5.0 CONTAINMENT SYSTEM

5.1 CONTAINMENT SYSTEM STRUCTURE

5.1.1 DESIGN BASIS

The reactor containment completely encloses the entire reactor and reactor coolant system and ensures that essentially no leakage of radioactive materials to the environment would result even if gross failure of the reactor coolant system were to occur. The structure provides biological shielding for both normal and accident situations.

The principal design load on the containment structure is the internal pressure created by the hypothetical loss-of-coolant accident. As a minimum, the containment design must withstand the incident pressure load resulting from the complete blowdown of the reactor coolant through any rupture up to and including the hypothetical double ended rupture of the reactor coolant pipe. In addition, the containment must withstand the maximum pressure occurring during a subsequent long-term transient which is determined by the combined effects of heat sources such as residual heat and metal water reactions, structural heat sinks and the operation of other engineered safeguards utilizing only the emergency, on-site electric power supply.

The reactor coolant system contains 507,080 lbs. of water at a weighted average enthalpy of 602.1 Btu/lb for a total energy of about 305,300,000 Btu. No energy contribution from the steam system is included in the calculation of the containment pressure transient. The supports for the reactor coolant system are designed to withstand the blowdown forces associated with the sudden severance of the reactor coolant piping.

In the hypothetical accident, the reactor coolant is released through a double-ended break in the largest reactor coolant pipe, causing a rapid pressure rise in the containment. The reactor coolant pipe used in the accident is the 29 inch ID section because rupture of the 31 inch ID section requires that the blowdown go through both the 29 inch and 27-1/2 inch ID pipes and would therefore result in a less severe transient.

Additional energy is available for release from the following sources:

a) Stored heat in the reactor core.

b) Stored heat in the reactor vessel, piping and other reactor coolant system components.

c) Residual heat production.

d) Metal-water reaction energy.

e) Hydrogen-oxygen recombination reaction.

Five types of engineered safeguards are included in the design of this facility to assure containment integrity. These are:

a) The safety injection system which injects borated water into the hot leg and cold legs of each reactor coolant loop. This system limits damage to the core and also limits the amount of energy released from the core in the event of an accident involving a loss-of-coolant.

b) The containment spray system which is used for reducing containment pressure and for independently and rapidly removing iodine.

c) A steel-lined containment vessel described herein with continuously pressurized double penetrations and liner weld channels which form a leaktight barrier to the escape of fission products should a loss-of-coolant accident occur. In addition the pressurizing system will be continuously monitored and, when leakage is noted, the penetrations can be individually tested.

d) The air recirculation coolers which reduce containment pressure after an accident involving a loss-of-coolant. Air is recirculated through these coolers by the same fans which circulate air through the air recirculation filters for the removal of halogen and particulate fission products.

e) An isolation valve seal water system which assures a leg of water in lines penetrating the containment and eliminates a possible path of leakage through pipes and valves to the atmosphere.

5.1.2 CONTAINMENT SYSTEM STRUCTURE DESIGN

5.1.2.1 General Description

The reactor containment structure is a reinforced concrete vertical right cylinder with a flat base and hemispherical dome. A welded steel liner with a minimum thickness of 1/4 inch is attached to the inside face of the concrete shell to insure a high degree of leak tightness. The design objective of the containment structure is to contain all radioactive material which might be released from the core following a loss-of-coolant accident. The structure serves as both a biological shield and a pressure container. The containment structure is approximately 145 ft. high to the spring (tangent of dome to cylinder) line of the dome and has an inside diameter of 135 ft. The elevation and plan sections of the containment system are shown on Figures 5-1 and 5-2.

The cylindrical reinforced concrete wall is 5-1/2 feet thick below grade and tapers to 4-1/2 feet thick where it joins the dome. The concrete hemispherical dome is 4-1/2 feet thick. The flat concrete base mat is 9 feet thick with an additional thickness of concrete fill of approximately 2 feet over the bottom liner plate. The hemispherical dome, cylinder wall, and mat are of reinforced concrete, designed for all moments, axial loads and shears resulting from the loading conditions described herein. The design of the structural elements is more fully described in Sections 5.1.2.2 and 5.1.2.3.

The containment structure is inherently safe with regard to common hazards such as fire, flood and electrical storm. The thick concrete walls are invulnerable to fire and only an insignificant amount of combustible material, such as lubricating oil in pump and motor bearings, is present in the containment. A system of lightning rods is installed on the containment dome as protection against electrical storm damage. The containment structure is located at a high elevation with respect to the river level so that flooding of the river presents no hazard to the containment.

Internal structures consist of equipment supports, shielding, reactor cavity and canal for fuel transfer, and miscellaneous concrete and steel for floors and stairs. All internal structures are supported by the mat.

A 3 foot thick concrete ring wall serving as a partial radiation shield surrounds the reactor coolant system components and supports the polar-type reactor containment crane. A 2 foot thick reinforced concrete floor covers the reactor coolant system compartments. Removable concrete slabs are provided to permit crane access to the reactor coolant pumps. The four steam generators, pressurizer and various piping penetrate the floor. Spiral stairs provide access to the areas below the floor. Missile protection for the units penetrating the reinforced concrete floor is provided as described later in this section.

Three major radiation shields are also provided external to the ring wall. A 3 foot thick concrete wall is located in front of the main steam and feedwater piping penetrations. A 3-1/2 foot thick concrete wall with supplementary wings surrounds the two containment ventilation duct penetrations. The main access hatch is shielded by a labyrinth of precast concrete slabs.

Most of the high pressure piping runs within the ring wall. The annulus between the ring wall and the containment outside wall serves as a pipe chase. A 1 foot thick floor shields the piping from the areas accessible for inspection at power. Certain additional equipment, such as the regenerative heat exchanger and high pressure piping not within the ring wall are individually shielded. The containment ventilation system fans, coolers and filters are located in the annulus.

The refueling canal connects the reactor cavity with the fuel transport tube to the spent fuel building. The floor and walls of the canal are concrete, with the walls and shielding water providing the equivalent of 6 feet of concrete. The floor is 4 feet thick. The concrete walls and the floor are lined with 1/4 inch stainless steel plate. The linings provide a leakproof membrane that is resistant to abrasion and damage during fuel handling operations.

5.1.2.2 <u>Containment Leak Prevention</u>

a) General

Penetrations are designed with double seals so as to permit continuous pressurization during plant operation to prevent outleakage in the event of loss-of-coolant accident. In addition small steel channels are welded over all joints in the containment vessel liner to form chambers which will also permit continuous pressurization. Pressure in the penetrations and liner joint channels will be maintained above containment incident pressure by the Containment Penetration Pressurization System described in Section 5-4. This system also allows introduction of Freon or a similar tracer gas for leak detection as may be required should consumption of pressurizing air be excessive. These provisions, in addition to the Isolation Valve Seal Water System, effectively block all containment leakage paths.

Typical electrical and pipe penetrations are shown by Figure 5-3a. In general, a penetration consists of a sleeve imbedded in the reinforced concrete wall and welded to the containment liner. The weld to the liner is shrouded by a channel which is pressurized during plant operation to assure the integrity of the joint. The pipe, electrical conductor cartridge, duct or access hatch passes through the imbedded sleeve and the ends of the annulus are closed off. The annuli are also pressurized by an outside air supply to a value above the maximum expected during a loss-of-coolant accident. The plant air supply has backup supplies of nitrogen gas capable of 24 hours of service. A view of a typical penetration showing the pressurized areas is given in Figure 5-3b. Figure 5-1 shows a view of a weld seam channel.

b) Electrical Penetrations

Electrical conductors penetrating the containment range in size from No. 20 AWG stranded thermocouple leads to 7/8 inch solid copper rods. As shown by Figure 5-3a electrical penetrations consist of a sealed cartridge inserted into the sleeve imbedded in the reinforced concrete wall; the sleeves are 8 inch steel pipe.

The basic penetration cartridge consists of a 7 inch O.D. steel tube with welded end plates, through which pass the sealed conductors. The cartridges are of two types, the first being for straight-through conductors, and the second type being for cables which are jointed within the cartridge. The cable joints within the cartridge are of the sealed bayonet type with compression drawup. After the cartridges have been assembled, they are bench tested with Freon gas for leak tightness and then inserted into the sleeves. The cartridges are held tightly in the penetration sleeves by bolted flanges sealed with double O-rings at the inside of the containment wall. The cartridges are seal-welded to expansion bellows on the outside of the containment to completely close the annulus between the cartridges and sleeves.

The spaces between the O-rings, the annuli and the insides of the cartridges are pressurized by the outside air supply. Each of these spaces can be disconnected from the air supply for individual (and independent) halogen leak test.

c) Piping Penetrations

Approximately one hundred penetrations are provided for fluid carrying pipes and for air purge ventilating piping. Several capped penetrations are included as spares. Details of the penetrations are shown on Figure 5-3a.

Most pipes penetrating the containment connect to equipment inside and outside of the containment, and are for either high-temperature or moderate-to-low temperature service. Other pipes, such as for purge air, connect the containment volume to the outside atmosphere.

In all cases, a piping penetration consists of an imbedded sleeve with the ends welded to the penetrating pipe. The volume between pipe and sleeve is pressurized by the outside air supply, and each volume can be disconnected from the air supply for individual halogen leak test.

Penetrations for high-temperature pipes (steam and feedwater for example) have expansion bellows in the sleeve on the outside of the containment and cooling coils in the spaces between the pipes and sleeves to limit the concrete temperature adjacent to the sleeve to a maximum of 150°F. The modes of isolating these pipes during a high-pressure containment incident are covered in Section 5.2.

d) Access Port and Air Lock

An equipment hatch of approximately 16 feet I.D., built of welded steel and having a double gasketed flanged and bolted dished door, is located at grade (see Figure 5-4). Equipment up to and including the size of the reactor closure O-ring seals can be moved into and out of containment through this hatch. The dished door is handled by a auxiliary hoist extended from the frame of the containment polar crane. The hatch barrel is imbedded in the containment wall. All weld seams at the containment liner joint, at the flanges and in the dished door have channels for pressurization. The space between the double-gaskets of the door flanges is also continuously pressurized by the outside air supply.

A 7-foot I.D. personnel air-lock penetrates the dished door of the equipment hatch. The personnel air-lock is a double door, hydraulically-latched welded steel assembly. An equalizing valve connects the air-lock with the interior of the containment vessel for the purpose of equalizing pressure in the air-lock with that in the containment. Should the outer door of the air-lock fail to open due to a hydraulic malfunction, a telephone in the air-lock may be used to summon help. The outer door may also be opened from outside by means of a special tool, stored outside the containment, permitting egress from the air-lock.

