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CONVENTIONAL BUILDINGS FOR REACTOR CONTAINMENT

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Atomics International
Canoga, California

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REACTOR TECHNOLOGY

CONVENTIONAL BUILDINGS FOR REACTOR CONTAINMENT

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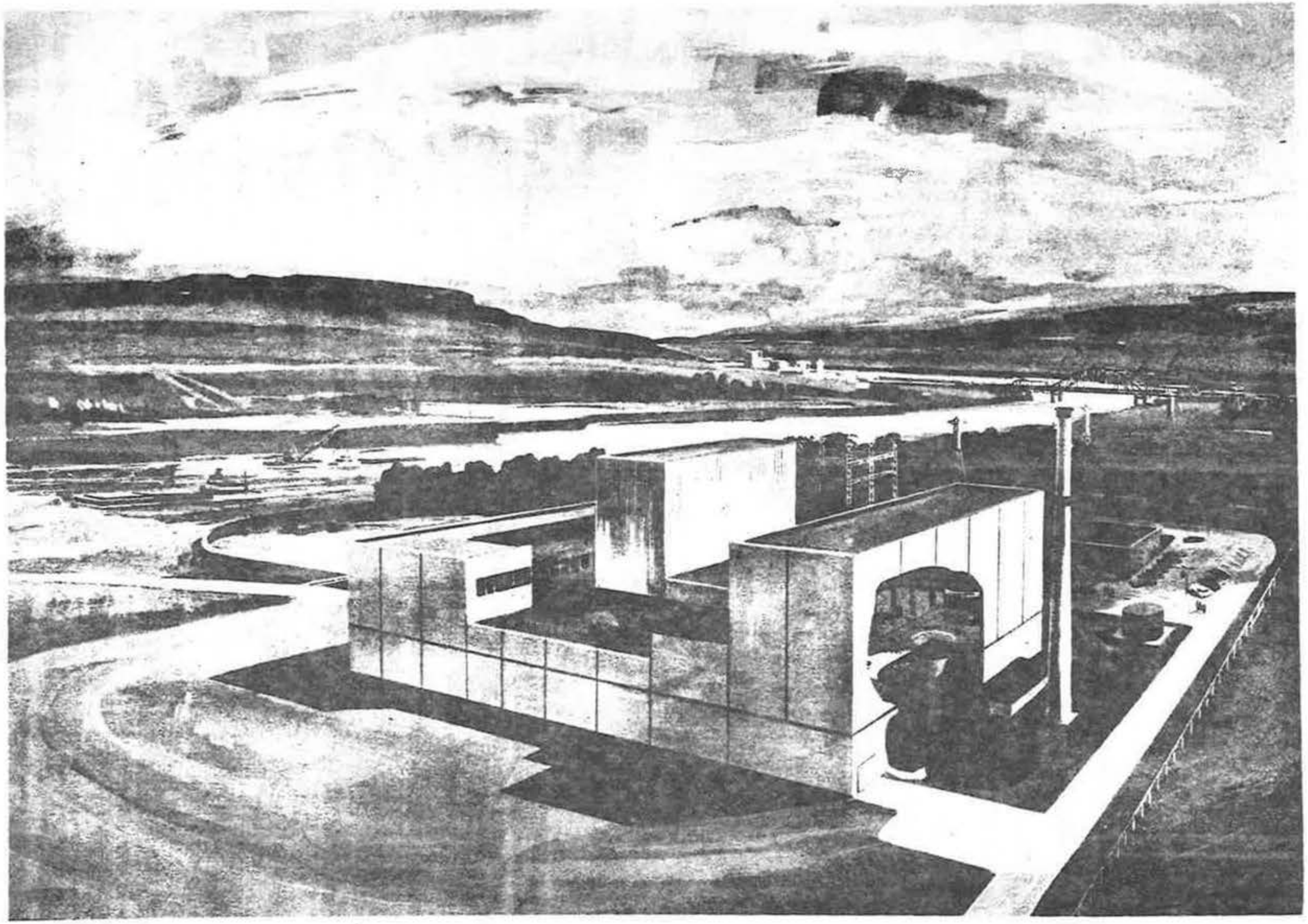
ABSTRACT

Measurements have been made of the air-leakage rates through structural components of conventional metal-panel and concrete buildings which may serve as containment for nuclear reactors. The component measurements included structural penetrations such as doors and louvers as well as materials such as caulking compounds, gaskets, and paints. Specimens were sealed inside of test vessels. Pressure differentials were generated across the specimen with each component installed in the manner of typical construction techniques. From measurements of the pressure difference as a function of time, the volumetric leak rates were computed. After the major leak paths were determined, additional tests were made with improved methods of construction. A detailed description and the results of every completed test are presented.

Leak-rate analytic expressions using the empirical constants resulting from these tests are presented; these predict the flow rates through building components as a function of size, method of construction, and pressure difference. The forms of the equations are such that the total leak rate of a building of any size can be computed for any excess pressure for which the component data are valid. Metal-panel and concrete models were constructed and tested; the results verified the calculations.

Detailed design configurations are presented for applications of the tested specimens in constructing and/or estimating leakage of a real structure. Limitations in the applicability, design and construction of low-leakage conventional structures are delineated. Methods are described for estimating leak rates, locating leak paths, and measuring the leakage rate of completed structures.

Buildings as normally constructed can be expected to leak on the order of 100 percent of their contained volume per hour. With improved construction methods, the leakage rate of large concrete buildings can be reduced to 1 percent of the contained volume per day at 5 psi. They can be constructed to leak less than 0.1 percent per day at 0.5 psi. Large metal-panel buildings can be designed and constructed to leak less than 5 percent per day but may require pressure control devices to prevent normal ambient air temperature and pressure changes from causing pressures which exceed design stress limits. The accuracy of using component test data to estimate leakage of a large structure is about 50 percent.



Conventional Building for Reactor Containment

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I. INTRODUCTION

At the present time in the United States, it is considered prudent to provide a barrier around a nuclear reactor because of elements associated with nuclear hazards. Such a barrier, by reducing the quantity of hazardous materials released to the environment, would protect the public against the ultimate effects of an accident which might otherwise result in the dissemination of harmful radioactivity. The degree of containment required is dependent on the power and type of reactor, the maximum accident hypothesized, the resultant temperature and pressure in the building after the hypothetical accident, and the leak tightness or leak rate of the enclosure.

Current standard safety practices for power reactor construction have, for the most part, utilized a steel shell as the structure needed to contain the reactor system. A steel shell is nonporous and relatively easy to seal, but construction of this type of shell is not standard for power-plant buildings and is expensive. However, structures fabricated in this manner have extremely low leak rates for the pressure differentials postulated after a maximum hypothetical accident. These accidents may be accommodated by conventional power-plant structures if the volume is made large enough to result in lower pressures, although the economics of very large sizes has not been evaluated.

If particular reactor systems can demonstrate that only a low pressure rise will occur at the time of the maximum accident, then conventional buildings made with curtain wall, metal-panel wall, tilt-up concrete, or cast-in-place concrete (modified to reduce leak rate, if necessary) may provide adequate containment at a reduced cost per power plant. Due to greater structural strength, prestressed concrete buildings may also be designed to contain reactors associated with higher pressures without large increases in volume. It is feasible to suppose that the economic savings from the use of more conventional materials and methods of construction in the fabrication of low-leakage buildings can be used in conjunction with measures which can be taken to reduce post-accident pressure so as to compete with the cost of a steel shell containment vessel.

The general objectives of this document are to provide useful and reliable technical data on the air-leakage rates of conventional buildings. It is believed that the document will serve as a guide to architects, designers, field inspectors, contractors, and regulatory authorities in the design, construction, and inspection of low-leakage conventional structures which have leakage characteristics that are predictable and controllable.

The basic leakage mechanisms which govern leakage from buildings and the analytical expressions which describe the flowrate are presented in Section II, Leakage Analysis. The techniques for obtaining, interpreting, and applying experimental data are described for laboratory measurement of building components and for testing completed structures.

Section III, Leakage Data, contains the experimental leakage data which were obtained on the leakage characteristics of various conventional building components, materials, and completed structures. Experimentally measured values of component leak rates are shown as a function of the differential pressure across each specimen. Limitations of the test data and tested component are indicated. Additionally, methods for improving leakage characteristics, and results of reduced leakage measurements of the components are presented. Since the tested specimen is but a representative fraction of the leak paths in a total structure, a prediction of the total leakage of a building involves the knowledge of all leak paths and their dimensions. The experimental program included summing and extrapolation techniques used to determine total building leakage. The validity of these techniques was established by experimental data obtained from representative building models which were constructed and tested.

Section IV, Application Data, includes typical applications of low-leakage conventional building components for reactor containment planning, design, and construction. Predicted leakage characteristics and recommended installation procedures are shown. When possible, the construction and installation procedures are patterned after methods common to the construction industry. Limitations to be observed in applying the data are also indicated.

A comparative economic analysis of various types of reactor containment structures is given in Section V, Economics.

The Appendix contains some special topics, nomenclature used, references, and standards and specifications.

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LEAKAGE ANALYSIS

II. LEAKAGE ANALYSIS

A. LEAKAGE MECHANISMS

1. Basic Formulae

Leakage from or into buildings is generated by: (a) pressure differential from wind as it flows over the building, (b) changes in external or internal air temperatures, (c) changes in barometric pressure, and (d) reactor incidents causing temperature and/or pressure changes in the building. The mechanisms by which fission products are released from buildings are either from mass transport along with the air volume release or from gaseous or solid diffusion. This latter mechanism has not been considered in this report as a means for releasing fission products.

There have been numerous definitions of leak rate from a reactor installation. These many definitions are primarily due to the different methods used for measuring the leak rate and to the different test pressures. Some of these leak-rate methods and test pressures have been summarized by Brittan.* In most discussions, the leak rate is defined as the volumetric loss computed from the rate of change of the pressure in the building, as follows:

$$\frac{dV_s}{dt} = \frac{V_i T_s}{T_i P_s} \frac{dP_i}{dt} \quad , \qquad \ldots(1)$$

where

T_s, P_s = standard temperature and pressure

T_i, P_i = temperature and pressure of building air

V_i = volume of building

V_s = volume of building air at standard conditions.

If dP_i/dt is an appreciable fraction of P_i, then the expression becomes approximate only, since implicit in the formulation is the assumption that flow-rate is linear with pressure differential across the building. This may or may not be true, as will be shown in the following discussion.

*See References, Reactor Housing, 5

Since air leak rates in a building may occur through cracks, orifices, pipes, capillaries, paints, or through porous material such as concrete, there are numerous possible relationships between leak rate and pressure differential. There are even further complications because of the possibility of parallel and series leakage from the building. Some simplified expressions of the relationships of leak rate to other parameters are as follows:*

for orifices

$$q = yca \sqrt{(P_i - P_o) 2 g_c / \rho} \ ,$$

for capillaries

$$q = va = \frac{d^2 a (P_i - P_o)}{32 \mu x} \ ,$$

for porous materials

$$q = am \frac{\overline{P}}{P_i} \frac{(P_i - P_o)}{x} \ ,$$

for paints and film

$$q = am \frac{(P_i - P_o)}{x} \ ,$$

for cracks

$$q = \frac{g_c b^3 L (P_i - P_o)}{12 \mu x} \ ,$$

$$b << L$$

*See References, Flow and Pressure, 1 through 23 where

a = area of specimen

b = crack width

c = coefficient of discharge

d = diameter of capillary

g_c = gravitational conversion factor

m = permeability

q = volumetric leak rate

v = linear velocity

x = thickness of specimen or length of capillary

y = expansion factor

L = crack length

$\overline{P}$ = average pressure

P_i = internal or upstream pressure

P_o = outward or downstream pressure

μ = viscosity of air

ρ = density of gas

From the equations above, it can be seen that flow or leak rates are proportional to pressure differentials of either the 1/2 or first power. The flow also depends on the type of gas, the dimensions of the opening, and the average pressure which exists across the opening. In this report the only interest is in flowrates of air; therefore, most of the parameters other than pressure differential and size of opening are constant. Henceforth, more simplified expressions relating flow and pressure differential can be utilized.

The leakage characteristics of a component or building consisting of combinations of the leak paths can be estimated in a manner which is analogus to electrical impedances. Consider the two simplified expressions:

$$q_{c_i} = C_{c_i} P_{c_i} \quad ,$$

and

$$q_{o_i} = C_{o_i} P_{o_i}^{1/2} \quad ,$$

where

q_{c_i} = volumetric leak rate through a crack

C_{c_i} = empirical constant for flowrate through the crack

q_{o_i} = volumetric leak rate through an orifice

C_{o_i} = empirical constant for flowrate through the orifice

P = pressure difference

The total leak rate through cracks in parallel is:

$$q_c = \sum C_{c_i} P_{c_i} \quad . \qquad \ldots(2)$$

Since

$$q_{c_1} + q_{c_2} + \ldots + q_{c_n} = q_c$$

and

$$P_{c_1} = P_{c_2} = \ldots = P_{c_n} = P_c \quad ,$$

then

$$q_c = P_c \sum C_{c_i} = C_c P_c \quad . \qquad \text{...(3)}$$

Similarly, the total leak rate through orifices in parallel is

$$q_o = C_o P_o^{1/2} \quad . \qquad \text{...(4)}$$

The total leak rate through cracks and orifices in parallel is

$$q_T = q_c + q_o \quad . \qquad \text{...(5)}$$

Since

$$P_c = P_o = P \quad ,$$

$$q_T = C_c P + C_o P^{1/2} \quad . \qquad \text{...(6)}$$

For cracks in series,

$$q_{c_1} = q_{c_2} = \ldots = q_c$$

and

$$P_{c_1} + P_{c_2} + \ldots + P_{c_n} = P_c \quad .$$

The total leak rate is then

$$q_c = \left(\frac{1}{\frac{1}{C_{c_1}} + \frac{1}{C_{c_2}} + \ldots + \frac{1}{C_{c_n}}} \right) P_c \quad . \qquad \text{...(7)}$$

Similarly, the total leak rate of orifices in series is

$$q_o = \left(\frac{1}{\frac{1}{C_{c_1}^2} + \frac{1}{C_{c_2}^2} + \ldots + \frac{1}{C_{c_n}^2}} \right)^{1/2} P_o^{1/2} \quad . \qquad \ldots(8)$$

When cracks and orifices are in series combinations, the total leak rate (using only the empirical constants of each of the individual leak paths and the overall pressure differential) is a very complicated function. A testing program, however, has experimentally demonstrated that an equation of the form

$$q_T = C_1 P + C_2 P^{1/2} \qquad \ldots(9)$$

very closely approximates leakage from complex components of a building structure. This means that the total leak path of a complex component can be considered as though composed of parallel leak paths.

The leak rate per unit leak path of a specific component or structural configuration is

$$q = \frac{q_T}{D} = \frac{C_1}{D} P + \frac{C_2}{D} P^{1/2} \qquad \ldots(10)$$

$$= AP + BP^{1/2} \qquad \ldots(11)$$

where

D = total dimension or number of leak path units

$A = \frac{C_1}{D}$

$B = \frac{C_2}{D}$

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The total leak rate of a component is

$$q_T = Dq \quad , \qquad \ldots(12)$$

and the total leak rate of a building or structure is the sum of all component leak rates,

$$Q = \sum q_T \qquad \ldots(13)$$

2. Calculation of Leakage Characteristics From Leakage Coefficients

a. Pressure Decay and Volume Loss

If the leakage coefficients of a component or a building are known, the leakage characteristics can be calculated using Equation 1, the basic leakage equation*

$$\frac{dV_s}{dt} = \frac{V_i T_s}{T_i P_s} \frac{dP_i}{dt} \quad .$$

But this volume loss rate is precisely equal to the leak rate

$$-\frac{dV_s}{dt} = q_T \quad . \qquad \ldots(14)$$

From Equation 9,

$$q_T = C_1 P + C_2 P^{1/2} = -\frac{V_i T_s}{T_i P_s} \frac{dP_i}{dt}$$

*Definitions of symbols are summarized in the Appendix under Nomenclature.

whence

$$\frac{dP_i}{dt} = -\frac{T_i P_s}{V_i T_s}\left(C_1 P + C_2 P^{1/2}\right) \quad . \qquad \ldots(15)$$

In a building, the pressure difference is

$$P = P_i - P_a \qquad \ldots(16)$$

where

P_a = atmospheric pressure.

If a building is subjected to an initial pressure input, the pressure difference as a function of time, if atmospheric pressure is constant, is

$$P(t) = \left[\left(\frac{C_2}{C_1} + \sqrt{P(0)}\right) e^{-\frac{T_i P_s}{2V_i T_s} C_1 t} - \frac{C_2}{C_1}\right]^2 \qquad \ldots(17)$$

where

P(0) = the initial pressure difference.

When $C_1 = 0$,

$$P(t) = \left[\sqrt{P(0)} - \frac{T_i P_s}{2V_i T_s} C_2 t\right]^2 \quad . \qquad \ldots(18)$$

When $C_2 = 0$,

$$P(t) = P(0) e^{-\frac{T_i P_s}{V_i T_s} C_1 t} \quad . \qquad \ldots(19)$$

In component testing, the pressure difference across a specimen is

$$P = P_i - P_o \qquad \ldots(20)$$

where

P_i = pressure on upstream side

P_o = pressure on downstream side.

When the downstream side of a test cell is open to the atmosphere (open cell), $P_o = P_a$ and the pressure difference across the test specimen as a function of time is given by Equations 17, 18, and 19.

For components tested in an isothermal, constant temperature closed system (closed cell),

$$\frac{V_i}{V_o} P_i + P_o = K \qquad \ldots(21)$$

where

V_i = volume of upstream side of test cell

V_o = volume of downstream side of test cell.

Then

$$P = \frac{V_i + V_o}{V_o} P_i - K \qquad \ldots(22)$$

and the pressure difference across the test specimen as a function of time is

$$P(t) = \left[\left(\frac{C_2}{C_1} + \sqrt{P(0)}\right) e^{-\frac{T_i P_s}{V_i T_s} C_1 t} - \frac{C_2}{C_1}\right]^2 . \qquad \ldots(23)$$

When $C_1 = 0$,

$$P(t) = \left[\sqrt{P(0)} - \frac{T_i P_s}{V_i T_s} C_2 t\right]^2 \qquad \ldots(24)$$

When $C_2 = 0$,

$$P(t) = P(0)e^{-\frac{2T_i P_s}{V_i T_s} C_1 t} \qquad \ldots(25)$$

Table II-1 shows the basic equations which describe building or test cell pressure decay and volume loss from leakage coefficients.

b. Pressure Rise and Volume Loss

Consider an internally generated linear increase of pressure in a building due to either a temperature increase or pressure increase. Then, analogous to Equation 15, the net rate of change of pressure with time is

$$\frac{dP_i}{dt} = \alpha - \frac{T_i P_s}{V_i T_s}\left(C_1 P + C_2 P^{1/2}\right) \qquad \ldots(26)$$

where

α = rate of increase of pressure.

When $C_2 = 0$, the pressure difference as a function of time is

$$P(t) = \frac{\alpha V_i T_s}{T_i P_s C_1}\left(1 - e^{-\frac{T_i P_s}{V_i T_s} C_1 t}\right) \qquad \ldots(27)$$

when the atmospheric pressure is constant. The fractional volume lost from the building is

$$\frac{\alpha V_i T_s}{T_i P_s C_i P_a}\left(1 - e^{-\frac{T_i P_s}{V_i T_s} C_1 t}\right) . \qquad \ldots(28)$$

TABLE II-1

PRESSURE DECAY AND VOLUME LOSS FROM LEAKAGE COEFFICIENTS

Parameter	Building or Open Test Cell	Closed Test Cell (upstream side)
Pressure difference	$P(t)$	$P(t)$
Pressure	$P(t) + P_a$	$\left[P(t) + K\right] \frac{V_o}{V_i + V_o}$
Pressure difference loss	$P(0) - P(t)$	$P(0) - P(t)$
Pressure loss	$P(0) - P(t)$	$\left[P(0) - P(t)\right] \frac{V_o}{V_i + V_o}$
Volume loss	$\frac{V_i T_s}{T_i P_s}\left[P(0) - P(t)\right]$	$\frac{V_i T_s}{T_i P_s}\left[P(0) - P(t)\right] \frac{V_o}{V_i + V_o}$
Fractional loss	$\frac{P(0) - P(t)}{P(0) + P_a}$	--

Definitions of symbols are summarized in the Appendix under Nomenclature

3. Determination of Leakage Coefficients from Pressure Decay Characteristics

The procedure used in determining component or building leakage coefficients is essentially the opposite of predicting the leak rate or pressure decay when the coefficients are known. In the determination of leakage coefficients, the decay of pressure with time is observed and, therefore, the differential pressure across the component or building at any time is known. Using the experimental data, the leakage coefficients are determined by fitting Equation 15 by least squares or graphical techniques. In a building or open cell, from Equation 16,

$$\frac{dP_i}{dt} = \frac{dP}{dt} \qquad \text{...(29)}$$

when the atmospheric pressure is constant. In a closed cell, from Equation 22,

$$\frac{dP_i}{dt} = \frac{V_o}{V_i + V_o} \frac{dP}{dt} \quad . \qquad \text{...(30)}$$

To facilitate measurement and minimize effects of ambient temperature fluctuations, a pressure-reference system can be installed in a building or upstream side of a test cell. Measurements are made of the pressure difference between the reference system and the building or upstream side of the test cell. Thus, if a reference system is used,

$$\frac{dP_i}{dt} = \frac{d(P_i - P_r)}{dt} \quad , \qquad \text{...(31)}$$

where

P_r = pressure in reference system.

When using a reference system, the pressure difference across a building or specimen in an open cell is measured or calculated from

$$P = (P_i - P_r) - (P_a - P_r) \quad . \qquad \text{...(32)}$$

In a closed cell with a reference system, the pressure difference across a specimen is measured or calculated from

$$P = (P_i - P_r) - (P_o - P_r) \quad \ldots(33)$$

where P_o and P_i are related as shown in Equation 21.

B. MEASUREMENTS OF COMPONENTS

1. Measurement System Description

The majority of components tested were measured in either of two leak test cells. The air leakage rates of building materials and components were measured at various pressure differentials up to 10 psi in both a large 512-ft^3 test cell and small 3.2-ft^3 test cell.

The large test cell design, shown in Figure II-1, consists of two 10-ft-diam hemispheres constructed of 3/16-in. steel. The total internal volume of

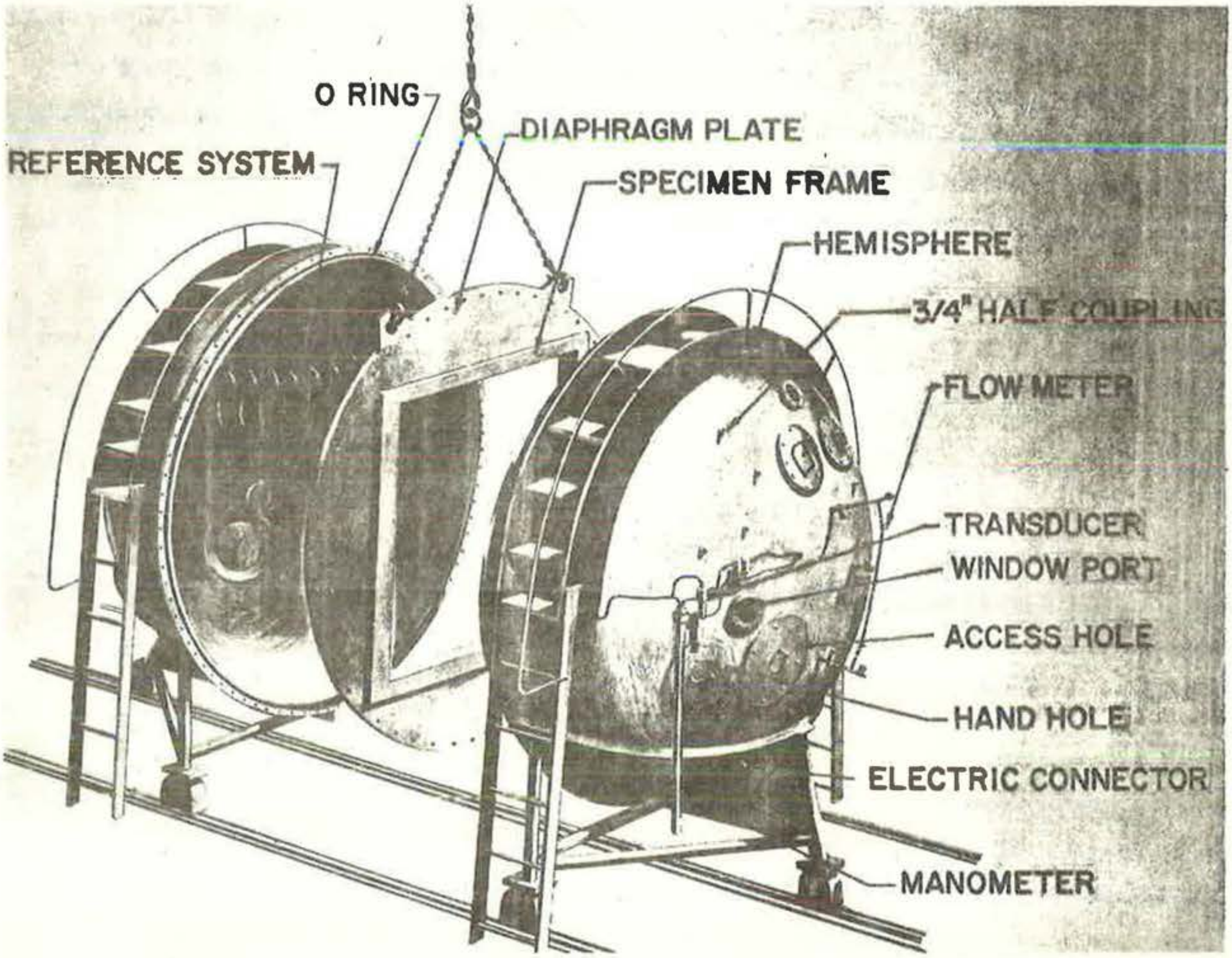

Figure II-1. Exploded View of Reactor Housing Test Cell

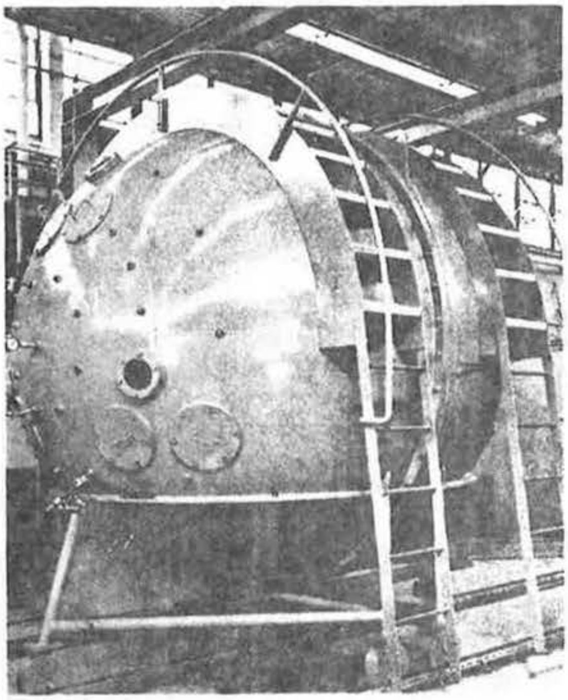

Figure II-2. Large Test Cell

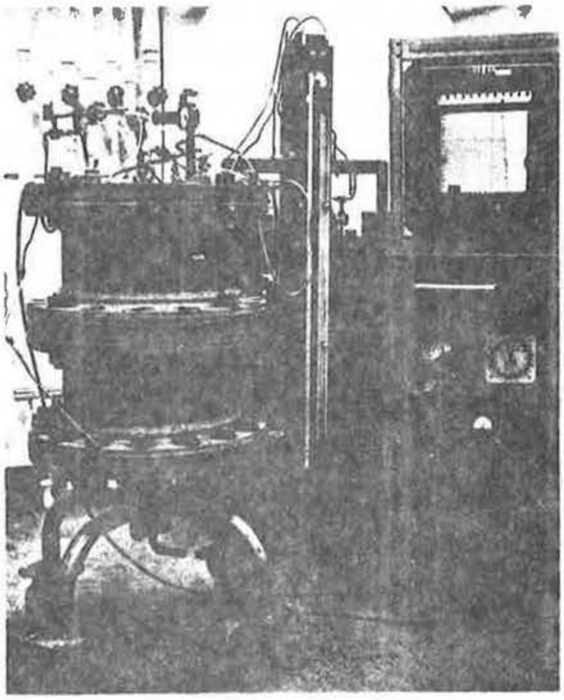

Figure II-3. Small Test Cell

the test cell is 512 ft^3; the total weight is four tons. Figure II-2 shows the assembled test cell, which has been designed so that the air leak rate through test specimens can be measured as a function of pressure differential. A photograph of the small test cell is shown in Figure II-3.

In order to better simulate building leakage, wherever possible, full-size or large components were tested. Test specimens are mounted on one of three 10-ft-diam by 1/2-in.-thick steel diaphragm plates. Each plate has a 6-ft-square mounting frame made respectively of 4-, 8-, and 12-in. channel iron welded symmetrically in the plates (Figure II-1).

Each hemisphere in the large cell has five 10-in.-diam handholes, one 18-in.-diam access hole, three 6-in. windows, and sufficient 3/4-in. nominal pipe thread half-couplings located for measuring pressure and flowrates (Figure II-1). Each of the hemispherical heads is supported by a saddle on three legs with 8-in.-diam grooved wheels. These heads roll on three tracks, each 30 ft long, which permit approximately 10 ft of travel for each head. Hemisphere separation in the open position is approximately 10 ft. This space is used to insert the test specimen, which is mounted on a diaphragm plate, into the sphere. The tracks are anchored to the concrete floor by tiedown clips, and are shimmed to ±1/8-in. tolerance. Ladders with handrails and nonskid rungs are provided for access to the bolts at the top of the sphere. A 2-ton bridge with trolley hoist is located above the test cell for mounting the test specimen into the sphere, as shown in Figure II-1.

Surrounding the opening of each hemisphere head is a 2-in. -thick, welded ring flange of 114-3/8-in. ID and 119-1/2-in. OD. A 115-1/2-in. -diam neoprene O-ring is inserted in each flange, and the 1/2-in. diaphragm plate is bolted between the two hemispheres through 50 equally spaced holes. Each port is also provided with a ring insert welded to the face of the sphere. The small test cell has a maximum specimen size capability of 1-ft^2 and is formed by two metallic cylinders into which one of several 1/2- to 2-in. -thick plates may be O-ring mounted.

2. Preparing Specimens for Test

A number of preliminary tests were made to eliminate structural leaks in the test unit. All welds and joints in the cell surface were soap-bubble tested at 2 psi pressure. The welds between the diaphragm plates and mounting channels were tested by closing the opening in the plate and adding Freon under pressure to one hemisphere. Freon leaking through the welds was detected by means of a halogen leak detector. All detected leaks were corrected either by rewelding or painting with Glyptal paint before tests were made.

Each plate used to close the 6- by 6-ft openings in the three diaphragm plates of the large cell was also used to mount a test specimen. These support plates consisted of 3/4-in. -thick steel, 6-1/2 by 6-1/2 ft. Sixteen nuts were welded to each plate at positions which would fit within the 6- by 6-ft opening in the diaphragm plates. Threaded studs were supplied in lengths to fit the 4-, 8-, or 12-in. channels which were part of the diaphragm plates. A flat rubber gasket was cemented to the support plate to form a seal between this plate and the diaphragm plate. A layer of vacuum grease was applied to the rubber gasket, and a support plate was bolted to each of the diaphragm plates by means of the correct studs and clips. Figure II-4 shows a typical specimen mounted on a support plate.

For specimens such as doors and hatches, a fitted angle frame was welded to the support plate, and a hole was cut inside this frame to allow air

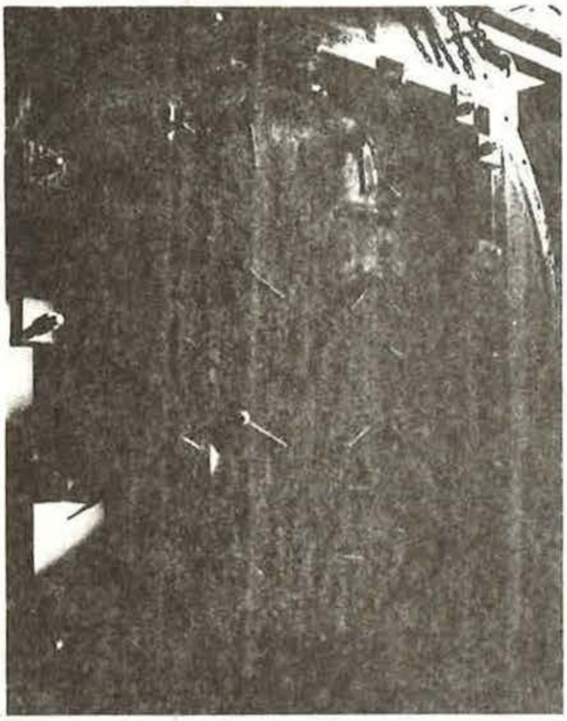

Figure II-4. Typical Specimen Mounted on Support Plate and Installed in Diaphragm Plate

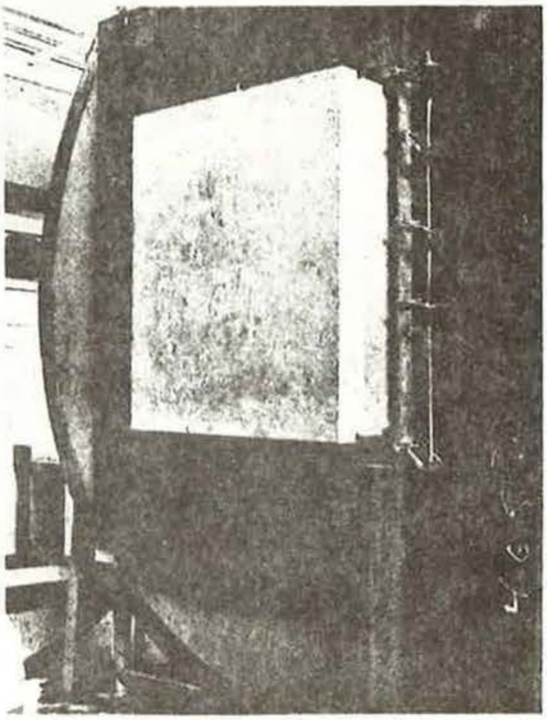

Figure II-5. Roof Hatch Installed on Support Plate Showing Clamping Arrangement

movement. All welds were filled and covered with caulking compounds. The specimen was clamped to the angle frame with C-clamps on a rubber gasket (see Figure II-5). The support plate previously mounted on the diaphragm plate was then installed in the cell. Freon gas was added under pressure to one hemisphere, and the joints between the specimen and the mounting frame were tested with a halogen detector to ensure the absence of all undesired leaks or to determine the location of the leak through the specimen. The leakage characteristics of the specimen were measured only if there were no other leaks present other than through the component being tested.

Materials such as metal wall panels were cut to fit a 2- by 4-ft channel frame. The panel was mounted in the frame with Epoxy potting compound poured in thin layers until all four edges were completely covered (Figure II-6). The frame was then attached to a blanking plate, using clamps and rubber gasket or Apiezon sealant in a manner as shown in Figure II-5. Similar tests to those described above were made to determine the presence of unwanted leaks before these specimens were evaluated.

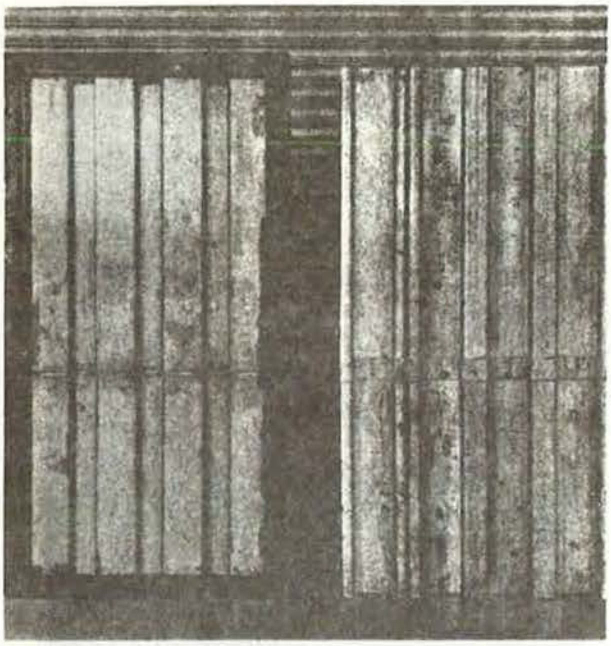

Figure II-6. "Robertson" Metal Wall Panel and Mounting Frame

Concrete slabs and similar wall sections were made in 6- by 6-ft sections, and were installed in the openings of the diaphragm plates, as shown in Figure II-7. Smaller 1-ft^2 specimens were tested on diaphram plates in the small test cell, as shown in Figure II-8. The specimens were sealed in place by means of Epoxy and Thiokol sealing compounds.

To facilitate the mounting of test specimens, dollies were built to hold a diaphragm plate and support plate assembly in the vertical position. One specimen may be under test while two more are being prepared for test in another area. When a new specimen is ready, the dolly is wheeled into position under the hoist. This arrangement allows continual testing of different specimens with a minimum downtime for the cell.

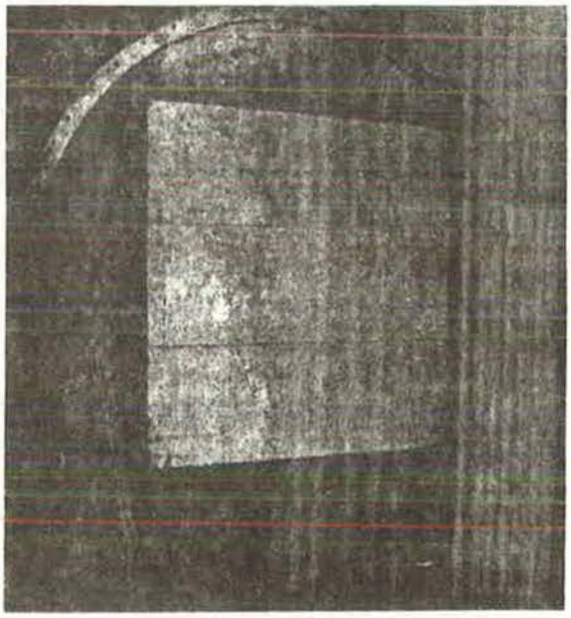

Figure II-7. Concrete Specimen Installed in Diaphragm Plate and Dolly Used to Support Plates

3. Instrumentation

A rotary compressor was used to develop pressure or vacuum in either hemisphere, depending on the direction of leakage to be studied. For some tests, it was desired to measure the pumping rates required to develop a given pressure differential. Brooks Full-view rotameters of various capacities were used for this purpose.

Since many readings of pressure vs time were necessary, data were taken on a strip chart recorder. Strain

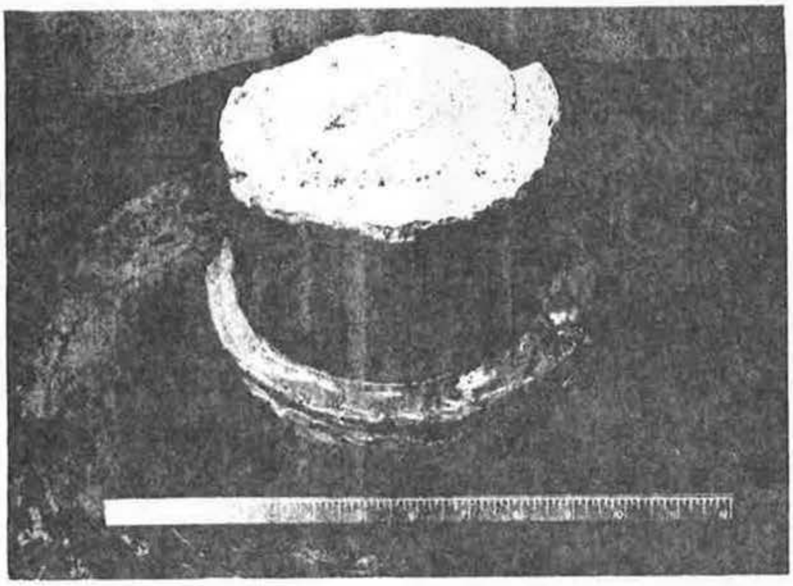

Figure II-8. Concrete 1-ft^2 Section on Diaphragm Plate

gage differential transducers were used to measure the pressure difference between the low-pressure hemisphere and the reference system. The pressure difference between the two hemispheres (the driving pressure across the test specimen) and the pressure difference between one hemisphere and the atmosphere were also measured. The transducer outputs were fed to a control unit designed to record them, in order, for 15 sec. The recording cycle was adjustable within a range of from 1 to 120 min with one timer and 15 min to 7 days with another. It was, therefore, possible to record pressure differentials from 10 to 0 psi over long time periods.

The test cell was originally installed in an area not thermally stable. Ambient temperature fluctuations were reflected as pressure changes in the cell and between the two hemispheres. A number of temperature measurements taken inside the cell showed a vertical thermal gradient which followed external temperature changes. To compensate for thermal effects, reference systems consisting of 50 ft of 3/8-in. copper tubing were suspended in each hemisphere. The position of these coils, shown in Figure II-9, was determined by measuring the pressure difference between the coil and cell under varying ambient temperatures. The coil was moved until no measurable pressure difference occurred between the reference and cell or the ambient temperature ranged from 60 to

27<

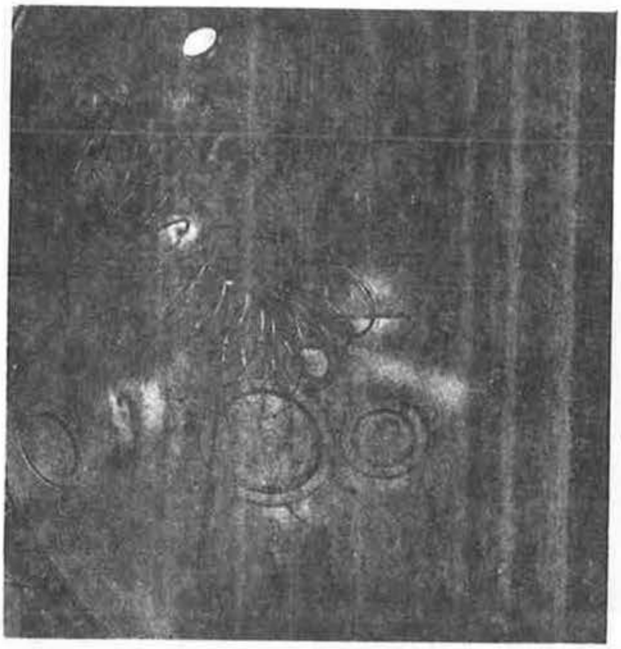

Figure II-9. Reference Coil Mounted in Position

90°F. Although "no measurable" pressure difference between a hemisphere and its reference was observed, the nature of the measuring system implies that no unknown temperature difference exists between the two hemispheres. Such difference in temperature would lead to a pressure response at the transducers. Temperatures were recorded when extremely low leak rates were measured.

During the latter phase of this program, the entire test assembly previously described was moved outside. To minimize the effect of temperature differences between each hemisphere, a 3-in. layer of insulation was applied to the test cell. Also, a portable insulating dome, which rode along the same track as the leak test cell, was used as a cover while tests were made (see Figure II-10).

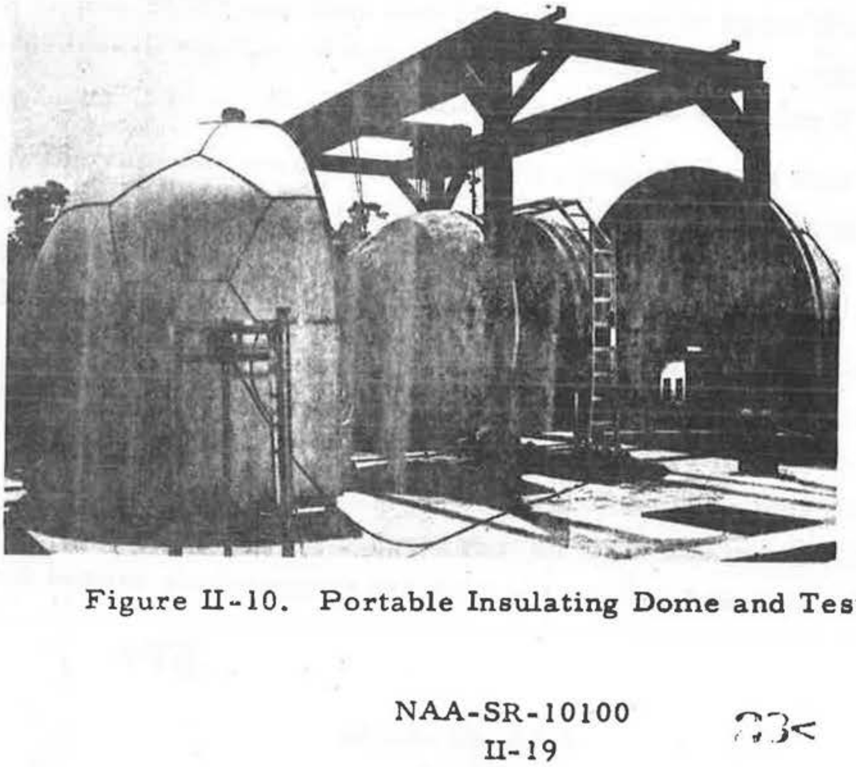

Figure II-10. Portable Insulating Dome and Test Cell

4. Determining Leakage Coefficients

The majority of components are tested by first evacuating or pressurizing the upstream side of the test cell until the desired pressure differential is obtained across a specimen. After allowing a suitable time for the system to reach equilibrium, the recording system is started and the pressure differential is recorded as a function of time.

When fast-leaking specimens are measured, the downstream side of the test cell is allowed to remain at atmospheric pressure. One of the following procedures is then followed:

a) A desired pressure differential is developed across the specimen. The decay of pressure vs time is then recorded and the leak rate is directly proportional to the change of pressure differential (Equation 15).

b) A constant flow-rate of air is removed or introduced into the closed hemisphere until an equilibrium pressure differential results. These data are taken at various flow rates and equilibrium pressures to obtain a flow rate vs pressure curve.

If a reference system is used, the change of pressure differential between the cell and the constant reference pressure is proportional to the leak rate (Equation 31).

When a component is measured in the closed test system, the leak rate is proportional to the change of pressure differential across the specimen (Equation 30). Since the two halves of the test cell are equal in volume,

$$V_i = V_o \quad ;$$

then, from Equation 22,

$$P = 2P_i - K$$

and

$$\frac{dP_i}{dt} = \frac{1}{2}\frac{dP}{dt} \quad .$$

In a closed cell with a reference system, the leak rate is proportional to the change of pressure differential between the cell and the reference pressure (Equation 31). The pressure difference across a specimen is determined by measurement or from Equation 33.

The leakage coefficients are determined by fitting the experimental data to Equation 15 using least squares or graphical techniques.* If either coefficient is zero, the data are fitted to reduced forms of Equation 15.

C. TESTING COMPLETED STRUCTURES

A completed structure which is to be leak tested is first inspected for obvious sources of leaks. Following correction of any such sources the building is tested to determine the leakage. In the event that leakage exceeds design specifications, various methods of leak detection can be employed. The test equipment and procedures outlined below have been used successfully in determining building leakage.

1. Methods of Leak Detection

The term "leak detection" applies to the location of the leak in the building with sufficient accuracy so that repairs can be made. A number of leak detection methods have been applied in various laboratories; however, most of these methods are suitable primarily for a rather limited range of pressures. The systems discussed are those suitable for low-pressure leak detection.

a. Rate-of-Rise

This method is not satisfactory for routine leak hunting as it is very slow in application. However, it may be used for determining whether or not some portion of the building is contributing more to the leak than others. The

*An example of the calculation is given in the Appendix.

method is essentially as follows: The building is partially evacuated and then isolated from the pump by means of appropriate valves. The rate of pressure rise is then observed by means of an appropriate measuring device, preferably a continuous recording instrument.

Repeated measurements of the rate-of-rise of the pressure as various potential leak paths are sealed off can give an indication of a potential leak. Another advantage of this method is that knowledge of the overall leak rate of the system is available as each leak path is sealed. This allows one to determine the contribution that the leak path had been making to the entire building system, provided no other paths have been created by cycling.

b. Pressurized System

In this method of leak detection, the pressure inside the building is raised above atmospheric so that gas will leak to the outside. A soap solution may then be painted over the surface of the system being studied, and when a leak is covered, a bubble will form. This method may also be used as a means of observing the rate of pressure loss in a manner similar to that described above. This method of detection is particularly adaptable to roof inspection. The entire roof may be immersed in about 0.5 in. of water, after which air pressure leaking out of the building causes observable bubbles in the water solution itself. Leaks can often be located with this method by the use of listening devices. In some cases, increased sensitivities can be obtained by use of specialized frequencies. Another application of the pressure method is to introduce a halide gas into the building (Freon is the best), and to probe the surface of the system with a suitable leak detector.

c. Partial Vacuum

This method involves the application of a soap solution inside the building with the system partially evacuated. It has restricted possibilities because of pressure limitations imposed by the necessity of personnel occupancy in the low-pressure regions (3/4 atm inside a building requires the use of oxygen masks for personnel occupancy). Soap solution is applied to the inside surface of the system, and the formation of soap bubbles is observed. This method can also be used in conjunction with the rate-of-rise method previously discussed. However, the leakage paths, which are characterized during a partial vacuum, may change in leakage value and location when the building is pressurized.

d. Sealing Material

The procedure here is to paint, brush, spray, or caulk the suspected portion of the system until a rate of change of pressure inside the building indicates that a leak has been covered. The indicating device may be any pressure sensitive type. The sealing systems may temporarily or permanently seal the leaks.

e. Vacuum Box

This method is similar to that of evacuating the building and placing a soap solution over the particular section of building being tested. The advantage of this method is that personnel do not have to be enclosed inside of an evacuated system. The frequent difficulty encountered is that of adequately sealing the vacuum box around the section being tested. The vacuum box may be used in conjunction with all of the typical vacuum detection techniques.

2. Test Equipment

The equipment and procedure outlined below for pressure testing a complete building structure and for determining leakage is intended to be illustrative only.

a. Pressure Reference System

The pressure reference system consists of an arrangement of 1/2-in.-diam copper tubing, located at various positions in the building, which most nearly exhibit the same effective temperature readings as the building atmosphere. The reference system must be checked for leak tightness since no leakage of the system can be tolerated. The reference tubing is only installed if the reference method is used in calculating the building leakage.

b. Pressure Sensing Instrumentation

Pressure information must be available between (1) the reactor building and the pressure reference system, and (2) the reactor building and outside atmosphere. The pressure sensing device should be accurate at least

±0.03 in. of water or equivalent. The accuracy required is dependent on the leakage rate of the building, test period, number of pressure readings, method of calculating the leakage, etc.

c. Temperature System

Temperature sensing devices are placed at various positions in the reactor building (as with the pressure reference system) which will most likely show the best relative temperature of the building environment. The accuracy of the temperature devices should be nearly the same value as the required accuracy of the pressure sensing device. Assuming the pressure reference system is a true gas thermometer, the need for temperature systems is reduced when the reference method is used in calculating the building leakage.*

d. Humidity Sensing Device

If steam leaks occur in the building during the test or if water condenses out of the air, the change in water vapor pressure will indicate an error in the building leakage rate. Accurate wet and dry bulb temperatures must be made at all times.

e. Circulation Blowers

Circulation blowers should be used if the type of building tested requires a circulation of air and if the heat from the fan motors does not contribute substantially to local area hot spots.

3. Test Procedure

a. Pressurizing the Reactor Building

Dry air is slowly added to the building until the required pressure has been reached. The building is held at this pressure until an equilibrium condition has been obtained. For a very low leakage building, the equilibrium period may take several hours. The reference system must be open to the reactor building atmosphere during this period. Blowers may be used during this period.

b. Recording Data During Pressure Decay Run

1) At the start of the run, the reference system must be closed to the reactor building atmosphere.

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*Errors in the reference system method due to temperature variations are discussed under References, Reactor Housing, 5 and 24.

2) The following data must be obtained at 1/2- or 1-hr intervals for low leakage buildings and more frequently for buildings of faster leak rates:

a) All temperatures from sensing devices in temperature system

b) Humidity inside of reactor building

c) Pressures between inside of building and reference system and between the inside of the building and outside atmosphere.

c. Leak Rate Calculations

The vapor pressure is determined by standard humidity vapor pressure curves (or equation) and all pressures below are corrected for water vapor pressure.

