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CONTAINMENT SYSTEMS EXPERIMENT

PART I

DESCRIPTION OF EXPERIMENTAL FACILITIES

C. E. Linderoth

March 1970

AEC RESEARCH &
DEVELOPMENT REPORT

BNWL-456

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By

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Physics and Engineering Division

March 1970

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CONTAINMENT SYSTEMS EXPERIMENT
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C. E. Linderoth

ABSTRACT

The physical features of the Containment Systems Experiment are described in sufficient detail to provide the reader an insight into the capabilities of the installations for studies of credible accidents to nuclear reactor systems.

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CONTAINMENT SYSTEMS EXPERIMENT
PART I
DESCRIPTION OF EXPERIMENTAL FACILITIES

C. E. Linderoth

INTRODUCTION

In 1963, the Atomic Energy Commission's Division of Reactor Development authorized Pacific Northwest Laboratory (then Hanford Laboratories) to proceed with an experimental program for investigating the behavior of reactor containment systems and related engineered safeguards under maximum-credible-accident (MCA) conditions for pressurized and boiling water power reactors. The program was to be closely related to several others in the Division's nuclear safety program, including laboratory investigations of reactor fuel meltdown and fission product release and transport behavior at the Nuclear Safety Pilot Plant (NSPP), Oak Ridge National Laboratory, and the Loss of Fluid Test (LOFT) at the National Reactor Test Station.

Since authorization of the Containment Systems Experiment (CSE) in November, 1963, one area of major effort has been the scope, design, and installation of the test facility. This document describes the essential experimental facilities designed and constructed to permit achievement of the CSE program objectives.

PROGRAM OBJECTIVES

The primary purpose of the CSE program is to evaluate on a significant engineering scale the effectiveness of natural processes and engineered safeguards in limiting the release of fission products to the environs following a reactor accident. The secondary purpose is to investigate engineering aspects of hypothesized loss-of-coolant accidents, including the dynamic effects of a rupture in high temperature coolant piping and the leakage characteristics of representative containment systems.

The program is directed toward investigating the loss-of-coolant accident in reactors of the pressurized or boiling water types fueled with UO_2.

In line with these broad purposes, the following specific program objectives were identified as a basis for development of engineering tests and related research and development.

- To determine the effect of natural processes such as agglomeration and settling, diffusional deposition, and condensation of water vapor on reduction of airborne fission product concentration in containment systems, and application of experimental data to the evaluation of available analytical models.
- To determine the effectiveness of both active and passive engineered safeguard systems in reducing fission product concentration in the containment atmosphere. Active safeguard systems employ water sprays and air filtration methods, whereas a passive system might achieve pressure suppression by means of a containment water pool. Measured values will be compared with those calculated from analytical models.
- To evaluate the effectiveness of different methods of pressure reduction in containment vessels. Methods include water pool pressure suppression, cooling the contained atmosphere, and heat transfer to low temperature materials inside containment and through the containment membrane to the atmosphere.
- To determine the amount of leakage of fission product activity from containment under a range of postaccident conditions and to compare these values with those calculated from both low and high temperature air leakage rate tests and fission product concentration in the containment vessel.

- To determine, both inside and outside a reactor vessel, the transient and dynamic pressures, temperatures, stresses, coolant flow rates, and hydraulic forces resulting from the sudden rupture of a high temperature water system. Measured values will be compared with those calculated from analytical models.

Achievement of these objectives will permit improvements in the design of engineered safeguard systems. In addition, results will permit more realistic analyses of the consequences of potential major accidents involving fission product release.

GENERAL FACILITY DESCRIPTION

The 221-T Building (Figure 1) is located in the northwest corner of the 200W Area of the Hanford reservation. The building, one of the original plutonium separation plants, was deactivated from production services in the late 1950's and since has served, in part, for equipment reclamation. The northeast end of the building, not in active service when the CSE program was authorized, was selected to house the experimental equipment. The salient features of the building area are shown in Figure 2. Also shown are the required major renovations and additions to the building. Figures 3 and 4 portray the general layout of some of the major experimental equipment within the building. Not shown are the offices for the staff which are located on the first floor northeast of the aerosol generating stations and on the second floor northeast of the control room.

One of the advantages of housing the CSE in 221-T was the availability of required utilities. In general, the utilities were present either in the second floor gallery or in the basement, and thus only renovation and extension to desired demand points was required. A new steam header, however, was required from the point at which the main entered the building, about 400 ft away. Table 1 presents a list of the main utilities, their source, capacity, and principal use for the CSE.

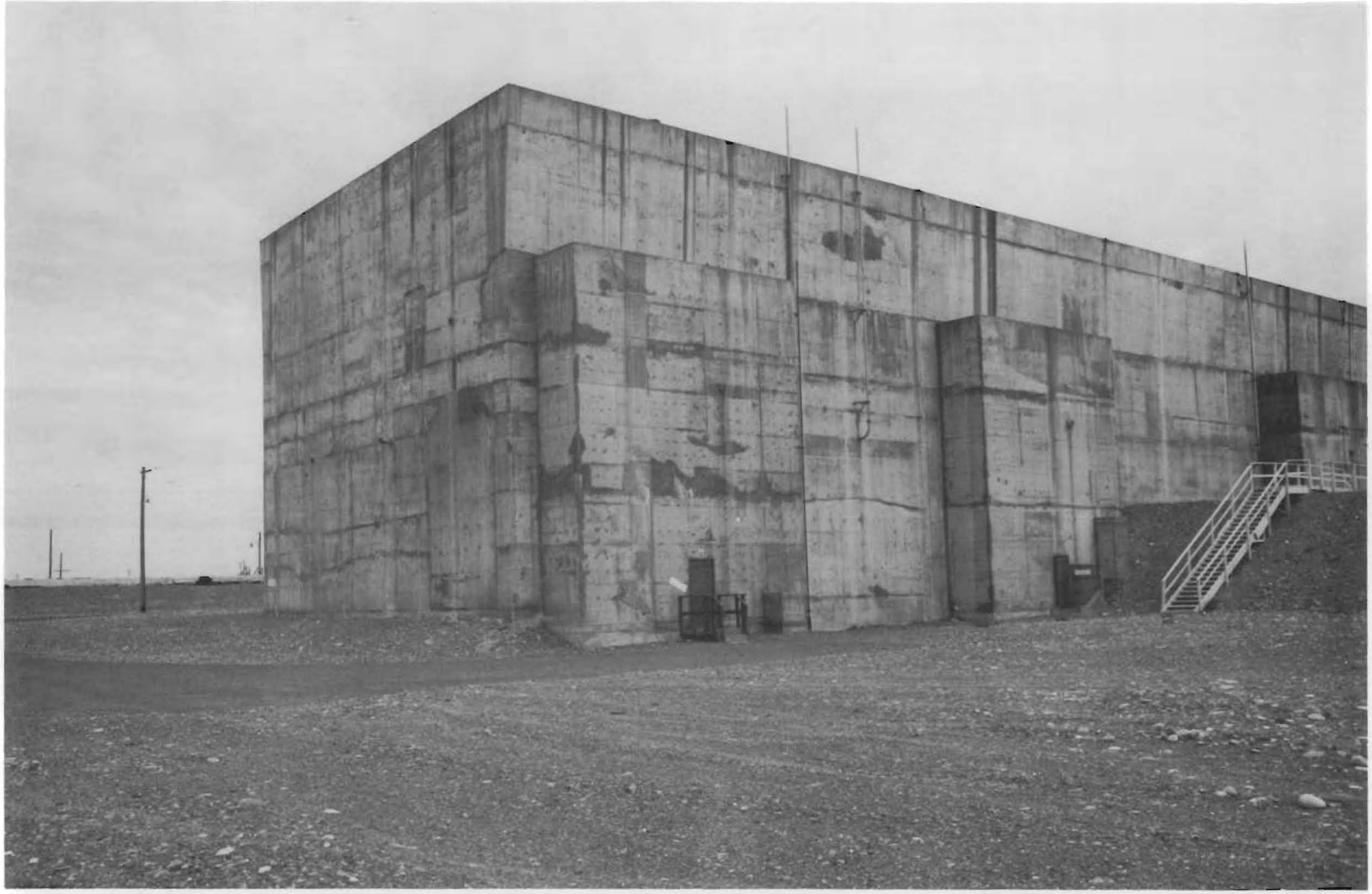

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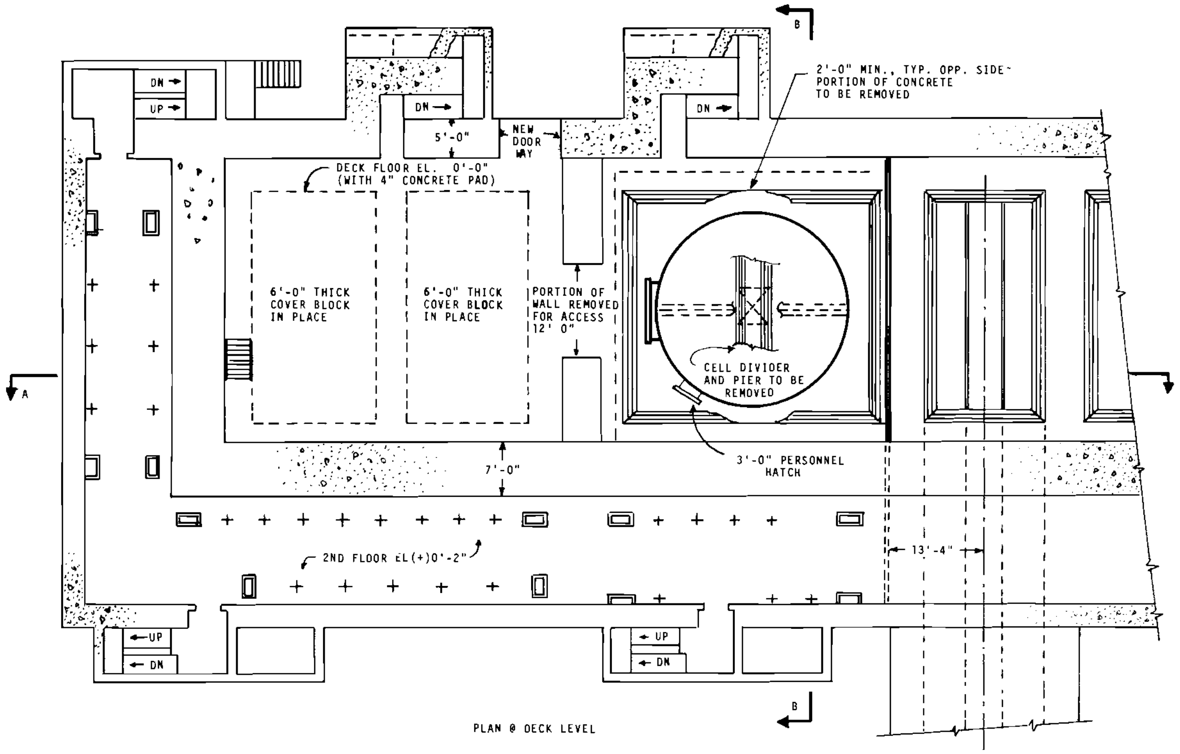
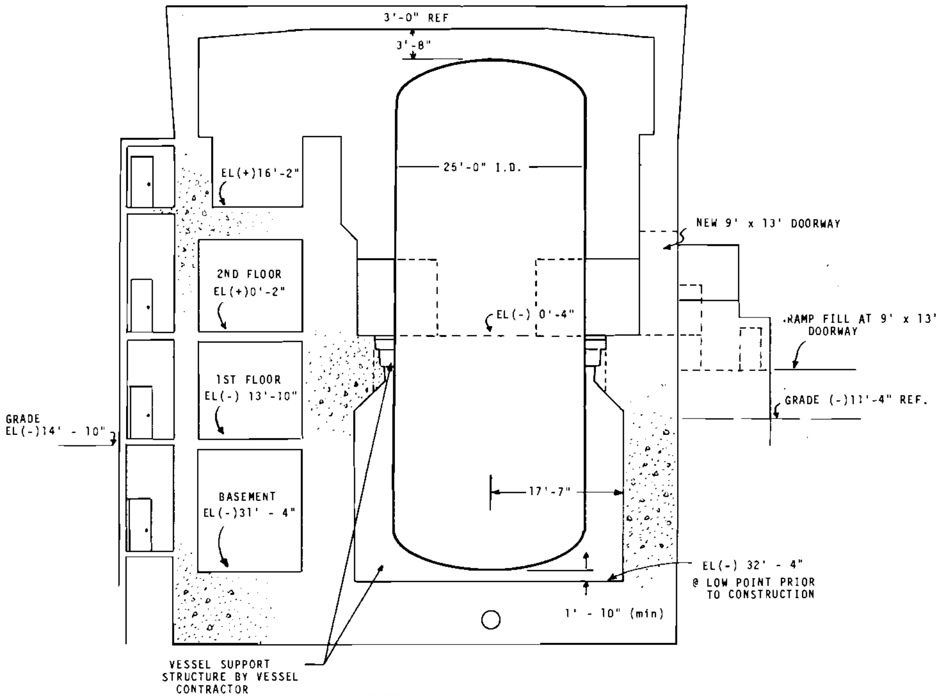
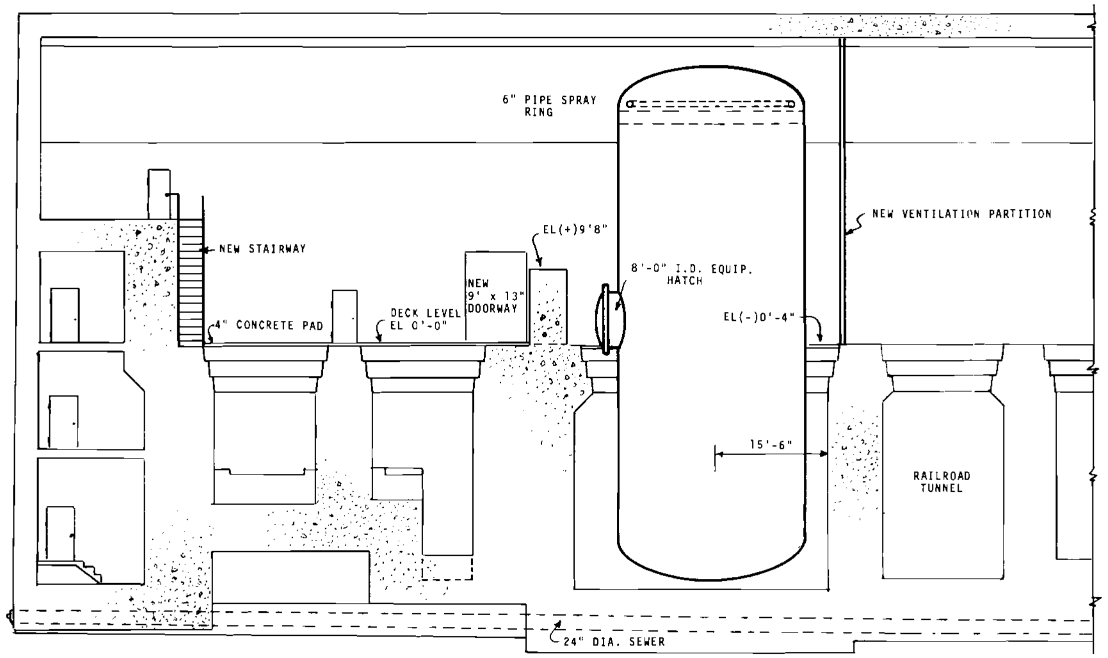
FIGURE 1. Head End of 221-T Building Prior to CSE



PLAN @ DECK LEVEL



SECTION "B-B"



SECTION "A-A"

GENERAL NOTES

1. Vessel Shall Be Designed, Constructed, Inspected And Stamped In Accordance With ASME Unfired Pressure Vessel Code.
2. Vessel Material To Be In Accordance With ASTM Spec. A300-58.
3. Design Pressure and Temperature: - 75 PSIG, 320 F.
4. Vessel And Support Shall Be Designed, Fabricated And Installed For Earthquake Forces Per Seismic Probability Zone No. 2 As Required By The Uniform Building Code.
5. Pressure Test Vessel With Air At 94 PSIG.
6. Leakage of The Vessel To Be Determined At 75 PSIG By Soap Bubble Test. Leaks Shall Be Repaired And Vessel Shall Be Re-Tested.

FIGURE 2. Containment Vessel Arrangement in the 221-T Building

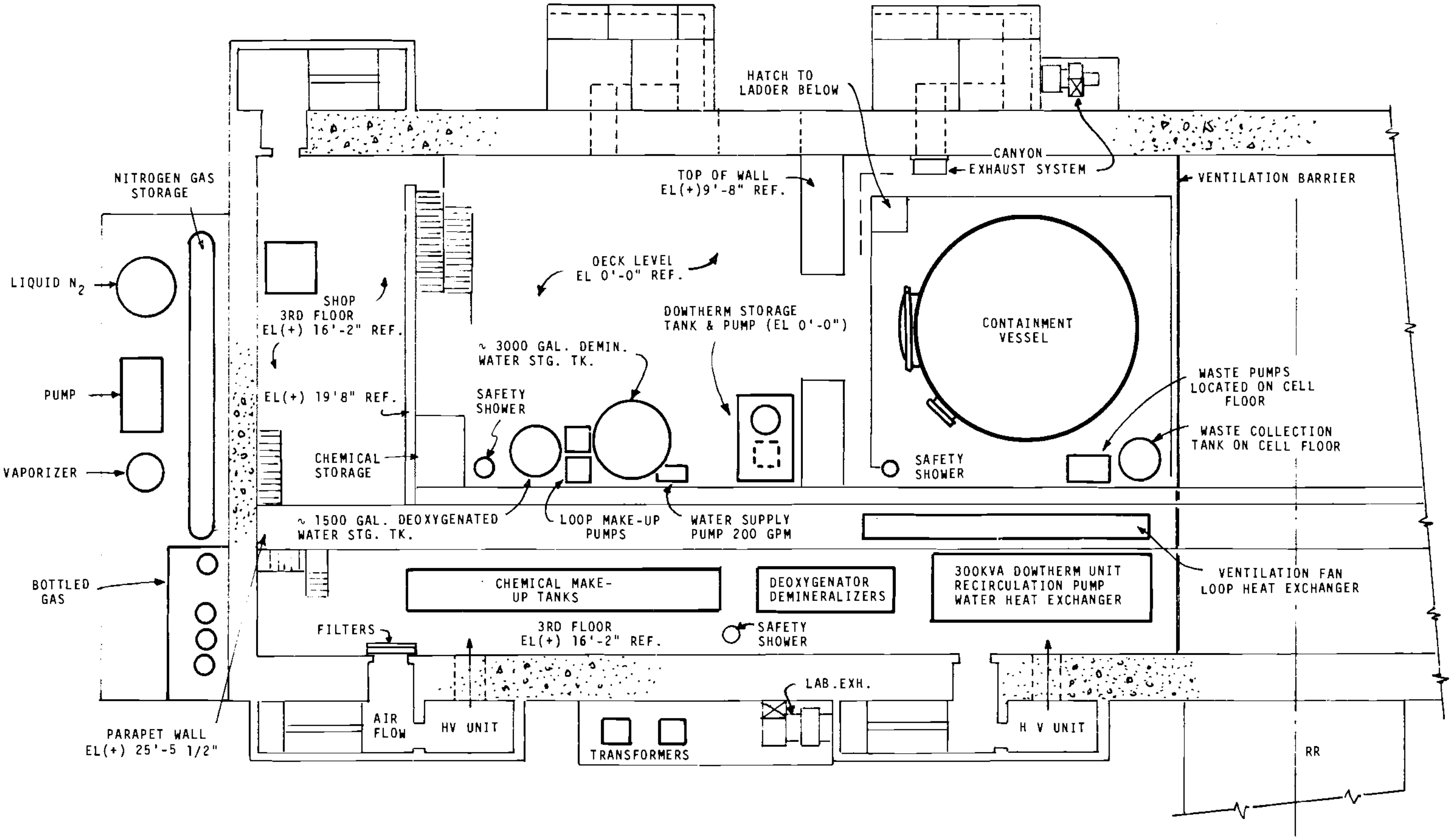


FIGURE 3. Equipment Arrangement in the 221-T Building

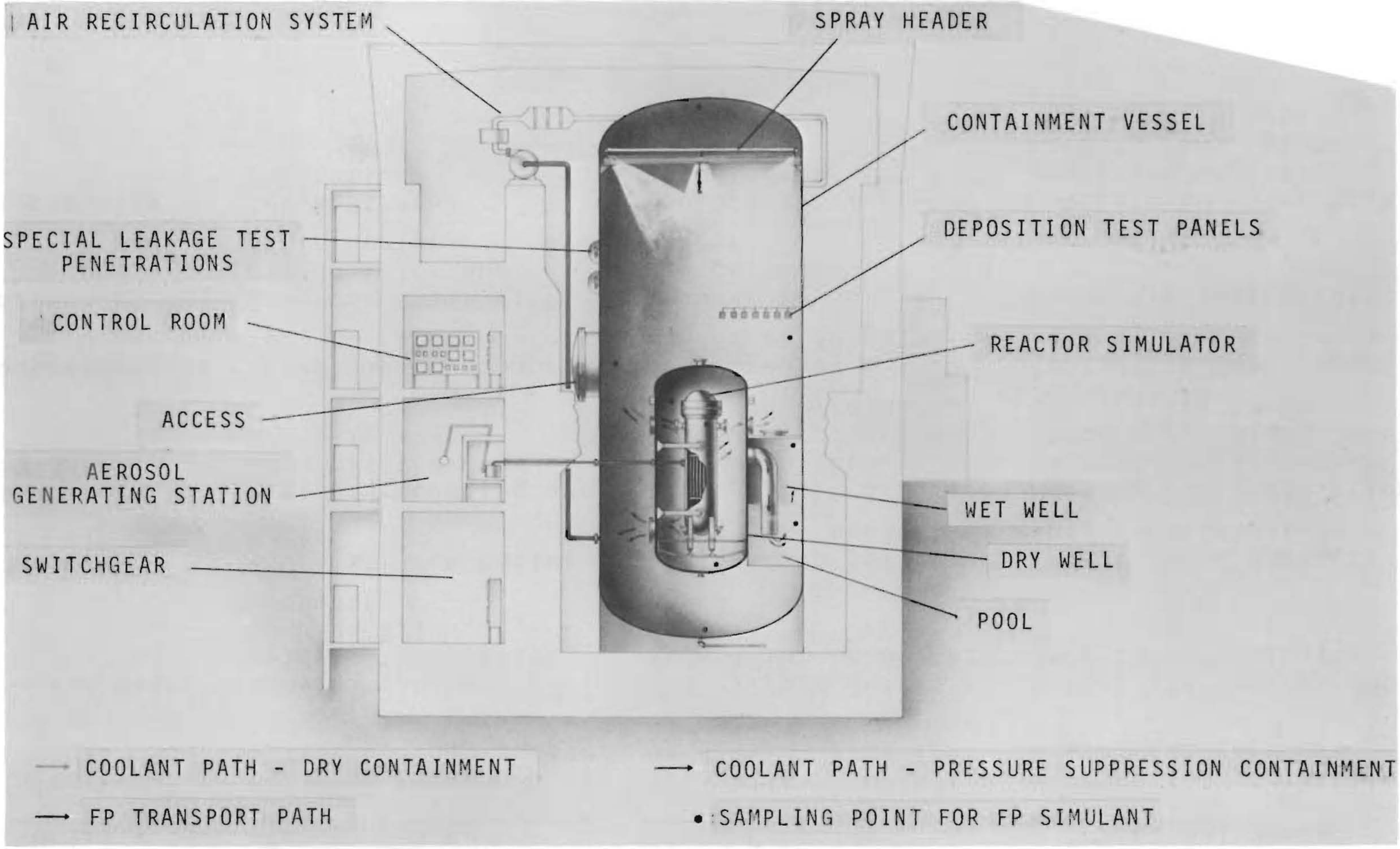


FIGURE 4. Containment Systems Experiment

TABLE 1. Process Utilities for CSE

Utility	Source	Capacity	Principal Demand
Sanitary Water	Columbia River - filtered, chlorinated	500 gal/min delivered by a 4-in. header at 90 psig	Heating and ventilation units; sanitary use
Process Water	Same as sanitary water but separated by a backflow preventer	500 gal/min delivered by a 4-in. header at 90 psig	Serves all systems subject to contamination
Steam, 225 psig	200 West Area boiler house	500 gal/min delivered by a 2-in. header	Injection of aerosols into containment(1)
Steam, 100 psig	Pressure reducing station off the main 225 psig system	4000 gal/min delivered by a 6-in. header. Pressure reduced as required by demand.	Heating and ventilation; to heat containment atmosphere; miscellaneous utility needs
Compressed Air	Dehumidifier, compressor, no after-cooler	Delivered by a 4-in. header at 80 psig	Pressurize containment vessel for leak tests
Instrument Air	Compressed air with oil-demister and after-cooler	Reduced to 50 psig and delivered in 2-in. header	Pneumatic instruments
Electricity	200 West Area substation	Two 300-KVA 220/440V transformers	Dowtherm-to-water heat exchanger, agitators, motors, fans, lights, induction furnaces, etc.(2)

---

1. *In order for the 225 psig steam to serve as the motive force, a superheater had to be installed before the jet.*
2. *The available electric power is not sufficient for the heating of dummy cores.*

TABLE 1. (contd)

Utility	Source	Capacity	Principal Demand
Process Waste	All uncontaminated waste water except sanitary	6-in. header in basement gallery; gravity flow to swamp	Heating and ventilation units, condensed steam, induction heating coils condenser cooling water
Contaminated Waste	Containment vessels and laboratories	200 gal/min pumped from cell bottom to sample tanks before discharging to cribs	
Sanitary Waste	Lavatories, wash basins, showers, etc.	4-in. header in basement gallery; gravity flow to tile field	
Demineralized Water	Ion-exchange of process water	35 gal/min	High pressure loop, containment vessel spray, laboratory
Demineralized-deoxygenated water	Anion exchange of demineralized water	4 gal/min	High pressure loop
Oxygen, Propane, Helium	Bottled gas station located on east dock	---	Laboratories
Nitrogen	Cryogenic system on east dock	1-in. header from 3000 psig storage; reduced as required	Pressurization of simulator; blanket for water storage tanks

The 221-T building was well suited both in physical size and services to accommodate the CSE program as originally conceived and proposed. However, in May 1966, the Division of Reactor Development and Technology authorized an augmented and accelerated program calling for increased emphasis on hydraulic considerations of a loss-of-coolant accident. The main piece of experimental apparatus for these studies is the reactor simulator vessel. A separate building next to 221-T was erected so that the initial hydraulic studies could be conducted independent of, and concurrent with, studies of aerosol transport and behavior conducted in the containment vessel. The location of this building addition (277-T) and its general features are shown in Figure 5.

EXPERIMENTAL EQUIPMENT

The program, and hence the experimental facilities, developed from the philosophy that results must be general to permit their application in other than specifically tested situations, and accurate to permit their use with reasonably small safety factors. Design of the facilities was influenced by the decision to use simulants for fission products to achieve, in the contained atmosphere, the level of concentration that could be assumed in the event of a maximum credible accident of a water-cooled power reactor.(1) The use of simulants allowed control of exposure to levels acceptable for contact operations and maintenance. As a result, there was no need to limit the size of the major facilities because of shielding or equipment limitations such as range of manipulators. However, the physical size of the facilities was limited by the 72-ft vertical height and the 32-ft × 35-ft cross section of the cell in the 221-T building where the containment vessel was located.

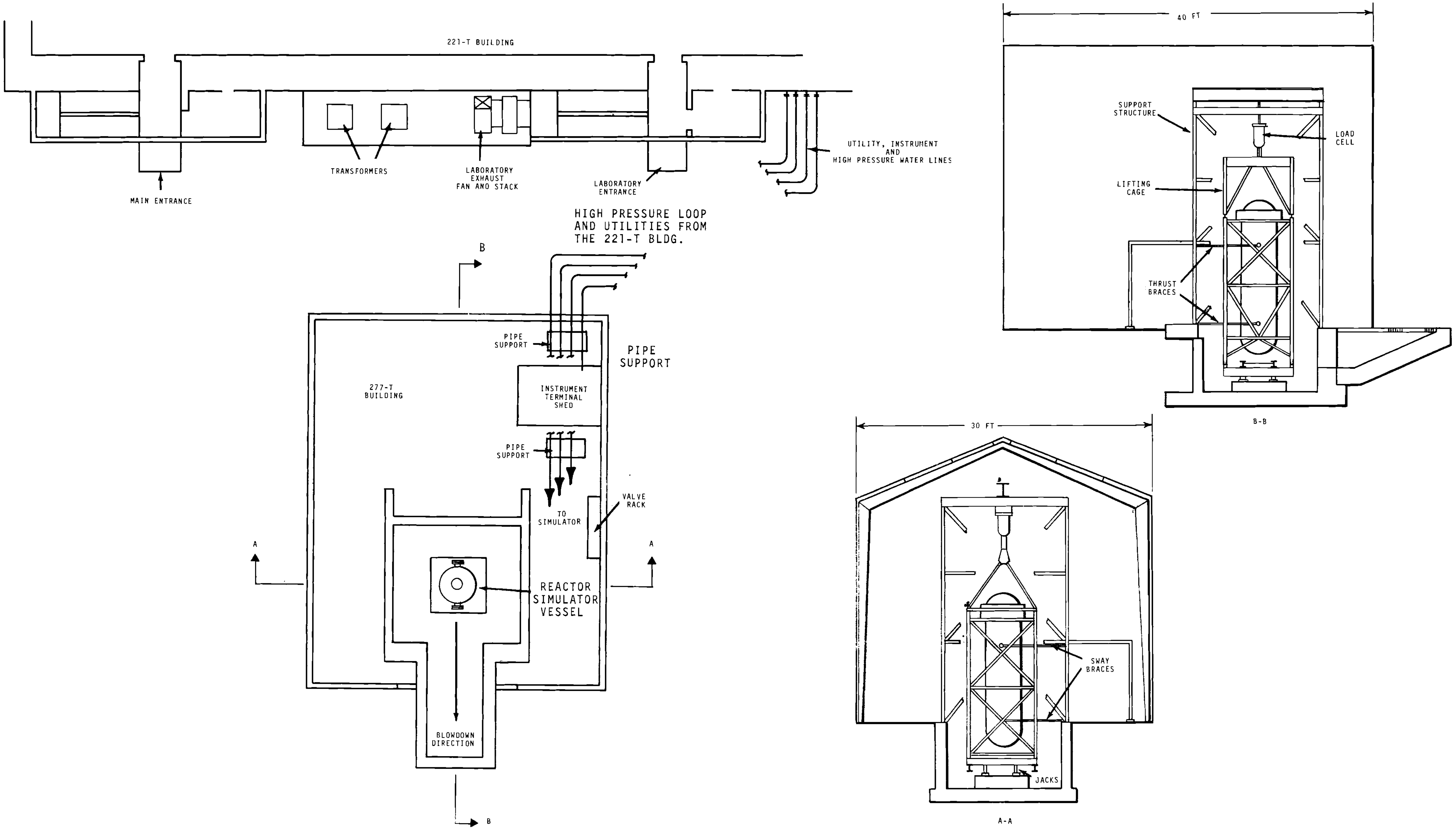


FIGURE 5. Facility for Blowdown Studies

The supporting engineering equipment was then installed on the canyon deck and the third floor galleries in locations most convenient in relation to the containment vessel. The laboratories, offices, lunchroom, control room, utilities, and restrooms were fitted into the other galleries.

In the sections following, only the experimental equipment is discussed in detail. Peripheral equipment descriptions are included only to the extent necessary to describe the experimental capability of the CSE.

CONTAINMENT SYSTEMS

The containment systems vessel is, in actuality, three integral vessels consisting of an outer vessel (the containment vessel), an inner vessel (the drywell), and a compartmented section between the outer surface of the drywell and the inside surface of the containment vessel (the wetwells). The systems were designed to permit maximum flexibility for studying both the dry and waterpool pressure suppression containment concepts for water-cooled reactors. With modifications, other containment concepts or other reactor types could be studied. For example, by the addition of insulation on all sides of the wetwells and changing the downcomer design, ice-filled compartments for pressure suppression can be studied. Also by adding equipment to heat sodium to about 400 °F and by providing a means for transferring the molten metal into the containment vessel, sodium aerosols can be formed for fission product transport studies pertinent to liquid metal-cooled reactors.