Closures are of the double-gasketed type and spaces between the double-gaskets are continuously pressurized by the outside air supply. Pressure is relieved from the double-gasket spaces prior to opening the joints and during the time that personnel are within containment. A second smaller-diameter personnel air-lock is provided as an alternate means of access and egress from the containment. The alternate air-lock is similar to the main air-lock in all respects except for size.

e) Fuel Transfer Penetration

A 20 inch O.D. fuel transfer penetration is provided for fuel movement between the refueling transfer canal in the reactor containment and the spent fuel pit. The penetration, as indicated by Figure 5-4 consists of a 20 inch stainless steel pipe installed inside a 24 inch pipe. The inner pipe acts as the transfer tube and connects the reactor refueling canal with the spent fuel pit. The tube is fitted with a standard gate valve in the spent fuel pit and a valve or blind flange with double gaskets with pressurized annulus inside the containment. This arrangement prevents leakage through the transfer tube during accident conditions. The outer pipe is welded to the containment liner and provision is made, by use of a special seal ring, for pressurizing all welds essential to the integrity of the penetration during plant operation. Bellows expansion joints are provided on the outer pipe to compensate for any differential movement between the two pipes.

The annulus between the inner and outer pipes on the containment end of the transfer tube is continuously pressurized by the outside air supply.

f) Construction Openings

One 27 inch I.D. opening with a bolted and double-gasketed cover is located in the dome at the top of the vessel. This opening is for construction ventilation and will be permanently closed at the conclusion of the construction work. After the cover is bolted in place, removable external concrete shielding is installed over the opening. The space between the gaskets is pressurized by the outside air supply.

Large equipment will be passed into the reactor containment through a temporary opening in the side wall. This opening will be permanently closed after this equipment is in place and before the containment is completed and finally tested.

5.1.2.3 Design Stress Criteria

a) Design Loads

The loads utilized in the design of the reactor containment structure will be computed in accordance with the formula given in Table 5-1.

TABLE 5-1
LOAD CAPACITY OF STRUCTURAL ELEMENTS

Loading Combination	Required Load Capacity of Section
Operating plus loss-of-coolant incident	$0.95D + 1.5P + 1.0 \left[T + TL\right]$
Operating plus loss-of-coolant incident plus maximum conceivable earthquake	$0.95D + 1.25P + 1.0 \left[T' + TL'\right] + 1.25E$

D: Dead load of structure including effect of any hydrostatic pressure.

P: Incident pressure load.

T: Load due to maximum temperature gradient through the concrete shell and mat based upon temperature associated with 1.5 times incident pressure.

TL: Load exerted by the exposed liner based upon temperature associated with 1.5 times incident pressure.

T': Load due to maximum temperature gradient through the concrete shell and mat based upon temperatures associated with 1.25 times incident pressure.

TL': Load exerted by the exposed liner based upon temperatures associated with 1.25 times incident pressure.

E: Load due to acceleration from the design earthquake and includes the combination of horizontal and vertical components of acceleration.

The incident pressure load, P, is based on the reference incident pressure of 47 psig. The reference incident pressure contains a 2.8 psi margin above the pressure peak calculated for the double-ended reactor coolant pipe break with engineered safeguards operating at reduced effectiveness on emergency diesel power. (Refer to Section 12.2.3 for the pressure transient analyses.)

If the wind load "W" exceeds the earthquake load, "W" will be used in lieu of "E" for loading combination No. 2.

No member will have a load capacity less than that required by Table 5-1 for the greatest loading combination.

The design loads are based upon the factors employed in Part IV-B, "Structural Analysis and Proportioning of Members - Ultimate Strength Design" of ACI318-63 with consideration given to the refinement of the incident pressure calculation and the greater severity of reduced dead loads for tension members.

b) Reinforced Concrete

Concrete reinforcement used in the containment structure will conform to ASTM A432 with a minimum yield strength of 60,000 psi. The load capacity of the tension elements will be based upon the yield stress of the reinforcing steel. The load capacity of flexural and compression elements will be determined in accordance with ACI318-63. The load capacity so determined will be reduced by a capacity reduction factor "ϕ" which will provide for the possibility that small adverse variations in material strengths, workmanship, dimensions and control, while individually within required tolerances and the limits of good practice, occasionally may combine to result in under capacity. The coefficient "ϕ" will be 0.90 for tension and flexure and 0.85 for diagonal tension, bond, and anchorage.

c) Liner

The liner will be carbon steel plate conforming to ASTM A442-60T Grade 60 with a minimum yield point of 32,000 psi. The liner plate thickness is one-quarter inch for the base and three-eighths inch for the wall and dome.

The load capacity will be based upon the yield stress of the liner. Sufficient anchorage will be provided to ensure elastic stability of the liner.

Insulation will be provided for the lower portion of the side wall so as to limit the maximum liner temperature and thereby avoid excessive compressive stress in the steel plate.

d) Rock

The containment vessel will be founded on firm rock. A safe allowable bearing pressure will be determined from field samples procured and tested by an independent testing laboratory. A detailed description of subsurface conditions is found in Chapter 1.

5.1.2.4 General Code Requirements

The structural design will meet the requirements established by the latest edition of the "State Building and Construction Code for the State of New York" so far as these provisions are applicable. All concrete structures will be designed, detailed, and constructed in accordance with the provisions of "Building

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Code Requirements for Reinforced Concrete (ACI318-63) so far as these provisions are applicable (Reference ACI318-101(c)).

5.1.2.5 Materials Code Requirements

a) Concrete

All concrete materials will be in accordance with ACI318-63. Portland Cement will conform to "Specifications for Portland Cement", ASTM C-150-4, Type I (normal), or Type II (moderate heat of hydration requirement), or Type III (high early strength). Shrinkage compensating cement will be used in areas where the elimination of secondary stresses due to shrinkage is of importance. Concrete aggregates will conform to "Specifications for Concrete Aggregates", ASTM C-33-64.

Water for mixing concrete will be clean and free of injurious quantities of substances harmful to the concrete or the reinforcing steel.

Calcium chloride or an admixture containing calcium chloride will not be used where it may come in contact with prestressing steel or the liner.

The strength of the concrete will be specified and shown on the drawings so as to meet the following requirements:

1. For flexural elements the extreme fiber stress in compression will conform to the limits established in ACI318-63.
2. The shear as a measure of diagonal tension will conform to the limits established in ACI318-63.
3. The minimum ultimate compressive strength for a standard cylinder of reinforced concrete to be used in this design will be 3000 psi in 28 days, or higher as required. In areas where lean fill will be required, not reinforced except for shrinkage and temperature stresses, the concrete will have a compressive strength of 2000 psi in 28 days.

The concrete will be sampled and tested during construction in accordance with ACI318-63 to ensure compliance with the specifications. An independent testing laboratory will be retained to design the concrete mixes, take samples and perform all tests.

b) Reinforcing Steel

All concrete reinforcement will be deformed bars and will conform to the requirements of "Specification for Deformed Billet Steel Bars for

Concrete Reinforcement", ASTM A305-56T. Reinforcing steel conforming to these specifications has a minimum tensile strength of 90,000 psi.

All splicing and anchoring of the concrete reinforcement will be in accordance with ACI318-63. To insure the integrity of the splices as actually installed on the containment reinforcing, quality control utilizes a random sampling procedure. The splices randomly selected in the field are either radiographed or removed and tested to destruction.

c) Liner Materials

With the exception of the equipment and personnel hatches, none of the liner components are subject to low ambient temperatures. Normal internal temperatures will be maintained between a minimum of 50°F and a maximum of 120°F. The liner material is ASTM A442, Gr. 60, which has a yield point of 32,000 psi and is a low carbon/high manganese steel made with a grain structure that exhibits an NDTT lower than -20°F without heat treatment in thicknesses less than one inch. This material is specified primarily to insure ductility during winter fabrication and during the pressure and leak tests that are performed on the liner before the reinforced concrete structure is poured around it. Because the equipment and personnel hatches can be exposed to low ambient temperature, they are constructed of ASTM A201, Gr. B., firebox steel normalized by heating to 1700°F and cooling in still air and Charpy tested to a minimum of 15 ft-lb at -50°F.

One weld specimen is prepared for each 50 feet of weld performed by each welder and Charpy tested to a minimum of 15 ft-lb at -50°F. The welds for shop fabricated components as well as the field erected structure will be spot radiographed where such inspection is physically possible. The radiograph inspection will be to the minimum requirements established by paragraph UW-52 of the ASME Code for Unfired Pressure Vessels. Where spot radiographing cannot be accomplished, welds will be liquid penetrant inspected. Procedures and acceptance standards for the liquid penetrant inspection will be in accordance with Appendix VIII of the ASME Code for Unfired Pressure Vessels. The qualification of welding procedures and welders will be in accordance with Section IX "Welding Qualifications" of the ASME Boiler and Pressure Vessel Code.

Containment materials are listed in Table 5-2.

TABLE 5-2
REACTOR CONTAINMENT MATERIALS OF CONSTRUCTION

Item	Material Specification
A. Liner	
Shell, Bottom, and Dome Plates	ASTM A442, Gr. 60
Piping Penetration Sleeves	ASTM A333, Gr. 0
Piping Penetration Reinforcing Rings	ASTM A442, Gr. 60
Piping Penetration Sleeve Reinforcing Bar Anchoring Rings and Plates	ASTM A442, Gr. 60
Rolled Shapes	ASTM A131, Gr. C
Reinforcing Bar Bridging Rings	ASTM A204, Gr. C, Firebox normalized
Reinforcing Bar Anchoring Ring and Plates	ASTM A300, Cl. 1, Firebox A201, Gr. B
Equipment Hatch Insert	ASTM A300, Cl. 1, Firebox A201, Gr. B
Equipment Hatch Flanges	ASTM A300, Cl. 1, Firebox A201, Gr. A
Equipment Hatch Head	ASTM A300, Cl. 1, Firebox A201, Gr. B
Personnel Hatch	ASTM A300, Cl. 1, Firebox A201, Gr. B
B. Welding Electrodes	
Material Joined	Specification
Carbon Steel to Carbon Steel	ASTM-E7018
Stainless Steel to Stainless Steel	ASTM-E308
Carbon Steel to Stainless Steel	ASTM-E310
C. Concrete Shell and Interior Structure	
Reinforcing Steel	ASTM A432, Designation 14S and 18S
Cement	ASTM C150, Types I, II & III
Structural Steel	A-36

5.1.2.6 Seismic Criteria

The site seismology is described in Chapter 1. The specific seismic stress criteria for the containment vessel are presented in Section 5.1.2.3.

For those systems or components (except containment) necessary for safety, stresses equal to or slightly exceeding yield are acceptable in some cases however, there will be no loss of function for such systems incident to a design earthquake horizontal acceleration of 0.1 g.