If the measurements of the pressure decay extend over an appreciable range of pressure, the leakage coefficients of the building can be determined by curve fitting methods. Since the leak rate is directly proportional to the internal pressure differential (Equation 15), the fractional loss of contained air is

$$\frac{P_i(0) - P_i(t)}{P_i(0)}$$

where

$P_i(t)$ = pressure in building

$P_i(0)$ = initial pressure in the building

$P(t)$ = pressure difference from Equation 17.

If the building pressure is measured, the fractional loss is

$$1 - \frac{T_i(0)}{P_i(0)} \frac{P_i(t)}{T_i(t)} \qquad \ldots(34)$$

34<

where

$P_i(t)$ = pressure in the building

$T_i(0)$ = initial temperature in the building

$T_i(t)$ = temperature in the building.

Using the reference system method in low-leakage containment buildings, the fractional loss of contained air is

$$\frac{T_i(0)}{P_i(0)}\left(\frac{P_i(0) - P_r}{T_i(0)} - \frac{P_i(t) - P_r}{T_i(t)}\right) \quad \ldots(35)$$

where

P_r = reference pressure (negligible temperature lag).

CONTENTS
LEAKAGE DATA

LEAKAGE DATA SHEETS

III. LEAKAGE DATA

A. PURPOSE OF LEAKAGE DATA

A reactor containment structure must meet the pressure and leakage requirements established by the safety analysis of the reactor. The structure must also be capable of being constructed at low cost and with long-term reliability while still meeting engineering standards. Curtain wall, metal-panel, and concrete structures can provide such containment provided that the pressure and leak-tightness capabilities of these more conventional materials and construction methods are known. This section contains the experimental leakage data which were obtained to permit the planning and design of conventional structures for low-leakage reactor containment purposes.

B. METHODS OF OBTAINING LEAKAGE DATA

Measurements were made of the air-leakage rates through structural components of metal-panel and concrete buildings which may serve as housing for nuclear reactors. Components were tested to determine leak paths in metal and concrete structures. These paths occur at joints and through porous materials such as concrete. General components were tested such as doors, louvers, valves, caulking materials, paints, etc. In addition, miscellaneous components were tested such as gaskets, seals, screws, etc. After the major leak paths were determined, additional tests were made with improved methods of construction.

Specimens were sealed inside of test vessels and pressure differentials generated across them. Tests were made with each component installed in the manner of typical construction techniques. From measurements of the pressure differential as a function of time, the empirical leakage coefficients* were determined which can be used to predict the flow rates through building components as a function of size, method of construction, and pressure differential. Metal-panel and concrete models were constructed and tested to check the methods which were developed for estimating leak rates, locating leak paths, and measuring the leakage rate of completed structures. A detailed description and the results of every completed test are included in this section.

*Methods of determining leakage coefficients from test data are given in the Appendix.

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The techniques for obtaining, interpreting, and using these data are presented in Section II. The application of these data is provided in Section IV to enable the calculation of anticipated leakage and to permit the design and construction of a structure to meet some specified leakage.

C. LEAKAGE DATA SHEET DESCRIPTION

The leakage data are presented in a format to facilitate accessibility. All components are grouped within four basic categories: A. General, B. Concrete, C. Metal Panel, and D. Miscellaneous. A complete table of contents of all components within a basic category has been placed at the beginning of each category group. Each component has been given a title which either describes the component function or is the actual name of the specimen tested. The experimental method used and all the data available for each component are placed on an individual Leakage Data Sheet.

Each data sheet is assigned a code number to permit easy reference and identification. Leakage Data Sheets are designated LDS, followed by a letter which represents the category group of the tested specimen. The category letter is followed by a number which indicates the component tested as it is sequentially listed within the category. When more than one variety of a component was tested, it is identified by a parenthetical number following the component number. For example: LDS C-3(2) is a Leakage Data Sheet, Category C (Metal Panel), Data Sheet 3 (Edge Laps), Test 2 (Multiple Caulking with Crimping).

Incorporated into each Leakage Data Sheet, when applicable and available, is the following information.

1) Component (name or description)

2) Purpose (of test)

3) Test specimen description

    a. Test and mounting design

    b. Leak path description

    c. Manufacturer and type

4) Leak test data

a. Empirical leakage coefficients

b. Leak rate vs pressure curves

c. Applicable pressure range

d. Extrapolation

5) Limitations

6) Recommendations.

The empirical leakage coefficients are defined in Section II. The leak rate per unit leak path of each component or structural configuration is

$$q = AP + BP^{1/2} \quad . \qquad \ldots(11)$$

On the Leakage Data Sheets, the empirical leakage coefficients, A and B, have the following units:

A = cfm per unit leak path per in. of water pressure

B = cfm per unit leak path per in.$^{1/2}$ of water pressure.

CONTENTS
LEAKAGE DATA SHEETS

A. GENERAL

LEAKAGE DATA SHEET	No. A-1	Page 1 of 2

COMPONENT

Bulkhead Fitting

PURPOSE

Reduction of air leakage through conduit pipe penetrations in metal wall buildings

TEST SPECIMEN DESCRIPTION

Test and Mounting Design: See Figure A-1.

Description of Specimen: A 1-in. pipe bulkhead fitting has a 1-1/2-in.-diam neoprene O-ring mounted on each side of sheet metal. Both O-rings are screwed into compression against sheet metal.

Installation Procedure: Standard; see Figure A-1 for detail.

Leak Path Description: The leak paths are around the neoprene O-ring and around the threads between the pipe insert and the bulkhead fitting.

Manufacturer and Type: M. M. Myers Electric Products, Inc.; Scru-Tite.

LEAK TEST DATA

Empirical Constants: Value for each 1-in. pipe fitting
$A = 2.0 \times 10^{-8}$ $B = 0.0$

Applicable Pressure Range: Test data were up to 10 in. of water, as described. Further experiments were performed at 5 psi, using a different type of mounting design. The leakage rate remained the same.

Extrapolations: Assuming that a proper seal is obtained around the pipe threads, the leak rate for pipe fittings greater than 1-in. should be proportional to the diameter of the O-ring. The type of tape used was "Thred Tape Pipe Joint Sealer," a Teflon tape by Crone Packing Co., Morton Grove, Del. (see Figure A-1).

LIMITATIONS

Opening through bulkhead must be corrected size.

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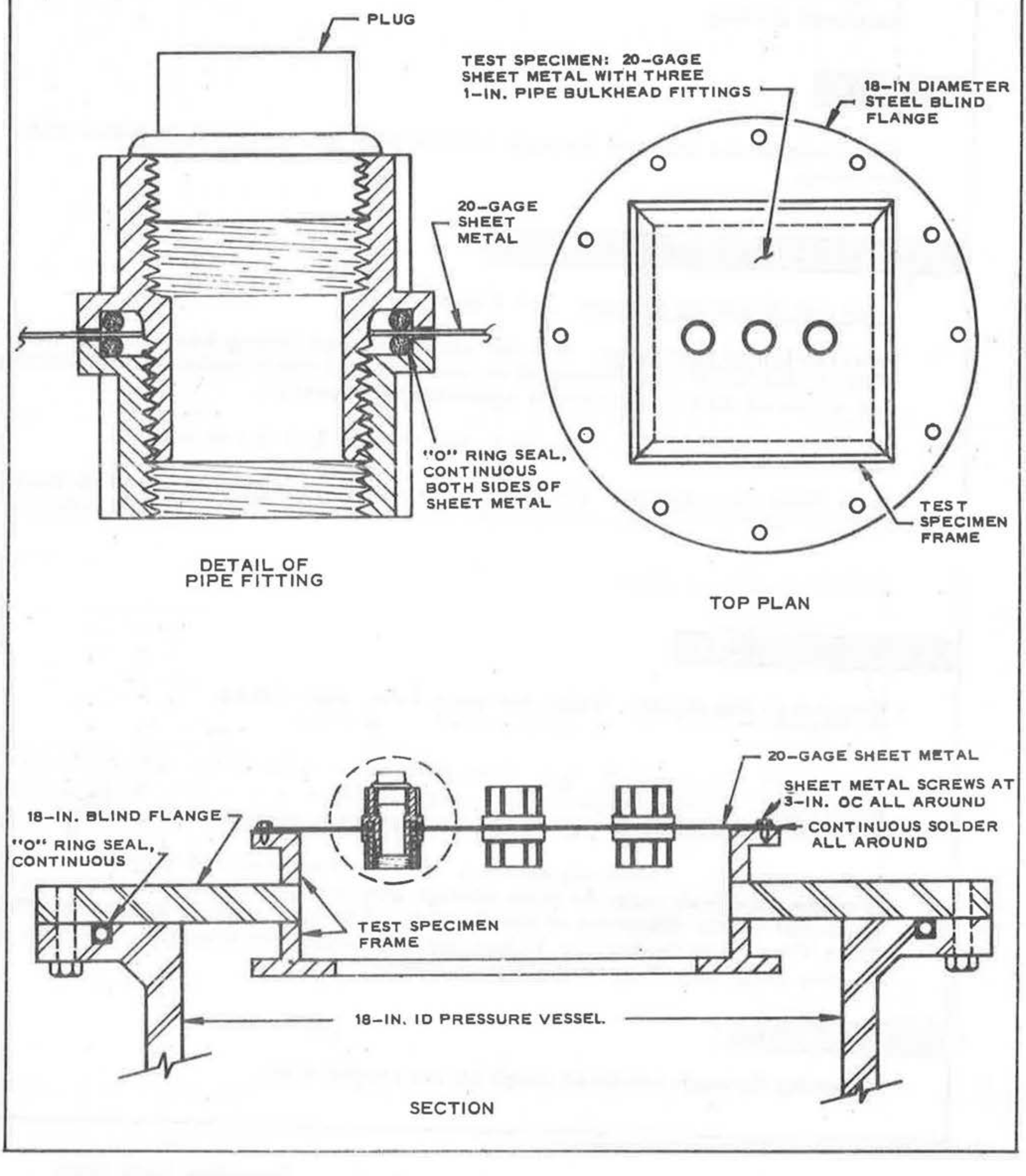
LEAKAGE DATA SHEET	Figure A-1	Page 2 of 2



LEAKAGE DATA SHEET	No. A-2	Page 1 of 2

COMPONENT

Butterfly Valve

PURPOSE

Determination of air leakage through a quality-type butterfly valve at various pressures

TEST SPECIMEN DESCRIPTION

Test and Mounting Design: See Figure A-2.

Description of Specimen: The 12-in. valve is bolted between 2 flanges by means of 12 bolts. The steel valve is seated against a continuous neoprene gasket. An air actuator operates the valve so that the valve is normally completely closed or completely open.

Installation Procedure: The flanges are attached to the mounting plate by means of a continuous gas-tight weld.

Leak Path Description: The leak paths are (1) around the valve and gasket, and (2) around the valve shaft.

Manufacturer: Keystone.

LEAK TEST DATA

Leak Rate: <0.018 ft^3/day at 13.8 psig (no detectable leak)

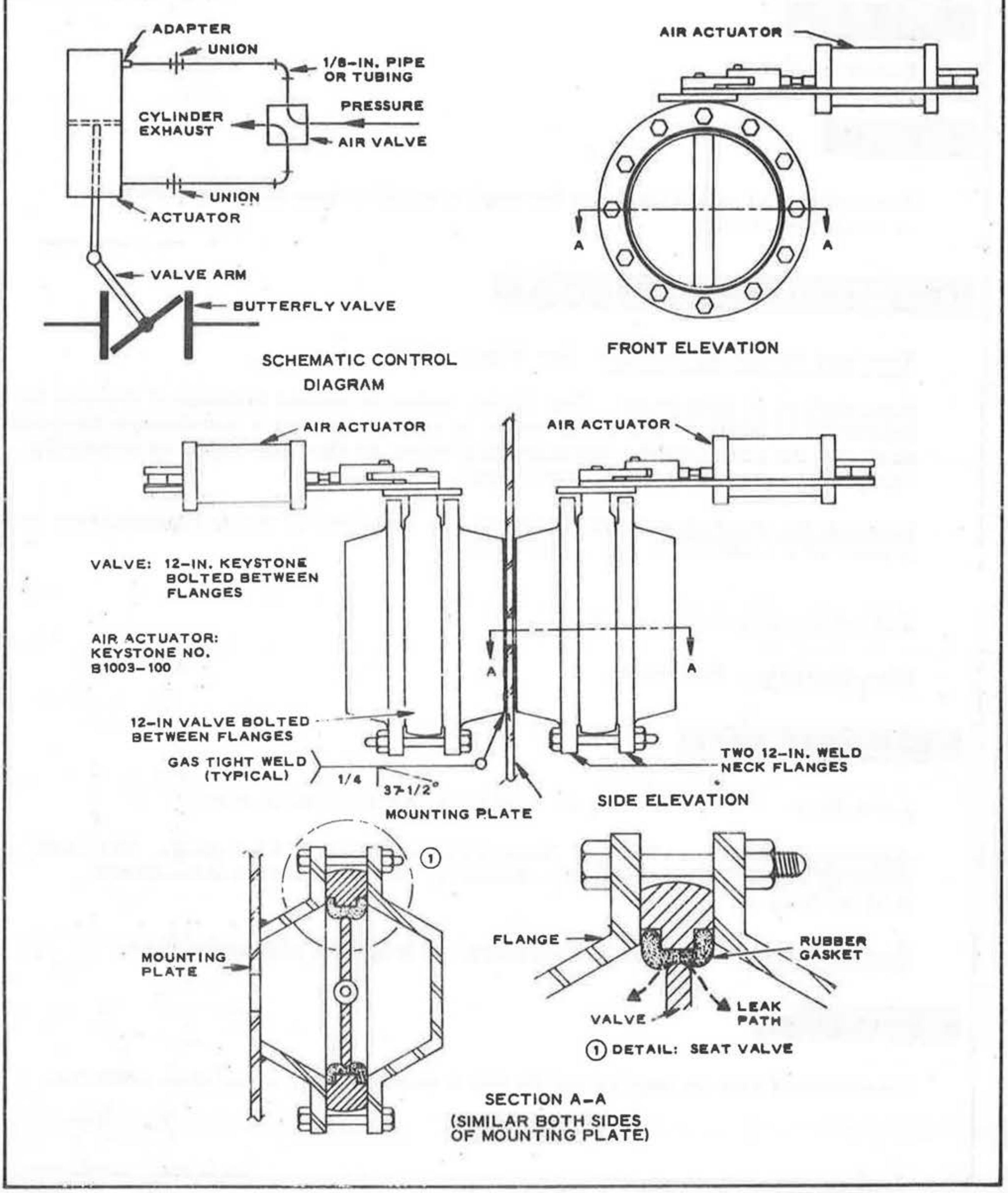
Applicable Pressure Range: Data were obtained at 13.8 psig. The leak rates at higher pressures are unknown, but probably do not exceed 0.02 ft^3/day up to 20 psi.

Extrapolations: Leak is proportional to length of circumference.

LIMITATIONS

Limitations are as expressed by the manufacturer, otherwise unknown.

LEAKAGE DATA SHEET	Figure A-2	Page 2 of 2



LEAKAGE DATA SHEET	No. A-3(1)	Page 1 of 2

COMPONENT

Conduit Packing

PURPOSE

Determination of the effectiveness of epoxy resin in sealing conduit penetrations to reactor containment shells

TEST SPECIMEN DESCRIPTION

Test and Mounting Design: See Figure A-3(1). (Reference: NAA-SR-MEMO-4850, by H. Nadler.)

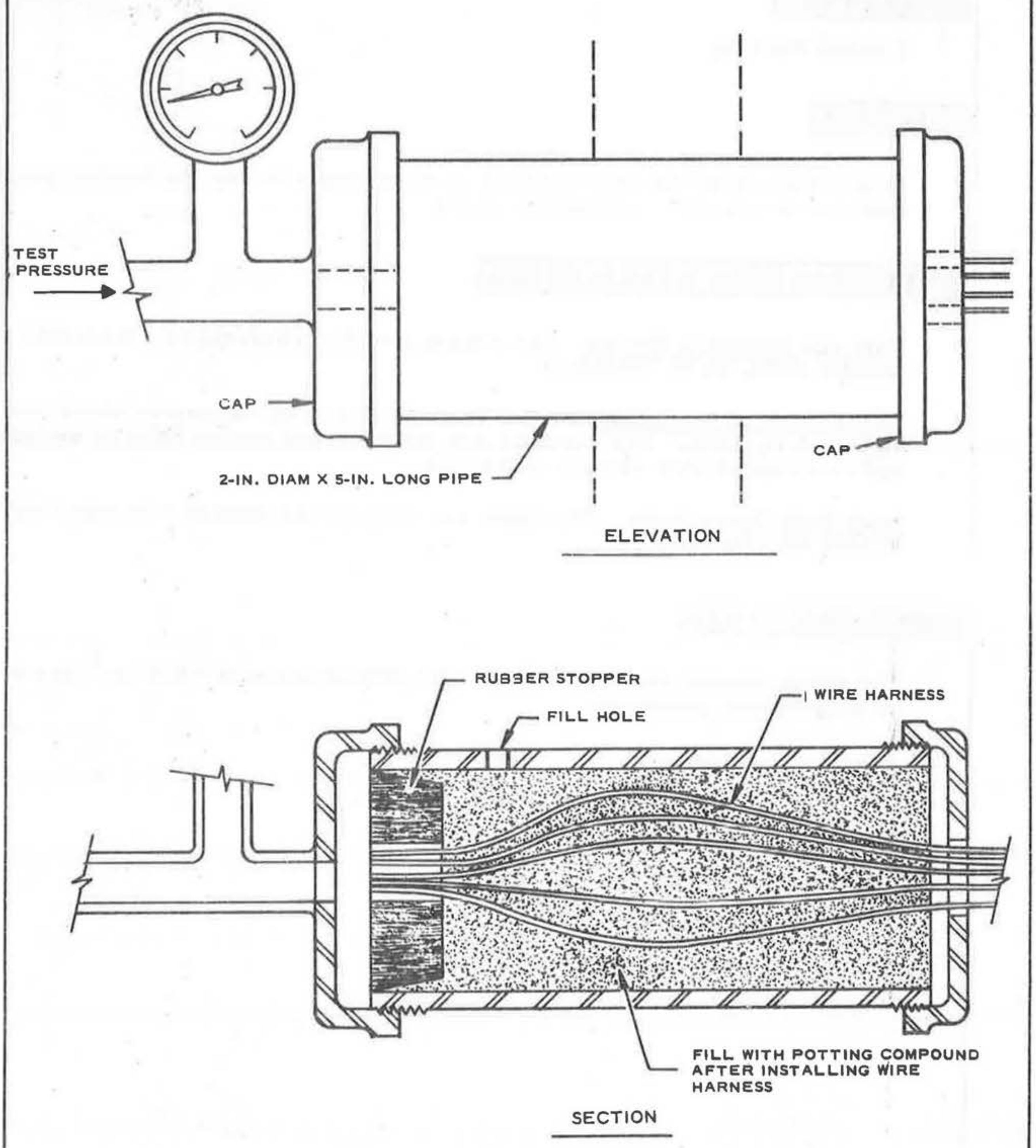
Description of Specimen: A seal is made in a 2-in.-diameter black iron nipple, 5 in. long. The conduits are stripped and sealed bare or stripped and re-covered with various materials.

Leak Path Description: The leaks are through the potting compound and around the conduits.

LEAK TEST DATA

The epoxy conduit seals give leak-tight performance of ~0.5 cm^3/day at 20-psig helium pressure.

LEAKAGE DATA SHEET	Figure A-3(1)	Page 2 of 2



LEAKAGE DATA SHEET	No. A-3(2)	Page 1 of 4

COMPONENT

Conduit Seals

PURPOSE

Evaluate and measure the air-leakage characteristics of sealants for conduit seal-offs.

TEST SPECIMEN DESCRIPTION

Test and Mounting Design: See Figure A-3(2).

Installation Procedure:

Case 1: The completed specimen is mounted to a conduit pipe and flange. The flange is sealed to the diaphragm plate with polybutene.

Case 2: For a penetration requiring the sealing of many wires, a trough design can be used as shown. This method is discussed in HW-64972, "Sealing Materials for PRTR Structural Openings," by H. L. Floyd.

Description of Specimen:

Case 1: Tests are performed using 2 and 3-in. conduits, sealing 1 to 8 cables. After a portion of the sheath (outer jacket of the cable) is stripped and after the appropriate amount of damming is applied, the sealants are poured around the insulated wires while the conduit is either in the horizontal or vertical position.

Case 2: The cables are laid in the trough and the sheath (outer jacket of the cable) is stripped in that portion which makes contact with the sealant. Sand or Chico A is poured into the trough to about 2 in. from the top, as shown. A minimum of 1 in. of sealant is than poured around the stripped sheath.

Name and Manufacturer:

1) Chico Type A Sealing Compound (cement), Chico Company
2) Silastic RTV 601 (silicone rubber), Dow-Corning
3) Micro-Preg (epoxy), Westrup Corporation
4) SIKA Eposy Crack Sealer, SIKA Chemical Corp.
5) Resweld No. 2 (epoxy), H. B. Fuller.

LEAKAGE DATA SHEET	No. A-3(2)	Page 2 of 4

LEAK TEST DATA

Empirical Constants: Value for each seal.

Case 1:

Chico A
$A = 1$ to 2×10^{-5} $\quad B = 10^{-9}$

Silastic RTV 601
$A = 10^{-9}$ $\quad B = 10^{-9}$

Micro-Preg
$A \approx 10^{-9}$ $\quad B = 10^{-9}$

SIKA Epoxy Crack Sealer
$A = 10^{-9}$ $\quad B = 10^{-9}$

Case 2:

Resweld No. 2
No leakage detected (as reported in HW-64972).

Applicable Pressure Range: The air-leakage data are applicable to pressures of at least 4 psig. The Chico A can probably be used up to the design pressure as stated by the manufacturer. (See Limitations — SIKA Crack Sealer.)

Extrapolations: The above leak rates are directly proportional to the pressure. Since the leakage data are given in cfm/in. water pressure, a pressure of 100 in. of water would leak 100 times the above rate. A larger diameter conduit would have a greater surface area of sealant but should also have a greater depth of sealant. Therefore, any change in leak rate relative to conduit size is small.

LIMITATIONS

Case 1:

Chico A — The conductors need the maximum of separation before the sealant is poured in place. The Chico conducts electrical current, so jackets of the conductors must not be damaged. There is also no bond between the insulating jacket and Chico cement. This is the only material tested with a detectable leak.

Silastic RTV 601 — (a) The Silastic does not bond to a polyvinyl conductor jacket. (b) The sealant is a two-part compound requiring accurate measurements.

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Micro-Preg — The sealant is a two-part compound requiring accurate measurements and must be poured in separate layers to prevent foaming. It is the most toxic of the sealants tested. The penetration is extremely good and therefore requires careful damming.

SIKA Crack Sealer — The sealant is a two-part mixture requiring accurate measurements. The sealant is soft when fully cured (Durometer hardness of 20-25). Therefore, the seal can be easily ruptured by movement of the cable or by continued application of high pressure.

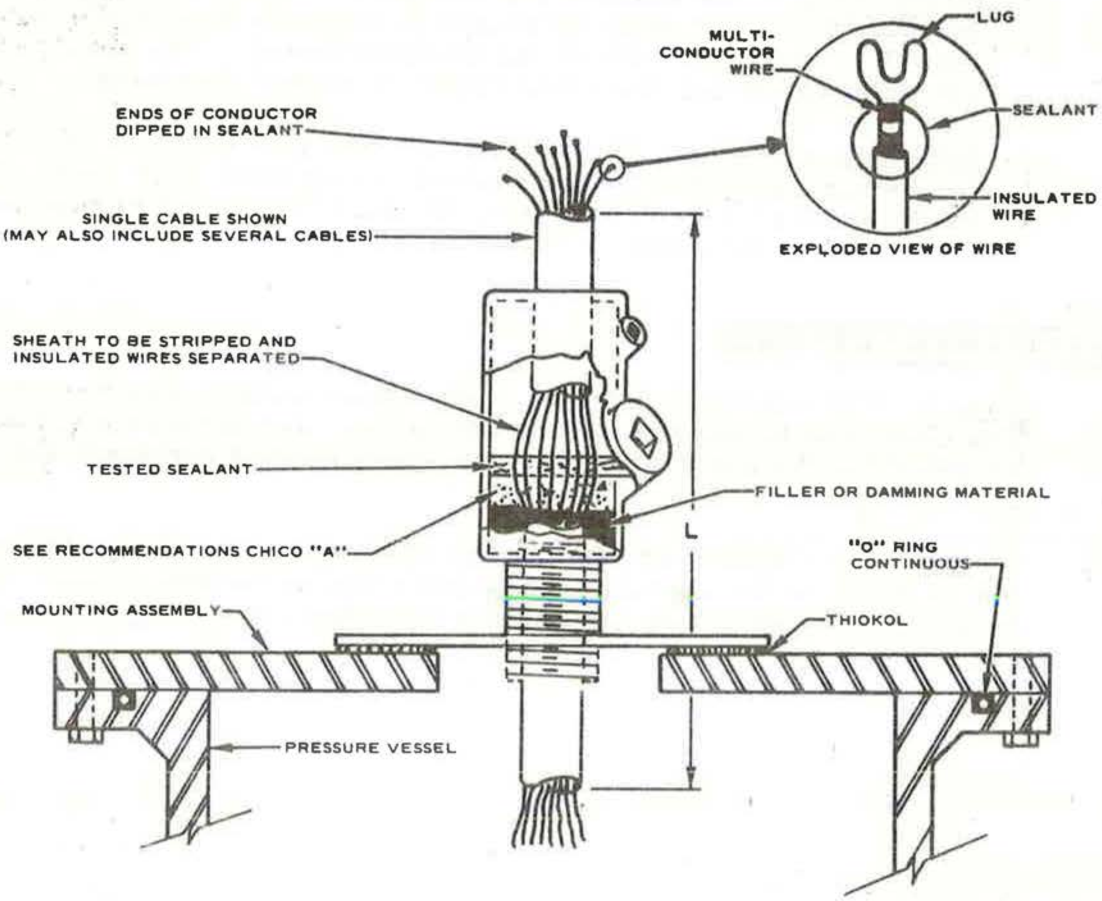
RECOMMENDATIONS

Case 1: For minimum leakage, a dual-pour method may be considered. The Chico can be used to anchor the cables, and SIKA or Micro-Preg can be added for the gas seal. This dual-pour method combines the advantages of each sealer.

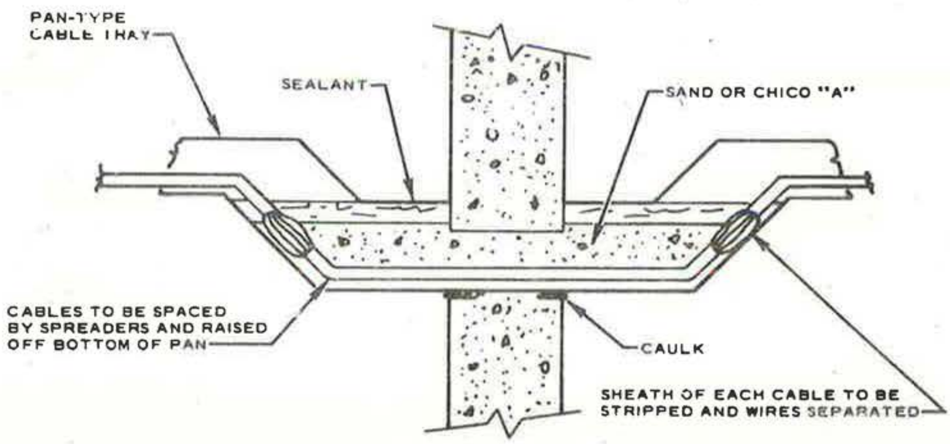
Case 2: Use Chico A or sand as the filler and either Resweld No. 2 or Micro-Preg as the sealant. The cables can be located so that others can be added later by coring the sealant and filler, inserting the new cables, and resealing.

LEAKAGE DATA SHEET	No. A-3(2)	Page 4 of 4

CASE 1 CONDUIT SEAL-OFFS



CASE 2 TROUGH-TYPE SEAL



LEAKAGE DATA SHEET	No. A-4(1)	Page 1 of 6

COMPONENT

Hollow Metal Door

PURPOSE

Determination of air leakage through standard personnel doors

TEST SPECIMEN DESCRIPTION

Test and Mounting Design: See Figures A-4(1)a and A-4(1)b.

Description of Specimen: The 16-gage surface sheets are completely welded to framing channel around the entire perimeter of door, with no seams visible on edges or surfaces of door.

Installation Procedure: Standard, as stated by the manufacturer.

Leak Path Description: The leak paths are through the door seal (weather stripping and floor seal) and through the lock jamb section.

Manufacturer and Type: Dusing and Hunt, Inc.; "Pyro-Dor" Model SA.

LEAK TEST DATA

Empirical Constants: Value for one door.

1) With metal interlocking weather strip [Figure A-4(1)c]
   Pressure tending to close unit
   A = 12 B = 34

2) With gasketed interlocking weather strip [Figure A-4(1)d]
   Pressure tending to open unit
   A = 4.9 B = 27

   Pressure tending to close unit
   A = 4.3 B = 22

Applicable Pressure Range: The data are applicable to pressures up to 7 in. of water. (See comments under Limitations.)

Extrapolations: The test data were obtained from a 30- by 60-in. door. The greater portion of the leak occurred at (1) the corner joints of the weather stripping, (2) the joints between the floor seal and weather

LEAKAGE DATA SHEET	No. A-4(1)	Page 2 of 6

stripping, and (3) the lock jamb section. Therefore, the same data can be applied to any size door of this type without scaleup or extrapolations.

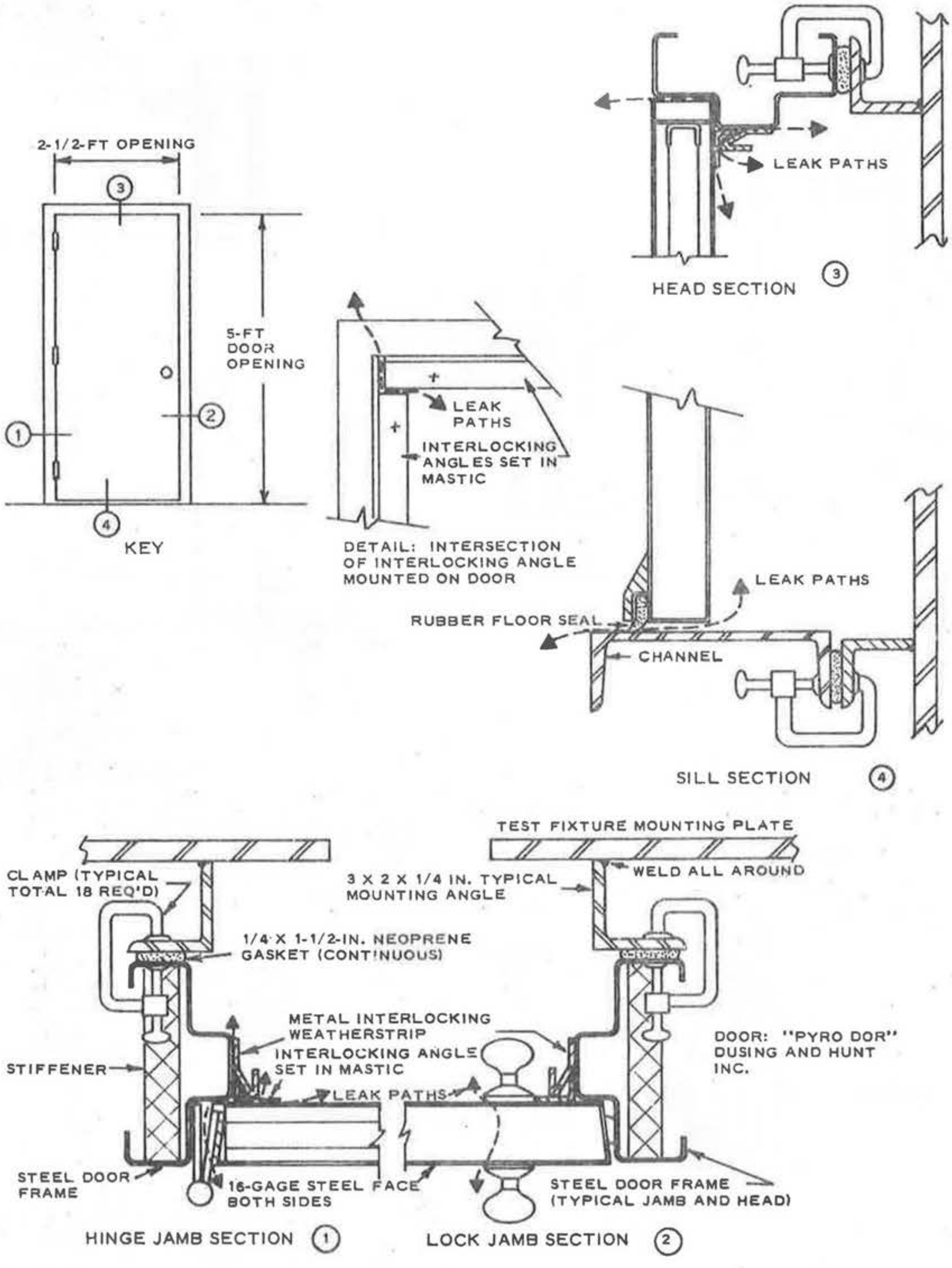
LIMITATIONS

The repeatability of the test data after several months of normal usage of the door is unknown. Since the bending and shear properties of the latch mechanism are unknown. the extrapolation of air-leakage data at pressures greater than 7 in. of water is questionable.

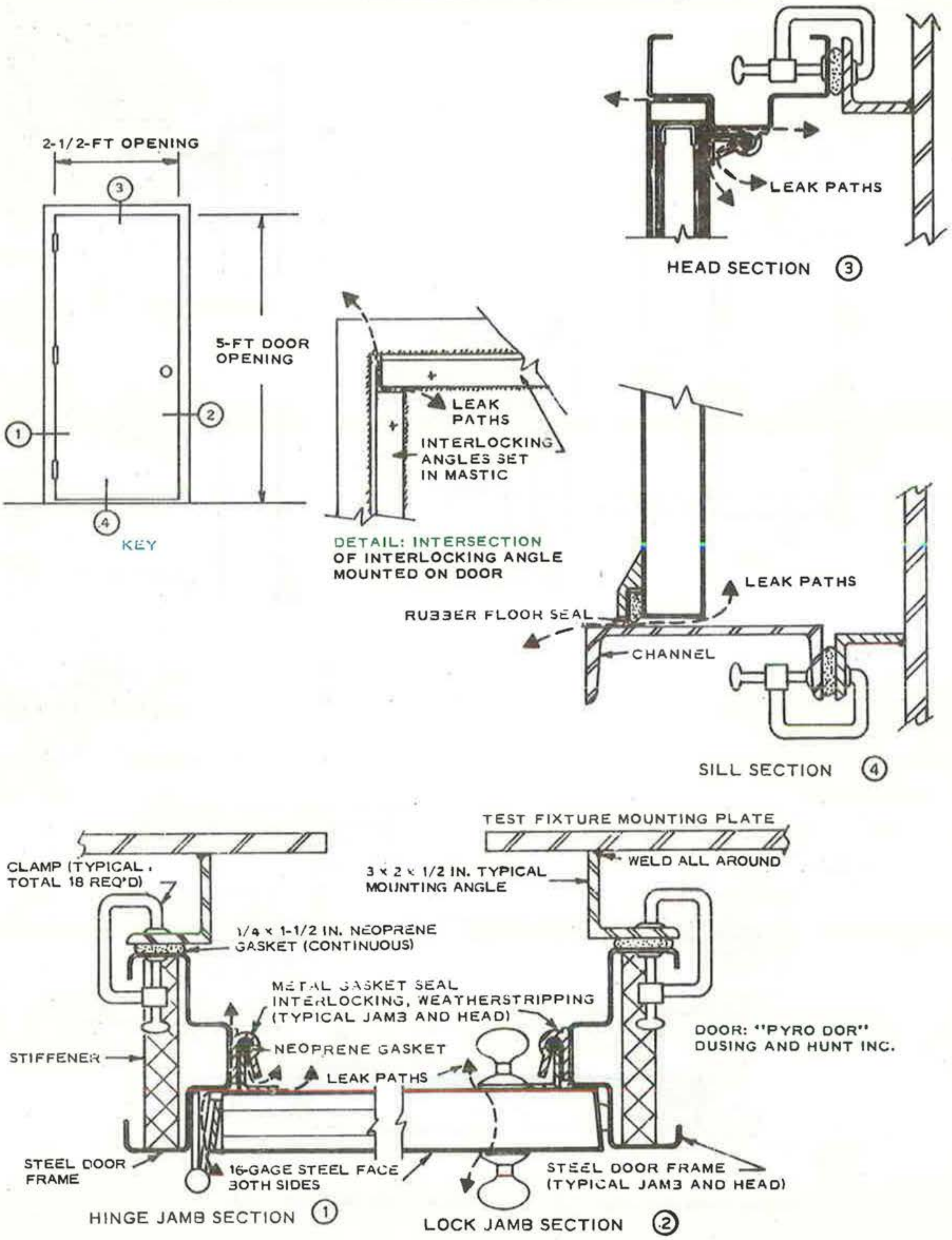
RECOMMENDATIONS

In mounting the weather stripping, a mastic should be placed between the female section and door frame and between the male section and door.

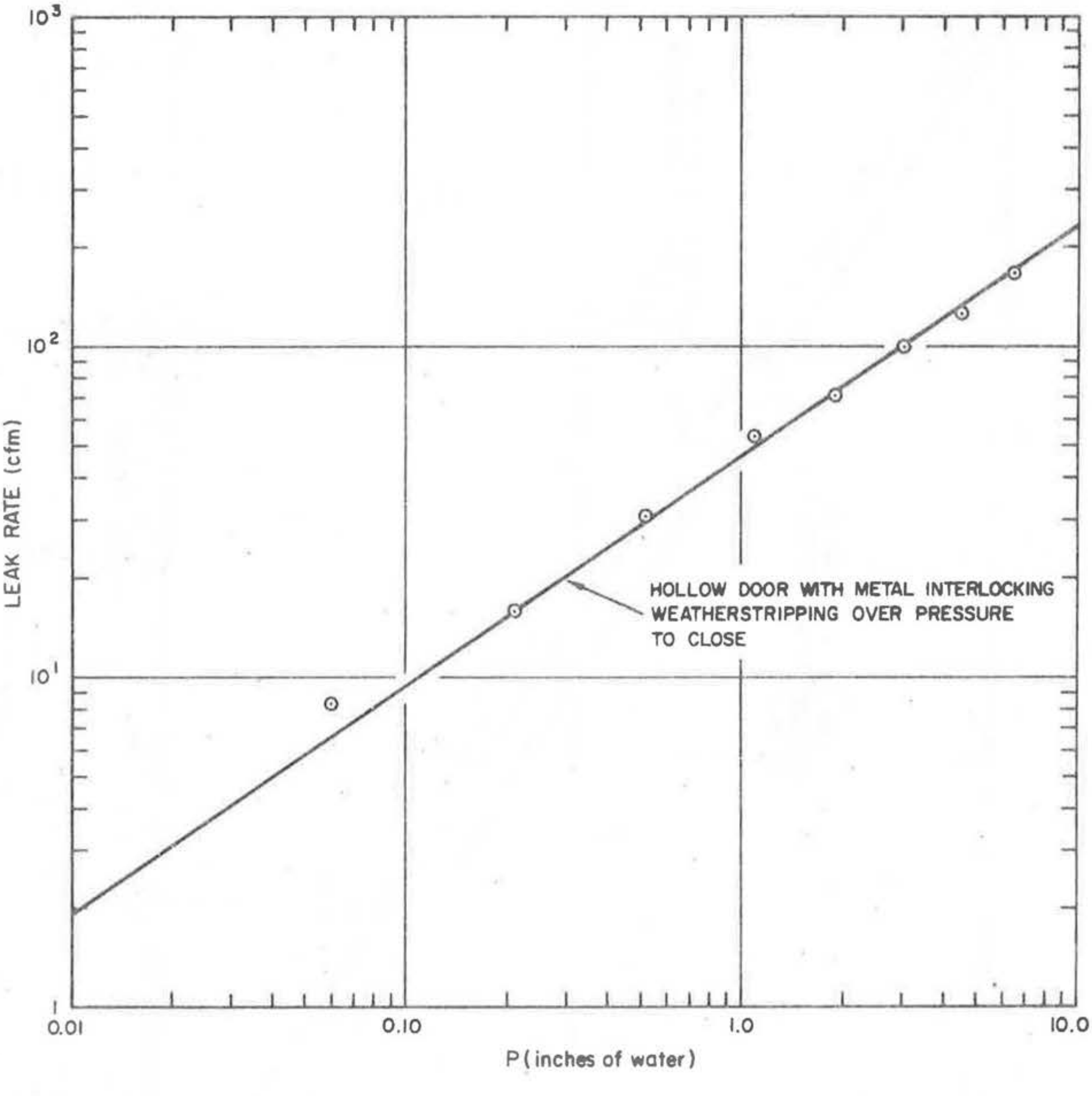
LEAKAGE DATA SHEET	Figure A-4(1)a	Page 3 of 6



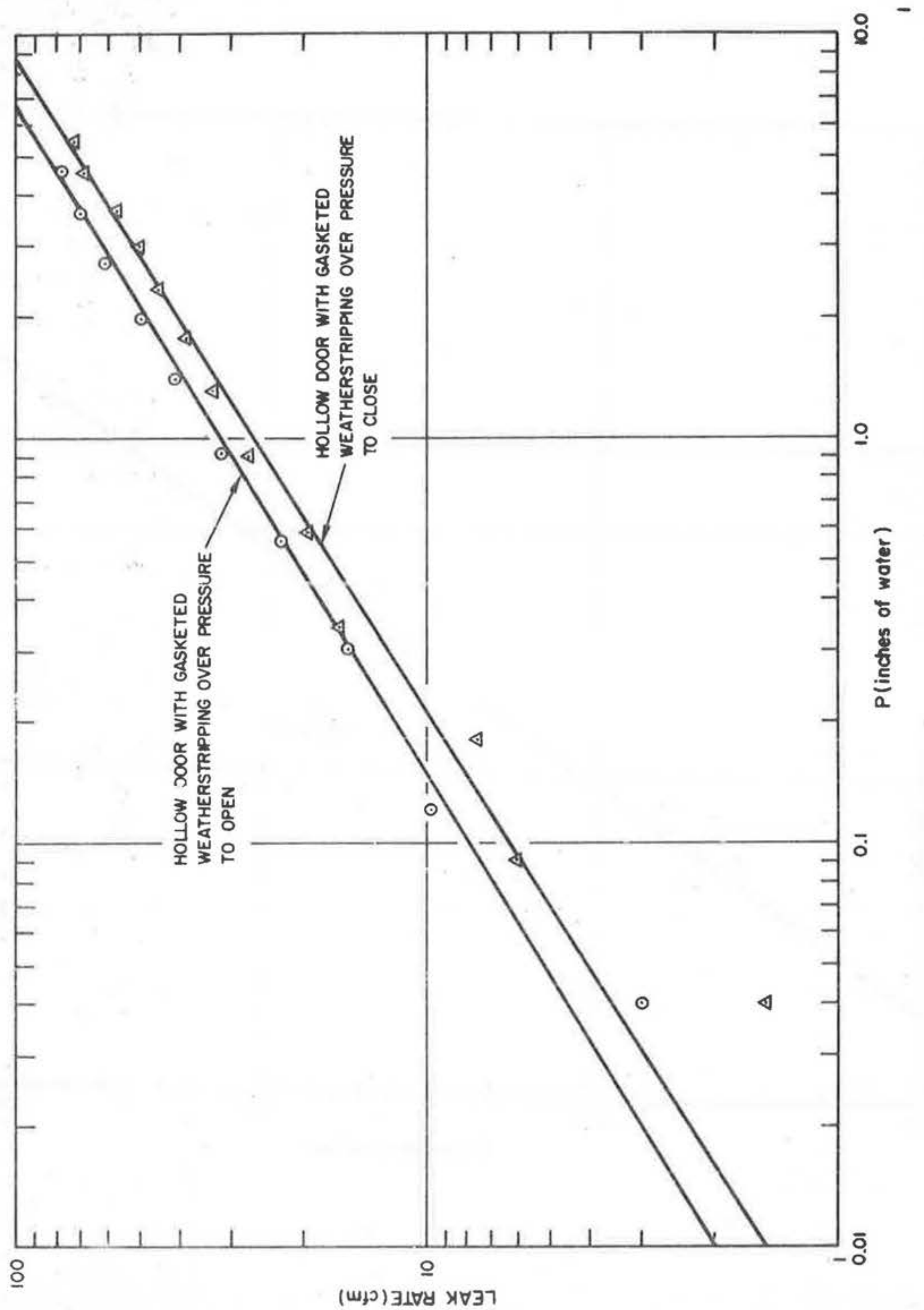
LEAKAGE DATA SHEET	Figure A-4(1)b	Page 4 of 6



LEAKAGE DATA SHEET	Figure A-4(1)c	Page 5 of 6



LEAKAGE DATA SHEET	Figure A-4(1)d	Page 6 of 6



LEAKAGE DATA SHEET	No. A-4(2)	Page 1 of 4

COMPONENT

Metal Door With Sound Insulation

PURPOSE

Determination of air leakage through standard personnel doors

TEST SPECIMEN DESCRIPTION

Test and Mounting Design: See Figure A-4(2)a.

Installation Procedure: Standard, as described by manufacturer.

Description of Specimen: Door is 1-3/4 in. thick, flush design; face panels are formed of 16-gage cold-rolled, stretcher-leveled sheet steel. A crack-closer provides sponge neoprene compression sealing at threshold when door is closed.

Manufacturer and Type: Sonicbar; Type DM2F-48.

Leak Path Description: The leak paths are through the door seal (weather stripping and floor seal) and through the lock joint section.

LEAK TEST DATA

Empirical Constants: Value for one door. [Figure A-4(2)b]

Pressure tending to open unit
A = 23 B = 41

Pressure tending to close unit
A = 0 B = 35

Applicable Pressure Range: The air-leakage rate is applicable to pressures up to 7 in. of water. (See comments under Limitations.)

Extrapolations: The test data were obtained from a 30- by 60-in. door. In extrapolating to a larger door, the constant B will remain approximately the same. This is the leakage through the corners, joints, and lock jamb section. The constant A will vary in direct relation to the length of seal (periphery of the door) and may be scaled up or down.

LEAKAGE DATA SHEET	No. A-4(2)	Page 2 of 4

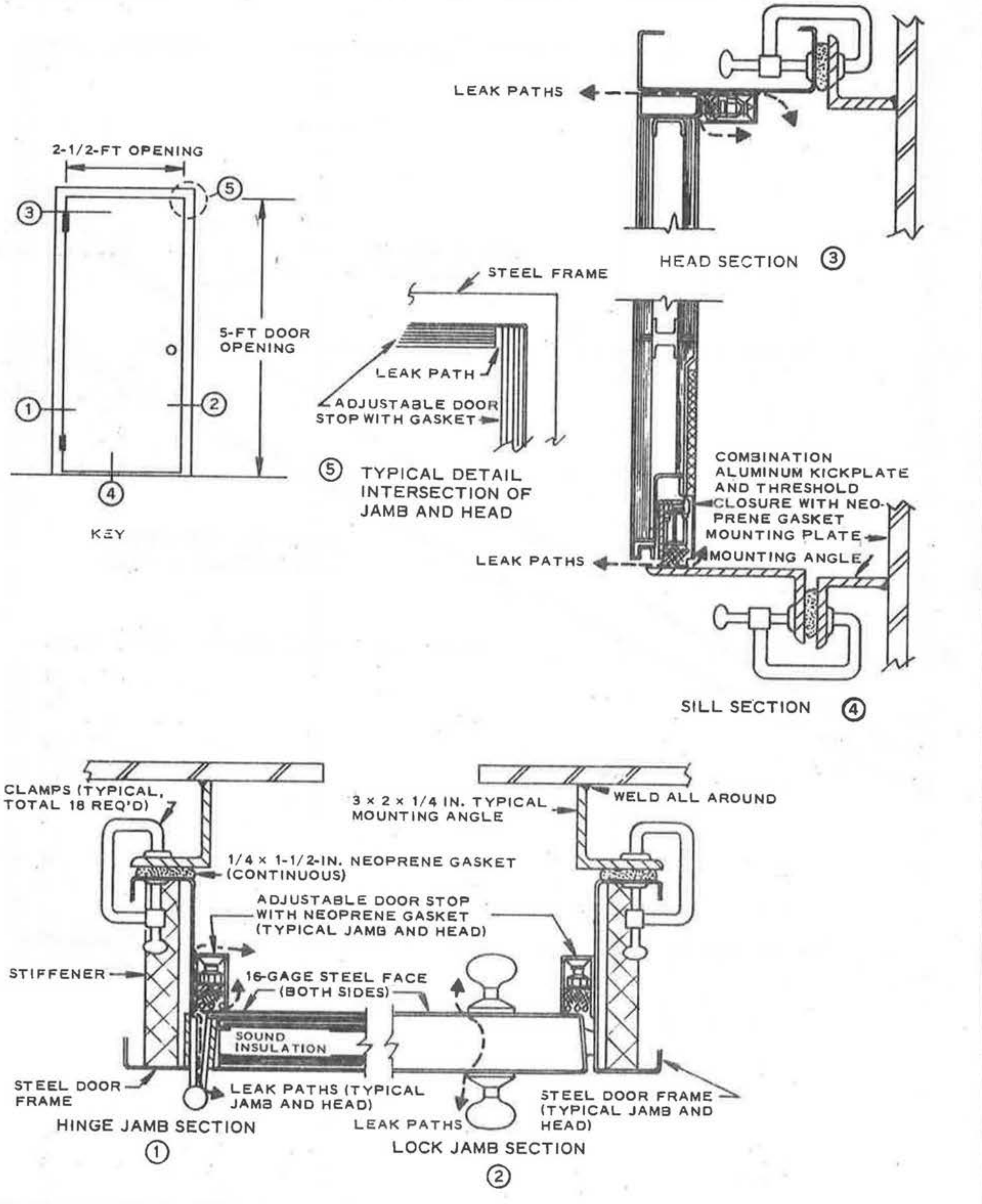
LIMITATIONS

The test data were obtained from a new specimen, and neither the wearability nor repeatability of the data after months of service is known. The bending and shear strength of the latch mechanism are not stated by the manufacturer, so that leak rates at pressures greater than 7 in. are not predictable. Probably turbulent flow is present, and linear scaleup in pressure is not applicable.

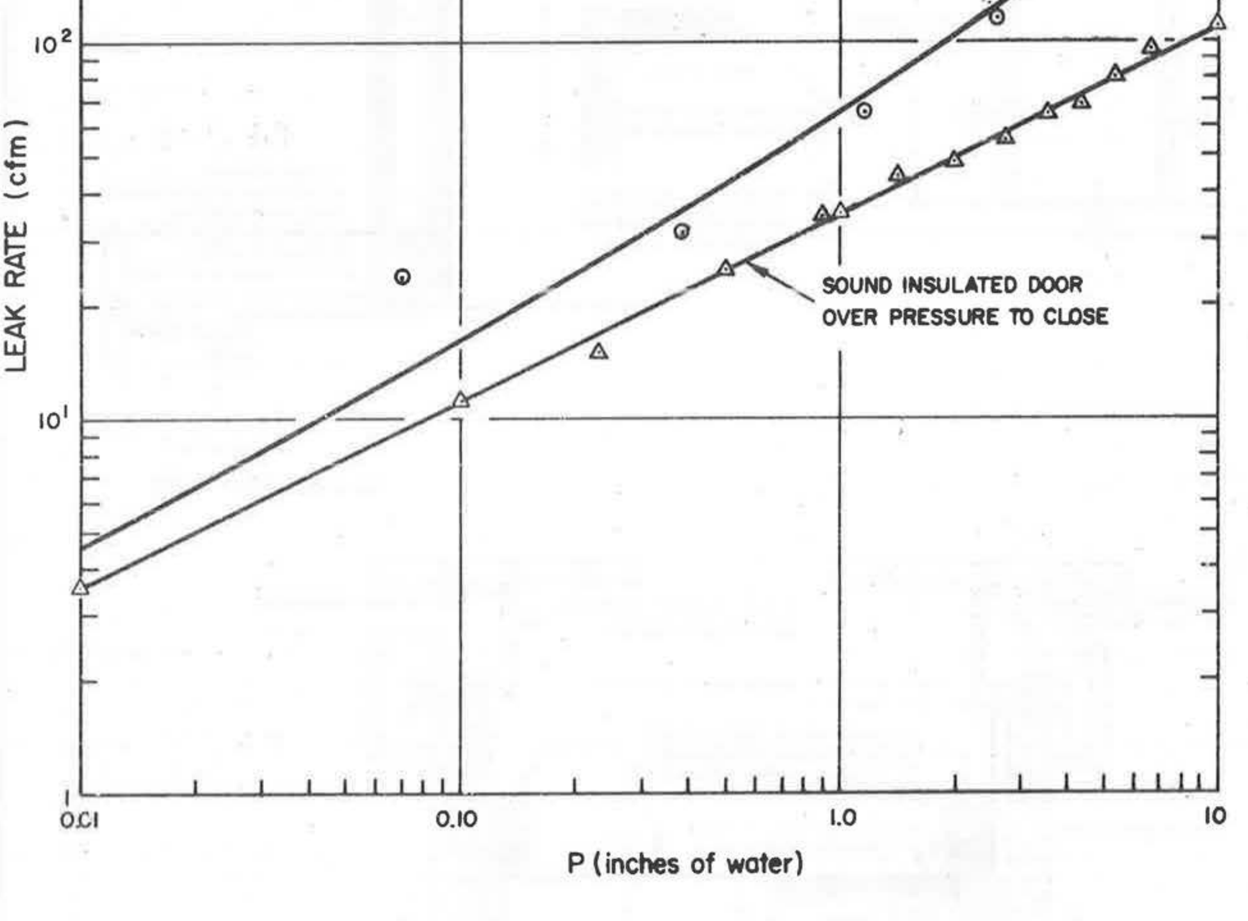
RECOMMENDATIONS

None (impractical for low-leakage containment).