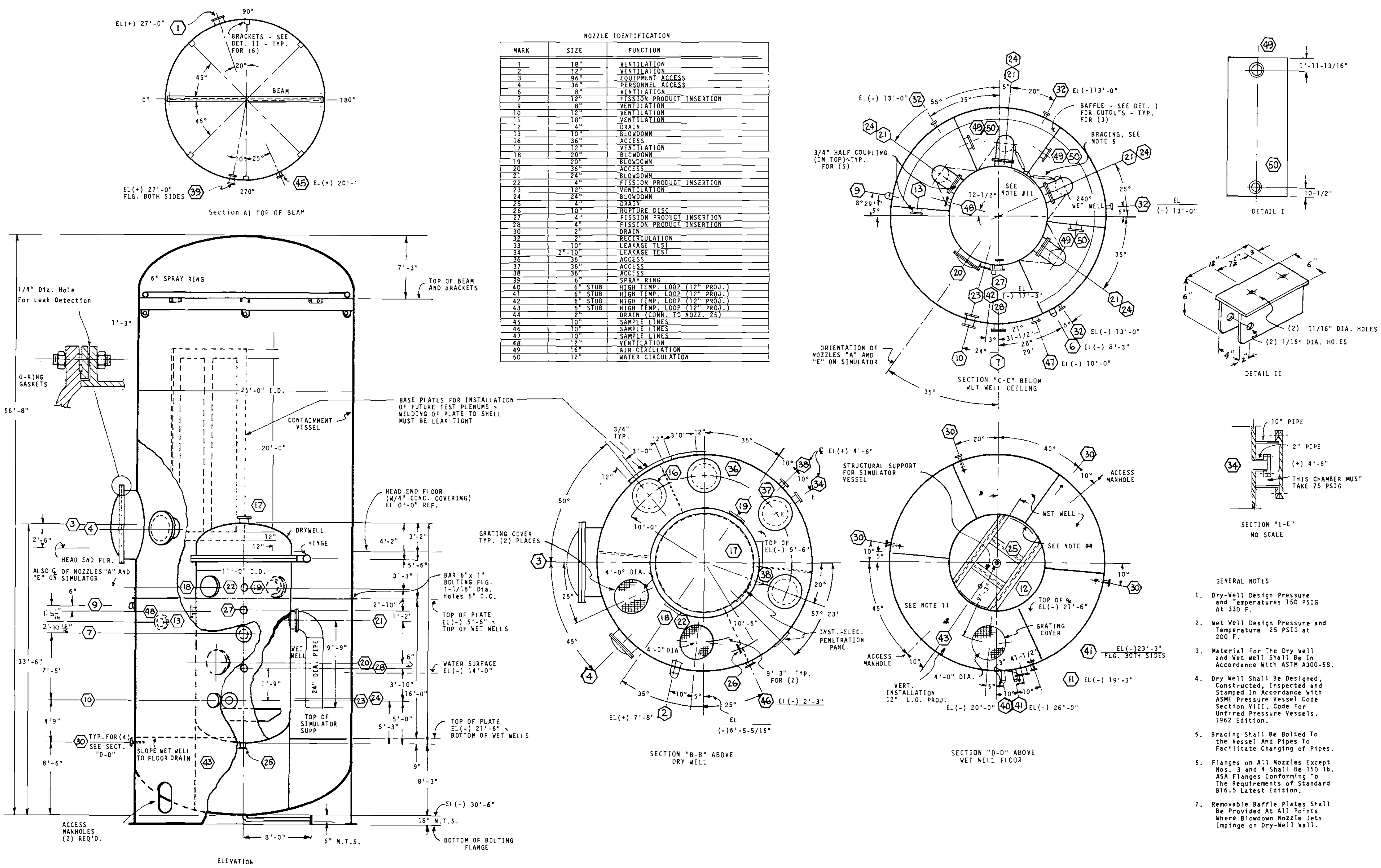
The vessels were not patterned after any specific reactor containment vessels, but rather the design scope stressed an appropriate experimental tool for studying the effectiveness of various reactor containment systems on a scale of about 1/5 linear based on 1000 MW nuclear power generation plants. The somewhat disproportionate length to diameter ratio of the CSE containment vessel, as compared to the commonly visualized hemispherical shape of power and experimental reactor containment vessels, resulted from the need to obtain the maximum free-fall height for spray studies on the removal of fission products from the atmosphere.

The significant features of the containment systems vessels are shown in Figures 6 through 8. All three of the components were designed, fabricated, and tested in accordance with ASME Pressure Vessel Code, Section VIII, for Unfired Pressure Vessels, 1962 Edition. The experimental program dictated the inclusion of several special considerations in the scope and design efforts. These were necessary because the systems were to be frequently and suddenly pressurized by releasing the thermal energy stored in the reactor simulator when simulating a loss-of-coolant accident. Thus, the design of vessel walls and structural components to support frequent pulse loads produced by reactions to the steam-water jet issuing from one of the nozzles of the reactor simulator vessel was necessary.

Containment Vessel

The 30,086 ft^3 containment vessel is 66 ft-8 in. high and 25 ft in diam. It was designed for maximum operating conditions of 75 psig and 320 °F and was tested at 93.75 psig prior to its acceptance from the designer and vendor. The carbon steel plate, SA 212-B, ranged in thickness from 0.75 in. for the heads, and 0.672 in. for the bottom shell quarter down to 0.645 in. for the upper three quarters of the shell.

Although most of the features of the containment vessel shown in Figure 6 are self-explanatory, several are not. First, the doubler reinforcement plates welded to the exterior surface from 38 degrees to 90 degrees are intended for



NOZZLE IDENTIFICATION

MARK	SIZE	FUNCTION
1	18"	VENTILATION
2	12"	VENTILATION
3	96"	EQUIPMENT ACCESS
4	36"	PERSONNEL ACCESS
6	8"	VENTILATION
7	12"	FISSION PRODUCT INSERTION
9	8"	VENTILATION
10	12"	VENTILATION
11	18"	VENTILATION
12	4"	DRAIN
13	10"	BLOWDOWN
16	36"	ACCESS
17	12"	VENTILATION
18	20"	BLOWDOWN
19	20"	BLOWDOWN
20	36"	ACCESS
21	24"	BLOWDOWN
22	4"	FISSION PRODUCT INSERTION
23	12"	VENTILATION
24	24"	BLOWDOWN
25	4"	DRAIN
26	10"	RUPTURE DISC
27	4"	FISSION PRODUCT INSERTION
28	4"	FISSION PRODUCT INSERTION
30	2"	DRAIN
32	2"	RECIRCULATION
33	10"	LEAKAGE TEST
34	2"-10"	LEAKAGE TEST
36	36"	ACCESS
37	36"	ACCESS
38	36"	ACCESS
39	6"	SPRAY RING
40	6" STUB	HIGH TEMP. LOOP (12" PROJ.)
41	6" STUB	HIGH TEMP. LOOP (12" PROJ.)
42	6" STUB	HIGH TEMP. LOOP (12" PROJ.)
43	6" STUB	HIGH TEMP. LOOP (12" PROJ.)
44	2"	DRAIN (CONN. TO NOZZ. 25)
45	10"	SAMPLE LINES
46	10"	SAMPLE LINES
47	10"	SAMPLE LINES
48	12"	VENTILATION
49	16"	AIR CIRCULATION
50	12"	WATER CIRCULATION

GENERAL NOTES

1. Dry-Well Design Pressure and Temperatures 150 PSIG At 330 F.
2. Wet Well Design Pressure and Temperature 25 PSIG at 200 F.
3. Material For The Dry Well and Wet Well Shall Be In Accordance With ASTM A300-58.
4. Dry Well Shall Be Designed, Constructed, Inspected and Stamped In Accordance With ASME Pressure Vessel Code Section VIII, Code For Unfired Pressure Vessels, 1962 Edition.
5. Bracing Shall Be Bolted To the Vessel And Pipes To Facilitate Changing of Pipes.
6. Flanges on All Nozzles Except Nos. 3 and 4 Shall Be 150 lb. ASA Flanges Conforming To The Requirements of Standard B16.5 Latest Edition.
7. Removable Baffle Plates Shall Be Provided At All Points Where Blowdown Nozzle Jets Impinge on Dry-Well Wall.

FIGURE 6. Containment Vessel

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FIGURE 7. Interior View of Containment Vessel During Construction

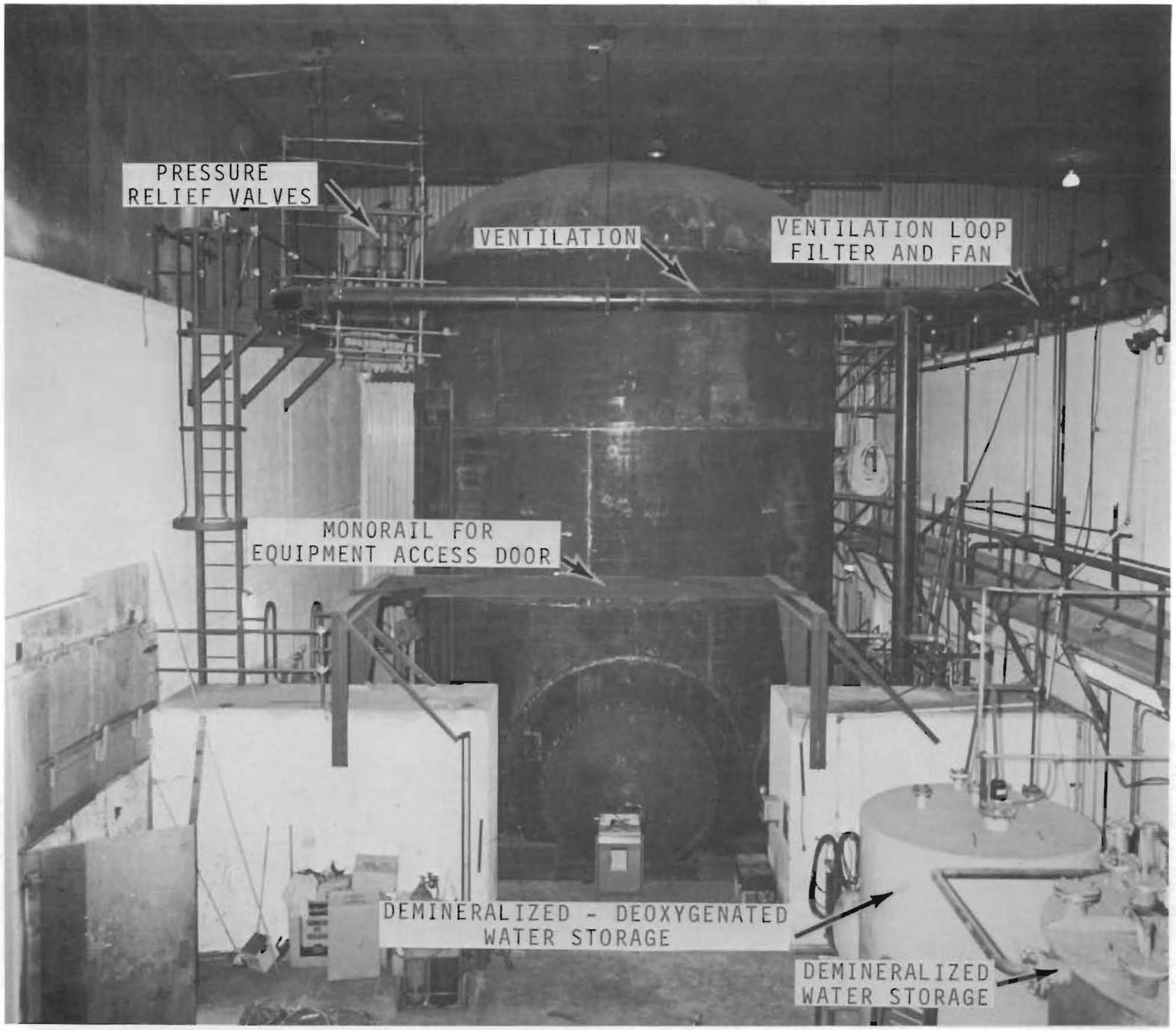

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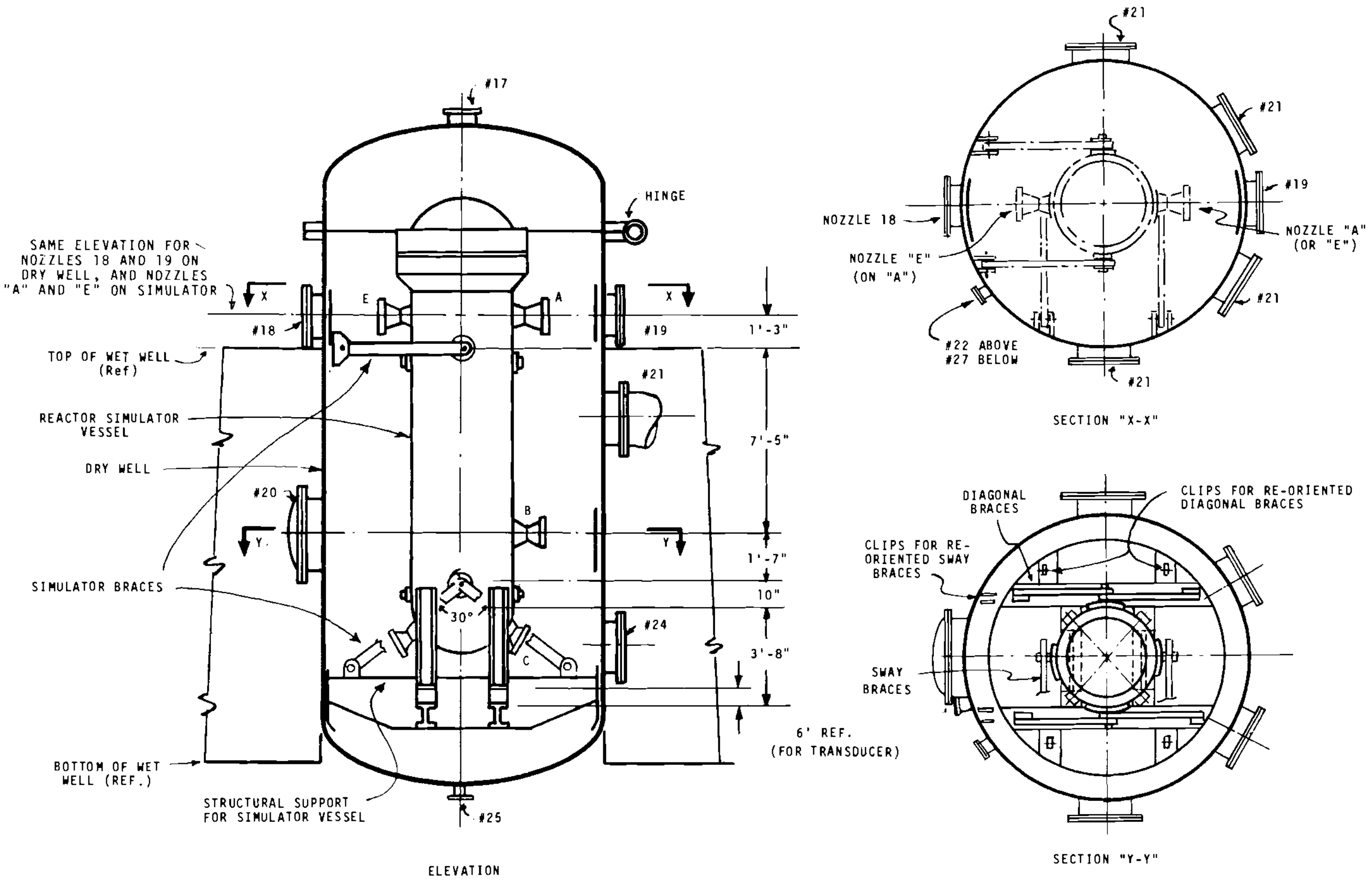
FIGURE 8. View of Upper Half of Containment Vessel

future attachment of a plenum to simulate the multiple-barrier containment concept. Second, a standard flanged closure was selected for the eight-ft equipment access penetration (nozzle 3) rather than an air-lock door. This selection was for reasons of economy and to facilitate future attachment of a large duct with appropriate seals for studying the effectiveness of the ducted pressure relief containment concept should such studies be deemed appropriate. Third, because the design and procurement of the containment systems preceded the detailed design of the penetrations for the process and experimental piping and/or electrical and instrument systems, many of the penetrations were closed temporarily with weld caps. This was necessary in order to conduct the pressure tests on the containment vessels system as required by the code prior to accepting the vessels from the vendor. Prior to the first leak test experiment, most of these caps were removed and replaced with penetrations for the process and experimental piping and/or electrical instrument systems. The penetrations, discussed in more detail later, were patterned after those of power reactors.

Drywell

The drywell shown in Figure 6 and in more detail in Figure 9 was designed for a maximum pressure of 150 psig and a temperature of 330 °F. This vessel is 25 ft high and 11 ft in diameter. It was pneumatically tested at 187.5 psig before acceptance from the vendor. The heads are standard ASME elliptical 2:1 dished heads with a minimum thickness of 0.688 in. The minimum shell thickness is 0.669 in. Without the reactor simulator vessel installed, the gross volume of the drywell is 2270 ft^3; while net volume with the simulator is 2020 ft^3. The size of the drywell and the reactor simulator vessel resulted from linear scaling of a proposed 1000 MW_e power reactor at the time CSE was scoped and design criteria prepared.



GENERAL NOTES

1. Tests Will Be Made With The Reactor Simulator Located As Shown or Located Either 1'-0" To The Right Or 1'0" To The Left of the Centerline of the Drywell. A Similar Combination May Be Used But With Vessel Rotated 180° (See Sect. Y-Y).
2. Removable Baffle Plates Shall Be Provided At All Points Where Blowdown Nozzle Jets Impinge on Dry-Well Wall.

FIGURE 9. Drywell - Simulator Vessel Arrangement

The drywell top is hinged to provide access to the reactor simulator vessel. Of equal importance is that, by opening the lid, the free fall height of spray solutions is increased from about 25 ft to 50 ft in the center of the containment vessel.

Penetrations for instrument and utility services are provided as in the containment vessel. In addition, the drywell has several penetrations for blowdown venting. Four are 24-in. flanged openings connecting to the downcomer pipes into the wetwells and are shown in Figure 9 (nozzle 21). These will be normally used for studies on the pressure suppression concept of containment. Four other 24-in. flanged (nozzle 24) and blinded penetrations are provided near the level of the bottom blowdown nozzles as an alternate method of venting into the wetwells.

For studies on dry containment, three flanged openings (nozzles 18, 19, 20) are placed into the main containment volume directly in line with the two top and the middle simulator nozzles. This alignment permits simulation of the energy release in the event of a pipe rupture between the drywell and containment vessel walls. These three nozzles are blinded for pressure suppression studies. Incorporated into the drywell are structural members for supporting the simulator vessel, lugs for the attachment of the lateral bracing, and lugs for the attachment of baffle plates. The attachments are located so that any pulse loadings due to blowdown will be redistributed by circumferential rings to the wetwell floor, ceiling, and walls, and thence to the containment vessel wall. The baffles are required to prevent excessive stresses in the drywell wall due to hot spots from the water jet during blowdown.

Wetwells

The wetwells are four adjacent chambers occupying two-thirds of the annular space between the drywell and containment vessel shells. The remainder of the annular space is used for access to lower levels and for a pipe, electrical, and instrument chase.

The walls and the partitions between wetwell segments support the drywell. The ceiling of the wetwells provides a working level platform in the containment vessel. The overall height of the wetwells is 16 ft and the gross volume enclosed is 4220 ft^3. The wetwells are designed for maximum operating conditions of 25 psig and 200 °F.

The size and the design pressure and temperature of the wetwells were based on transient conditions estimated from blowdown experiments using the reactor simulator vessel in the containment vessel. The General Electric Company staff at San Jose, California, calculated the estimated transient conditions with the use of their mathematical model for pressure suppression.

Each partition between the wetwells has two nozzles, one near the top to permit vapor circulation between compartments, and one near the bottom to permit liquid circulation. Blinds can be installed on these nozzles in the event less than the four compartments are desired for studies.

Protective Coating

All interior surfaces of the containment vessel (including the interior and exterior surfaces of the drywell and wetwells) were painted with one prime coat of Phenoline 301* and two coats of Phenoline 302.* The surfaces were prepared for painting in accordance with the Steel Structure Painting Council Specifications SSPC-SP-6-63.

---

* *Tradename of a product manufactured by the Carboline Company, St. Louis, Mo.*

Since the coating of the CSE vessels was to be exposed to cycles of steam-air mixtures up to temperatures of 275 °F, atmospheres containing radioactive materials, the abrasive action of 600 °F water jetted from the reactor simulator, and spray solutions containing chemicals and decontamination solutions, the coating was chosen specifically for the CSE system rather than for one typically used in power reactors. Also a prime consideration in the selection was the effect that vaporized solvents from the coating would have on the fission products and, subsequently, on the experimental results of the fission product transport studies.

The actual choice of this coating was determined by a series of comparative laboratory tests made on a group of selected coatings to find the most suitable coating for the projected service.

Weight, Volume, and Surface Relationships

As stated previously, the containment systems were not patterned or modeled after any specific reactor containment building. However, in order to maintain the component parts in physical perspective, a 1/5 linear scale of a 1000 MW_e reactor containment system was adopted as a guideline. The factor was used to assure that the temperature and pressure transients with time resulting from a blowdown would approximate those of a commercial power reactor dry containment system. Absolute adherence to scaling factors was not possible or necessary. For example, surface-to-volume relationships cannot be physically scaled, since the area of the containment vessel increases linearly with the diameter, while the volume increases as the square of the diameter. Rather, the emphasis during design was to provide a facility suitable to collect appropriate experimental data for fitting to and evaluating calculational models. Tables 2 through 5 provide the essential physical characteristics of the containment systems for the most common foreseen engineering calculations.

TABLE 2. Containment Systems Weight

Containment Vessel		Weight, lb	
Top Head		19,300	
Cylinder		153,000	
Bottom Head		19,300	
Penetrations, Doubler Plates, etc.		22,700	
Internal Components		12,300	
	Total	226,600	226,600
Drywell			
Top Head with Flange		12,000	
Cylinder		16,800	
Bottom Head		3,600	
Skirt		6,000	
Internal Components		7,000	
Penetrations, Reinforcing plates (containment section)		6,000	
Penetrations, Reinforcing plates (wetwell section)		20,000	
	Total	71,400	71,400
Wetwells			
Floor and Ceiling		17,400	
Partitions		11,900	
Stiffeners		29,000	
Penetrations		5,000	
	Total	63,300	63,300
	Containment Systems Weight		361,300
	Support Skirt		10,000
	Total Weight		371,300

TABLE 3. Containment Systems Volumes

	Volume, ft^3
Wetwells (4)	4,134
Drywell	2,270
Containment Vessel (not including wetwells and drywell volume)	23,682
Total Contained Volume	30,086

NOTE: Tabulated volumes are net amounts. (Net Volume = gross volume of component - volume of steel enclosed)

TABLE 4. Surface Areas and Thicknesses for Heat Transfer Calculations

Containment Vessel	Area, ft^2	Average Thickness, ft
Top Head	678	0.063
Bottom Head	678	0.063
Cylinder (excluding wetwell segment)	3,494	0.074
Wetwell Segment	838	0.079
Drywell		
Top Head (including flange assembly)	249	0.15
Bottom Head	131	0.057
Cylinder (excluding wetwell segment)	268	0.09
Wetwell Segment	376	0.10
Wetwells		
Ceiling	361	0.096
Floor	324	0.087
End Walls	224	0.11

NOTE: Average Thickness defined as:

$$t_{avg} = \frac{\text{Weight of Component}}{\text{Density of Steel} \times \text{Area of Component}}$$

TABLE 5. Deposition Surfaces*

Containment Vessel (does not include surfaces inside drywell or wetwells)	Area, ft^2
Containment Vessel Shell	4,753
Nozzles	195
Drywell to -5 ft 6 in. Deck	614
Deck, Top	642
Deck, Underneath	132
Lower Deck, Top	132
Lower Deck, Underneath	564
Drywell Shell (excluding wetwell segment)	208
Drywell, Bottom Head	135
Drywell Skirt, Both Sides	654
Spray Ring	159
Beam	188
Wetwell, both end walls	448
Ladders	50
Total	8,874
Drywell (does not include surface of simulator vessel)	
Drywell Shell Area	951
Nozzles	109
Simulator Vessel Support	208
Baffle Assemblies	46
Inside of Blowdown Vent	252
Total	1,566
Wetwell (one compartment)	
Ceiling	74
Floor	65
Outside of Blowdown Vents	70
Partitions (including stiffness)	273
Containment Vessel Segment	238
Drywell Segment	81
Total	801
Wetwells (all compartments) 4 × 801	3,204

---

* *All surfaces listed above are coated with Phenoline 302 a product of the Carboline Co., St. Louis, Mo.*

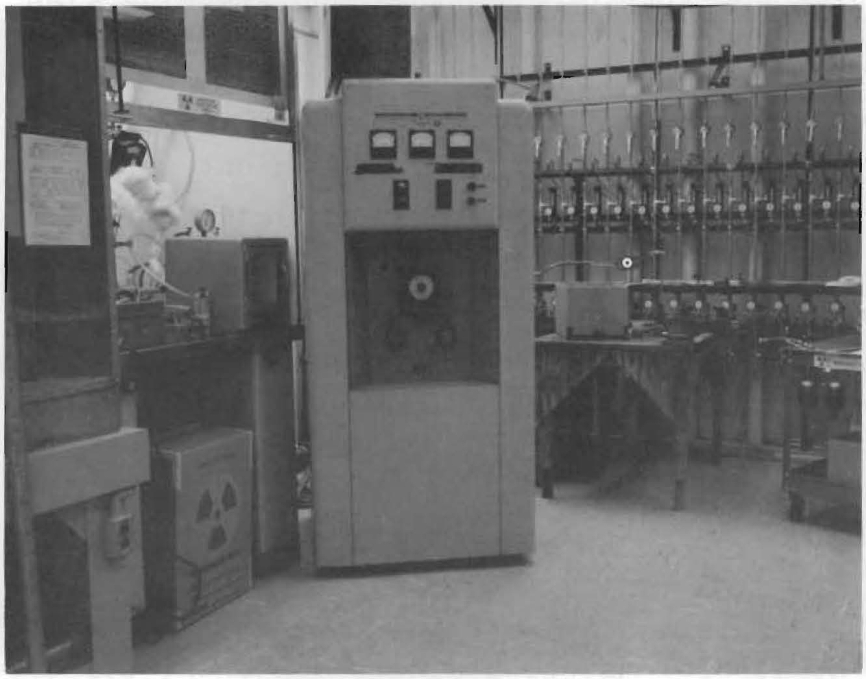
AUXILIARIES FOR AEROSOL TRANSPORT AND BEHAVIOR STUDIES

A primary purpose of the containment systems vessels is the study of aerosol transport and behavior in containment. A considerable amount of auxiliary equipment is provided to achieve this objective, including an aerosol injection system, aerosol samplers, liquid pool samplers, wall condensate samplers, deposition samplers, and an atmosphere purge system. These, along with certain engineered safeguard systems, are discussed in this section.

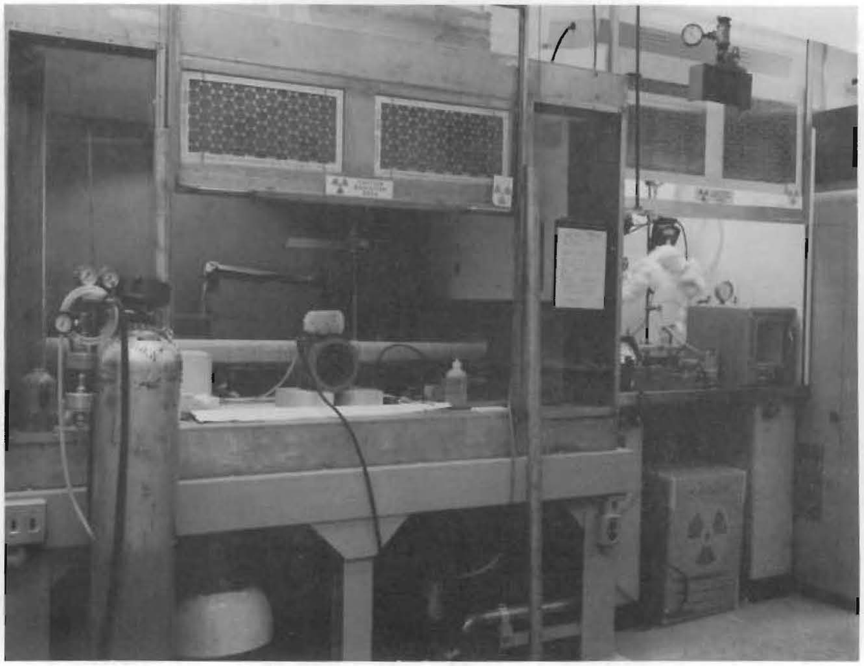
In general, the procedure for these experiments will be to pressurize and heat the containment systems either with process steam or by a simulator vessel blowdown. An aerosol will be generated in the laboratory and injected into the drywell. The aerosol may be a single component e.g., iodine, or a mixture of components such as UO_2 fumes, cladding fumes, iodine, barium, cesium, tellurium, ruthenium, and xenon. These components will be traced with appropriate radioactive isotopes in order to provide the necessary analytical sensitivity. The transport and fate of the aerosol components will be determined by the analysis of samples taken throughout the containment systems as a function of time. The actual sampling of the contained atmosphere will be controlled remotely. However, contact retrieval of the samples will be made after the run is completely over and the vessel atmosphere purged with fresh air.

Aerosol Generation Equipment

The aerosol generating station consists of a cave, two standard radiochemical hoods, and high frequency induction units. This equipment, shown in Figures 10 and 11 is in the basement and first floor laboratories located in the galleries close to the containment vessel. The cave has 6 in. steel walls and is equipped with manipulators (not shown). For early



20 kW - 400 KILOCYCLE GENERATOR



CAVE AND HOOD FOR AEROSOL GENERATION

FIGURE 10. Aerosol Generation Laboratory

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FIGURE 11. High Frequency Generator

studies, the cave was equipped with a sliding plastic door face to increase visibility and permit manual operation. Because of personnel radioactive exposure levels, the plastic face was replaced with a 6-in. steel face and lead glass windows. The manipulators also were installed at that time.

Uranium oxide and cladding fumes are generated inside the cave and volatilization of the highly radioactive fission product aerosol components also occurs there.(2) The standard radiochemical hoods located at each end of the cave serve as auxiliary volatilization stations for the less hazardous radioactive components of the aerosol. These components of the aerosol are transferred to the cave via lines through the ends of the cave wall and are mixed with those generated within the cave. The mixture flows from there through the injection line and into the drywell. Table 6 summarizes the aerosol components, and their amount, and the point and methods of vaporizing for those materials used in the simulant mixture for the CSE studies.

TABLE 6. Aerosol Generation Summary

Component	Volatilization Site	Furnace Type	Wt., g*
Clad	Cave	Induction	25
UO_2	Cave	Induction	280
Elemental I	Cave	Resistance	100
Methyl Iodide	Fume Hood	None**	1-2
Cesium Oxide	Cave	Induction	10-15

---

* *Amount charged to furnace, all of which is not vaporized or transferred to the drywell.*

** *Evaporates at room temperature.*

A schematic of the injection line and a photograph of the control panel are shown in Figures 12 and 13. The illustration shows the discharge of fission products into the drywell. The discharge, however, could be piped into the wetwells, or the pipe chase, the reactor simulator vessel, or up into the upper room of the containment vessel should studies so require. Also shown is the line for either steam or air which is used to preheat and pressurize the systems. The motive force is provided by a steam jet. Since the containment systems may be at pressures of up to 75 psig, the use of 225 psig steam is necessary to obtain desired flow rates against this back pressure. Among the advantages of the technique are that the generating apparatus need not be designed for operation under pressure and that inert friable materials such as glass can be used for the aerosol generation apparatus. Other significant features of the system are:

- The line is wrapped with electrical heating tape and insulated to maintain the aerosol at a temperature greater than 250 °F to prevent condensation of steam carrier gas. The need for a minimum 250 °F temperature was determined experimentally in the ADF laboratory.(1)
- The 225 psig steam line is also electrically heated and a superheater is provided to assure dry or superheated steam. Development studies have indicated that steam quality can affect aerosol behavior. The use of steam for jetting the fission products into the vessels is consistent with imagined sequence of events in the event of an MCA. Steam will be a primary motive force during an MCA for moving the fission products out of the reactor and dispersing them throughout the containment vessel.
- Aerosol samplers are located in the line near the point of discharge so that the amounts and forms of the aerosol components entering containment can be determined.