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All structures and components, including equipment and systems, are classified as follows:

TABLE 5-3
CLASSIFICATION FOR SEISMIC DESIGN

1. Definition of Classes

Class I

Those structures and components whose failure might cause or increase the severity of a loss-of-coolant accident or result in an uncontrolled release of excessive amounts of radioactivity. Also, those structures and components vital to safe shutdown and isolation of the reactor.

Class II

Those structures and components which are important to reactor operation but not essential to safe shutdown and isolation of the reactor and whose failure could not result in the release of substantial amounts of radioactivity.

Class III

Those structures and components which are not related to reactor operation or containment.

2. Buildings and Structures

Class	Items
I	Containment (including all penetrations and air locks, the concrete shield, the liner and the interior structures)
I	Spent fuel pit
I	Control room
I	Auxiliary building
III	Turbine room
III	Buildings containing conventional facilities

3. Equipment, Piping and Their Supports

I	Reactor Control and Protection System
I	Radiation Monitoring System
I	Process Instrumentation and Controls

TABLE 5-3 (cont'd)

I	Reactor
	Vessel and its supports Vessel internals Fuel assemblies RCC assemblies and drive mechanisms Supporting and positioning members In-Core Instrumentation Structure
I	Reactor Coolant System
	Piping and Valves (Including Safety and Relief Valves) Steam generators Pressurizer Reactor Coolant Pumps
I	Chemical and Volume Control System
I	Containment Ventilation System
	Fans Filters Coolers Ducts Valves Louvers
I	Safety Injection System (including refueling water tank, safety injection, residual heat removal and containment spray pumps, thiosulfate tank, sprays and connecting pipe)
II	Storage Tanks
	Primary water storage tanks Condensate storage tanks Pressurizer relief tank
I	Reactor Auxiliary Systems
	Residual Heat Removal Loop Component Cooling Loop
II	Reactor Auxiliary Systems (excluding the above Class I items)
	Sampling system Spent fuel pit cooling loop
I	Fuel Transfer Tube
I	Containment Penetration and Weld Channel Pressurization System (including air supplies)
I	Isolation Valve Seal Water System

TABLE 5-3 (cont'd)

I	Emergency Power Supply System
	Diesel generators and fuel oil storage tank D-C power supply system Power distribution lines to equipment required for emergency Transformers and switchgears supplying the engineered safeguards Control panel boards Motor control centers
I	Control Equipment, Facilities and Lines Necessary for the above Class I items
I	Waste Disposal System
	Moisture separator Waste holdup tanks Sump tanks Spent resin storage tanks Gas decay tanks Compressors Seal water heat exchangers Gas strippers Evaporators Gas stripper preheaters Evaporator condensate demineralizers Gas stripper feed pumps Evaporator bottoms storage tanks Waste holdup tanks recirculating pumps Sump tank pumps Interconnecting waste gas piping
III	Waste Disposal System
	All elements not listed above as Class I
I	Polar Crane in Containment
III	Other Cranes
	Manipulator crane Other cranes
III	Conventional equipment, tanks and piping, other than I and II classes
I	Service Water and Fire Protection Pumps and Piping

The design of Class I structures and components will utilize the "response spectrum" approach in the analysis of the dynamic loads imparted by earthquake. The seismic design will be based on the acceleration response spectrum curves for the El Centro earthquake,[1] which will be normalized to 0.1 g at zero period. This analysis will be applied to all structures and components or parts thereof having responses which may be interdependent considering their natural periods, using the appropriate damping factors in Table 5-4.

TABLE 5-4
DAMPING FACTORS

	Component	Per Cent of Critical Damping
1.	Containment structure	7.0
2.	Concrete support structure for reactor vessel and steam generators	5.0
3.	Steel assemblies	
	a) Bolted or riveted	2.5
	b) Welded	1.0
4.	Vital piping systems	0.5
5.	Concrete structures above ground	
	a) Shear wall	7.0
	b) Rigid frame	5.0

5.1.2.7 Corrosion Allowance

No corrosion allowance is required in the design of the liner, which has a minimum thickness of 1/4 inch. The exposed surface of the liner will be given a protective coating of three coats of sprayed vinyl plastic paint to a total thickness of 6 to 8 mils.

The outer surface of the steel will be in direct contact with the concrete which provides adequate corrosion protection due to the alkaline properties of concrete.

5.1.2.8 Accessibility Criteria

Limited access to the containment through personnel air locks is possible with the reactor at power. This type of access would be restricted to the annular area between the crane support wall and the containment shell primarily for inspection and maintenance of the air recirculation equipment and the in-core ion chamber drives. Before personnel enter the containment vessel, the

(1) TID-7024 "Nuclear Reactors and Earthquake", August 1963. Chapter 1.

concentration of radioactive gases and airborne particulates will be checked. Since only negligible fuel defects are expected for this core (much less than the 1% fuel rod defects assumed in the design) purging of the containment will not normally be required. If purging is necessary, the system will reduce the radioactivity level to the doses defined by 10CFR20.

The primary reactor shield will be designed so that access to the primary equipment compartment would be limited by the activity of the primary system equipment and not the reactor. Opening of the containment equipment hatch or both doors in the personnel locks will occur only during cold shutdown conditions not involving changes in the core reactivity.

Refueling will be carried out with borated water in the refueling cavity so that the core is always in a substantially subcritical condition. Operations which may change core reactivity, such as replacement of fuel or control rods, will be performed only when the equipment hatch and personnel locks are closed. The fuel transfer penetration tube would be under a 35 foot water seal at this time.

5.1.2.9 Missile Protection

All high pressure equipment in the reactor coolant system is surrounded by barriers which will prevent any missile generated in a loss-of-coolant accident from reaching the reactor container liner.

The basic missile barrier consists of the three foot thick reinforced concrete ring wall which surrounds the reactor coolant system and the two foot thick reinforced concrete floor which covers the loop compartments. Additional missile shield structures surround the upper shells of the steam generators and pressurizer to block any missiles from these components or which might escape by way of the annular openings between these vessel shells and the floor. A missile shield structure is also provided over the control rod drive mechanisms to block any missiles which might be generated in the event of a fracture of the pressure housing of any mechanism.

A complete analysis of the missile generating potential of a reactor coolant system rupture will be performed during plant design to confirm the adequacy of the various missile barrier structures described above.

As an example of the type of analysis which will be performed, the inherent ability of the concrete ring wall and floor to stop missiles was evaluated for Indian Point Unit No. 2. This study was based on analysis performed for the Army Package Power Reactor (APPR)[1] but for the higher energy coolant condition of Indian Point Unit No. 2.

The APPR study showed that the generation of credible missiles (a 2-inch valve, a 2-foot length of 2-inch pipe, a 2-foot length of 2-inch diameter steel bar) having speeds in excess of 500 ft/sec is very unlikely. For the Indian Point Unit No. 2, a 2-foot length of 2-inch steel pipe could reach a maximum speed of 650 ft/sec if its contents of high temperature reactor coolant were released to atmospheric pressure. This condition conservatively assumes the conversion of all of the available thermal energy of the coolant to kinetic energy of the pipe. This missile is analogous to the self propeled missile described in "U. S. Reactor Containment Technology", ORNL-NSIC-5, Vol. I, Chapter 6.

The APPR studies of missile penetration into reinforced concrete were based upon U. S. Navy information in NavDocks Bulletin No. P-51. These studies showed that the penetration of a 2-foot length of 2-inch steel pipe traveling at 500 ft/sec and impacting end-on will be approximately 19 inches in normally reinforced concrete. The same missile, traveling at 650 ft/sec as calculated for Indian Point Unit No. 2 conditions, would have a total penetration of 24 inches based on the NavDocks correlation. A 2-foot length of 2-inch steel bar, having the same weight per unit of projected impact area, has the same calculated penetrating power. Objects with complicated shapes, such as valves, will have smaller ratios of weight to impact area and will therefore have lower penetrating ability.

In addition to the concrete ring wall and other special missile barriers, the steel liner of the containment also has significant resistance to penetration by missiles. Calculations of the resistance of the 3/8-inch steel liner show that a velocity in excess of 100 feet per second is necessary for a 2-foot long, 2-inch diameter steel bar to penetrate the liner. This calculation is based on the correlation developed by the Stanford Research Institute[2] using the assumption of a stiffly supported plate (a 4-inch span between supports without concrete

(1) Hazards Summary Report for the Army Package Power Reactor, APAE-2 Alco Products, Inc., July 27, 1955.

(2) Work summarized in ORNL-NSIC-5, "U. S. Reactor Containment Technology," Vol. I, Chapter 6, August 1965.

backing). A check of this value using the formulation attributed to the Ballistics Research Laboratory[3] and used in the APPR Hazards Summary Report indicates that a higher velocity of approximately 180 feet per second is necessary for the same missile to achieve penetration of the liner.

The possible damage due to the impact of various types of aircraft on the reinforced concrete reactor containment structure has been evaluated. The results of these calculations show that the proposed containment would remain effective following the impact of most present day aircraft, even at speeds which they attain only at service altitudes.

Specifically, these studies showed that all classes of aircraft except high performance military jets and the proposed supersonic transport, striking the containment at its thinnest point (4.5 feet of reinforced concrete) in a perpendicular trajectory at design cruising velocity, would not penetrate to the liner. Even the jets and supersonic transports would be stopped if the impact were at a glancing angle or if the plane's altitude were not head-on (e.g. a flat spin, or ricocket after first contacting ground).

The concrete structure considered was assumed to have a crushing strength of 3000 psi and 1.4% reinforcement. The actual containment structure will have more than this amount of reinforcement. A conservative allowance was made for energy absorption in airframe and engine deformation based on data from actual air crashes compiled by the Bureau of Safety of the Civil Aeronautics Board.

In no case would the aircraft or any part thereof have sufficient energy to penetrate the containment without extensive loss of velocity and deformation of its shape. The additional protection of the reactor system by the concrete operating deck, missile shields above the reactor steam generators and pressurizer, and secondary shield walls would prevent such an accident from causing a loss of reactor coolant.

(3) U. S. Army Ballistics Research Laboratory, Aberdeen Proving Grounds, Maryland.

5.2 CONTAINMENT ISOLATION

5.2.1 DESIGN BASES

The following measures are provided for isolation of pipes penetrating the containment to prevent release of radioactivity following a loss-of-coolant accident.

1) The piping through each penetration is designed to withstand at least the reference incident pressure. The piping is inherently isolated when it connects with closed piping systems which meet the following criteria:

a) A closed piping system outside the containment blocks the release of radioactivity if it is designed for pressures above the containment incident pressure and it is supplied with seal water injection in accordance with the principles of the Isolation Valve Seal Water System, Section 5.2.2.

b) A closed piping system inside the containment (one which does not connect to the containment atmosphere or a source of radioactivity within the containment) blocks release of radioactivity if it is designed for pressures above containment incident pressure and if it is protected against rupture or missile damage resulting from a loss of coolant accident.