LEAKAGE DATA SHEET	Figure A-4(2)a	Page 3 of 4



LEAKAGE DATA SHEET	Figure A-4(2)b	Page 4 of 4



LEAKAGE DATA SHEET	No. A-4(3)	Page 1 of 4

COMPONENT

Individual Dogging Door, Marine Type

PURPOSE

Determination of air leakage through personnel door

TEST SPECIMEN DESCRIPTION

Test and Mounting Design: See Figure A-4(3)a.

Description of Specimen: The door is fabricated from sheet-metal steel with no seams. The door is held closed by means of individual dogs which clamp the door coaming firmly against the rubber gasket at the periphery of the door.

Installation Procedure: The angle coaming is fastened to the door frame by use of a continuous air-tight weld.

Leak Path Description: The leak paths are through the door seal at the periphery of the door (angle coaming) and through the individual dogging shafts.

LEAK TEST DATA

Empirical Constants: Value for one door.

1) Hand tight: [Figure A-4(3)b]
   - Pressure tending to open unit
     A = 0.019 B = 0.17
   - Pressure tending to close unit
     A = 0.023 B = 0.24
2) Dogs hammered tight:
   - Pressure tending to open unit
     A = 0.026 B = 0.19
   - Pressure tending to close unit
     A = 0.14 B = 0.22

Applicable Pressure Range: The data should be applicable at pressures up to the design pressure as stated by the manufacturer.

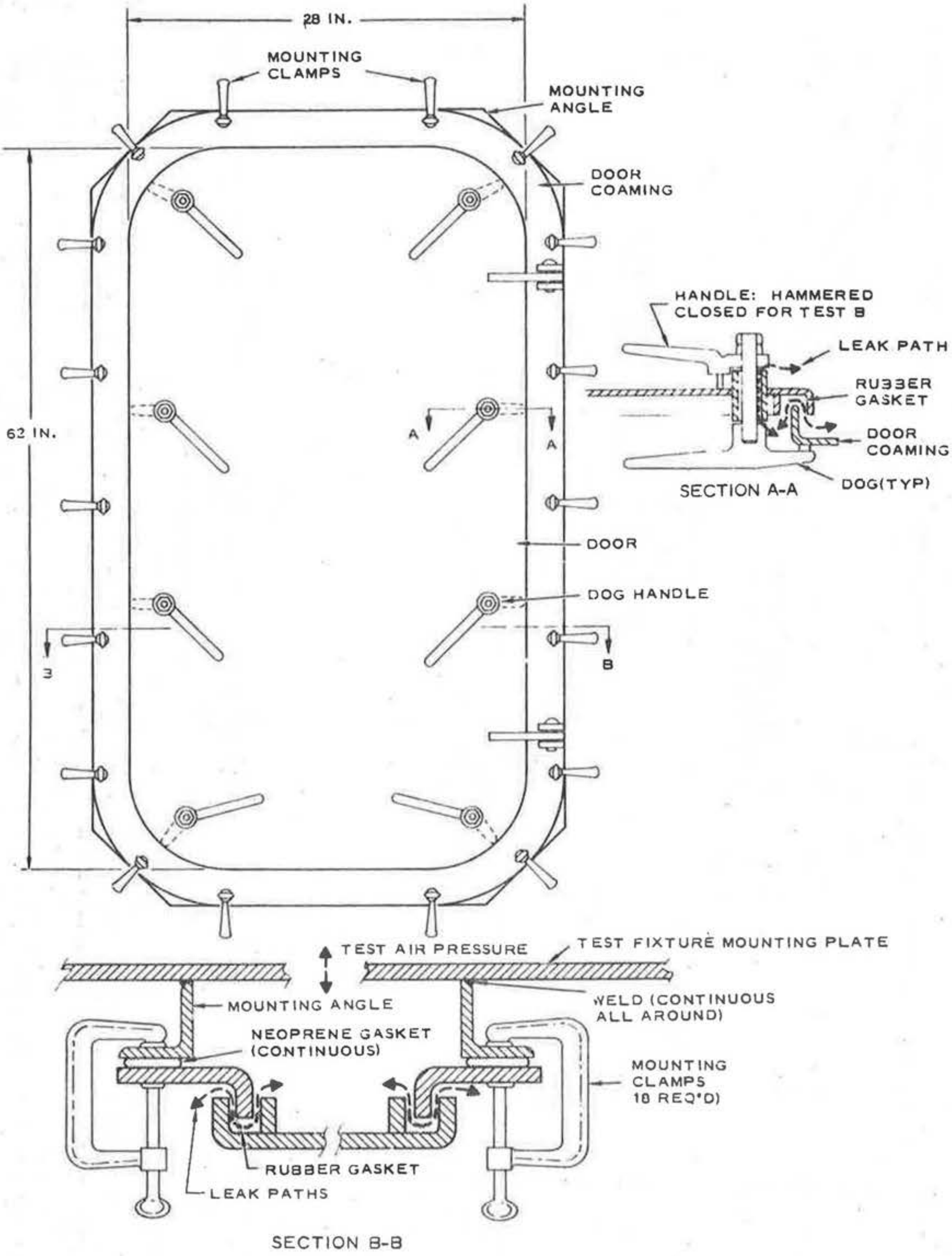
LEAKAGE DATA SHEET	No. A-4(3)	P ge 2 of 4

Extrapolations: The greatest portion of the leak appeared to be through the eight individual dogging shafts. Therefore, during extrapolation to a larger size door, only the number of individual dogs are important. A door with twice the number of dogs would leak approximately twice the rate. Hammering dogs increased leakage in both cases.

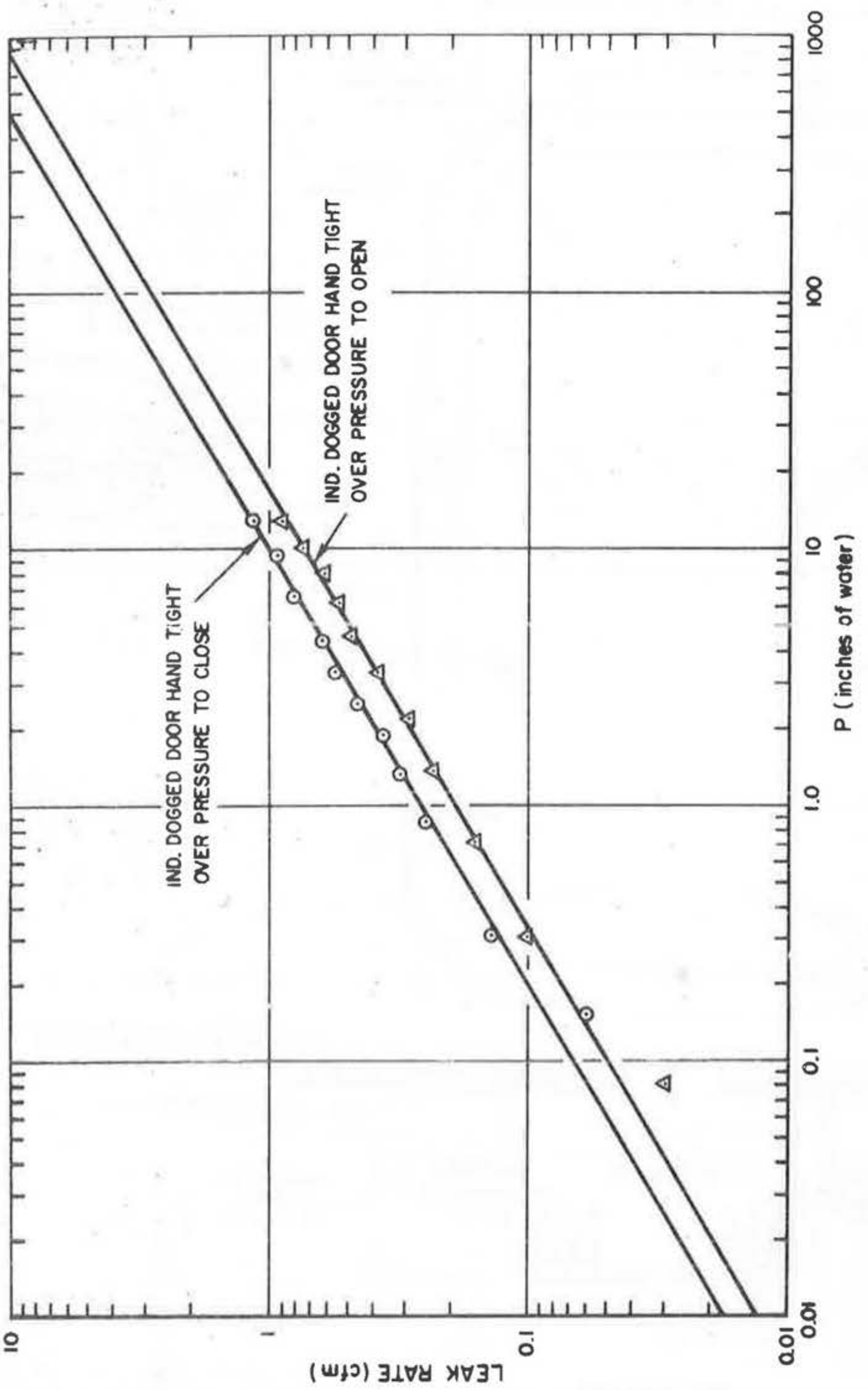
RECOMMENDATIONS

1. Replace the seal packing around the dogging shafts with an improved packing.
2. Reseal rubber gasket to door channel.
3. For one-way doors, dog bolt assemblies may be welded to one side of door. This eliminates leakage around shafts.

LEAKAGE DATA SHEET	Figure A-4(3)a	Page 3 of 4



LEAKAGE DATA SHEET	Figure A-4(3)b	Page 4 of 4



LEAKAGE DATA SHEET	No. A-4(4)	Page 1 of 6

COMPONENT

Quick Acting Door, Marine Type

PURPOSE

Determination of air leakage through personnel door

TEST SPECIMEN DESCRIPTION

Installation and Test Design: See Figure A-4(4)a.

Description of Specimen: The door is fabricated from sheet-metal steel with no seams. The door is held closed by means of eight individually adjusted dogs which are connected to one handwheel. The dogs clamp the door coaming evenly against the rubber gasket at the periphery of the door.

Installation Procedure: The angle coaming is fastened to the door frame by use of a continuous air-tight weld.

Leak Path Description: The leak paths are through the door seal at the periphery of the door (angle coaming) and through the handwheel shaft packing.

Manufacturer and Type: Julius Mock and Sons, Inc.; Quick Acting, Marine Type.

LEAK TEST DATA

Empirical Constants: Value for one door

1) As received* [Figure A-4b]

   Pressure tending to open unit

   A = 0.25 B = 0.18

   Pressure tending to close unit

   A = 0.071 B = 0.42

2) Cleaned door seal and adjusted dog swivel guides [Figure A-4(4)c]

   Pressure tending to open unit

   A = 0.0017 B = 0.040

   Pressure tending to close unit

   A = 0.00011 B = 0.026

*As received, the door coaming bearing edge was irregular.

LEAKAGE DATA SHEET	No. A-4(4)	Page 2 of 6

3) Repaired edge of angle coaming [Figure A-4(4)d]

Pressure tending to open unit
A = 0.0023 B = 0.011

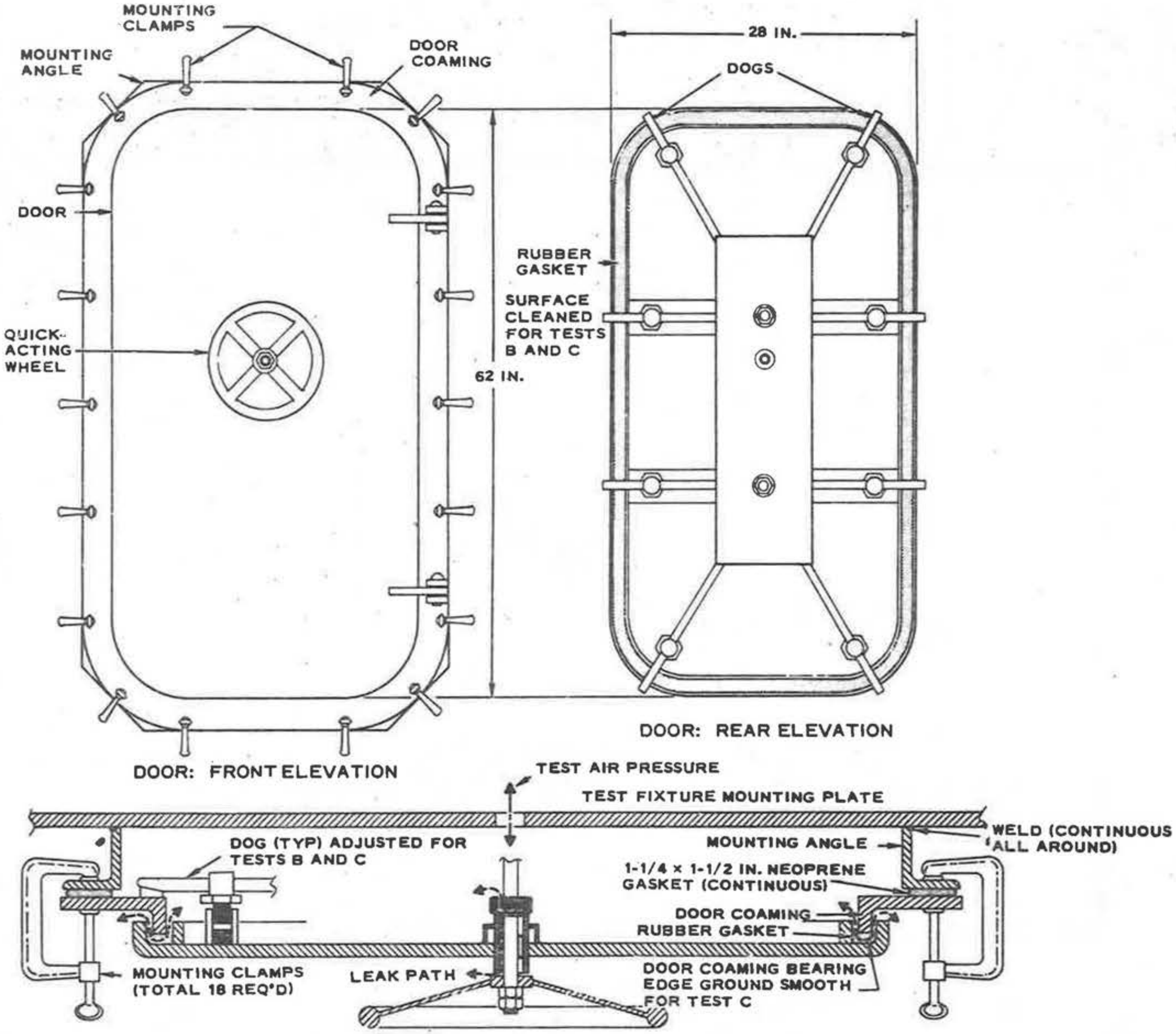
Pressure tending to close unit
A = 0.00086 B = 0.00106

Applicable Pressure Range: The data should be applicable at pressures up to the design pressure as stated by the manufacturer.

Extrapolations: The test data from the 25- by 60-in. door can be extrapolated to a large size since the maximum leakage area is at the periphery.

LIMITATIONS

1. The integrity of the wheel shaft packing and rubber gasket after months of wear is unknown.
2. Rubber gasket may require resealing to door channel.



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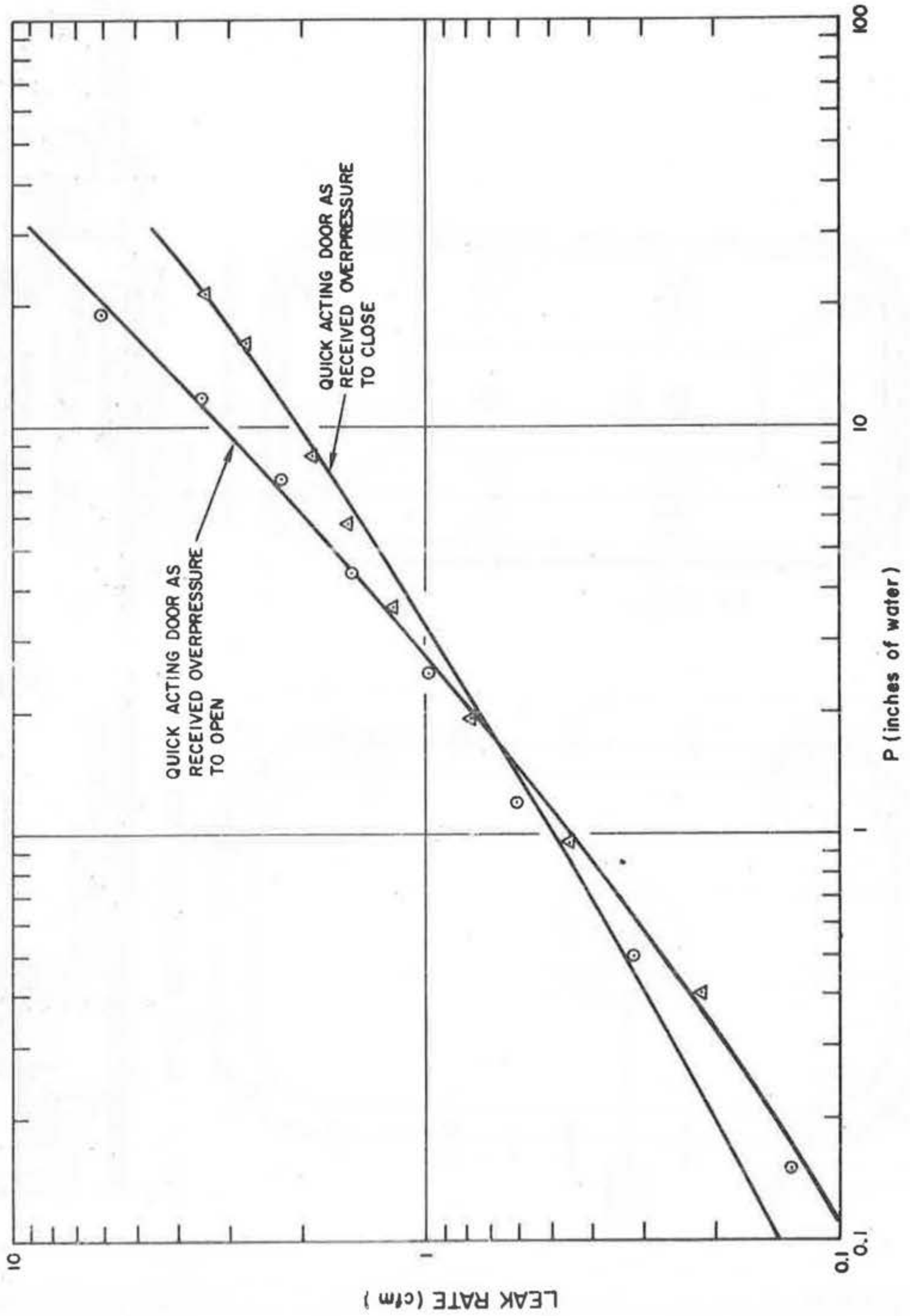
A Division of North American Aviation Inc.

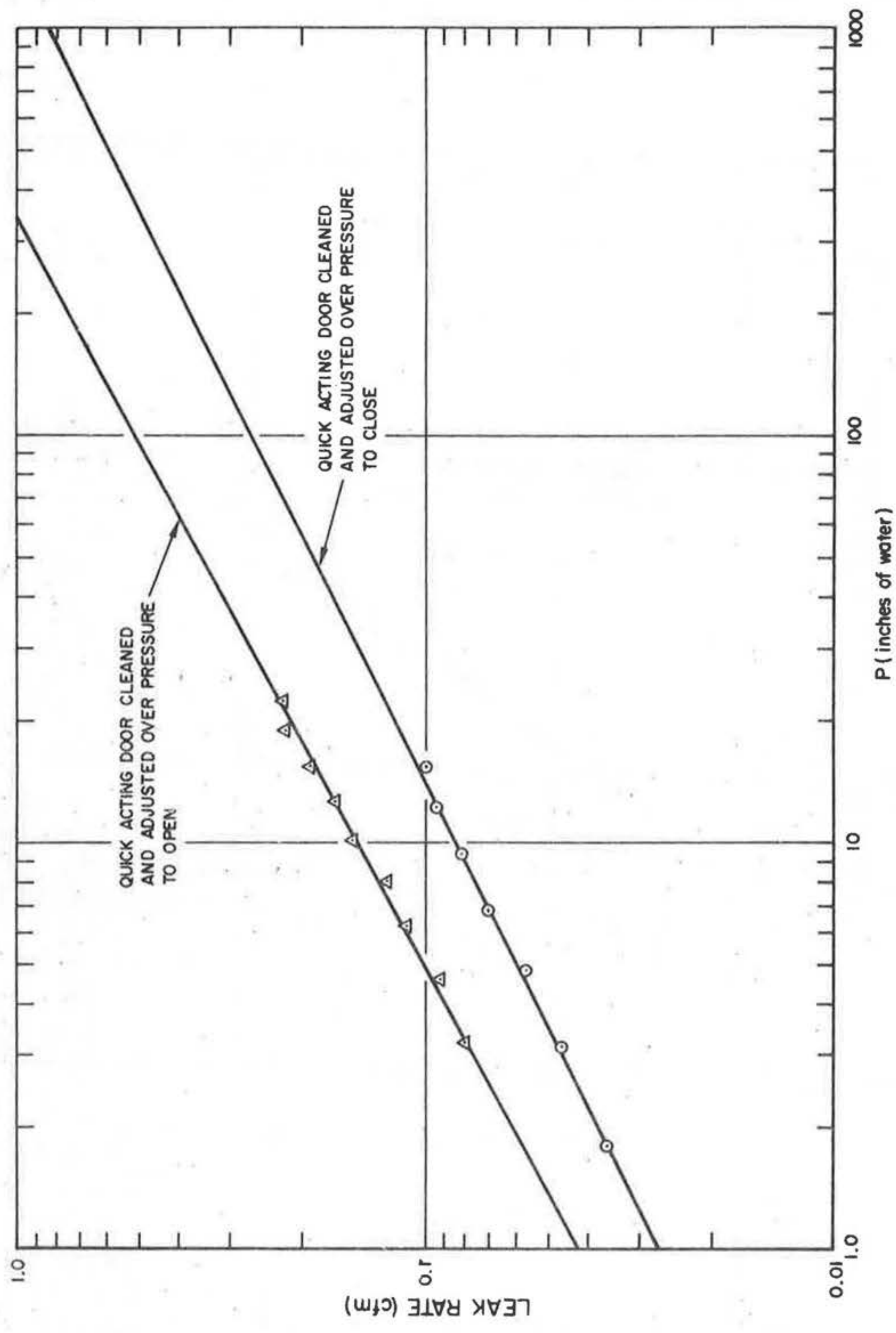
LEAKAGE DATA SHEET

Figure A-4(4)a

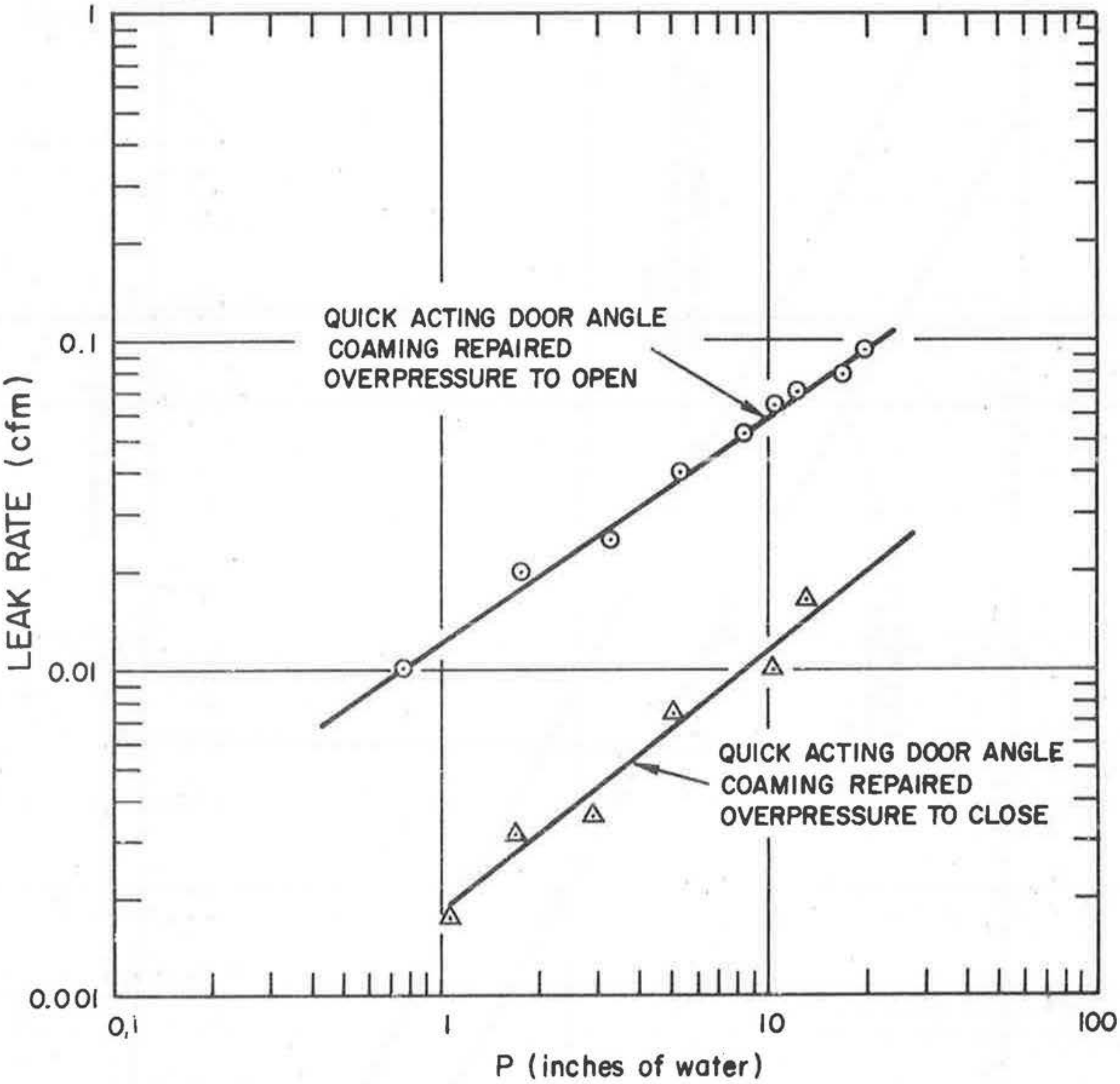
LEAKAGE DATA SHEET	Figure A-4(4)b	Page 4 of 6



LEAKAGE DATA SHEET	Figure A-4(4)c	Page 5 of 6



LEAKAGE DATA SHEET	Figure A-4(4)d	Page 6 of 6



LEAKAGE DATA SHEET	No. A-5	Page 1 of 3

COMPONENT

Electrical Fittings, Wall Mounting and Bulkhead Type

PURPOSE

Determination of air leakage through various types of fittings

TEST SPECIMEN DESCRIPTION

Test and Mounting Design: See Figure A-5.

Description of Specimen:

Test 1. Wall mounting receptacle: has a nonbonded resilient insert with shore hardness of ~20 surrounding 5 pins.

Test 2. Bulkhead receptacle: may have a resilient insert bonded to shell or vitreous insulators fused to pins and shell.

Installation Procedure: Both receptacles must have a neoprene resilient gasket between wall and fitting. Caulking must be placed on the gasket of the wall receptacle so as to reduce the leak along the screw path.

Leak Path Description: Wall mounting receptacle: the leak paths are through the gasket, along the screw, between the insert and shell, and between the insert and pins. Bulkhead receptacle: the leak paths are through the gasket and possibly around the insert (depending on the type).

LEAK TEST DATA

Empirical Constants: Value for each 1-in. pipe fitting

Test 1. Wall Mounting Receptacle
$A = 5.16 \times 10^{-4}$ $B = 0.65 \times 10^{-4}$

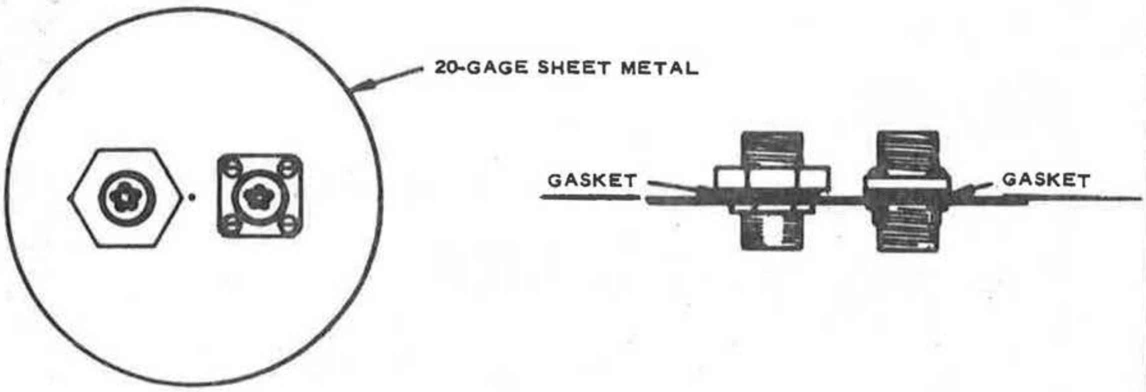
Test 2. Bulkhead Receptacle
No detectable leak. $< 10^{-9}$ cfm

Applicable Pressure Range: The data should be applicable at pressures as stated by the manufacturer.

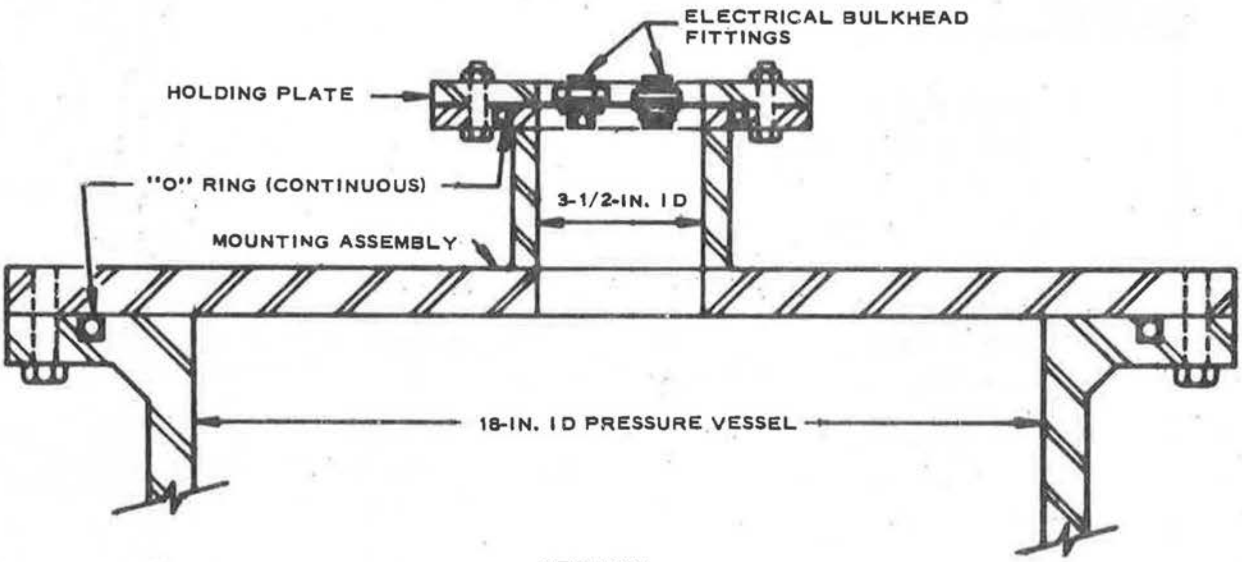
LEAKAGE DATA SHEET	No. A-5	Page 2 of 3

Extrapolations: Since the bulkhead type does not leak, no extrapolations are necessary. The majority of the leak of a wall mounting receptacle is around the insert (see Figure A-5). An approximation of the leak rate can be determined by assigning half the leak rate to the area between the insert and pins and the other half to the area between the insert and shell. Therefore, as the number of pins is increased from 5 to 10, the leak rate would be 1.5 times larger (assuming the same size shell).

LEAKAGE DATA SHEET	Figure A-5	Page 3 of 3



PLAN AND ELEVATION: ELECTRICAL FITTINGS TEST ASSEMBLY



SECTION
(SHOWING HOLDING PLATE, MOUNTING ASSEMBLY, AND PRESSURE VESSEL)

LEAKAGE DATA SHEET	No. A-6	Page 1 of 3

COMPONENT

Hatch, Roof

PURPOSE

Determination of air leakage through conventional roof access hatch

TEST SPECIMEN DESCRIPTION

Test and Mounting Design: See Figure A-6a.

Description of Specimen: A neoprene gasket is used in the 30- by 36-in. roof hatch. The top is a one-piece metal cover with welded corners; it uses a spring latch and a compensating spring hinge.

Leak Path Description: The leak path is between the hatch cover and the hatch frame at the continuous rubber gasket which is provided for sealing.

LEAK TEST DATA

Empirical Constants: Value for one roof access hatch

Pressure tending to open
A = 9.3 B = 13

Pressure tending to close
A = 0 B = 19

Applicable Pressure Range: The data were obtained from pressures up to a differential of 20 in. of water. The deformation of the specimen and leakage characteristics at higher pressures is not known.

Extrapolations: Since larger specimens have different leakage characteristics due to heavier metal, heavier compensating spring hinges, and other factors, extrapolations from these data are not recommended.

RECOMMENDATIONS

Quick acting holddown clamps should be placed at each side of the hatch so that an even pressure of the hatch cover against the seal can be attained. (See untested design, Figure A-6b.)

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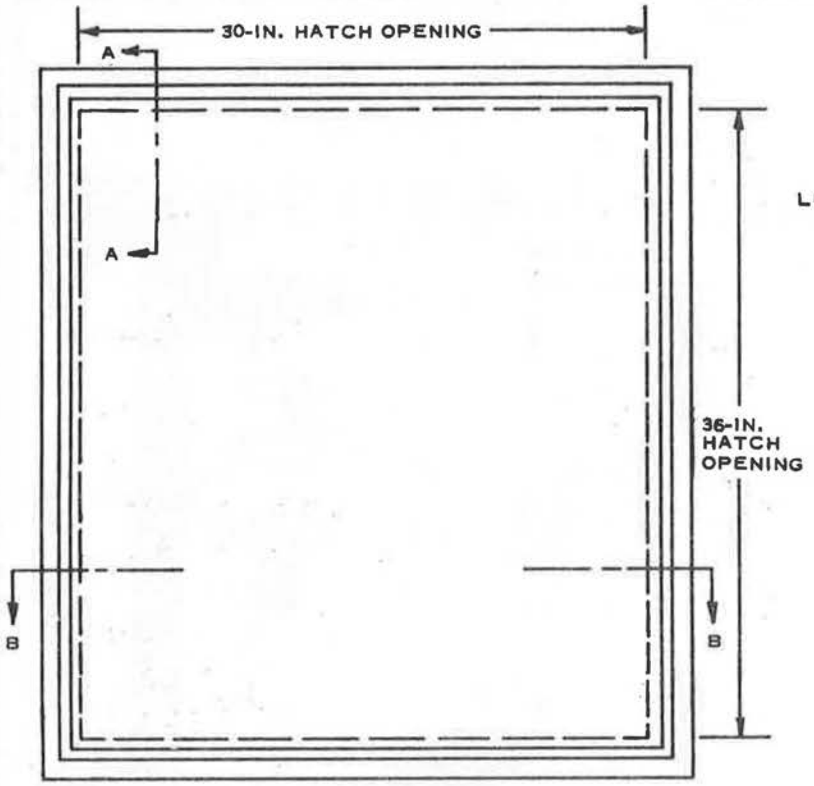
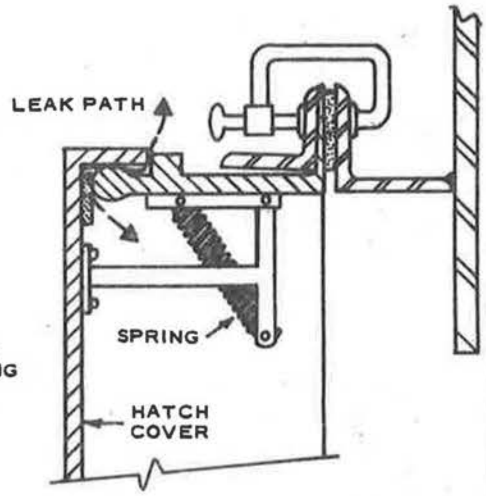
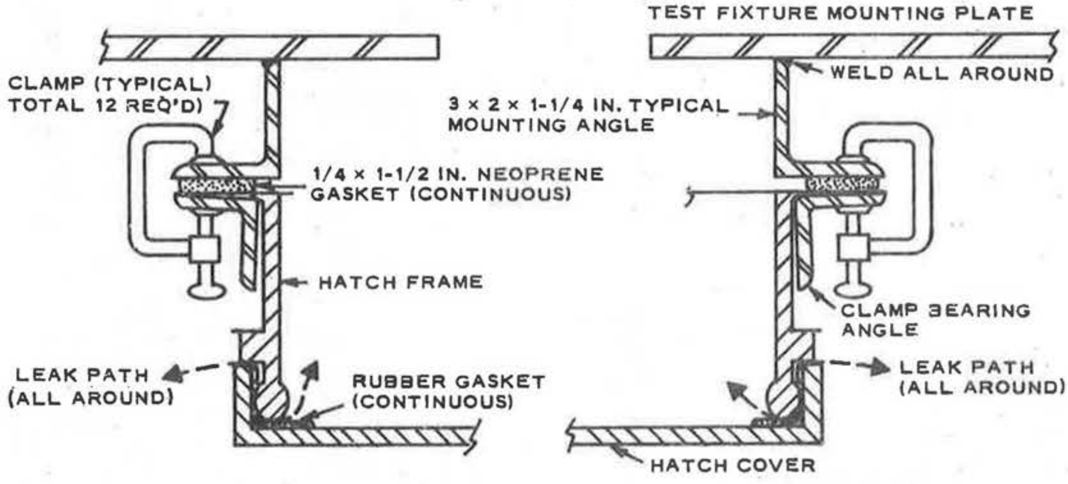
LEAKAGE DATA SHEET	Figure A-6a	Page 2 of 3



HATCH (TOP)



SECTION A–A



SECTION B–B

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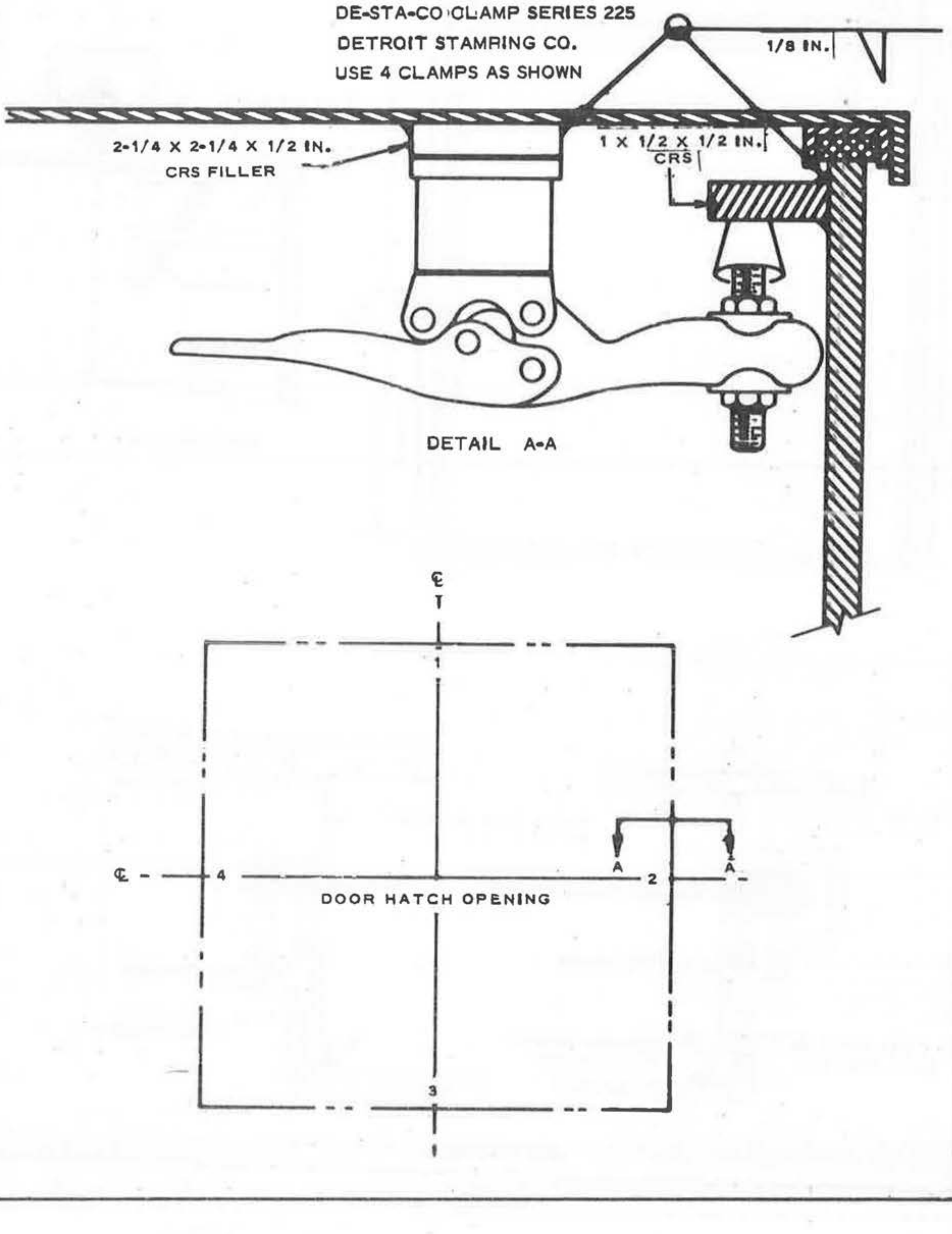

LEAKAGE DATA SHEET	No. A-7	Page 1 of 3

COMPONENT

Louvers, Gasketed

PURPOSE

Determination of air leakage through standard gasketed louvers

TEST SPECIMEN DESCRIPTION

Test and Mounting Design: See Figure A-7.

Installation Procedure: The louver is sealed to a test frame by a continuous neoprene gasket, and the test frame is welded to the mounting plate.

Description of Specimen: The louver is fabricated from 16-gage cold-galvanized steel. Sponge neoprene is used for the stripping and end seals on all five blades.

Leak Path Description: The leak paths are around the total periphery of each blade (between sponge rubber and metal contact).

Manufacturer and Type: Airolite Company; Type 925, air-tite head.

LEAK TEST DATA

Empirical Constants: Value for one louver

1) Using a 10-lb closure force
   A = 7.8 B = 33
2) Using a 20-lb closure force
   A = 6.8 B = 25
3) Using a 30-lb closure force
   A = 6.7 B = 27

Applicable Pressure Range: The air leakage is applicable to pressures up to at least 7 in. of water. (See comments under Limitations.)

Extrapolations: The test data were obtained from a 20- by 21-in. louver with five blades. The leak rate data can be scaled up or down according to the number of blades since the majority of the leak is at the end seals. This is the reason increased closure force did not improve the leak rate.

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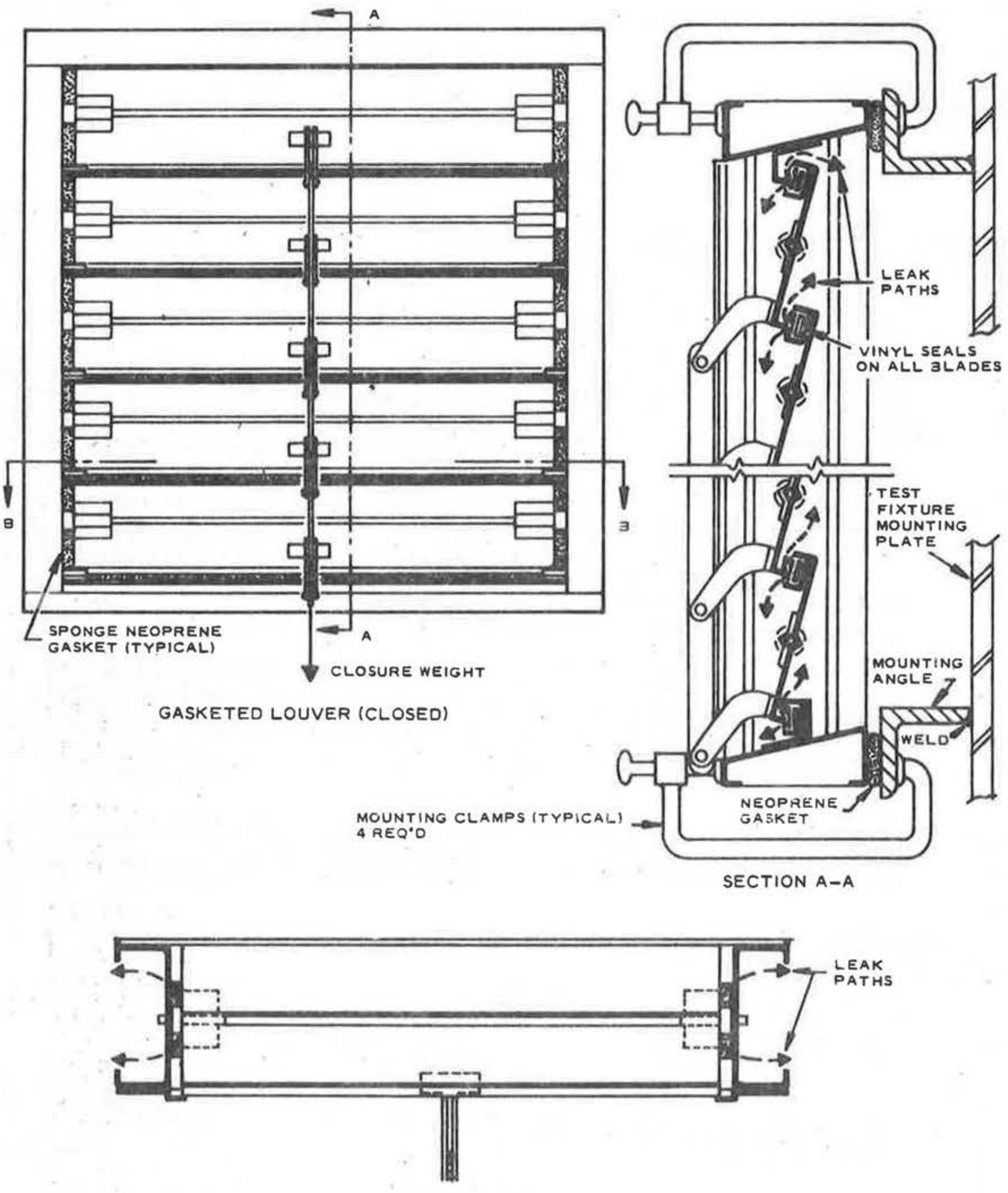
LIMITATIONS

Since the data were obtained from a new specimen, the repeatability of the test data after months of service is unknown. The test data should be applicable up to the bending strength of the blades, which should be considerably greater than 7 in. of water. Turbulent flow probably exists.

RECOMMENDATIONS

None (not practical for low-leakage structures).

LEAKAGE DATA SHEET	Figure A-7	Page 3 of 3



LEAKAGE DATA SHEET	No. A-8	Page 1 of 3

COMPONENT

Roofing (5-Ply Asphalt and Gravel)

PURPOSE

Leak-rate evaluation of 5-ply asphalt and improvement

TEST SPECIMEN DESCRIPTION

Test and Mounting Design: See Figure A-8.

Description of Specimen: The specimen consists of a 2- by 4-ft fluted metal panel with an edge lap assembled with sheet metal screws. Over this panel a sheet of 1-1/2-in. Celotex insulation is installed. The roofing is installed by applying hot asphalt to the surface of the Celotex insulation and then applying a sheet of tar paper. Another layer of hot asphalt is applied to the surface of the paper and a tar paper sheet is applied to this hot asphalt. This process is continued until five layers of asphalt and tar paper have been formed. Then hot asphalt is applied to the top paper surface on which gravel would be laid. The specimen uses techniques meeting ASTM Std. Nos. 250 and 312.

Leak Path Description: The 5-ply built-up roofing will act as a continuous membrane since all laps of the tar paper are sealed by continuous layers of hot asphalt. In this type of containment member, the leakage occurs through the membrane itself. No resistance to flow is assumed for the edge lap.

Manufacturer and Type: H. H. Robertson; M Type, Q-panel, Section No. 3 (fluted outer panel). Celotex Corp.; Celotex roof insulation.

LEAK TEST DATA

Empirical Constants: Value for 1 ft^2 of roofing

$A = 6.0 \times 10^{-5}$ $\quad$ $B = 0$

Applicable Pressure Range: The data should be applicable to 5 in. of water pressure.

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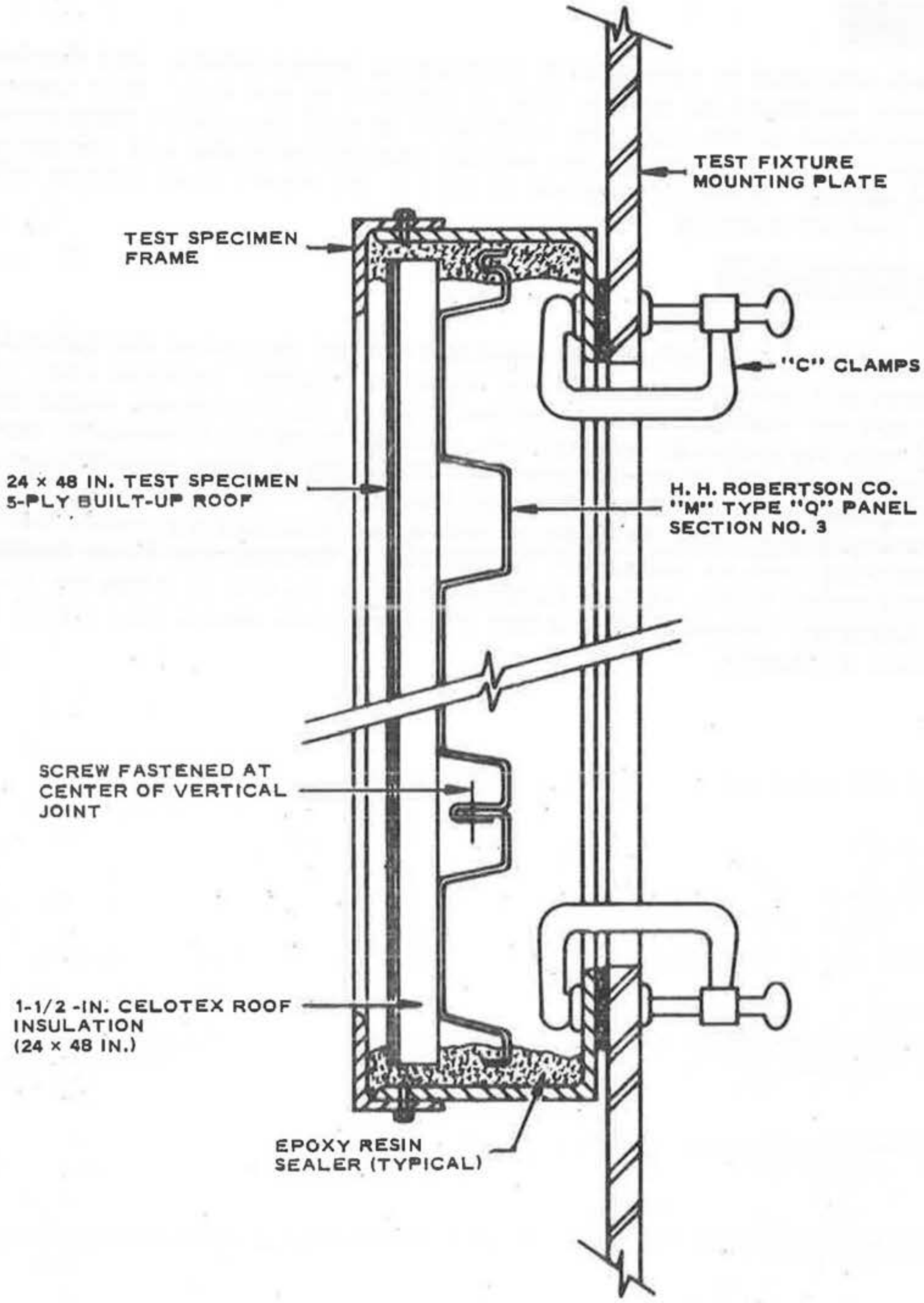
LIMITATIONS

Asphalt will tend to soften with increasing temperature, and the leakage rate may increase as the roofing is exposed to the sun. It is important that the edges of the built-up roofing be sealed securely; otherwise, leakage will occur through the porous insulation slabs and out the unsealed edges. Pressures greater than 5-in. water may tend to lift the 5-ply roof off decking.