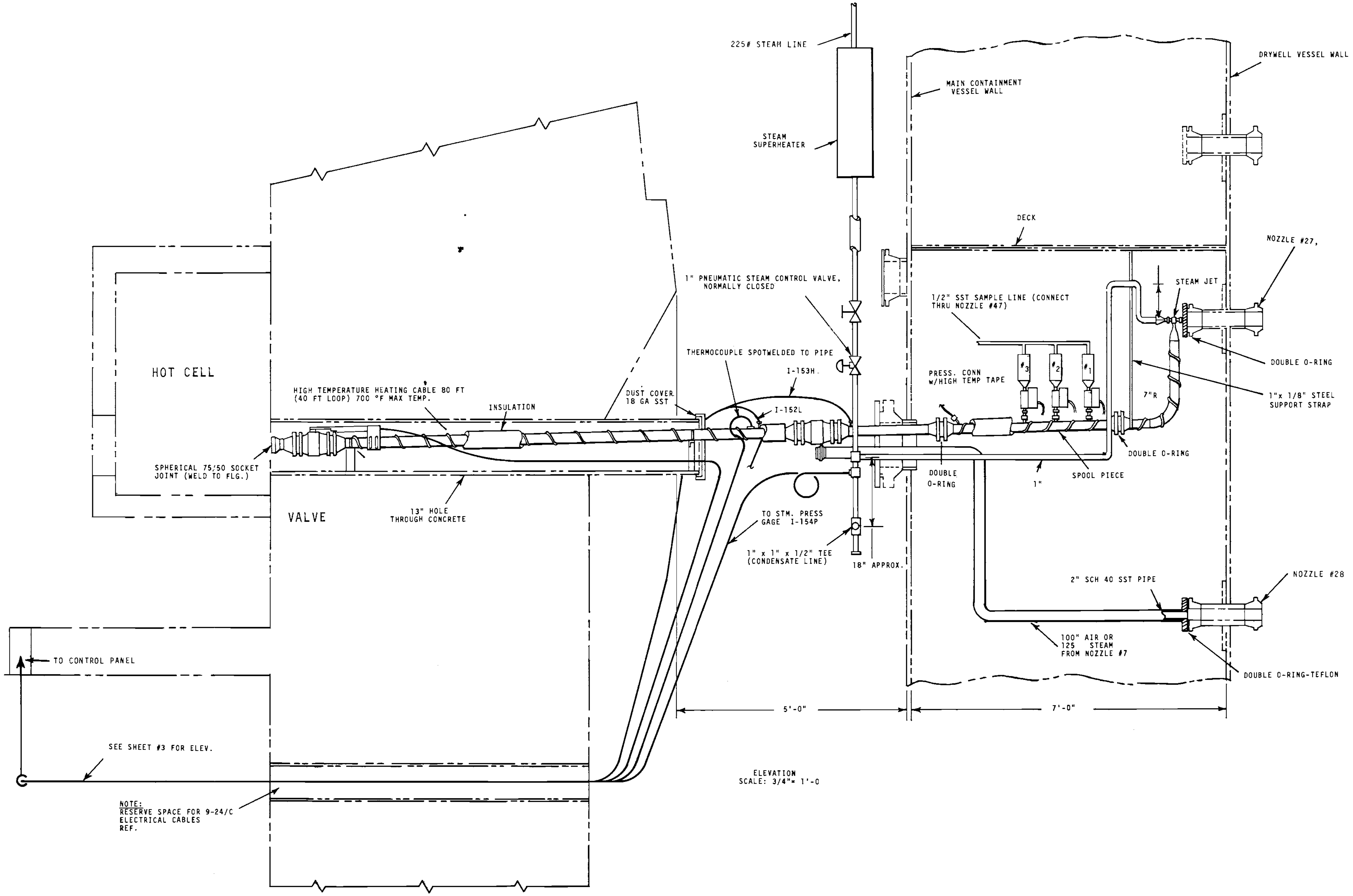

FIGURE 12. Aerosol Injection Line

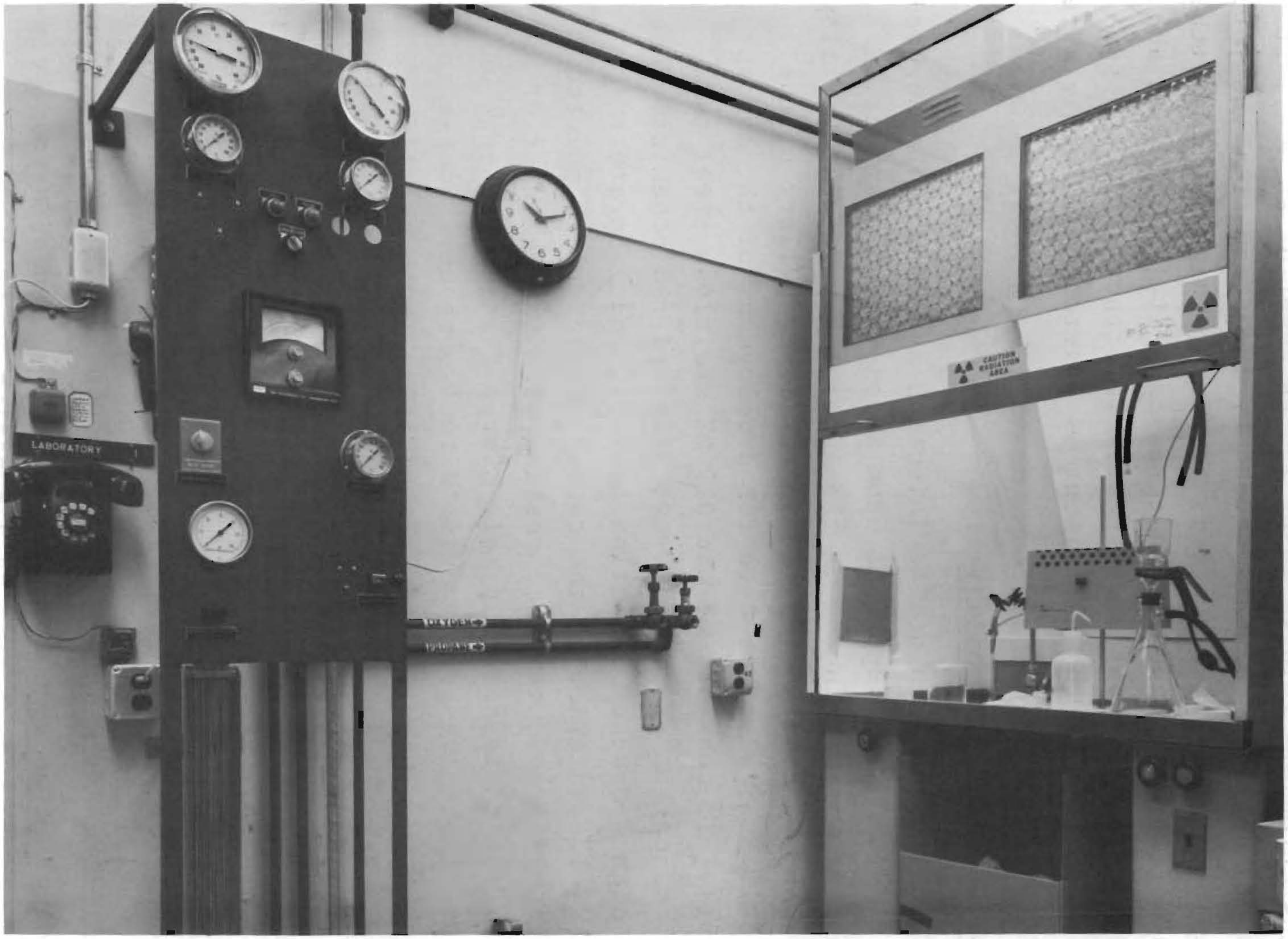

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FIGURE 13. Control Panel for Aerosol Injection

As the aerosol is continuously released into the drywell (the most probable release point in the event of an MCA), it is dispersed by the currents caused by the steam from the jet. When injection of the aerosol is complete, the steam may either be shut off or continued at a decreasing rate starting at about 200 lb/min to represent decay heat. In either case, the sampling phase part of the experiment is started immediately after the aerosol is in the vessel.

Aerosol Development Facility

The actual design of the injection system and the aerosol sampling system was dependent upon a considerable amount of development work conducted in the Aerosol Development Facility (ADF). This facility, located in the lower gallery of the 221-T Building, also was used for development of the aerosol simulants. It consists of one 0.9 m^3 stainless steel tank, one 1.5 m^3 carbon steel tank, two standard radiochemical fume hoods, high frequency induction heaters, and laboratory benches. The interior of the carbon steel tank is painted with Phenoline 302, the same coating used on the interior surfaces of the containment vessel. Large flanged openings on the tops of both vessels provide direct personnel access to the vessels between experiments. In addition, both vessels are equipped with numerous nozzles for purposes of liquid circulation, gas sampling, visual observations, liquid sampling, and particulate sampling. Because the tanks are small, only small amounts of simulants need be generated for the ADF studies. Thus the radioactive traced simulants can be generated in the fume hoods rather than in a cave.

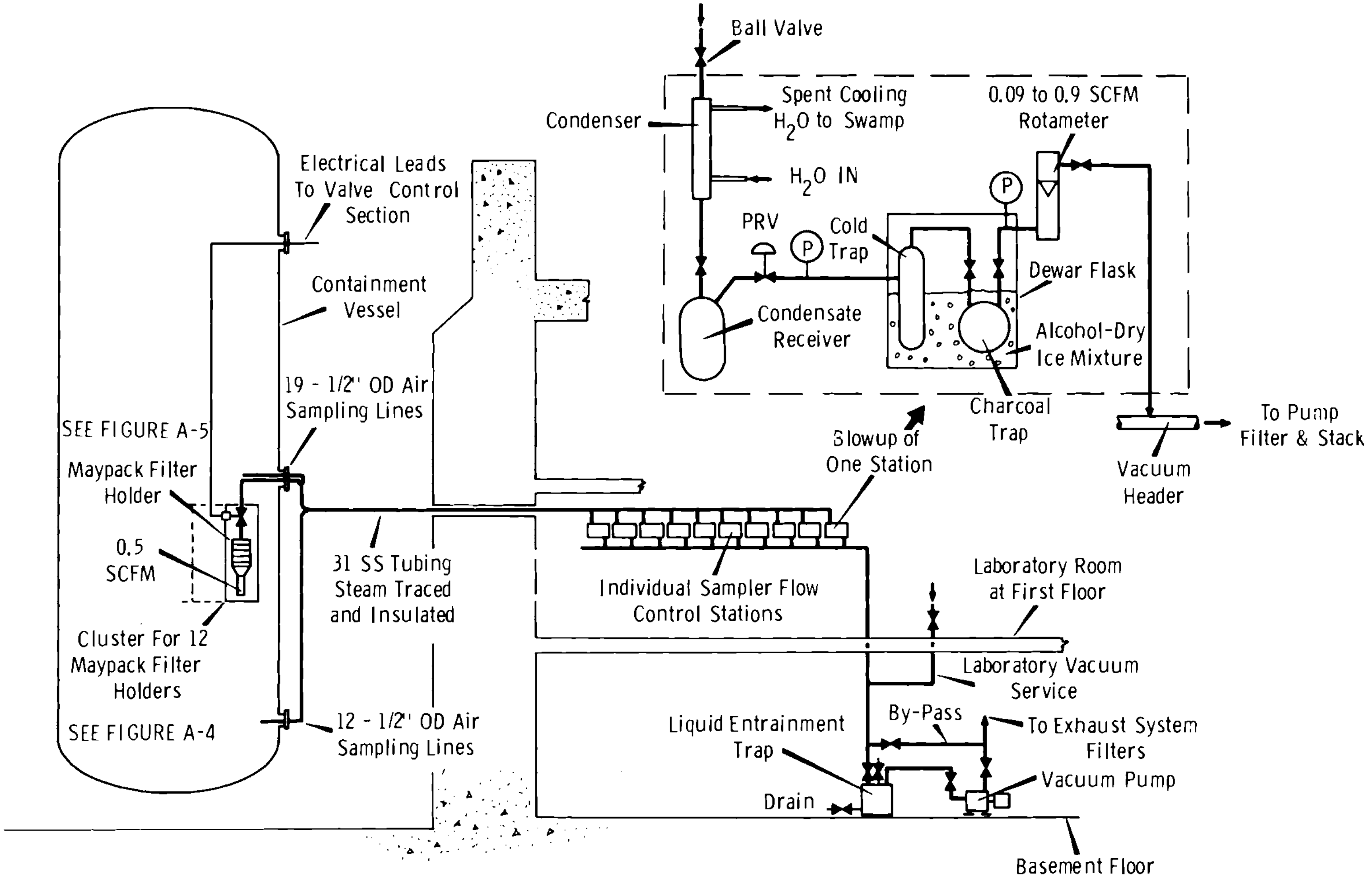
Aerosol Sampling Equipment

To permit measurement of the distribution of aerosol components within containment as a function of time after release, several sampling systems are provided, the most complex of which is the aerosol sampling system.

The flowsheet for this system is shown in Figure 14. The scheme consists primarily of assembled cartridges of multiple filters and adsorbents located inside containment which sample both the chemically active volatile components and the particulate components. The filters remove the cesium oxide, the uranium, and the cladding particulates, but not the methyl iodine or elemental iodine. Following the filters in the cartridge is a series of silver-coated copper screens which are effective for removing elemental iodine. The final adsorbent in the cartridge is a bed of activated charcoal for removing methyl iodine. This particular series of filters and adsorbents, a result of development work in the ADF laboratory, was found to be an effective aerosol sampler for the simulant used in CSE.(3) Also included in the system are a heated transfer line to the laboratory, a condenser to collect condensate, cold traps to collect inert gaseous components, and the necessary flow control apparatus. Pressure in the containment vessel during the early part of an experiment is sufficient to establish and maintain sample gas flow to the exhaust system. Later, as condensation proceeds and the pressure in containment drops, the differential pressure necessary to maintain desired flow is obtained by means of a vacuum pump.

Figures 15 and 16 show the filter holder and Maypack cartridges as they were designed and constructed, and Figure 17 presents the detailed design of the Maypack. Initially, 15 assemblies, each with 12 Maypacks, were provided to sample the contained atmosphere. Transfer lines were installed to permit an expansion to 30 assemblies for the more advanced and complicated experiments.

Each of the 12 solenoid valves of an assembly is individually controlled so that samples of the atmosphere can be taken at a specified point in containment as a function of time. A system of pulleys, cables, and winches is provided for raising



GENERAL NOTE

All Air Sampling Lines to the Sampler Stations Shall Be Steam Traced and Insulated to Maintain Air Samples at 250 - 300°F.

FIGURE 14. Aerosol Sampling Flowsheet

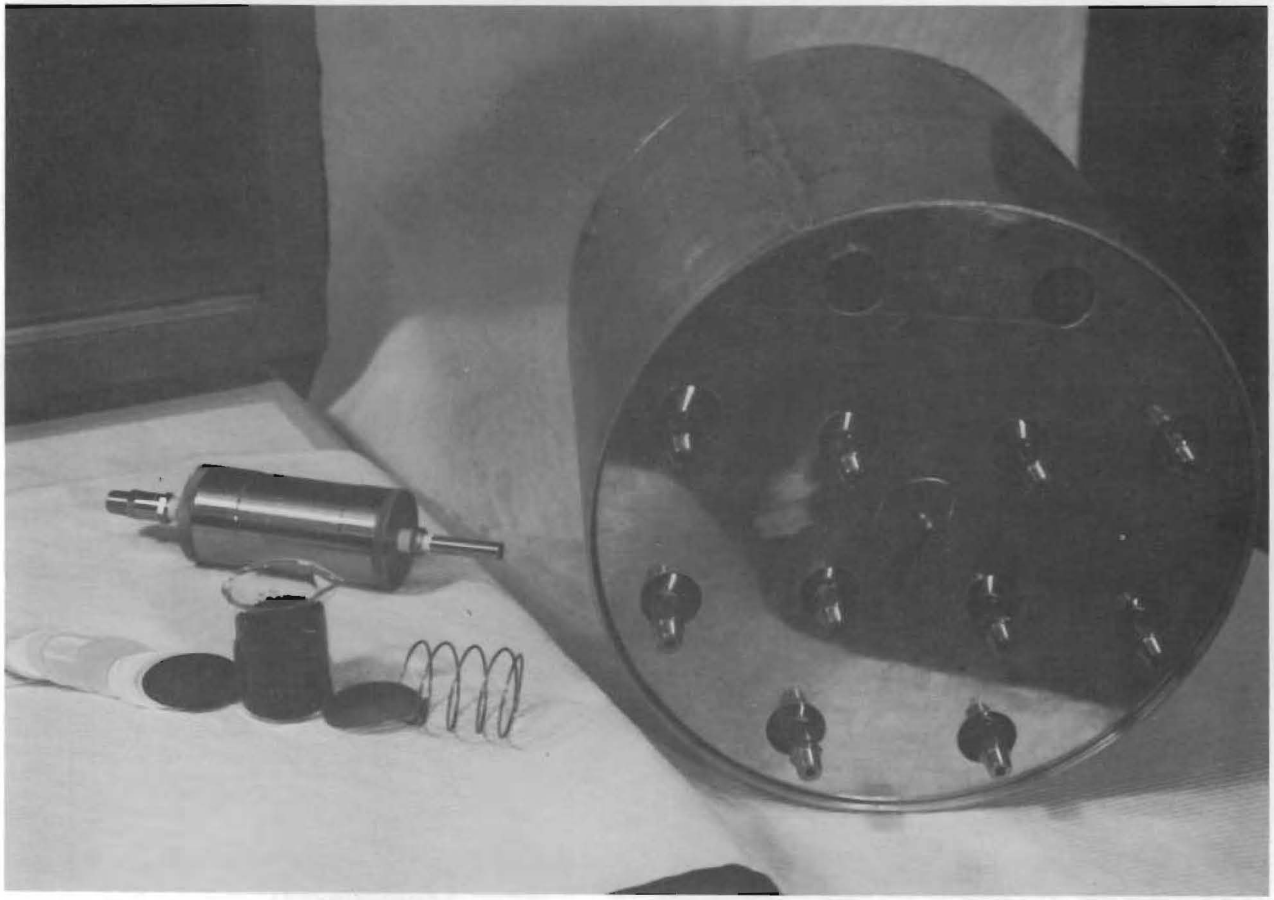


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FIGURE 15. Sample Cluster and Maypack

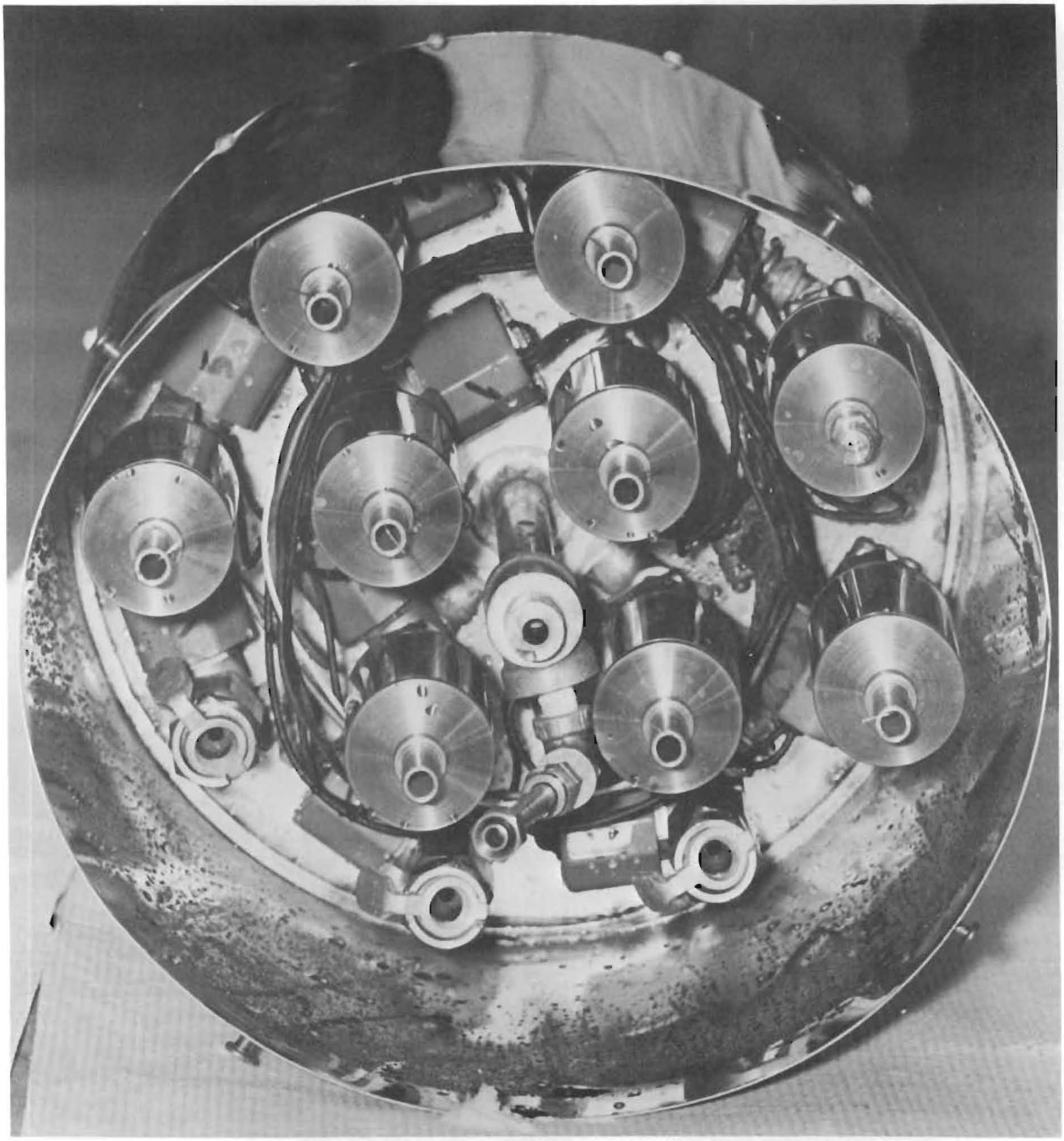

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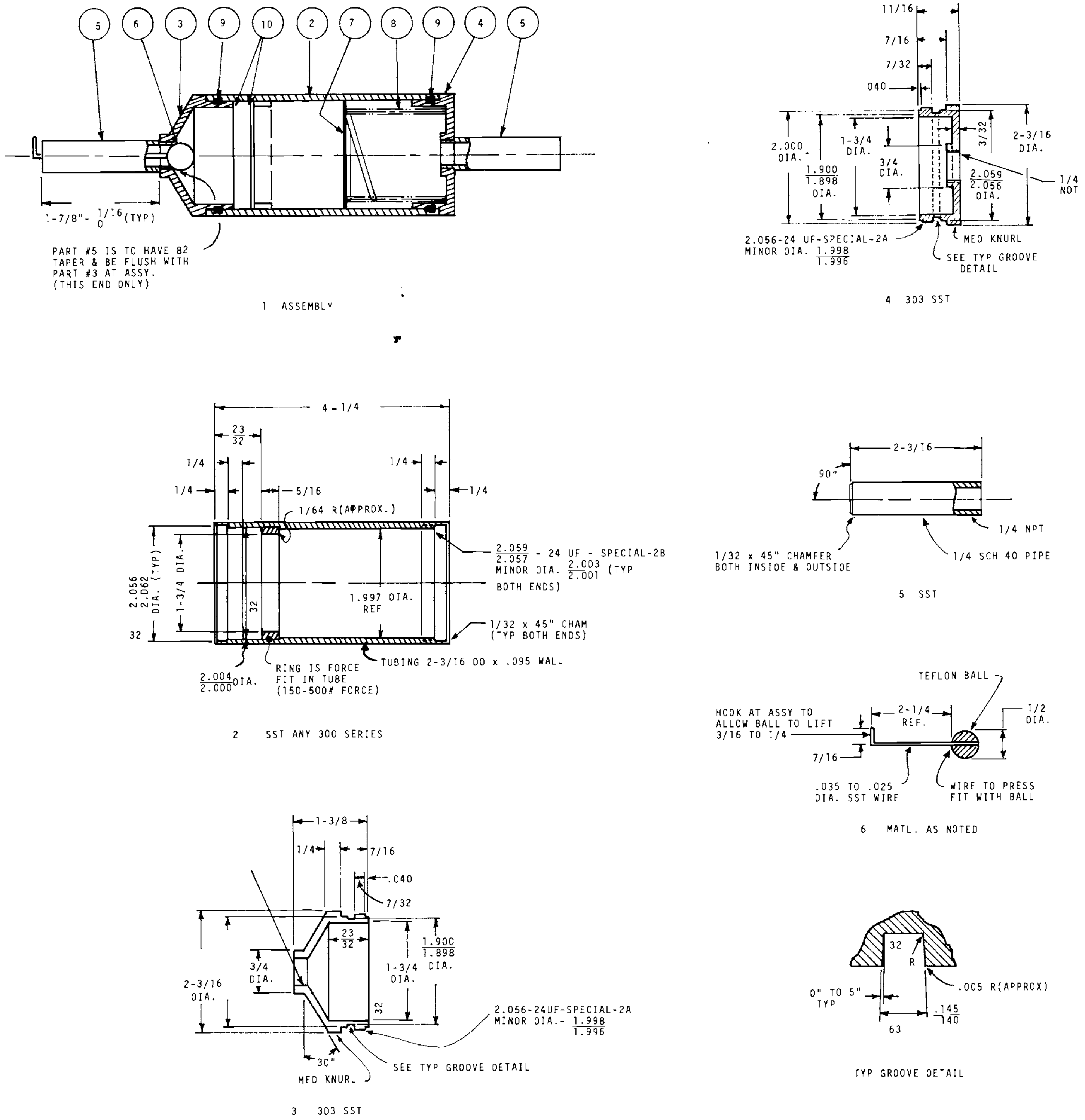
FIGURE 16. Partially Assembled Cluster



1	ASSEMBLY	
2	SHELL	
3	NOSE	
4	BACK	
5	NIPPLE	
6	CHECK VALVE	
7	SCREEN 1-31/32 DIA.-30 MESH $\frac{.015}{.012}$ WIRE	SST
8	SPRING 1-5/8 OD x 266, 4-1/2 TURNS .054 WIRE ENDS SQUARED BY BLENDING	SST, ASTM A313-63
9	O-RING	#2-134 VITON
10	GASKET $\frac{2.000}{1.995}$ OD x 1-3/4 ID x 1/16 THK.	TEFLON

GENERAL NOTES

UNLESS OTHERWISE SPECIFIED

1. TOLERANCES: FRACTIONAL ± 1/64, DECIMAL ± .005, ANGULAR ± 0"30'
2. ALL MACHINED SURFACES ^{63} (ASA B46.1-1962)
3. BREAK CORNERS AND REMOVE ALL BURRS
4. PARTS #3 & 4 TO FIT INTERCHANGABLY WITHOUT BINDING IN PART #2 IN EACH LOT
5. ALL PARTS TO BE FREE FROM GREASE OR OTHER FOREIGN MATERIAL. COAT THDS ON PARTS 2, 3 & 4 WITH MOLYBDENUM DISULPHIDE OR FLUOROCARBON LUBRICANT
6. ALL MATL. TO BE AS SPECIFIED OR APPROVED EQ QUALITY

FIGURE 17. Details of Maypack Filter Holder

or lowering an assembly to a desired location. Flexible Teflon tubing serves as the transfer line from an assembly to the vessel wall where it connects to a 0.5-in. diam stainless steel tube. The stainless tube penetrates the vessel wall and then is gathered into a bundle with the other sample lines. The bundle of stainless steel tubes continues the run into the laboratory to the final sampling and metering equipment (Figure 18). The transfer line bundle is steam-traced from the containment vessel to the laboratory to prevent condensation. Supplementary thief Maypacks samples can be taken from nozzles. of the containment vessel for immediate radiochemical analysis. However, retrieval of the main samples taken by the Maypack located within containment is postponed until all phases of the experiment have been completed and the containment vessel is thoroughly purged with fresh air.

Each terminal aerosol sampling station in the laboratory consists of a condenser, condensate receiver, cold trap, refrigerated charcoal trap for noble gas collection, rotameter, and the appropriate valves and gages required for flow control. The total gas volume is determined by adding the gas volume equivalent of the condensate collected to the volume as indicated by the rotameter with time, and by applying the necessary pressure and temperature corrections.

Additional Sampling Equipment

Samples of the atmosphere yield information on the gas phase concentration of the aerosol as a function of time, but disclose little or none regarding other possible depositions of the aerosol components. For these data, the studies rely on several other systems employing liquid pool samples as a function of time, condensate samples from isolated portions of the vessel as a function of time, deposition coupon samples and finally, samples of the liquid at the end of a study for material balance calculations.

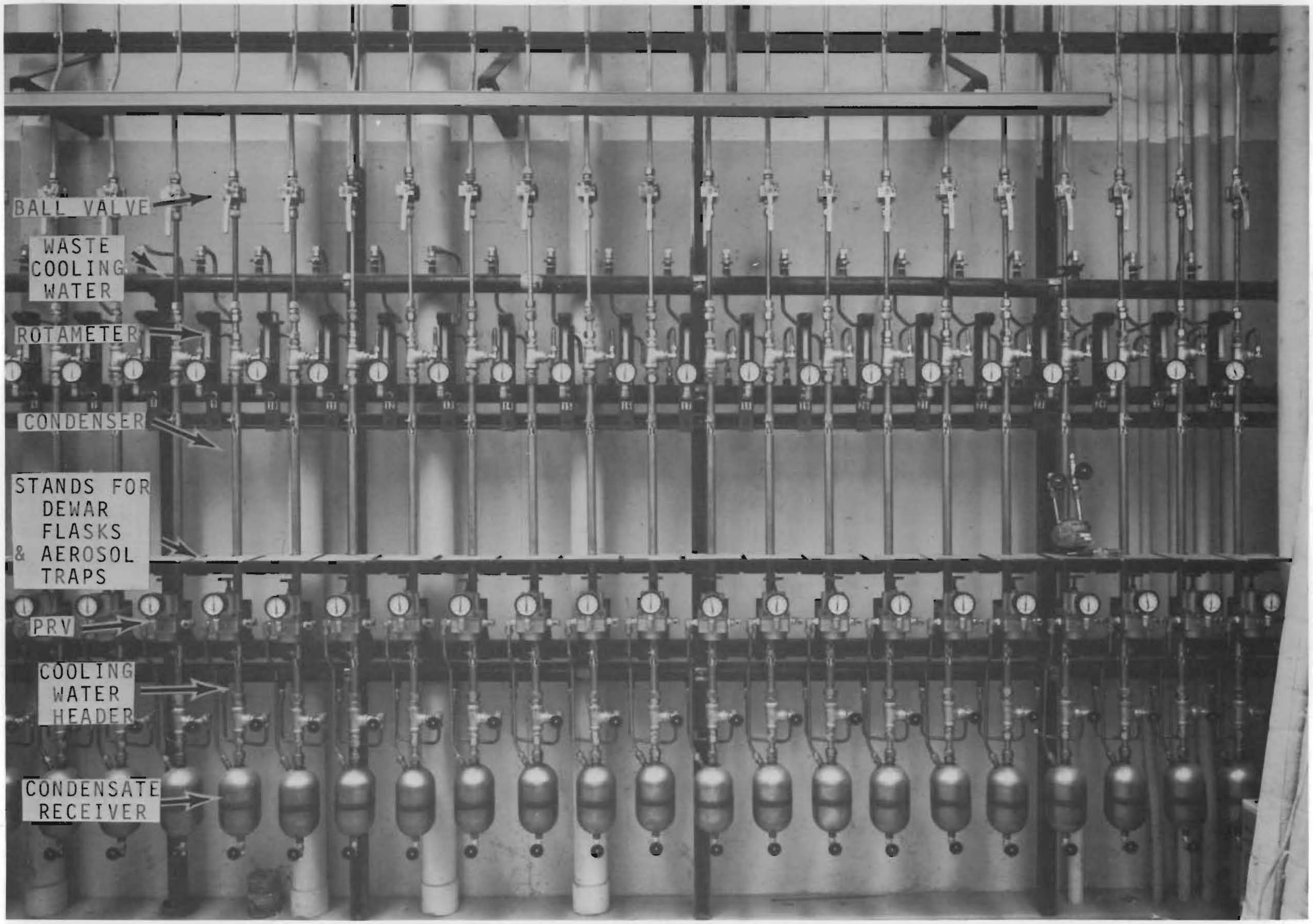


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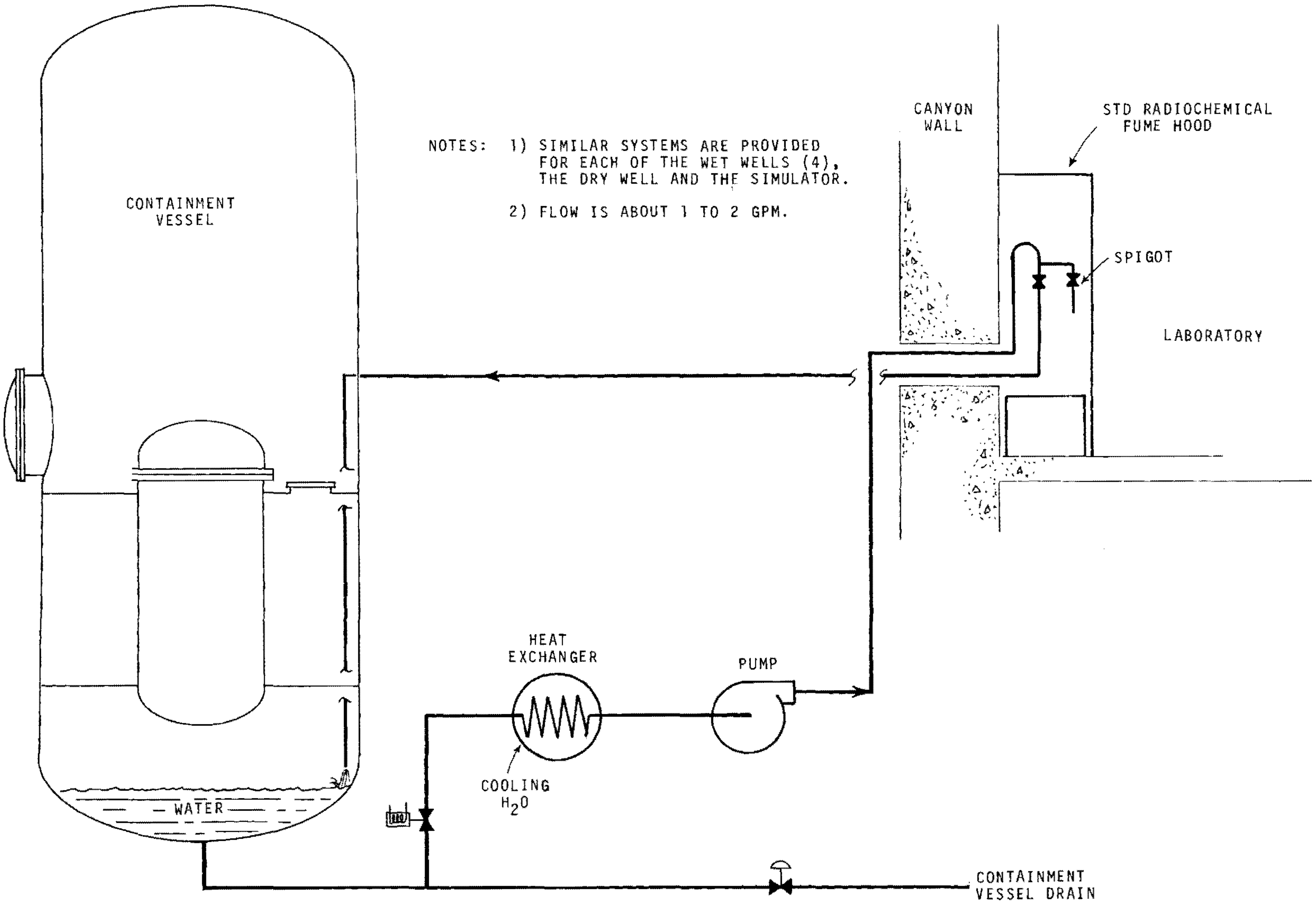
FIGURE 18. Final Aerosol Sampling Stations

Provision made to sample seven pools of water as a function of time consists of a loop for each of the four wetwells, and one each for the containment vessel, the drywell, and the reactor simulator vessel. A schematic of this is shown in Figure 19, and Figures 20 and 21 show some of the equipment installed. Each circulating system has a separate pump, heat exchanger, a sample spigot, and associated transfer lines and valves. The heat exchanger is necessary to prevent flashing of the sample when the sample spigot is opened. Volumetric samples will be taken and radiochemically counted directly under known geometries.