Piping penetrations in this category do not require isolation valves outside the containment.

2) An isolation valve will be installed outside the containment to isolate pipes which do not meet the above criteria for closed piping systems.

a) The valve will be automatically operated upon high containment pressure in lines where flow direction is out of the containment and where the line is not required to operate following the loss of coolant as one of the engineered safeguards.

b) A check valve will be used where flow direction is normally into the containment.

c) A manual valve will be used to isolate lines which are always closed when the containment is sealed.

In all cases, the effectiveness of the isolation valve seal is assured by a water leg established in the line between the containment and the closed valve. The Isolation Valve Seal Water System is described in Section 5.2.2.

3) Each ventilation system purge duct will be isolated by two quick-closing, tight-sealing butterfly valves. One valve is installed inside and the other outside the containment. The valves are closed except during purging of the containment. The valves can be closed either manually or automatically upon a signal of high

radiation level in the containment. The space between the valves is pressurized above incident pressure when the valves are closed during normal plant operation.

The following measures are provided to isolate pipes penetrating the containment to prevent release of radioactivity in the event of a line rupture outside the containment.

1) Lines connecting to a closed piping system within the containment are inherently isolated and require no isolation valve or seal water injection.

2) For lines connecting to the reactor coolant system, or to any significant source of radioactive fluid within the containment, an isolation valve (or in special cases, a blind flange) will be installed inside the containment.

a) The valve will be remotely operated from the central control room in lines where flow direction is normally out of the containment.

b) A manual valve will be used to isolate lines which are always closed when the containment is sealed.

c) A check valve will be used in lines where the flow direction is into the containment.

3) As a special case, a valve or a blind flange is provided inside the containment in the spent fuel transfer tube to prevent leakage of spent fuel pit water into the containment during plant operation.

5.2.2 ISOLATION VALVE SEAL WATER SYSTEM

5.2.2.1 Design Bases

The Isolation Valve Seal Water System assures the effectiveness of the containment isolation valves in the event of a loss-of-coolant accident by providing a water seal between the containment and an isolation valve in any line which can communicate with the inside of the containment. This system performs the same function as the "Block Valve Seal Water System" which was incorporated in the Malibu plant design.

5.2.2.2 System Design

The Isolation Valve Seal Water System flow diagram is shown in Figure 5-5. The seal water system functions after a loss-of-coolant accident to establish a water leg between the potential source of radioactivity in the containment and the closed isolation valve or closed piping system outside the containment. The water leg blocks leakage of the containment atmosphere through valve seats and stem packings. The water leg is established using gas bottle pressurization so that the motive force for the water seal does not depend on electrical power.

The system is arranged to allow the water leg to be established manually or automatically. Manual seal water injection is provided for all lines which penetrate the containment except those that cannot communicate with the containment atmosphere. Automatic seal water injection is provided for piping that communicates with the containment atmosphere and can be void of water in the event of a loss-of-coolant accident. The lines without the automatic injection feature are those which will have a water leg established by virtue of their function or operation. Table 5-5 lists a few representative lines penetrating the containment, their means of isolation, and the seal water injection provisions.

Automatic operation of the system will be initiated by a high containment pressure signal. Lines which normally operate at high pressure are serviced by an injection header with relief protection. A local reading water level indicator is included on each water leg to provide evidence of the presence of the water seal. Radiation levels adjacent to the containment will be low enough following any loss of coolant accident to allow checking of all level indicators shortly after the system operates.

Reliable operation is assured by duplication of instrument channels and provisions for periodic testing of isolation and injection valve operation. Each automatic isolation valve can be tested for operability at times when the line is not required for normal service. Automatic injection valves will be similarly tested. The capacity of the system to deliver water at the required rate will be verified during the preoperational test period of plant construction and startup.

TABLE 5-5

Service	Penetration: Quantity	Penetration: Size	Containment Isolation: Inside	Normal	Outside	Normal	Temperature & Fluid Inside Pipe Hot = 200°F: Fluid	Temp.	Probable Outside Isolation Valve Type	Seal Water Injection
Nitrogen Supply	1	1"	Check	-	Gas Reg	Closed	Gas	Cold	Diaphragm	A
Demineralized Water	1	2"	Check	-	RSV	Closed	Liquid	Cold	Diaphragm	M
Service Air	1	2"	Check*	-	RSV	Open	Gas	Cold	Diaphragm	A
Steam	4						Gas	Hot		No
Feedwater	4						Liquid	Hot		No
Steam Generator Blowdown	4						Liquid	Hot		No
Primary Drain Header	1	2"	0	-	RSV	Open	Liquid	Cold	Diaphragm	A
Primary Vent Header	1	2"	0	-	RSV	Open	Gas	Cold	Diaphragm	A
H_2 Analyzer	1	1/2"	RSV	Closed	RSV	Open	Gas	Cold	Diaphragm	A
Letdown Line	1	3"	RSV	Open	RSV	Throttle	Liquid	Hot	Globe	M
Charging Line	1	3"	Check	-	C.S./Check	Throttle	Liquid	Cold	Check	M
Containment Spray	1	10"	Check	-	RSV	Closed	Liquid	Cold	Gate	M
Safety Injection	1	3"	RSV	Closed	MSV	Open	Liquid	Cold	Gate	M
R. C. Pumps Cooling H_2O										
In	4	4"		-	C.S.		Liquid	Cold	Globe	M
Out	4	4"	0	-	C.S.		Liquid	Cold	Globe	M
Sampling	2	3/8"	RSV	Closed	RSV	Closed	Liquid	Hot	Globe	A
Fuel Transfer Tube	1	20"	Flange	Closed	RSV	Closed	Air	Cold	Gate	No
Refueling H_2O Fill and Drain	1	8"	0	-	MSV	Closed	Liquid	Cold	Gate	M
Ventilation Coolers										
Cooling H_2O In	1	10"	0	-	MSV	Open	Liquid	Cold		No
Cooling H_2O Out	1	10"	0	-	MSV	Open	Liquid	Cold		No
Reactor Coolant Seal Water	4	2"	Check	-	RSV	Throttle	Liquid	Cold	Globe	M

*Safety Injection flow path.

A-Automatic
M-Manual

RSV-Remote operated stop valve
MSV-Manual operated stop valve
C.S.-Closed System

5.3 CONTAINMENT VENTILATION SYSTEM

5.3.1 DESIGN BASIS

The air recirculation cooling capacity of the ventilation system is sized to remove the normal heat loss from equipment and piping in the reactor containment during plant operation and to remove sufficient heat from the reactor containment following the initial loss-of-coolant accident pressure transient to keep the containment pressure from exceeding safe limits. The fans and cooling units continue to remove heat after the loss of coolant and reduce the containment pressure to near atmospheric within the first 24 hours.

With the recirculation capacity of the system required by the above basis, the filtration capability of the system will be able to provide an average reduction factor in the halogen fission product inventory in the containment of 10.7 over the first two hours with 4 of the 5 fans operating.

5.3.2 SYSTEM DESIGN

The containment ventilation system has five air handling units with common, headered ducting to assure adequate distribution of filtered and cooled air throughout the containment. Each air handling unit consists of a direct-connected motor-driven centrifugal fan, a cooling coil, and a filtration assembly which contains a moisture separator, a roughing filter, an absolute filter, and a highly activated charcoal filter in series.

Each air handling unit (fan, cooler and filters) has a capacity of 65,000 cubic feet per minute under the conditions of the hypothetical loss of coolant accident.

In normal operation, the filter units are bypassed and the air passes through the cooling coils, through the fans and through the distribution ducts to various parts of the containment. Following a loss of coolant, the air passes through the filter units after being cooled and is then distributed. The ventilation system also includes steam heating coils to heat the containment atmosphere when required by cold weather.

The air handling units and major air ducts are located in the annular space outside the crane support wall where the equipment is protected from any missiles associated with a loss-of-coolant accident and where limited access is possible during plant power operation for inspection and maintenance. The air ducts are arranged to draw air from the points of highest radioactivity and to deliver air to areas of low radioactivity. Inlet and exhaust locations are selected to assure elimination of stagnant air pockets in the containment.

Under normal conditions, namely, plant operation and shutdown, the Containment Ventilation System provides heating and cooling and assists in providing ventilation. During operation, heat is released from vessels, equipment and piping to the containment atmosphere. Since the containment is completely sealed from the external atmosphere during normal operation, no ventilation or cooling air enters or leaves the containment. By recirculating the containment atmosphere through coolers, the temperature inside the containment vessel is maintained at or below 120^{o}F to prevent damage to instrumentation and electrical wiring. The system also cools the concrete primary shield by circulating air through the annular space between the insulated reactor vessel and the shield.

During maintenance and refueling shutdowns, the air recirculation system distributes the tempered ventilation air supplied by the purge system. In winter months, the air is heated to maintain a minimum temperature of 50^{o}F inside the containment; at other times, the recirculating ventilation air is cooled to provide comfortable working conditions.

The fans, motors, electrical connections, and all other equipment in the containment necessary for operation of the system are designed to operate under the high moisture and temperature conditions following a loss of coolant. Fan motors are sized to operate under the higher loads imposed by the high-density vapor-air mixture in the containment after a loss of coolant. During normal plant operation with normal air density the fan motors will operate well below rated load.

5.3.3 AIR RECIRCULATION COOLING

The air recirculation cooling function of the Containment Ventilation System is accomplished under post-accident conditions using the fans and coolers in any four of the five air handling units. These four units have sufficient capacity to prevent the building of containment pressure to a point imparing the integrity of the containment leaktightness following any loss-of-coolant accident. The cooler in each air-handling unit consists of transverse flow, finned cooling coil banks which utilize river water for cooling.

5.3.4 AIR RECIRCULATION FILTRATION

The post-accident air recirculation filtration function can also be accomplished using any four of the five air handling units. In each unit, air is passed through the cooler and then through the moisture separator and filter assembly before it is distributed throughout the containment.

During normal operation the filters are not in use. Power operated louvers, which fail open in each unit, close off the flow path through the filters and allow recirculation air flow to bypass the filters. In this way, the high degree of charcoal activation is maintained. The louvers are activated by a high containment pressure signal.

The louvers are designed for minimum leakage so that essentially all of the air flow will pass through the filters. The filter units are designed to withstand the maximum differential pressure developed by the fans under accident conditions without developing internal leaks or being dislodged from their frame seals.

