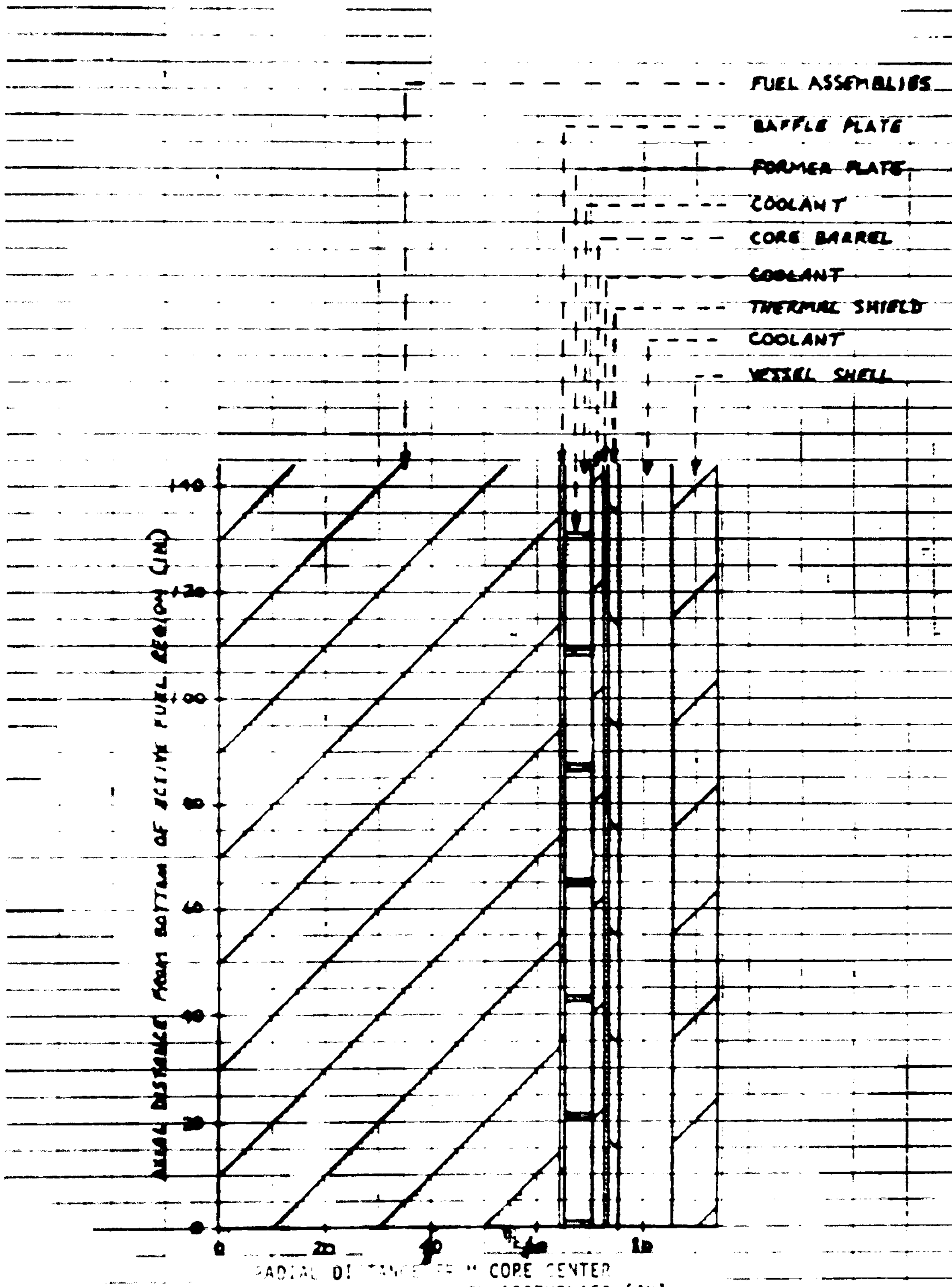


FIGURE 13 - Relative Dimensions of TMI-2 Core and Radially Adjacent Baffle and Downcomer Regions

TABLE 11 - RADIALLY ADJACENT CORE REGION DATA SUMMARY

Parameter	Units	Value	Comment
Baffle Plates			
geometry	-	-	vertical retangular plates
length	in	166±3	-
width	in	8.6/17.2/43.0	-
thickness	in	0.9±.3	-
# plates	-	24/8/4	total
material	-	stainless steel	assumed
stainless steel	lb	22250±10%	all plates together
Former Plates			
geometry	-	-	horizontal perforated disc segment
total area	ft^2	17.8	1 elevation, 1 side
flow area	ft^2	1.4±.4	1 elevation, perforations
thickness	in	0.9±.3	assumed
# plates	-	8	# elevations
material	-	stainless steel	assumed
stainless steel	lb	4940±10%	all elevations
Core Barrel			
geometry	-	-	cylindrical
length	in	166±3	-
O.D.	in	145.0	-
I.D.	in	141.2	-
material	-	stainless steel	assumed
stainless steel	lb	40930±10%	-
Thermal shield			
geometry	-	-	cylindrical
length	in	166±3	-
O.D.	in	151	-
I.D.	in	147	-
material	-	stainless steel	-
stainless steel	lb	44820±10%	-
Flow Areas			
between baffle plates and core barrel	ft^2	17.8±10%	-
through holes in former plates	ft^2	1.4±50%	1 elevation
between core barrel and thermal shield	ft^2	3.2±20%	-
between thermal shield and vessel ID	ft^2	35.8±10%	-

4.2.1.2 Core Barrel

The core barrel is a flanged stainless steel cylinder about 14 feet long, 145 inches in outside diameter, and 2 inches thick. The core barrel surrounds the baffle region and extends axially between the lower grid assembly, which is bolted to it, and the upper fuel assembly tie plate. The core barrel structurally supports the weight of the fuel assemblies, lower support plate, lower grid, flow distributor, and incore instrument guide tubes. The outside surface of the core barrel also forms the inner boundary of the flow annulus which guides the primary coolant from the vessel inlet to the core inlet.