RECOMMENDATIONS

An application of a reflective material should decrease the softening problem of 5-ply roofing. Thick layers of asphalt between each ply will decrease the leakage rate. Another type of improvement would be to use other coal tar polymer emulsions, such as Koppers Company, Inc. Bituplastic 33, as recommended in GNEC 168 "Containment Membrane Development for the Bonus Reactor Building." These materials, as well as the 5-ply tar, may be used on wells, as membranes under walls and foundations, and as base slab membranes. Bituplastic 33 or Koppers waterproofing pitch, either applied in three layers of 0.065 in. or 3/16 in., respectively, leaked $1/10^4$ of the test specimen which was tested at 1 in. of water pressure.

LEAKAGE DATA SHEET	Figure A-8	Page 3 of 3



SECTION

LEAKAGE DATA SHEET	No. A-9	Page 1 of 2

COMPONENT

Multistrand Conductors

PURPOSE

To measure the air leakage through wire conductors (between the conductor and insulating jacket)

TEST SPECIMEN DESCRIPTION

Test and Mounting Design: See Figure A-3(2), Case 1

Installation Procedure: A section of the sheath from a multiconductor cable is removed and the exposed portion of the cable sealed in a conduit seal-off. The seal-off is attached to a short conduit pipe which is welded to a flange. The flange is then sealed to a test diaphragm plate by use of polybutene.

Description of Specimen:

1) Cable — 10 conductor, 7 strand, 14 gage each conductor

2) Cable — TV-39 conductor
code EP-937X-156 mil-R-y855-11-60-60E34 4060

The cables were tested for air leakage, using as many as 8 cables in parallel and using cable lengths from 1 to 33 ft. In all cases, leakage was measured before and after sealing each conductor with epoxy.

LEAK TEST DATA

Empirical Constants: Value for 1 ft of cable

Cable (10 conductor)
$A = 3.7 \times 10^{-5}$

Cable — TV (39 conductor)
$A = 1.7 \times 10^{-4}$

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Applicable Pressure Range: The data should be applicable to pressures of at least 10 psig.

Extrapolations: The leak rate is directly proportional to the number of cables (or conductors) and inversely proportional to the length of cable.

LIMITATIONS

Many types of cables are being used and each will have a leak rate characteristic of that cable. However, the above data should give a "ball park" leak rate for most conductors.

RECOMMENDATIONS

The above leak rates will be somewhat reduced (by approximately a factor of 5) when the ends of the conductors are attached to lugs and soldered. The leakage can be further reduced by dipping the conductor ends in conductive epoxy (such as HYSOL-K2) prior to attaching a solderless connector.

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B. CONCRETE

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CONTENTS
LEAKAGE DATA SHEETS

B. CONCRETE

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COMPONENT

Concrete, Suggested Mixture

PURPOSE

Uniform mix for component testing

TEST SPECIMEN DESCRIPTION

Test and Mounting Design: See Figure B-4a.

Description of Specimen: The following data represent the mix specifications for concrete test materials unless otherwise noted.
Compression strength in 28 days = 5000 psi.

Specified Design Mix

Cement (sacks/yd^3)	7.75
Cement (lb)	729
Sand (lb)	1196
No. 3 gravel (lb)	1832
Water (lb)	264
Total weight (lb)	4021
Water (gal)	31.7
Water (gal/sack)	4.23
Slump, calculated (in.)	2 to 4
Plastiment admixture per sack, Sika Chem. Co. (oz)	2
Maximum allowable water (gal)	33

The supplier of the transit-mixed concrete was the Consolidated Rock Products Co. and Colton Cement (Mojave Type II cement).

In order to verify compliance to specifications, the AI field engineer was present at Consolidated. The following loading was witnessed for a 2-yd^3 batch of concrete:

Cement	as ordered
Sand 2536 (lb)	144 in excess approved by AI
No. 3 gravel 3664	as ordered
Water added at plant (gal)	42
Water in aggregate (moisture)	17.2
Plastiment (oz)	30
Water added at job (gal)	12

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Mixing and placing was performed according to Specifications for Ready-Mixed Concrete, ASTM C94. Complete mixing of the concrete was begun within 30 min after the cement was intermingled with the aggregates.

LEAK TEST DATA

Empirical Constants: Value for 1 ft^2 of concrete, 1-in. thick

Coefficient A varies from

$$1.2 \times 10^{-5} \text{ to } 1.6 \times 10^{-6}$$

for different samples and occasionally varied as a function of curing time (A increased to the higher leak rate only).

Extrapolations: Use of the highest leak coefficient for the design mix specified will cause little over-estimation of the leak rate for most buildings. Since high-leaking cracks are most likely to occur for large pours and large surfaces, these values are verified for laboratory purposes only. The data can be extrapolated up to at least 40 psi for any size (realizing that the flow rate is directly proportional to the area and inversely proportional to the thickness).

Prestressed concrete has leak rates similar to those above.

LIMITATIONS

The variability in the observed leakage coefficients can be due to:

1) cracks
2) specimen mounting leaks
3) curing methods
4) water-cement ratio variations
5) aggregate sizes

LEAKAGE DATA SHEET	No. B-1 (2)	Page 1 of 3

COMPONENT

Concrete Aggregates and Admixtures

PURPOSE

Evaluate the effect of water-cement ratio, admixtures, and other parameters on concrete leakage

TEST SPECIMEN DESCRIPTION

Test and Mounting Design: See Figures B-1 (2) and B-4a

Description of Specimen: Series 1 and 2 consist of concrete blocks 11-1/2 by 11-1/2 by 4 in., and Series 3 is comprised of 2-ft by 4-ft by 6-in. blocks. All specimens were prepared by Raymond G. Osborne Laboratories, Inc. The effect of all anomalies such as placement, curing, etc., except as shown in the listing below, is considered insignificant for these tests.

CONCRETE MIX PROPORTIONS AND TEST RESULTS

Mix Code No.	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
Aggregate												
Maximum size (in.)	1	1	1	1	1	1.5	2	1	1	1	1	1
No. 3 gravel (lb)	1821	1895	1768	1823	1825	1155	1117	1820	1854	1735	1820	1840
No. 2 gravel (lb)	--	--	--	--	--	842	785	--	--	--	--	--
No. 1 gravel (lb)	--	--	--	--	--	--	196	--	--	--	--	--
W.C. Sand (lb)	1319	1263	1390	1320	1320	1219	1112	1320	1342	1256	1320	1333
Cement (lb)	595	595	595	564	538	564	581	595	595	595	595	595
Water												
Weight (lb)	308	315	315	317	325	292	285	308	287	288	308	296
Maximum volume (gal.)	37	37.8	37.8	38	39	35	34.2	37	34.5	34.6	37	35.5
W/C ratio	0.518	0.53	0.53	0.562	0.603	0.518	0.49	0.518	0.482	0.484	0.518	0.498
Slump	4	3	3	5	5	3.25	3	3	2	3.5	2.75	1.25
Admixture	none	none	none	none	none	none	none	none	(1)	(2)	(3)	(4)
28-day compressive strength (psi)	5358	4846	5340	5669	4920	5395	4956	6218	6657	4225	5614	4590
Leakage (10^{-6} cfm/in.-ft^2/in. H_2O)												
Series 1	3.8	1.60	0.87	7.6	28	19	20	20	95	8	16	8.3
Series 2	4.2	0.87	0.95	10.1	34	24	17	26	65	8.5	17	9.8
Series 3	3.8	1.2	3.4	9.3	17	13	16	12	4.3	7.8	16	4.6

(1) Retarding agent
(2) Air entrainment resin solution
(3) Waterproofing agent
(4) Acceleration agent

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Extrapolations: The data can be extrapolated up to at least 40 psi for any size (assuming that the flowrate is directly proportional to the area and inversely proportional to the thickness).

LIMITATIONS

A small hole (probably the result of water capillary) was found in Series 2, Code XII. Sealing the hole with epoxy reduced the leakage by a factor of 3 to the value as shown. Series 1 and 2, Code IX had many water capillaries, none of which were sealed. No capillaries were observed in Series 3 of Code IX.

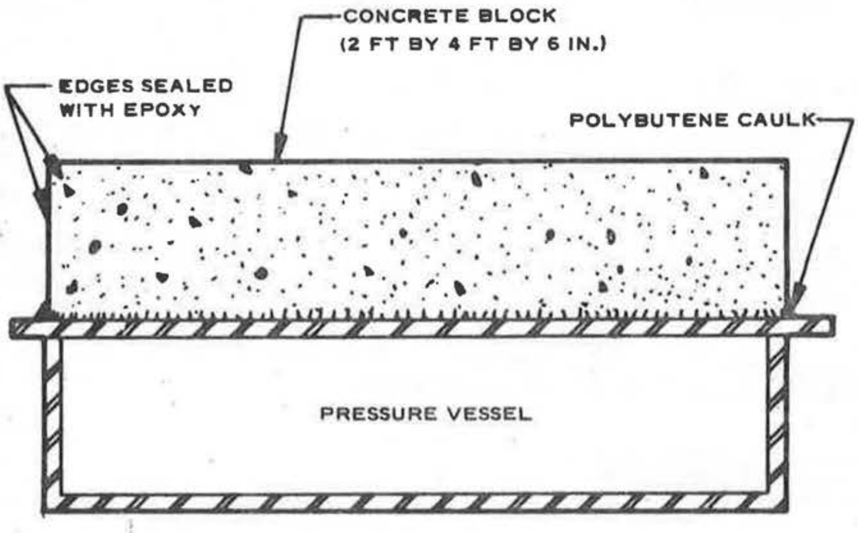
A statistical analysis of the test result data (excluding Code IX) shows the following:

1) Mean Empirical Constant: Value for 1 ft^2 of concrete, 1-in. thick

$$A = 12 \times 10^{-6}$$

2) Fractional Standard Deviation = 0.75. The small deviation of the test specimens shows that many types of mixes are acceptable for predicting leakages through concrete. A mix requiring a retarding agent is the exception of those tested. The value of the same mix with a vacuum-treated cure is given in B-2 (2).

LEAKAGE DATA SHEET	Figure B-1 (2)	Page 3 of 3



LEAKAGE DATA SHEET	No. B-1 (3)	Page 1 of 1

COMPONENT

Water-Cement Ratio

PURPOSE

Determination of the variations of air leakages in concrete due to the water content during mixing

TEST SPECIMEN DESCRIPTION

Test and Mounting Design: See Figure B-4a.

Description of Specimen: Two specimens 11-1/2 by 11-1/2 by 4-in. are poured. The mixes are identical except that water is added to the second specimen.

Installation Procedure: The sides of the specimen are coated with an epoxy resin. Epoxy is used to seal the specimen to the diaphragm plate.

Leak Path Description: Since this is a single leak path component, the leak path is through the concrete only.

LEAK TEST DATA

Empirical Constant: Value for 1 ft^2 of concrete, 1-in. thick

Water-to-cement ratio: 31 gal/yd
$A = 2.8 \times 10^{-6}$ $B = 0$
Water-to-cement ratio: 36.4 gal/yd
$A = 2 \times 10^{-5}$ $B = 0$

Applicable Pressure Range: The data are applicable from 0 to 40 psig.

Extrapolations: The data can be extrapolated to any size (realizing that the flowrate is directly proportional to the area and inversely proportional to the thickness).

LEAKAGE DATA SHEET	No. B-2 (1)	Page 1 of 3

COMPONENT

Prestressed Concrete (including cold joint)

PURPOSE

To determine the air leakage through prestressed concrete at various pressures

TEST SPECIMEN DESCRIPTION

Test and Mounting Design: See Figure B-2 (1).

Installation Procedure: The specimen was painted on the four 5-1/2-in. sides with several coats of epoxy paint and then sealed in a 6 by 6-ft test frame. Leakage rates across 36 ft^2 of concrete were measured.

Description of Specimen: (1) The concrete panels 6 ft by 6 ft by 5-1/2 in. are prestressed with 5/8-in. diameter high-tensile steel rods at 12 in. o/c each way with the nut anchors flush with the outside surface. 300-psi stress is evenly distributed in the finished product. Four pickup inserts are installed to facilitate erection. (2) The cold joint panel is fabricated the same as above but is formed in two pours, 6 by 3 ft each, thereby producing a cold joint at the centerline. The casting times of the cold joint were separated by 24 hr.

Both panels were cured a minimum of 7 days before stressing.

Specifications: (Compressive strength of test cylinders varied from 5,500 to 8,400 psi - 28 day)

1. Materials

a) Cement	Victor Type 3, rapid hardening
b) Sand	100
c) Aggregate	No. 3
d) Water	Van Nuys tap water
e) Admixture	Plastiment

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LEAKAGE DATA SHEET	No. B-2 (1)	Page 2 of 3

2. Mix proportions per sack of cement

a) Cement (lb)	94 (1 sack)
b) Sand (lb)	141
c) Aggregate (lb)	235
d) Water (lb)	47
e) Plastiment (oz)	3

3. Type of Mixer: Smith Turbine Mixer

4. Jacking force:	20,600 lb/rod
Final force:	19,500 lb/rod
Average prestress	300,000 $lb/in.^2$

LEAK TEST DATA

Empirical Constants: Value for 1 ft^2, 1-in. thick

1. Single pour

$A = 6 \times 10^{-5}$ $\quad$ $B = 0$

2. Double pour (cold joint)

$A = 6 \times 10^{-5}$ $\quad$ $B = 0$

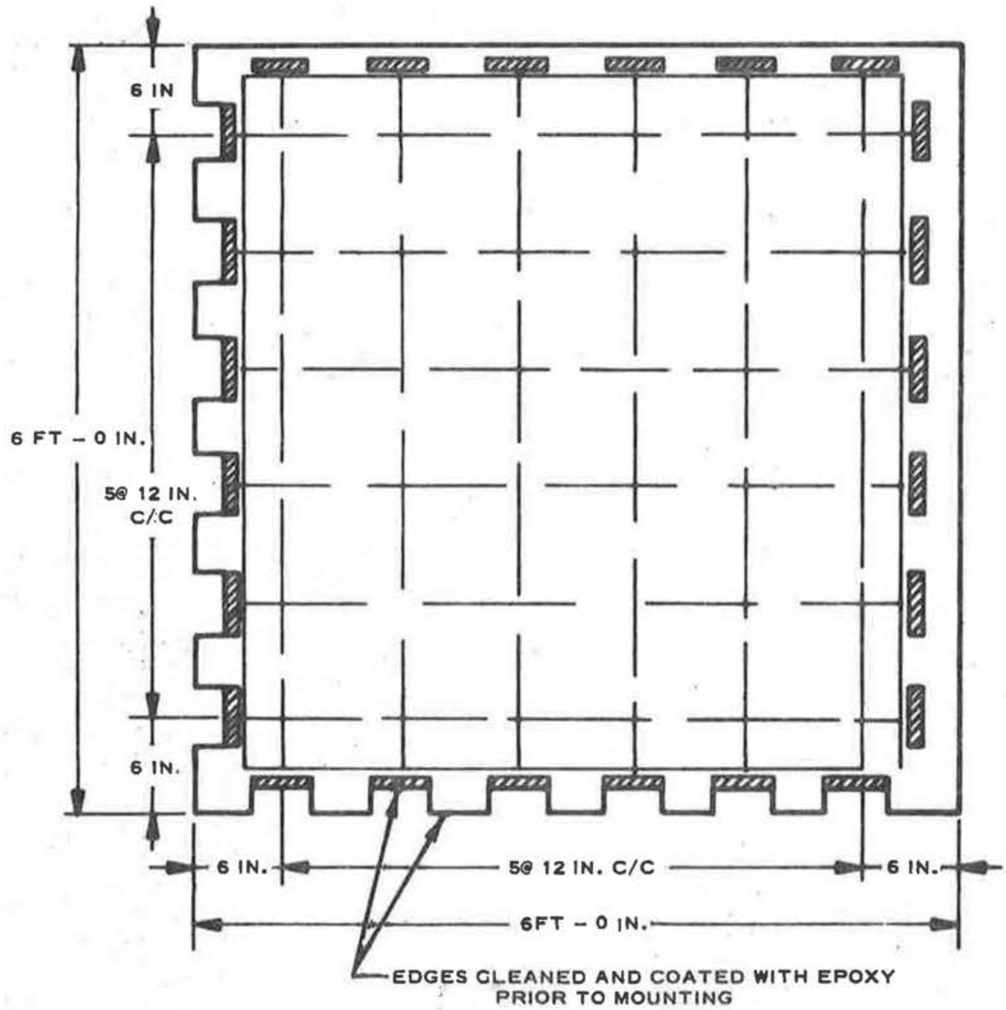
Applicable Pressure Range: The specimens are tested at pressures up to 100 in. water. (See comments under Limitations).

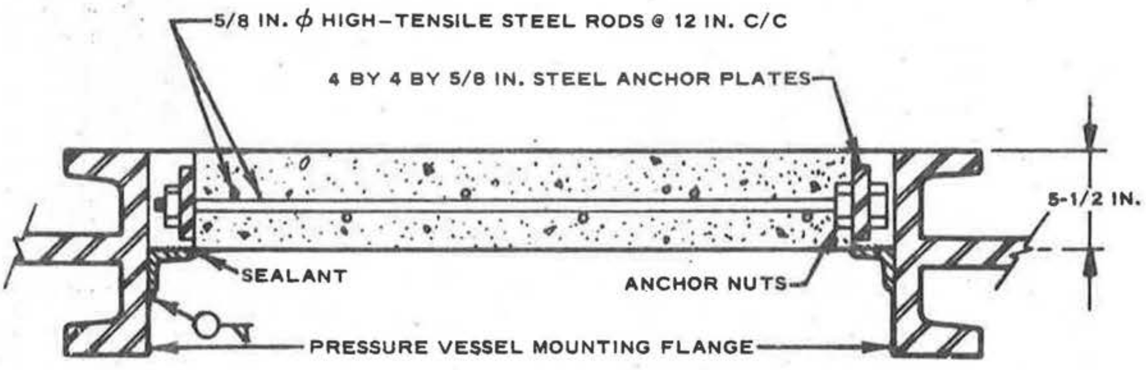
Extrapolations: The test data are obtained from a concrete specimen 6 ft by 6 ft by 5-1/2 in. The data are given in cfm/ft^2 by 1-in. thick at 1-in. water pressure and are directly proportional to both the surface area and pressure, and inversely proportional to the concrete thickness.

LIMITATIONS

The best concrete practices must be followed, such as placing, compacting, and curing. Unless the anchorages are sealed, the air travels along the steel and thus reduces by half the leak path across the concrete. The estimate of the joint leakage was obtained by measuring the leakage across the entire 36-ft^2 surface and then remeasuring the specimen after sealing the surface of the joint. The difference was deemed due to leakage through the joint.

LEAKAGE DATA SHEET	Figure B-2 (1)	Page 3 of 3





LEAKAGE DATA SHEET	No. B-2 (2)	Page 1 of 1

COMPONENT

Vacuum-Treated Concrete

PURPOSE

To evaluate the effect of vacuum-treating concrete

TEST SPECIMEN DESCRIPTION

Test and Mounting Design: See Figure B-4a.

Description of Specimen: Sixteen concrete testing specimens were prepared from four different mixtures by Raymond G. Osborne Laboratories, Inc.; two regular-cured and two vacuum-treated concrete specimens (11-1/2 by 11-1/2 by 4 in.) were made from each mixture.

CONCRETE MIX PROPORTIONS AND TEST RESULTS

Constituent	Code			
	I	II	III	IV
Cement (lb)	595	564	538	595
Sand (lb)	1310	1310	1298	1333
No. 3 gravel (lb)	1809	1800	1790	1840
Water (lb)	317	329	346	298
W/c ratio	0.532	0.583	0.643	0.502
Slump (in.)	3-3/4	5	6	3-1/2
Admixture	none	none	none	Plastiment
Water (gal)	38.0	39.5	41.5	35.8
Comp. Strength, 28 d (psi)	5182	4121	4422	5412
Leakage, Regular cure (*)	2.4	3.0	0.79	2.1
	1.5	1.84	0.74	2.5
Leakage, Vacuum-treated (*)	2.4	1.6	1.85	2.38
	2.15	2.5	1.57	2.3

Regular cure: mean = 1.86×10^{-6}, standard deviation = 0.81×10^{-6}
Vacuum treated: mean = 2.09×10^{-6}, standard deviation = 0.37×10^{-6}
*10^{-6} cfm/in.-ft^2/in. H_2O

Extrapolations: The data can be extrapolated up to at least 40 psi for any size.

LEAKAGE DATA SHEET	No. B-3	Page 1 of 2

COMPONENT

Concrete Curb to Curb Angle

PURPOSE

Leak rate evaluation and improvement

TEST SPECIMEN DESCRIPTION

Test and Mounting Design: See Figure B-3.

Description of Specimen: A 4-ft by 6-in. by 4-in. wide concrete curb was bolted to a curb angle with two anchor bolts at 3.0 ft O.C. The following seals were used between the angle and concrete curb:

Test No. 1: 3M, Weatherbon Ribbon Sealer and Primer
Test No. 2: mastic, preformed nonresilient tapes
Test No. 3: neoprene gasket and mastic (the mastic is applied to both the curb and curb angle before the neoprene is installed).
Test No. 4: neoprene gasket

Installation Procedure: An 18-gage wall section is sealed to the curb angle with mastic and sheet metal screws. The perimeter of the concrete curb and wall section is sealed to the test frame with an epoxy resin as shown in Figure C-12a.

LEAK TEST DATA

Empirical Constants: Value for 1 ft of seal

Test No. 1: A >5
Test No. 2: A<10^{-8}
Test No. 3: A <10^{-8}
Test No. 4: A >5

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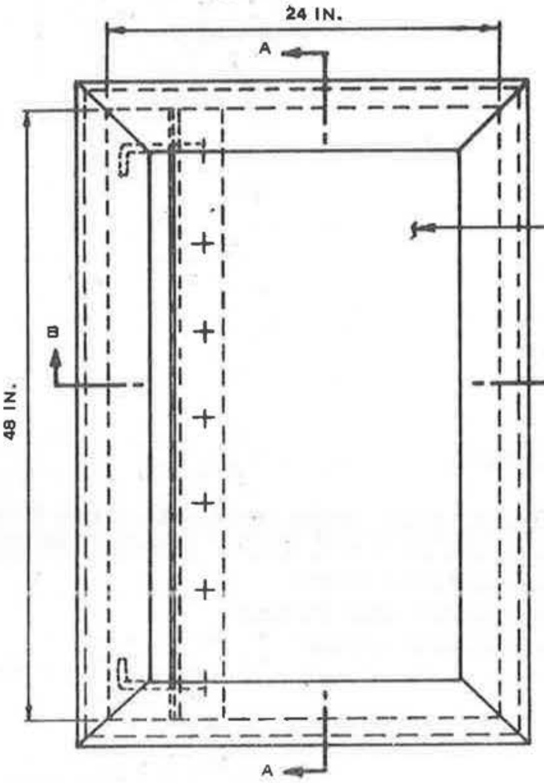
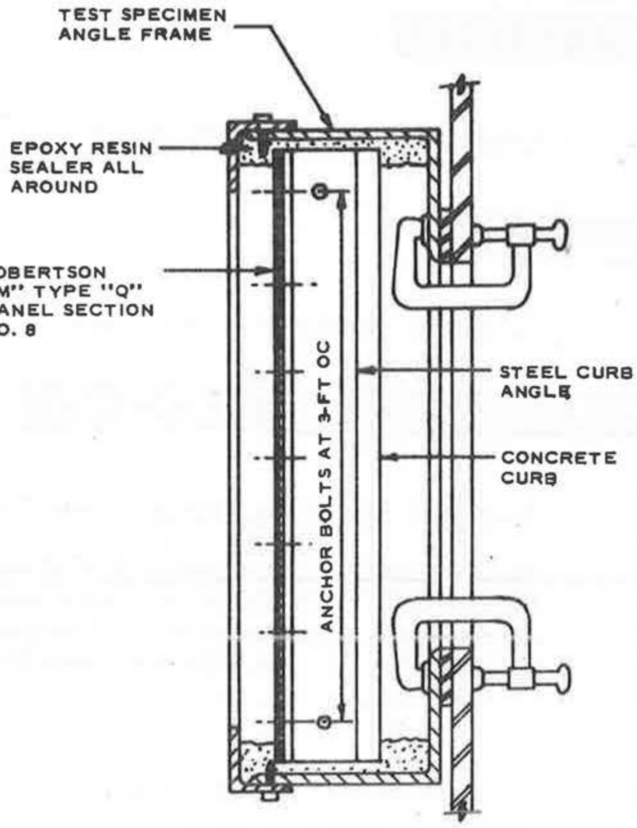
LEAKAGE DATA SHEET	Figure B-3	Page 2 of 2

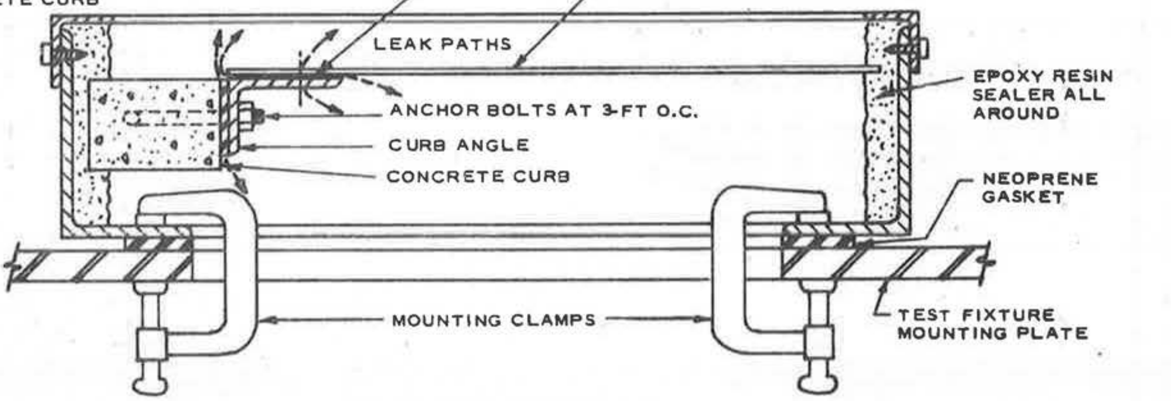


FRONT



VERTICAL SECTION A-A

TEST NO. 1:
3M RIBBON SEALERS AND PRIMER BETWEEN ANGLE AND CONCRETE CURB
TEST NO. 2:
MASTIC BETWEEN ANGLE AND CONCRETE CURB
TEST NO. 3:
NEOPRENE GASKET AND MASTIC BETWEEN ANGLE AND CONCRETE CURB.
TEST NO. 4:
NEOPRENE GASKET BETWEEN ANGLE AND CONCRETE CURB



HORIZONTAL SECTION B-B

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LEAKAGE DATA SHEET	No. B-4	Page 1 of 4

COMPONENT

Concrete Leakage, Area and End Effects

PURPOSE

To determine the amount of air leakage due to various size ruptures of impervious coatings on concrete

TEST SPECIMEN DESCRIPTION

Test and Mounting Design: See Figures B-4a and B-4b.

Description of Specimen: A 11-1/2- by 11-1/2- by 4-in. block of concrete is sealed on each of the 4- by 11-1/2-in. sides. Tests are made with the top of the block (1) bare, (2) covered with Thiokol and Al sheets except for a 6-in. diam surface area opening, and (3) covered with Thiokol and Al sheets except for a 1/4-in. diam surface area opening.

Installation Procedure: The block is sealed in the mounting plate using Thiokol.

Leak Path Description: The leak path is through the concrete only.

LEAK TEST DATA

Empirical Constant: Value for each specimen

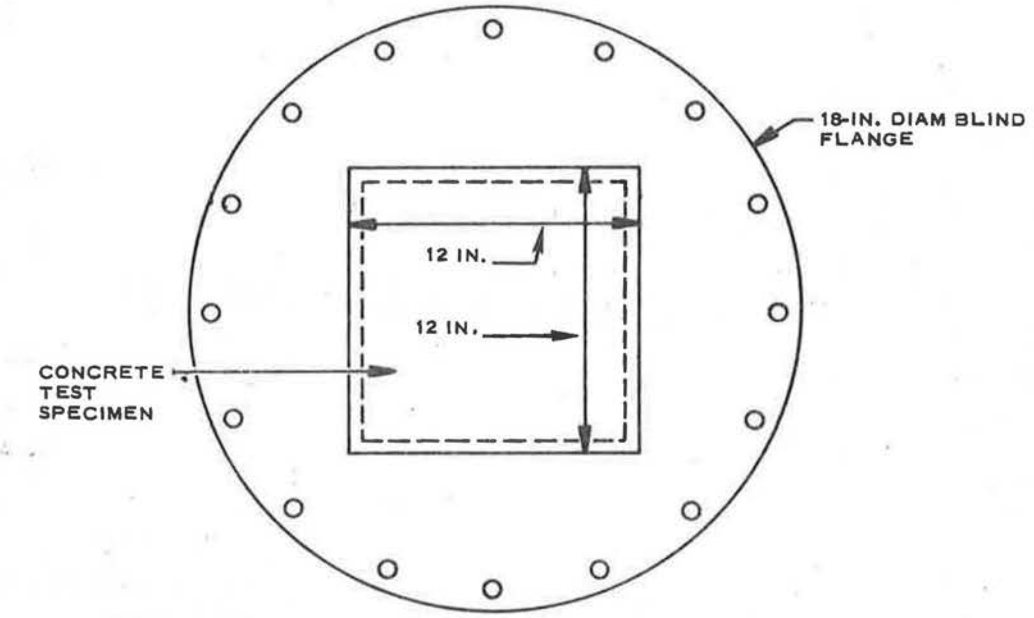
Test 1: Bare concrete 11-1/2 by 11-1/2 by 4-in. (132 $in.^2$ bare surface area)
$A = 7 \times 10^{-7}$ $B = 0$
Test 2: Covered except 6-in. diam opening (28 $in.^2$ bare surface area)
$A = 2.5 \times 10^{-7}$ $B = 0$
Test 3: Covered except 1/4-in. diam opening (0.05 $in.^2$ bare surface area)
$A = 0.73 \times 10^{-7}$ $B = 0$

Applicable Pressure Range: The data are applicable up to the design pressure of the building when the seal coat covers the inside surface of the concrete structure. These data are applicable up to 100 in. of water pressure.

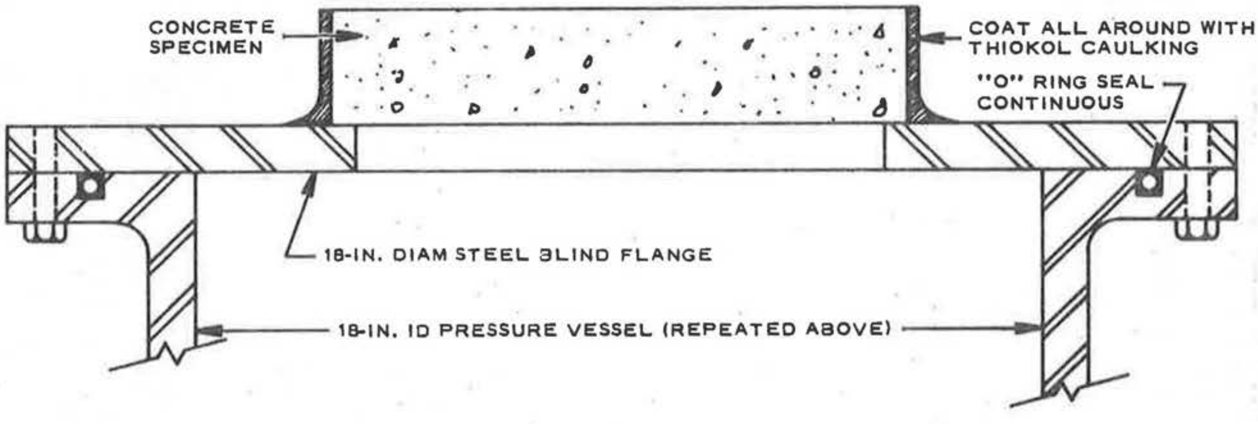
LEAKAGE DATA SHEET	No. B-4	Page 2 of 4

Extrapolations: The leak rate depends on the ratio of the size of the opening to the concrete area covered, the concrete thickness, and possibly the undefined parameters, such as the effective tortuosity. However, a pin hole in a 1-ft^2 surface can be "guessed" as contributing 10% of the leakage through a 1-ft^2 uncoated area. The method of extrapolation is uncertain at the present time and should not be attempted for voids in sealants covering concrete.

APPLICATION DATA SHEET	Figure B-4a	Page 3 of 4



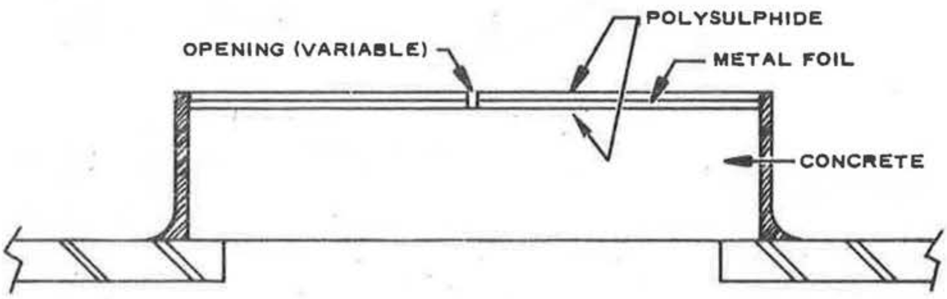
PLAN VIEW



LEAKAGE DATA SHEET	Figure B-4b	Page 4 of 4

(SEE FIGURE B-4a FOR PLAN VIEW)

AREA AND END EFFECT



LEAKAGE DATA SHEET	No. B-5	Page 1 of 2

COMPONENT

Cold Joints in Concrete

PURPOSE

Determination of air leakage through cold joints

TEST SPECIMEN DESCRIPTION

Test and Mounting Design: See Figure B-5.

Description of Specimen: A cold joint is made in concrete from two separate pours, five days apart, in the 1-ft^2 test frame. No special effort is made to form a perfect joint since reinforcement bars are not used nor is the first pour saturated with water just prior to the second pour. This is considered a "worst case" specimen (1-ft-long by 4-in.-thick concrete).

Installation Procedures: The sides of the specimen are sealed with an epoxy resin and attached to the diaphragm with epoxy.

Leak Path Description: The data show the leak path is through the cold joint. In a "best case" specimen, the significant leak path is through the concrete and not just the cold joint. [For leakage through prestressed cold joints, see LDS B-2(1)].

LEAK TEST DATA

Empirical Constants: Value for 1 ft of joint

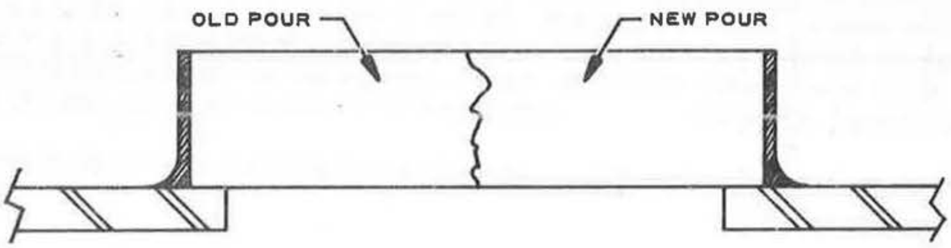
"Worst case" $A = 2.4 \times 10^{-4}$ $B = 0$

Applicable Pressure Range: The equation is applicable to the design pressure of the building, assuming the crack does not fail from application of high pressures.

Extrapolations: The equation can be extrapolated to any length of cold joint, but the thickness effect is unknown. The coefficient A is reduced to $A = 4.0 \times 10^{-5}$ when a 1/2-in.-wide layer of epoxy resin is placed over the top of the crack on concrete which typically leaks 3×10^{-6} cfm/ft^2 through 4 in.

LEAKAGE DATA SHEET	Figure B-5	Page 2 of 2

(SEE FIGURE B-4a FOR PLAN VIEW)



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LEAKAGE DATA SHEET	No. B-6	Page 1 of 2

COMPONENT

Contraction Joints

PURPOSE

Determination of air leakage through various types of contraction joints

TEST SPECIMEN DESCRIPTION

Test of Mounting Design: See Figure B-6 (same as for expansion joints).

Description of Specimen: Can be any type of contraction joint.

Installation Procedure: The dummy joints which introduce cracking must be 1/4 to 1/3 the thickness of the concrete and constructed according to the best practices of joint construction.

Leak Path Description: Assuming the concrete cracks at the joint, the leak path will be the same as described under Expansion Joints.

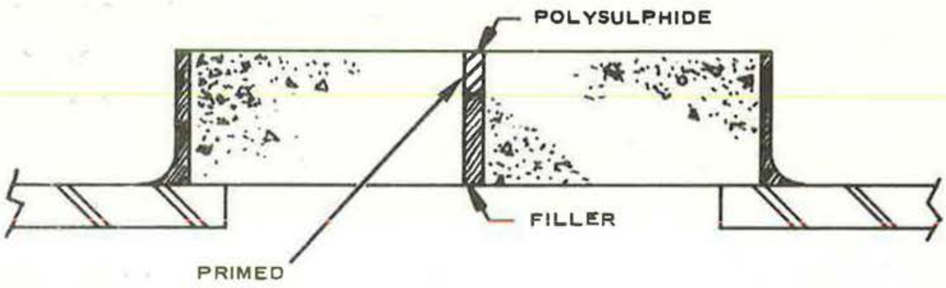
LEAK TEST DATA

See LDS B-8

LEAKAGE DATA SHEET	Figure B-6	Page 2 of 2

(SEE FIGURE B-4a FOR PLAN VIEW)

EXPANSION JOINTS



LEAKAGE DATA SHEET	No. B-7 (1)	Page 1 of 2

COMPONENT

Unstressed Cracks in Concrete

PURPOSE

Determination of air leakage in concrete due to various sized cracks

TEST SPECIMEN DESCRIPTION

Test and Mounting Design: See Figure B-7 (1).

Description of Specimen: A crack is formed in a concrete specimen 11-1/2 by 11-1/2 by 4 in. by means of a failure in a nonreinforced cold joint. The sides of the specimen are sealed with an epoxy resin.

Installation Procedure: The specimen is sealed to the diaphragm plate by use of an epoxy resin. Measurements of the mean crack distance are made.

Leak Path Description: The air leakage through any crack is much greater than through the concrete itself; therefore, the crack is considered the principal leak path.

LEAK TEST DATA

Empirical Constants: Value for 1 ft of crack

Equation for determining crack leakage for air:

$A = 0.069$ $B = 0.1$

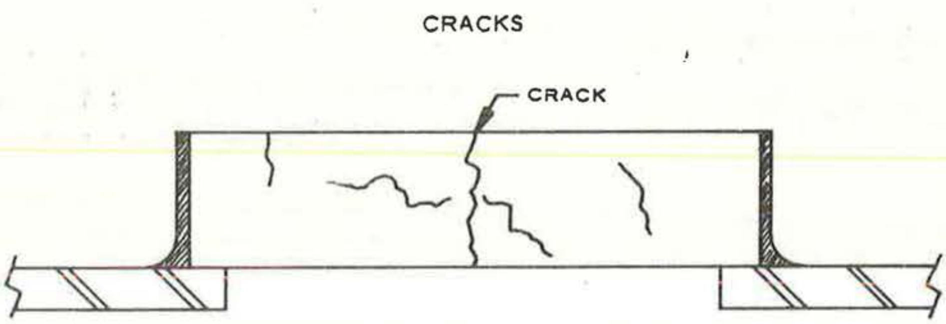
A crack in concrete may contain both crack and orifice coefficients. The specimen has a mean crack width of 12 mils (LDS D-3).

Applicable Pressure Range: The equation is applicable to the design pressure of the building assuming the crack width remains constant during various pressures.

Extrapolations: See LDS D-3 for dimension extrapolation.

LEAKAGE DATA SHEET	Figure B-7(1)	Page 2 of 2

(SEE FIGURE B-4a FOR PLAN VIEW)



LEAKAGE DATA SHEET	No. B-7(2)	Page 1 of 3

COMPONENT

Stress Cracks in Concrete

PURPOSE

Determine leakage characteristics of concrete when cracked at various depths.

TEST SPECIMEN DESCRIPTION

Description of Specimen: Block A_1 [see Figure B-7(2)] is a nonreinforced specimen (3-1/2 by 11-1/2 by 11-1/2 in.) that is cracked completely through. The concrete was separated, cleaned with a brush, joined, and painted on the 3-1/2 by 11-1/2-in. side with epoxy. Block A_2 (same size) was cracked by means of a failure in a nonreinforced cold joint. Specimen was not separated and cleaned of loose debris.

Block B [see Figure B-7(2)] is a reinforced specimen (2 ft by 4 ft by 6 in.) that was cracked by subjecting the block to stresses above the design stress and beyond the elastic limit of the steel.

Block C [see Figure B-2(1)] is a prestressed specimen (6 ft by 6 ft by 6 in.) which was poured so as to form a cold joint. The specimen was stressed in flexure until a 6-ft crack formed in the cold joint across the outside surface.

LEAK TEST DATA

Empirical Constants: Value for 1 ft of crack

Block A_1

$A = 2.8 \times 10^{-3}$ $B = 0$

Block A_2

$A = 0.069$ $B = 0.1$
(calculated crack width: 2.5 mil)

Block B

$A = 7.9 \times 10^{-5}$ $B = 0$
(crack in shape of a wedge; width varied from 0 to 22 mil)

Block C

No detectable leakage (estimated crack penetrated to depth of prestressed steel)

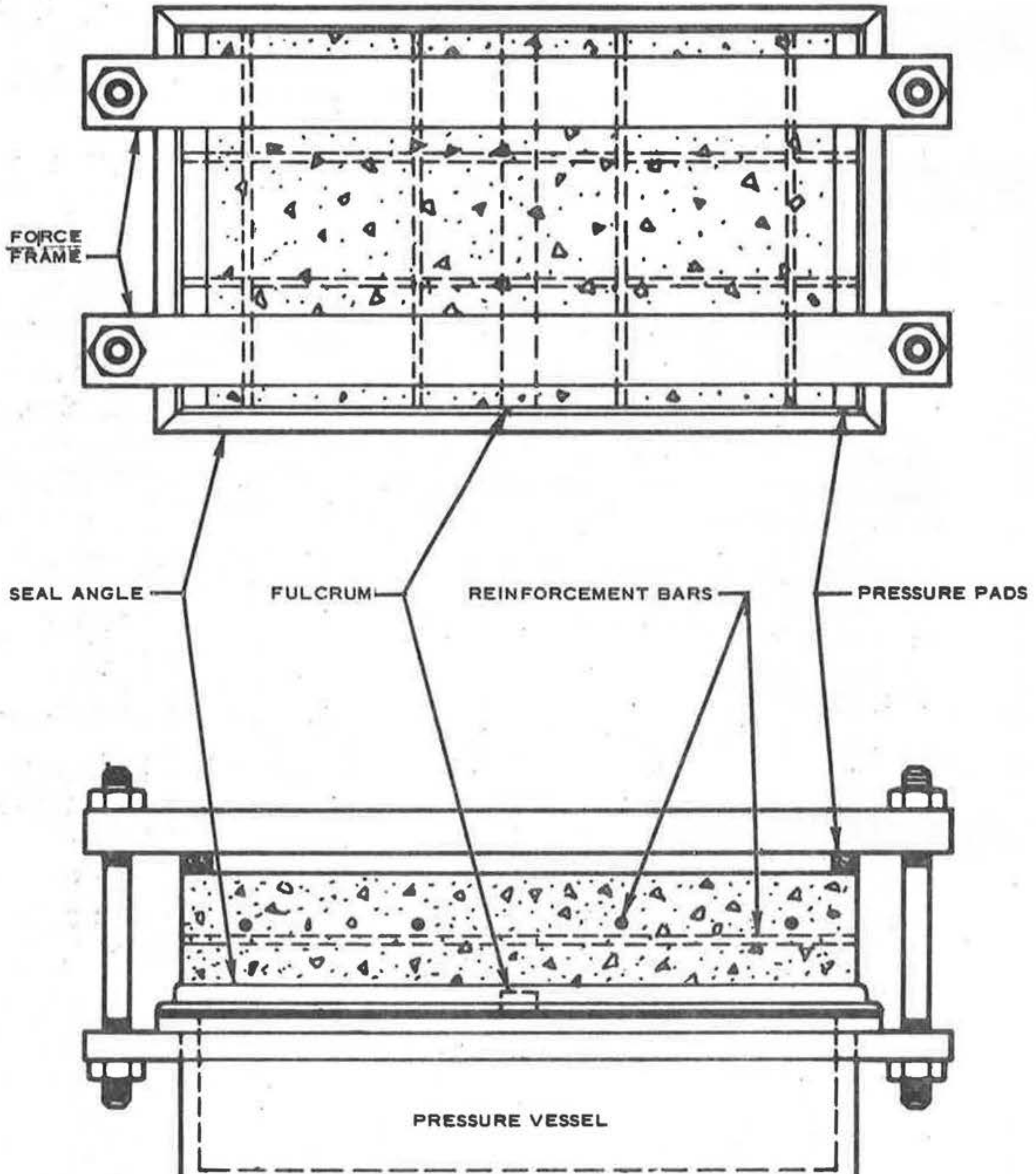
Extrapolations:

1) When cracks appear completely through the concrete, the crack equation as discussed on LDS D-3 may be used.

2) When a single crack appears on one surface, the additional leakage due to that crack may be insignificant.

3) When many cracks appear, such as during an overpressure of a building, the leakage through the concrete may be calculated by assuming the cracks propagate approximately to the neutral axis. The concrete thickness which is under compression is assumed to be uncracked. Therefore, the leakage is through that thickness of the concrete which is uncracked [see LDS B-1(1)].

LEAKAGE DATA SHEET	Figure B-7(2)	Page 3 of 3



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LEAKAGE DATA SHEET	No. B-8	Page 1 of 2

COMPONENT

Expansion Joints

PURPOSE

Determination of air leakage through various types of expansion joints

TEST SPECIMEN DESCRIPTION

Test and Mounting Design: See Figure B-6.

Description of Specimen: The concrete block is 11-1/2 by 4-in. thick with 1/2-in. joint. The Thiokol compound (structure-seal, Martin-Marietta Co.) is placed in the joint at various depths of the crack width.

Installation Procedure: Normal procedures are to: (1) coat the joint with a primer, (2) place the bed at the desired depth before the sealant is applied, and (3) fill the remaining portion of the joint with the joint sealer (follow recommendations as stated by the manufacturer).

Leak Path Description: The leak paths across the joint are: (1) between the sealing compound and primer, and (2) in the concrete at the immediate area of primer and sealing compound.

Manufacturer:

Presstite Division of America, Marietta Co.

LEAK TEST DATA

Empirical Constants: Value for 1 ft of joint

1) Joint filled 1/2-in. depth
   $A = 3.6 \times 10^{-5}$ $B = 0$
2) Joint filled 2-in. depth
   $A = 4.0 \times 10^{-6}$ $B = 0$
3) Joint filled 3-in. depth
   $A = 2.5 \times 10^{-6}$ $B = 0$
4) Joint filled 4-in. depth
   $A = 2.1 \times 10^{-6}$

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LEAKAGE DATA SHEET	No. B-8	Page 2 of 2

Applicable Pressure Range: The applicable pressure is determined by the condition of the concrete and the performance index of the compound as stated by the manufacturer. The above test results were obtained at pressures of 10 and 20 in. of water.

Extrapolations: The data can be extrapolated to any length and are independent of concrete thickness.

If the leak value of concrete with the 4-in. thickness, 1/2 in. of polysulphide is assumed to be due to concrete leakage only, then the leak per foot of the other joints can be obtained by subtracting the leak value of the 4-in. specimen from that of the other test joints. Since the value of the 4-in. joint seal is small, it can be neglected when the depth of the seal is small. Extrapolation of the leakage can be made as a function of the depth of the caulking in the crack, i.e., a 1-in. depth of caulking should leak 8×10^{-6}/ft.

RECOMMENDATIONS

1) A proper relationship must exist between the elasticity of the seal, depth of the seal, width of the joint, and joint movement. In some cases the depth of the seal and joint width ratio can be obtained from the caulk sealant manufacturer.

2) In general, a wider joint and shallower seal will withstand the maximum movement before seal failure. However, a shallower seal also has the maximum leakage rate.

3) The caulk sealant should be applied so that only the two opposite surfaces are bonded. The seal should not bond to the filler or to the bottom of the formed groove.

4) For maximum bond between the caulk and concrete, use primer on both side walls.

5) Avoid using oil or wax-coated premolded strips which may contaminate the joint area.

LEAKAGE DATA SHEET	No. B-9	Page 1 of 3

COMPONENT

Frame Inserts

PURPOSE

Determination of air leakage around metal frames cast in concrete

TEST SPECIMEN DESCRIPTION

Test and Mounting Design: See Figure B-9 and B-4a.

Test 1: Five metal inserts 11-1/2 by 4 in. are cast in concrete block 11-1/2 by 11-1/2 by 4 in. The total surface area between concrete and metal is 115 by 4 in.

Test 2: Two end plates of 11-1/2 by 4 in. are cast in concrete with anchor bolts.

Leak Path Description: The leak path is between the metal frame and the concrete.

LEAK TEST DATA

Empirical Constants: Value for each lineal ft

Test 1: frame 12 by 4 in.
$A = 9 \times 10^{-4}$ $B = 0$

Test 2: frame 12 by 4 in.
$A = 1.3 \times 10^{-4}$ $B = 0$

Applicable Pressure Range: The test data are obtained at 100-in. water and should be applicable up to the design pressure of the building.

Extrapolations: Data can be extrapolated directly to 10 psig when anchors are used. These data are obtained by subtracting the leakages of the sealed joints from the frame or insert and concrete.

Recommended Method: Empirical constant $A = 4 \times 10^{-6}$, $B = 0$ (see LDS B-8)

LEAKAGE DATA SHEET	No. B-9	Page 2 of 3

LIMITATIONS

In Test 1, anchors are not attached to the framing, thus enhancing the possibility of metal-to-concrete bond failure. This is considered nearly the "worst case" when standard techniques are used.

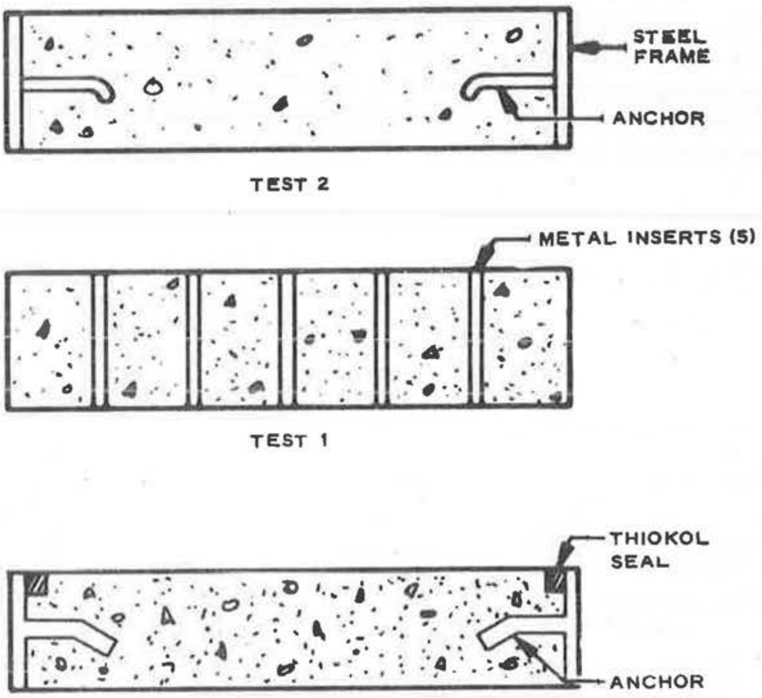
RECOMMENDATIONS

Always use anchors when casting metal frames in concrete, and leave a 1/2- to 1-in. joint between the concrete and frame for filling with thiokol. This is most important when inserts for mounting doors, etc, are welded to the cast-in-place frame. The temperature-induced expansion from the welding procedure seems to effect the bond. An air leakage rate of 1.4×10^{-2} cfm/ft of frame has been observed in the concrete model test described in LDS D-4.