5.3.5 RELIABILITY AND TESTING

A high degree of mechanical reliability is incorporated in the Containment Ventilation System. The system operates prior to the accident because it is used during plant operation to control temperature inside the containment. The capacity of four of the five air handling units is adequate to prevent over pressurization and to effect fission product inventory reduction. In the event of a failure of outside electric power concurrent with a loss of coolant accident, the fans and the pumps supplying cooling water for the air coolers will be started automatically and supplied with power from the emergency diesel power supply. The louvers on the air handling units are arranged to divert air flow through the filters in the event of failure of motive power to the louver operator. Any one of the elements of the activated charcoal filters in each of the air handling units can be removed and tested periodically for effectiveness in removal of elemental and organic iodine. Such tests will be conducted in an environmental test loop located on the plant site. In addition, periodic, in-place testing of the filtration assemblies will be made using freon or other suitable aerosols to verify the leak-tightness of individual filter elements and their frame seals.

The louvers on each air handling unit can be operated periodically to assure continued operability. The degree of leak tightness of the louver assemblies will be established by test at the time of installation.

A fire protection system is installed in each air-handling unit to protect against charcoal ignition in the event that forced air flow is lost after a high loading of fission products is reached following a core meltdown.

5.4 CONTAINMENT PENETRATION PRESSURIZATION SYSTEM

The function of the containment penetration pressurization system is to prevent leakage of containment air through penetrations and liner weld joints under all conditions by supplying air above containment maximum incident pressure to the positive pressure zones incorporated in the penetration design. The design features of the penetrations are described in Section 5.1.2.2. Figure 5-3b shows a typical penetration with the pressurized areas highlighted.

The containment penetration pressurization system is shown on the Process Flow Diagram, Figure 5-6. The system utilizes a regulated supply of clean and dry compressed air from either of the plant compressed air systems to maintain pressure in all penetrations and weld joint channels whenever plant operating conditions require the containment to be closed. The penetrations and weld channels are grouped in four independent zones, each supplied by its own air receiver.

Nitrogen cylinders provide a standby source of gas pressure for each zone. The regulators on the nitrogen supply are set to deliver at a slightly lower pressure than the normal regulated air supply pressure.

Thus, in the event of failure of the normal air supply pressure, the penetration pressure requirements will automatically be maintained by the nitrogen supply.

Each penetration air supply line can be isolated for leak testing. A capped tubing connection is provided in each supply line to allow injection of the leak-test gas.

Leakage from the system (and potential leakage from penetrations) is checked by continuous measurement of the integrated makeup air flow.

5.5 INSPECTION AND TESTING

5.5.1 CONTAINMENT SYSTEM STRUCTURE PREOPERATIONAL INSPECTION AND TESTS

Preoperational inspections and tests are performed in several stages which lead finally to the leak rate tests. First, the containment mat and lower portion of the side walls are erected and lined. This portion of the liner will be tested for seam leakage with air pressure or freon by means of the steel channel compartments described in Section 5.1.2.2. After partial construction of interior walls and structures, the containment liner and the reinforced concrete building wall are completed. This is accomplished by erecting a section of the liner with the channels over all seams. After testing the welds with freon and making repairs if necessary, the reinforced concrete is placed in back of this completed and tested section of liner. This procedure is repeated until the entire structure, sidewalls and hemispherical dome, is completed and tested. The next test is the air test at 54 psig for one hour, for the purpose of demonstrating structural integrity after the completion of the entire containment structure.

5.5.2 INITIAL LEAK RATE TEST

Without pressurization of all penetrations and weld seam channels, the design leak rate is 0.1 percent of the contained volume in 24 hours at the reference incident pressure of 47 psig. It has been demonstrated that, with good quality control during erection, this is a reasonable requirement. Large containers approximately the size of this vessel normally show leak rates of the order of 0.1% per day or less, however, this leakage occurs principally at penetrations, closures and at imperfect liner weld seams. Leakage through these paths is blocked by the Containment Penetration Pressurization System.

The basis of the leak rate test is the reference volume method. The entire reference volume system is pressurized to a minimum of 100 psi gage with air containing 20 weight percent freon. All reference volume joints are bagged with plastic and the system held at this pressure for 48 hours. The reference volume system, especially the joints, is checked with a halogen leak detector to demonstrate integrity.

In addition to the usual calculation of leak rate as a function of pressure differential, air is returned to the reactor containment at the conclusion of the test through a precision gas meter until the differential pressure is returned to its original condition. This provides a check on the calculated leak rate. Reactor containment ambient temperature and humidity are also measured during the course of the test to provide further backup information.

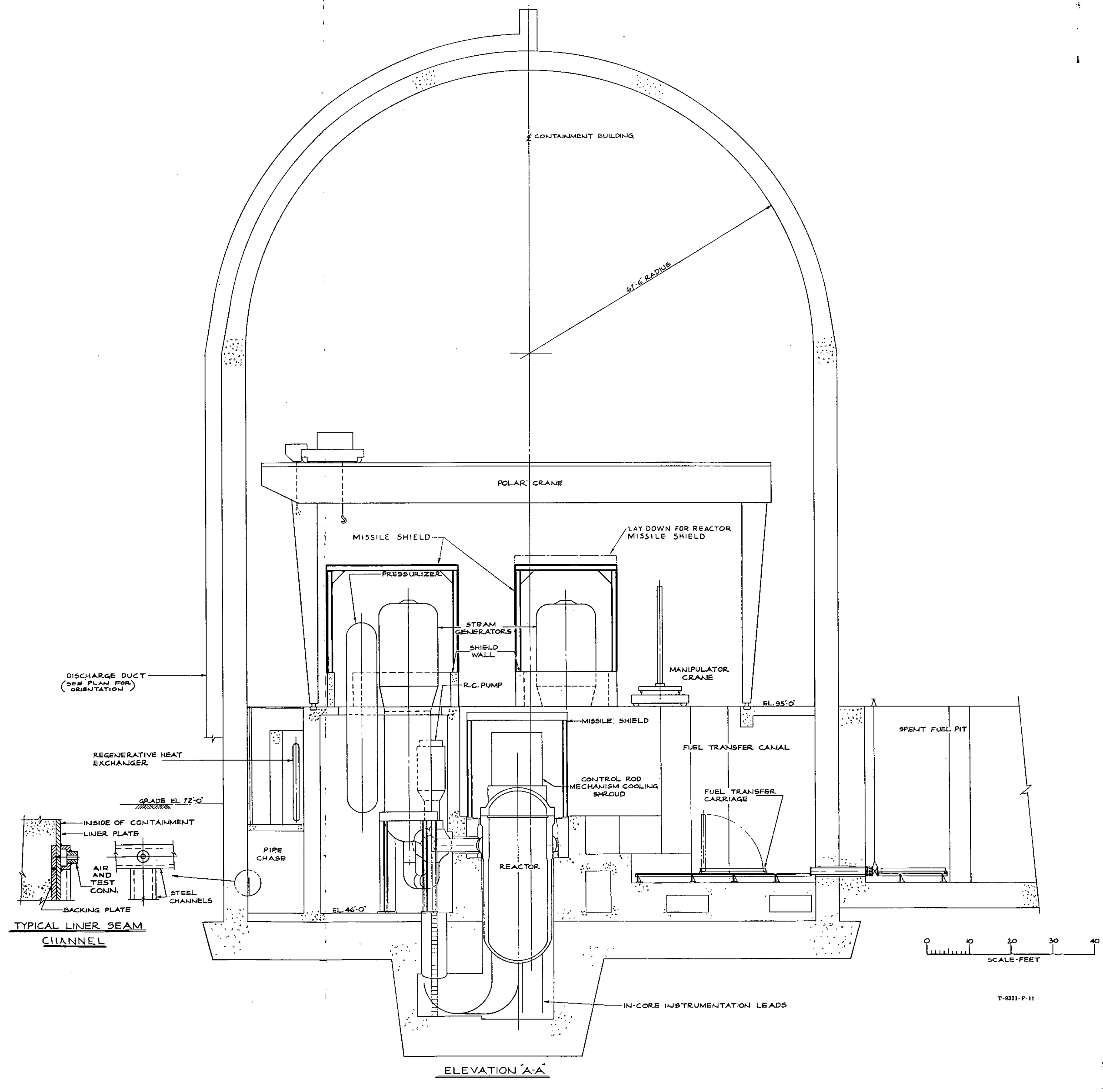
The initial leak rate test consists of establishing a leak rate at 47 psig and at one other lower pressure. Because the containment is a thick walled concrete structure, short term temperature or meteorological variations will not have any appreciable effect on the containment ambient temperature and pressure. It should, therefore, be possible to establish meaningful leak rates in a shorter term test than might be required on a bare steel vessel. The containment will be held at each test pressure for a minimum of 24 hours. During these leak-rate tests the penetration positive pressure zones and liner weld channels which will be normally pressurized by the penetration pressurization system will remain unpressurized.