4.2.1.3 Thermal Shield

The thermal shield is a stainless steel cylinder with an outside diameter of 151 inches and a wall thickness of 2 inches. The thermal shield completely surrounds the core barrel. The barrel and the shield are separated by a 1 inch space, normally occupied by primary coolant. The thermal shield reduces the incident neutron flux at the vessel wall and minimizes gamma heating of the wall material. The shield extends axially from the lower grid assembly where it is bolted, to the upper fuel assembly tie plate where it is radially pinned to the core barrel. Between the thermal shield and the inside wall of the reactor vessel is a 10 inch annulus. This annulus together with the smaller annulus between the core barrel and thermal shield constitutes the downcomer. The downcomer forms the primary coolant flow path between the cold leg piping and lower plenum.

4.2.2 Axial Orientation

Figure 4 previously showed a longitudinal cross section of the reactor vessel and internals. Neglecting the upper and lower plenums, a cylindrically shaped region extends a foot or so above and below the active core. This region is occupied by fuel assembly end fittings, a lower core support plate, and an upper assembly tie plate. Dimensional and material data for these components is summarized in Table 12.

4.2.2.1 Assembly End Fittings

Figure 7 previously showed the general configuration of the upper and lower fuel assembly end fittings. The end fittings are cast from stainless steel and held together axially by the fuel assembly guide tubes. The guide tubes are attached by lock-welded nuts to a grilled plate in each end fitting. The plate allows the passage of coolant flow through the end fittings. Alignment pins position the end fittings within close tolerances to an upper tie plate and a lower core support plate.

The upper end fitting incorporates a holddown spring to oppose upward hydraulic forces on the grill plate during full flow conditions[2,14]. As shown in Figure 14[8], a hollow post at the center of the end fitting provides a retaining fixture for the orifice and burnable poison rod assemblies and a mixing cup to house the upper end of the instrument tube with its coolant thermocouple. The bridgework on top of the upper end fitting provides a structure[14] for handling the assembly during fuel shuffling and loading operations.

TABLE 12 - AXIALLY ADJACENT CORE REGION DATA SUMMARY

Parameter	Units	Value	Comment
Fuel Assy Upper End Fitting			
geometry	-	-	square, cage-like structure
total length	in	6.2±2	excluding upper grid extension
cross section dimensions	in	8.54x8.54	-
minimum flow area	in^2	40±10	grill plate region
material	-	304 SS	-
stainless steel	lb	22±2	-
Fuel Assy Lower End Fitting			
geometry	-	-	square cage-like structure
total length	in	4.4±1.5	excluding lower grid extension
cross section dimensions	in	8.54x8.54	
minimum flow area	in^2	40±10	grill plate region
material	-	304SS	-
stainless steel	lb	16±2	-
Upper Tie Plate			
geometry	-	-	perforated disc
diameter	in	141.2	-
thickness	in	3.3±1	-
# perforations	-	177	1 per fuel assembly
perforation diameter	in	6±2	-
total flow area	ft^2	34.8±10	through perforations
material	-	stainless steel	assumed
stainless steel	lb	7680±1000	-
Lower Core Support Plate			
geometry	-	-	perforated disc
diameter	in	141.2	-
thickness	in	4.8±1.5	-
# perforations	-	708	4 per fuel assy assumed
perforation diameter	in	2 ± 1	-
total flow area	ft^2	15.4±5	through perforations
material	-	stainless steel	assumed
stainless steel	lb	16670±3000	-