A second liquid sampling system was installed outside the containment systems vessel to assist in material balance determinations. This system consists of a metering station by which a known fraction of the discarded waste is drawn off and stored in a sampler tank. The tank itself is equipped with an agitator to assure that samples taken for analysis are representative. A picture of the equipment and the flowsheet for the proportional sampling system are shown in Figures 22 and 23. Since the sample storage tank (TK-1) serves for several liquid wastes, the discarding of wastes proceeds from the least contaminated pool to the most contaminated. The sample hold-up tank is flushed between discharges to minimize cross contamination.

Sampling for particulate matter and condensate involves relatively simple systems. For the first, deposition panels are used. These consist of stainless steel plates to which are fastened 2.5-in. diam coupons of various materials. The plates are permanently affixed to an unpainted portion of the inside containment vessel wall at an elevation of about plus 3 ft and at 250 degrees. Before an experiment, the coupons are attached to the plates by means of bolts and wing nuts. In addition, deposition coupons will be attached to each



NOTES: 1) SIMILAR SYSTEMS ARE PROVIDED FOR EACH OF THE WET WELLS (4), THE DRY WELL AND THE SIMULATOR.

2) FLOW IS ABOUT 1 TO 2 GPM.

FIGURE 19. Recirculating Liquid Sampling System

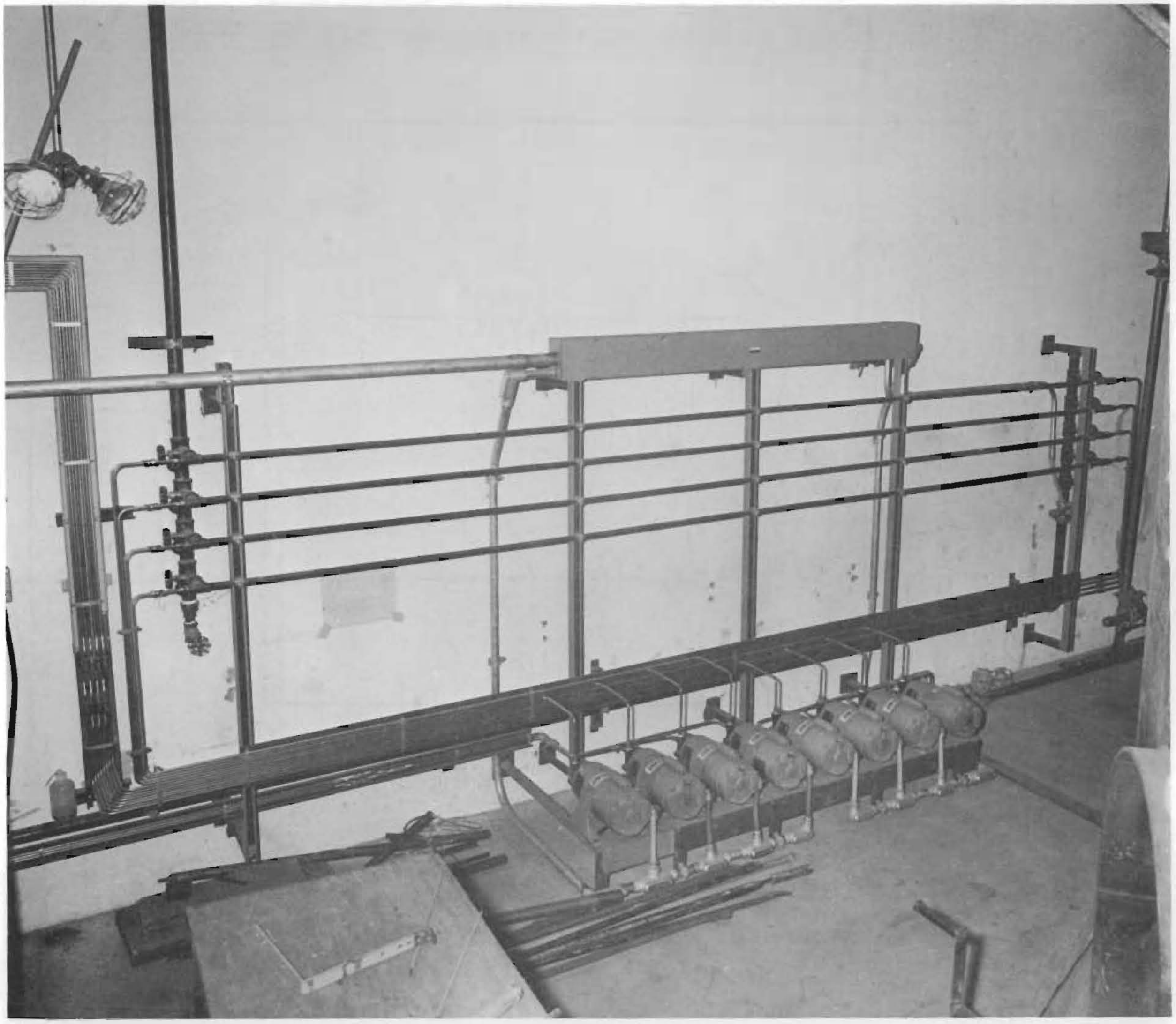


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FIGURE 20. Pumps and Heat Exchangers for Liquid Sampling Loops

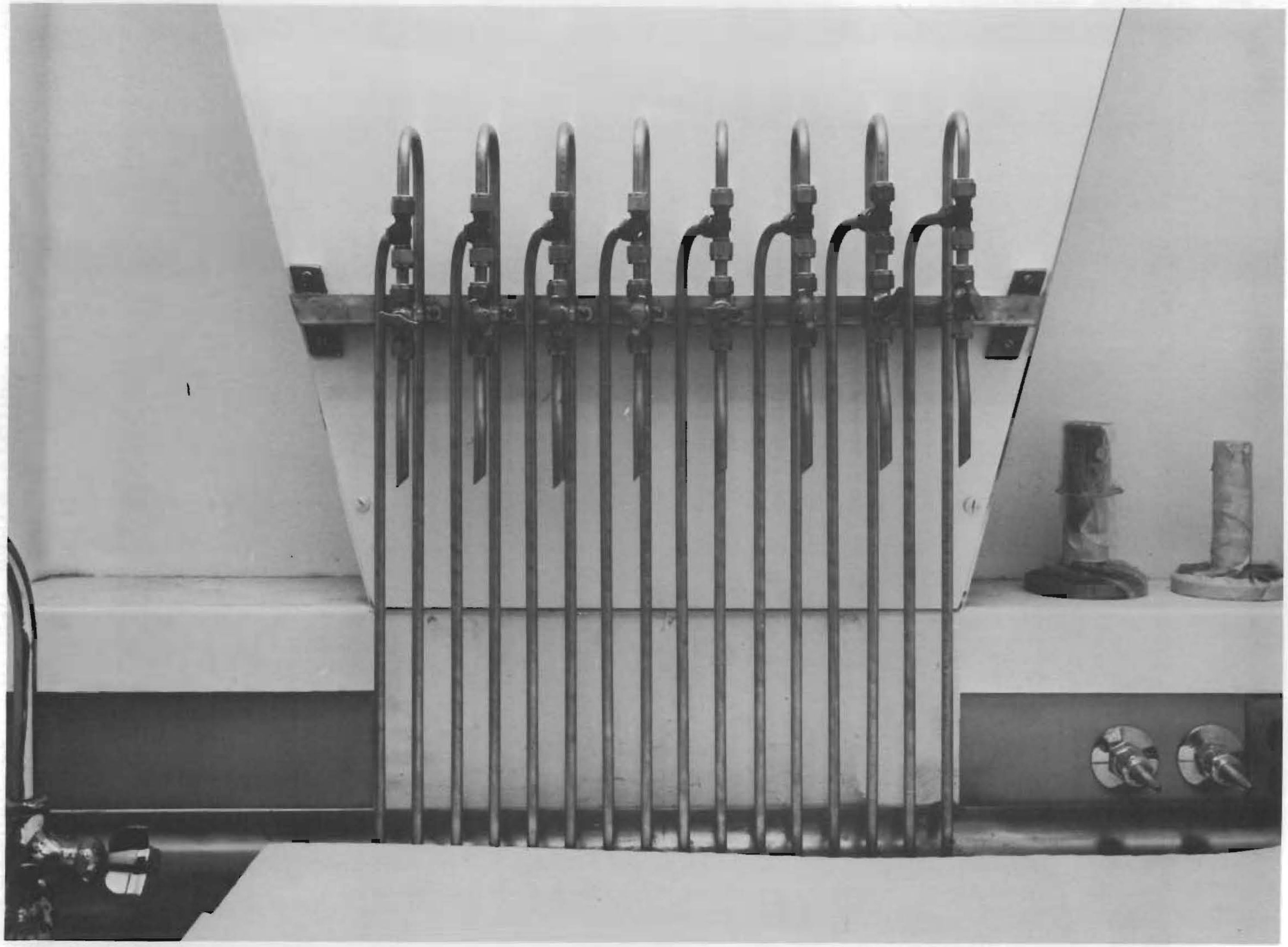

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FIGURE 21. Liquid Sample Ports Located in Fume Hood

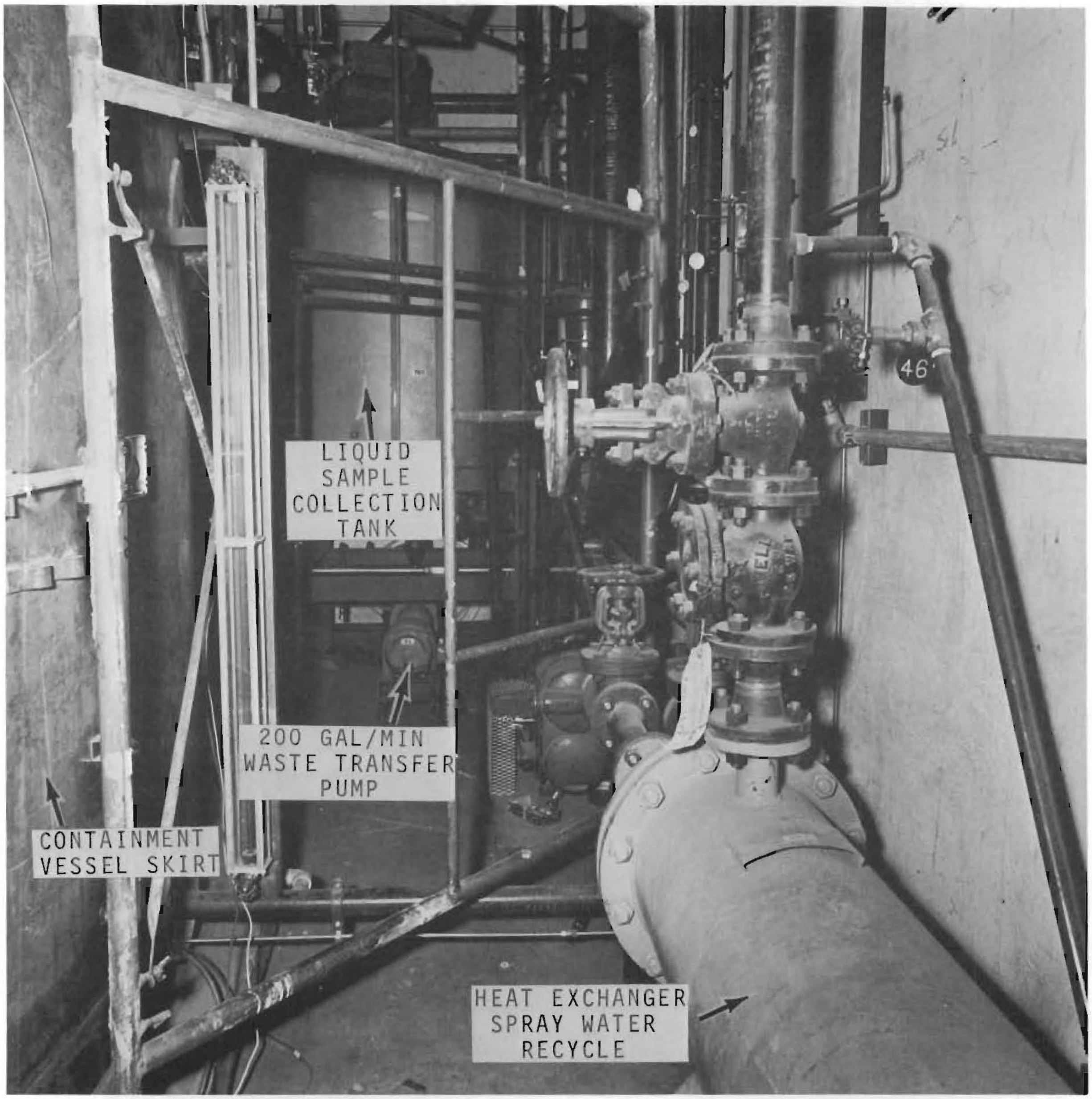

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FIGURE 22. Liquid Waste Piping at Cell Floor

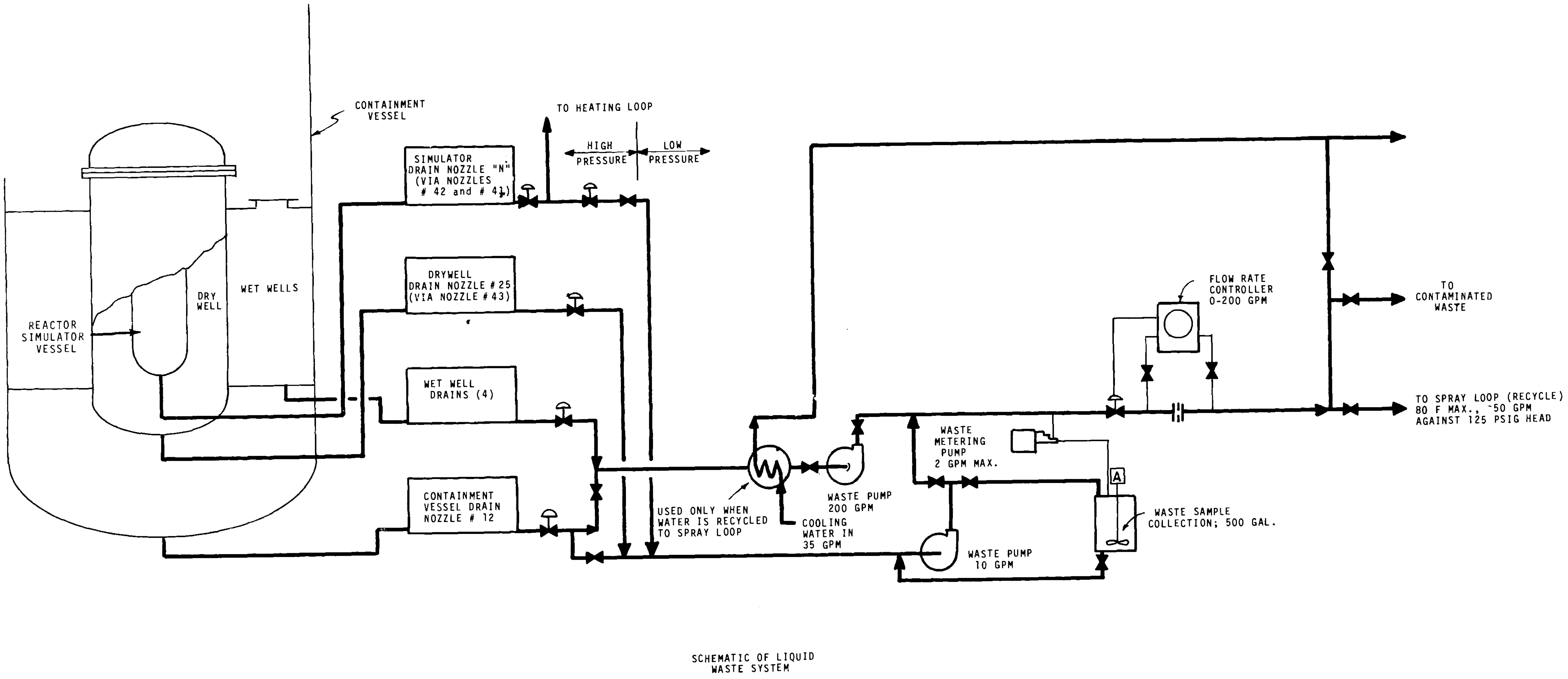


FIGURE 23. Schematic of Liquid Waste System

Maypack holder to measure deposition on noncondensing surfaces at various locations. Upon completion of the experiment, and access to the inside of the vessel is again permitted, the coupons are manually removed and taken to the laboratory for analysis. Except for the few minutes required to analyze them, some coupons of each of the materials are left on the deposition panel at all times in order to obtain information on deposition as a function of time and exposure.

The vessel wall condensate sampling system consists of a section of the containment vessel wall 2 ft wide and 30 ft high, to which are attached collection troughs about 10 ft apart vertically. Isolation of the area is achieved by 1 in. × 1 in. stainless steel angles along each edge for the entire vertical length. Each trough drains through half-inch stainless steel tubing to a collection tank outside the containment vessel. The collection tanks are vented back into containment. Periodically, the sample tanks are drained, the volume collected and recorded, and the sample taken to the laboratory for analysis. A schematic of the condensate collection system is shown in Figure 24. For spray studies, this system is converted to collecting rain samples. The drain lines from the troughs are disconnected and then connected to 4 funnels located in the vapor space.

A stainless steel angle iron trough is also installed completely around the interior circumference of the containment vessel and is located about 1 ft above the deck (wetwell roof). This trough is designed to collect all the moisture that condenses and flows down the walls. The condensate is piped to a laboratory sample station and then back to the containment vessel sump. Sampling frequency varies with the phase of the experiment. A sample is taken every 5 to 10 min immediately after aerosol injection while, near the end of the study, only one sample is taken every 4 hours or so.

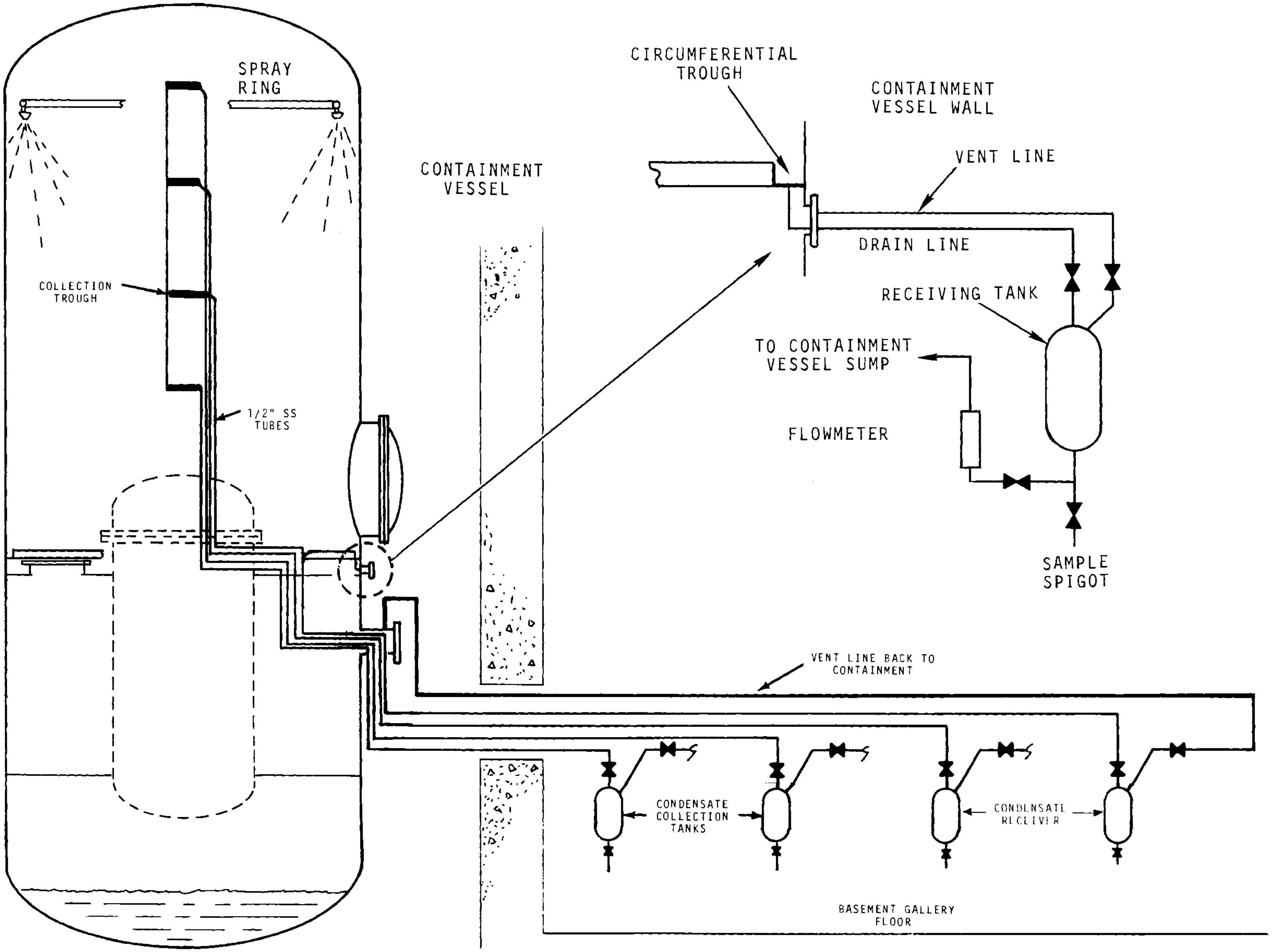


FIGURE 24. Schematic of Condensate Collection System

Spray Systems

The flowsheet for the spray system is shown in Figure 25. This system was designed to provide as much experimental flexibility as possible since the effect of spray on both pressure reduction and removal of airborne radionuclides is of interest.(4) As distribution and droplet size are of interest and importance to pressure reduction studies, so are the effects of chemical additives, recirculation of spray, and nozzle orientation of importance to fission product removal from a contained atmosphere.

Two spray header distribution systems, one for experimental purposes and one for washing down the walls after an experiment has been completed, are used. The latter is a 6-in. pipe carbon-steel spray ring located at the 27.5-ft elevation, slightly below the intersection of the shell and the top head of the containment vessel. The ring is equipped with 48 pipe nipples to permit use of the various nozzles and nozzle combinations. Details of the stainless steel experimental spray header and distribution system are shown in Figure 25. The distributor is equipped with 12 threaded pipe nipples to permit changing from one type of nozzle to another (fog nozzle, hollow cone, full cone). A goose neck is attached to each nipple to which is attached the nozzle. Use of the goose neck permits filling the header with spray solution prior to starting experiment. Thus the spray duration can be accurately recorded since flow will start and stop immediately upon opening or closing a ball valve in the main header. Constant flow, up to 150 gal/min, is maintained by observing the pressure in the header between the control valve and containment vessel, and manually adjusting the control valve.

The stainless steel system permits a variety of chemicals to be pumped through the system without the risk of corrosion to the pipes. Demineralized water is also used in the chemical

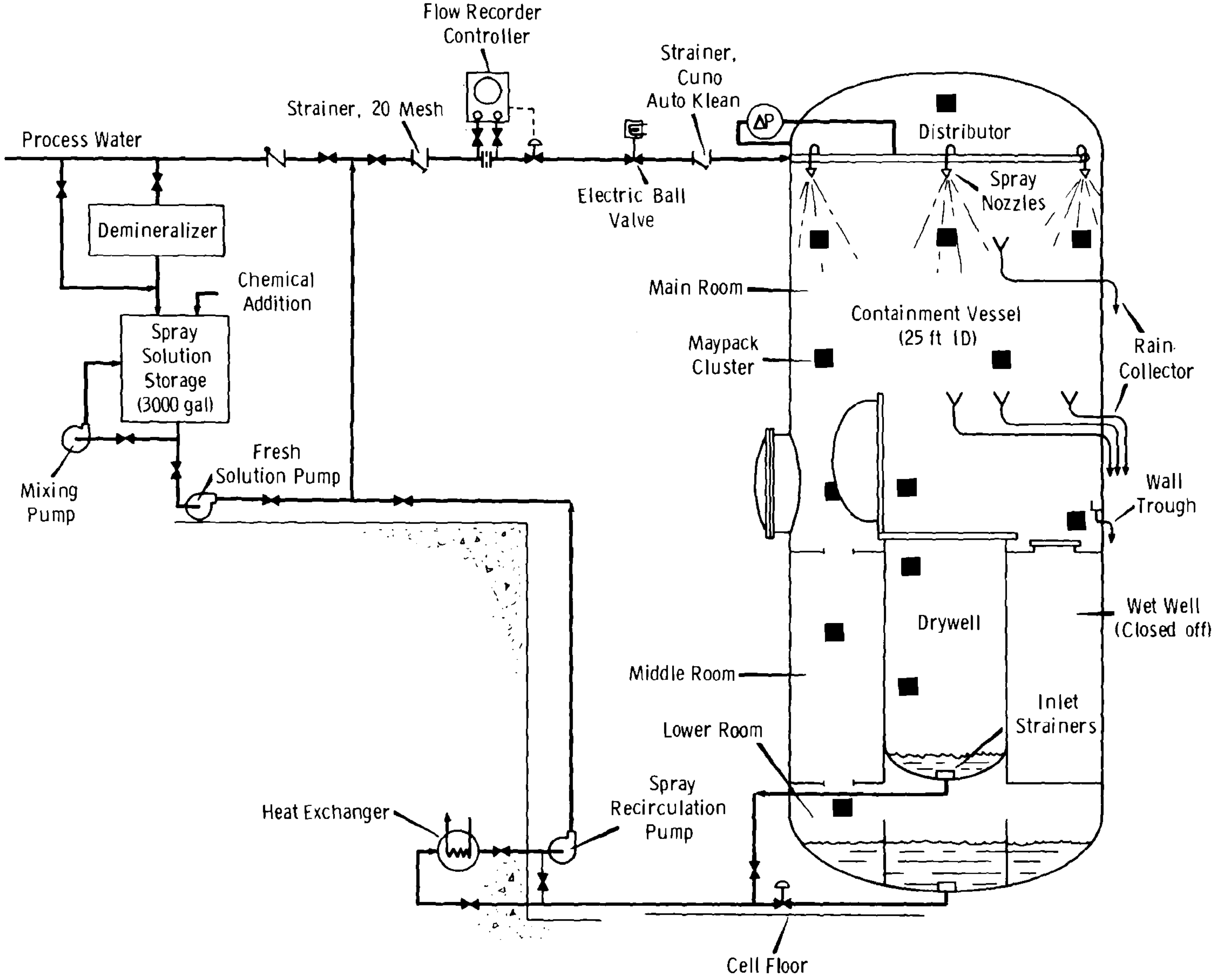


FIGURE 25. Spray Ring Header System

make-up in order to assure that the solutions do not contain unknown amounts of dissolved material that may effect the performance of the spray. However the system is so piped that process water could be used.

Recirculation of the spray solution that collects in the sumps is also possible. The drywell can be drained to the containment vessel sump from where it can be pumped at rates up to 150 gal/min back into the spray header system. The solution can go directly back into the header or pass through a heat-exchanger for removal of heat prior to entering the header.

Insulation

Since the containment vessel is inside a building, the external ambient temperature will vary only a small amount (±10 °F) as compared with the seasonal and diurnal changes of a containment system for a power reactor. The small temperature variation permits the use of one inch of insulation for the heated leak tests, for studies involving condensation coefficients, and for aerosol deposition. One-inch-thick glass fiber insulating board (6.0 lb/ft^3 density, $k = 0.026$ Btu/$hr\text{-}ft^2\text{-}°F/ft$) with factory applied aluminum foil facing is to be installed for those experiments where insulation is required. Provisions were made to add two more inches of insulation if future experiments indicate a need to reduce heat-loss from the containment vessel. This arrangement would permit further studies on the effect of the lower heat loss and lower condensation rates on fission product transport and behavior.

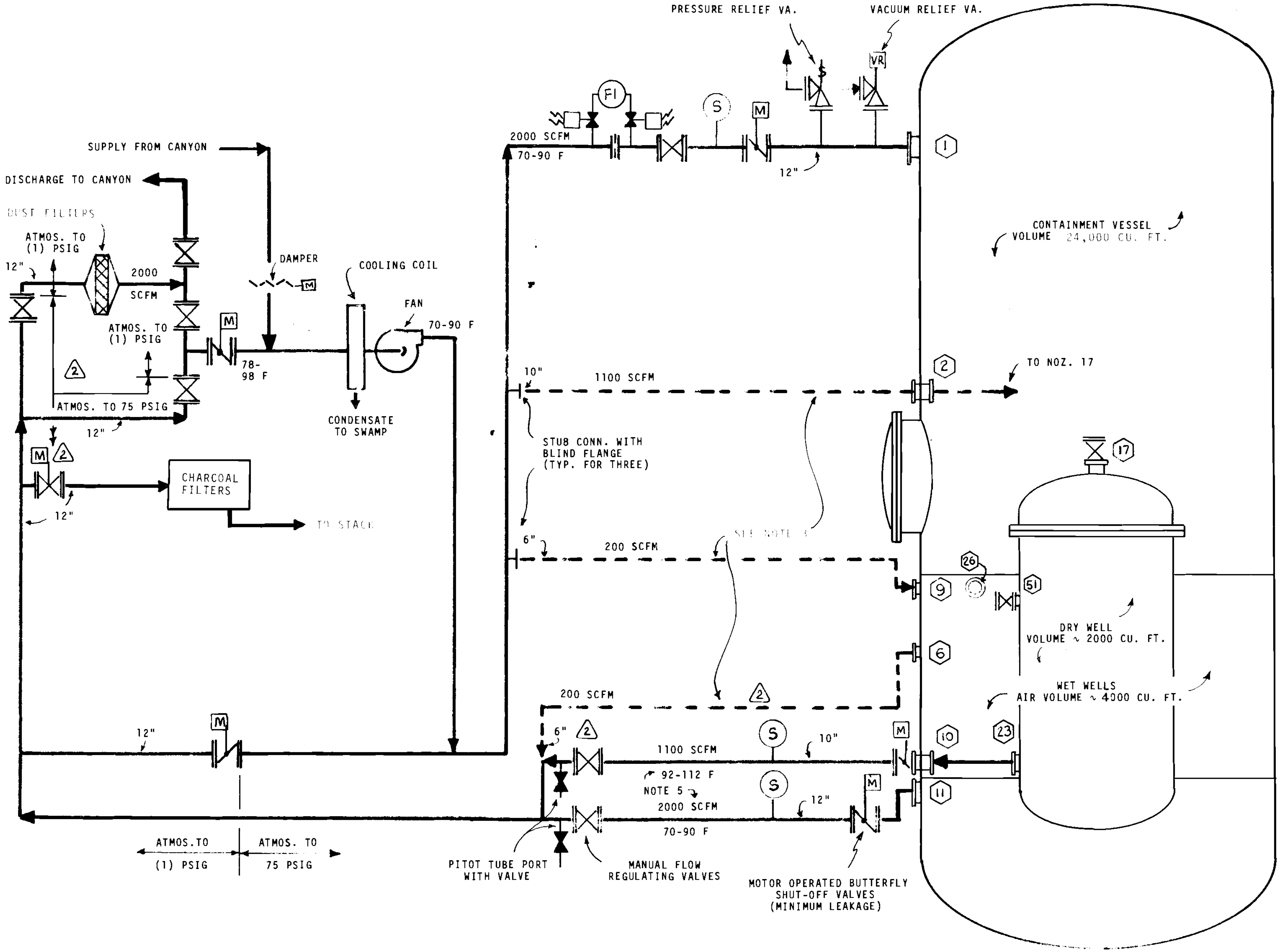
Ventilation

A recirculating ventilation loop is provided primarily for purposes of temperature control prior to a blowdown experiment. A secondary purpose is to remove foreign material (dust) from the contained air prior to a fission product transport and behavior study. The system is designed to operate either as a closed loop or as a once-through ventilation system with the exhaust discharging to the 221-T Canyon or, if the air is contaminated, to a large stack via a charcoal filter. Prior to a fission-product transport and behavior experiment, the closed loop is operated until a sample of the air in the containment vessel shows less than 500 particles/cm^3. After an experiment, the once-through system is operated until radiochemical analyses of atmospheric samples indicate that conditions are satisfactory for entry of personnel to recover samples.