5.5.3 CONTAINMENT SYSTEM STRUCTURE POST OPERATIONAL TESTS

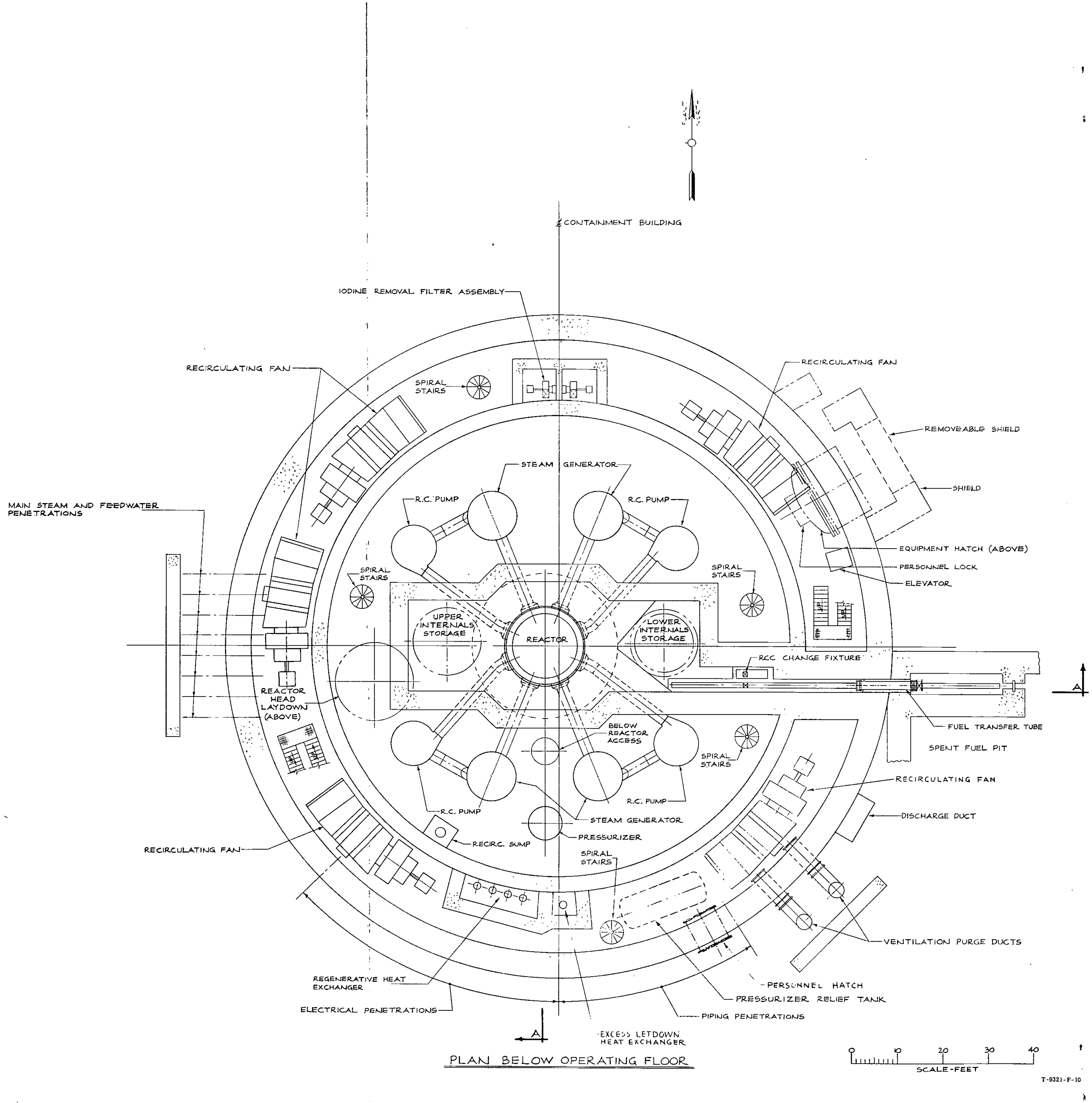
The continuous check of air usage of the Penetration Pressurization System makes frequent leak testing of the containment unnecessary. The initial leak test can be repeated as necessary, however, at cold shutdowns. The reference volume system used in the initial leak test will remain installed for this purpose. Leak test pressures up to the reference incident pressure of 47 psig can be tolerated without damage to equipment or instrumentation by simple precautions such as opening equipment vents.

The in-leakage to the containment through the pressurized penetrations is minimized by periodic leakage tests of the penetration pressurization system. This system is tested by isolating it from the pressure source and observing rate of pressure decay. In addition, during normal operation, an integrating air supply flow recorder indicates abnormal system air consumption. Detection of system leak rates of a magnitude significant to the results of the continuous containment leakage monitoring will be used to determine the need for repair of the pressurization system, liner weld or penetration leaks.

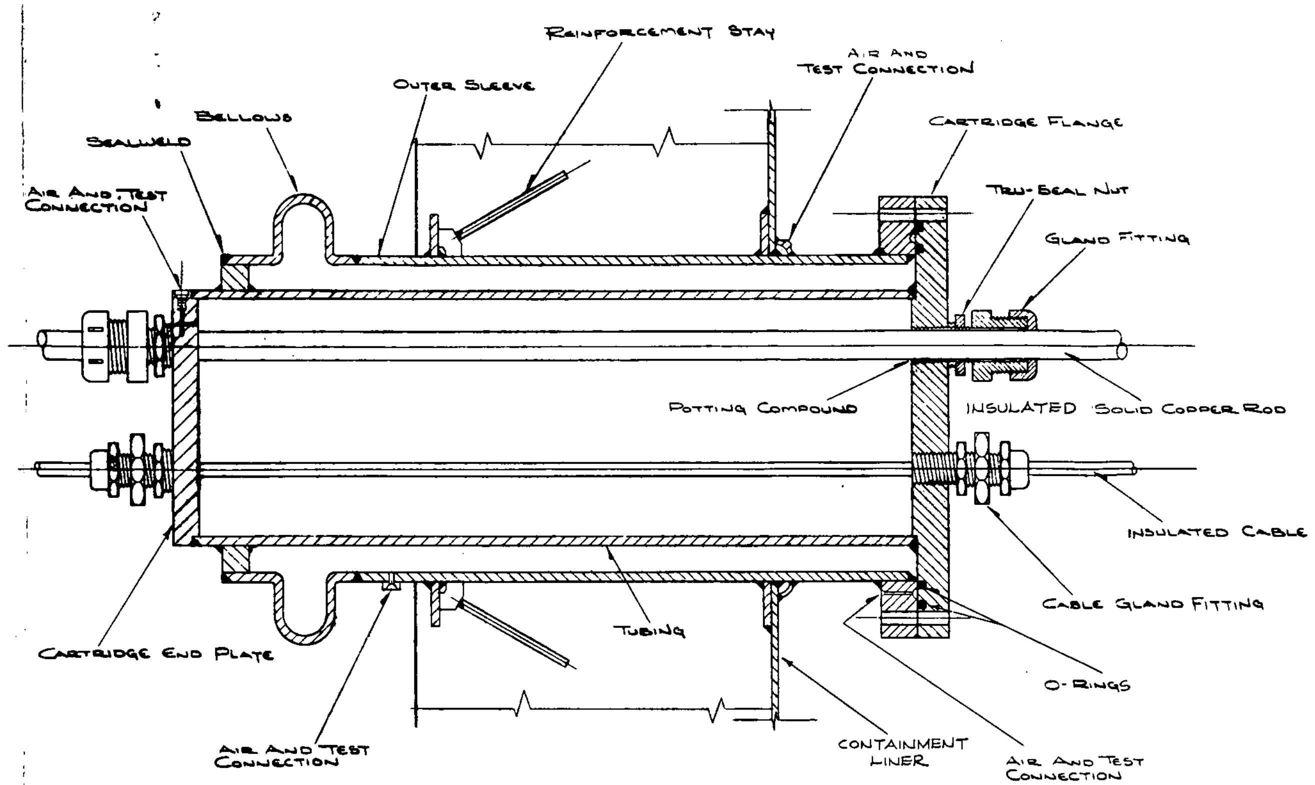
As previously stated, provisions are made for leak tests of all penetrations and liner weld channels. Such tests will be performed whenever there is any indication of excessive leakage. Each pressurized volume of each penetration can be disconnected from the air supply for individual and separate halogen leak tests. Provisions have been made to pressurize the personnel hatch with tracer gas in order to test the tightness of the hatch and door gaskets. If the excessive leakage is not located by the penetration tests, all weld seams can be tested for leakage by using the channels previously described. Fittings are permanently installed in the steel channels and are readily accessible.