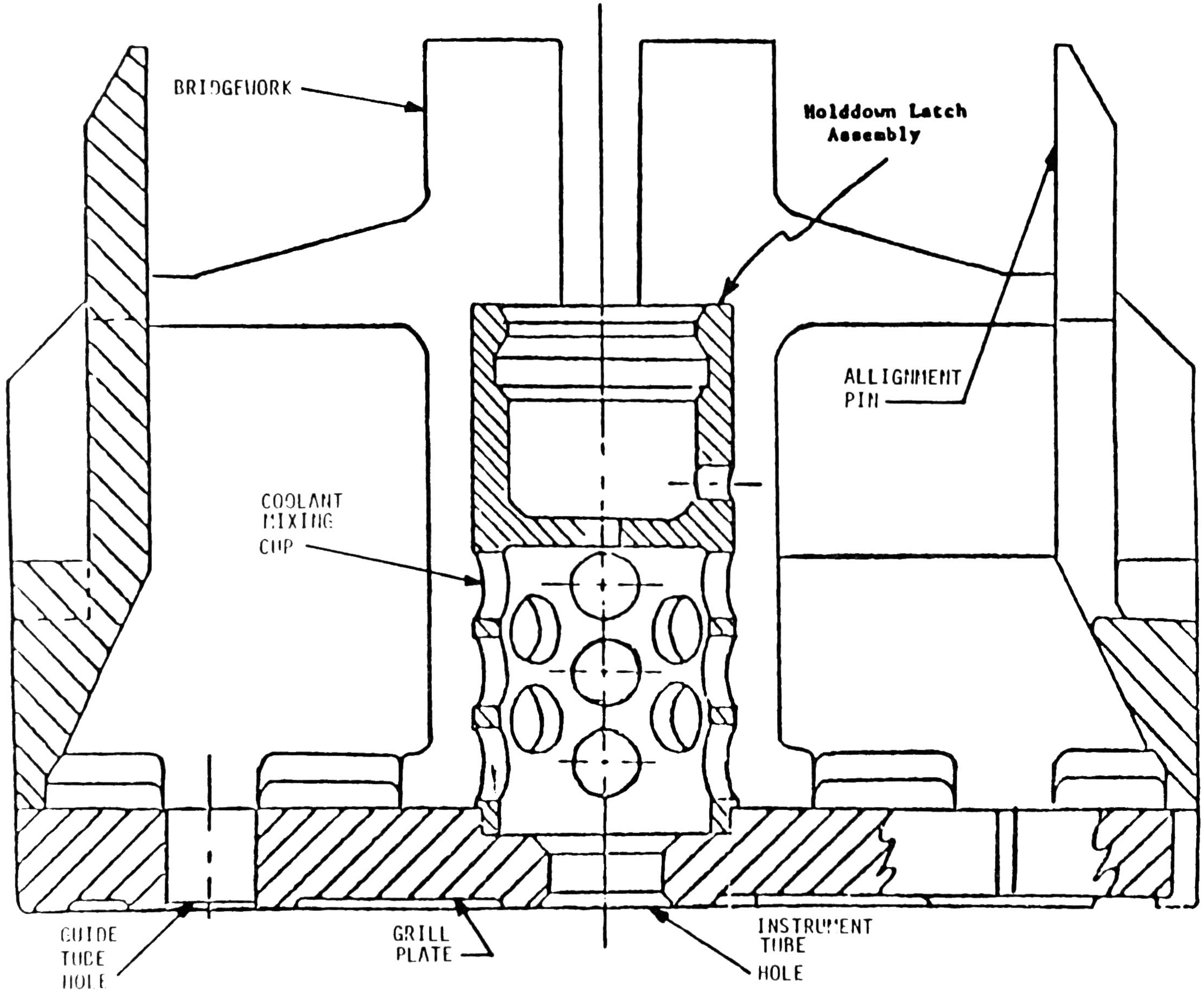


FIGURE 14 - Logitudinal Cross Section of TMI-2 Upper Fuel Rod Assembly End Fitting

The lower fuel assembly end fitting incorporates a central connection for the instrument tube. The bottoms of the fuel rod end plugs are in contact with the end fitting grill plate. As previously stated in Section 4.1.1.4, axial motion of the fuel rods is restrained by the spacer grid contact points in the active region.

4.2.2.2 Upper Tie Plate

The upper core tie plate is a large performated stainless steel disc located directly above the fuel assembly end fittings. The tie plate is part of the upper plenum assembly and is bolted to the lower flange of the plenum cylinder. The tie plate is also supported by the control rod assembly guide tubes which are suspended from the plenum cover. The control rod assembly guide tubes are bolted to the upper tie plate, directly above the previously mentioned perforations.

The tie plate aligns the lower ends of the control rod assembly guide tubes with the upper ends of corresponding fuel assemblies. Alignment studs on the top of each fuel assembly end fitting seat with close tolerance into small holes on the under side of the tie plate. The large perforations in the tie plate provide the coolant flow paths between the active core region and the plenum region. The upper core tie plate is illustrated in Figure 15.

4.2.2.3 Lower Support Plate

The lower plate is a large perforated stainless steel disc located directly below the fuel assemblies. This plate is the uppermost portion of the lower grid assembly and is bolted to a flange on top of the steel cylinder that surrounds the grid assembly.

FIGURE 15 - TMI-2 Upper Core Tie Plate
(Courtesy of Babcock and Wilcox Co.)

The fuel assembly lower end fittings rest on the lower core support plate. Symmetric perforations in the plate direct coolant flow into the bottom of each fuel assembly and position the instrument tube. The fuel assemblies are aligned with respect to the perforations by pads bolted to the support plate. A drawing of the lower core support plate is shown in Figure 16.