LEAKAGE DATA SHEET	Figure B-9	Page 3 of 3

(SEE FIGURE B-4a FOR MOUNTING METHOD)

FRAMES



RECOMMENDED METHOD

LEAKAGE DATA SHEET	No. B-10	Page 1 of 2

COMPONENT

Grout

PURPOSE

Determine the leakage characteristics of a standard nonshrink grout. This test does not determine the bonding characteristics of the grout to concrete.

TEST SPECIMEN DESCRIPTION

Test and Mounting Design: See Figure B-10.

Description of Specimen: The specimens are 6 in. in diameter and of varying thickness. The aggregate and mix design (by weight) is as follows:

1 part Embeco aggregate
2 parts Portland cement
3 parts sand
water-stiff consistency

Manufacturer and Type: Master Builders Company; type of admix, Embeco

LEAK TEST DATA

Empirical Constants: Value for 1 ft^2 of grout, 1-in. thick

$A = 8 \times 10^{-7}$ $B = 0$

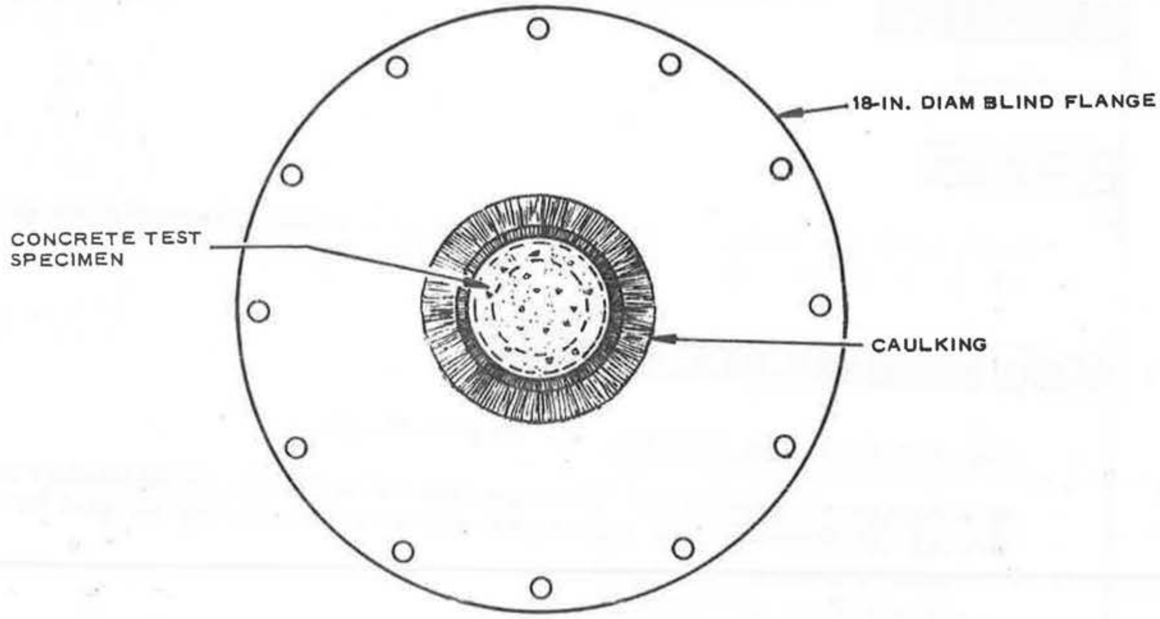
Applicable Pressure Range: Assuming data to be reasonably accurate, the data are applicable to the design pressure of the building.

Extrapolations: The data can be extrapolated directly to 10 psig. The value is directly proportional to the area and inversely proportional to the thickness.

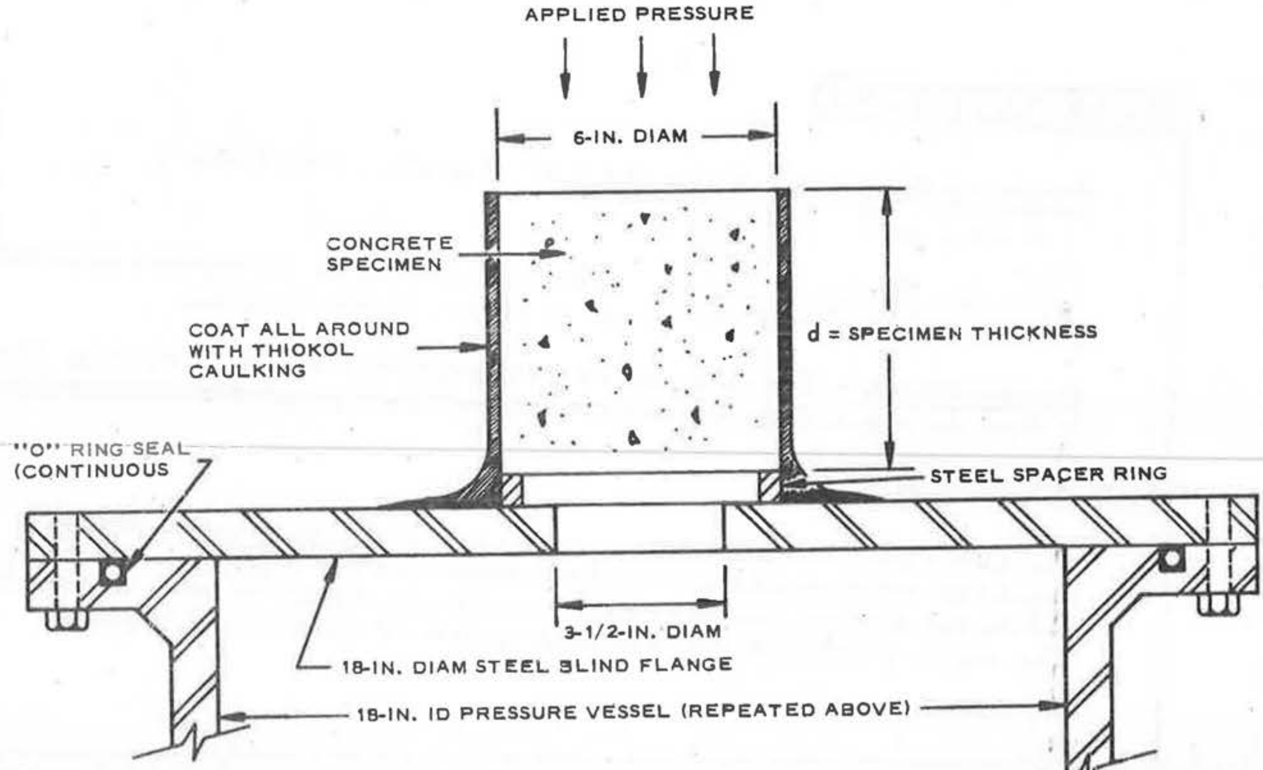
LIMITATIONS

The above data are only the leakage rate of a good nonshrink grout. It should be recognized that standard practices for mixing the grout, preparing the surface for grouting, and placing the grout must be enforced. The major portion of the leak may appear at the bonding surface.

LEAKAGE DATA SHEET	Figure B-10	Page 2 of 2



TOP PLAN



SECTION

LEAKAGE DATA SHEET	No. B-11(1)	Page 1 of 4

COMPONENT

Concrete Paint, Vinyl Base Membrane

PURPOSE

Leak rate reduction of concrete

TEST SPECIMEN DESCRIPTION

Test Design: See Figure B-11(1).

Leak Path Description: The leakage can occur through either the membrane itself or mechanical defects produced during painting, such as pinholes.

Manufacturer and Type: Surface Engineering Co.; Secoton Hi-build Vinyl Membrane Coating No. 2860.

Description and Properties: A medium-high viscosity, high-solids vinyl resin base coating contains a high percentage of inert film-forming components, stabilizers, and pigments.
Bridging ability: none.
Bonding strength: integral on concrete.
Elongation: slight (not an elastic coating).
Tensile strength: excellent film continuity (not a membrane coating).
High-temperature limit: 300°F dry heat, 212°F wet heat.

Manufacturer's Suggested Application Method: Concrete surfaces shall be rubbed or grout-finished to provide uniformly smooth surface. Seal coat shall be No. 2825-M primer, thinned with No. 4581 slow vinyl solvent at a ratio of 1 part solvent to 3 parts primer, and sprayed at 150 ft^2/gal. The membrane coating should be sprayed on to a thickness of 20 mils at a rate of 20 ft^2 gal.

Test Specimen: 29 mils thick

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LEAKAGE DATA SHEET	No. B-11(1)	Page 2 of 4

LEAK TEST DATA

Empirical Constant: Value for 1 ft^2

$A = 1.9 \times 10^{-6}$

Test Pressure Range: 0 to 28 in. water

Extrapolation: Value for 1 ft^2, 1 mil thick

$A = 5.5 \times 10^{-5}$

The leakage data may be applied to any area which can be uniformaly coated. The pressure and vacuum leakage values were determined to be the same within ±5% accuracy. The coefficient is believed valid up to 10 psi and from 5 to 60 mils thick.

LIMITATIONS

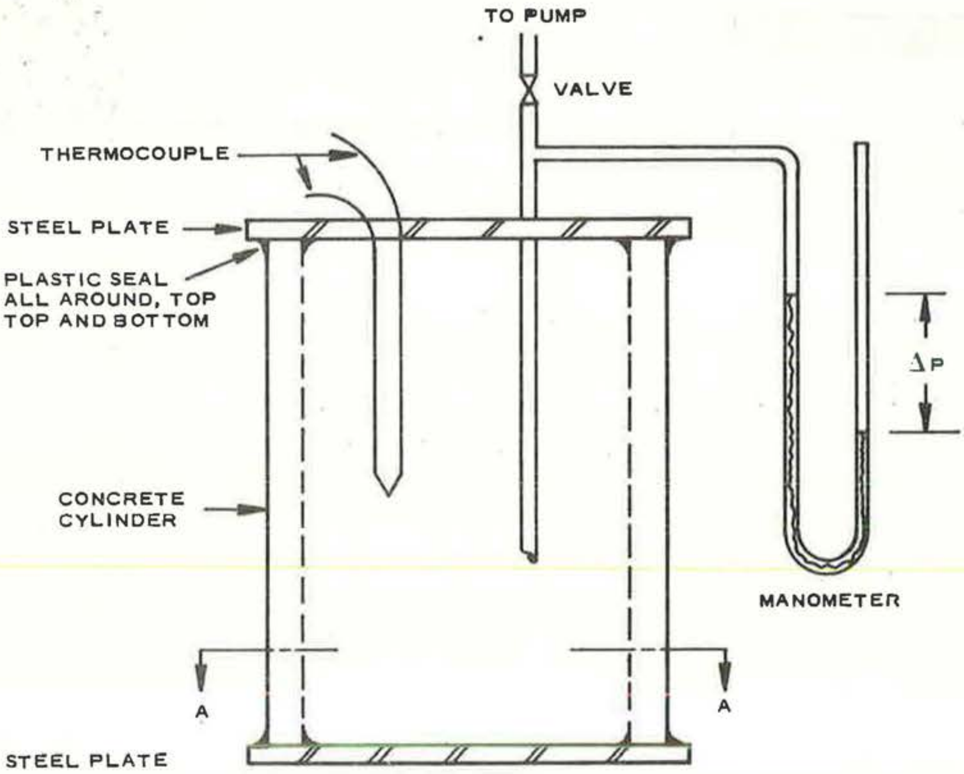
1) Due to the interconnections of capillaries in concrete, it is necessary that no pinholes be present in the membrane; otherwise the leakage rate cannot be predicted from the applied coating.
2) When applied as recommended, this material has no bridging ability and, therefore, the concrete surface must be grout-finished and troweled smooth.
3) This material when dry is only slightly flexible and will probably crack when the concrete cracks so that the leakage rate will not be reduced by the applied coating. All nonelastic coatings will fall in this same category.
4) If any penetrations are made in the concrete after painting, coating material should be applied in the recommended manner, being sure to overlap both the existing coating and the edge of the penetration.
5) The manufacturer recommends the use of licensed applicator contractors.

LEAKAGE DATA SHEET	No. B-11 (1)	Page 3 of 4

RECOMMENDATIONS

Increase thickness with multiple coats, being careful to fill in pinholes in previous coat.

LEAKAGE DATA SHEET	Figure B-11(1)	Page 4 of 4



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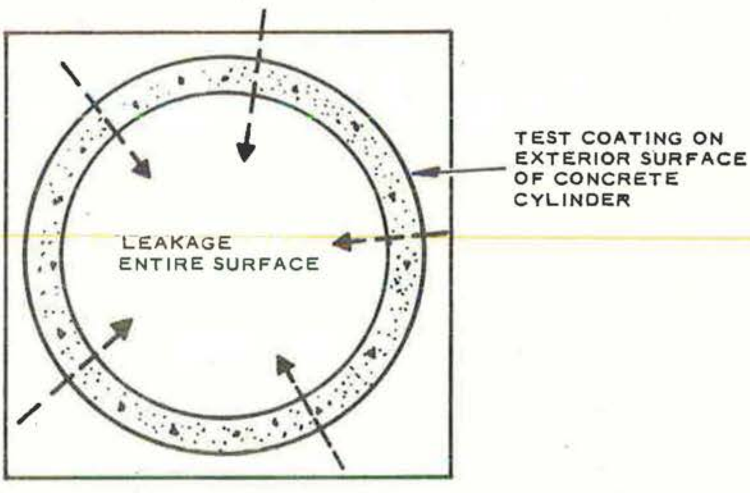


SECTION A–A

LEAKAGE DATA SHEET	No. B-11(2)	Page 1 of 2

COMPONENT

Concrete Paint, Vinyl Base Membrane

PURPOSE

Leak rate reduction of concrete

TEST SPECIMEN DESCRIPTION

Test Design: See Figure B-11(1).

Leak Path Description: See LDS B-11(1).

Manufacturer and Type: Surface Engineering Co.; Perma-Skin Multicoat Vinyl Coating No. 2980.

Description and Properties: A low-viscosity, medium-solids vinyl resin solution of low plasticizer content, fully stabilized, and pigmented for exterior exposure.
Bridging ability: none
Bonding strength: up to 40 psi when applied over recommended primers
Elongation: up to 400%
Tensile strength: excellent film continuity (not a membrane-type coating)
High-temperature limit: 180°F maximum

Manufacturer's Suggested Application Method: Bare concrete surfaces should be neutralized with 10% solution of phosphoric or muriatic acid, rinsed, and permitted to dry. Use No. 2706 or No. 2825-M primers, diluted with No. 4258 vinyl solvent, at a rate of 200 ft^2/gal. Spray only No. 2910 Perma-Skin red lead as intermediate coating at 100 ft^2/gal for a 2-mil coating. Topcoats shall consist of No. 2980 Perma-Skin coating sprayed at the rate of 100 ft^2/gal for a 2-mil coating. At least two topcoats should be applied.

Test Specimen: 24 mils thick

LEAKAGE DATA SHEET	No. B-11(2)	Page 2 of 2

LEAK TEST DATA

Empirical Constant: Value for 1 ft^2

$A = 1.5 \times 10^{-7}$

Test Pressure Range: 0 to 28 in. water

Extrapolations: Value for 1 ft^2, 1 mil thick

$A = 3.6 \times 10^{-6}$

The leakage data can be applied to any area which can be uniformly coated. The pressure and vacuum leakage values were determined to be the same within ±5% accuracy. The coefficient is believed valid up to 10 psi and from 5 to 60 mils thick.

LIMITATIONS

1) This material, when dry, is elastic and can be elongated up to 400% without cracking so that concrete cracks within this limit should not cause openings in the coating which would destroy the integrity of the film.
2) See notes 1, 2, 4 and 5 under Limitations of LDS B-11(1).

RECOMMENDATIONS

1) When applying topcoats, use alternating colors to insure uniform coverage of each coat. Apply more than two topcoats.
2) Coat concrete on both sides.

LEAKAGE DATA SHEET	No. B-11(3)	Page 1 of 2

COMPONENT

Concrete Paint, Vinyl Base Membrane

PURPOSE

Leak rate reduction of concrete

TEST SPECIMEN DESCRIPTION

Test Design: See Figure B-11(1).

Leak Path Description: See LDS B-11(1).

Manufacturer and Type: Soc-Co. Plastic Coating Co.; Soc-Co. Plastic No. V-500.

Description and Properties: A vinyl plastic dissolved in thinner to produce a solution.
Bridging ability: none
High temperature limit: 140°F wet heat, 160°F dry heat

Manufacturer's Suggested Application Method: Concrete surfaces will be grout-finished and then leached with 10% muriatic acid. The concrete should be sealed with one spray coat of Socco No. 5-Hi Vis. Ten coats of Socco No. V-500 should be sprayed on at the rate of 15 ft^2/gal to obtain a 10-mil coating.

Test Specimen: 14 mils thick

LEAK TEST DATA

Empirical Constant: Value for 1 ft^2

$A = 2.1 \times 10^{-8}$

Test Pressure Range: 0 to 26 in. water

LEAKAGE DATA SHEET	No. B-11(3)	Page 2 of 2

Extrapolations: Value for 1 ft^2, 1 mil thick

$A = 2.9 \times 10^{-7}$

The leakage data can be applied to any area which can be uniformly coated. The pressure and vacuum leakage values were determined to be the same within ±5% accuracy. The coefficient is believed valid up to 10 psi and from 5 to 60 mils thick.

LIMITATIONS

1) This paint will not bridge voids or holes in the concrete and therefore requires a smooth troweled concrete surface.
2) See notes 1, 3, and 4 under Limitations for LDS B-11(1).

RECOMMENDATIONS

Increase thickness with multiple coats, being careful to fill in pinholes in previous coat.

LEAKAGE DATA SHEET	No. B-11(4)	Page 1 of 2

COMPONENT

Concrete Paint, Vinyl Base Membrane

PURPOSE

Leak rate reduction of concrete

TEST SPECIMEN DESCRIPTION

Test Design: See Figure B-11(1).

Leak Path Description: See LDS B-11(1).

Manufacturer and Type: Keratin, Inc.; Coverseal vinyl coating system

Description and Properties: A three-coat vinyl membrane system
Bridging ability: good
Elongation: good

Manufacturer's Suggested Application Method: The concrete surface to be sand blasted; major cracks to be caulked with Coverseal vinyl filler. As a primer coat, spray Coverseal adhesive No. 2710B at the rate of 200 ft^2/gal. Spray Coverseal No. 3856 at the rate of 25 ft^2/gal as the intermediate coat. Top coat with color-selected Coverseal No. 2450H at the rate of 60 ft^2/gal.

Test Specimen: 85 mils thick

LEAK TEST DATA

Empirical Constant: Value for 1 ft^2

$A = 3.3 \times 10^{-8}$

Test Pressure Range: 0 to 160 in. water

LEAKAGE DATA SHEET	No. B-11(4)	Page 2 of 2

Extrapolations: Value for 1 ft^2, 1 mil thick

$A = 2.3 \times 10^{-6}$

The leakage data can be applied to any area which can be uniformly coated. The pressure leakage value was determined to within ±5% accuracy. The coefficient is believed valid up to 10 psi and from 40 to 200 mils.

LIMITATIONS

1) When applied as recommended, this material will bridge all but major voids, which will have to be filled with caulking material before painting.
2) This material, when dry, is elastic and will probably not crack when the concrete cracks so that membrane integrity will be maintained.
3) See notes 1, 4, and 5 under Limitations for LDS B-11(1).

RECOMMENDATIONS

Increase thickness with multiple coats, being careful to fill in pinholes in previous coat.

LEAKAGE DATA SHEET	No. B-11(5)	Page 1 of 2

COMPONENT

Concrete Paint, Vinyl Base Membrane

PURPOSE

Leak rate reduction of concrete

TEST SPECIMEN DESCRIPTION

Test Design: See Figure B-11(1).

Leak Path Description: The leakage can occur either through the membrane itself or mechanical defects produced during painting, such as pinholes.

Manufacturer and Type: Surface Engineering Company; Secoton Elastic Vinyl Membrane Coating No. 2810.

Description and Properties:

A medium-high viscosity, medium-high solid vinyl resin solution of high plasticizer content, fully stabilized and pigmented for exterior exposure.

Bridging ability: up to 1/2 in.
Bonding strength: up to 40 psi applied over No. 2825-M high bond primer
Elongation: up to 300% at 70°F
Tensile strength: 1600 to 1650 psi at 70°F
High-temperature limit: 180°F maximum

Manufacturer's Suggested Application Method: Concrete surfaces shall be rubbed or grout-finished to provide uniformly smooth surface. Surfaces shall be wet with Tite-Crete, polyvinyl acetate solution, mixed 3 parts Tite-Crete to 1 part water. A seal coat should be sprayed at a coverage rate of 150 ft^2/gal of No. 2825-M high-bond primer. The seal coat should be diluted with No. 4581 slow vinyl solvent at a ratio of 1 part solvent to 3 parts primer. Two coats of Vinyl Membrane Coating No. 2810-1 shall be sprayed over the primer at the rate of 100 ft^2/4 gal. Joints shall be spray-coated prior to applying the overall membrane coating to produce a coating of 20 mils at the joint. An equal thickness shall again be applied when the overall membrane coating is done.

Test Specimen: 22 mils thick

LEAKAGE DATA SHEET	No. B-11(5)	Page 2 of 2

LEAK TEST DATA

Empirical Constant: Value for 1 ft^2

A = 6.7×10^{-6}

Test Pressure Range: 0 to 26 in. water

Extrapolations: Value for 1 ft^2, 1 mil thick

A = 1.4×10^{-4}

The leakage data can be applied to any area which can be uniformly coated. The pressure and vacuum leakage values were determined to be the same within ±5% accuracy. The coefficient is believed to be valid up to 10 psi and from 5 to 60 mils thick.

LIMITATIONS

1) When applied as recommended, this material will bridge voids or holes up to 1/2 in. and therefore does not require a grout surface.

2) This material, when dry, is elastic and can be elongated up to 300% without cracking so that any concrete cracks of this dimension may remain sealed almost as well as the balance of the concrete.

3) See notes 1, 4, and 5 under Limitations for LDS B-11(1).

RECOMMENDATIONS

Increase thickness with multiple coats, being careful to fill in pinholes in previous coat.

LEAKAGE DATA SHEET	No. B-11(6)	Page 1 of 2

COMPONENT

Concrete Paint, Epoxy Base Membrane

PURPOSE

Leak rate reduction of concrete

TEST SPECIMEN DESCRIPTION

Test Design: See Figure B-11(1).

Leak Path Description: See LDS B-11(1).

Manufacturer and Type: Carl H. Biggs Co., Inc.; Protective coating PC-621.

Description and Properties: An unmodified epoxy resin coating with 6% hardener required for proper polymerization.
Bridging ability: none
Flexibility: good
High-temperature limit: 210°F

Manufacturer's Suggested Application Method: Concrete surface should be grout-finished and troweled smooth. No primer is necessary. Spray four 1-mil coats of PC-621 at the rate of 250 ft^2/gal, allowing one hour between coats.

Test Specimen: 14 mils thick

LEAK TEST DATA

Empirical Constants: Value for 1 ft^2

$$A = 1.8 \times 10^{-8}$$

Test Pressure Range: 0 to 28 in. water

LEAKAGE DATA SHEET	No. B-11(6)	Page 2 of 2

Extrapolations: Value for 1 ft^2, 1 mil thick

$A = 2.5 \times 10^{-7}$

The leakage data can be applied to any area which can be uniformly coated. The pressure and vacuum leakage values were determined to be the same within ±5% accuracy. The coefficient is believed valid up to 10 psi and from 4 to 60 mils thick.

LIMITATIONS

1) This material requires a catalyst to polymerize the resin and therefore must be made up as needed since the pot life is one hour.
2) See notes 1, 2, 3, and 4 under Limitations for LDS B-11(1).

RECOMMENDATIONS

Increase thickness with multiple coats, being careful to fill in pinholes in previous coats.

LEAKAGE DATA SHEET	No. B-11(7)	Page 1 of 2

COMPONENT

Concrete Paint, Epoxy Base Membrane

PURPOSE

Leak rate reduction of concrete

TEST SPECIMEN DESCRIPTION

Test Design: See Figure B-11(1).

Leak Path Description: See LDS B-11(1).

Manufacturer and Type: Carboline Company; Carboline epoxy 150 finish.

Description and Properties: An epoxy-amine resin (catalyst added prior to application) which is allowed to harden after application. Solids content is 64% by wt.
Bridging ability: poor
Elongation: poor
Flexibility: good
High-temperature resistance: 180°F continuous, 220°F noncontinuous

Manufacturer's Suggested Application Method: Concrete surfaces shall be grout-finished and troweled smooth. The concrete should be painted with Carboline epoxy 150 primer by either brush or spray. The primer may be diluted with Polyclad thinner and applied at the rate of 320 ft^2/gal. The primer should dry for 6 hr before top coat is applied. Two coats of Carboline epoxy 150 finish may be applied by brush or spray at the rate of 160 ft^2/gal.

Test Specimen: 16 mils thick

LEAK TEST DATA

Empirical Constant: Value for 1 ft^2

$A = 3.4 \times 10^{-7}$

LEAKAGE DATA SHEET	No. B-11(7)	Page 2 of 2

Test Pressure Range: 0 to 26 in. water

Extrapolations: Value for 1 ft^2, 1 mil thick

$A = 6.2 \times 10^{-6}$

The leakage data can be applied to any area which can be uniformly coated. The pressure and vacuum leakage values were determined to be the same within ±5% accuracy. The coefficient is believed valid up to 10 psi and from 5 to 60 mils thick.

LIMITATIONS

1) This material requires a catalyst to harden the paint and therefore must be made up as needed since the pot life is 6 hr.
2) See notes 1 through 4 in Limitations of LDS B-11(1).

RECOMMENDATIONS

Increase thickness with multiple coats, being careful to fill in pinholes in previous coat.

LEAKAGE DATA SHEET	No. B-11(8)	Page 1 of 2

COMPONENT

Concrete Paint, Epoxy Base Membrane

PURPOSE

Leak rate reduction of concrete

TEST SPECIMEN DESCRIPTION

Test Design: See Figure B-11(1).

Leak Path Description: See LDS B-11(1).

Manufacturer and Type: Soc-co Plastic Coating Company; Soc-co Plastic No. 7-AT.

Description and Properties: An unmodified epoxy resin coating requiring a catalyst to cause polymerization.
Bridging ability: none

Manufacturer's Suggested Application Method: Concrete surface should be grout-finished and troweled smooth. After curing, wire-brush surface thoroughly. Reduce 3 parts Soc-co Plastic No. 7-AT with 1 part solvent No. 7 and apply to concrete as a primer coat. After drying, apply one coat of full strength plastic at the rate of 150 ft^2/gal.

Test Specimen: 28 mils thick

LEAK TEST DATA

Empirical Constant: Value for 1 ft^2

$A = 1.1 \times 10^{-6}$

Test Pressure Range: 0 to 28 in. water

LEAKAGE DATA SHEET	No. B-11(8)	Page 2 of 2

Extrapolations: Value for 1 ft^2, 1 mil thick

$A = 3.0 \times 10^{-5}$

The leakage data can be applied to any area which can be uniformly coated. The pressure and vacuum leakage values were determined to be the same within ±5% accuracy. The coefficient is believed valid up to 10 psi and from 5 to 60 mils thick.

LIMITATIONS

1) This material requires a catalyst to polymerize the resin and therefore must be made up as needed since the pot life is 1 hr.
2) See notes 1, 2, 3, and 4 under Limitations for LDS B-11(1).

RECOMMENDATIONS

Increase thickness with multiple coats, being careful to fill in pinholes in previous coats.

LEAKAGE DATA SHEET	No. B-11(9)	Page 1 of 2

COMPONENT

Concrete Paint, Rubber Base Membrane

PURPOSE

Leak reduction of concrete

TEST SPECIMEN DESCRIPTION

Test Design: See Figure B-11(1).

Leak Path Description: See LDS B-11(1).

Manufacturer and Type: Products Research Company; PRC 402 rubber coating.

Description and Properties: A two-part liquid rubber compound which cures to a flexible rubber coating.

Bridging ability: good
Adhesion in peel: 25 lb/in. of width
Tensile strength: 250 psi
Elongation: 300%
High-temperature limit: 225°F

Manufacturer's Suggested Application Method: No large pits or voids should be present in the surface of the concrete. The surface should be sand-blasted or wire-brushed for final cleaning. PRC Primer No. 1 should be applied by brush at the rate of 350 ft^2/gal and should be worked into the surface. After mixing with accelerator, PRC 402 should be sprayed at the rate of 60 ft^2/gal.

Test Specimen: 49 mils thick

LEAK TEST DATA

Empirical Constant: Value for 1 ft^2

$A = 1.8 \times 10^{-7}$

LEAKAGE DATA SHEET	No. B-11(9)	Page 2 of 2

Test Pressure Range: 0 to 26 in. water

Extrapolations: Value for 1 ft^2, 1 mil thick

$A = 8.7 \times 10^{-6}$

The leakage data can be applied to any area which can be uniformly coated. The pressure and vacuum leakage values were determined to be the same within ±5% accuracy. The coefficient is believed valid up to 10 psi and from 20 to 100 mils thick.

LIMITATIONS

1) When applied as recommended, this material will bridge many pits and voids but large pits should be first filled with putty before applying primer.
2) This material, when cured, is elastic and will probably maintain its continuity when the concrete cracks, thereby keeping the concrete sealed.
3) This material requires an accelerator to cure the rubber; this limits the pot life to one hour so that the material must be made up as needed.
4) This coating is black in color but may be covered with decorative paint to obtain other colors.
5) See notes 1 and 4 under Limitations of LDS B-11(1).

RECOMMENDATIONS

Double thickness of coating by applying second coat after first coat has cured, being sure to seal all pinholes.

LEAKAGE DATA SHEET	No. B-11(10)	Page 1 of 2

COMPONENT

Concrete Paint, Asphalt-Gilsonite Mastic

PURPOSE

Leak reduction of concrete

TEST SPECIMEN DESCRIPTION

Test Design: See Figure B-11(1).

Leak Path Description: See LDS B-11(1).

Manufacturer and Type: Pittsburgh Coke and Chemical Co.; Pitt. Chem. Insul-mastic No. 4010 Vaporseal.

Description and Properties: A mastic composed of a mixture of asphalt, gilsonite, solvent, and flaked mica and asbestos.

Bridging ability: excellent
Elongation: good
High-temperature limit: 250°F

Manufacturer's Suggested Application Method: The cured concrete surface should be sand-blasted to remove dirt and grease. The surface should be primed with Insulmastic No. 4132. Structural cracks and expansion joints should be filled with No. 507 caulking compound. Such joints should be covered with a glass-cloth membrane embedded in wet mastic. Apply No. 4010 mastic, by spray, at the rate of 22 ft^2/gal. A more uniform coat will be obtained by making many sweeps over the surface.

Test Specimen: 72 mils thick

LEAK TEST DATA

Empirical Constant: Value for 1 ft^2

$A = 1.0 \times 10^{-7}$

LEAKAGE DATA SHEET	No. B-11(10)	Page 2 of 2

Test Pressure Range: 0 to 28 in. water

Extrapolations: Value for 1 ft^2, 1 mil thick

$A = 7.2 \times 10^{-6}$

The leakage data can be applied to any area which can be uniformly coated. The pressure and vacuum leakage values were determined to be the same within ±5% accuracy. The coefficient is believed valid up to 10 psi and from 65 to 200 mils thick.

LIMITATIONS

1) When applied as recommended, this material will bridge all but the very large pits and voids which should be filled with caulking compound before painting.
2) This material will remain elastic and will not crack when the concrete cracks so that a continuous membrane is maintained.
3) This mastic is black in color but may be colored by painting, after cure, with Pitt. Chem. Insul-mastic No. 261 Color Coat.
4) See notes 1, 2, 3, and 4 under Limitations for LDS B-11(1).

RECOMMENDATIONS

Increase thickness of coating by applying multiple coats, being sure to fill in pinholes in previous coat.

LEAKAGE DATA SHEET	No. B-11(11)	Page 1 of 2

COMPONENT

Concrete Paint, Phenolic Base Membrane

PURPOSE

Leak rate reduction of concrete

TEST SPECIMEN DESCRIPTION

Test Design: See Figure B-11(1).

Leak Path Description: See LDS B-11(1).

Manufacturer and Type: Carboline Co.; Phenoline 305 finish.

Description and Properties: A modified phenolic with high solids requiring a curing agent before application.

Bridging ability: poor
Flexibility: fair to good
High-temperature limit: 200°F continuous, 250°F noncontinuous

Manufacturer's Suggested Application Method: No concrete hardeners or curing compounds should be used in the concrete. The concrete should be grout-finished and troweled smooth while still "green." The concrete should either be sand-blasted or etched with 15% muriatic acid to roughen the surface. The primer coat shall be Phenoline 305 primer diluted with Phenoline 305 thinner at 1-1/2 pt/gal and sprayed at the rate of 200 ft^2/gal. Two coats of Phenoline 305 finish, diluted 1 pt/gal with thinner, should then be sprayed at the rate of 280 ft^2/gal, allowing each coat to dry before spraying next coat.

Test Specimen: 34 mils thick

LEAKAGE DATA SHEET	No. B-11(11)	Page 2 of 2

LEAK TEST DATA

Empirical Constant: Value for 1 ft^2

$A = 3.5 \times 10^{-9}$

Test Pressure Range: 0 to 28 in. water

Extrapolations: Value for 1 ft^2, 1 mil thick

$A = 1.2 \times 10^{-7}$

The leakage data can be applied to any area which can be uniformly coated. The pressure and vacuum leakage values were determined to be the same within ±5% accuracy. The coefficient is believed valid up to 10 psi and from 6 to 60 mils thick.

LIMITATIONS

1) This material requires a catalyst as a curing agent and therefore must be made up as needed since the pot life is 90 min.
2) See notes 1, 2, 3 and 4 under Limitations of LDS B-11(1).

RECOMMENDATIONS

In order to obtain the very low leakage through this paint, it is necessary to eliminate all pinholes in the paint film.

LEAKAGE DATA SHEET	No. B-11(12)	Page 1 of 2

COMPONENT

Concrete Paint, Oil-Mica Base Mastic

PURPOSE

Leak reduction of concrete

TEST SPECIMEN DESCRIPTION

Test Design: See Figure B-11(1).

Leak Path Description: See LDS B-11(1).

Manufacturer and Type: Pittsburgh Coke and Chemical Co., Pitt Chem. Insul-mastic No. 3911 Mica-mastic

Description and Properties (Product Data Sheet MS-5): An oil-mica mastic containing 50% processed oils and 15 to 25% ground flake mica.

Bridging ability: excellent
Elongation: good
High-temperature limit: 180°F

Manufacturer's Suggested Application Method: The cured concrete surface should be sand-blasted to remove dirt and grease. Seal all surfaces with Insul-mastic No. 4906 primer. Use mica-mastic caulking compound No. 5135 to fill cracks and expansion joints. Reinforce cracks and joints with nylon or glass-fiber membrane, embedded in wet mica mastic, and apply mica mastic No. 3911 at the rate of 25 ft^2/gal.

Test Specimen: 61 mils thick

LEAK TEST DATA

Empirical Constant: Value for 1 ft^2

$A = 2.1 \times 10^{-8}$

LEAKAGE DATA SHEET	No. B-11(12)	Page 2 of 2

Test Pressure Range: 0 to 26 in. water

Extrapolations: Value for 1 ft^2, 1 mil thick

$A = 1.3 \times 10^{-6}$

The leakage data can be applied to any area which can be uniformly coated. The pressure and vacuum leakage values were determined to be the same within ±5% accuracy. The coefficient is believed valid up to 10 psi and from 50 to 200 mils thick.

LIMITATIONS

1) When applied as recommended, this material will bridge all but the very large pits and voids which should be filled with caulking compound before painting.
2) This material will remain elastic and will not crack when the concrete cracks, thereby maintaining the continuous membrane.
3) See notes 1, 4, and 5 under Limitations for LDS B-11(1).

RECOMMENDATIONS

Increase thickness of coating by applying multiple coats, being sure to fill in pinholes in previous coat.

LEAKAGE DATA SHEET	No. B-12	Page 1 of 3

COMPONENT

Pipe Penetrations Through Concrete

PURPOSE

Determination of air leakage through various types of pipe penetrations in concrete

TEST SPECIMEN DESCRIPTION

Test and Mounting Design: See Figure B-12.

Description of Specimen:

Specimen 1: A 4.5-in.-diam steel pipe was cast in a concrete block 11-1/2 by 11-1/2 by 4 in. thick.

Specimen 2: Identical to specimen 1 except that space was left between the concrete and pipe which was filled with epoxy resin.

Specimen 3: Identical to specimen 1 except that a 6-1/2-in. -diam pipe was attached to a 9-in. -diam flange (1 in. thick) which was cast in the center of the 4-in. -thick concrete block. A void 1/2 in. wide was left between the concrete and pipe for caulking. All specimens were coated on the edges with epoxy resin and mounted as shown in Figure B-12.

Installation Procedure: The placing of the concrete and surface preparation of the pipe shall conform to the standard ASTM specifications. The concrete blocks were attached to the mounting plate with epoxy resin.

Leak Path Description: The leak paths are through the concrete and at the region where the concrete and pipe join.

LEAK TEST DATA

Empirical Constants: Value for each specimen

Specimen 1: Pipe cast in concrete

$A = 5.7 \times 10^{-6}$ $B = 0$

Specimen 2: Pipe sealed in concrete with epoxy resin

No detectable leak

LEAKAGE DATA SHEET	No. B-12	Page 2 of 3

Specimen 3: Pipe and flange

$A = 3 \times 10^{-3}$ $B = 2 \times 10^{-2}$

Applicable Pressure Range: Pressures have been taken to 5 psi without change of leakage characteristics. Leakage characteristics at greater pressures have not been determined.

Extrapolations: See Limitations below.

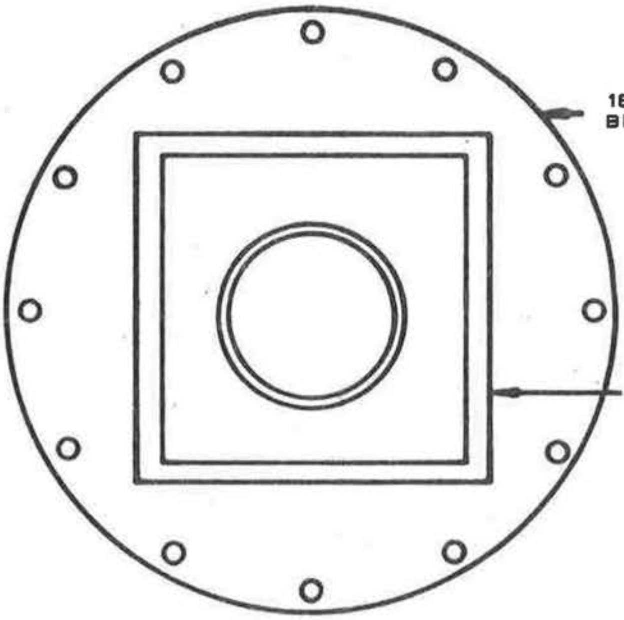
LIMITATIONS

At this time the leakage characteristics of pipe penetrations of large pipes are unpredictable since the water ratio, curing time, and method of curing, will have an effect on the shrinkage of the concrete and the type of possible failure between the pipe and concrete. The pipe flange was constructed of stainless steel and considered a "worst case."

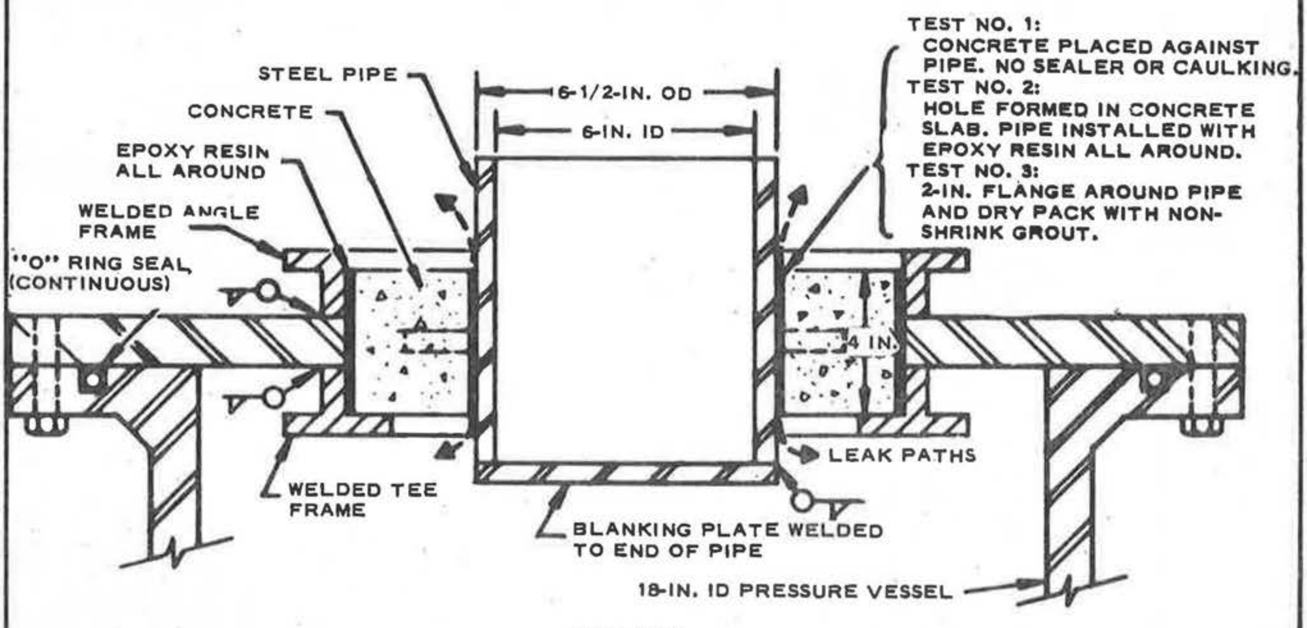
RECOMMENDATIONS

Construct an expansion joint between the pipe and concrete and fill with polysulphide or a flexible epoxy resin according to the manufacturer's specifications.

LEAKAGE DATA SHEET	Figure B-12	Page 3 of 3



TOP PLAN



SECTION

LEAKAGE DATA SHEET	No. B-13	Page 1 of 2

COMPONENT

Reinforcing Bars in Concrete

PURPOSE

To determine the contribution of reinforcing bars to air leakage in concrete

TEST SPECIMEN DESCRIPTION

Test and Mounting Design: See Figure B-13 and B-4a.

Description of Specimen: Nine reinforcement bars, 10 in. long, were cast in a concrete specimen 11-1/2 by 11-1/2 by 4 in. so that the bars were parallel and perpendicular to the block along the two 11.5 by 11.5-in. surfaces.

Leak Path Description: The leak path of interest is along the surface between the reinforcement bars and concrete to the edge of the concrete.

LEAK TEST DATA

Empirical Constants: Value for 1-ft rod length. No detectable leak above that due to concrete at 100 in. water.

Applicable Pressure Range: The data are applicable up to the design pressures of the building (0 to 200 in. water pressure difference).

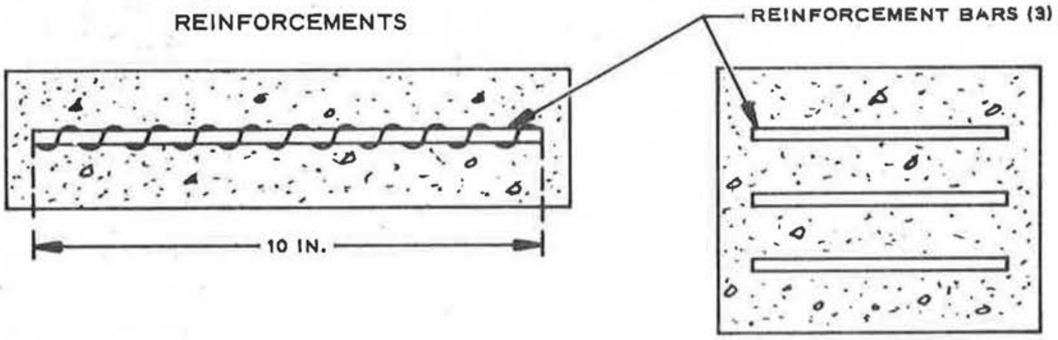
Extrapolations: Since no detectable leak was found, no extrapolations are necessary (detectable leak above that of concrete).

LIMITATIONS

Concrete of a different mix may leak more; however, the leak path is not normally along the length of the reinforcement bar and, therefore, the leak rate perpendicular to the direction of pressure difference can be considered to be insignificant. Exception: a crack in the concrete may run parallel to and around the bars. No data are available for the latter case.

LEAKAGE DATA SHEET	Figure B-13	Page 2 of 2

(SEE FIGURE B-4a FOR MOUNTING METHOD)



LEAKAGE DATA SHEET	No. B-14	Page 1 of 3

COMPONENT

Tie Rods in Concrete

PURPOSE

Determination of air leakage when tie rods are used in concrete.

TEST SPECIMEN DESCRIPTION

Test and Mounting Design: See Figure B-14 and B-4a.

Description of Test Specimen: Nine 1/4-in.-diam tie rods were cast perpendicular to the large area in reinforced concrete to simulate actual conditions; the specimen size was 11-1/2 by 11-1/2 by 4 in. The data are compared to a bare block of concrete without penetrations.

Installation Procedure: The placement of the concrete around the rebars and tie rods conforms to standard practices.

Leak Path Description: The leak path is through the bonding at the surface between the tie rods and concrete.

LEAK TEST DATA

Empirical Constants: Value for one 4-in. rod, 1/4-in. diameter

$A = 1.5 \times 10^{-5}$ $B = 0$

Applicable Pressure Range: The data are applicable up to the design pressures of the building.

Extrapolations: The data give a fair implication of the amount a tie rod would leak, and the data can be extrapolated unless the tie rod is in the path of a crack. (See Component: Crack in Concrete.) The data can be extrapolated proportionally to the circumference of the tie rod and inversely proportional to the length. The number of tie rods normally used per ft^2 of concrete make their contribution negligible if they are left in place and the leak rate is estimated for one entire building. Removal of the tie rod with subsequent grouting of the hole is not recommended.

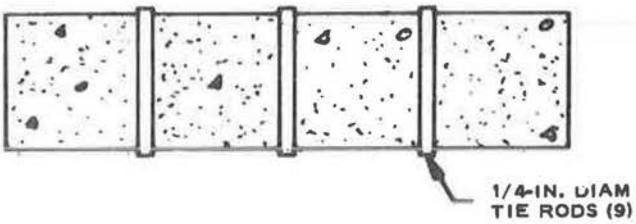
LEAKAGE DATA SHEET	No. B-14	Page 2 of 3

LIMITATIONS

The concrete specifications required a minimum ultimate compression strength of 5000 psi at 28 days. Concrete which has other specifications (such as 2500-psi strength) may give a different leak rate since the water content would be greater. Therefore, the above leak rate gives only a relative figure for the specimen tested.

LEAKAGE DATA SHEET	Figure B-14	Page 3 of 3

(SEE FIGURE B-4a FOR MOUNTING METHOD)



LEAKAGE DATA SHEET	No. B-15	Page 1 of 1

COMPONENT

Thickness Variations, Concrete

PURPOSE

Determination of air leakage through various thicknesses of concrete

TEST SPECIMEN DESCRIPTION

Test and Mounting Design: See Figure B-10.

Description of Specimen: A 6-in.-diam core of concrete 8 in. long was used as Specimen 1. After test data were obtained from Specimen 1, the core was cut into two parts which produced Specimens 2 and 3.

Installation Procedure: Each concrete specimen was coated and sealed to the diaphragm plate with Thiokol.

Leak Path Description: All leak paths have been sealed off except through the concrete.

LEAK TEST DATA

Empirical Constants: Value for ft^2 x 1-in. thick

Specimen 1: $A = 9.7 \times 10^{-6}$ $B = 0$

Specimen 2: $A = 9.7 \times 10^{-6}$ $B = 0$

Specimen 3: $A = 9.7 \times 10^{-6}$ $B = 0$

Specimens 2 and 3: $A = 10 \times 10^{-6}$ $B = 0$

Applicable Pressure Range: Applicable up to 200 in. water (gage).

Extrapolations: Tests were performed at pressures up to 11 psig, and preliminary data show that extrapolations can be carried to much higher pressures. See LDS B-1(1), Page 2 of 2.

LEAKAGE DATA SHEET	No. B-16	Page 1 of 3

COMPONENT

Water Stops, Rubber

PURPOSE

Determination of air leakage through water stops

TEST SPECIMEN DESCRIPTION

Test and Mounting Design: See Figure B-16 and description below.

Description of Specimen: The 9-in. water stop was cast in concrete using a 1/2-in. spacer. The concrete specimen was 4 in. thick and 11-1/2-in. square.

Installation Procedure: The concrete block was coated on the sides with epoxy resin and then attached to the diaphragm plate using additional epoxy resin.

Leak Path Description: The leak paths are through the concrete and between the concrete and water stop.

LEAK TEST DATA

Empirical Constants: Value for 1 ft

For pressures less than 25 in. water pressure

$A = 1.6 \times 10^{-3}$ $B = 0$

For pressures greater than 25 in. water pressure

$A = 1.2 \times 10^{-3}$ $B = 11 \times 10^{-3}$

Applicable Pressure Range: The test data should be applicable up to the design pressure of the building.

Extrapolations: The data can be extrapolated to any length and for the pressure ranges noted above.

LEAKAGE DATA SHEET	No. B-16	Page 2 of 3

LIMITATIONS

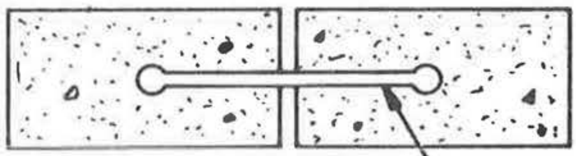
The concrete did not form a perfect bond to the water stop; a visual spacing was left, and thus, a leak path.

RECOMMENDATIONS

Metal water stops may have less leakage than neoprene water stops. Concrete slabs with greater than 4 in. thickness may not crack around water stops or between outside surface and water stop.

LEAKAGE DATA SHEET	Figure B-16	Page 3 of 3

(SEE FIGURE B-4a FOR MOUNTING METHOD)



CONTENTS
LEAKAGE DATA SHEETS

C. METAL PANEL

LEAKAGE DATA SHEET	No. C-1	Page 1 of 3

COMPONENT

Corner Flashing, Insulated Metal Panel

PURPOSE

Leak rate evaluation and improvement

TEST SPECIMEN DESCRIPTION

Test and Mounting Design: See Figure C-1

Description of Specimen: The specimen consists of two sections of fluted metal panel. The joint between these sections is closed with a 20-gage sheet metal flashing strip. The flashing is attached to the panels with sheet metal screws and neoprene washers on 6-in. centers with 1/8 by 1-in. composition rubber seal and 3M Car Seam Sealer caulking compound between the flashing and metal panels. There are 7 ft 8 in. of joint in this specimen with 18 sheet metal screws.

Leak Path Description: The leakage occurs between the two faces of the rubber seal strip and the metal components as well as around the sheet metal screws.

Manufacturer and Type:

H. H. Robertson Company; M-type Q-panel, Section No. 3.

Hamilton Rubber Mfg. Company; Composition rubber seal strip, durometer hardness 55 to 65, average tensile strength 1300.

Minnesota Mining and Mfg. Company; Car Seam Sealer caulking compound.

LEAK TEST DATA

Empirical Constants: Value for 1 ft

For 1 ft of joint and 2 sheet metal screws per ft

$A = 2.3 \times 10^{-3}$ $B = 0$

Applicable Pressure Range: The test data should be applicable to 5 in. water pressure. At higher pressures, the sheet metal will deform and increase the leakage rate.