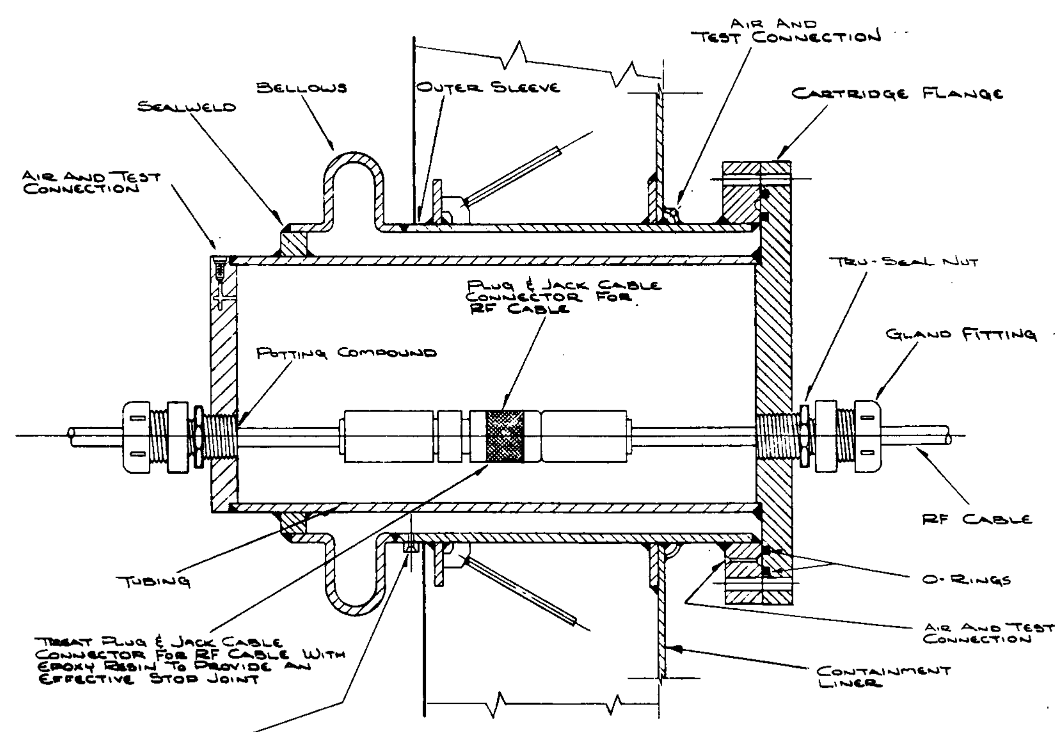
CONTAINMENT ELEVATION SECTION
FIG. 5-1



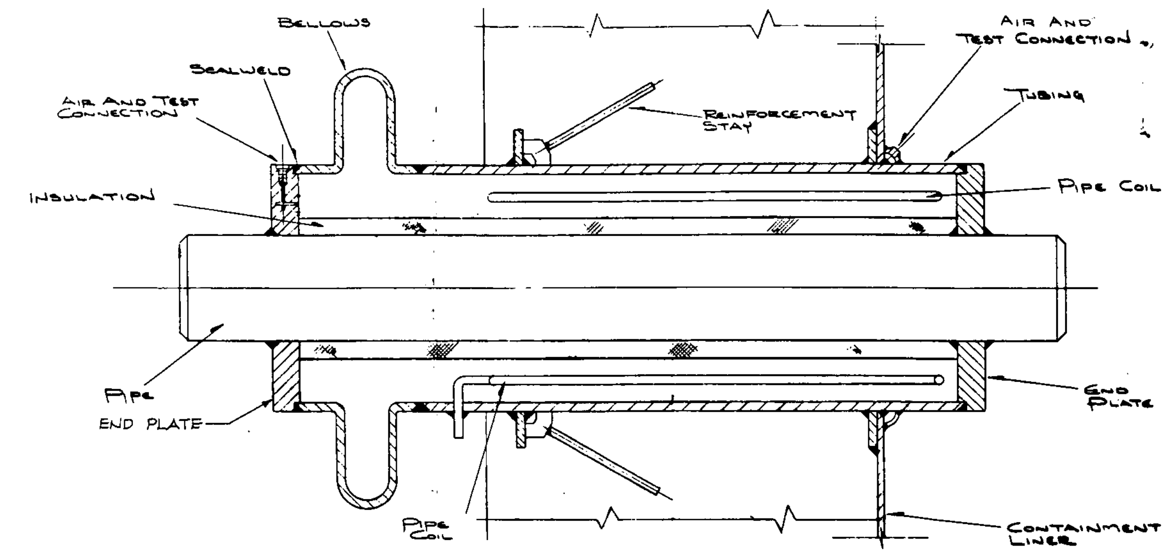
CONTAINMENT PLAN SECTION
FIG. 5-2



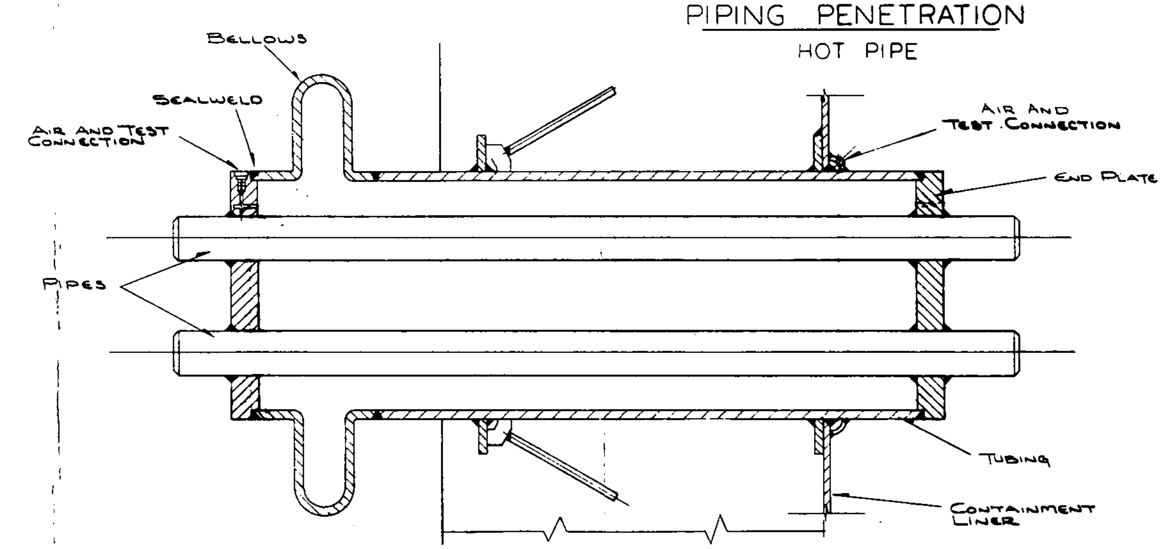
ELECTRICAL PENETRATION
STRAIGHT - THROUGH CONDUCTOR



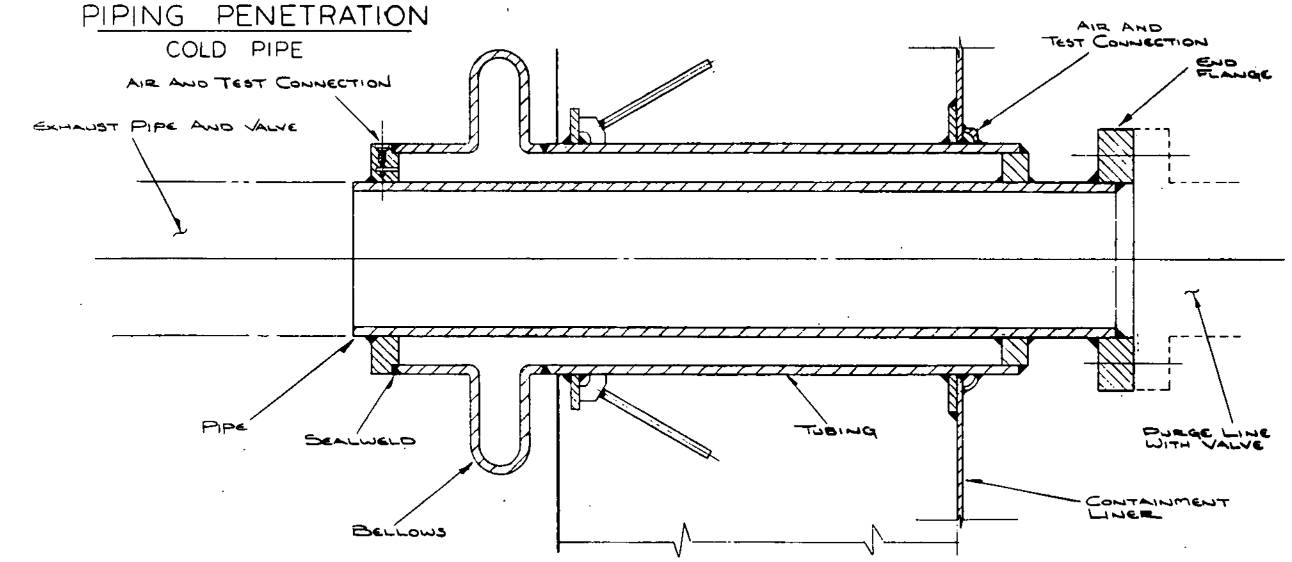
ELECTRICAL PENETRATION
JOINTED CONDUCTOR



PIPING PENETRATION
HOT PIPE



PIPING PENETRATION
COLD PIPE



PIPING PENETRATION
PURGE PIPING

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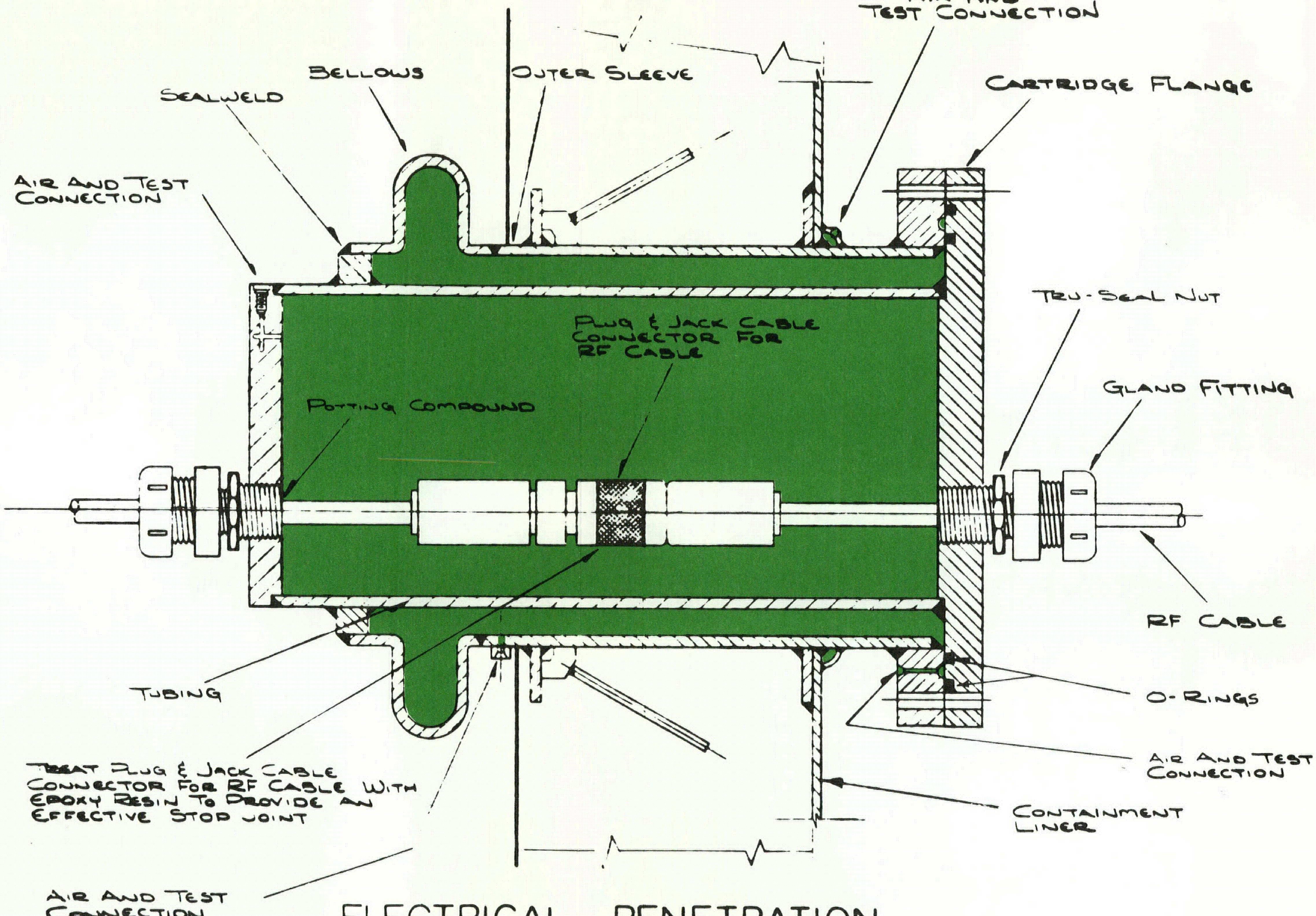
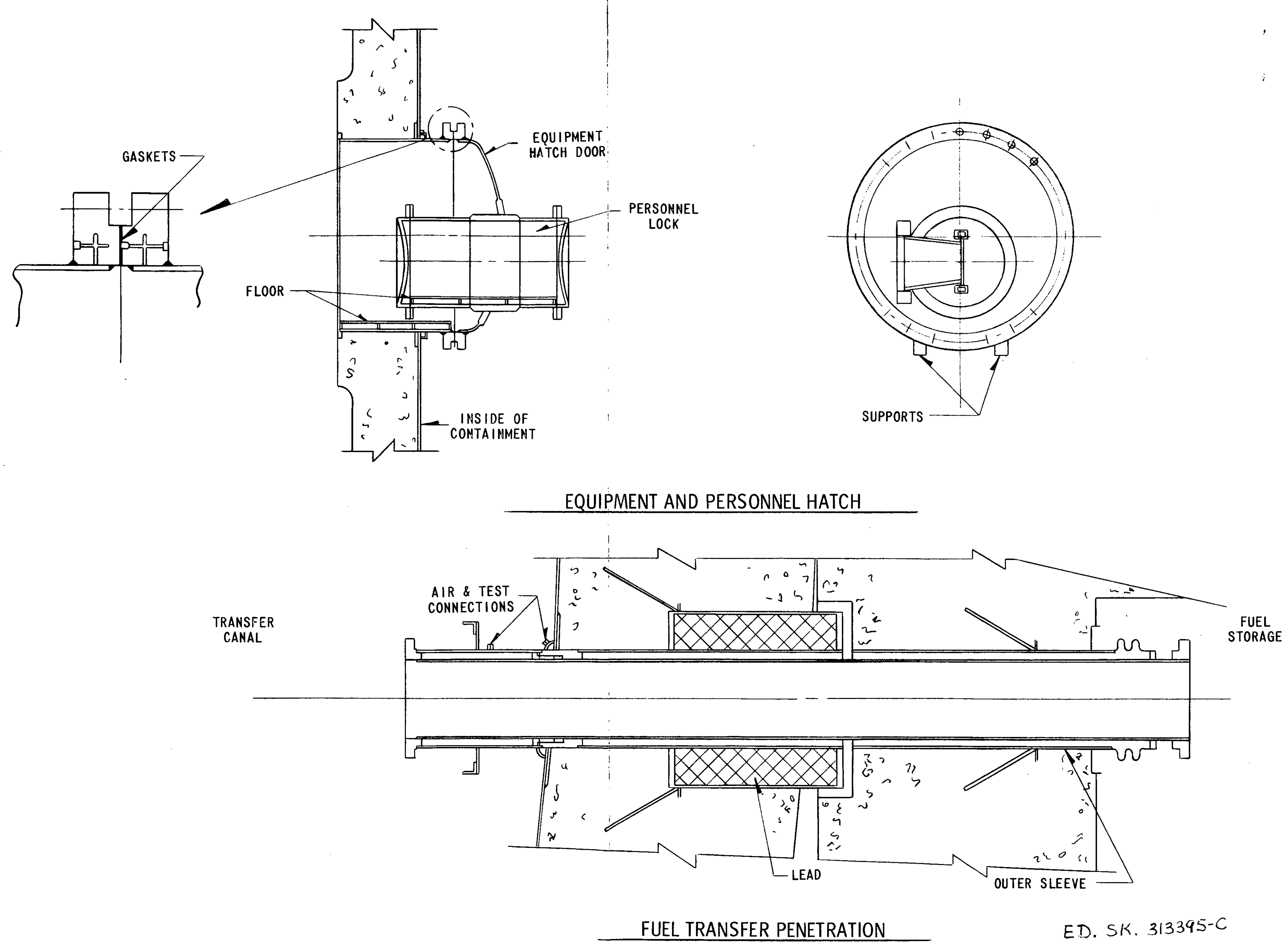
TYPICAL CONTAINMENT PENETRATIONS
FIG. 5-3a