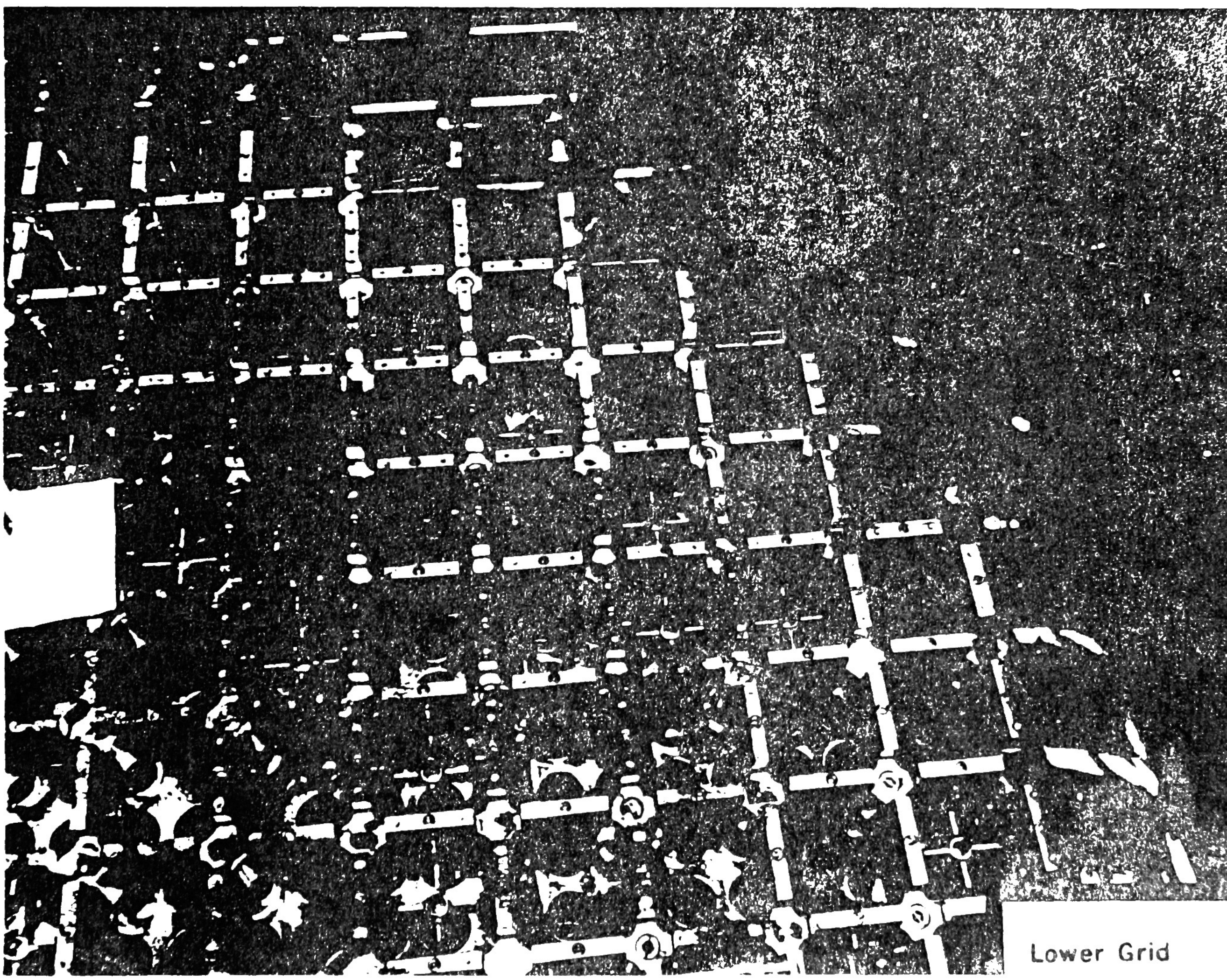


FIGURE 16 - TMI-2 Lower Core Support Plate
(Courtesy of Babcock and Wilcox Co.)

5.0 REACTOR MATERIALS

This section discusses the solid materials inventory and basic properties of the TMI-2 core region. Approximations have been made when warranted by the lack of more detailed information.

5.1 Material Inventory

The overall material inventory of the core is summarized below for both active and adjacent core regions.

5.1.1 Active Core Region

The active core contains fuel, structural materials, neutron absorbers, and trace materials used for instrumentation, neutron sources and insulation. The form, composition, volume and weight of material in each category is indicated in Table 13. Only the initial core condition is considered in the table provided; i.e., the contributions of fission and corrosion products and coolant crud deposition are neglected. On the basis of total mass inventory, the fuel, structural, and absorber materials constitute about 70, 27, and 3% of the active core, respectively.