The flowsheet for the ventilation system is presented in Figure 26, and Figures 27 through 29 show some of the equipment. The maximum capacity of 2000 scfm permits a turnover of contained air every 15 min. The isolation valves, which can be closed remotely immediately prior to initiation of an experiment, and the pipes immediately attached to the containment vessel are designed for a pressure of 75 psig so that an aerosol decontamination loop may be added if desired. The rest of the loop, which includes the fan, the filters, and the heat exchanger, is designed for atmospheric pressure. The low-pressure part of the system is protected with pressure relief devices in the event leaking valves or an operating error permit the pressurized gases in the containment vessel to reach the low pressure portion of the ventilation loop.

The flow of air in containment is downward from where it enters near the top of the vessel (nozzle 1) to exit near the bottom of the vessel (nozzle 11). Remotely controlled valves installed on the drywell top (if closed) and the walls of the wetwells permit these portions of the vessel to be included or excluded from the flow of ventilation air as desired.

Pressure relief valves are installed in the main ventilation loop header adjacent to the containment vessel because of potential overpressurization of the containment vessels.



SYMBOLS

(FI) FLOW INDICATOR

(S) SAMPLING CONNECTION SEE SK-2-3594

GENERAL NOTES

1. CANYON AIR TEMPERATURE SURROUNDING CONTAINMENT VESSEL 70 TO 90 F.
2. VENTILATION LINES FROM THE DRYWELL TO CONTAINMENT VALVES SHALL BE DESIGNED FOR 150 PSIG.
3. DASHED LINES - ALLOW FOR FUTURE DESIGN AND INSTALLATION.
4. SIZE BLOWER, COOLER, FILTER AND LOOP FOR 2000 SCFM AND 30,000 BTU/HR.

FIGURE 26. Containment System Ventilation Loop

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FIGURE 27. Exhaust Side of Ventilation Loop

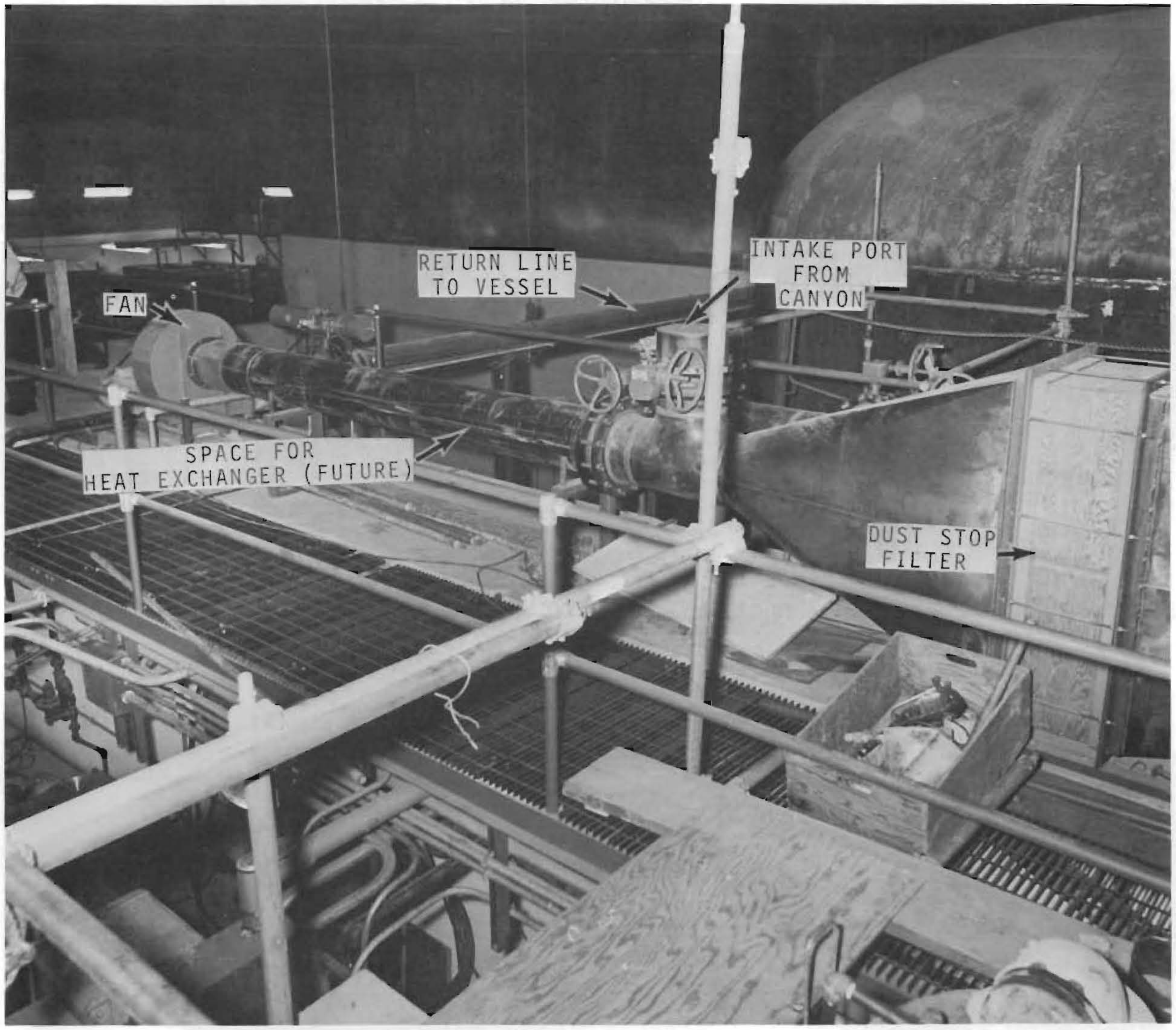

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FIGURE 28. Dust Filter and Fan of Ventilation Loop

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FIGURE 29. Line and Filter for Exhausting Contaminated Air

Vacuum-breaking devices are also included because appreciabbe aerosol sampling will be conducted when gases inside the vessel are at atmospheric pressure (removal of gases at these conditions will create a vacuum potential). Vacuum relief also may be required for experiments on ducted pressure relief. These experiments would deplete air in containment, and the subsequent condensation of contained steam would create a vacuum.

Containment Systems Penetrations

All penetrations were designed to be leak-tight at the maximum differential pressure and temperature obtainable as specified by the design criteria for the containment vessel. Thus, in addition to preventing leakage from the containment vessel to the atmosphere, the criteria called for preventing leakage between the wetwells and drywell and also from these vessels to the containment vessel. Second, since study of containment vessel leak rates was a major experimental objective, the criteria called for the ability to detect and measure any leakage that might occur past the containment boundary. Third, the criteria called for the ability to permit local tests of certain individual penetrations without pressurizing the whole system.

For the liquid and gas lines to and from containment, double valves were required with a tap between the valves to draw off and measure any leakage past the inner or primary containment valve. Also where practical, a double O-ring seal in flanged joints to the containment vessel was called for, and a tap between the O-rings was specified to sample for leakage past the inner ring. Electrical penetrations required terminals both inside and outside the containment vessel with a sealed pipe sleeve in between. A sample tap is installed on the sleeve to check for leaks past the inside terminal or connector. Leakage between the insulation and the conductor is prevented by breaks in the insulation at the terminals.

The provisions for detecting leakage are quite simple. Each of the sample taps are fitted with a short piece of tubing to which a rotometer can be attached by means of a length of plastic tubing. During the leak-test phase of the program, all the penetrations were monitored for leakage by dipping the flexible tubing in a graduate of water. If leakage was detected a rotometer was connected and the rate of leakage measured.(5)

The ability to collect and measure the leakage at individual leak points permitted audits of the adequacy of leakage measurements obtained by applying the ideal gas laws used for actual containment vessels.

A listing of all penetrations and their functions is provided in Appendix A. Figure 30 shows typical penetrations and Figure 31 presents some schematic details.

REACTOR SIMULATOR VESSEL

A reactor simulator vessel was constructed for use in experiments to study the hydraulics and energy transport which occurs during a loss of coolant accident.

The objective of the experiments include testing of the validity of mathematical models used for predicting the consequences of a loss-of-coolant reactor accident. The vessel can be mounted either in the drywell of the containment vessel or in a test stand exclusive of containment. The vessel (Figure 32) is mounted upright in its framework with the discharge nozzles directed horizontally. This blowdown apparatus is instrumented to measure internal pressures, temperatures, liquid level, void fraction of the fluid in the exit duct, mass of fluid remaining in the vessel, thrust reaction forces, shell stresses, and forces on dummy reactor core structures. This extensive instrumentation enables the testing of many aspects of the mathematical model predictions.

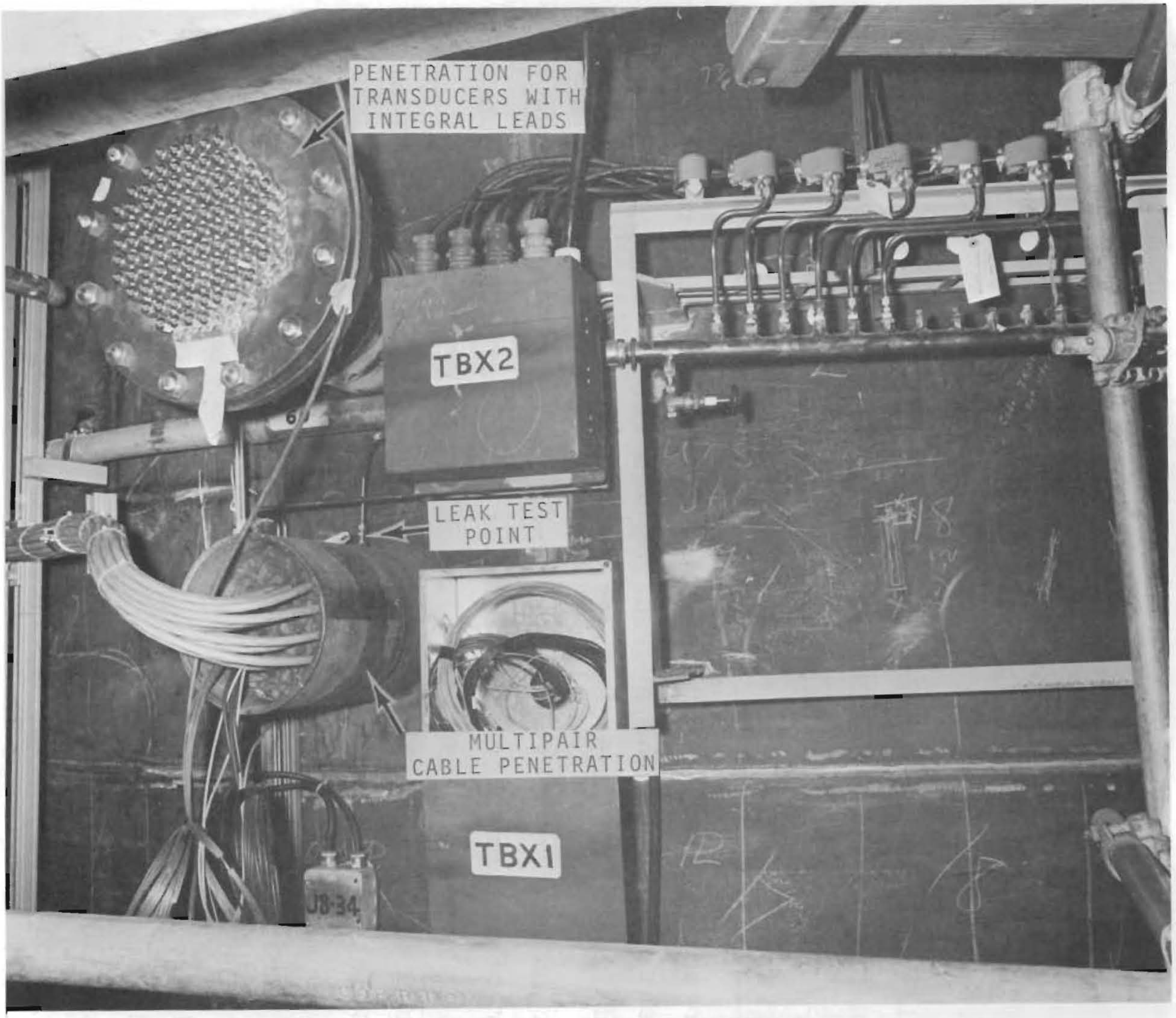

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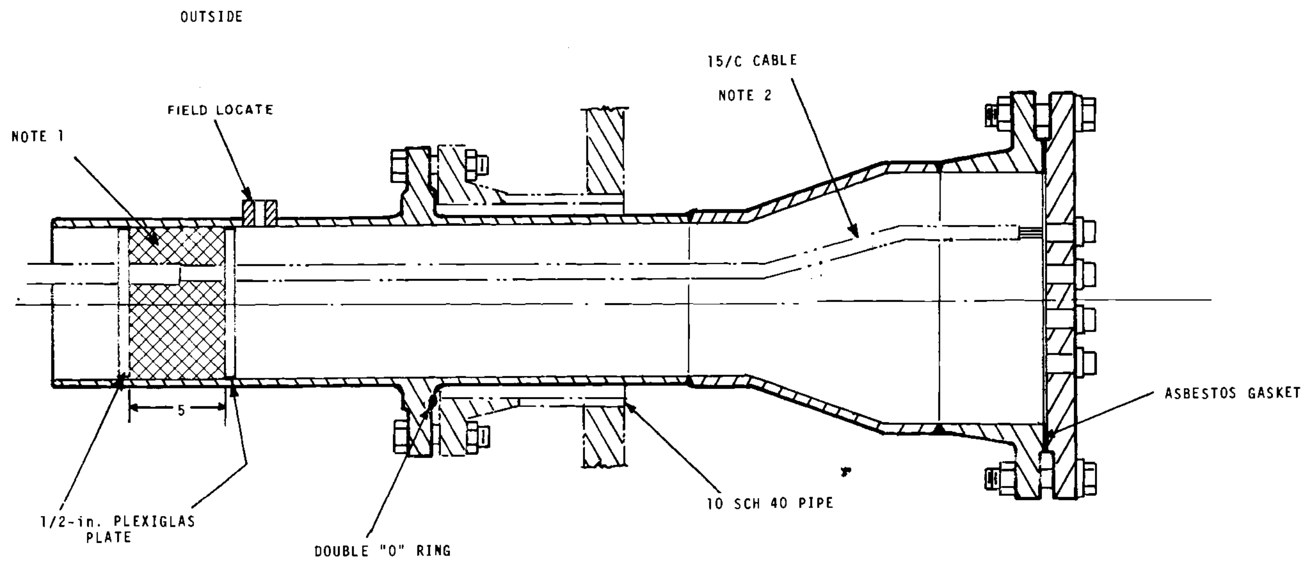
FIGURE 30. Electrical and Instrument Penetrations



ELECTRICAL FEED THROUGH FOR MAYPACK SAMPLER

NOTES

1. POTTING COMPOUND TO BE PREPARED AND POURED IN ONE QUART BATCHES TO TOTAL FILL. USE DUCT SEAL TO CLOSE ALL CREVICES BEFORE FILL.

2. REMOVE CABLE SHEATH AS SHOWN. ALLOW 12" OF CABLE SLACK.

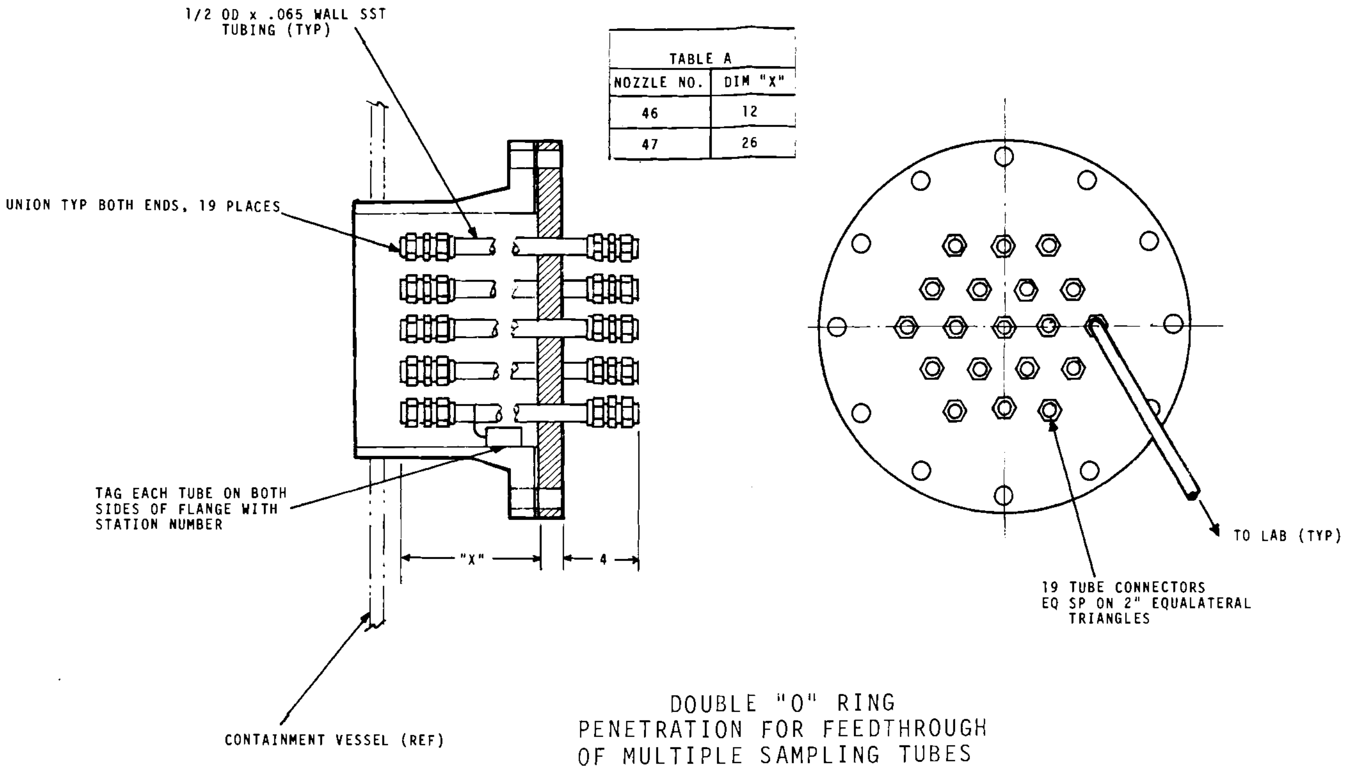
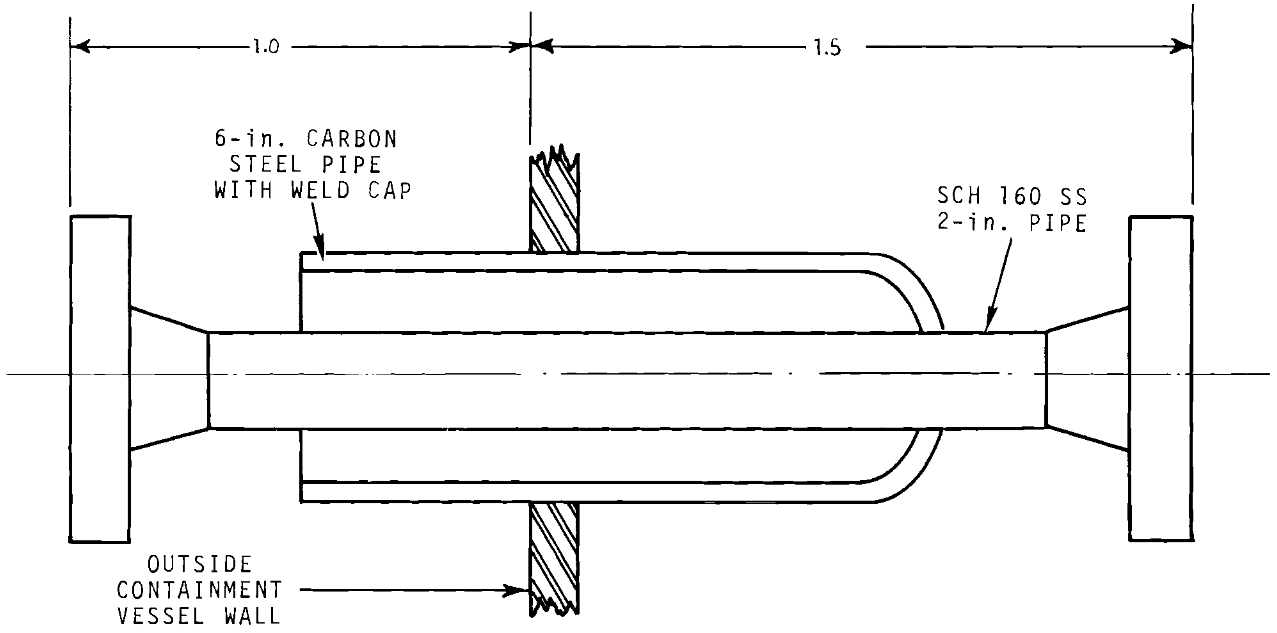


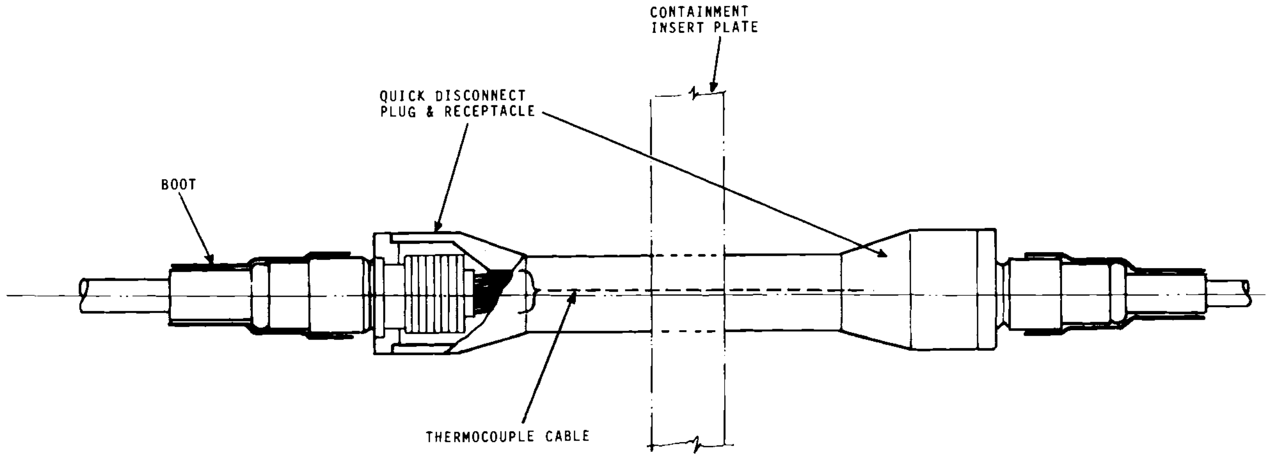
TABLE A

NOZZLE NO.	DIM "X"
46	12
47	26

DOUBLE "O" RING PENETRATION FOR FEEDTHROUGH OF MULTIPLE SAMPLING TUBES

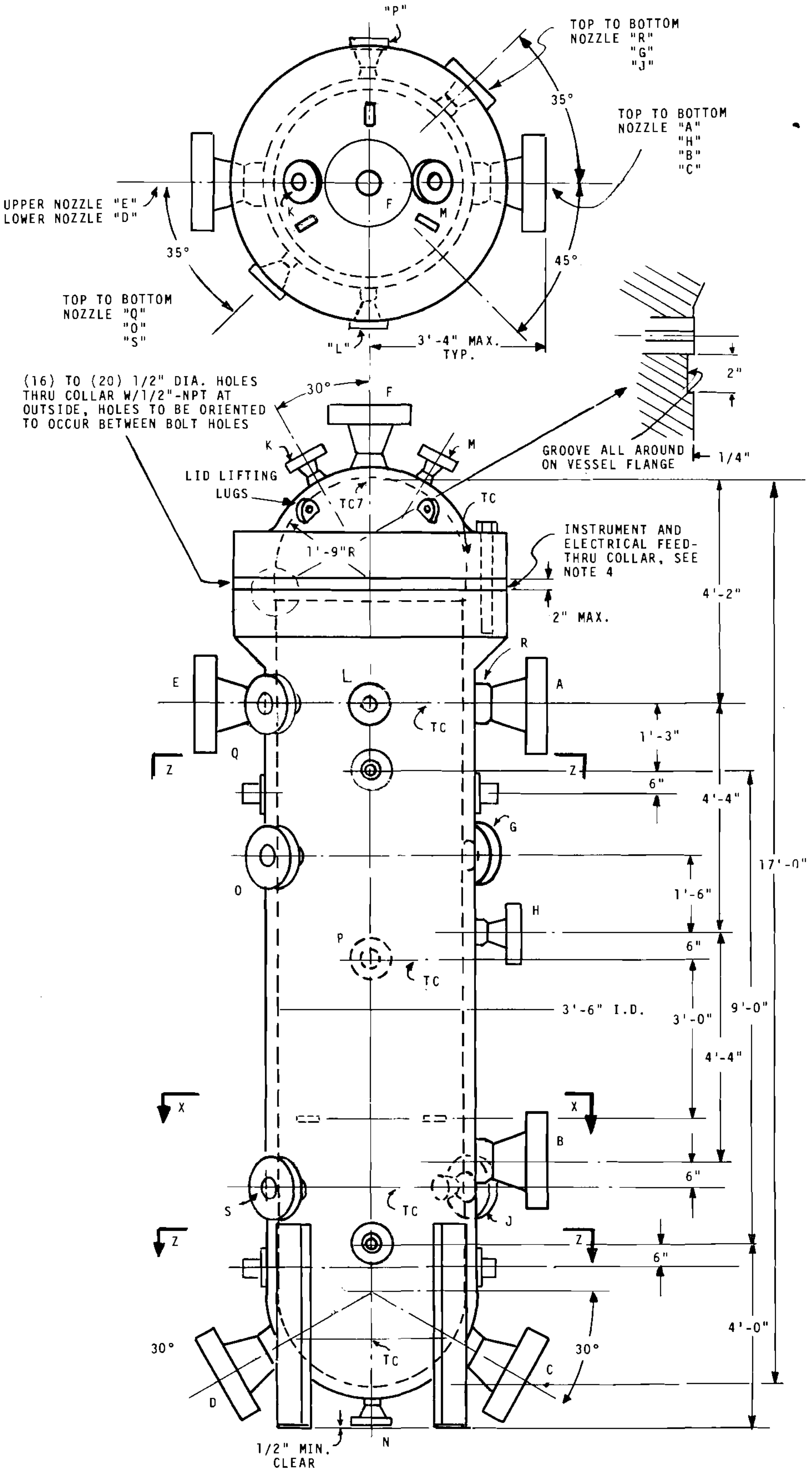


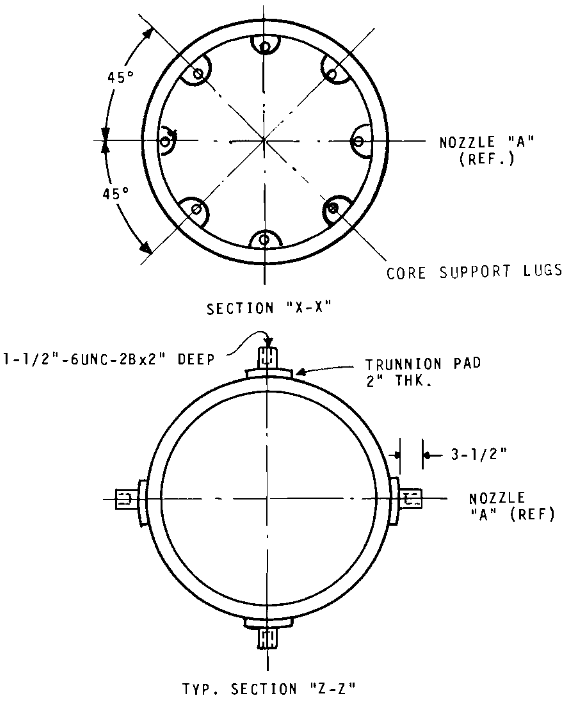
HIGH PRESSURE - HIGH TEMPERATURE LINE PENETRATION



THERMOCOUPLE - LEAD FEED THROUGH

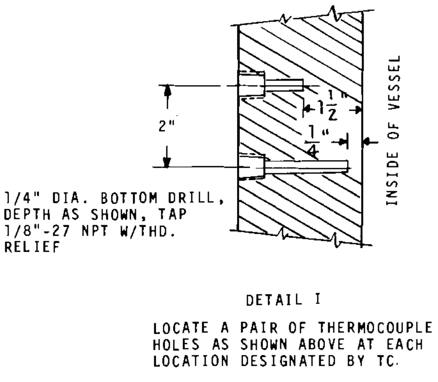
FIGURE 31. Schematic of Typical Penetrations





NOZZLE IDENTIFICATION

MARK	SIZE	FUNCTION
A	8"	BLOWDOWN
B	8"	BLOWDOWN
C	8"	BLOWDOWN
D	8"	BLOWDOWN
E	8"	BLOWDOWN
F	6"	WATER SPRAY SYSTEM AND HEATING ELEMENT INSERTION
G	4"	FISSION PRODUCT INSERTION
H	4"	AUXILIARY
J	4"	FISSION PRODUCT INSERTION
K	2"	PRESSURIZED AIR INLET AND PRESSURE GAGE PORT
L	2"	LOOP OUTLET
M	2"	SAFETY AND RELIEF VALVE PORT
N	2"	LOOP INLET
O	4"	FISSION PRODUCT INSERTION
P	2"	TEMPERATURE ELEMENT
Q	4"	FISSION PRODUCT INSERTION
R	4"	FISSION PRODUCT INSERTION
S	4"	FISSION PRODUCT INSERTION



DETAIL I

LOCATE A PAIR OF THERMOCOUPLE HOLES AS SHOWN ABOVE AT EACH LOCATION DESIGNATED BY TC.

GENERAL NOTES

1. VESSEL SHALL BE DESIGNED, FABRICATED, TESTED, AND STAMPED IN ACCORDANCE WITH ASME BOILER AND PRESSURE VESSEL CODE SECTION III, NUCLEAR VESSELS.
2. MAXIMUM ALLOWABLE WORKING PRESSURE TO BE 2750 PSIG AT 600 F.
3. VESSEL WILL BE COVERED WITH 3" OF INSULATION.
4. THE INSTRUMENT AND ELECTRICAL FEED THRU COLLAR WILL NOT ALWAYS BE USED DURING VESSEL OPERATING CONDITIONS, THEREFORE VESSEL SHALL BE DESIGNED FOR USE WITH OR WITHOUT COLLAR.
5. THERMOCOUPLES IN FLANGE, (TC9), ONE AT MID-DEPTH

FIGURE 32. Reactor Simulator Vessel Diagram

General Description

The reactor simulator vessel was designed and constructed for 2750 psig and 600 °F service in accordance with Section III of the ASME Code for Nuclear Vessels. For design purposes, the stress analysis as required by Paragraph N-142 of the Code assumed the worst transient for the estimated 500-cycle service of the vessel to assure a cumulative damage factor of less than 1.0. The worst transient was defined as a blowdown from a nominal 8-in. diam 1500 lb nozzle, with water heated to 600 °F and pressurized to 2500 psia. In addition, several quality control tests were requested over that required by the Code and these are listed in Appendix B.

The reactor simulator vessel was sized by the use of about a one-fifth linear scale of a 1000 MW_e power reactor proposed at that time. This same scale was used for the drywell and containment vessels. The intent was to proportion the stored energy of the water vessel to the rest of the system so that temperature pressure transients with time of the CSE would approach those of a 1000 MW_e reactor in the event of an MCA. This consideration also permitted determination of the required blowdown nozzle sizes (nominal 8-in. 1500 lb nozzles or 6.8-in. ID). The 24-ton vessel as shown in Figures 32 and 33 has a capacity of 150 ft^3 and is made from carbon steel to ASTM A-212-B and ASTM A-105-II. All the wetted surfaces are clad with metallurgically bonded Type 304 SS. Minimum clad thickness is 1/16 inch.

Two blowdown nozzles were specified in the bottom head and two near the top of the barrel in order to achieve a blowdown of 2 × MCA by using either pair together if such tests proved needed. In addition one blowdown nozzle was specified immediately below the core support lugs in order to study the forces resulting from a blowdown in that area. The core support lugs, designed to withstand a load of 100,000 lb, places a 75 psi maximum allowable differential across the core.

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FIGURE 33. Reactor Simulator Vessel

Numerous small nozzles were specified for injection of the fission-product simulant into and below the core area, for heating loop pipe connections in and out of the vessel, and for facilitating installation of some instrument transducers inside the vessel.