LEAKAGE DATA SHEET	No. C-1	Page 2 of 3

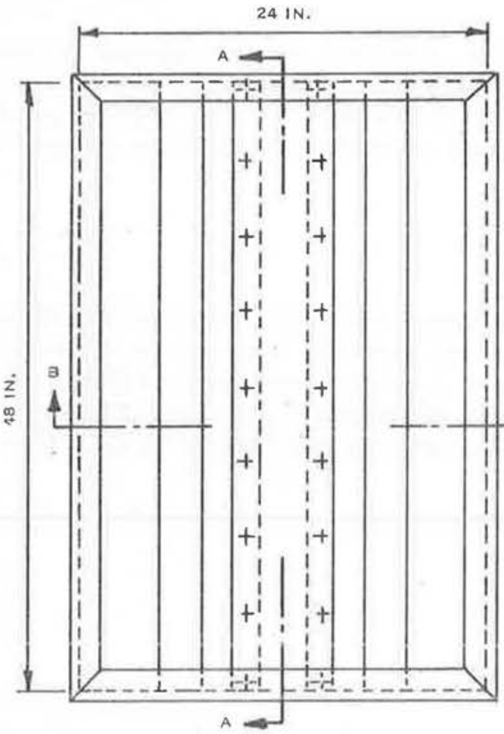
LIMITATIONS

The use of sheet metal screws on 6-in. centers sealed against a hard rubber seal strip creates ripples in the span between screws which are difficult to seal and which cause the high leakage rate. This is particularly true when thin-gage metal is used on both sides of the rubber strip.

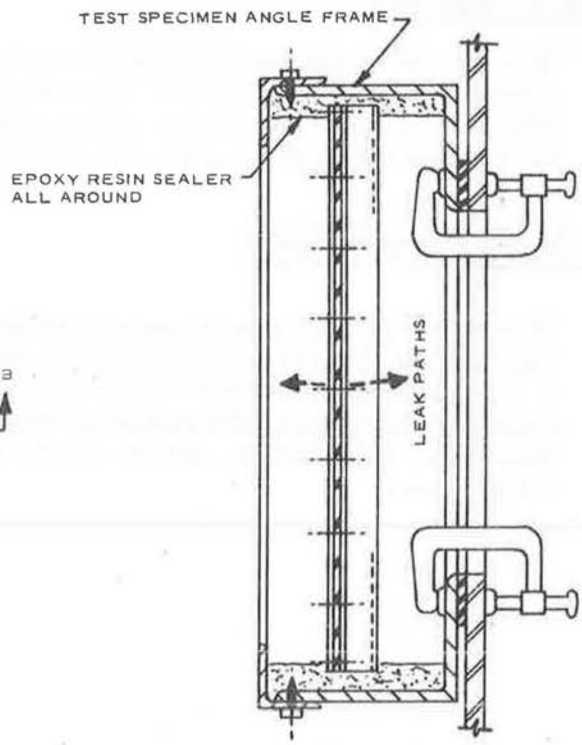
RECOMMENDATIONS

The flashing could be attached to the metal panels by use of 3M Weatherban Ribbon Sealer with stiffening bars to prevent ripples in the flashing. A second improvement would be to use a preformed nonresilient sealer such as Presstite, (Division of Martin-Marietta Company) Plastic Sealer Tape No. 579 series, which would not require stiffening bars. (See LDS C-6.)

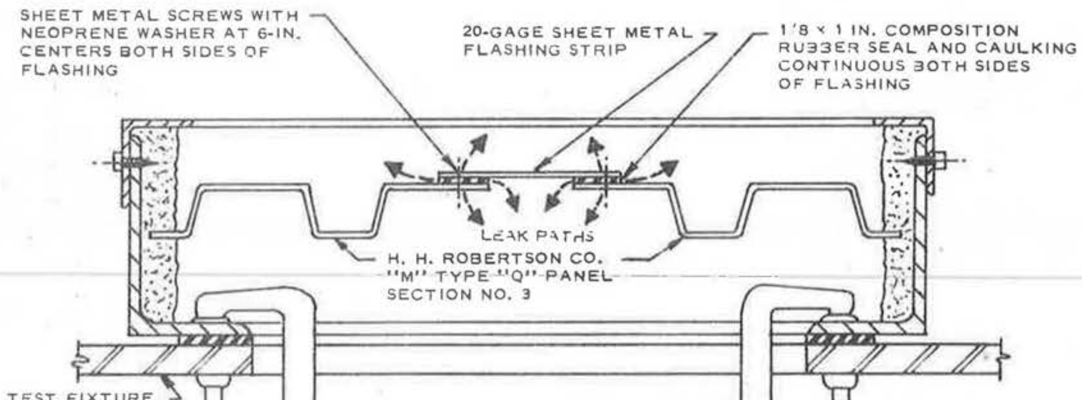
LEAKAGE DATA SHEET	Figure C-1	Page 3 of 3



FRONT



VERTICAL SECTION A–A



HORIZONTAL SECTION B–B

LEAKAGE DATA SHEET	No. C-2	Page 1 of 4

COMPONENT

Eave Joint to Fluted Wall Panel

PURPOSE

Leak rate evaluation and improvement

TEST SPECIMEN DESCRIPTION

Test and Mounting Design: See Figures C-2a and C-2b.

Description of Specimen: The specimen consists of a section of flat inner panel to represent the wall and a section of fluted outer panel to represent the roof. The two sections are connected by 20-gage metal flashing attached to the flat panel by sheet metal screws on 6-in. centers and to the fluted section with screws at the centerline of each low flute. The joint between the flashing and flat panel is sealed with 1/8- by 1-in. composition rubber strip and RP-545 caulking compound. The open flutes between the flashing and roof section are filled with a premolded composition rubber closure supplied by the manufacturer of the metal panels. A series of tests is run to determine the leakage through the flute-flashing joint with virgin closures, caulked closures, and caulked closures bolted in place.

Leak Path Description: In Test 1 (Figure C-2a), the leakage occurred between the rubber and the fluted panel, as large openings could be seen. When the closure was caulked (Figure C-2b) before installation, the leakage was still around the rubber insert, since the openings were too large to be completely sealed by the type of caulking used. When the closures were bolted in place after being covered with caulking (Test 3) the leakage occurred between the closure and metal flute, as the metal was too stiff to be forced against the rubber closure.

Manufacturer and Type:

H. H. Robertson Company; M-type Q-panel Section No. 8; Section No. 3, premolded flute closures; and RP-545 caulking material.

Hamilton Rubber Mfg. Company; Composition rubber seal strip, durometer hardness 55 to 65, tensile strength 1300.

LEAKAGE DATA SHEET	No. C-2	Page 2 of 4

LEAK TEST DATA

Empirical Constants: Value for 1 ft

The leakage per ft of flute-flashing joint only is presented below:

No.	Test	A	B
1	Premolded flute closure, no caulk:	6.5	0
2	Premolded flute closures, caulked:	9.0×10^{-2}	0
3	Premolded flute closures, caulked and bolted in place:	8.1×10^{-2}	0

Applicable Pressure Range: These data should be applicable to 5 in. water pressure. At higher pressures, the rubber closures which are not bolted in place will cause an increased leakage.

LIMITATIONS

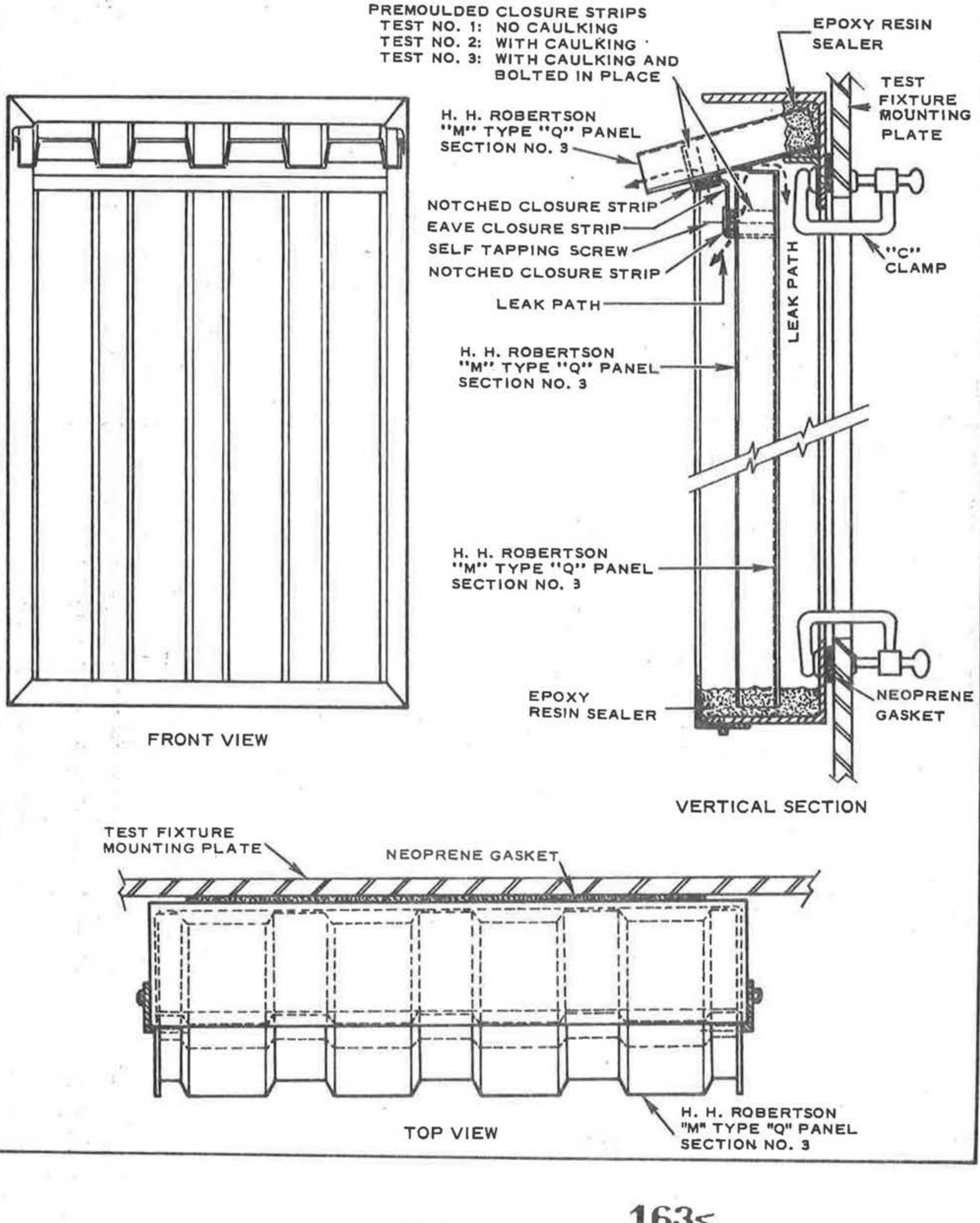
If a metal panel building is designed where the roof will consist of only a flute panel member, the leakage will be of orders of magnitude larger than any other panel component. The use of premolded rubber closures to seal the flutes does not reduce the leakage rate to acceptable levels.

RECOMMENDATIONS

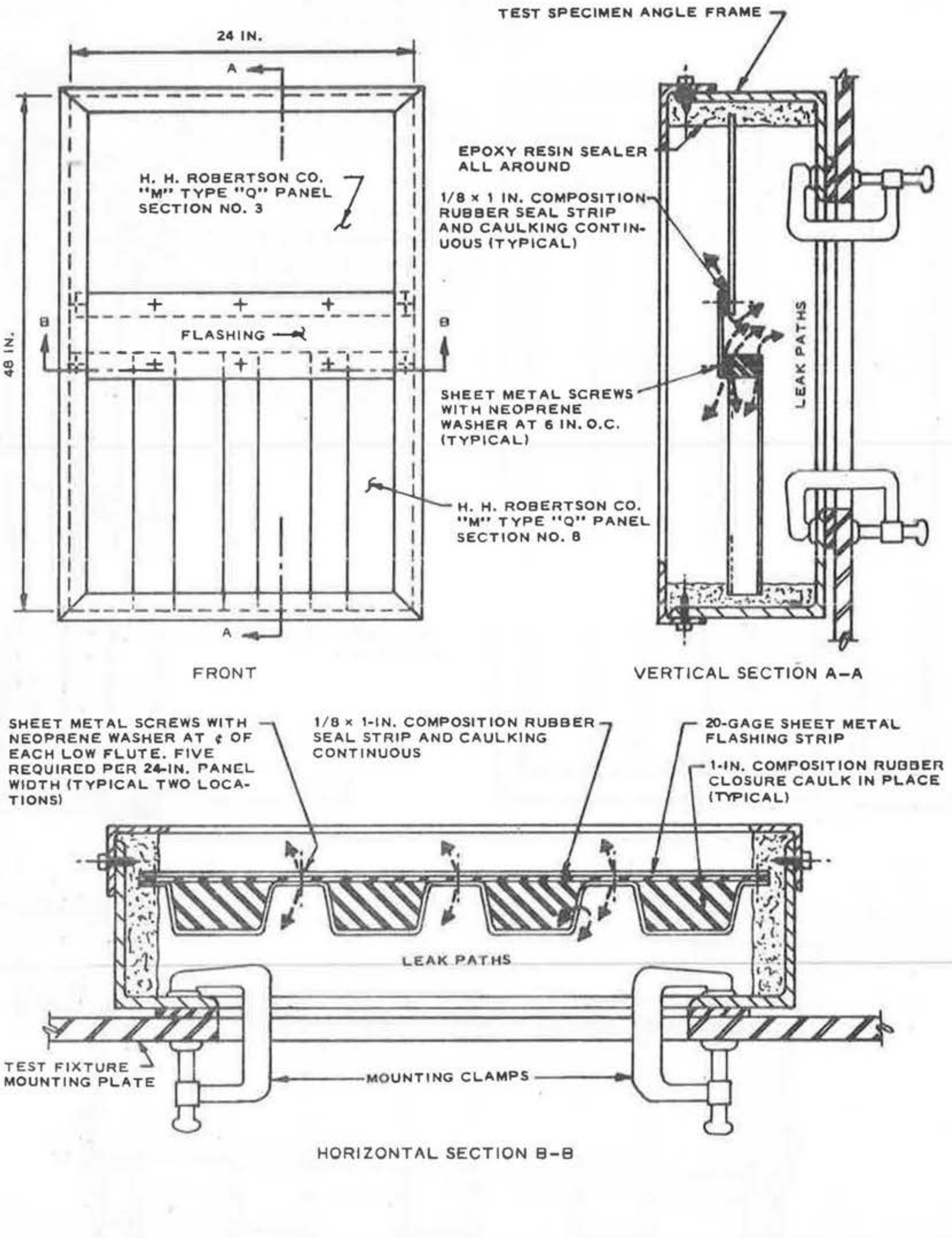
Roofs on metal panel buildings should be designed to consist of a flat inner panel and the standard fluted outer panel. The transition between wall and roof would then be between two flat panel units which could be flashed as at the corners.

Premolded closures used in conjunction with a polysulphide sealant should make a tight seal as the sealant will adhere to both the rubber and the metal.

LEAKAGE DATA SHEET	Figure C-2a	Page 3 of 4



LEAKAGE DATA SHEET	Figure C-2b	Page 4 of 4



LEAKAGE DATA SHEET	No. C-3(1)	Page 1 of 3

COMPONENT

Edge Laps

PURPOSE

Leak rate evaluation and improvement

TEST SPECIMEN DESCRIPTION

Test and Mounting Design: See Figure C-3(1)

Description of Specimen: The specimen consists of two metal panels, a flat inner panel and a fluted outer panel, assembled so that series leakage occurs through both panel laps. There is a 3-ft 10-in. length of edge lap in each panel. The female section of the lap contains caulking material installed by the manufacturer. Three edge lap configurations were tested, as received, dimpled on 6-in. centers, and sheet metal screws on 6-in. centers.

Leak Path Description: In Test 1, assembled as received, the leakage occurs between the caulking material and the metal in each panel. In Test 2, the leakage occurs at the dimples, where the caulking material is squeezed out so that the two metal sections make contact, as well as between the caulking and the metal. In Test 3, the leakage occurs around the sheet metal screws and between the caulking and the metal.

Manufacturer and Type: H. H. Robertson; M-type Q-panel, Section No. 3 (outer panel) and Section No. 8 (inner panel).

LEAK TEST DATA

Empirical Constants: Value for 1 ft

Dual Panel Tests:

No.	Test	A	B
1	As received:	1.5×10^{-3}	5.0×10^{-3}
2	Dimpled on 6-in. centers:	3.4×10^{-3}	4.0×10^{-3}
3	Sheet metal screws on 6-in. centers:	1.7×10^{-3}	0

LEAKAGE DATA SHEET	No. C-3(1)	Page 2 of 3

Since both panels are sealed in the mounting frame, the total leakage is dependent on the leakage through two joints in series. The leakage coefficients for a single panel edge lap are calculated and presented below.

Single Panel Tests

No.	Test	A	B
1	As received:	3.1×10^{-3}	7.3×10^{-3}
2	Dimpled on 6-in. centers:	6.8×10^{-3}	5.1×10^{-3}
3	Sheet metal screws on 6-in. centers:	3.6×10^{-3}	0

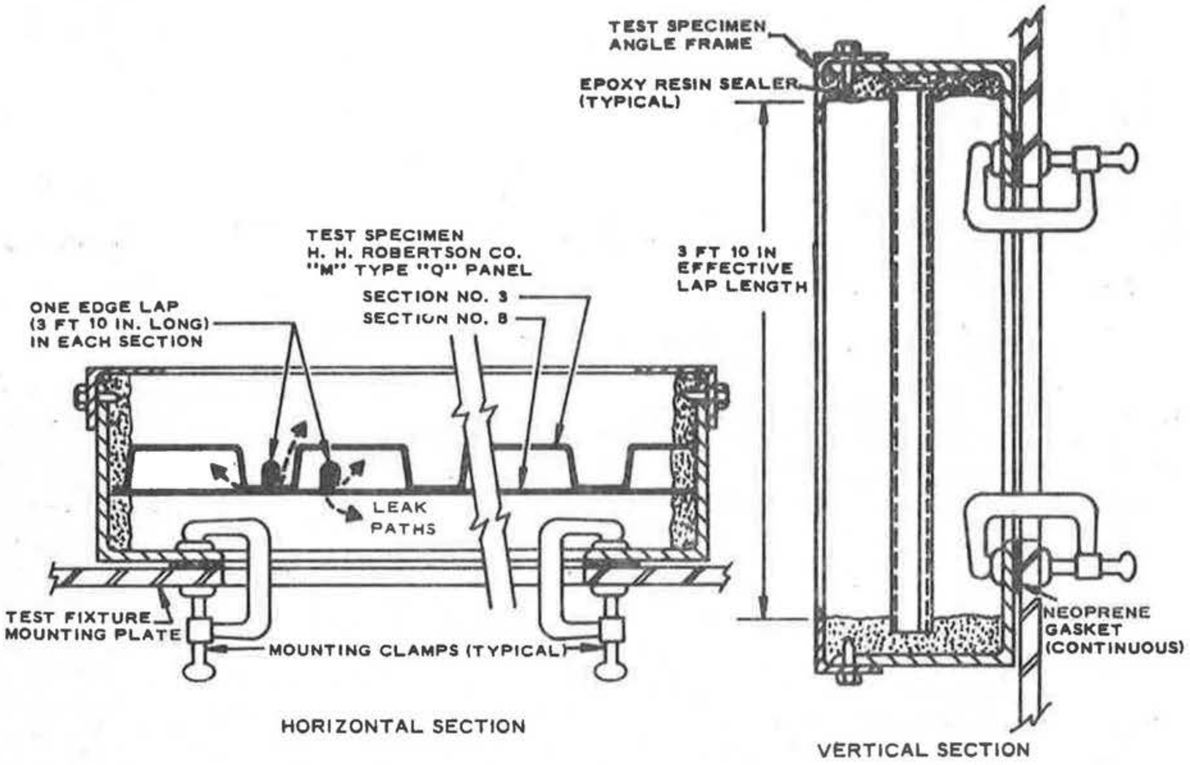
Applicable Pressure Range: The test data should be usable to 5-in. water pressure. At higher pressures, the sheet metal may tend to deform and open up the lap joints, or the caulking material may flow.

LIMITATIONS

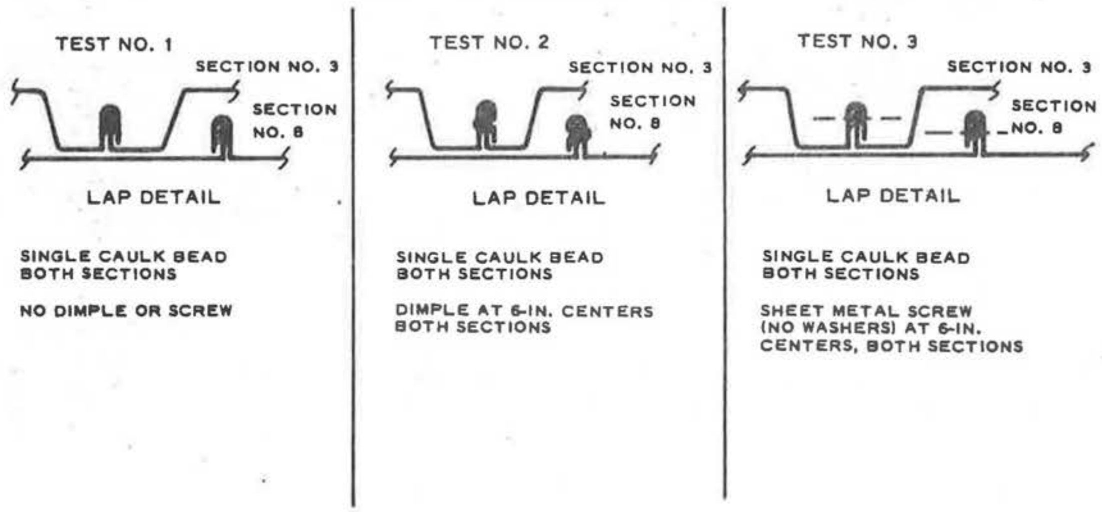
The assembly of insulated metal panels is a manual operation and therefore the tightness of the edge lap may vary throughout the building. This variation will effect the leakage coefficients but the values presented in this data sheet should be considered the lower limits of the leakage coefficients since the joints were assembled under laboratory conditions. The reproducibility of the leak rate is not expected to be repeatable to within a factor of two unless improved methods of caulking are used.

Dimpling Effects: Dimpling is a method of securing the end lap joint and thereby reducing the tendency of the two adjacent panels to separate. Leakage data are shown in Figure C-3, Test 2. During the dimpling process, the two panels must have the proper alignment before securing or the male segment may be only partially secured and will not seal properly into the caulk. As the dimpling tool compresses the joint during the dimpling process, the caulk is squeezed away from the surrounding area, leaving a thin layer of caulk. This caulk is unable to fill the void as the tool is removed and portions of the joint spring back to their original position. The difference between the single panel coefficients of Tests 1 and 2 is $\sim 3.6 \times 10^{-3}$ P cfm/ft and can be interpreted as due to 7 dimples, or 5×10^{-4} P cfm/dimple.

LEAKAGE DATA SHEET	Figure C-3(1)	Page 3 of 3



EDGE LAP - GENERAL TEST ARRANGEMENT - SMALL SPECIMEN



LEAKAGE DATA SHEET	No. C-3(2)	Page 1 of 3

COMPONENT

Edge Laps

PURPOSE

Leak rate evaluation and improvement

TEST SPECIMEN DESCRIPTION

Test and Mounting Design: See Figure C-3(2).

Description of Specimen: The specimen consists of four 6-ft length flat panels with tongue and groove edge laps. There are three edge lap joints for a total of 16-1/2 ft. For the first test, the manufacturer's caulking material was removed from the female component of the joint and was replaced by 3M Car Seam Sealer caulking material. After the panels were assembled, a continuous bead of Car Seam Sealer caulking material was laid in the groove on the back side of the edge lap. This specimen was tested with no dimpling or crimping. For the next test, four panels were again assembled, with the manufacturer's installed caulking material replaced with two layers of Car Seam Sealer caulking material. The edge laps were first tested with dimples on 12-in. centers. The same specimen was then tested with dimples on 6-in. centers. The fourth test consisted of four panels assembled as a unit with a double layer of Car Seam Sealer caulking material. The edge laps were continuously crimped for this test.

Leak Path Description: In Test 1, the leakage occurs between the caulking material and the metal of each panel. In Tests 2 and 3, the leakage occurs at the dimples, where the caulking material is squeezed out so that the two metal sections make contact, as well as between the caulking and the metal. In Test 4, the leakage occurs at the continuous crimp, similar to Tests 2 and 3, as well as between the caulking and the metal.

Manufacturer and Type:

Metal Panels: H. H. Robertson; M-Type Q-panel, Section No. 8

Caulking Material: Minnesota Mining and Manufacturing Company; Car Seam Sealer Caulking Compound.

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LEAKAGE DATA SHEET	No. C-3(2)	Page 2 of 3

LEAK TEST DATA

Empirical Constants: value for 1 ft

Test	Edge Lap Treatment	A	B
1.	Back-caulked, no crimp:	6.8×10^{-3}	2.6×10^{-3}
2.	Double layer of caulk, dimpled on 12-in. centers:	1.5×10^{-4}	1.1×10^{-4}
3.	Double layer of caulk, dimpled on 6-in. centers:	6.9×10^{-4}	0
4.	Double layer of caulk, crimped continuously:	2.3×10^{-6}	7.4×10^{-6}

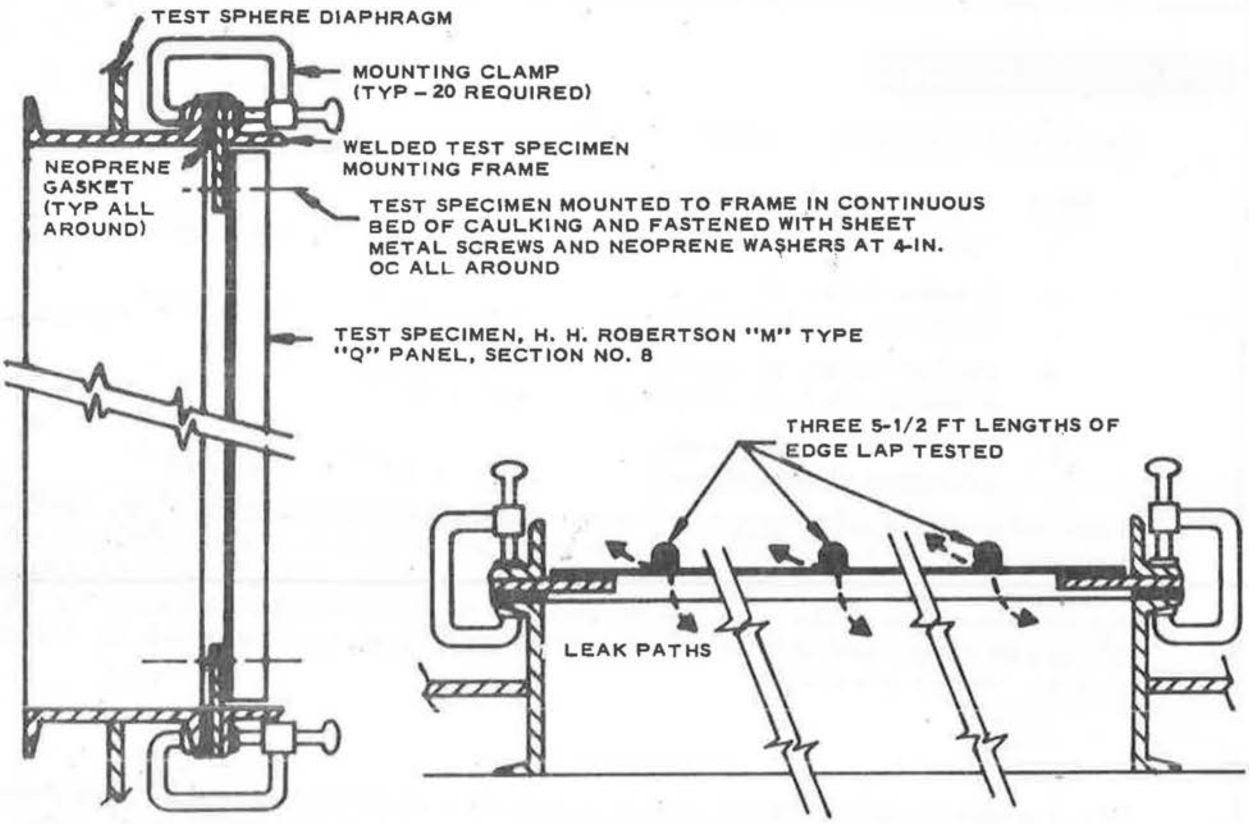
Applicable Pressure Range: The test data should be usable to 5-in. water pressure. At higher pressures, the sheet metal panels will tend to deform and open the lap joints, increasing the leakage rate. At higher pressures this sealant flows out of the joint. Experiments have shown that panels (5 by 12 ft) which are supported only at the perimeter will "pop out" as much as 3.3 in. at 6 in. water pressure.

LIMITATIONS

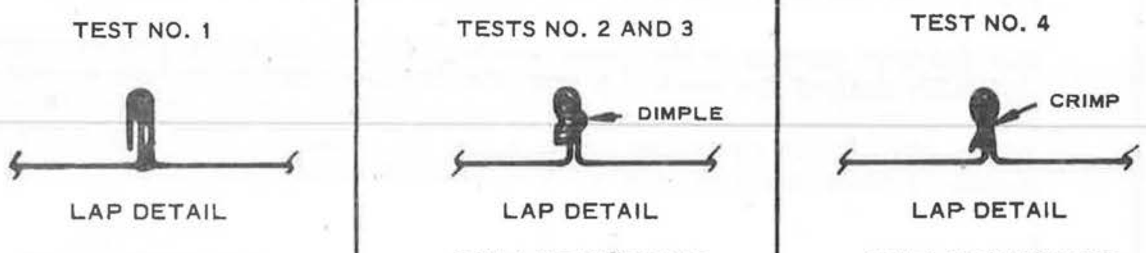
The assembly of insulated metal panels is a manual procedure and therefore the tightness is dependent on a high degree of workmanship. The continuous crimping of edge laps with a double layer of caulking in the female seam approaches the tight seam which is independent of workmanship. The values of leakage coefficients presented in this data sheet should be considered the lower limits since the joints were assembled under laboratory controlled conditions. High temperatures cause separation of oil-based materials, resulting in an improper seal.

For perfect mating of the joint, care must be taken to use straight panels and fully extend the male lip into the female section before dimpling. Care must also be employed in the continuous crimp process since pressures often build up in the caulk area, forcing the joint apart. For further comments see LDS C-3(3), Limitations, page 2 of 3.

LEAKAGE DATA SHEET	Figure C-3(2)	Page 3 of 3



EDGE LAP – GENERAL TEST ARRANGEMENT – LARGE SPECIMEN



TEST NO. 1	TESTS NO. 2 AND 3	TEST NO. 4
SINGLE CAULK BEAD IN FEMALE SECTION PRIOR TO ASSEMBLY	DOUBLE CAULK BEAD IN FEMALE SECTION PRIOR TO ASSEMBLY	DOUBLE CAULK BEAD IN FEMALE SECTION PRIOR TO ASSEMBLY
BACK CAULK (CONTINUOUS) AFTER ASSEMBLY	TEST NO. 2: DIMPLE AT 12-IN. CENTERS AFTER ASSEMBLY	CONTINUOUS CRIMP FULL LENGTH AFTER ASSEMBLY
NO DIMPLE OR CRIMP	TEST NO. 3: DIMPLE AT 6-IN. CENTERS AFTER ASSEMBLY	

LEAKAGE DATA SHEET	No. C-3(3)	Page 1 of 3

COMPONENT

Edge Laps

PURPOSE

Leak rate evaluation and improvement

TEST SPECIMEN DESCRIPTION

Test and Mounting Design: See Figure C-3(3).

Description of Specimen: The specimen consists of two 1-ft lengths of metal panel cut to include male and female components of an edge lap. In one series of tests the caulking material in the female section is supplied by the panel manufacturer. In other tests, this caulking is replaced by other caulking compounds.

Leak Path Description: The leakage occurs through the interface between metal and caulking compound, if dimpling is used.

Manufacturer and Type:

H. H. Robertson Company; M-type Q panel, Section No. 8 and RP-545 caulking material.

Martin-Marietta Company, Presstite Division; Permagum sealing compound No. 576.1 (1-1/2-in. tape).

Martin-Marietta Company, Presstite Division; Structureseal, polysulfide caulking compound, No. 1176.5.

LEAK TEST DATA

Empirical Constants: Value for 1 ft

Test	A	B
Single layer RP-545, no dimple [See LDS C-4(1)]	3.1×10^{-3}	7.3×10^{-3}
Single layer RP-545, dimpled 6-in. centers. [See LDS C-4(1)]	6.8×10^{-3}	5.7×10^{-3}

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LEAKAGE DATA SHEET	No. C-3(3)	Page 2 of 3

Test	A	B
Single layer RP-545, dimpled 3-in. centers:	1.5×10^{-3}	2.7×10^{-4}
Double layer RP-545, no dimple:	0.4×10^{-6}	2.8×10^{-6}
Single layer polysulphide, no dimple (full female section):	10^{-9} cfm/ft at 20-in. water pressure	
1- by 1/4-in. layer Permagum, no dimple:	10^{-9} cfm/ft at 20-in. water pressure	
1- by 1/4-in. layer Permagum, dimpled 10-in. centers:	5.4×10^{-7}	0

Applicable Pressure Range: The test data should be usable to 20-in. water pressure. However, at higher pressures, the metal panels in a full-scale structure will deform and cause increased leakage through the joint.

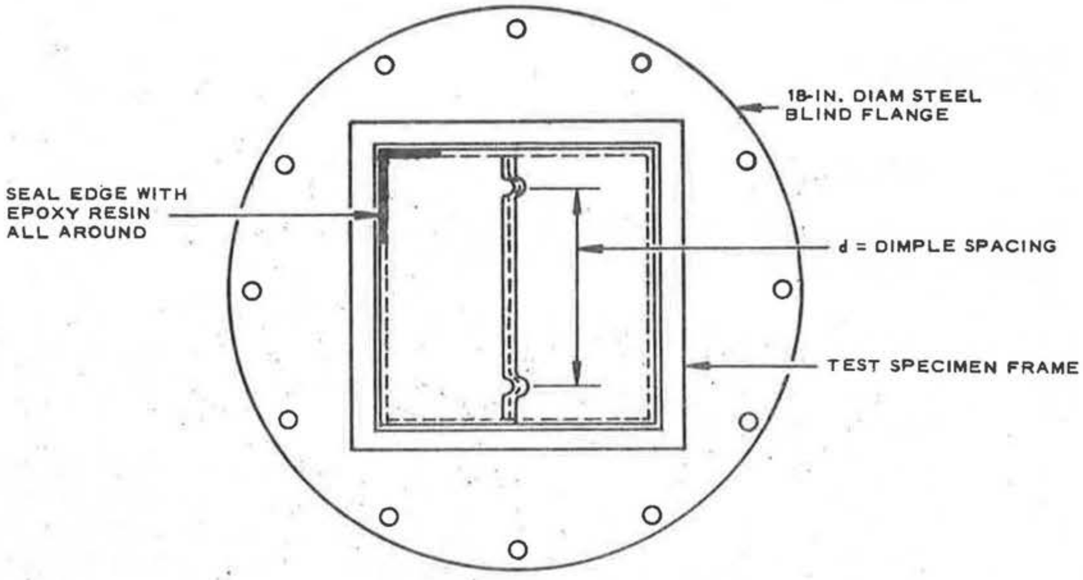
LIMITATIONS

As shown in the various tests of edge lap joints, the single bead of caulking, installed in the female part of an edge lap by the manufacturer, is not sufficient to seal this joint. An increased amount of caulking, to fill the female part, will reduce the leakage rate by at least a factor of 1000. The use of sheet metal screws or closely spaced dimples in the assembled joint will reduce the leakage but, in some cases, can actually increase the leakage rate. Continuous crimping of the assembled joint will produce a tight configuration. The use of nonresilient-type caulking materials such as Permagum or two-part polysulfide polymers will reduce the leakage to nonmeasurable rates at 20-in. water pressure differential if joints have rigid backing.

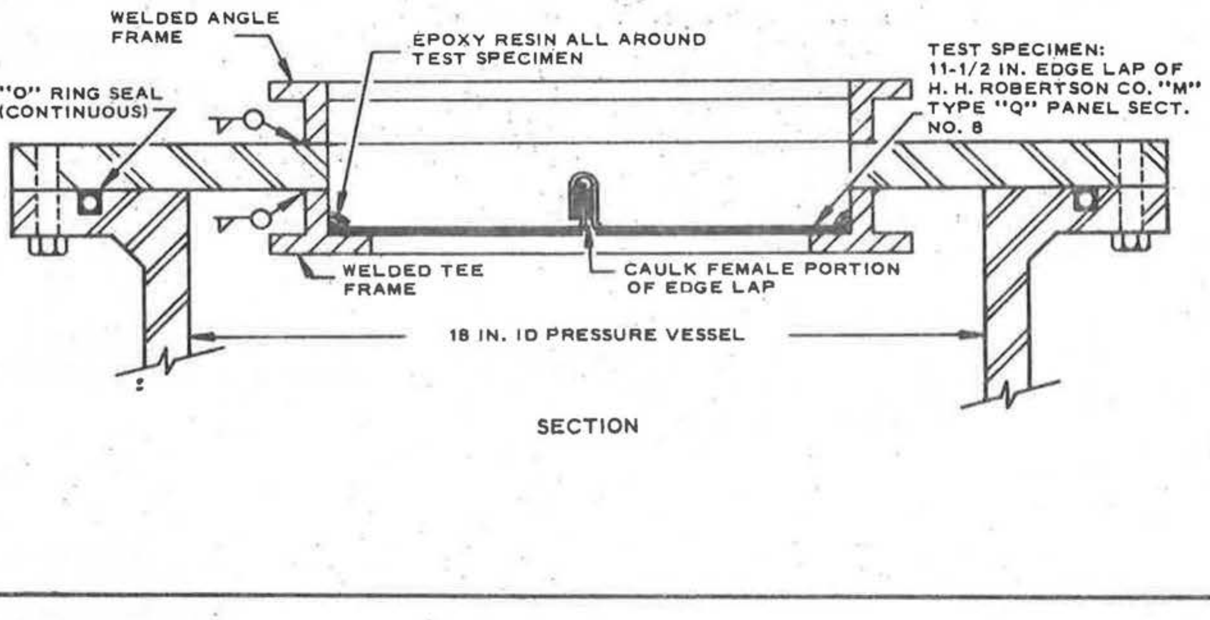
New male panels should be designed which have a longer protrusion into the female lip, thus enhancing the likelihood of a seal with the caulking layers previously placed there.

For further comments, see LDS C-3 (2). Limitations, page 2 of 3.

LEAKAGE DATA SHEET	Figure C-3(3)	Page 3 of 3



TOP PLAN



SECTION

LEAKAGE DATA SHEET	No. C-4(1)	Page 1 of 3

COMPONENT

End Laps

PURPOSE

Leak rate evaluation and improvement

TEST SPECIMEN DESCRIPTION

Test and Mounting Design: See Figure C-4(1).

Description of Specimen: The specimen consists of 11-1/2 in. of the flat inner panel of a 2-panel assembly.

Test 1: The end lap is caulked with "Presstite" caulking tape, rolled into a 3/8-diameter rope to simulate a caulking gun, and the two members are attached to a girt with sheet metal screws through the lap on 10-in. centers. The caulking compound spreads over a width of 1-1/2 in. when the two metals are compressed.

Test 2: The end lap contains Robertson RP-545.

Leak Path Description: The leakage occurs between the caulking material and the metal surfaces as well as around the sheet metal screws.

Manufacturers and Type:

H. H. Robertson Company; M-type Q-panel, Section No. 8 (inner panel).

Martin-Marietta Company, Presstite Division; Permagum sealing compound No. 576.1 (1-1/2-in. tape).

LEAK TEST DATA

Empirical Constants:

Test 1: This specimen leaks less than 10^{-9} cfm/ft of lap at 20 in. of water pressure with two sheet metal screws at 10-in. centers centrally located in the lap.

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LEAKAGE DATA SHEET	No. C-4(1)	Page 2 of 3

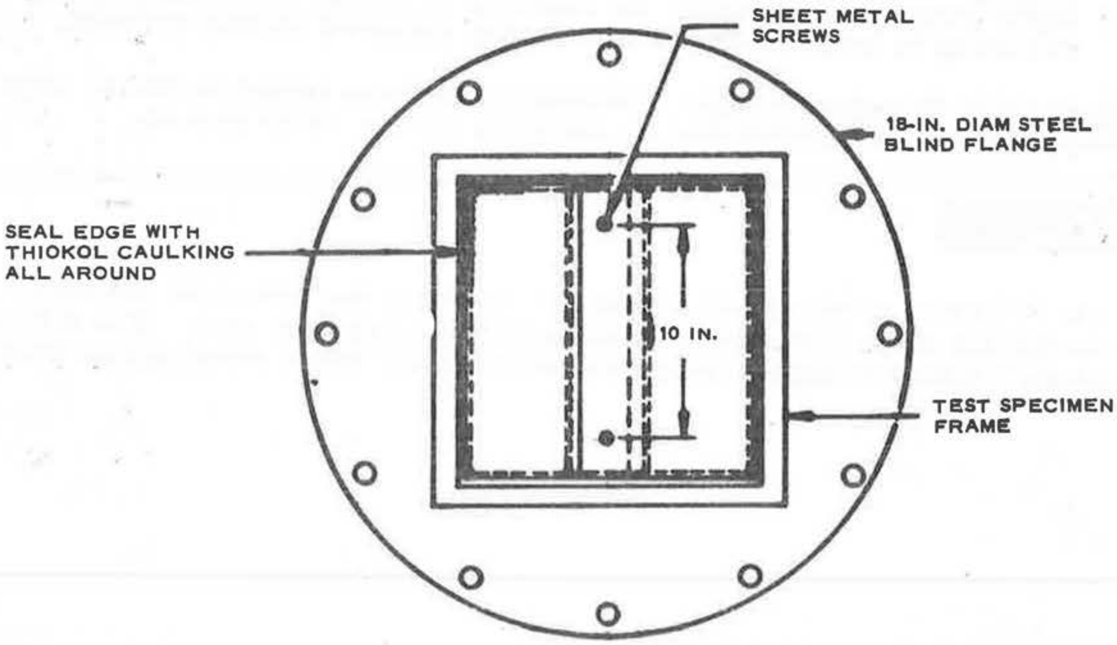
Test 2: This specimen leaks less than 10^{-9} cfm/ft of lap at 20 in. of water pressure; however, the caulking is forced out of the end lap, resulting in large leakage rates during extended testing periods.

Applicable Pressure Range: Permagum has been tested to 20-in. water pressure and has maintained its integrity over a 24-hr period.

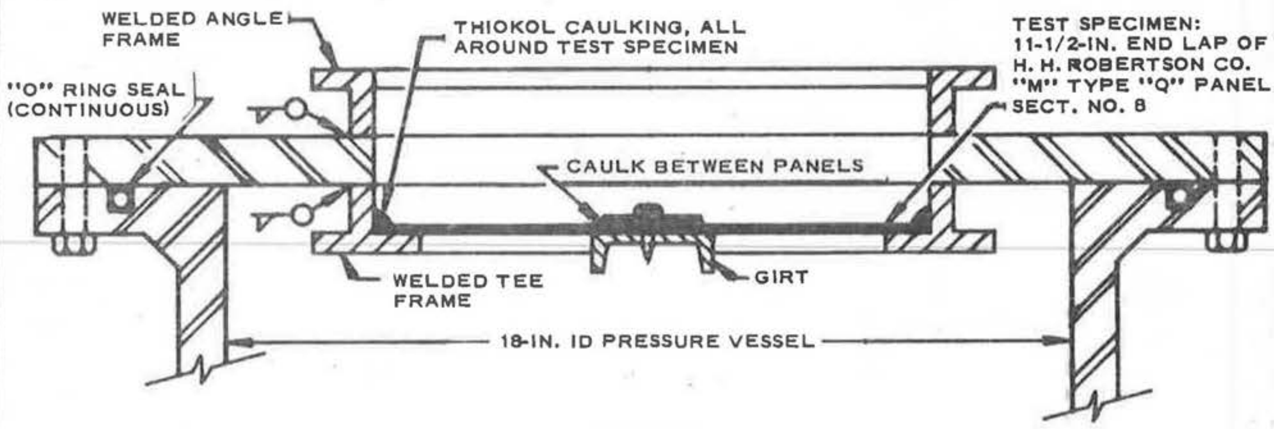
LIMITATIONS

The Presstite product was tested to determine the minimum distance needed for sheet metal screws for a satisfactory leak rate. The RP-545 product flowed at higher pressures with 10-in. sheet metal screw spacing.

LEAKAGE DATA SHEET	Figure C-4(1)	Page 3 of 3



TOP PLAN



SECTION

LEAKAGE DATA SHEET	No. C-4(2)	Page 1 of 3

COMPONENT

End Laps

PURPOSE

Leak rate evaluation and improvement

TEST SPECIMEN DESCRIPTION

Test and Mounting Design: See Figure C-4(2).

Description of Specimen: The specimen consists of two metal panels, a flat inner panel, and a fluted outer panel, assembled so that series leakage occurs through both panel end laps. There is a 22-in. end lap in each panel. Caulking material is placed in the joint between the two metal sections at the end lap and then the metal pieces are assembled with sheet metal screws on 6-in. centers to form the test panels. Two types of caulking material, both supplied by the manufacturer, were tested.

Leak Path Description: In both tests, the leakage occurred between the caulking and the metal surfaces as well as around the sheet metal screws.

Manufacturer and Type: H. H. Robertson; M-type Q-panel, Section No. 3 (outer panel) and Section No. 8 (inner panel); black oil base caulking rope; and RP 545 caulking compound.

LEAK TEST DATA

Empirical Constants: Value for 1 ft

Dual Panel Tests:

End Lap Type	A	B
Oil base caulking rope:	1.4×10^{-3}	1.1×10^{-3}
RP-545:	8.2×10^{-5}	0

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LEAKAGE DATA SHEET	No. C-4(2)	Page 2 of 3

Since both panels are sealed in the mounting frame, the total leakage is dependent on the leakage through two joints in series. The leakage coefficients for a single panel end lap are calculated and presented below.

Single Panel Tests: cfm/ft with two sheet metal screws

End Lap Type	A	B
Oil base caulking rope:	2.8×10^{-3}	1.7×10^{-3}
RP-545:	1.6×10^{-4}	0

Applicable Pressure Range The test data should be usable to 5-in. water pressure. At higher pressures, the sheet metal may tend to deform and open the end laps, causing increased leakage.

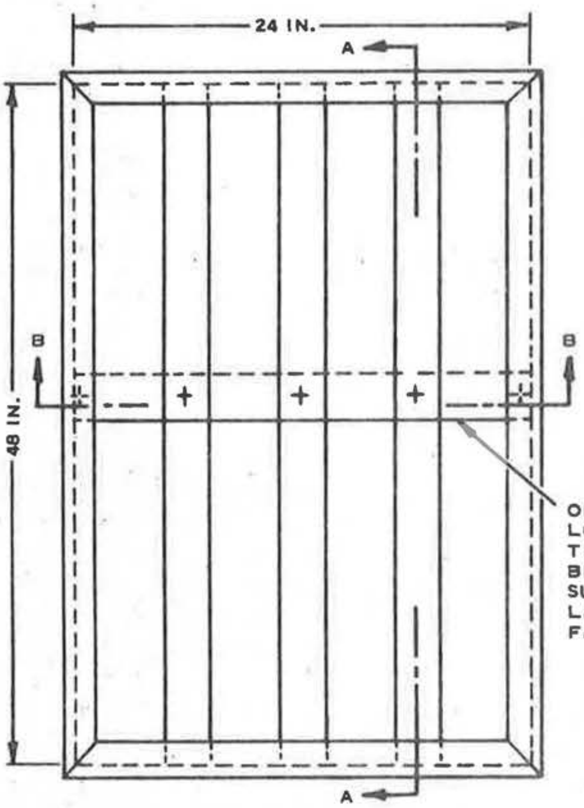
LIMITATIONS

The leakage coefficients were determined with the sheet metal screws passing through the caulking in the joint. If the caulking is not applied so that the screw holes are filled, the leakage around the base screws will be larger than tested and these coefficients will be incorrect. It is important that the manual application of caulking in the end lap results in a properly positioned caulk.

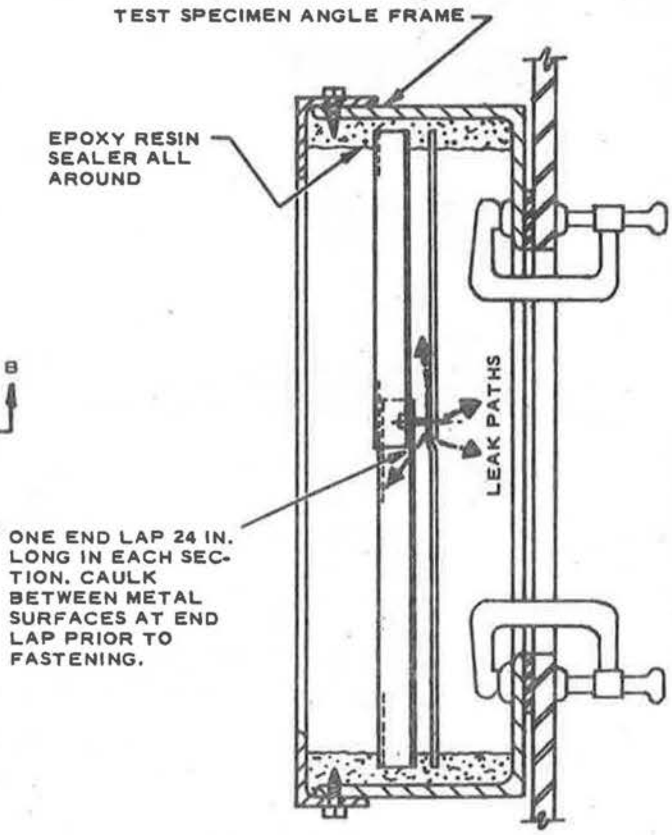
RECOMMENDATIONS

As in other tests of metal panel joints, the use of nonresilient caulking materials or adhesive polysulfide polymers will reduce the leakage by orders of magnitude.

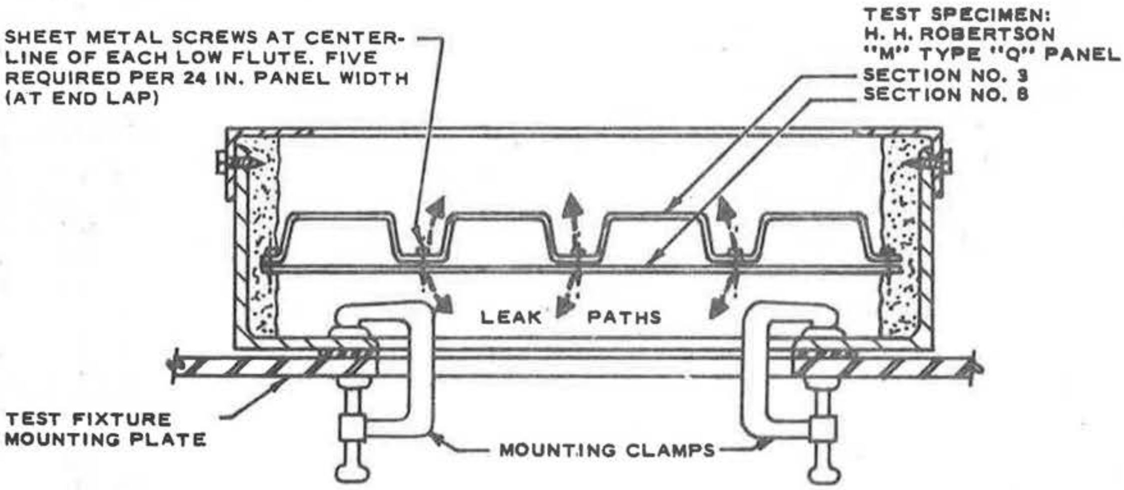
LEAKAGE DATA SHEET	Figure C-4(2)	Page 3 of 3



FRONT



VERTICAL SECTION A–A



HORIZONTAL SECTION B–B

LEAKAGE DATA SHEET	No. C-5(1)	Page 1 of 3

COMPONENT

End-Edge Lap Intersection

PURPOSE

Leak rate evaluation and improvement

TEST SPECIMEN DESCRIPTION

Test and Mounting Design: See Figure C-5(1).

Description of Specimen: The specimen consists of a 2- by 4-ft dual panel section consisting of flat inner panels and fluted outer panels arranged so that there are two end-lap - edge-lap configurations in series. In the first test, RP-545 caulking material is used in the end laps, and the edge laps are filled with caulking material supplied by the manufacturer. In the second test, the intersection is dimpled to form a tight joint.