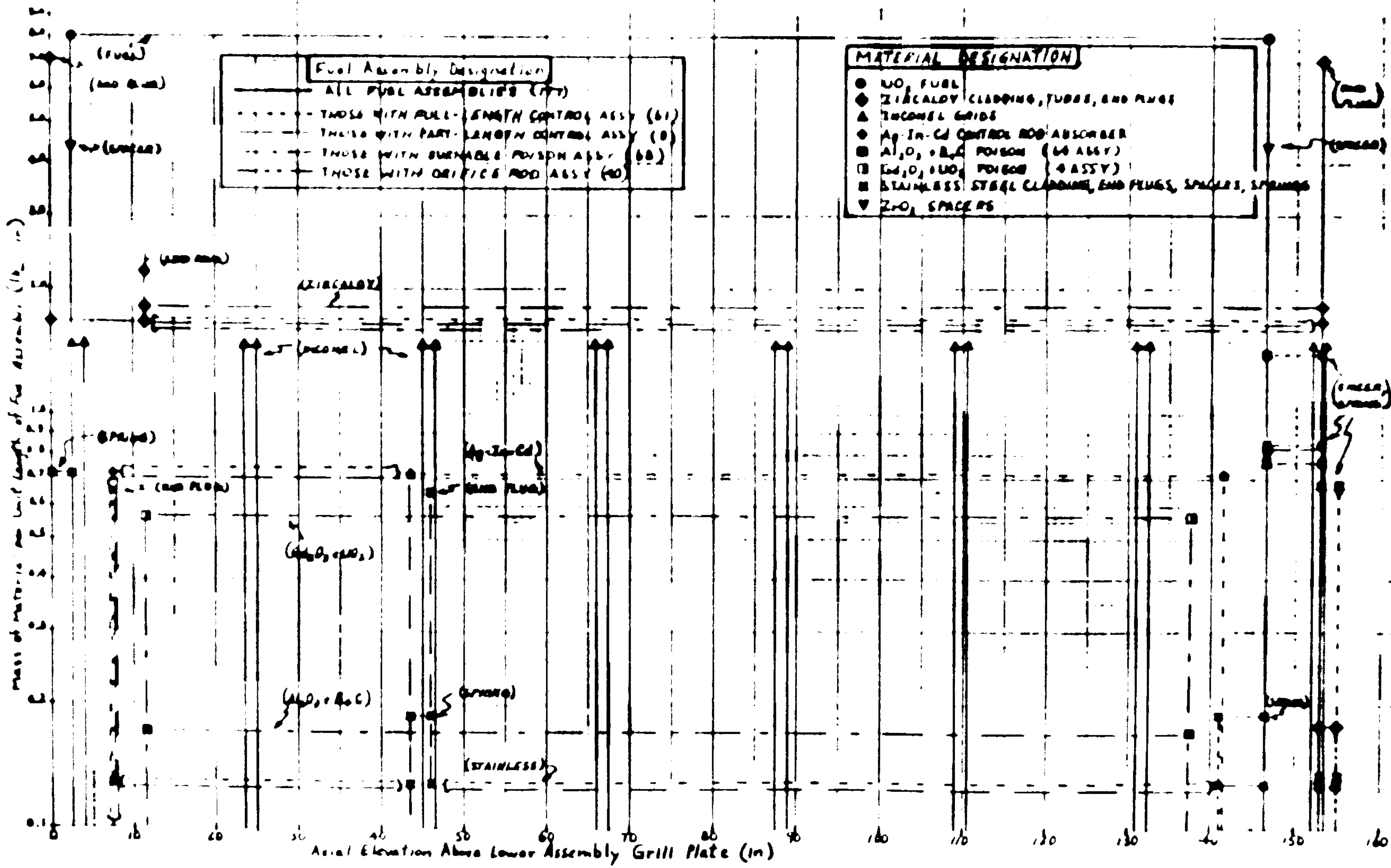
The axial distribution of assembly materials between the end-fitting grill plates is illustrated in Figure 17. The four types of assemblies present at TMI-2 are indicated. The ordinate axis represents the local "concentration" of mass in units of pounds per axial inch of fuel assembly. It is evident that the material cross section of the core depends on elevation as well as radial position. Also, with the exception of UO_2 fuel, inconel grids, and fuel rod spacers and end plugs, the assemblies

TABLE 13 - ACTIVE CORE REGION MATERIALS INVENTORY*

Category	Form	Composition	Volume (ft^3)	Weight (lb)
Fuel	ceramic pellets	UO_2	324.3	205140
Absorbers	metal aloy rod	Ag-In-Cd	9.55	6060
	ceramic pellets	B_4C in Al_2O_3	7.29	1380
	ceramic pellets	Gd_2O_3-UO_2	0.46	290
Structures	fuel cladding	Zircaloy-4	109.7	44440
	guide tubes	Zircaloy-4	6.65	2690
	instrument tubes	Zircaloy-4	0.62	250
	control cladding	304SS	2.70	1350
	poison rod cladding	Zircaloy-4	4.04	1640
	orifice rod cladding	304SS	0.13	60
	spacer grids	Inconel-718	5.24	2670
	spacer sleeves	Zircaloy-4	0.64	260
	plenum springs	(stainless)	3.10	1550
	ceramic spacers	ZrO_2	2.13	730
	metallic spacers	(stainless)	0.90	450
	end plugs	304SS	0.28	140
	end plugs	Zircaloy-4	3.69	1490
Trace	SPND	rhodium-inconel	-	-
	T/C	chromel-alumel	-	-
	background detector	(cobalt)	-	-
	neutron source	AM-Be-Cm	-	-
	instrument thimble clad	inconel	-	-
	instrument calibration tube	(inconel)	-	-
	insulation	(ceramic)	-	-

*Estimated uncertainty < 10%

FIG 17: AXIAL DISTRIBUTION OF MASS IN TMI-2 FUEL ASSEMBLIES



contain different amounts of Zircaloy, absorber material, poison material, and stainless steel. Material concentration and property gradients are likely to have led to at least some variation in local core damage conditions during the core uncovery period.

5.1.2 Adjacent Core Region

The adjacent core region contains structural materials only. The form, composition, volume, and weight of the various components are summarized in Table 14. The amount of material immediately surrounding the core obviously represents a significant amount of heat capacity as well as a physical barrier to core movement.

5.2 Material Properties

Some of the basic physical properties of the TMI-2 core materials are presented in this section. In terms of evaluating the accident behavior of the core, heat transfer and melting point properties are emphasized. Gas release characteristics are also included for the fuel. Oxidation and mechanical strength properties are included for the main structural materials. Multiple references are quoted in some cases to indicate that a range of values is possible because of material property uncertainty, particularly at elevated temperatures. The core materials have been divided into categories corresponding to fuel, structural, absorber, and trace materials. The melting point, density, and heat of fusion properties of the most prevalent materials have been summarized in Figure 18 for later reference in this report.