Another feature of the vessel is the instrument lead feedthrough collar located between the vessel barrel and the removable top head. This collar was provided for instrumenting dummy cores of various degrees of sophistication. Since the collar may not be necessary for all the series of tests planned, the vessel closure was designed to seal with or without the collar in place. Opening and closing of the vessel is facilitated by the use of tensioners.

As mentioned previously, the simulator is to be used first as an experimental tool to study the hydraulics of an MCA blowdown, and second to simulate the pressure-temperature transients in containment. The general location of the simulator for the blowdown studies was shown in Figure 5 and the supporting structure is shown in detail in Figure 34.

In order to conduct the fission-product transport experiments and the blowdown studies simultaneously and expeditiously, it was necessary to locate the simulator so the two studies could progress independently of each other. The site chosen was west of the 221-T Building and as close as possible to minimize piping runs. The 277-T Building provides for weather protection of the equipment. Two large doors, 12 ft wide by 18 ft high, were provided. One of these, the south door, was designed for equipment access, while the north door was to serve as a vent during blowdown. Both doors must be fully open during a test.

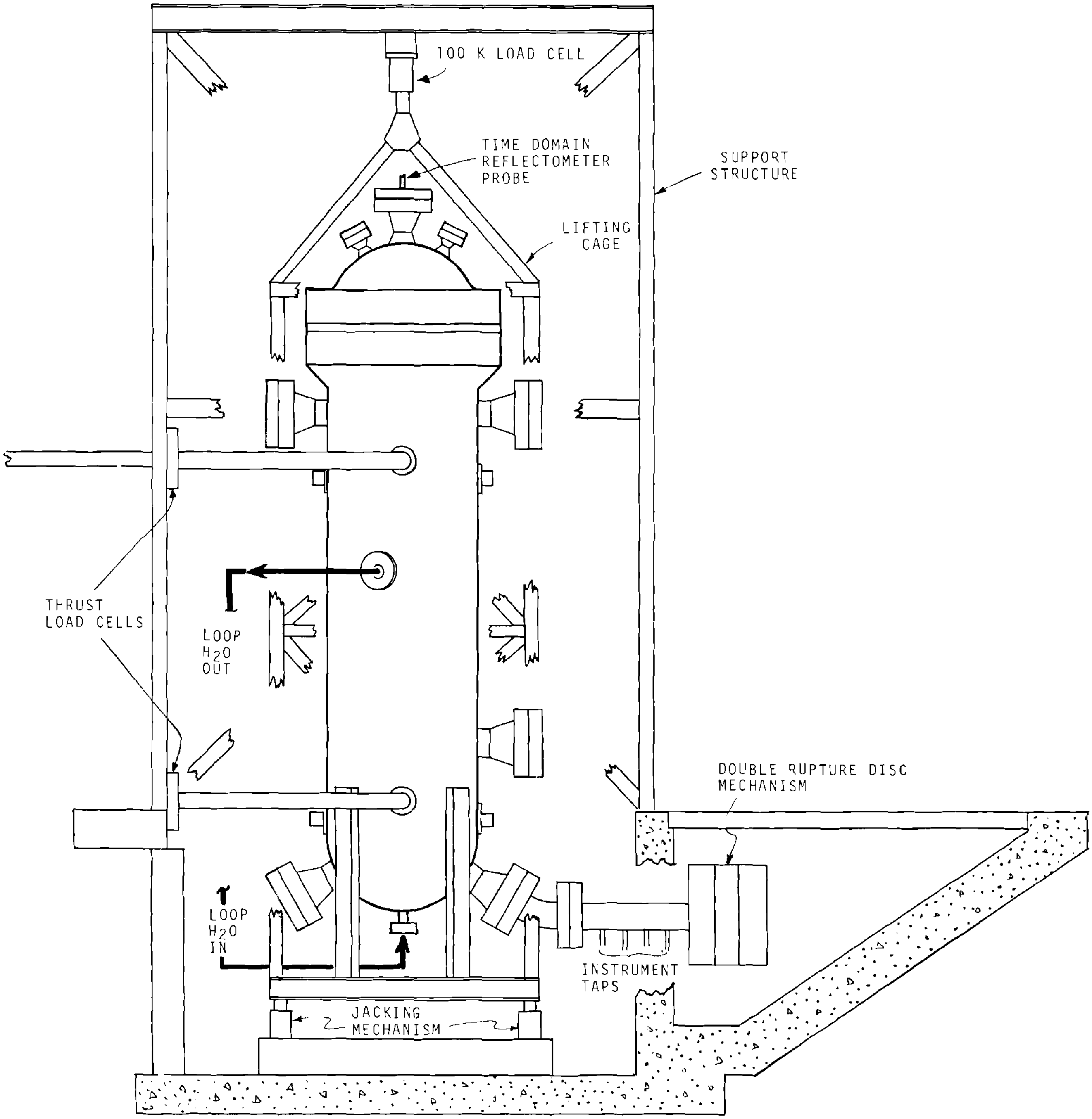

FIGURE 34. Simulator Structure Support for Hydraulic Studies

Structural Support

The simulator is held in a lifting cage suspended at the top by rigid structural steel framework during an experiment. A 100,000-lb load cell is incorporated into the suspension system to obtain data on the rate of water ejection during blowdown. Lateral bracing is provided both in the direction of primary thrust and also at right angles to the primary thrust. The lateral braces, in the direction of the thrust, also incorporate load cells for the experimental purpose of obtaining data on thrust forces. Because the thrust transmitted to these braces may vary due to initial blowdown temperatures and pressures, or because of variations in nozzle size by orifice adjustments, the system was designed to accept load cells of 50,000, 100,000, and 200,000 lb capacity. The orifice size for a blowdown may be a nominal diameter for a 2, 4, 6 or 8-in. schedule 160 pipe. Before and after an experiment, the simulator stands in its cage on jacks (Figure 35) set in the concrete footing in the floor of the pit. All four jacks are interconnected to achieve uniform up or down motion as desired.

Installation of the simulator in the drywell differs considerably because of space limitations and the more important programmatic considerations. The main purpose for installing the simulator in the drywell is to simulate the pressure-temperature transients that would occur under conditions of dry containment or pressure suppression containment. Prior to this installation, all the research and development data on blowdowns to be evaluated by this vessel are to be obtained. As a result, the simulator will not be instrumented to obtain liquid levels, thrust forces, void fraction, thermal stresses, or pressure drops as it was in the 227-T Building. It will be necessary to instrument it only for process control reasons (pressure and temperature of the water).

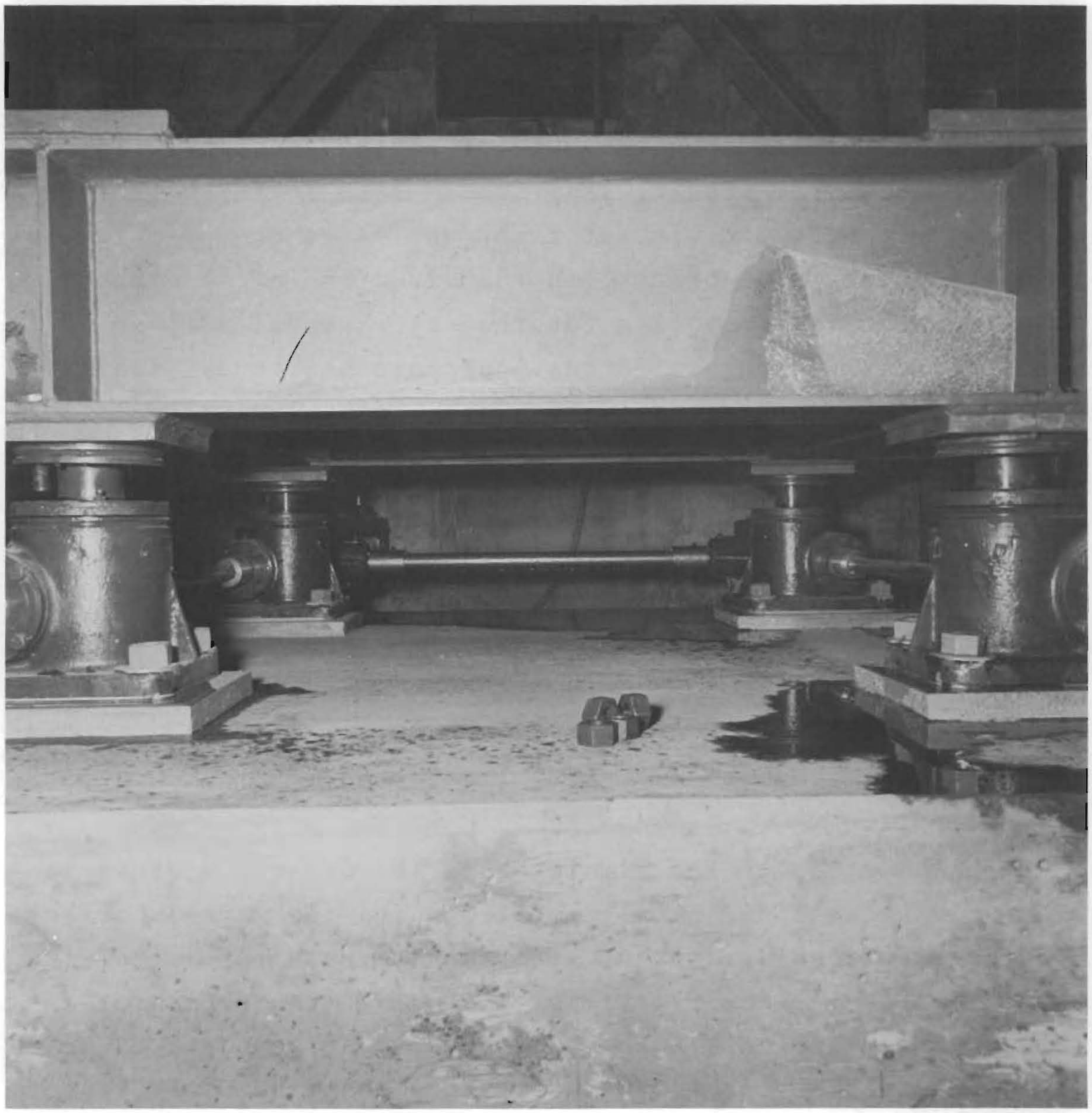

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FIGURE 35. Jacking Mechanism for Reactor Simulator Vessel

In the drywell, the simulator will stand on its legs on a structural steel framework installed near the bottom head of the drywell. The lateral bracing, for the sole purpose of maintaining the vessel vertical, will be attached to lugs on the drywell wall. The lugs are so positioned to transmit the thrust faces out through the radial braces reinforcing the wetwells floor and ceiling. The simulator can be placed so that blowdowns can be directed out through nozzles 18, 19 or 20 (see Figure 9) of the drywell in order to simulate dry containment. For pressure suppression, these nozzles can be blinded and 4-in. thick carbon steel plates attached to the drywell wall in line with the blowdown trajectory. These jet deflector plates are required to prevent hotspots in the drywell wall which could create undesirably high local stresses.

AUXILIARIES FOR REACTOR SIMULATOR VESSEL

The major auxiliaries provided along with the reactor simulator for either the hydraulic or the pressure-temperature transient studies in containment are the systems to heat and pressurize the water, and a mechanism to trigger the release of the heated and pressurized water. In addition, as many as three or four dummy reactor cores may be required to fully study all blowdown parameters.

External Heating Loop

Temperature and pressure for the simulator water (600 °F and 2500 psig) are achieved by recirculating the water through an external heat exchanger loop and by pressurizing with a nitrogen blanket. While the water is being heated, overpressurizing with nitrogen is always necessary because the temperature of the water leaving the heat exchanger must always be higher than that required for an experiment in order to provide the desired vessel water temperature. While this method is satisfactory for a PWR condition, it is not acceptable for a

BWR study. For a BWR study, the simulator is isolated from the loop after the desired water temperature is reached. Then the nitrogen in the vessel dome is vented until the pressure in the dome indicates saturation has been reached. The main components of the loop include an electric-to-Dowtherm* heat exchanger, a Dowtherm-to-water heat exchanger, a pressurizer, a canned motor pump, injection pumps, the loop piping, control valves, and a shutdown heat exchanger. All these are shown in the flowsheet (Figure 36) along with a schematic portrayal of the associated process control instrumentation. Pictures of the essential pieces of the loop are shown in Figures 37 through 39.

Pressurization

The nitrogen blanket for the heated water is supplied at 3000 psig by a cryogenic system located outside of the 221-T Building along the east wall (Figure 40). The nitrogen, after reduction to suitable pressures by appropriate regulating stations, is used also for back-pressurizing the double rupture disc mechanism and for gas blanketing the stored demineralized-deoxygenated water.

Rupture Mechanism

The double rupture disc mechanism (Figure 41) is the primary device used for triggering a blowdown event. Premature rupture of the discs is prevented by controlling the pressure between the two discs with nitrogen so that the differential pressures across each disc are less than their rating. The triggering of the blowdown event is accomplished by either venting the space or by overpressurization. Either method works satisfactorily. However, early studies indicate that the overpressurization technique yields a sharper break of the inner disc and a more rapid rupture.

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* *Tradename of a product manufactured by the Dow Chemical Co.*

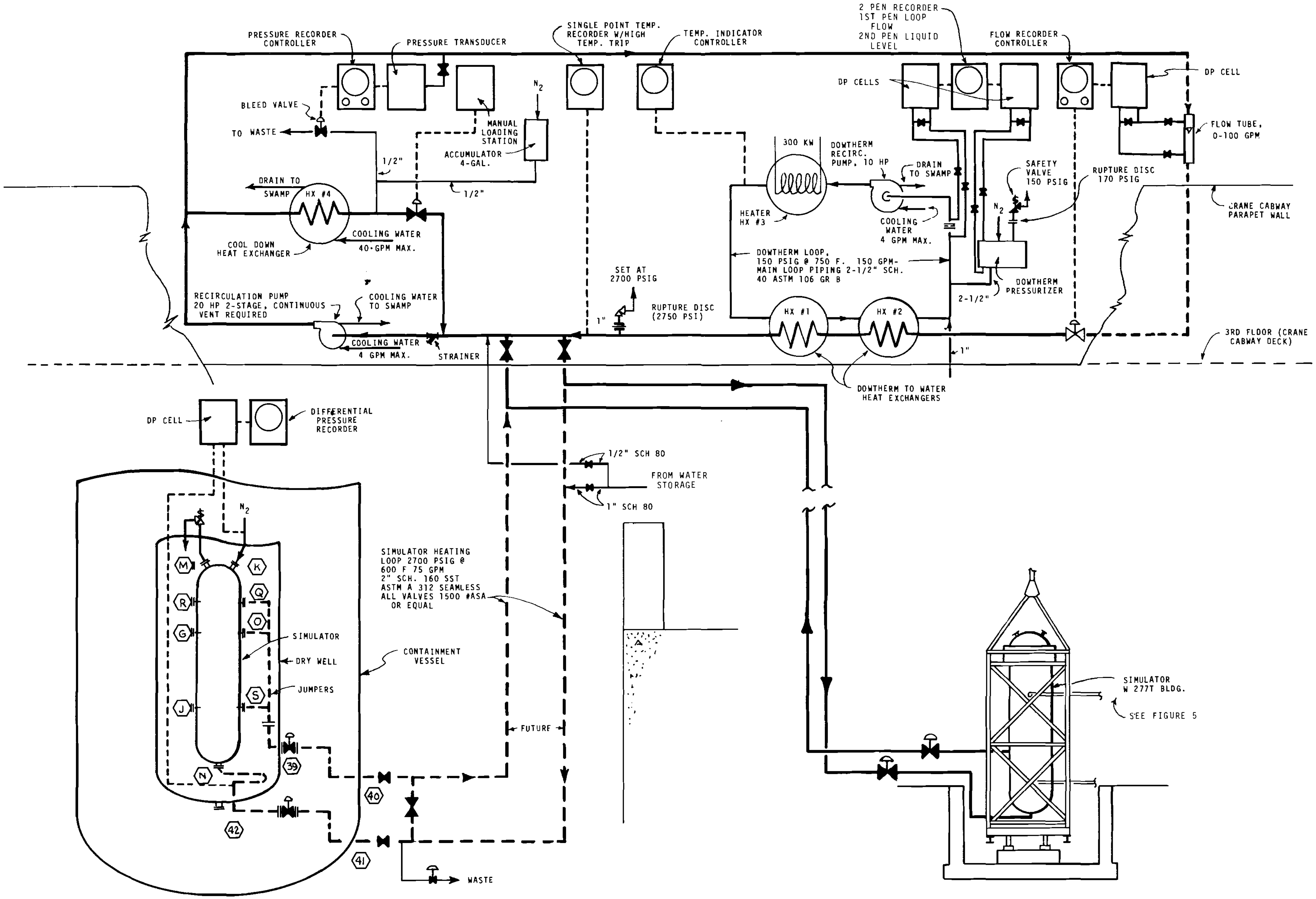

FIGURE 36. Reactor Simulator Vessel Heating Loop

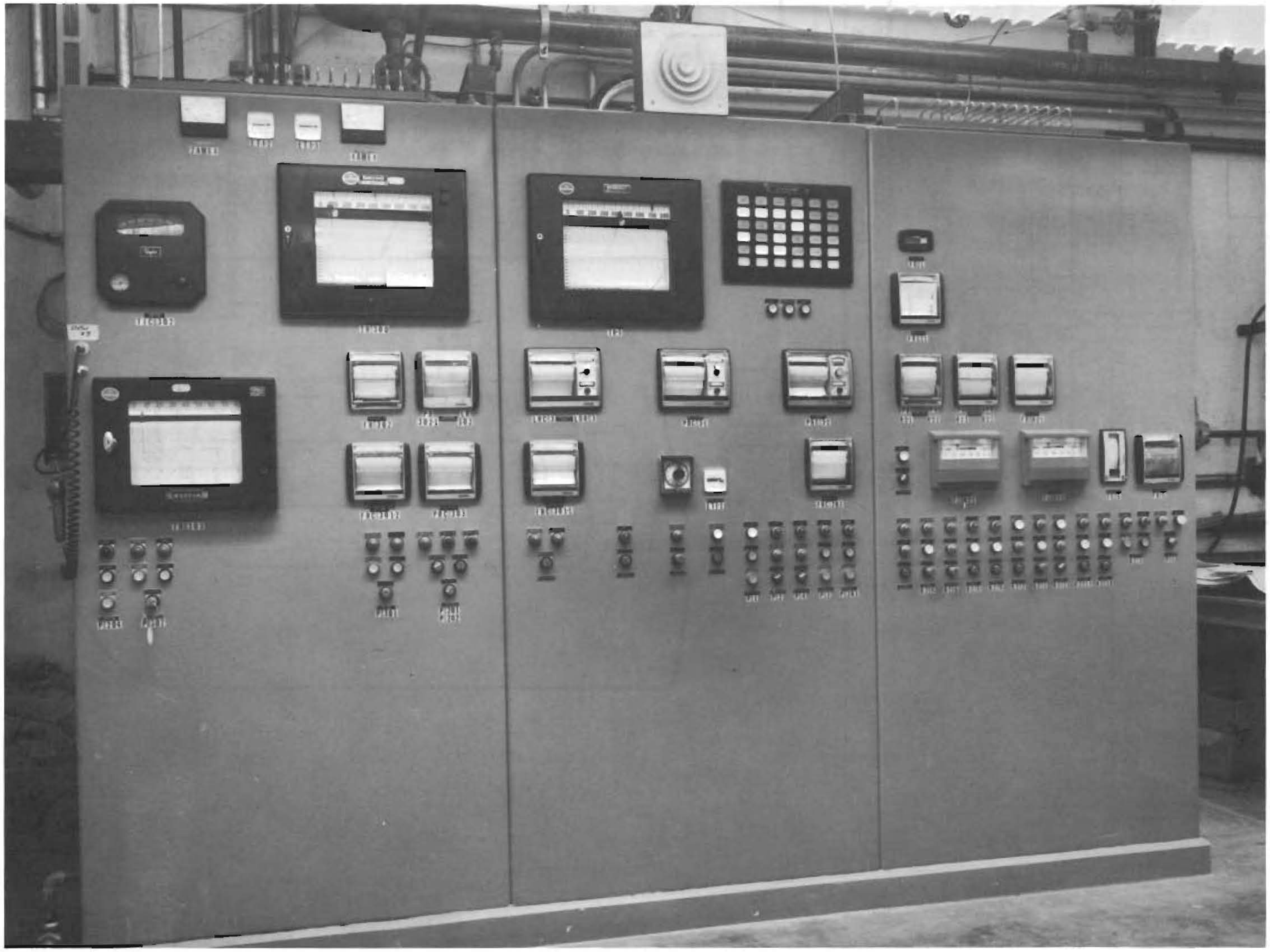

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FIGURE 37. Control Panel, Heating and Ventilation Loops

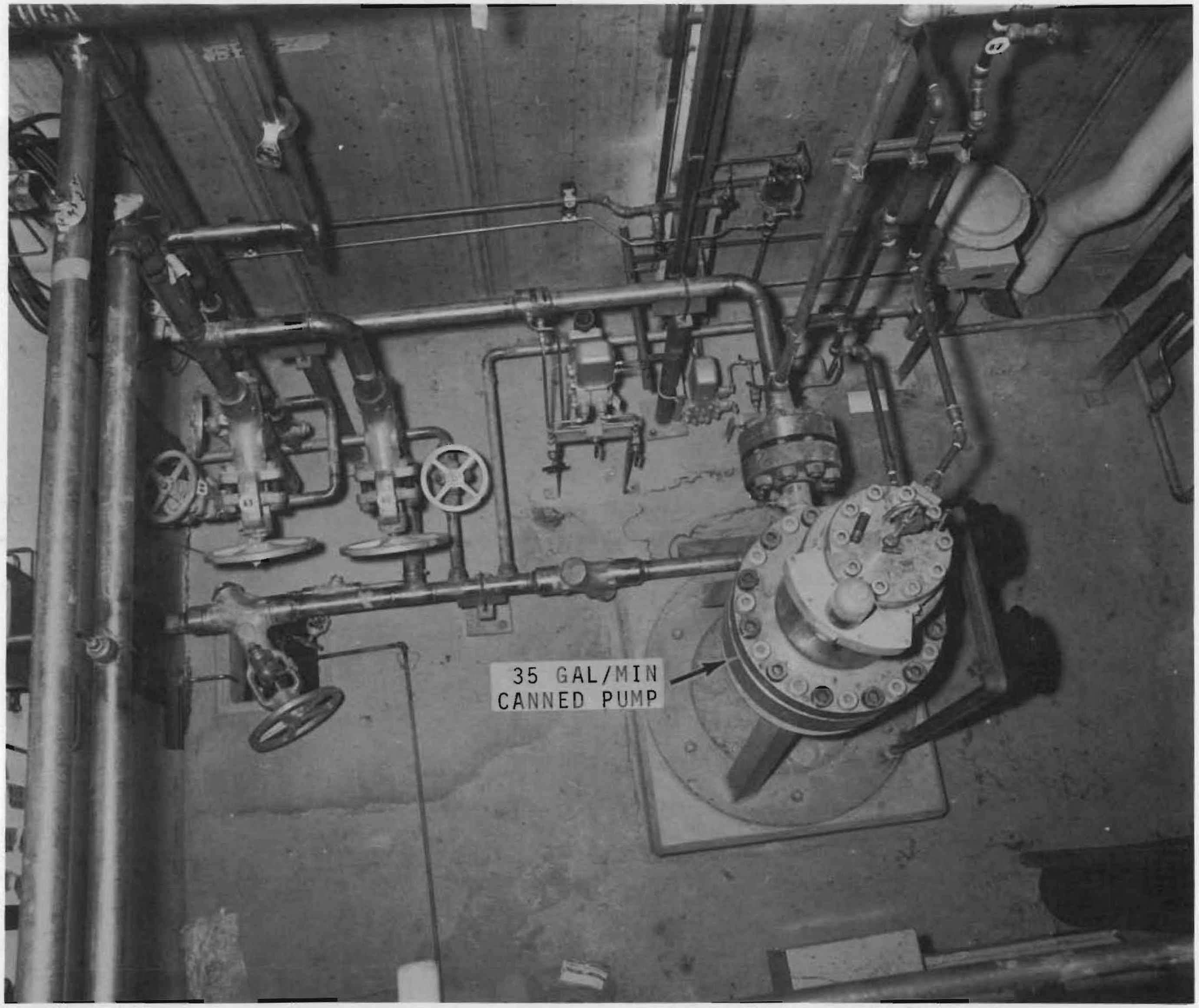

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FIGURE 38. Heating Loop Pump and Associated Piping

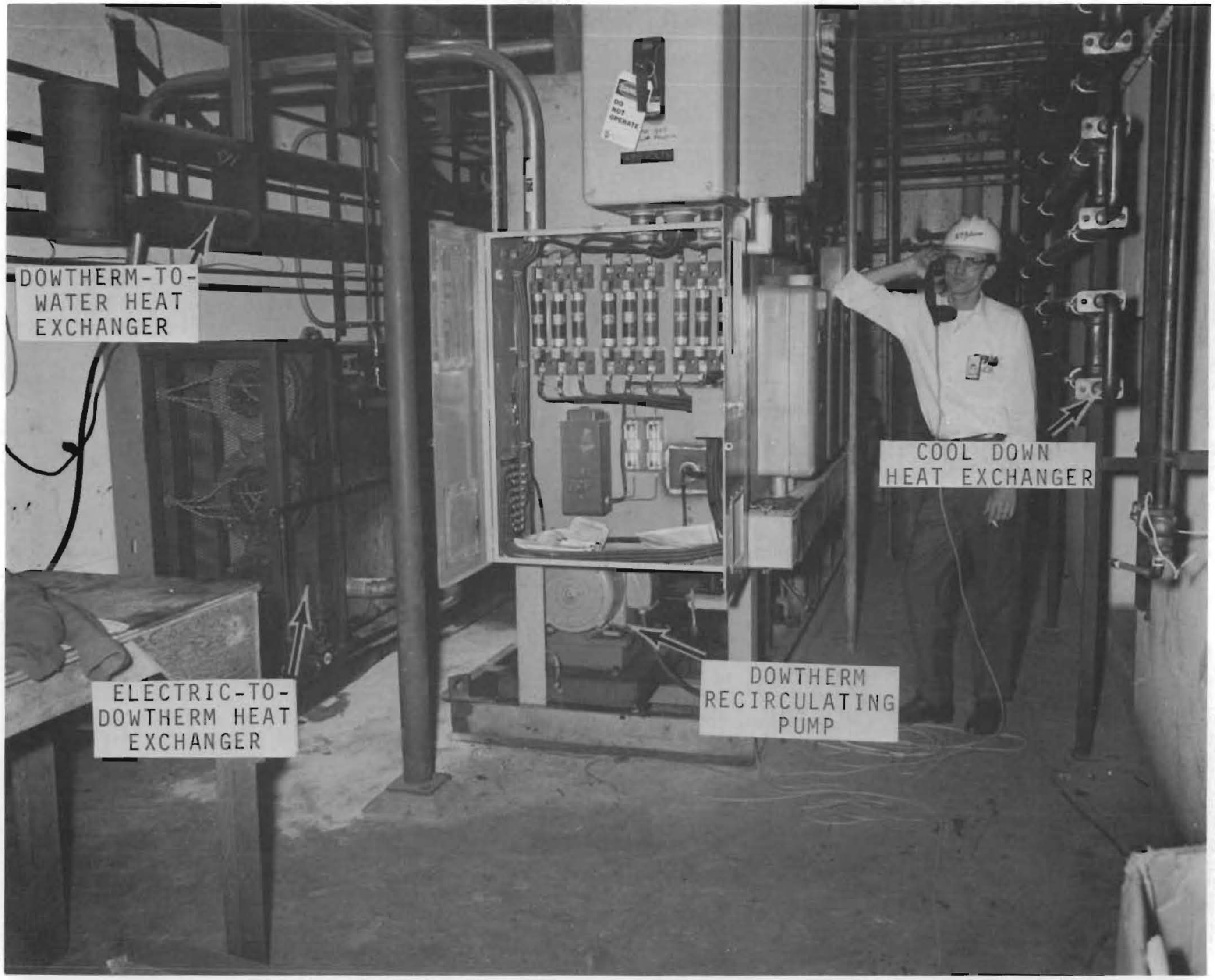

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FIGURE 39. Loop Heat Exchangers

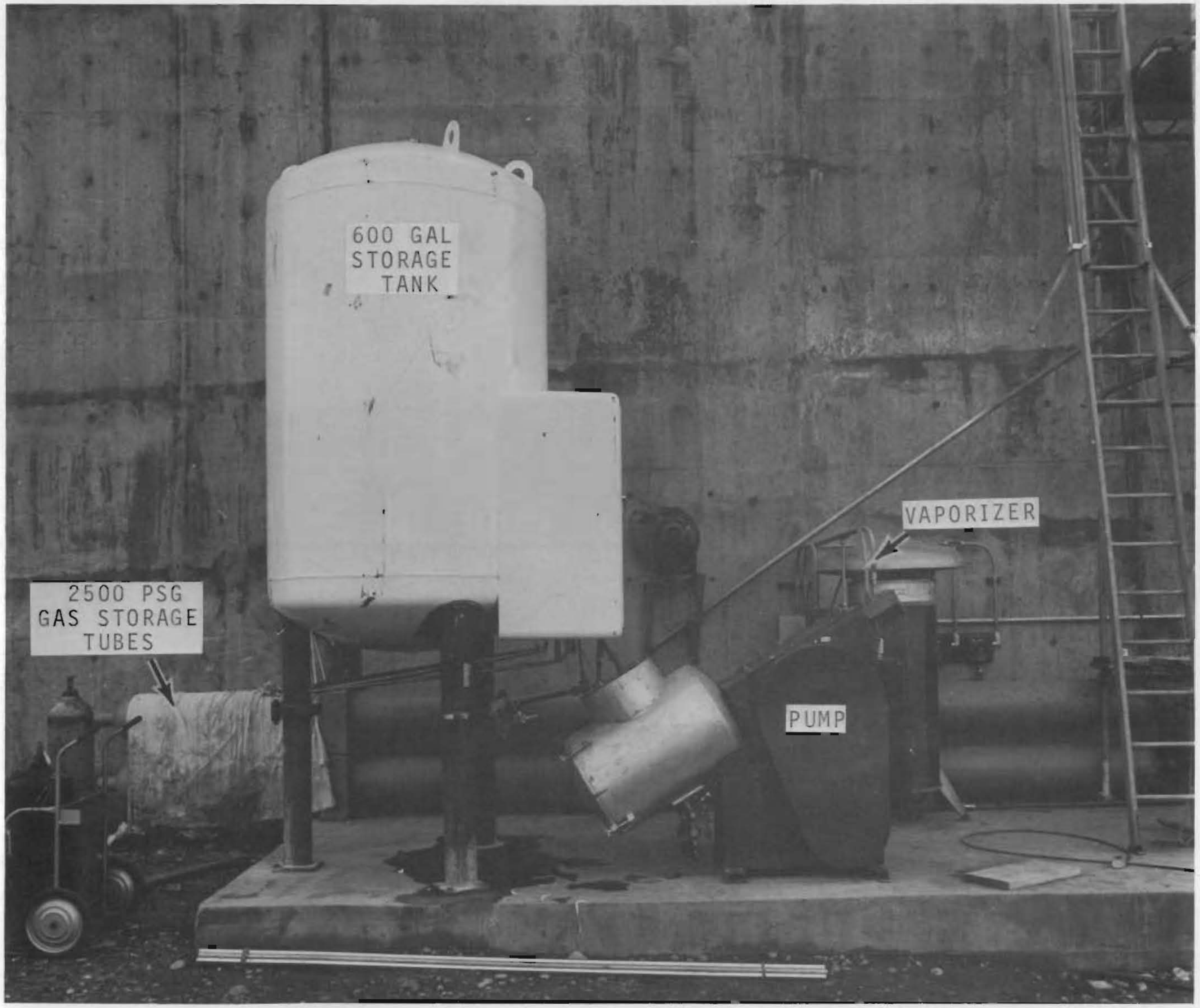

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FIGURE 40. Liquid Nitrogen Storage and Vaporization Station

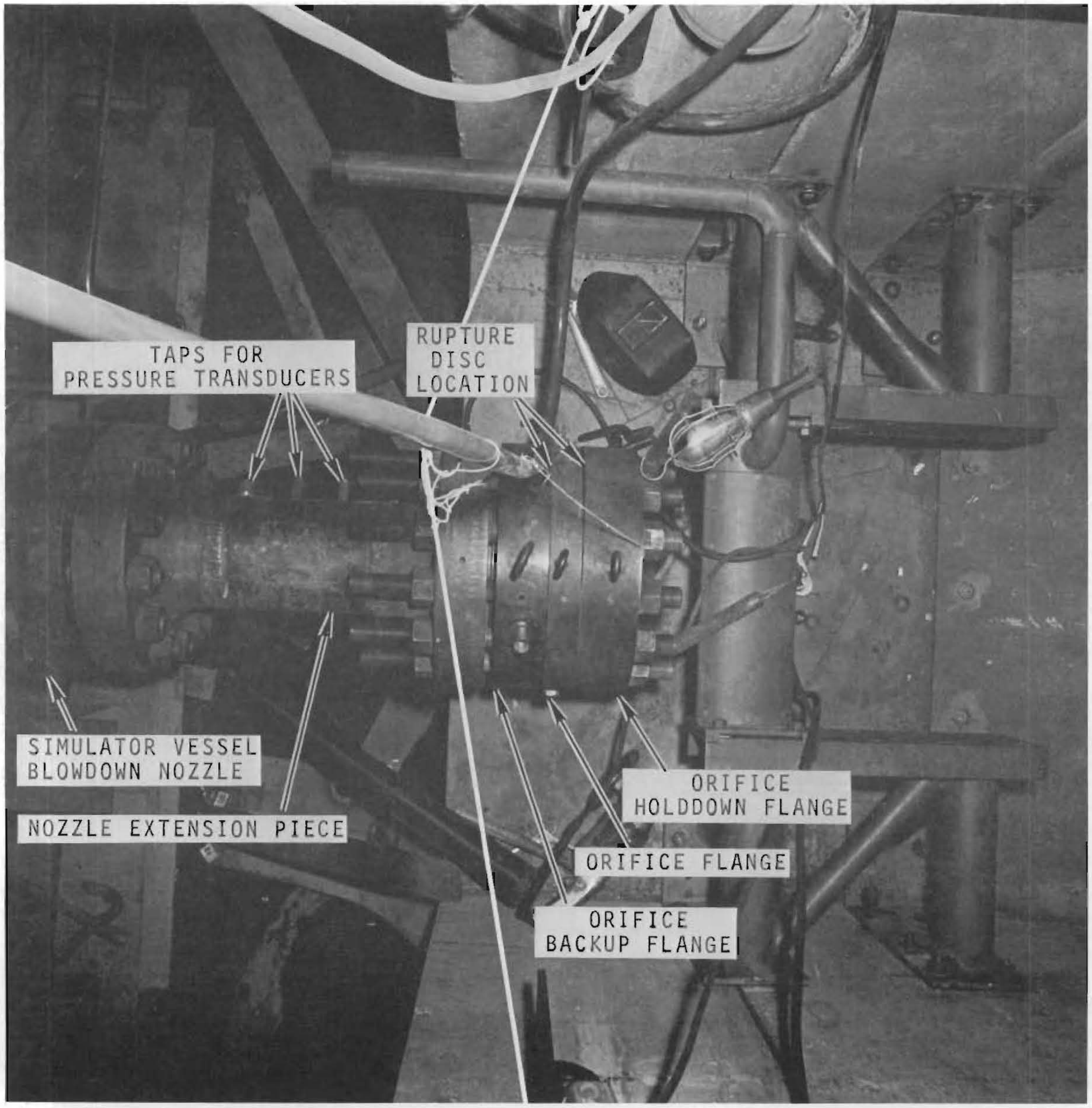

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FIGURE 41. Double Rupture Disc Mechanism

Dummy Cores

The dummy cores to be designed and installed in the simulator are for the purpose of obtaining a knowledge of short-term and long-term forces on the core, dwell time of coolant in a core during blowdown, postblowdown steam flow through a core and, if possible, two-phase flow rates through a core.