Leak Path Description: The leakage occurs between caulking material and metal in the four edge-lap folds which form the intersection.

Manufacturer and Type: H. H. Robertson Company; M-type Q-panel, Section No. 8 (flat inner panel), Section No. 3 (fluted outer panel), and RP-545 caulking material.

LEAK TEST DATA

Since the test panel contains edge and end-lap leakage paths as well as intersection leak paths, the leakage through the intersection is the difference between the complete specimen leakage and the sum of the end-edge lap leakage.

Empirical Constants: Value for one intersection

Dual Panel Tests:

Type	A	B
Manufacturer's caulking, no dimple:	8.2×10^{-3}	1.9×10^{-3}
Manufacturer's caulking, dimpled at intersection:	8.2×10^{-3}	1.5×10^{-3}

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LEAKAGE DATA SHEET	No. C-5(1)	Page 2 of 3

Since there are two intersections in series, the leakage through a single panel intersection joint was calculated and is given below.

Single Panel Test:

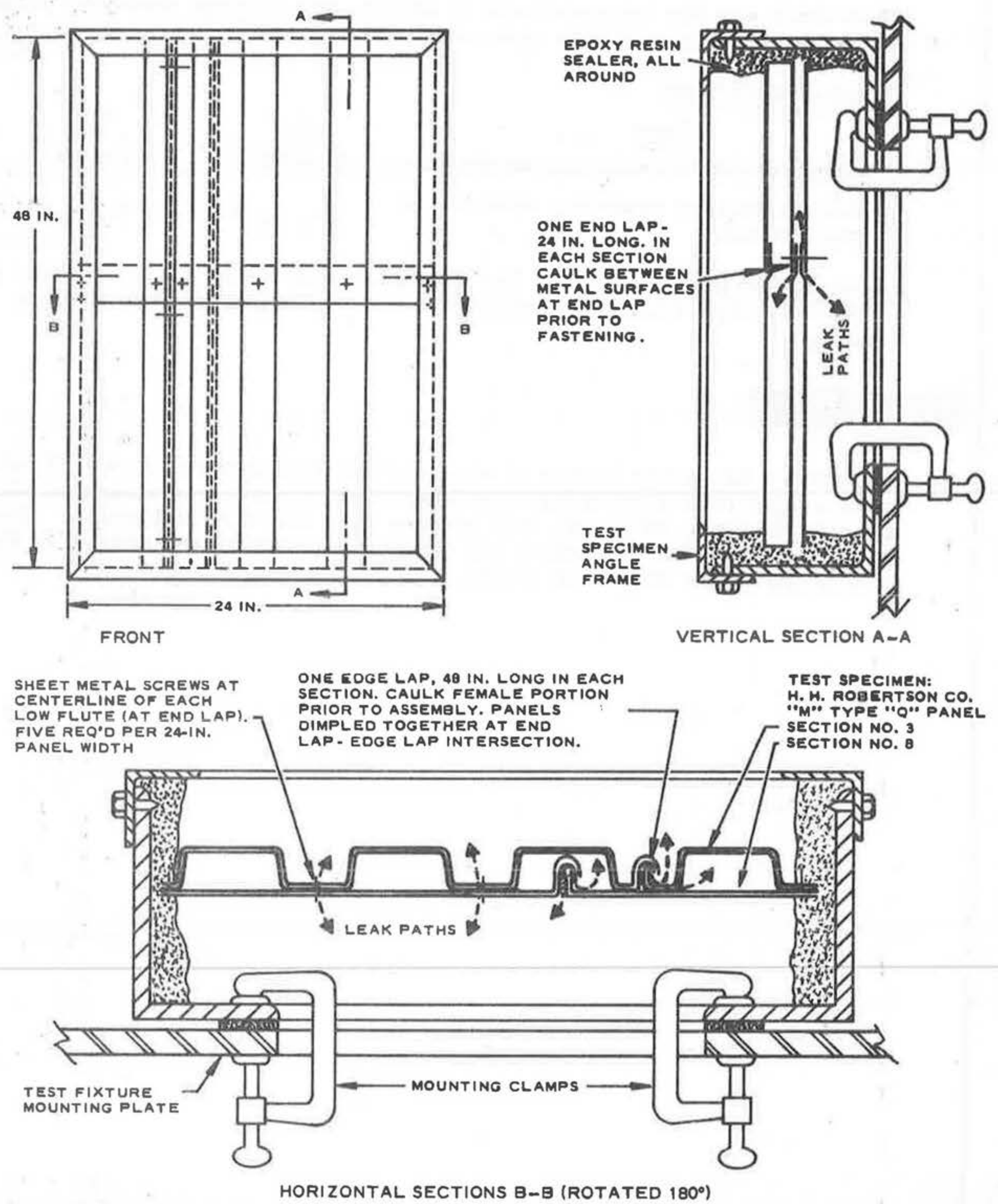
Type	A	B
Manufacturer's caulking, no dimple:	16×10^{-3}	2.7×10^{-3}
Manufacturer's caulking, dimpled at intersection:	16×10^{-3}	2.1×10^{-3}

Applicable Pressure Range: The specimen was tested to 3-in. water pressure but the data should be usable to 5-in. water pressure in a large building.

LIMITATIONS

Since there are many layers of metal at the intersection, it is difficult to make a tight joint even though caulking is used. If special care is not taken in the field, this joint will be less tight and will leak more. Above 5-in. pressure, the structure will deform and change the degree of tightness in the joints which are tested.

LEAKAGE DATA SHEET	Figure C-5(1)	Page 3 of 3



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LEAKAGE DATA SHEET	No. C-5(2)	Page 1 of 3

COMPONENT

End-Edge Lap Intersection

PURPOSE

Leak rate evaluation and improvement

TEST SPECIMEN DESCRIPTION

Test and Mounting Design: See Figure C-5(2).

Description of Specimen: The specimen consists of four panels containing end-lap joints assembled to form a 6- by 6-ft panel with three edge laps. The end laps and edge laps are caulked with Car Seam Sealer before assembly. The panels are assembled so that the end lap can be fastened to a girt with neoprene washers and sheet metal screws on 4-in. centers. The edge laps are back-caulked with Car Seam Sealer and then are crimped continuously. In order to determine the leakage through the intersection, the leakage is measured for the specimen and is measured again after the intersections are sealed tight by means of a polysulfide material.

Leak Path Description: The leakage occurs between the caulking and metal; it is possible that, at the intersection where four panels overlap, the caulking material has been squeezed out and the leakage occurs between metal and metal surfaces.

Manufacturer and Type:

H. H. Robertson Co.; M-type Q-panel, Section No. 8 (flat inner panel)
Minnesota Mining and Manufacturing Co.; Car Seam Sealer caulking compound

LEAK TEST DATA

Empirical Constants: Value for one intersection

Test	A	B
Edge lap back caulked and crimped continuously, end lap attached to girt:	7.4×10^{-3}	0

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LEAKAGE DATA SHEET	No. C-5(2)	Page 2 of 3

Applicable Pressure Range: The test data should be usable to 5-in. water pressure. At higher pressures, the sheet metal panels will deform and increase the rate of leakage through this joint.

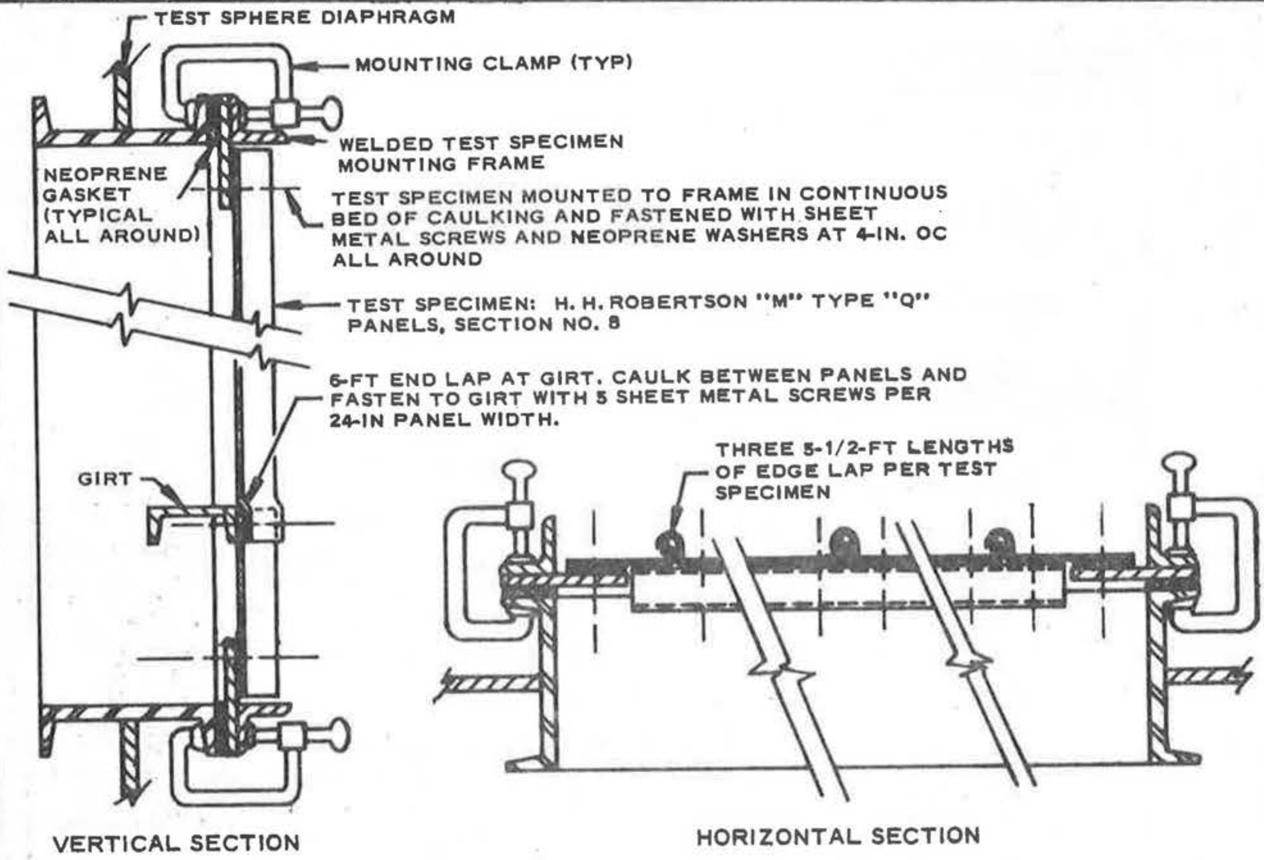
LIMITATIONS

The assembly of four panels to construct a tight joint where they overlap is difficult and requires much care. If the joint is not made carefully, this can be a source of large leakage.

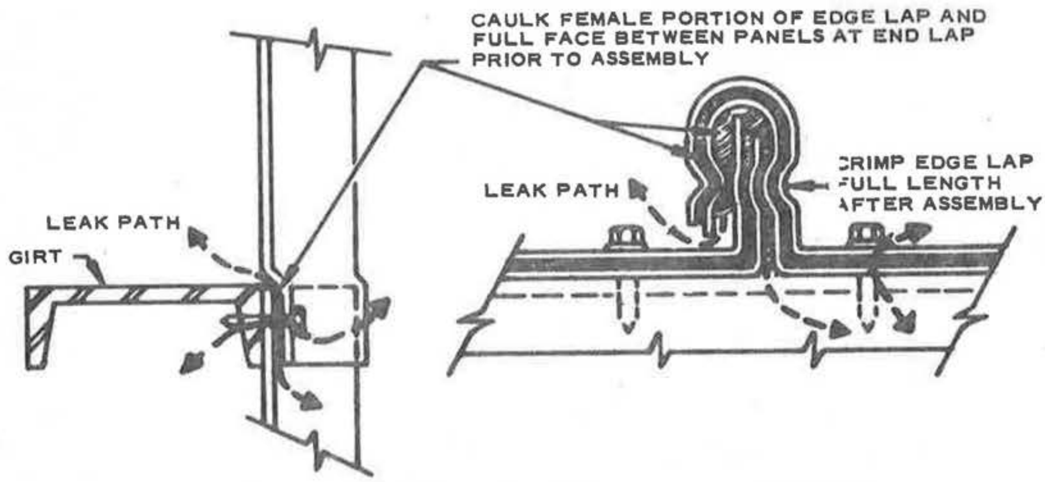
RECOMMENDATIONS

The joint where tour panels meet could be sealed more tightly by substituting a polysulfide or polybutene adhesive caulking material in the edge laps at the panel end.

LEAKAGE DATA SHEET	Figure C-5(2)	Page 3 of 3



END LAP – EDGE LAP INTERSECTION – GENERAL TEST ARRANGEMENT



ENLARGED VIEW – END LAP – EDGE LAP INTERSECTION
(THREE INTERSECTIONS PER TEST SPECIMEN)

LEAKAGE DATA SHEET	No. C-6	Page 1 of 3

COMPONENT

Flashing, Sheet Metal

PURPOSE

Leak rate evaluation and improvement

TEST SPECIMEN DESCRIPTION

Test and Mounting Design: See Figure C-6.

Description of Specimen: The specimen consists of two 1-ft lengths of 18-gage metal flashing with 90° bonds. The unit is held together with sheet metal screws on either 10- or 5-in. centers. The void between the flashing is filled with various caulking materials. The assembly is mounted on the test plate with thiokol caulking compound which does not leak.

Leak Path Description: The leakage occurs between the two metal faces and the caulking compound as well as around the sheet metal screws.

Manufacturer and Type: H. H. Robertson Company; Caulking compound RP-545, Permagum.

LEAK TEST DATA

Empirical Constants: Value for 1 ft

The leakage coefficients per foot of flashing joint are presented below:

Test	A	B
RP-545, two sheet metal screws on 10-in. centers:	1×10^{-5}	0
Permagum 576, on 10-in centers:	1×10^{-9}	0
Three sheet metal screws on 5-in. centers with RP-545:	1.3×10^{-5}	0

Applicable Pressure Range: The test data are applicable to 25-in. water pressure for the small area tested. At higher pressures (and with larger areas between rigid frames) the sheet metal will deform and increase the leakage rate.

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LEAKAGE DATA SHEET	No. C-6	Page 2 of 3

LIMITATIONS

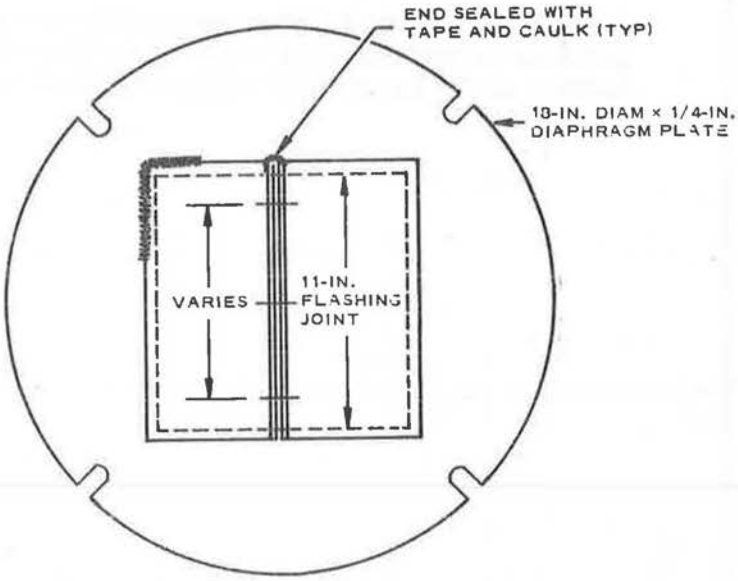
A thick layer of caulking materials is required to compensate for irregularities in the flashing created by the use of sheet metal screws. Thinner layers could be used if stiffening bars are used to prevent these ripples.

LEAKAGE DATA SHEET	Figure C-6	Page 3 of 3

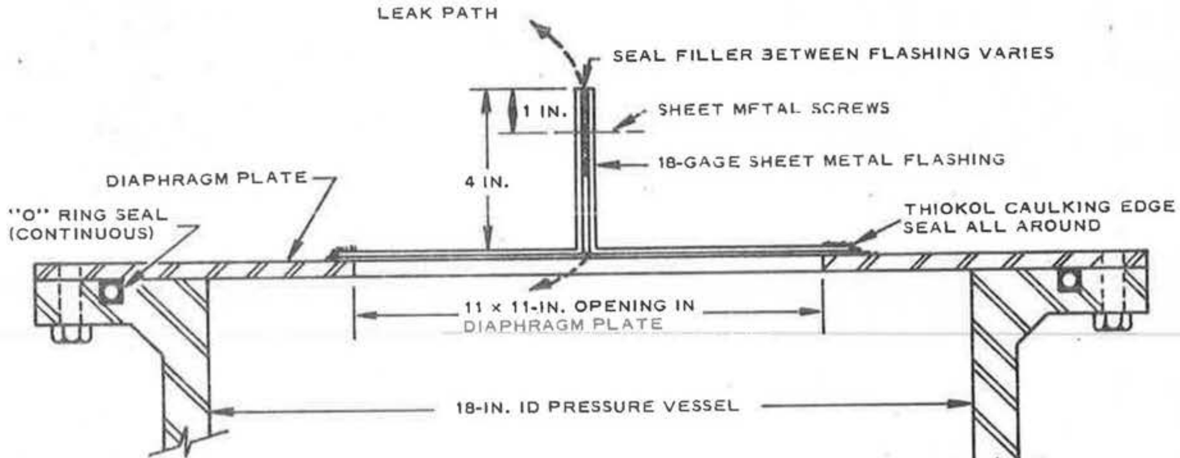
TEST NO. 1:
1/4-IN. DIAM CAULK BEAD BETWEEN FLASHING
2 SHEET METAL SCREWS WITH WASHERS AT 10-IN. OC

TEST NO. 2:
1/4-IN. DIAM CAULK BEAD BETWEEN FLASHING.
3 SHEET METAL SCREWS WITH WASHERS AT 5-IN. OC

TEST NO. 3:
1/4 × 1-IN. RUBBER SEAL STRIP BETWEEN FLASHING.
2 SHEET METAL SCREWS WITH WASHERS AT 10-IN. OC



TOP PLAN



SECTION

LEAKAGE DATA SHEET	No. C-7	Page 1 of 3

COMPONENT

Frame Angle Inserts

PURPOSE

Determination of a sealing method of reducing the leakage rate between an angle and sheet metal such as at the curb or frame inserts.

TEST SPECIMEN DESCRIPTION

Test and Mounting Design: See Figure C-7.

Description of Specimen: The joint is represented by an angle 3 by 3 by 1/4 in. by 12 in. long and one foot of 18-gage sheet metal in which various compounds are placed between the angle and sheet metal.

Installation Procedure: The specimen is mounted on the testing plate by use of a thiokol.

Leak Path Description: Since all exposed surfaces (except the test area) are covered with thiokol, the leak path is considered to be between the angle and sheet metal.

LEAK TEST DATA

Leakage Rates: Air leakage is not detectable for the following three tests (assume coefficient $A = 10^{-9}$):

Test 1: 1/4-in. diam caulk bead (H. H. Robertson, RP-545) is placed between the sheet metal and angle. Two sheet metal screws (10 in. apart) with neoprene rubber washers are used to fasten the sheet metal to the angle.

Test 2: Same as Test 1, except screws are placed 5 in. apart.

Test 3: 1/4-by 1-in. rubber seal strip is caulked on both sides with caulking (Permagum) and fastened between the sheet metal and angle with sheet metal screws 10 in. apart.

Air leakage was detectable for Test 4. Test 3 was repeated without caulking; it showed a leak rate of greater than 1 cfm/ft of joint.

LEAKAGE DATA SHEET	No. C-7	Page 2 of 3

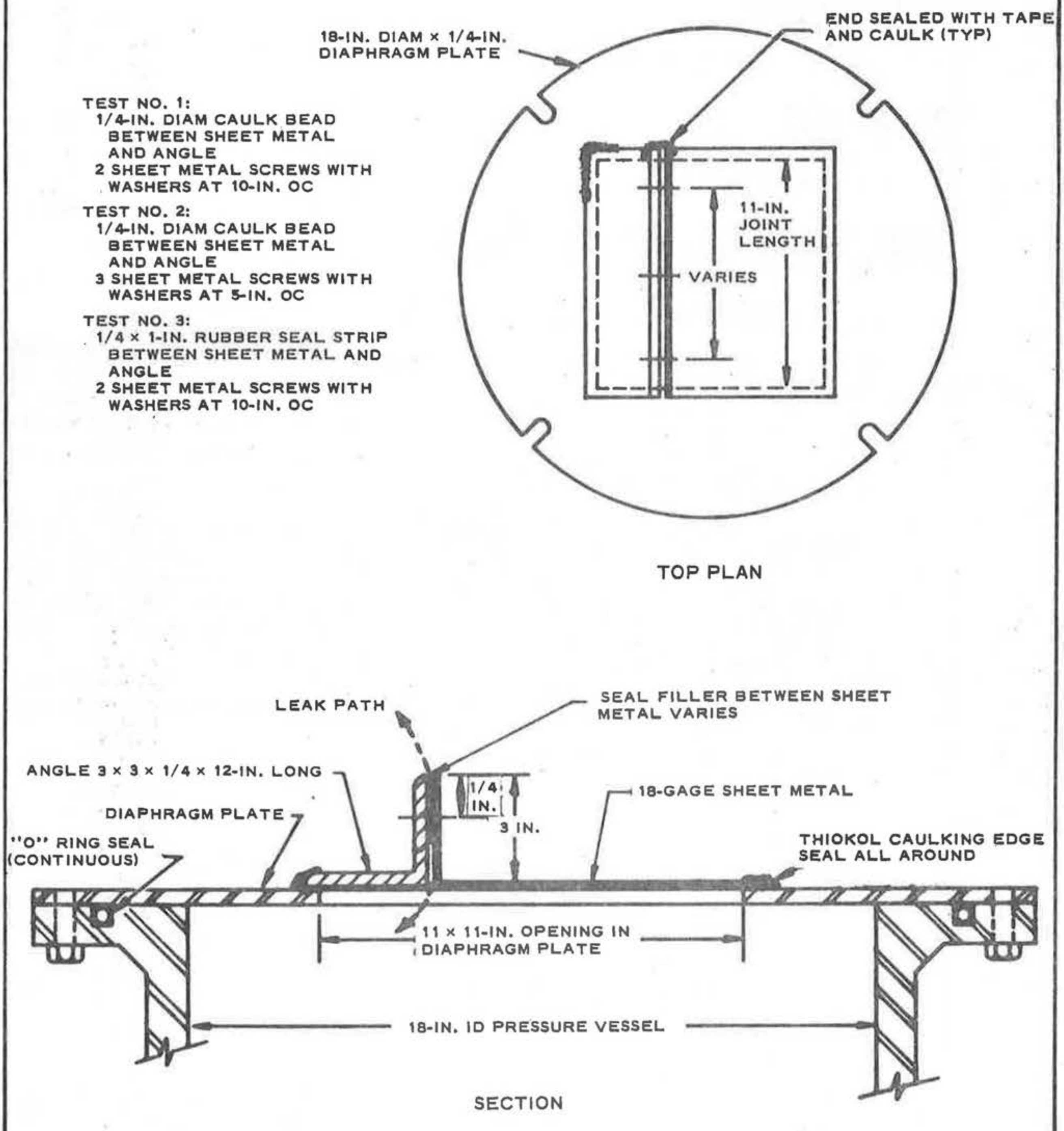
LIMITATIONS

Rubber by itself is not satisfactory to reduce the leakage when used as a sealer between two thin pieces of metal or between thin metal and an angle. As the screws are tightened, the metal ripples and voids appear between the rubber and metal midway between the screws.

RECOMMENDATIONS

Caulking should be polyvinyl sulphide or polybutene.

LEAKAGE DATA SHEET	Figure C-7	Page 3 of 3



LEAKAGE DATA SHEET	No. C-8	Page 1 of 5

COMPONENT

Sill Angle to Wall Panel

PURPOSE

Leak rate evaluation and improvement

TEST SPECIMEN DESCRIPTION

Test and Mounting Design: See Figure C-8a.

Description of Specimen: The tested specimen consists of the inner Robertson panel and a curb angle. The curb angle is adjacent to another angle which simulated a concrete curb (assumed treated to a smoothness approximating that of the lower angle). The first test consisted of standard practices where no caulking was used. The others can be seen in the design shown in Figure C-8a.

Leak Path Description: The leakage can occur between the curb angle and the metal siding or between the curb angle and the angle which simulates the concrete. The accompanying data represent the leakage at the curb, and therefore leakage through concrete or leakage between concrete and the rubber or mastic on the curb angle must be estimated by other tests. Leak data for the latter are described in LDS B-3.

Leakage also occurs at the following places for each individual test:

Test 1: a) at weld imperfections

b) through the bolt holes

Test 2: a) through the sheet metal screws at curb angle to metal siding connection

Test 3: a) around or through the mastic and neoprene strip

b) through bolt holes and sheet metal screws which go through the metal

Manufacturer and Type:

H. H. Robertson, Pittsburgh, Pa.; Siding, M-type Q-panel, Section 8.
Manufacturer unknown; proprietary mastic, RP-545.
Hamilton Rubber Mfg. Co.; rubber seal.

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LEAKAGE DATA SHEET	No. C-8	Page 2 of 5

Description:

a) Metal panel: flat interior, 18-gage, zinc-coated steel.

b) Mastic: RP-545, no information available, proprietory mastic.

c) Gasket: rubber strips, durometer hardness 55-65, average tensile strength 1300, composition not known.

Application Method: A caulking gun is normally used to apply the mastic to the fixed surface. The curb angle is placed on top of mastic or rubber gasket and bolted in place. Since anchor bolts are usually placed in the footing, the mastic or the rubber gasket would be placed along the plane connecting the bolts. The diameter of the caulking roll should be at least 3/8 in. to insure a compressed area coverage of ~ 1 in.^{2} with a 0.1-in. thickness of caulking material between the two surfaces. In actual practice the concrete surface at the curb angle should be presealed with a membrane coating.

LEAK TEST DATA

Range: 0 to 10 in. of water, 2-ft length tested.

Coefficient: Value for 1 ft of curb

Leakage Coefficients: (See Figure C-8b for graph.)

Test	A	B
1	0.62	1.2
2	0.41	0.1
3	2.5×10^{-4}	0
See LDS C-7	10^{-9}	0

Extrapolations: Because of the rigidness of the curb angle, it is suggested that these data be extrapolated to only 20 in. of water, at which pressure (depending on joint size) the mastic will flow across the surfaces that it bridges and rupture. The deduced leakage from a curb detail composed of the curb angle to floor joinery of Test 1 and the curb angle to wall joinery of Test 2 is the sum of the coefficients of Tests 1 and 2. Thus, cfm/ft = $1.03P + 1.37P^{1/2}$. This assumes little or no leakage between the remaining leak paths of Tests 1 and 2 except those used in the calculation of the leak equation. This equation would be quite applicable as a lower limit even if concrete were used in Test 1.

LEAKAGE DATA SHEET	No. C-8	Page 3 of 5

LIMITATIONS

1) The tested components did not include the intersection between two metal panels, at an edge lap, with the curb angle. To eliminate leakage at this joint, the space between these panels must be back-filled with mastic in the interior of the building to assure a continuous seal between the curb angle and the joint.

2) The mastic must also be applied in the same manner in the corners of buildings where the curtain wall flashing and the curb angle join.

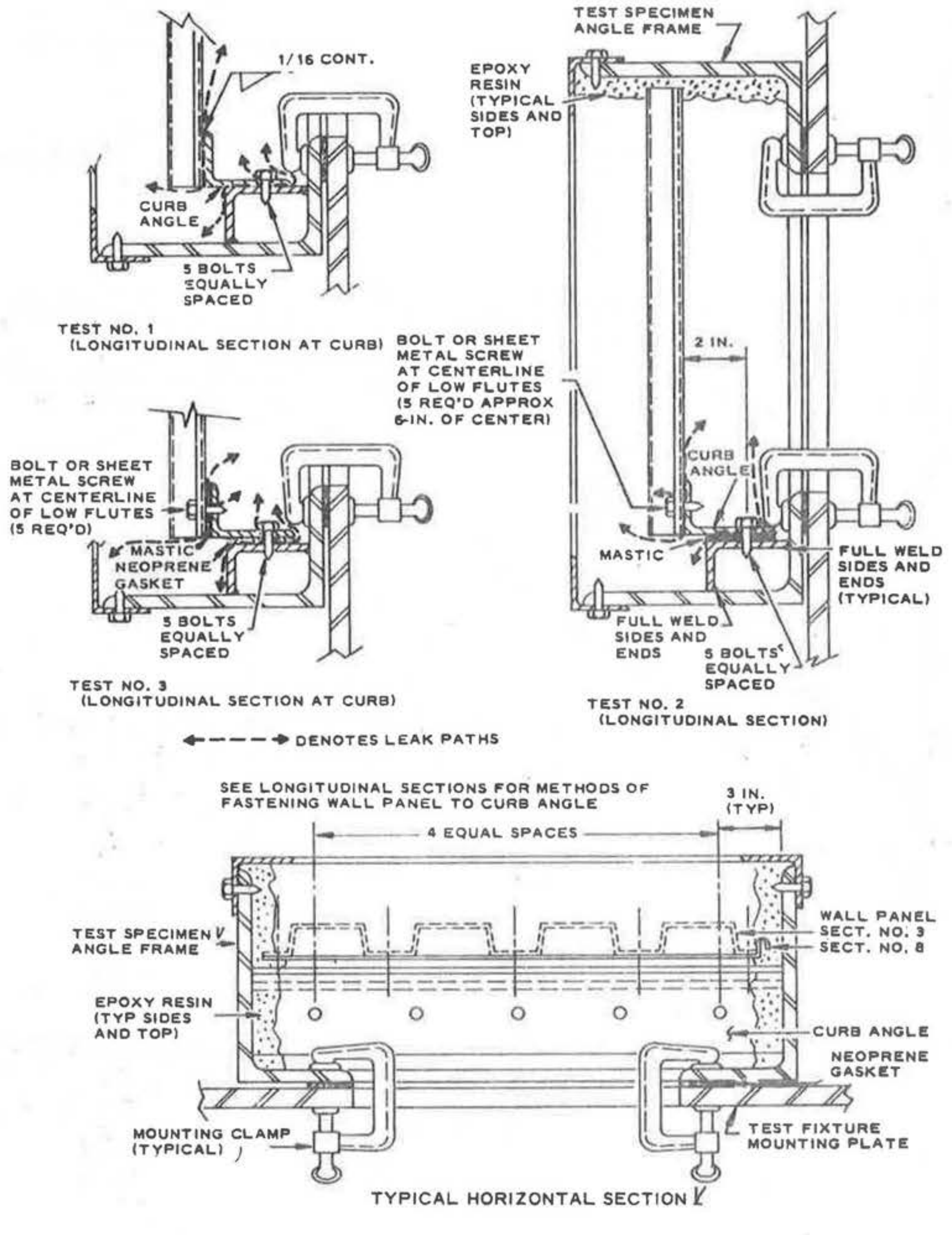
3) Sealing materials composed of oil-based compounds should be avoided since these compounds have a tendency to flow even at reduced pressures and have a tendency to change characteristics under certain atmospheric conditions. The nonskinning, nonresilient caulking compounds remain indefinitely uncured, permanently tacky, and are recommended.

4) Test 3 can be improved by replacing the rubber-type gasket with a nonresilient, nonskinning compound or a two-part rubber resilient compound such as polysulfide. The rubber gasket generally relies on pressure for sealing and does not adjust properly to the irregularities in concrete. The caulking material between the metal siding and curb angle or concrete and curb angle can be either resilient or nonresilient in preformed shapes or a bulk mastic.

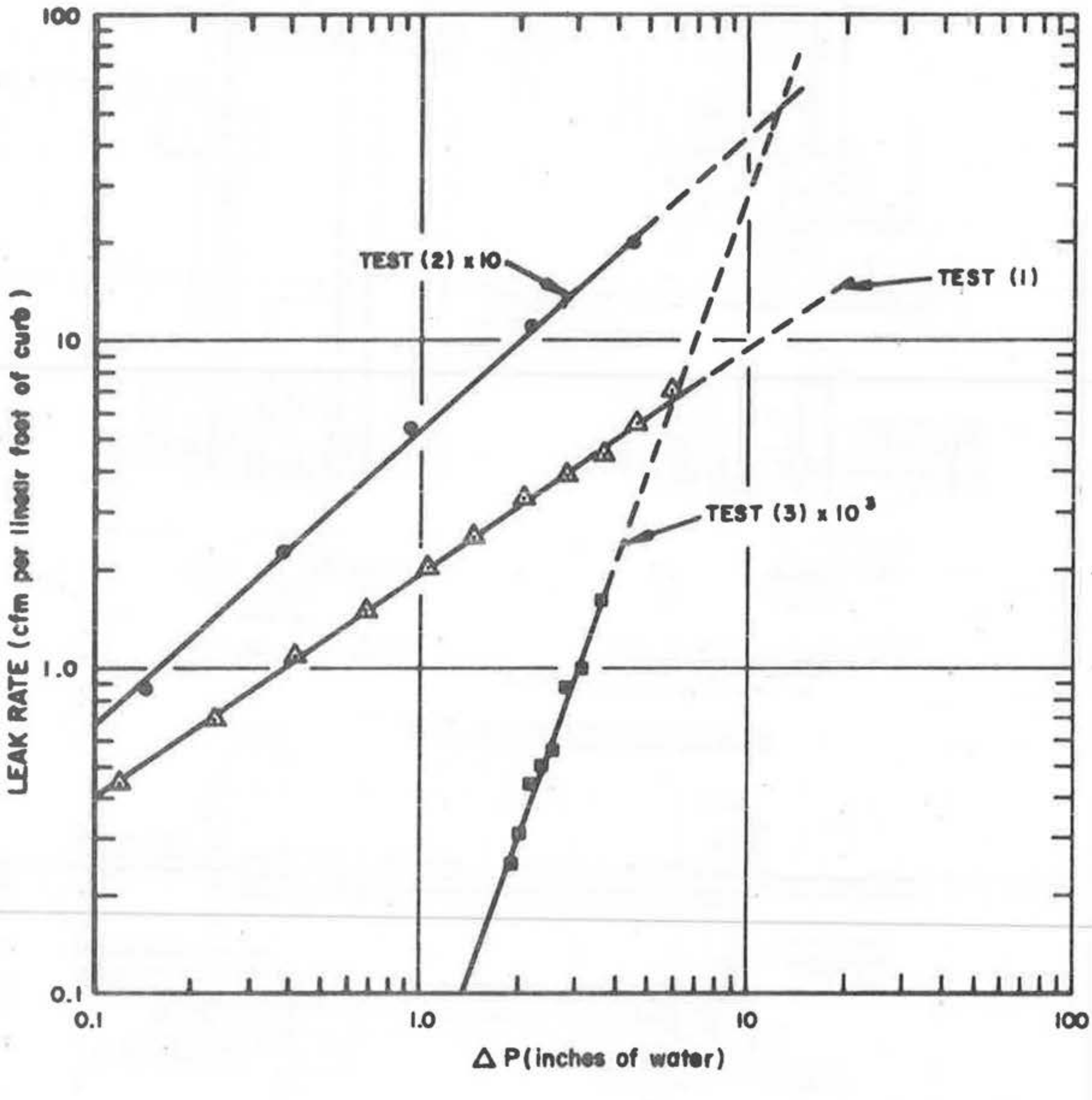
5) All leak paths through sheet metal screws and bolts can be reduced by using neoprene gaskets under metal washers. See LDS D-1.

6) Aging, weathering, and other characteristics that the sealing materials must meet for long-life reliability are found in the Appendix.

LEAKAGE DATA SHEET	Figure C-8a	Page 4 of 5



LEAKAGE DATA SHEET	Figure C-8b	Page 5 of 5



CONTENTS
LEAKAGE DATA SHEETS

D. MISCELLANEOUS

LEAKAGE DATA SHEET	No. D-1(1)	Page 1 of 3

COMPONENT

Gaskets, Rubber

PURPOSE

Determine the leakage characteristics of neoprene rubber gaskets as a function of gasket deformation

TEST SPECIMEN DESCRIPTION

Test and Mounting Design: See Figure D-1(1)

Description of Specimen: The test jig for testing the leakage of air through this gasket consists of a channel 1-1/2 in. wide to hold the gasket stock arranged in a rectangle 2 by 4 ft in size. The sealing edge consists of a 1/2-in. bar shaped to fit within the channel. The sealing edge is forced into the rubber gasket by tightening a number of bolts which are arranged around the test jig. The zero deformation setting is determined by tightening these bolts until the sealing edge is just making contact along the total length of gasket. The gasket is held in the channel and the corners are sealed with rubber cement.

Manufacturer and Type: Crown Products Co.; 1/4 by 1/2-in. neoprene gasket of durometer 66.

LEAK TEST DATA

Empirical Constants: Value for 12 ft of gasket

Deformation (in.)	Closure Pressure (psi)	Leak Rate Coefficients A	Leak Rate Coefficients B
0.035	75	0.13	0.034
0.075	200	0.043	0.037
0.112	335	0.010	0.025
0.150	510	0.0042	0.011
0.189	720	0.00091	0.0036

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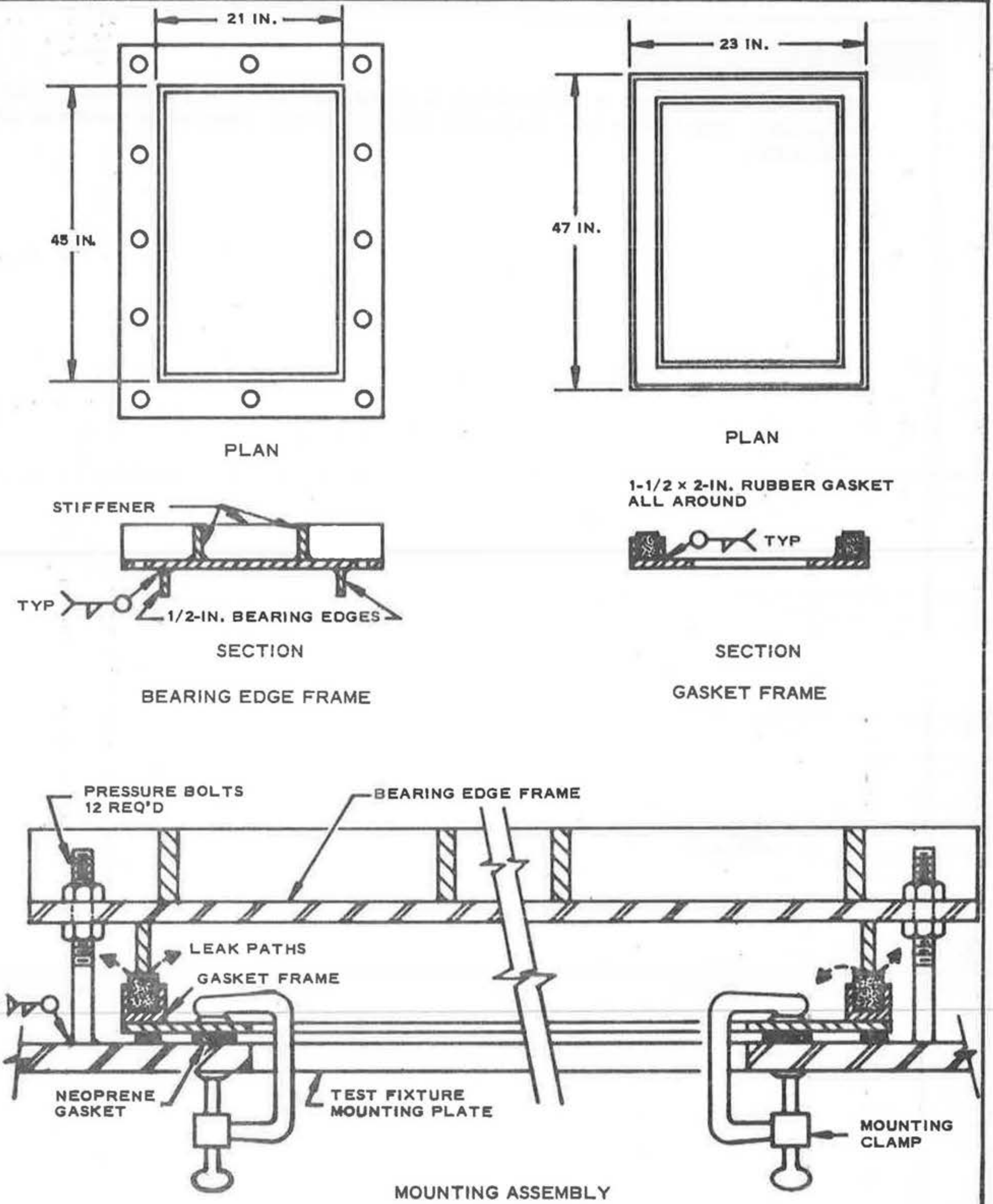
LEAKAGE DATA SHEET	No. D-1 (1)	Page 2 of 3

RECOMMENDATIONS

A softer rubber and a knife-edge bearing surface should be used where minimum leak rates are required and sufficient closure pressures are not available.

LEAKAGE DATA SHEET	Figure D-1(1)	Page 3 of 3



LEAKAGE DATA SHEET	No. D-1(2)	Page 1 of 3

COMPONENT

High-Temperature Gasket Materials

PURPOSE

Determination of air leakage through high-temperature gasket materials

TEST SPECIMEN DESCRIPTION

Test and Mounting Design: See Figure D-1(2)

Installation Procedure: The gasket materials are clamped in a device which simulates a closure: a gasket channel and knife edge. The knife edge compresses the gasket in the channel by means of calibrated springs. The springs and gasket are kept at a constant pressure for each test run. The specimens are tested with differential pressures up to 3 psig and compression forces of 10, 20, and 25 lb/linear in. All leak paths (except through gasket) are sealed with Thiokol.

Description of Specimen: (1) The Johns-Manville packing is composed of a core of loosely woven Inconel. This is covered with asbestos fibers which are coated with an Inconel foil. The outer layer is composed of fine nomel wires tightly braided to produce a finished packing. A 6-in. specimen was tested. (2) The Fiberfax ceramic fiber is made into a flexible 1/2-in. rope. A 5-in. specimen was tested.

Manufacturer: Inconel — asbestos gasket by Johns-Manville. Ceramic rope by the Carborundum Company.

LEAK TEST DATA

Empirical Constants: Value for 1-in. length

Inconel — asbestos packing:

1) Using a 10 lb/linear in. closing force
   A = 0.013   B = 0.076

2) Using a 20 lb/linear in. closing force
   A = 0.013   B = 0.076

3) Using a 25 lb/linear in. closing force
   A = 0.13   B - 0.076

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LEAKAGE DATA SHEET	No. D-1(2)	Page 2 of 3

Ceramic fiber rope:

1) Using a 10 lb/linear in. closing force
   $A = 2.76 \times 10^{-3}$ $B = 0$

2) Using a 20 lb/linear in. closing force
   $A = 2.2 \times 10^{-3}$ $B = 0$

3) Using a 25 lb/linear in. closing force
   $A = 1.95 \times 10^{-3}$ $B = 0$

Applicable Pressure Range: The air leakage data are applicable to pressures of at least 150 in. of water (6 psig).

Extrapolations: The data were obtained using air pressure up to 3 psig across the 5- and 6-in. specimens. Since the leak rate per linear inch is given, the data can be scaled up directly for the same diameter specimens.

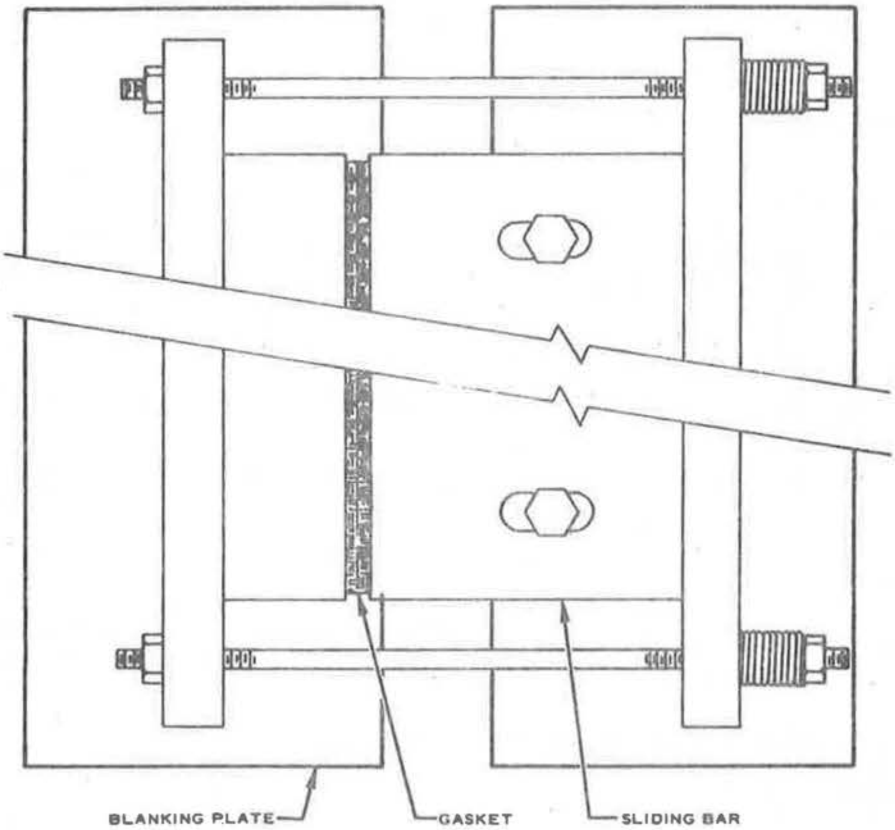
LIMITATIONS

All data were obtained with a constant compression force which is difficult to obtain in actual practice since the gasket meterials (especially the ceramic rope) have very little resilience even at normal room temperatures. The leakage characteristics at elevated temperatures are unknown.

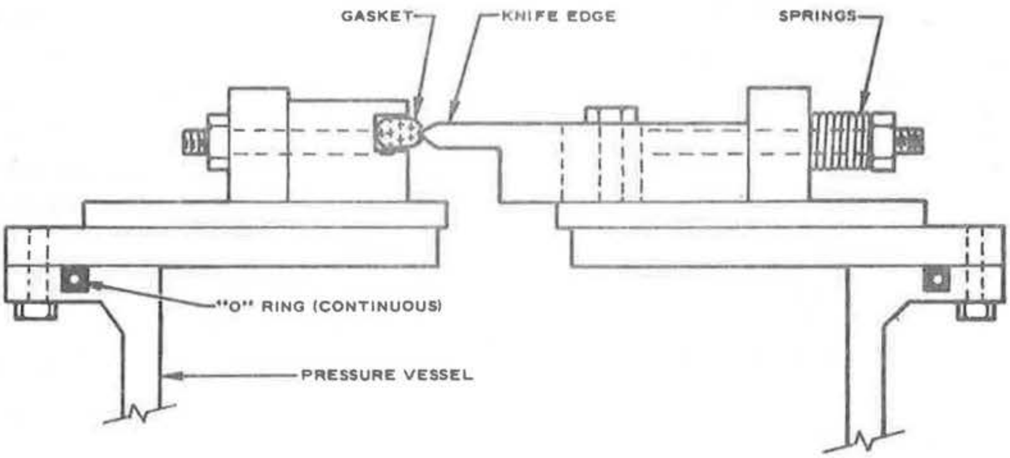
RECOMMENDATIONS

The leakage of the ceramic rope may decrease by a large factor by using a compression greater than 3 lb/linear in. and exchanging the knife edge for a convex-shaped edge of a radius equal to the gasket diameter. This will increase the likelihood of rupturing the material at the greater compression forces.

LEAKAGE DATA SHEET	Figure D-1(2)	Page 3 of 3



GASKET HOLDING DEVICE



SECTION SHOWING HOLDING PLATE, MOUNTING ASSEMBLY, AND VESSEL

LEAKAGE DATA SHEET	No. D-2	Page 1 of 12

COMPONENT

Models

PURPOSE

Model tests are conducted for the following purposes:

1) To establish means of predicting the leakage of a full-scale structure by designing it from results generated from component tests.
2) To determine methods for inspecting completed structures and evaluating the sources of leakage.
3) To find means of sealing leak paths built in by faulty construction and designs.
4) To use the leakage of a total structure as a means of evaluating individual component tests.
5) To establish guides for designing, inspecting, and testing full-size buildings from model experience.
6) To provide reasonable deductions about the potential economics of building a full-scale, low-leakage building using conventional materials.

TEST SPECIMEN DESCRIPTION

Metal Model: See Figure D-2a.

5-ply overhang roof, metal Robertson M-Type Q panel No. 8 on walls and a roof of Robertson M-Type Q fluted panel No. 3. The wall panels are cut to 5-1/2-ft lengths and left at the standard width of 2 ft. The roofing panel is cut to 7-ft lengths, and a 5-ply roofing of tar, felt, and gravel is applied. Panels are assembled in normal fashion with end laps meeting at steel girts for the 5- by 7-ft panels. The floor and curb are painted on the inside with 5-ply of a commercial epoxy concrete paint. A waster slab is also used which has a layer of pliofilm between the floor and waster slab. Dimensions of the model are such that the walls are 11 by 12 ft and the roof 14 by 14 ft. Thus, six 2-ft panels are on each wall below the girt, and six panels are above the girt. The roof has two sets of seven panels each on each side of the girt. All intersections are dimpled in order to obtain maximun contact. The volume of the model building is 1618 ft^3 with a wall surface of 528 ft^2, floor 122 ft^2, and roof 196 ft^2.

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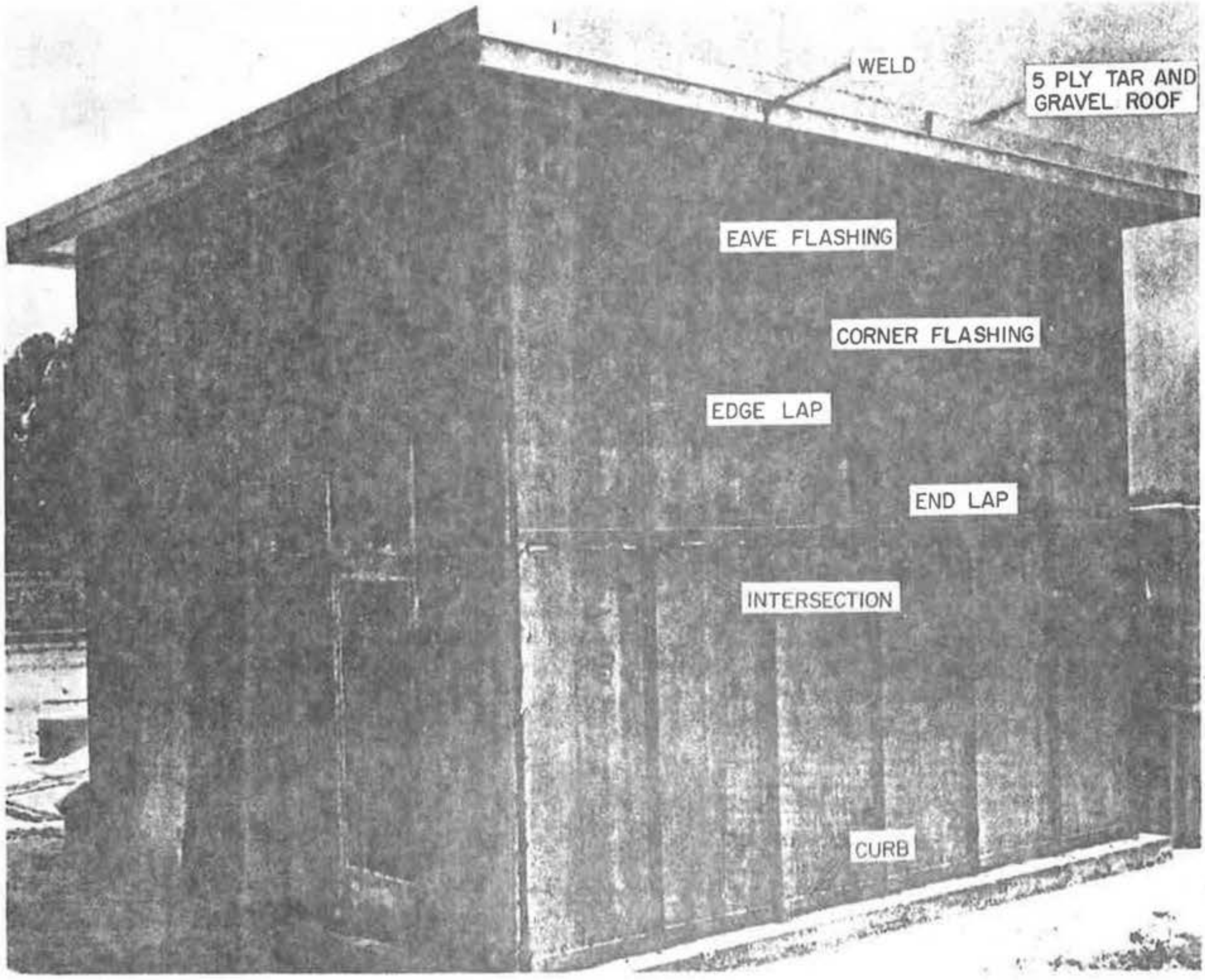
LEAKAGE DATA SHEET	Figure D-2a	Page 2 of 12



Two versions of the above model were made; these were parapet roof models on the same frame as the above model. The first roof was made of typical fluted panel and the eave-to-wall was designed as described in LDS C-2. No 5-ply roofing material of any type was used. The predominant leak was at the eave and at the flashings between the fluted panels and walls. In the second test, the fluted roof was removed and flat panels were placed on the roof. The resulting leakage rate was less than that of the first model because the rubber closures in the fluted panels were absent.