TABLE 14 - ADJACENT CORE REGION MATERIALS INVENTORY*

Component	Form	Composition	Volume (ft^3)	Weight (lb)
Baffle Plates	rectangular plates	stainless steel	44.5	22250
Former Plates	perforated plate segments	stainless steel	9.9	4940
Core Barrel	cylinder	stainless steel	81.8	40930
Thermal Shield	cylinder	stainless steel	89.6	44820
Assembly End Fittings	cage	stainless steel	13.4	6730
Upper Tie Plate	perforated plates	stainless steel	15.4	7680
Lower Support Plate	perforated plates	stainless steel	33.3	16670

*See Summary Data Tables 11 and 12 for estimated uncertainty.

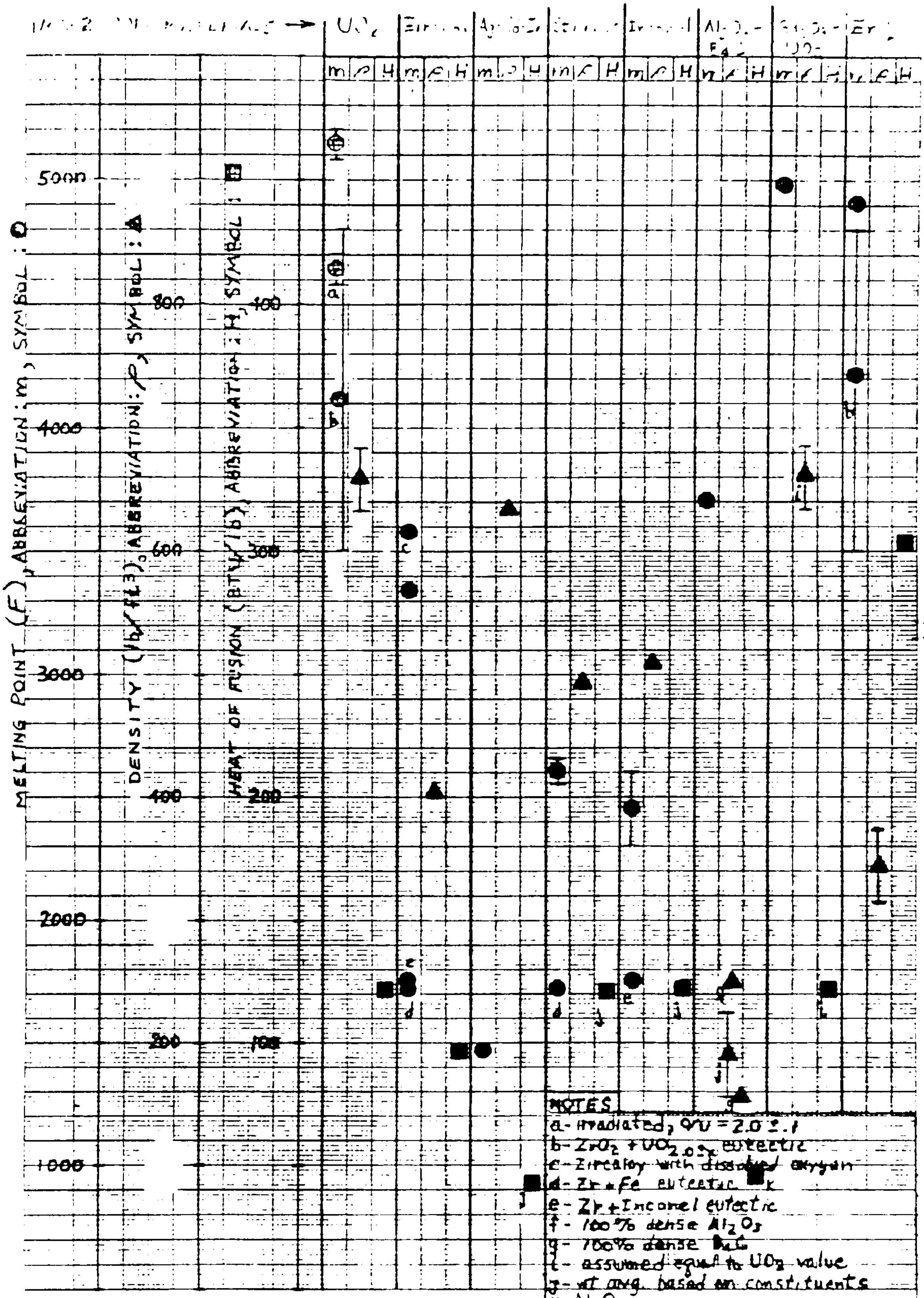


FIGURE 13 - Melting Point, Density and Heat of Fusion Summary for Various TMI-2 Core Materials

5.2.1 Fuel Material

The TMI-2 fuel is a UO_2 ceramic in the form of cylindrical pellets. The pellets consist of hot pressed and sintered UO_2 powder. The basic physical features of the pellet structure are fuel grains, grain boundaries, porosity within the grains and at the grain boundaries, and randomly distributed cracks dividing the pellet into irregular pieces.