The program was directed initially to the study of blowdown without a core, then to blowdown with an orifice plate as the first dummy core, and will continue with other cores. The number and complexity of these cores will depend on previous experimental findings. In addition to the orifice plate, as shown in the drawing (Figure 42), a sector of a core, a full core complete with dummy fuel rods and control rods, and a core capable of simulating decay heat are considered to be potential candidates of importance.

EXPERIMENTAL INSTRUMENTATION

Conduct of the containment vessel leak studies and the aerosol transport studies requires high-precision but relatively slow-response instrument transducers. These consist primarily of temperature, pressure, humidity, and air current monitors. All of these, with the exception of the air current monitor, are standard commercially obtainable items. The blowdown studies either outside or inside the containment vessel, on the other hand, require extremely fast-response sensors since the data collected are of a fast-transient nature. In fact, most of the data of interest will occur within the first second or few seconds of a blowdown and will involve the use of transducers to measure strain, force, liquid levels, and liquid densities, as well as temperature and pressure. Although a good many of the required sensors for the blowdown studies are commercially available, others had to be or will have to be developed for obtaining specific desired measurements.

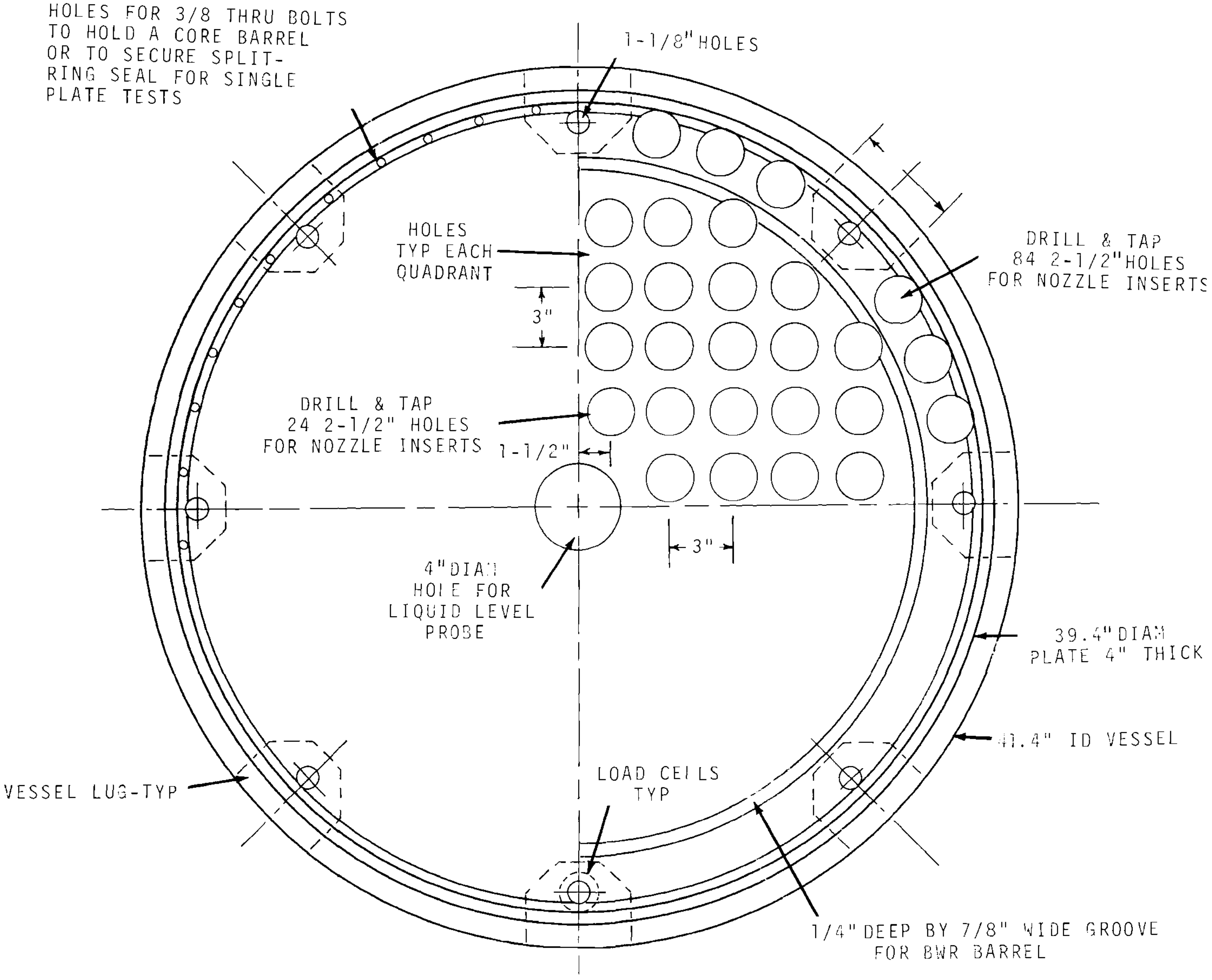

FIGURE 42. Orifice Plate, Dummy Core - Schematic

Details of the instrument systems will be reported in topical reports on specific experimental phases. However, there are several instrument features which, because of their uniqueness or because of their importance to the CSE, are discussed in the following paragraphs.

DIGITAL DATA ACQUISITION SYSTEM

The predicted large amount of physical and radiochemical experimental data resulting from each experiment dictated the need for electronic data processing. A digital computer was selected to collect and store the data on magnetic tape.

A PDP-7 computer, manufactured by the Digital Equipment Corporation, was purchased for the data logging purpose. The machine is basically the standard system supplied by the Corporation. It has a high-speed optical paper-tape reader and is also capable of punching the paper-tape. The central processing unit has the "normal" arithmetic option and is supplied with an 8192-word core of 18 bits per word. Two teletypes, Model 33 KSR, were supplied with the machine. A switch was installed to allow one teletype unit to operate near the computer, and a second teletype unit to be located approximately 70 ft from the computer in the radiochemical analysis counting room. Four magnetic tape units, the DECTAPE transports, were also included.

The machine is also equipped with a relay buffer consisting of an 8-bit relay register and filters to reduce noise from contact bounce. Under program control, the flip-flop register can be set to correspond to the contents of the accumulator and can be cleared. Each bit of the flip-flop register in the binary 1 condition energizes an associated relay in the relay register.

The computer is interfaced to both a low-speed and a high-speed multiplexer. These electronic switches are required in the blowdown experiments for the data acquisition. The low-speed multiplexer consists of relay and solid state switches, and an analogue-to-digital converter. The overall gross scanning rate for this multiplexer system, approximately 2000 points/sec, is sufficient for monitoring most of the signals during a typical CSE blowdown experiment.

The high-speed multiplexer is necessary to monitor very fast transients such as acoustical waves occurring in the primary vessel during a blowdown. This multiplexer has an overall gross scanning rate of 240,000 points/sec. The main components of this system are three analogue-to-digital converters, three DEC Type 139 E multiplexers with 24 Dec Type A103 solid state switches, and 24 amplifiers, one for each of the 24 monitored points. The operation of this multiplexer is triggered when a ground connection to a rupture disc on the blowdown nozzle is broken. The break is caused by disc rupture and signals the start of a blowdown.

One additional data acquisition function of the computer is the collection and storage of radiochemical analysis data from the aerosol transport studies. For this purpose, the computer was interfaced to four 256-channel analyzers through four analogue-to-digital converters. The computer is controlled for this operation from the counting room by the teletype located there. The multichannel analyzer analogue-to-digital converters are also located in the counting room. Each one of the four multichannel analyzer inputs is connected to a scintillation crystal and phototube set in separate lead brick caves. Each cave has four shelves corresponding to four different geometries used for the counting of a sample.

Block diagrams of the data acquisition hardware are shown in Figures 43 and 44 and pictures of the equipment are shown in Figures 45 and 46.

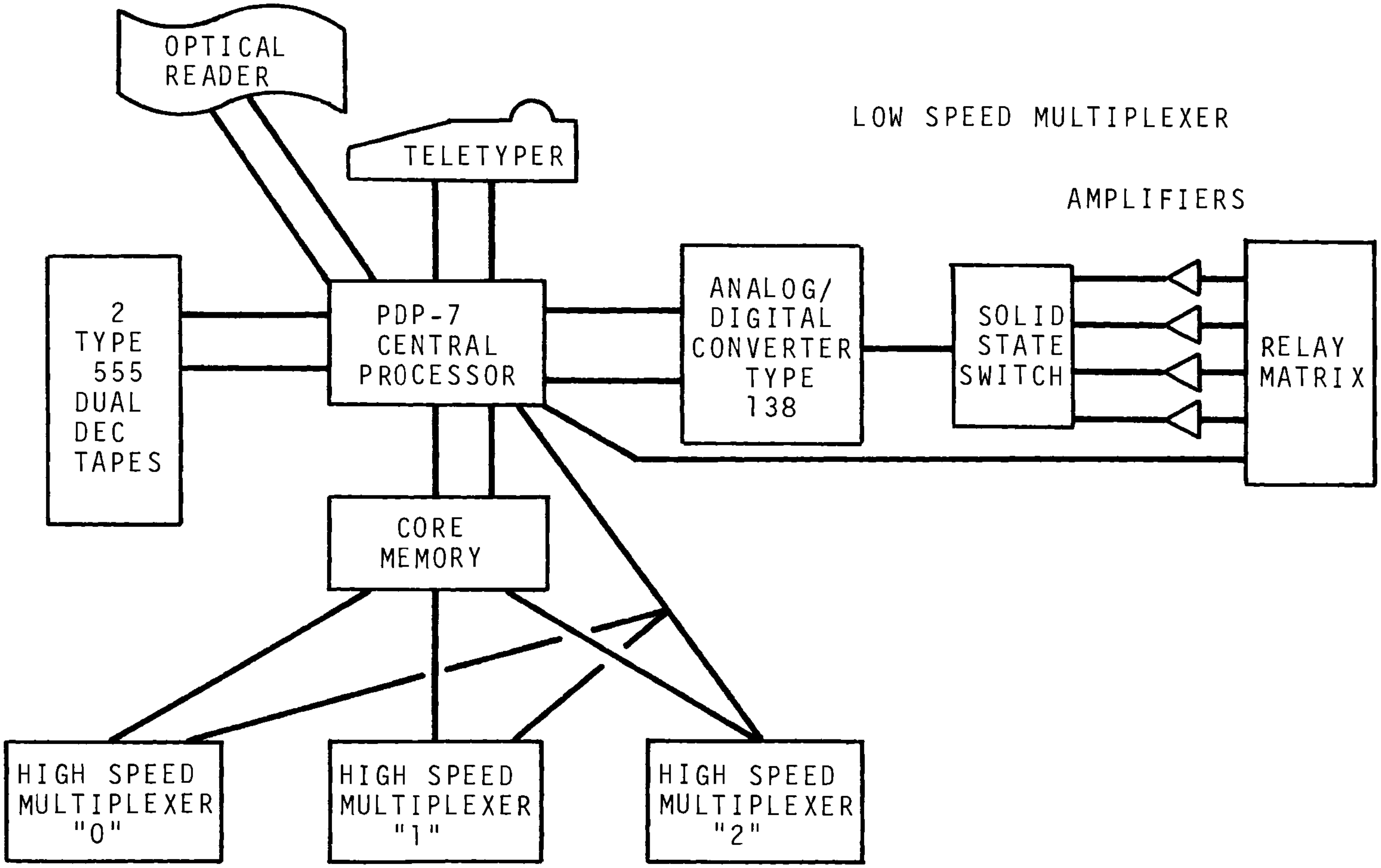

FIGURE 43. Block Diagram of PDP-7 Hardware Transient Data Acquisition

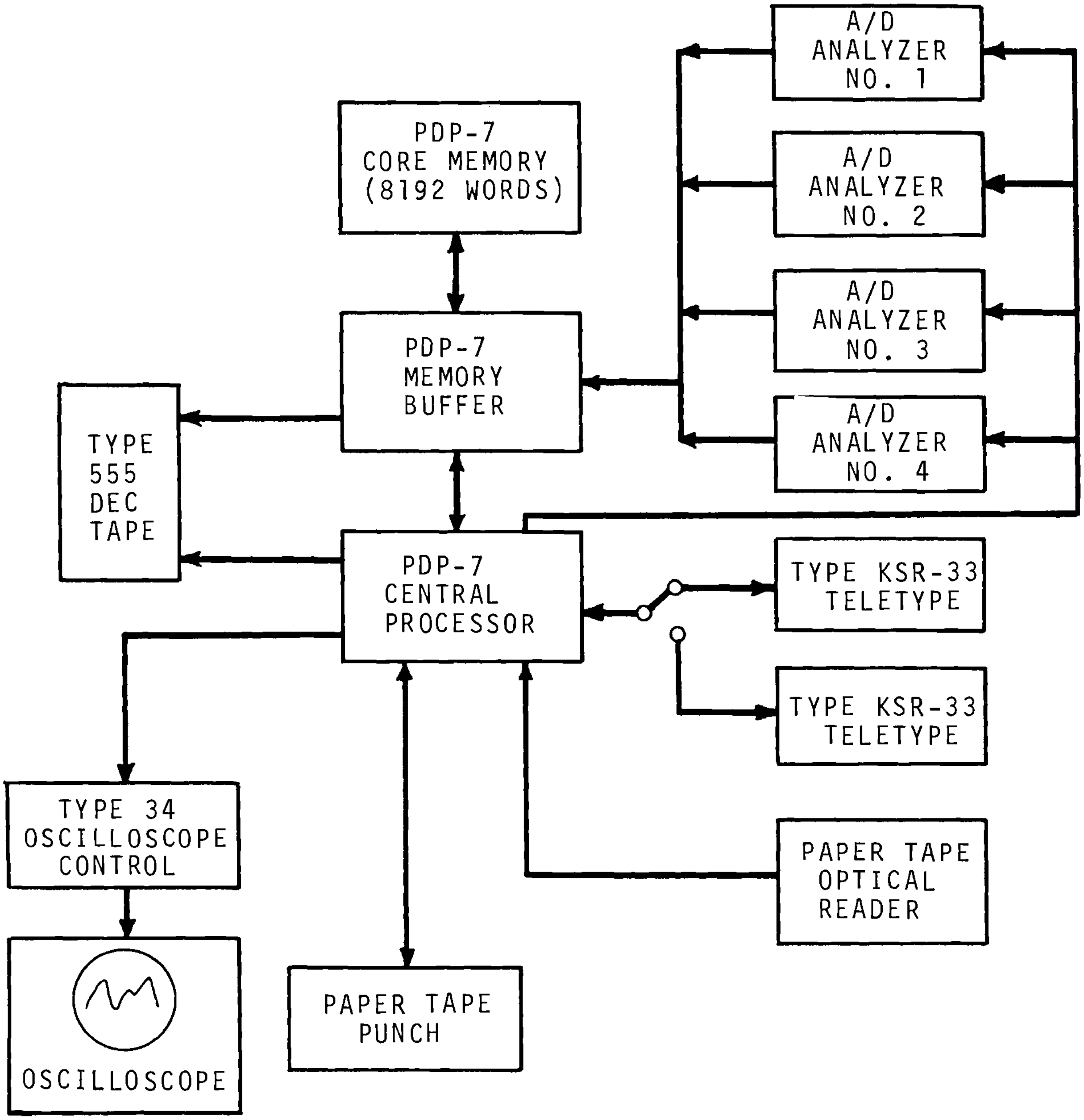

FIGURE 44. Block Diagram of PDP-7 Hardware Radiochemical Analysis Data Acquisition

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FIGURE 45. Digital Data Acquisition Console

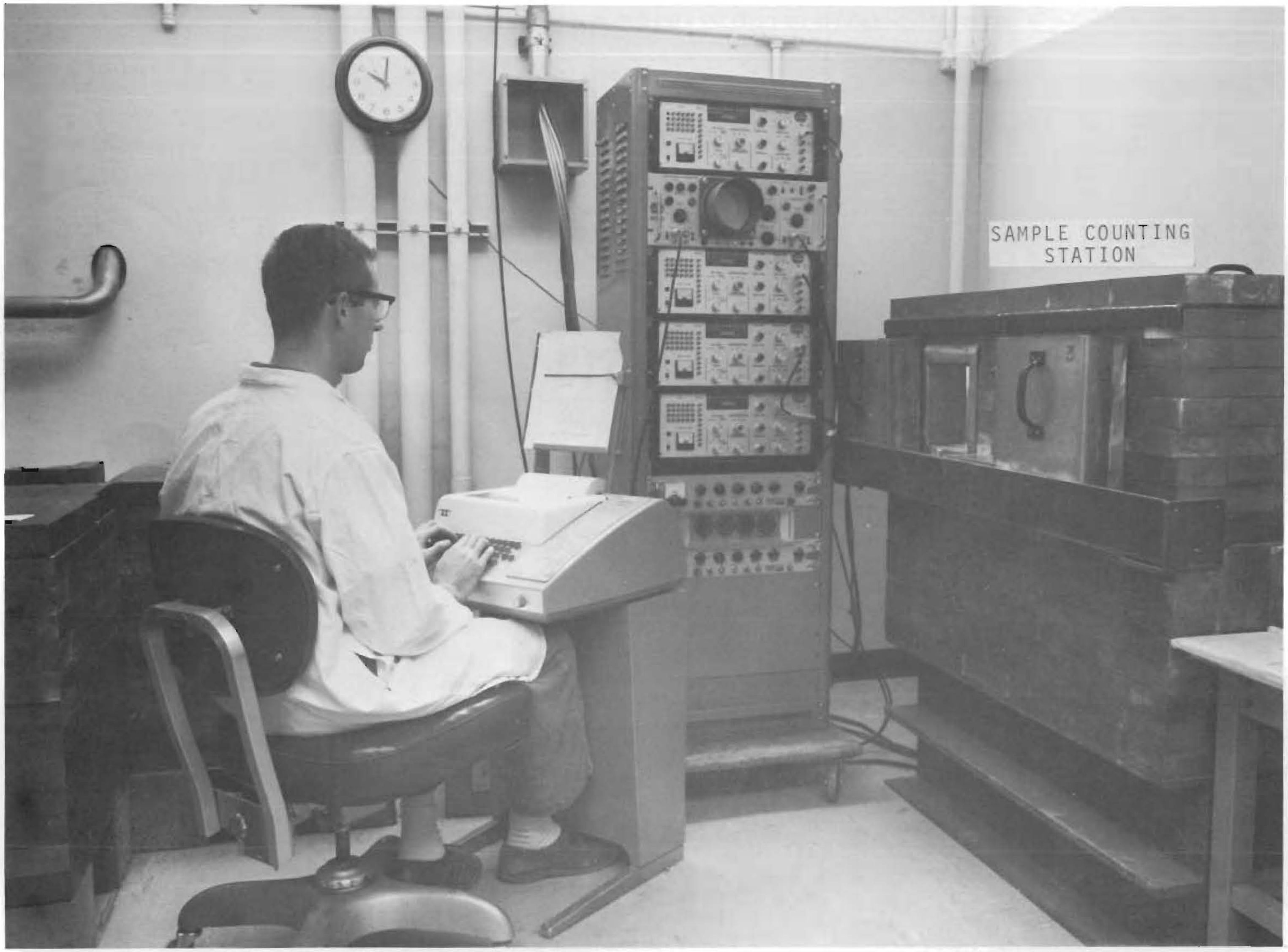

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FIGURE 46. Sample Counting Equipment

While immediate retrieval of the collected data is possible, the data is in a raw form and would require excessive man-hours to reduce and correlate. Therefore, programs have been so written that tapes of the raw data can be taken to the Computer Science Corporation for processing and for printouts in desired formats. Some typical formats include pressure temperature, liquid level, and thrust loads versus time graphs for the blowdown studies. For fission product transport, iodine and cesium concentrations versus time are typical graphs.

TIME DOMAIN REFLECTOMETER (TDR) LIQUID LEVEL PROBE

A liquid level probe based on the principle of time domain reflectometry (TDR) is being successfully used in the CSE simulator vessel at temperatures as high as 600 °F. A simple stainless steel probe with three surrounding angle pieces mounted in the vessel water is used as an extension of a coaxial cable. A traveling discontinuity in the cable occurs where a short circuit is caused by the water between the coaxial probe legs. A practical calibration resolution of 2 in. in 230 in. of liquid level has been achieved within the CSE configuration.

The three components comprising the system are the stainless steel probe shown in Figures 47 and 48, a 150 kHz pulser, and a commercial sampling oscilloscope. The observer sees on the oscilloscope a trace of a square pulse which is "chopped" on the time scale with rising liquid level. Insulation washers on the probe body cause less severe bumps on the trace, and the bumps serve as reference or calibration points on the trace itself.

In addition to this visual display, a converter has been attached to the oscilloscope vertical output and internal scan circuits to give an analog voltage output for a recorder or computer recording. The response time of this converter to an instantaneous complete vessel full-to-empty condition is less

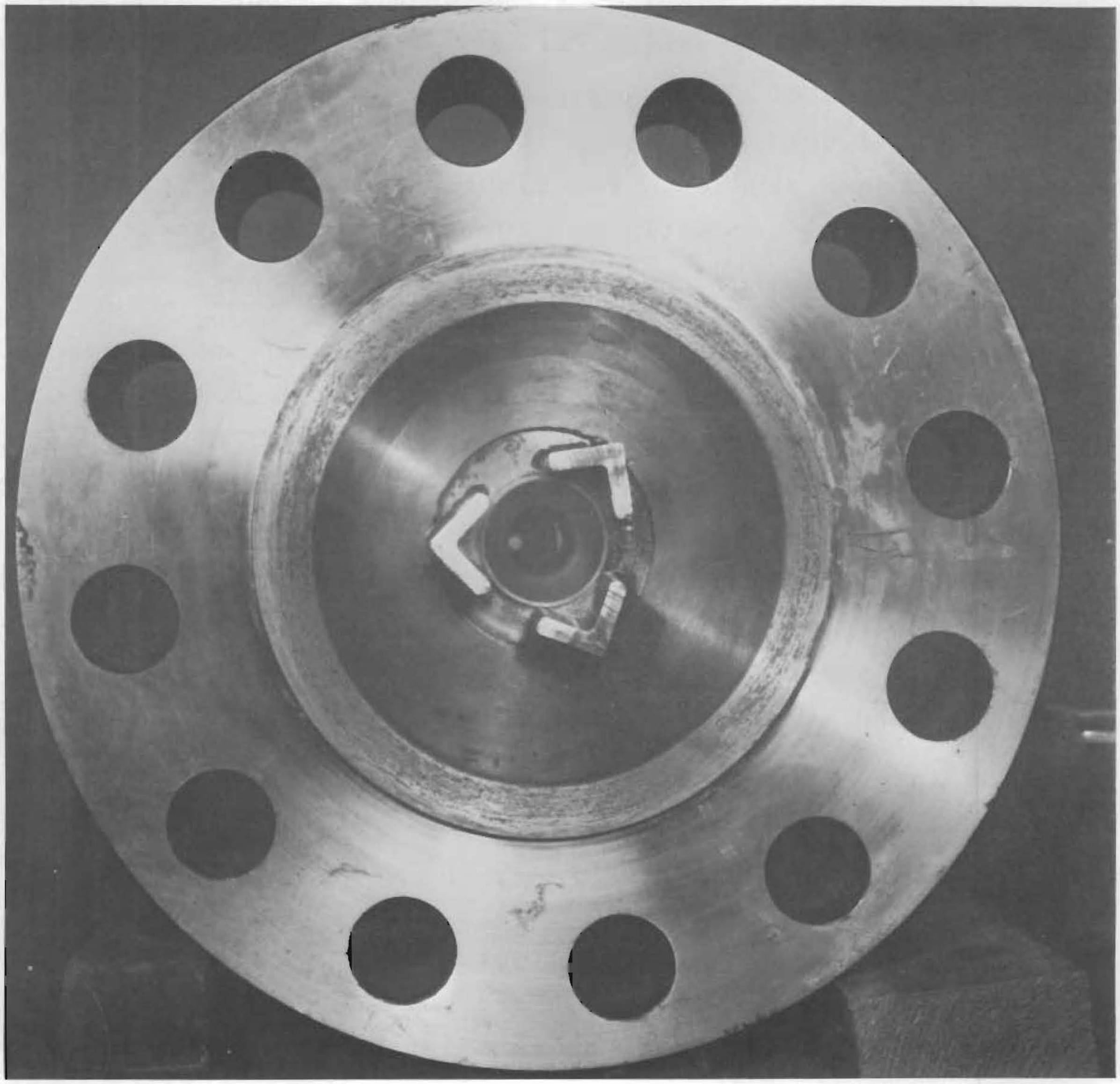

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FIGURE 47. End View of TDR Probe

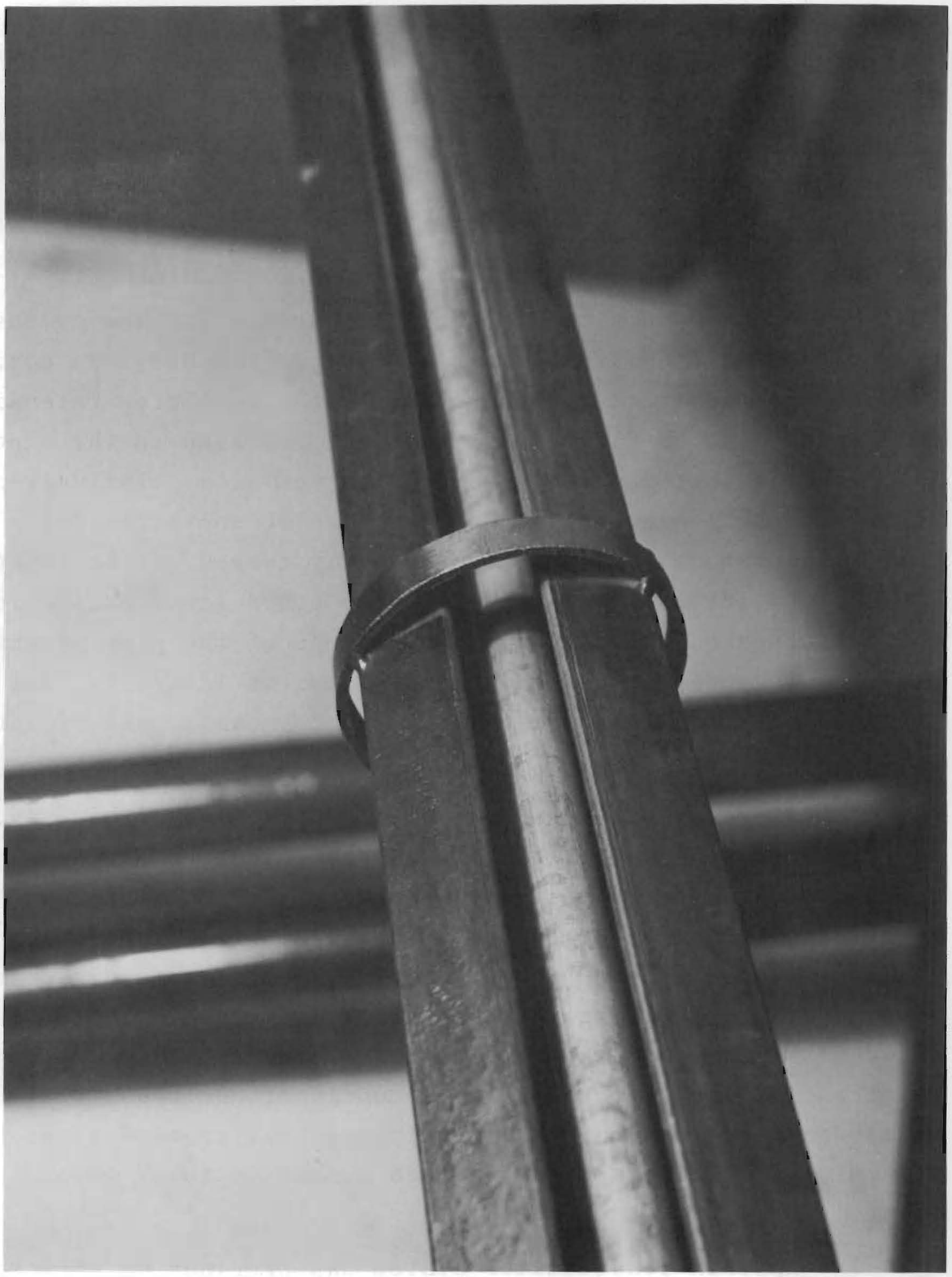

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FIGURE 48. Side View of TDR Probe

than 100 msec. The device gives a good map of falling liquid level during cold blowdowns and the saturated portions of other blowdowns under conditions as severe as 600 °F, 2485 psig. The TDR signal correlates well with stop-watch and tape recorded records of the end of two-phase flow at the blowdown nozzle.

NEUTRON DENSITOMETER FOR VOID FRACTION DETERMINATION

The neutron densitometer utilizes moderation and/or absorption effects of the steam-water mixture in the blowdown nozzle pipe on fast neutrons. Measurement of the resulting intensity of thermal neutron flux determines void fraction in the pipe. A commercial fast neutron generator serves as a relatively compact, convenient neutron source that can be energized for a brief measurement, and then conveniently turned off to remove any direct radiological hazard. Three boron lined proportional counters located around the circumference of the pipe provide separate measurements of the thermal neutron intensity, and a fourth boron counter provides a reference measurement of source intensity.

Installation of the relatively complex, laboratory style neutron generator involved design of efficient, rugged and protective mounting fixtures. Neutron generator maintenance required substantial upgrading of the dielectric insulation in the 200 kV high voltage power supplies. Count rate circuits incorporating special gain changing amplifiers provide four analogue signals for interfacing with the computer. A void fraction standard incorporating a bundle of 80 tubes (0.640-in. diam) was used to obtain the static calibration conditions by selectively filling a predetermined number of tubes with water.

The neutron densitometer system has provided an effective technique for determining void fraction of the two-phase mixture under rapidly flowing conditions in the thick walled blowdown nozzle pipe.

ADDITIONAL EXPERIMENTAL EQUIPMENT

As the experimental studies proceed, additional experimental equipment has or will be added to assist in the achievement of certain program objectives. Those already used, or now in service, include equipment to heat the contained air for heated leak tests and an air cleaning system inside the containment vessel for radioisotope removal studies. In the future, an aerosol decontamination train outside the containment vessel for one pass studies may be used. The use of ducted pressure relief equipment for pressure reduction studies is also a possibility. If programmatic considerations warrant, the effect of alternate downcomer designs on water pool pressure suppression or ice-filled compartment pressure suppression can be studied.