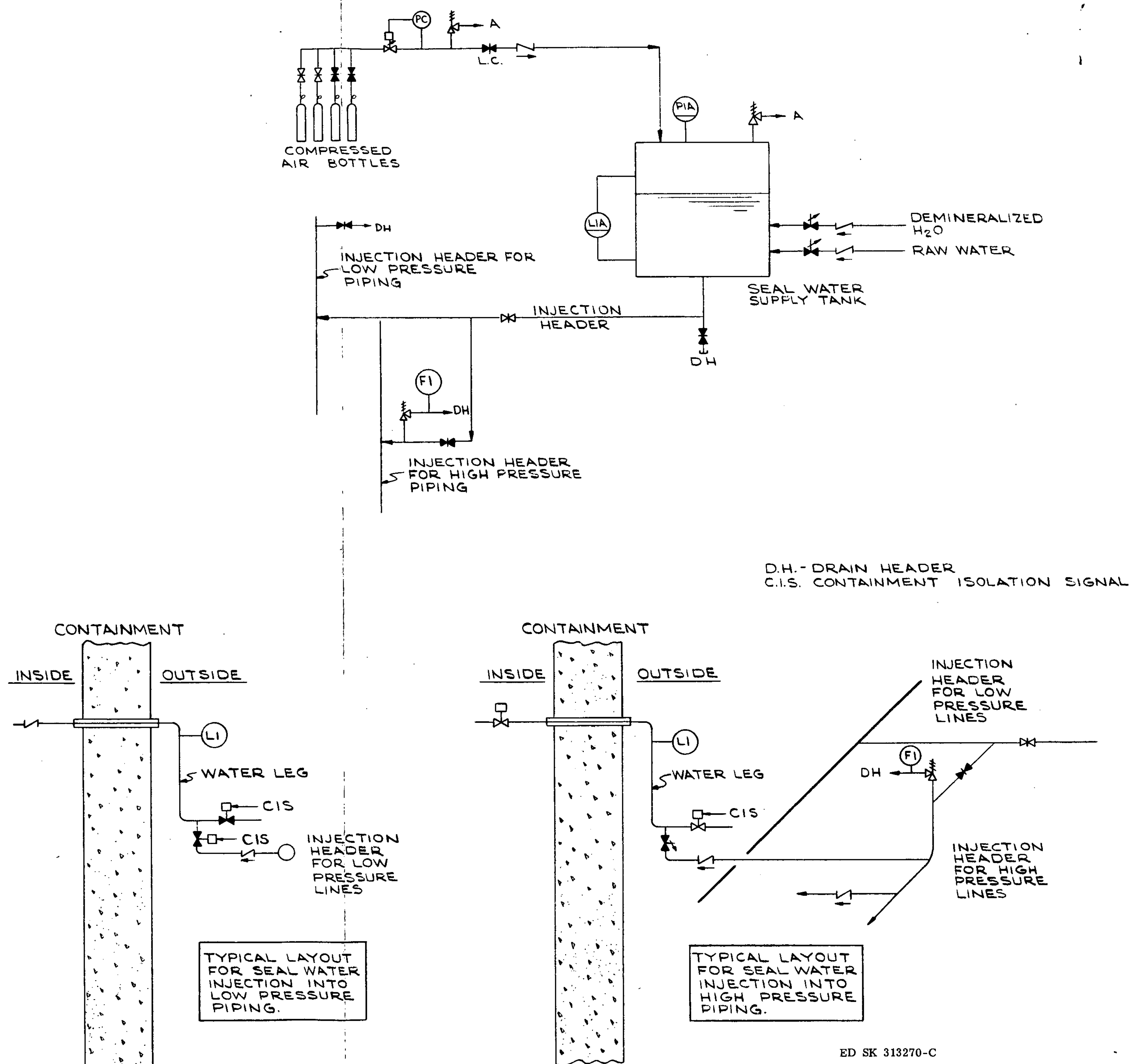
ELECTRICAL PENETRATION

JOINTED CONDUCTOR

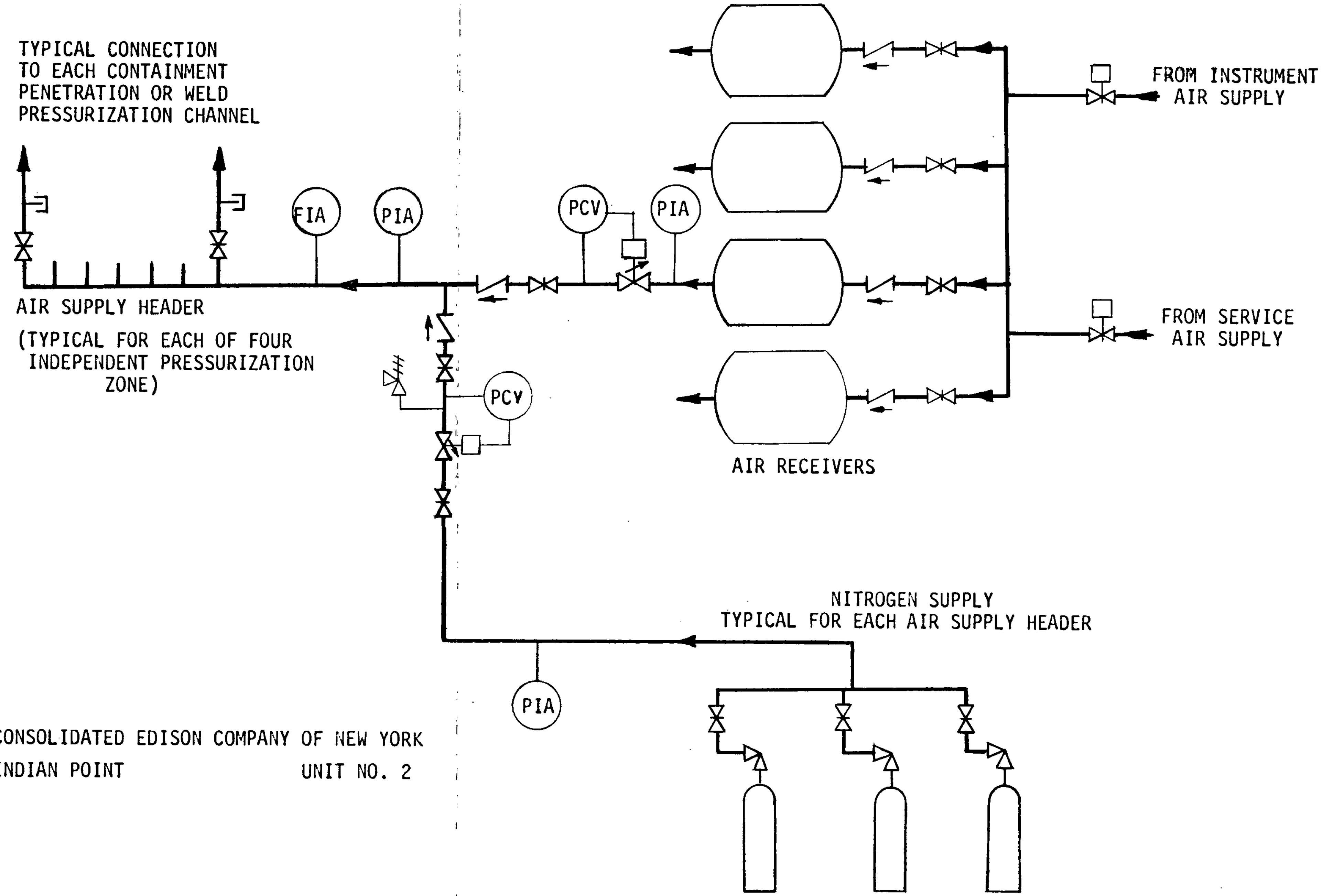
TYPICAL PENETRATION SHOWING PRESSURIZED AREAS
FIG. 5-3b



HATCHES AND FUEL TRANSFER PENETRATION
FIG. 5-4



ISOLATION VALUE SEAL WATER SYSTEM
FIG. 5-5



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PENETRATION AND WELD CHANNEL PRESSURIZATION SYSTEM
FIG. 5-6