The nominal pellet density is 633 lb/ft^3[2], about 92.5% of the theoretical value at room temperature. The pellet density is relatively high, compared to other core materials. Decreases in fuel density between 10 and 20% have been reported near the melting point, however[24]. The unirradiated stoichiometric UO_2 melting point is between 5070 and 5200°F[3,5,8,10,11,18,24]. The melting point can decrease with burnup, stoichiometry, and eutectic-related changes. A maximum burnup effect of about 300°F decrease in melting point at 50000 Mwd/MTU can be extrapolated from the results of one experiment for example[28]. A ± 10% change in O/U ratio can lower the melting point by 100 to 200°F[24]. This effect is relevant for application to failed TMI-2 rods given a steam environment. A liquid phase Zirconium and Uranium alloy can also exist at the fuel-clad surface at temperatures as low as 3500°F[29]. Still, the unalloyed UO_2 fuel has the highest melting point among the core materials as illustrated by the temperature scale in Figure 18. The heat of fusion of UO_2 is 121.3 ± 3 BTU/lb[11,24], a value comparable to that of several other core materials. The thermal conductivity, specific heat capacity, and thermal expansion properties of UO_2 are plotted versus temperature in Figure 19.

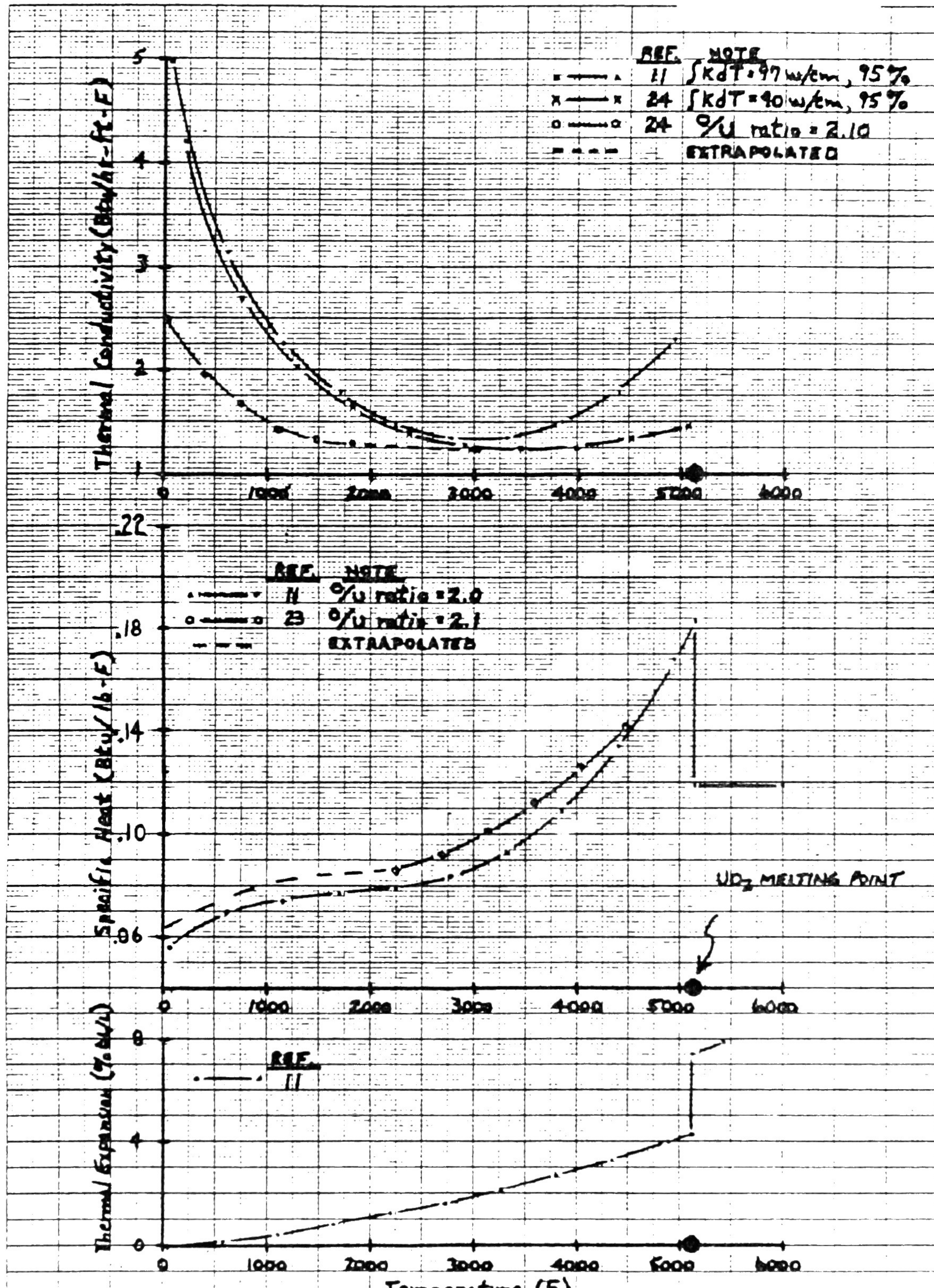


FIGURE 19 - UO_2 Thermal Conductivity, Specific Heat, and Thermal Expansion versus Temperature

The thermal conductivity curves represent 95% dense UO_2. A porosity correction factor of .93 to .96 should be applied to represent 92.5% dense UO_2[18,24]. The two upper conductivity curves correspond to $\int_0^{melt} kdt$ values of 90 and 97 w/cm. The lower conductivity curve shows the relative effect of an increased O/U ratio, in this case 2.10. The O/U ratio increases gradually with burnup, but again, could also increase given the presence of steam in failed TMI rods. A conservative $\int kdt$ value of 86 w/cm has been suggested for LOCA applications[24]. In any event, UO_2 has the lowest thermal conductivity of any core material with the exception of ZrO_2.