EQUIPMENT FOR HEATED LEAK TESTS

The heated leak test studies were for the purpose of comparing the leak rate of a containment vessel at ambient temperatures with the leak rate of a vessel at the temperature resulting from an MCA. The equipment designed and constructed for this purpose is shown in Figure 49. The containment was pressurized to a predetermined level with air, and the recirculating heating system then was used to raise the temperature and hence the pressure to the desired experimental level. A draft tube and deflector were provided immediately above the stack to prevent localized hot spots and resulting distortions in the containment vessel dome and the large overhead beam. The air was circulated continuously, and the steam to the heating coils was thermostatically controlled. The vessel was insulated for this test series, and for all subsequent tests.

AIR CLEANING SYSTEM

An artist's conception of the air-cleaning system inside the containment vessel is shown in Figures 50 through 52 and

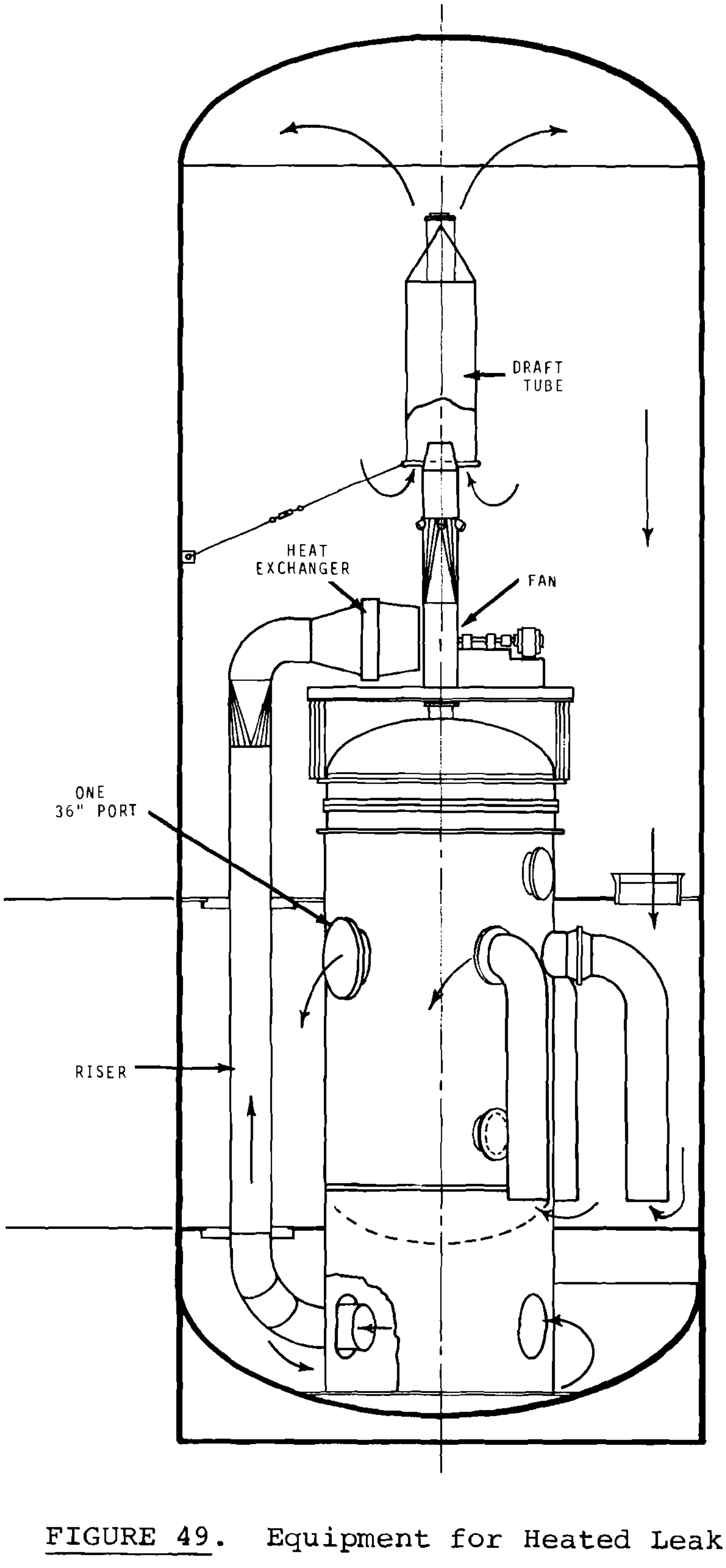

FIGURE 49. Equipment for Heated Leak Tests

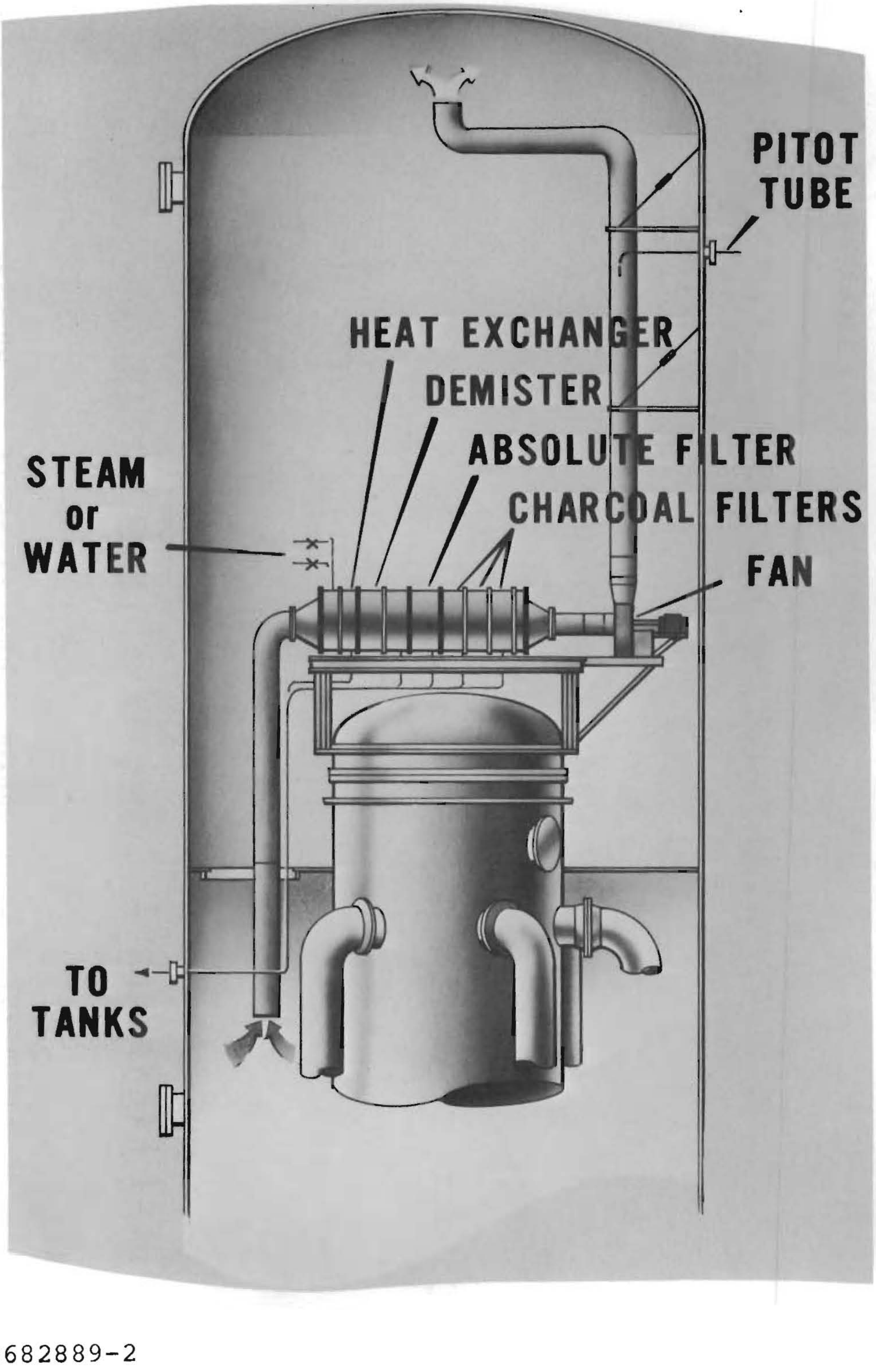

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FIGURE 50. Air Cleaning System Containment Systems Experiment

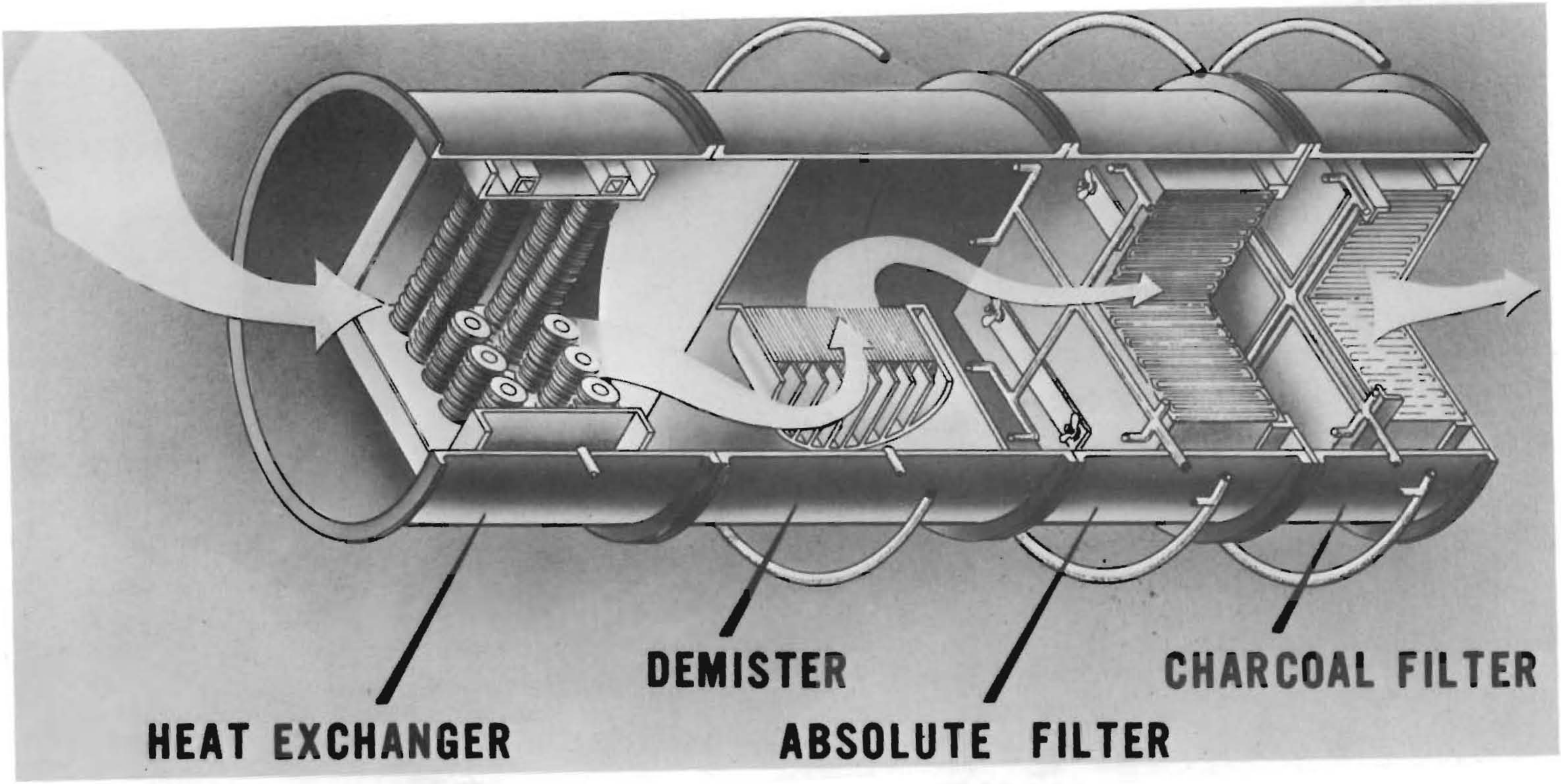

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FIGURE 51. Air Cleaning System Critical Components

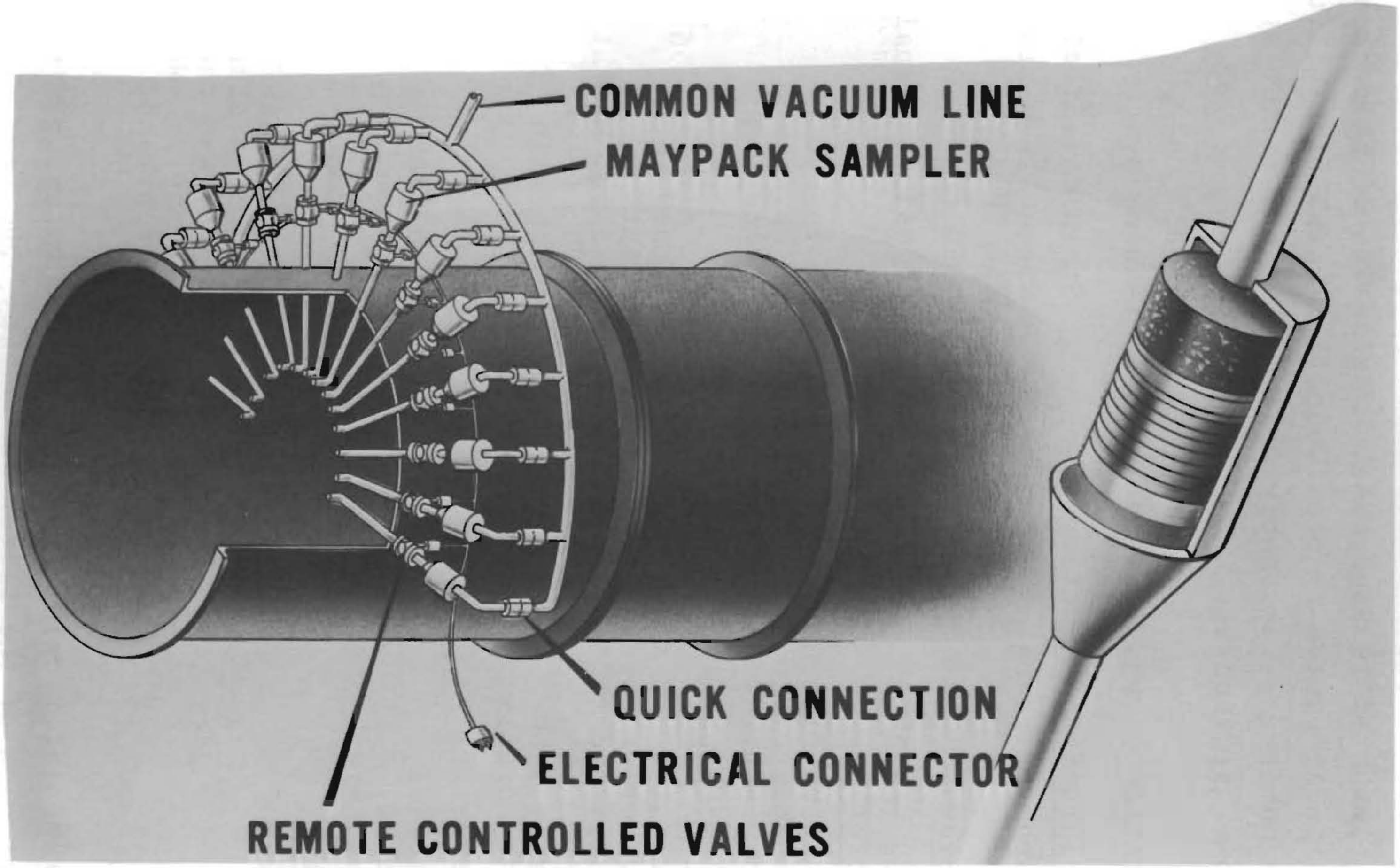

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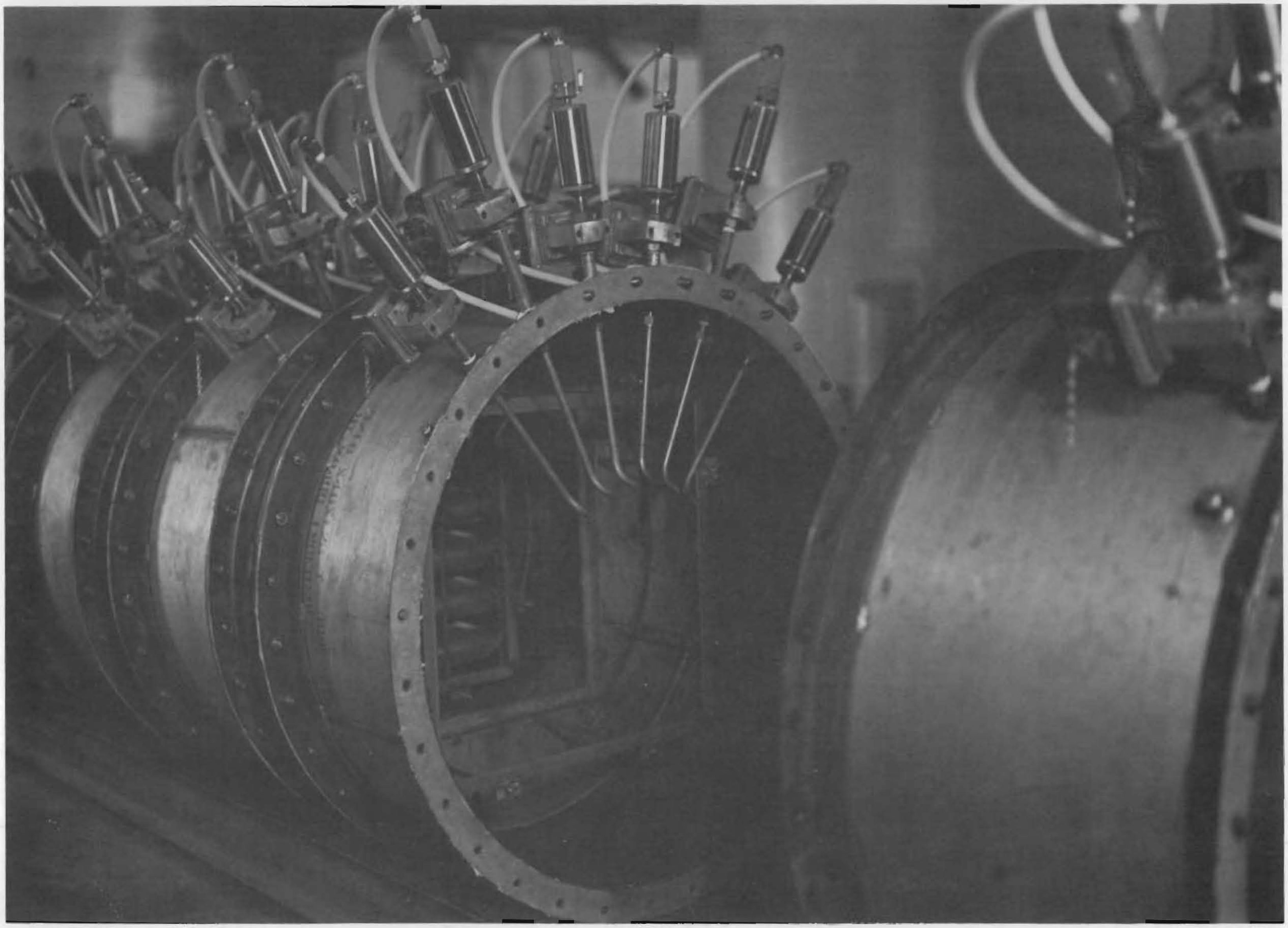
FIGURE 52. Air Cleaning System Remote Aerosol Sampling Arrangement

some physical details are given in Table 7. A picture of the assembled filter modules before installation in the containment vessel is presented in Figure 53. The design of this experimental system attempted to provide experimental flexibility at a scale comparing reasonably well with those filter systems used in power stations.

TABLE 7. Physical Data - Air Cleaning System

Material of Construction	Stainless Steel
Atmosphere	Steam-Air Mixture 250 °F
Air Flow	1050 cfm
Design Pressure	10 psi (internal)
Diameters	
Suction Pipe	14 in.
Discharge Pipe	14 in.
Component Modules	36 in.
Heat Exchanger	
Type	Finned Tube
Number of Rows Deep	Eight
Estimated ΔP	0.25 in. H_2O at 1000 cfm
Water Flow	15 gal/min
Face Area	4 ft^2
Demister	
Packing	Mesh Type
Depth	6 in.
Face Area	1.76 ft^2
Filters	
Type	Standard commercially available absolute filter and charcoal adsorbers. Maximum face area of 4 ft^2.

Experimental flexibility was provided by using a module concept for each of the filter components, the heat exchangers, the demister, the roughing filter, the absolute filter, and



Neg 0693139-4

FIGURE 53. Assembled Filter Module

three charcoal filters. Each module is flanged on both ends to permit any of the modules to be connected to any of the other modules. In this manner, any combination of components could be assembled in any order for an experiment. In addition, the mounting plates for the filters are designed to accommodate 24-in. × 24-in. filters or, with very slight modifications, to accommodate multiple filters not exceeding 24-in. × 24-in. in the total facial area. The nominal system flow of 1050 cfm will permit a turnover of the containment air once every 30 min with the wetwells open, or once every 26 min with the wetwells closed. This rate compares with turnovers ranging from as low as once every 10 to 15 min for some power plant systems, to once every 1 or 2 hr for others.

While the nominal gas flow is designed for 1050 cfm, the fan for the system is capable of about 2000 cfm. Air flow is sensed by a pitot tube in the stack and is indicated by a gage on an instrument panel outside of the containment vessel. The flow is kept constant by a damper in the fan's discharge duct. The damper is manually adjusted by means of a flexible shaft extending through a penetration in the containment vessel.

System flexibility is also achieved by designing these modules for an internal pressure of 10 psig which permits locating the filter system outside the containment vessel across any two major penetrations of the containment vessel. Should the option of a single pass test arrangement be desired, the discharge line can simply be repiped from the stack out through a large penetration of the containment vessel to provide a once-through system.

Two sample systems, one to collect and measure condensate and the other to sample the gas stream before and after each component, are provided. These systems are in addition to those discussed previously for aerosol transport studies.

Condensate samples will be taken from each module. The condensates will be routed outside the containment vessel through stainless steel tubing to individual tanks where the volumes will be recorded and aliquot taken for analysis. The arrangement for the aerosol sampling is shown in Figure 52. One of these assemblies will be installed after each of the components. Each assembly will have 6 samplers, each of which can be operated independently of the others. Thus, all samples can be taken simultaneously throughout the whole filter train and the efficiencies of the various components can be evaluated as a function of time and concentration.

The laboratory technician selects the sample he wishes to take and sets a selector switch for each sample assembly. At the specified time, he throws a master switch and one valve in each assembly will open simultaneously. The air will be drawn through the stainless steel tube, through the opened valve, and through the Maypack samples on to a vacuum header to the laboratory where condensers and cold traps will remove any of the aerosol penetrating the sampler. Except for certain modifications, this system is essentially the same as the Maypack cluster system.

DUCTED PRESSURE RELIEF

A ducted pressure relief system is simply a technique employed to vent the thermal energy from an MCA to the atmosphere prior to fission product release from the fuel. To achieve containment once the pressure is relieved, the vent duct is closed with large valves or with other devices such as an inflatable membrane. The venting process will sweep a large volume of noncondensables out through the duct with the steam and leave a mixture of steam and air in containment at close to atmospheric pressure. Without provision for vacuum breakers, the integrity of the structure would be endangered by a vacuum created in the containment building as the result of cooling.

The ducted pressure relief system visualized for CSE would consist of a 3 or 4-ft vent pipe attached to the equipment access port, with two motorized valves and an inflatable membrane installed between the valves. An appropriately sized vacuum breaker would be located between the port and the first valve. The pipe would extend to the large 221-T Building equipment access door to provide for discharge of the nonradioactive gases outside of the main building.

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APPENDIX A

PENETRATIONS - CONTAINMENT VESSELS: NOZZLES

APPENDIX A

PENETRATIONS - CONTAINMENT VESSELS: NOZZLES

TABLE A-1. Penetrations of Containment Vessels
Nozzles - Containment Systems Vessels

Designation Number	Location			Size, in.	Principal Function	Type of Connection(s)
	Vessel	Angle	Elevation			
1	Cont	70	27'	18	Cont Vent Air, In	12 in. Pipeline
2	Cont	285	7'8"	12	Vent Air, DW (Future)	
3	Cont	0	3'	96	Equipment Access	Bolted Door
4	Cont	315	2'6"	36	Personnel Access	Hinged Door
6	Cont	241	-8'3"	8		
7	Cont	270	-9'10"	12	Aerosol Injection	2 in. Injection Line 1 in. 200# Steam Line 2 in. Air Line 1 1/4 in. Elec Sleeve, 24 cond
9	WW	8	-6'4"	8	WW Vent Air (Future)	
10	Cont	285	-17'3"	12	DW Vent Air, Out	10 in. Pipeline from Nozzle 23
11	Cont	256	-19'3"	18	Cont Vent Air, Out	12 in. Pipeline
12	Cont	-	Bottom	4	Cont Drain	4 in. Pipeline
13	WW	5	-7'9"	10	Pressure Relief	10 in. Rupture Disc, flat gasket
16	WW-A	41	Ceiling	36	WW-A Access	36 in. Blind Flange, flat gasket
17	DW	-	Top	12	DW Vent Air, In	12 in. Butterfly Valve, flat gasket
18	DW	305	-4'	20	Direct Blowdown to Cont	20 in. Blind Flange, flat gasket
19	DW	105	-4'	20	Direct Blowdown to Cont or Aerosol Sampling	20 in. Blind Flange, flat gasket or 18 1/2 in. Tubing Sleeves
20	DW	305	-12'11"	36	Personnel Access	Hinged Door
21A	DW	35	-8'	24	Blowdown into WW-A	24 in. Open Pipe, flat gasket
21B	DW	95	-8'	24	Blowdown into WW-B	24 in. Open Pipe, flat gasket
21C	DW	155	-8'	24	Blowdown into WW-C	24 in. Open Pipe, flat gasket
21D	DW	215	-8'	24	Blowdown into WW-D	24 in. Open Pipe, flat gasket
22	DW	270	-4'	4	Aerosol Inj (Future)	4 in. Blind Flange, flat gasket
23	DW	285	-17'3"	12	DW Vent Air, Out	10 in. Pipeline to Nozzle 10 (Cont)
24A	DW	35	-17'	24	Blowdown into WW (Alt)	Blind Flange, flat gasket
24B	DW	95	-17'	24	Blowdown into WW (Alt)	Blind Flange, flat gasket
24C	DW	155	-17'	24	Blowdown into WW (Alt)	Blind Flange, flat gasket
24D	DW	215	-17'	24	Blowdown into WW (Alt)	Blind Flange, flat gasket

TABLE A-1. (contd)

Designation Number	Location			Size in.	Principal Function	Type of Connection(s)
	Vessel	Angle	Elevation			
30B	WW	70	-22'	2	Drain	2 in. Pipe to Drain Header
30C	WW	130	-22'	2	Drain	2 in. Pipe to Drain Header
30D	WW	190	-22'	2	Drain	2 in. Pipe to Drain Header
32A	WW	55	-13'	2	Water Addition	2 in. Pipe From Water Header
32B	WW	115	-13'	2	Water Addition	2 in. Pipe From Water Header
32C	WW	175	-13'	2	Water Addition	2 in. Pipe From Water Header
32D	WW	235	-13'	2	Water Addition	2 in. Pipe From Water Header
33	Cont	135	4'6"	10	Penetration Test	Blind Flange, flat gasket
34	Cont	145	4'6"	10	Penetration Test	Blind Flange, flat gasket
36	WW-B	88	Ceiling	36	WW-B Access	Blind Flange, flat gasket
37	WW-C	146	Ceiling	36	WW-C Access	Blind Flange, flat gasket
38	WW-D	206	Ceiling	36	WW-D Access	Blind Flange, flat gasket
39	Cont	280	27'	6	Spray Water	
40	Cont	266	-20'	6	High Pressure H_2O, Out	2 in. Pipe through 6 in. Sleeve, Welded, Double Valved
41	Cont	260	-26'	6	High Pressure H_2O, In	Sleeve, Welded, Double Valved
42	DW	264	-17'3"	6	High Pressure H_2O, Out	2 in. Pipe to Nozzle 40 Welded in 6 in. Sleeve
43	DW	305	-21'9"	6	High Pressure H_2O, In	2 in. Pipe from Nozzle 43 Welded in 6 in. Sleeve
44	Cont	250	-23'4"	2	DW Drain Line	From Nozzle 25
45	Cont	240	20'	10	Aerosol Sampling	Electrical
46	Cont	245	-2'3"	10	Aerosol Sampling	Tubing
47	Cont	248	-10'	10	Aerosol Sampling	Electrical and Tubing
48	DW	12	-6'9"	12	Ventilation	Butterfly Valve to WW-A
49B	WW-B	65	-7'7"	16	Ventilation between WW	Open
49C	WW-C	125	-7'7"	16	Ventilation between WW	Open
49D	WW-D	185	-7'7"	16	Ventilation between WW	Open
50B	WW-B	66	-20'7"	10	Water Circulation between WW	Open
50C	WW-C	125	-20'7"	10	Water Circulation between WW	Open
50D	WW-D	185	-20'7"	10	Water Circulation between WW	Open

TABLE A-2. Containment Vessel Penetration Panel Schedule

Designation	Size in.	Pipe Schedule	Service
P-1	1-1/4	80	1/4 in. Electrode for Simulator Heater
P-2	1-1/4	80	1/4 in. Electrode for Simulator Heater
P-3	1-1/4	80	Control Cable for Solenoids on 7 Maypack Samplers
P-4	1-1/4	80	1/4 in. Electrode for Simulator Heater
P-5	1-1/4	80	1/4 in. Electrode for Simulator Heater
P-6	1-1/4	80	Control Cable for Solenoid and CVT-1 and 2 (N_2-DOVs)
P-7	1-1/4	80	Conductivity Probe Electrical Leads
P-8	1-1/4	80	1 in. Tubing for Cooling Water to Transducers
P-9	1-1/4	80	Electrical Connector for Instrument Sensor Leads
P-10	1-1/4	80	1 in. Tubing for Cooling Water from Transducers
P-11	1-1/4	40	1 in. Tubing for Nitrogen Dumping of Double Rupture Discs
P-12	1-1/4	40	Spare
P-13	1-1/4	40	Spare
P-14	1-1/4	40	1 in. Tubing for Nitrogen to Simulator for Pressurizing
P-15	2	80	1 in. Water Hose to Bib for Utility
P-16	2	80	1/2 in. Tubing for Nitrogen to Double Rupture Discs
P-17	2-1/2	40	Spare
P-18	2-1/2	40	Spare
P-23	10	40	SS Tube Sheaths for Experimental Sensor Lines
P-24	10	40	SS Tube Sheaths for Experimental Sensor Lines
P-25	10	40	Electrical Connectors

TABLE A-3. Drywell Vessel Penetration Panel Schedule

Designation	Size, in.	Pipe Schedule	Service
P-6B	1-1/4	80	1/2 in. Tubing Nitrogen to Double Rupture Disc
P-7B	1-1/4	80	Spare
P-11B	1-1/4	40	1 in. Tubing Nitrogen Pressurization of Simulator
P-12B	1-1/4	40	1 in. Tubing Nitrogen Dump from Double Rupture Disc
P-13B	1-1/4	40	1 in. Tubing Transducer Cooling Water Outlet
P-14B	1-1/4	40	1 in. Tubing Transducer Cooling Water Inlet
P-15B	2	80	Electrical Conductivity Probe Lead Wires
P-16B	2	80	Electrical
P-19B	2-1/2	40	Simulator Relief into Containment
P-20B	2-1/2	40	Electrical and Electrical Connectors
P-24B	10	40	SS Tube Sheaths for Experimental Sensor Lines
P-27B	10	40	SS Tube Sheaths for Experimental Sensor Lines

APPENDIX B

ADDITIONAL TESTS REQUIRED FOR THE REACTOR SIMULATOR VESSEL

APPENDIX B

ADDITIONAL TESTS REQUIRED FOR THE REACTOR SIMULATOR VESSEL

The following tests were requested of the seller of the Reactor Simulator Vessel, and are over and above the tests called for by the ASME Code for Nuclear Vessels - Section III:

1. Shell material shall be radiographed at points of trunnion attachment before holes are drilled for nozzles. Trunnions shall not be located at points where radiographs or ultrasonic tests disclose material flaws which will result in stresses higher than those allowed by the Codes.
2. The ultrasonic inspection of the materials shall include 100% coverage. The reference specimens shall include a defect 50% smaller than standard and also one 50% larger to permit greater accuracy in estimating size of actual defects. All defects shall be recorded on a map of the exterior wall of the vessel using a linear coordinate system referenced to an appropriate and permanent origin.
3. The final inspection shall include an ultrasonic inspection in compliance with the specifications of N-321.1 of the ASME Code for Nuclear Vessel as amended by this specification. In addition, the liquid penetrant test shall include 100% coverage of the vessel shell.
4. Vessel cladding material shall show no separation from the base plate during the shear test in ASTM A264 Par. 7 (b) (2).
5. The vessel cladding material shall be inspected ultrasonically for unbonded areas. Any defective areas of one square inch or greater shall be repaired by welding. The reference specimen shall be of similar geometry and like materials, with a nominal unbonded area of one-half

square inch. All defects shall be recorded on a map of the interior wall of the vessel using a linear coordinate system referenced to an appropriate and permanent origin.

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