The nominal specific heat and thermal expansion properties of UO_2 are well characterized by MATPRO[11,23] correlations over a wide temperature range. An effect of O/U ratio on specific heat has been reported below 4500°F, as shown in the center plot in Figure 19. The specific heat of UO_2 is comparable to that of Zircaloy, but its thermal expansion is greater. Step changes in specific heat and thermal expansion properties occur when the melting point is reached at about 5100°F.

Figure 20 illustrates the temperature effect on UO_2 fission gas release behavior. This property is relevant to TMI-2 since the interpretation of fission product behavior has been applied to characterizing core temperature conditions. The curves shown represent correlations of various steady-state data sources. Fuel temperature uncertainty, burnup, and fabrication differences are reflected in the correlation data. These differences contribute significantly to the large variation between curves. The effects of off-normal fuel rod chemistry or eutectic formation during a

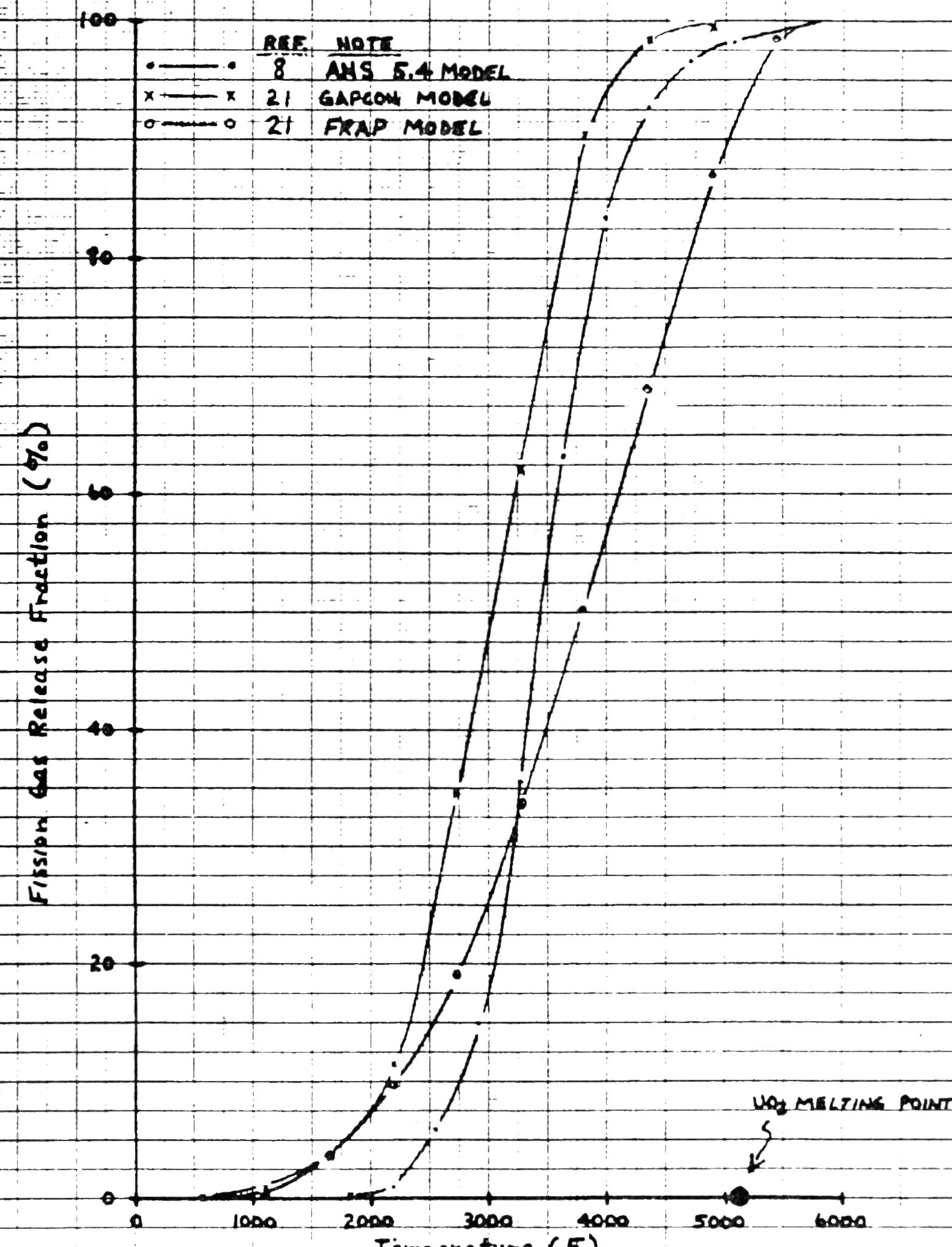


FIGURE 20 — Effect of Fuel Temperature on Steady State Fission Gas Release Correlations