The final model was constructed first by removing the top section of the building and reinstalling the panels and roofing. The latter model is the one under discussion.

Test 1: Initial leak rate measurement

Test 2: After sealing observed leaks

Test 3: After 6-month exposure

Test 4: After 12-month exposure

Test 5: Exposed to overpressure of 6 in. H_2O

LEAK TEST DATA

Estimation of Leak Rate: The leakage through each of the major leak paths of each metal model was estimated from previous experiments by assuming that all specifications were carried out correctly. These leak paths and the method of leakage estimation are shown in Table D-2. The estimate of the total leak rate of each structure was calculated as the sum of the individual component leakages.

Leak Rate Coefficients: Value for metal model (overhang roof)

	Estimated		Measured	
Test	A*	B*	A*	B*
1	1.61	0.34	1.4	0.34
2	1.4	0.34	1.4	0.36
3			1.14	0.32
4				No significant change
5				Leakage increased 15%

*10^3 ft^3/day

LEAKAGE DATA SHEET	Table D-2	Page 4 of 12

METAL PANEL MODEL SAMPLE CALCULATION
ESTIMATION OF LEAKAGE AT 1-in. H_2O (P = 1 in.)

Leak Path	Unit	No. of Units	LDS No.	Leakage Coefficients			
				Per Unit (cfm)		Per Component (cfm)	
				A	B	C_1	C_2
End lap	ft	48	C-4(2)	1.6×10^{-4}	0	0.008	0
Edge lap							
Cont. crimp	ft	55	C-3(2)	2.3×10^{-6}	7.4×10^{-6}	-	-
Single caulk	ft	83	C-3(2)	6.8×10^{-3}	2.6×10^{-3}	0.565	0.215
Double caulk	ft	83	C-3(2)	6.9×10^{-4}	0	0.057	0
End-edge intersection							
Type 1	each	15	C-5(1)	1.6×10^{-2}	2.1×10^{-3}	0.240	0.032
Type 2	each	5	C-5(2)	7.4×10^{-3}	0	0.037	0
Sill angle to panel	ft	48	C-8	1.2×10^{-4}	0	0.006	0
Sill angle to concrete	ft	48	C-8	1.2×10^{-4}	0	0.006	0
Sheet metal screw	each	156	D-5	9.8×10^{-6}	1.2×10^{-6}	0.002	-
Floor-painted	ft^2	128	B-11(6)	1.8×10^{-8}	0	-	0
Corner flashing	ft	48	C-1	2.3×10^{-3}	0	0.110	0
Roof flashing	ft	48	C-1	1.2×10^{-3}	0	0.058	0
Roofing	ft^2	196	A-8	6×10^{-5}	0	0.012	0
Curb	ft	48	B-3	10^{-8}	0	-	0
				Total	cfm	1.10	0.25
					$10^3 ft^3/day$	1.61	0.34

LEAKAGE DATA SHEET	No. D-2	Page 5 of 12

TEST SPECIMEN DESCRIPTION

Concrete Model (Figure D-2b)

The concrete model is constructed of precast panels and overhang roof which have a minimum 28-day strength of 3750 psi and an internal pressure capability of 5 psig. The foundation and floor slab are separated by a continuous membrane of tar paper and hot tar (total 100 lb/100 ft^2). The minimum 28-day strength of the foundation and floor slab is 2500 psi. Neoprene rubber water stops (9 in. wide by 3/8 in. thick) are cast in the wall panels and in portions of the column area so that all seals in the joints are continuous. A combination thiokol plus ribbon sealer is used at the eave joint, and thiokol plus butyl rod at the curb joint.

A 5-ft 10-in. by 3-ft door frame is cast in one of the panels. Several 5/8-in. anchors are welded to the frame and cast in the concrete for added strength. A quick acting marine-type door, as described and tested in previous reports, is welded to the frame.

The concrete specifications for the model, with the exception of the door panel, is described below:

Cement (sacks/yd^3)	6.25
Cement (lb)	588
Sand (lb)	1259
No. 3 gravel (lb)	1888
Water (lb)	264
Water (gal/sack)	5.28
Slump (in., calculated)	2 to 4
Plastiment admixture per sack (oz)	2
Max water allowable (gal)	33.9

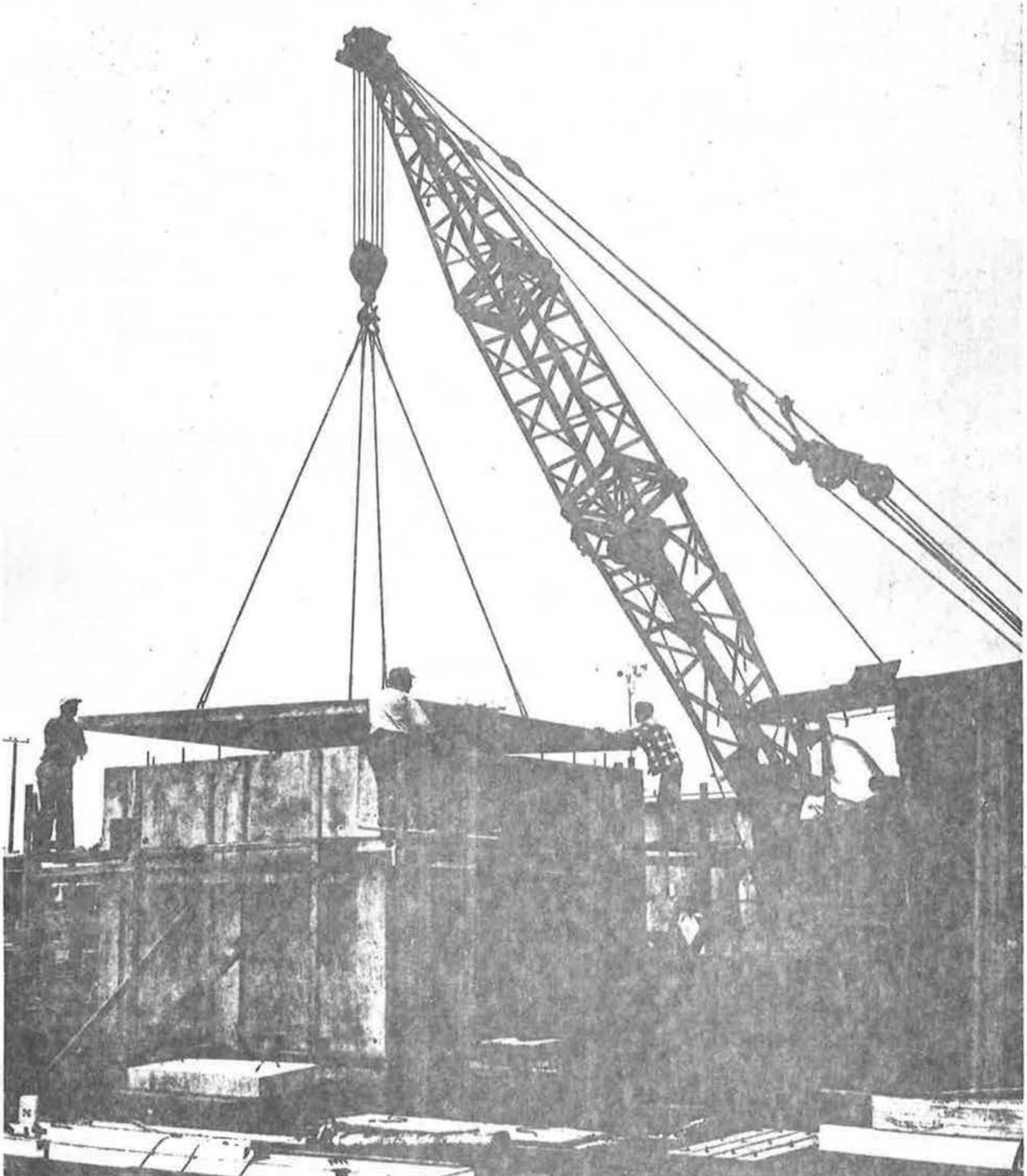
Quantities per yd^3 (aggregate surface dry)

The door panel is made from a nonshrink concrete to increase the tightness of the bond between the panel and door frame.

LEAK TEST DATA

Prediction of Leak Rate: By the use of information from previous experiments and, assuming that all specifications were carried out correctly, the major leak paths were used to estimate the total leakage of the structure. These leak paths are listed below:

LEAKAGE DATA SHEET	Figure D-2b	Page 6 of 12



LEAKAGE DATA SHEET	No. D-2	Page 7 of 12

Component	Units	No. of Units	Leak Rate per unit (cfm)	Total Leak Rate (cfm)	Total Leak Rate (ft^3/day)
Roof and 7 panels	ft^2	609	3.3×10^{-6}	2×10^{-3}	2.88
Door panel	ft^2	47	8×10^{-7}	3.7×10^{-5}	0.05
Floor	ft^2	162	3.3×10^{-6}	5.3×10^{-4}	0.77
Door frame joint	ft	17.75	1.3×10^{-4}	2.3×10^{-3}	3.30
Water stop joint a) in column b) in wall*	ft	80	3.0×10^{-3}	0.24	346.0
				Total	353.0

*See heading "Water Stop Seals in Concrete."

Testing of the Concrete Model: During construction of the concrete model, it became apparent that the model had to be tested in various phases in order to ascertain the leakage of each component and the reliability of the test cell data. This was due to known irregularities in construction which were different from those of test cell studies.

Testing the model shows the following data:

Phase	Description	Leak Rate (ft^3/day) at 1 in. H_2O
1	After door of model fitted and adjusted	2190
2	After eave resealed above panels (3 walls)	790
3	After eave resealed above panels (last wall)	790
4	After door frame sealed (polysulphide)	364
5	After door sealed at dogging area	360
6	After door seal removed, cleaned, and resealed	368
7	After painting inside walls with epoxy (1-yr exposure prior to painting)	6.33
8	After painting (6-mo. exposure after painting)	6.33

Unforeseen Events During Concrete Model Construction

1. Casting Water Stop Seal in Concrete

When the forms were removed from the walls, voids were found between the concrete and cast-in-place water stop. The voids existed in various degrees and, in some cases, for the total length of the panel. During the placement of the concrete (slump 3-1/2 in.), the water stop was not raised to allow the concrete to flow or to be pushed underneath the water stop, thus assuring satisfactory contact for a good seal. (See Figure D-2c.)

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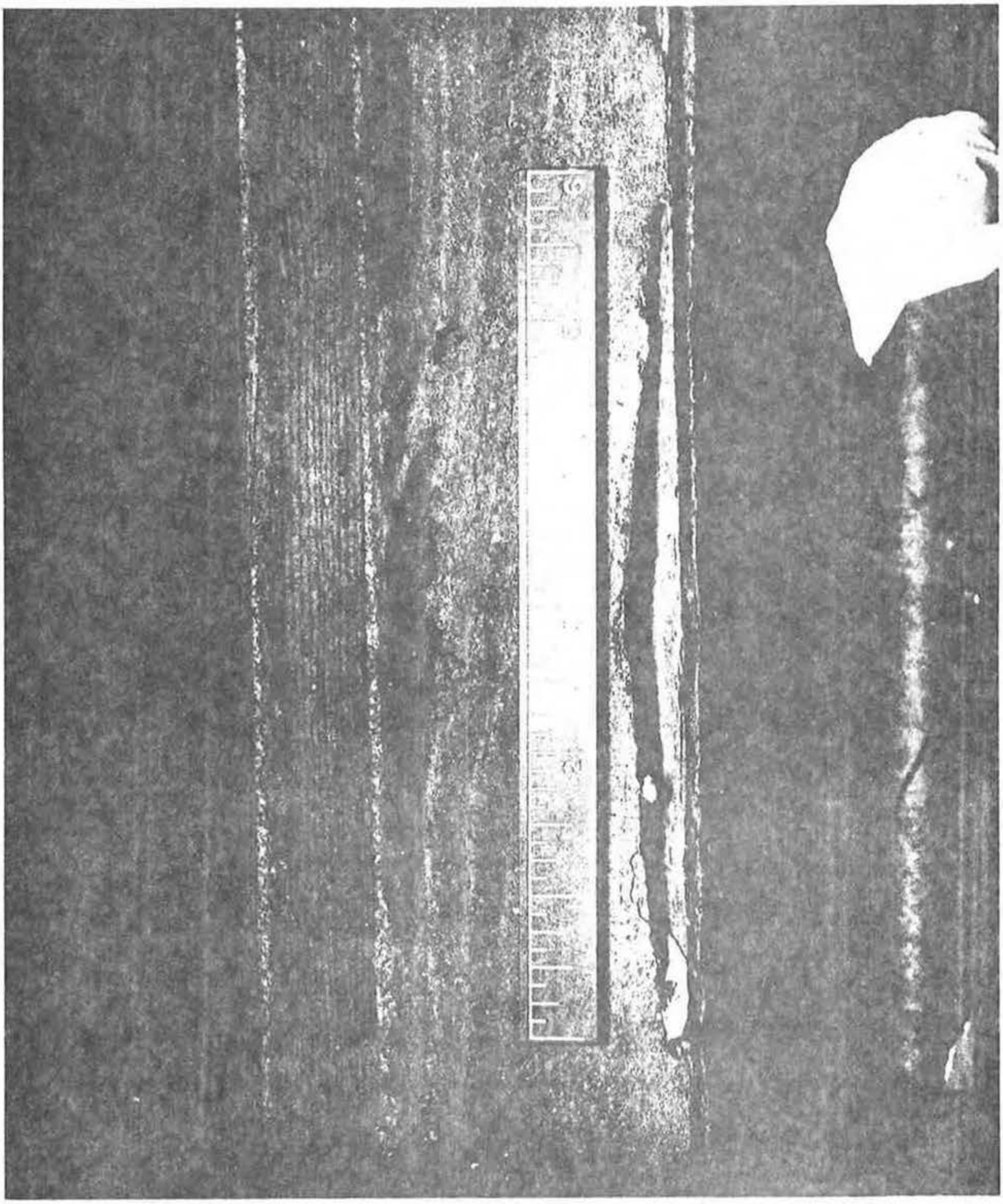
LEAKAGE DATA SHEET	Figure D-2c	Page 8 of 12



The door panel water stop seal was the exception. This panel was poured with a special aggregate to make nonshrink concrete, thus giving the concrete more flow (slump 5 in.) eventhough the water-to-cement ratio was the same as the above panels. The special aggregate is a pozzolith plastiment. No voids were found around the water stop area for the non-shrink concrete panel.

2. Installing Wall Panels

Just prior to lifting the panel in place, the curb surface was coated with polysulphide. After the panels were put in place and secured, the two-part polysulphide compound cured, resulting in a positive seal. After 2 to 3 days it was found that the wall anchor bolts (roof tiedown studs) would not match the roof pockets; consequently, most of the panels were shifted to a different position, which possibly resulted in a rupture of the curb seal. Nonshrink grout was packed between the wall panel and the curb after the panels were thought to be level.

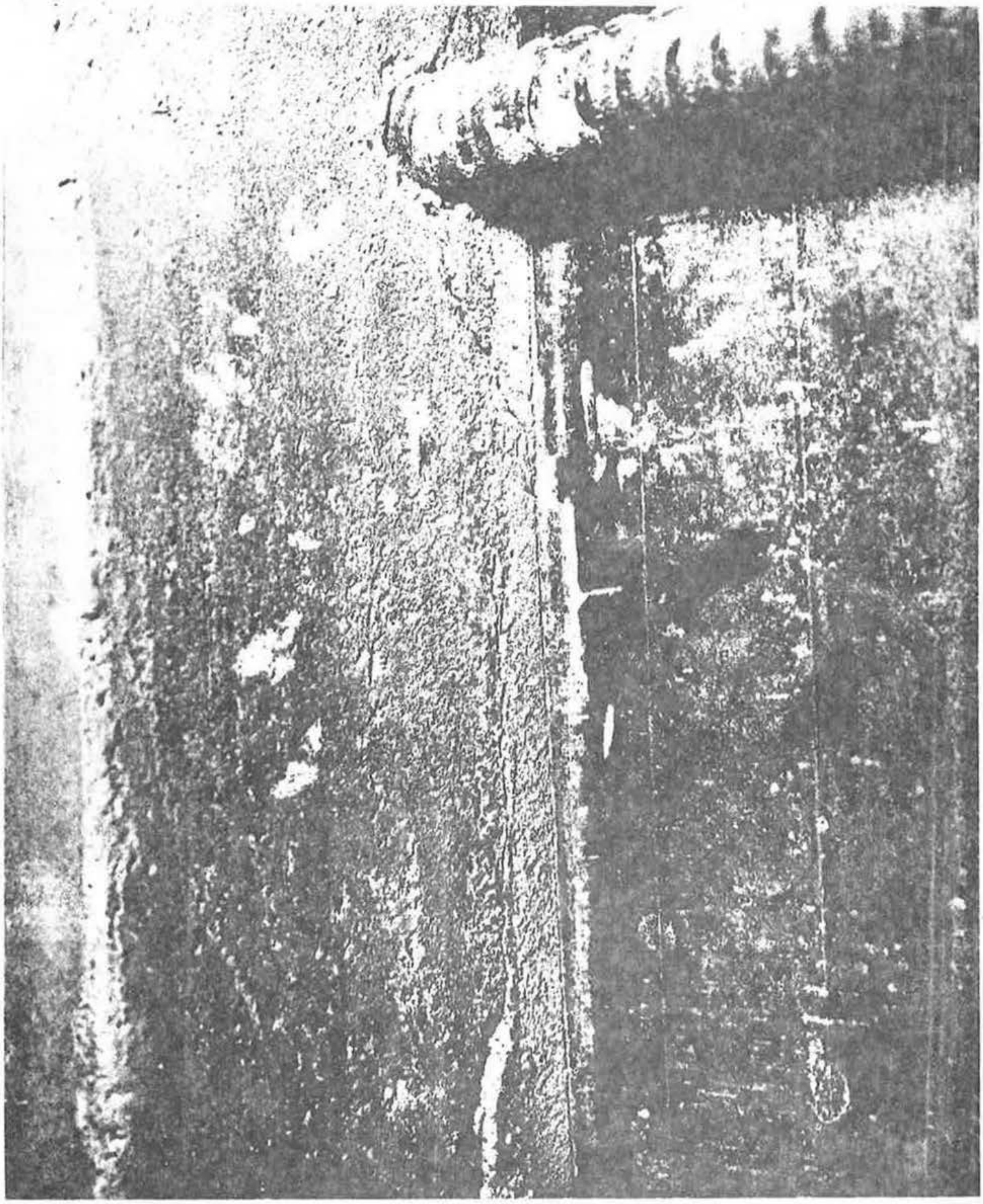
The design of the building required the reinforcement bars to protrude beyond the panels into the column area. This design necessitated the placement of the reinforcement bars next to the water stop. As the panels were tilted in place, the reinforcement bars from one panel jammed against the reinforcement bars of the adjacent panel. The bars were bent in order to make room, and large cracks formed between the bars and water stop. (See Figure D-2d.) Thus, there was a void on one side of the water stop due to improper forming and a crack on the opposite side of the water stop due to the re-bar movement. The defect was remedied by filling the void on the inside of the building with polysulphide, making a seal between the water stop and the uncracked portion of the concrete.

3. Installing and Repairing the Columns

The column forms were held together with slightly tapered tie rods which were removed after the concrete had set, thus leaving many holes in the columns. These holes were filled with a nonshrink grout. Although careful preparation and placement of the grout was emphasized, it was observed that the preparation of the grouting area between the panel and curb area did not include saturation with water as recommended by the manufacturer of the nonshrink grout. The manufacturer also stated that an amount of grout should be mixed which could be placed in about 20 min and that the grout should not be retempered by the addition of more water. Our contractor did not follow these recommendations and we are observing leaks in some of the 60-odd tie-rod holes.

When the forms were removed from the columns, several honeycomb areas were found which required chipping and refilling with a nonshrink grout. The area between the door panel and adjacent panel required nearly the full length of the column to be repoured with cement. For this section the repour was required for the inside of the column only. Since the slump of the column mix was 6 in., there should have been no honey-comb or void areas. It can only be concluded that the aggregate was too

LEAKAGE DATA SHEET	Figure D-2d	Page 10 of 12



large to flow around the many reinforcement bars or the pour was not adequately vibrated, or both.

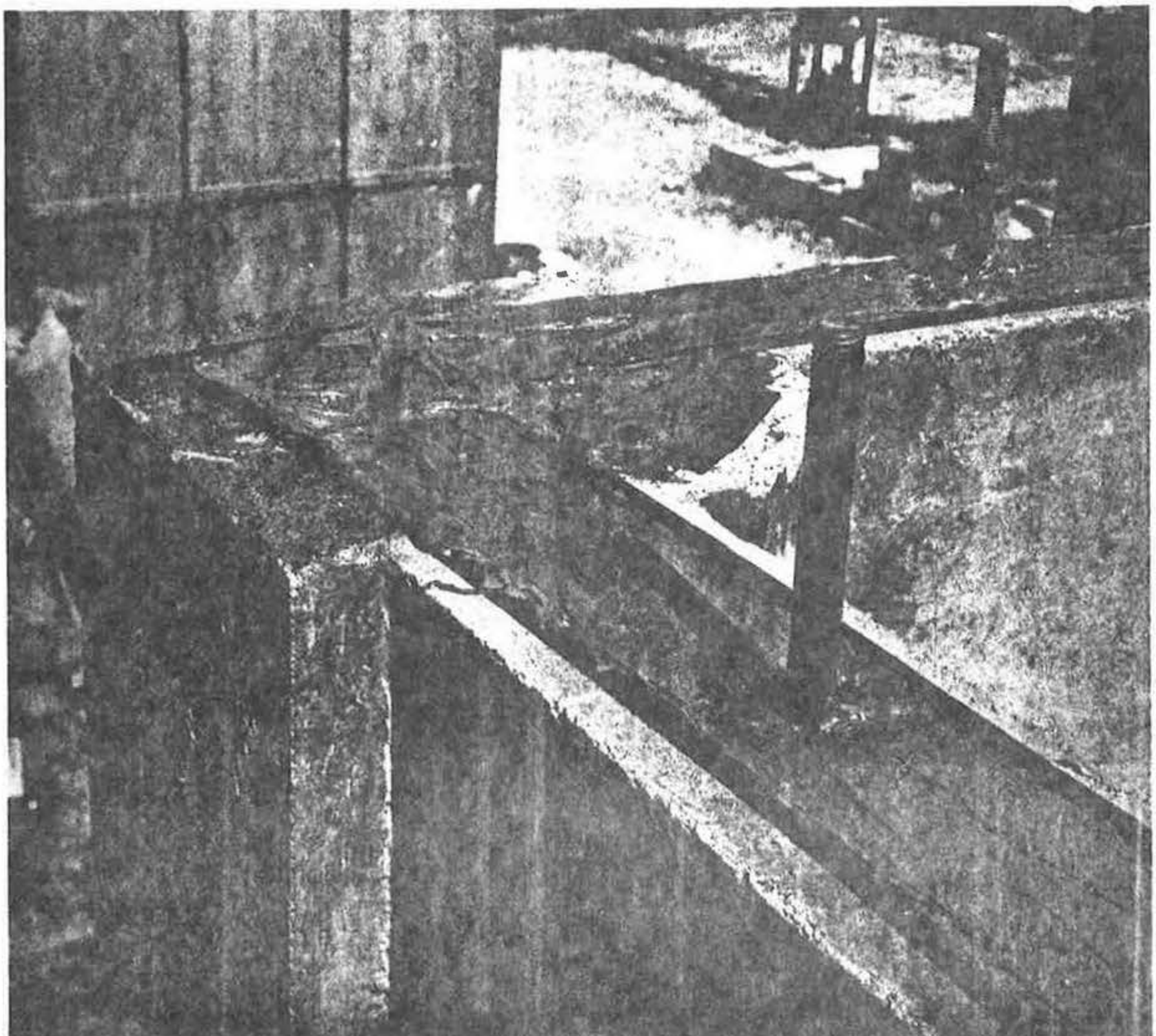
4. Installing the Roof Section

Prior to lifting the roof in place, a seal coat of 1/8 to 1/4 in. of polysulphide and polybutene ribbon seal strips was placed on top of the wall panels. (See Figure D-2e.) After the roof was lifted in place, it was apparent that there would be difficulty in tying down the roof so that there would be no gaps between the panels and roof. In one area an initial gap measured 1/2 in. which resulted in a need for additional sealant. As the anchor bolts were tightened, the gap was considerably reduced, but not enough (see data under "Testing of the Concrete Model"). An examination showed that the form surface was not level during the pour and thus the roof could not make a proper contact on all walls.

LIMITATIONS

1. The lack of reproducibility of model building tests compared to the component laboratory tests can be attributed to: (a) poor working habits of the modern workmen, and (b) the nonuniform physical nature of products, such as thin-gage metal panels, or aggregate size, moisture content, and mixing characteristics of concrete. The correct fitting of the edge lap in a metal building is especially difficult. Only uniform and undamaged panels can be used. Refer to individual Leakage Data Sheets for further discussions on limitations of individual components.
2. The term "air leak tightness" has a different meaning to each workman. Errors are compounded, mistakes are hidden instead of reported, and needless time is consumed on many nonessential tasks assumed by the workman in order to "improve the situation."
3. Many workmen are unfamiliar with the new sealants or new products used in concrete which results in improper interpretation of the manufacturer's instructions and improper application of these products.

LEAKAGE DATA SHEET	Figure D-2e	Page 12 of 12



LEAKAGE DATA SHEET	No. D-3	Page 1 of 3

COMPONENT

Orifice and Crack Test, Calibration

PURPOSE

Determine the validity of summing experimental data for parallel leakage, and to examine the significance of the coefficients A and B

TEST SPECIMEN DESCRIPTION

Test and Mounting Design: See Figure D-3.

Description of Specimen:

Test 1: Crack specimen constructed from four flat plates welded together to form a crack 0.005 by 2.75 in., 3.0 in. in depth.

Test 2: A 0.004-in. diam orifice specimen constructed from a 1-mil steel foil and sealed to a 1/4-in. diam opening. The diameter of the orifice is determined by use of a high-powered microscope.

Test 3: The same orifice (0.004-in. diam) is placed in parallel with a crack 0.005 by 0.5 in., 8 in. in depth.

Installation Procedure: The specimens are mounted on a 15-in. diam test plate, using a gas-tight continuous weld for the crack specimen and a thread seal and epoxy for the orifice specimen, either singly or in parallel.

LEAK TEST DATA

	Constants – Value for each specimen	
Test 1: Crack Specimen		
Experimental data	$A = 4.3 \times 10^{-3}$	$B = 0$
Theoretical	$A = 4.5 \times 10^{-3}$	$B = 0$
Test 2: Orifice Specimen		
Experimental data	$A = 0$	$B = 2.1 \times 10^{-4}$
Theoretical	$A = 0$	$B = 2.0 \times 10^{-4}$
Test 3: Combination Crack and Orifice		
Experimental data	$A = 2.3 \times 10^{-3}$	$B = 0.24 \times 10^{-3}$

LEAKAGE DATA SHEET	No. D-3	Page 2 of 3

Test 3: (Continued)

Theoretical $A = 3.1 \times 10^{-3}$ $B = 0.2 \times 10^{-3}$

Orifice Equation (Theoretical)

$$q(cfm) = 1.26 \times 10^{-5} d^2 P^{1/2} \text{ for laminar flow}$$

where

d is diameter of orifice in mils, P is pressure differential in inches of water, 1.26 is the constant $ft^3/[min\text{-}mils^2 P^{1/2}]$ combining the orifice coefficient, gravitational constant, and density of the air.

Crack Equation (Theoretical)

$$q(cfm) = 3.9 \times 10^4 (b^3 L/x) P \text{ for laminar flow.}$$

where

b is crack width in in., L is crack length in in., x is wall thickness in in., P is pressure differential in in. of water, 3.9 is the constant $ft^3/min\text{-}P$ combining the gravitational constant and viscosity of the air.

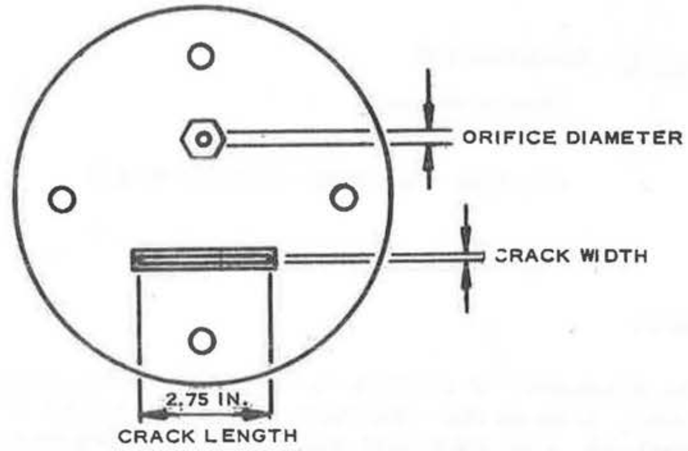
Applicable Pressure Range: 0 to 160-in. pressure differential.

LIMITATIONS

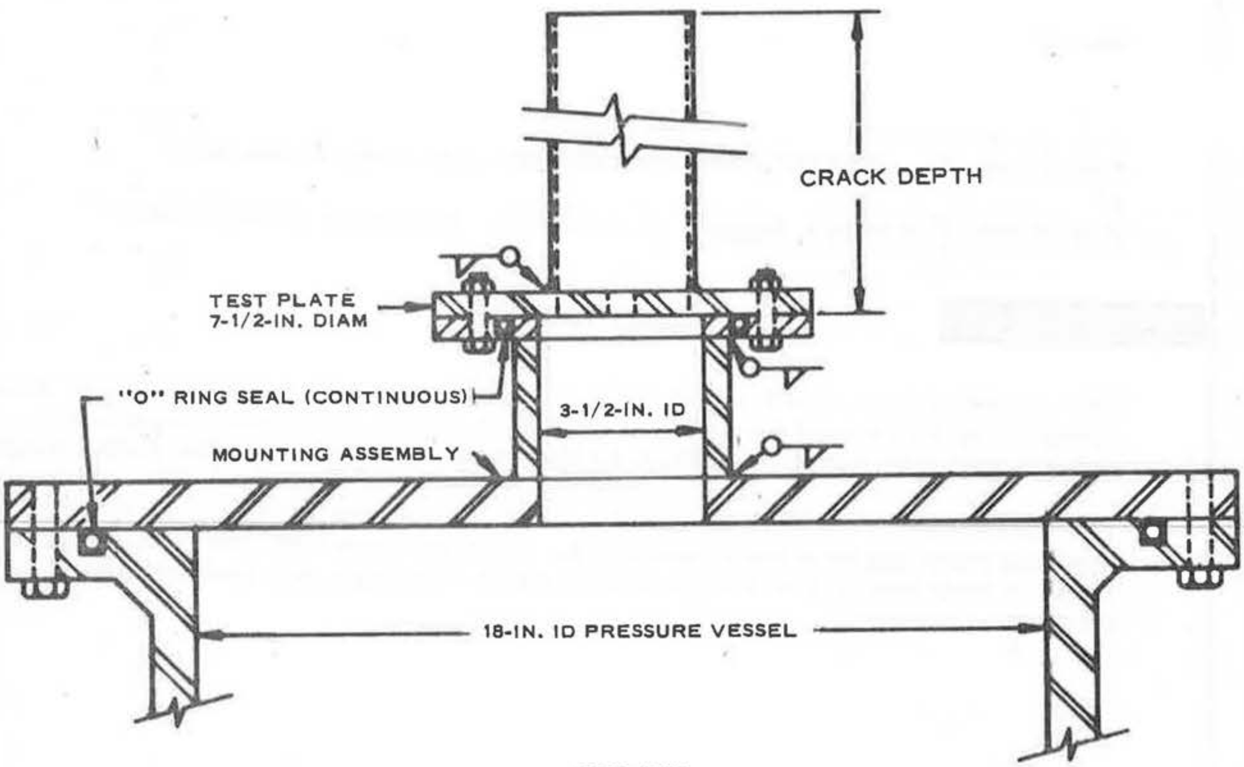
The combination crack and orifice experiment of Test 3 has not been completely validated since the crack was never measured separately. It is believed that some variation of the width existed over the 8-in. length.

The coefficients A and B can be used to estimate the total size of the opening existing in a test specimen. It is obvious that most of the specimens tested which are conventional have openings per foot of tested joint like those above.

LEAKAGE DATA SHEET	Figure D-3	Page 3 of 3



TOP PLAN – ORIFICE AND CRACK TEST PLATE
(MOUNTING ASSEMBLY AND PRESSURE VESSELS NOT SHOWN)



SECTION

(SHOWING TEST PLATE, MOUNTING ASSEMBLY, AND PRESSURE VESSEL)

LEAKAGE DATA SHEET	No. D-4(1)	Page 1 of 3

COMPONENT

Seals, Inflatable

PURPOSE

Determine the air leakage characteristics of various types of inflatable seals

TEST SPECIMEN DESCRIPTION

Test and Mounting Design: See Figure D-4(1).

Description of Specimen: Three seal bead configurations are tested (square bead, round bead, tee bead).

Installation Procedures: The seals are installed between two steel plates with metal spacers and manifolds. The pressure regions are shown in Figure D-4(1).

Leak Path Description: The leak path is between the bead head and cover plate only.

Type: Seals are standard products made for the aircraft industry.

LEAK TEST DATA

RESULTS*

Type of Seal	N_2 Seal Inflation Pressure (psig)	Change in Vacuum (ΔP) (μ)	Leak Rate ft^3/24 hr/in. of seal (x 10^{-5})
"O" ring bead	51	200	71
"O" ring bead	51	650	61
"O" ring bead	60	448	31
"O" ring bead	60	450	45
"O" ring bead	60	372	27
"O" ring bead	60	398	20
1/4-in. sq bead serrated edge	40	1046	89
1/4-in. sq bead serrated edge	40	407	30

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LEAKAGE DATA SHEET	No. D-4(1)	Page 2 of 3

RESULTS* (Continued)

Type of Seal	N_2 Seal Inflation Pressure (psig)	Change in Vacuum (ΔP) (μ)	Leak Rate ft^3/24 hr/in. of seal (x 10^{-5})
1/4-in. sq bead serrated edge	50	282	16
1/4-in. sq bead serrated edge	50	453	32
1/4-in. sq bead serrated edge	58	351	7
1/4-in. sq bead serrated edge	58	423	21
1/4-in. sq bead serrated edge	60	253	15
1/4-in. sq bead serrated edge	60	275	16
Tee bead head	40	550	2640
Tee bead head	45	128	6
Tee bead head	45	168	6
Tee bead head	50	124	6
Tee bead head	50	124	6
Tee bead head	55	116	6
Tee bead head	55	110	5
Tee bead head	60	142	7
Tee bead head	60	123	6

*For further information, see NAA-SR-2544

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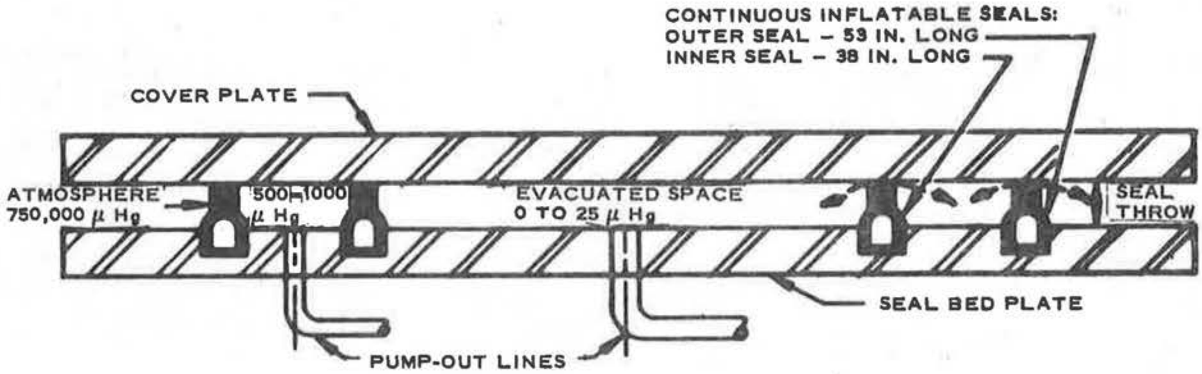
LEAKAGE DATA SHEET	Figure D-4(1)	Page 3 of 3



SECTION THROUGH SMALL STAND

LEAKAGE DATA SHEET	No. D-4(2)	Page 1 of 3

COMPONENT

Polyurethane Foam Seal — Impregnated with Asphaltic Bitumen

PURPOSE

To determine its air leakage properties at various air pressures as a percentage of the original volume under compression

TEST SPECIMEN DESCRIPTION

Test and Mounting Design: See Figure D-4(2)

Installation Procedure: The 13-in. specimen is mounted between two bars and sealed to the bars at the extreme ends with polybutene caulk. The bars are slotted and attached to the blanking plate with studs, allowing the seal to be compressed to any percent of its original volume. The bar is sealed to the blanking plate with polybutene caulk.

Description of Specimen: The joint sealer is polyurethane foam impregnated with asphalt bitumen. The test specimen is 13 by 1 by 3/4 in. with the 13 by 1-in. surface positioned against the angle iron.

Manufacturer: Asbiton (Canada) Limited

LEAK TEST DATA

Empirical Constants: Value for 1 ft of seal

Compressed to Percent of Original Volume (deformation)	Coefficients A	Coefficients B
25	4.6×10^{-2}	2.4×10^{-2}
23	3.1×10^{-2}	3.7×10^{-2}
21	2.9×10^{-2}	3.0×10^{-2}
18.7	6.0×10^{-3}	9.2×10^{-3}
16.7	1.4×10^{-3}	2.2×10^{-4}
14.7	1.0×10^{-4}	4.9×10^{-6}
12.5	0	0

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LEAKAGE DATA SHEET	No. D-4(2)	Page 2 of 3

Applicable Pressure Range: The applicable pressure range depends on the compression forces required to reduce the volume of the seal (see Limitations). When the polurethane foam is compressed for a no-leak seal, the applicable pressure range is probably greater than 50 psi.

Extrapolations: The test data can be extrapolated directly.

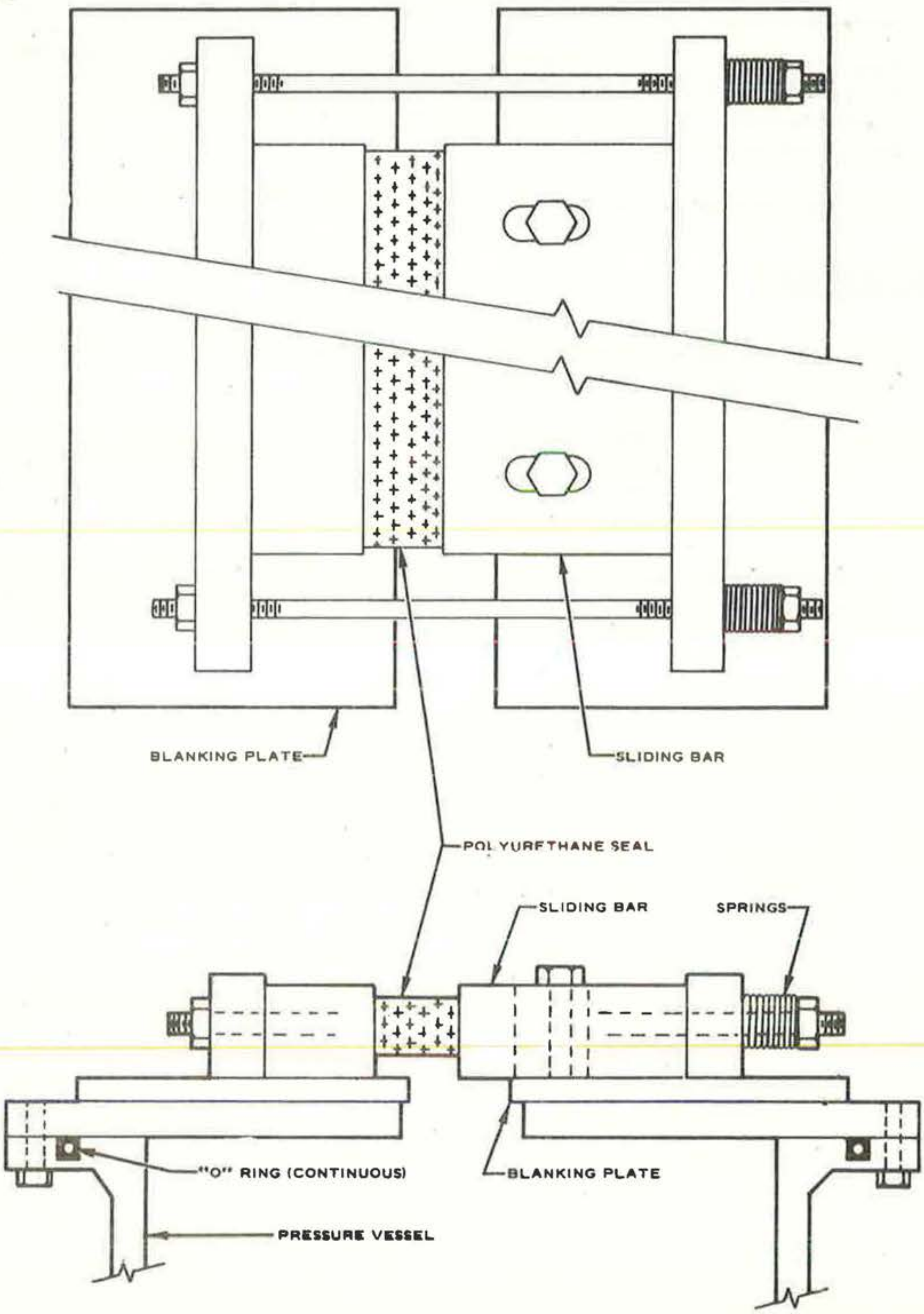
LIMITATIONS

The compression forces required to reduce the "Compriband" to a percentage of its original volume are as follows:

30%	9.7 psi
20%	17.5 psi
15%	52.5 psi
10%	200.0 psi

In order for the seal to obtain a minimum air leak characteristic, the compression forces must be between 52 and 200 psi. This probably limits the usage of the material to special applications.

LEAKAGE DATA SHEET	Figure D-4(2)	Page 3 of 3



LEAKAGE DATA SHEET	No. D-5	Page 1 of 3

COMPONENT

Sheet Metal Screws

PURPOSE

Study of air leakage through standard types of sheet metal screws and through improved installations

TEST SPECIMEN DESCRIPTION

Test and Mounting Design: See Figure D-5.

Description of Specimen: A series of eight galvanized sheet metal screws are used in each test. The washers are composed of a partially concave metal and neoprene combination and are not combined with the screws as one unit.

Installation Procedure: The screws fasten two layers of 18-gage galvanized sheet metal to a steel backing 1/4-in. thick. The screws are tightened until the concave washers become straight, thereby obtaining an even pressure along the total neoprene-to-metal surface. The proper torque is under investigation.

Leak Path Description: Since all edges of the sheet metal were sealed, the leak paths were (1) along the threads of the screw and between the washer and screw, and (2) along the threads of the screw and between the neoprene and sheet metal.

Manufacturer and Type: Fabricated Products, Inc.; Type A, 3/4-in. long galvanized steel neoprene top seal fasteners.

LEAK TEST DATA

Empirical Constants: Value for one screw

Test	Design	Leak Rate Coefficients
1	Rubber-backed steel washers	$A = 5 \times 10^{-5}$, $B = 0.68 \times 10^{-5}$
2	Vulcatex and brass washers	$A = 28 \times 10^{-6}$ $B = 10 \times 10^{-6}$
3	Vulcatex and rubber-backed washers	$A = 3 \times 10^{-8}$

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LEAKAGE DATA SHEET	No. D-5	Page 2 of 3

Test	Design	Leak Rate Coefficients
4	Rubber-backed washer and rubber seal strip between panel and girt	$A = 9.8 \times 10^{-6}$ $B = 1.2 \times 10^{-6}$
5	Vulcatex, rubber-backed washers and rubber seal strip between panel and girt	$A = 3 \times 10^{-8}$

Applicable Pressure Range: The data are applicable up to the design pressure of the building.

Extrapolations: The data can be extrapolated directly.

LIMITATIONS

In actual practice, when the holes are drilled through the sheet metal and girt, many sharp burrs are formed which damage the neoprene seal as the sheet metal screw is tightened.

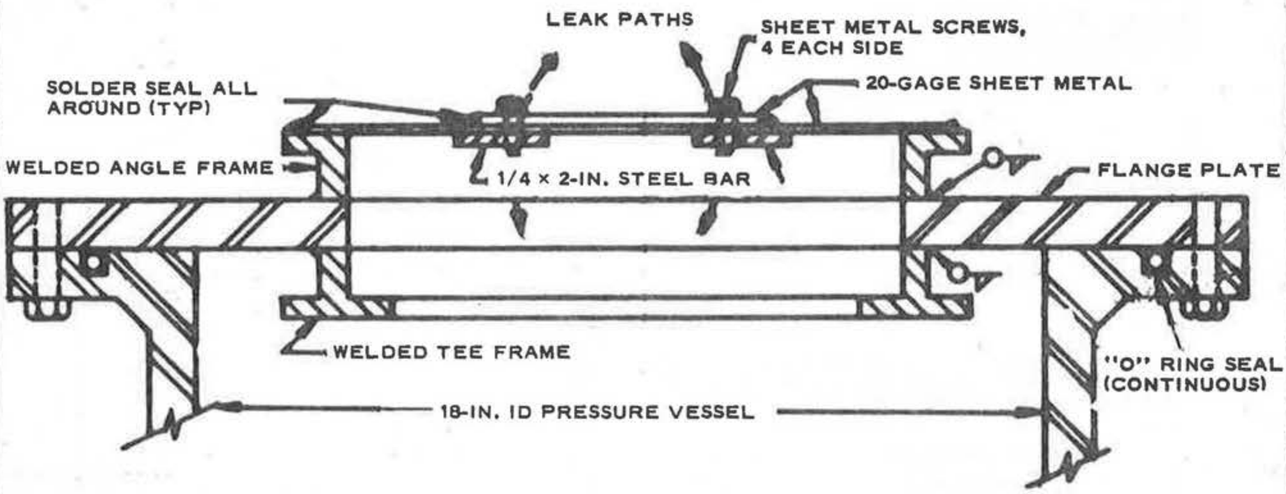
Usually a power tool is used to fasten the screw to the girt, in which case some screws are tightened beyond the rupture point of the neoprene or are not tightened sufficiently to have adequate contact between the neoprene and sheet metal. The reason for this is that occasionally the holes are drilled at an angle or through that portion of the girt that is of different thickness, and occasionally some of the screws have an excess amount of galvanizing which makes the tightening of the screw difficult. If the power tool is adjusted for the "worst case," the majority of the screws will be so tightened as to cause a complete failure of the neoprene seal.

The screws have to be fastened by use of the "sight method" whereby the neoprene rubber is depressed the exact amount. However, this is normally time-consuming since any tool used hides the screw and washer; this requires frequent removal of the tool.

RECOMMENDATIONS

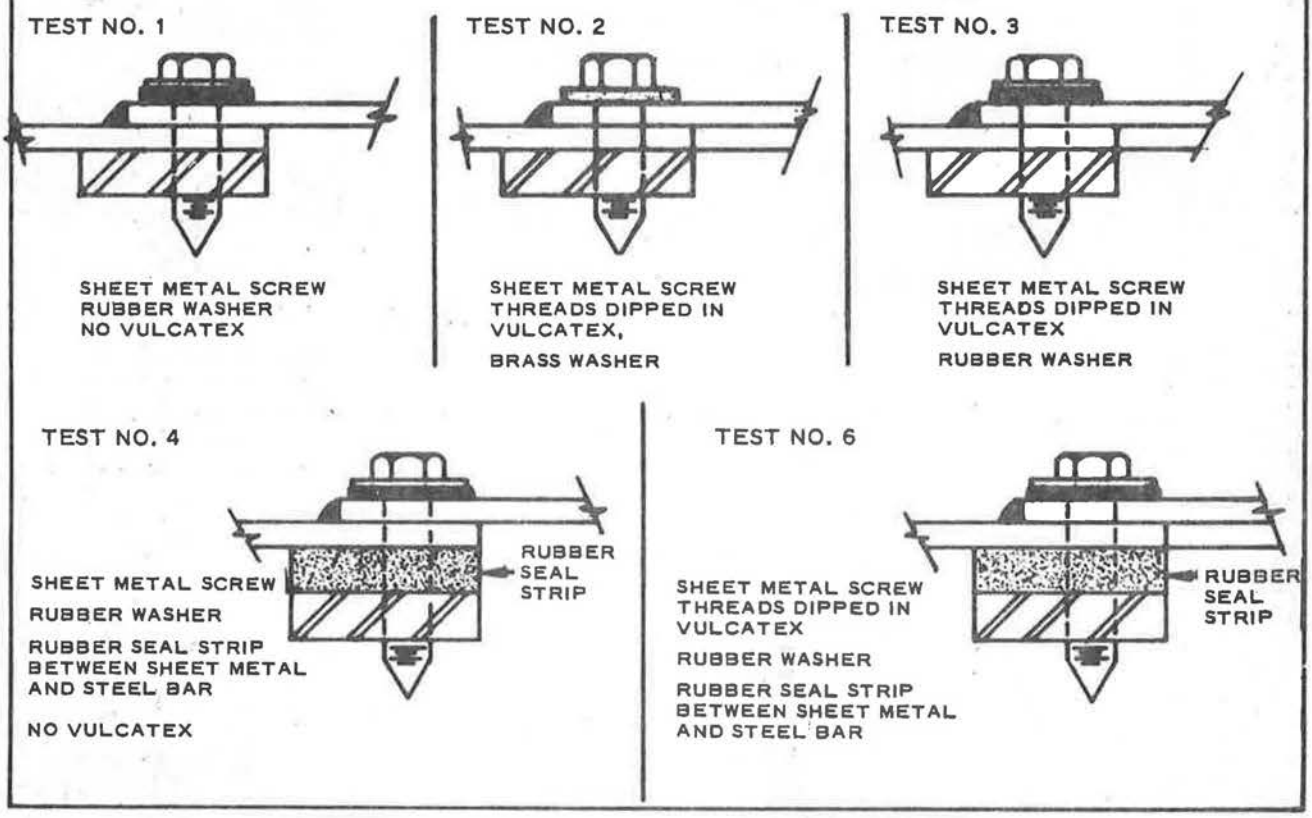
1. Use a deburring tool with the drill.
2. Use a sheet metal screw in which the metal washer is cup-shaped and an integral part of the screw. The neoprene gasket is sealed to the inside of the cup and is only compressed a definite amount even when excess force is used on the screw. This also removes the major leak source in which the placing of a caulking compound around the screw is not required.

LEAKAGE DATA SHEET	Figure D-5	Page 3 of 3



SECTION THROUGH GENERAL TEST ARRANGEMENT

SHEET METAL SCREW DETAILS:



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LEAKAGE DATA SHEET	No. D-6	Page 1 of 3

COMPONENT

Tapes, Pressure Sensitive

PURPOSE

Determination of air leakage through tapes which may be used to reduce air leakage along cracks, joints, etc.

TEST SPECIMEN DESCRIPTION

Test and Mounting Design: See Figure D-6.

Leak Path Description: The leak paths are through the tape backing and between the adhesive and sealing surface. During test, stainless steel was used as the surface.

Manufacturer and Type:

Permacel; No. 11GT217, Metal Foil Tape, 2-in. width.
Dutch Brand; No. 357 silver, waterproof cloth tape, 1-in. width.
Arno Pipe Wrap Tape; polyethylene backing, 2-in. width.

LEAK TEST DATA

Empirical Constants: Value for crack, 15-1/2 in. long by 1/4 in. wide

1. Permacel
   a. Aluminum backing: $A = 2.0 \times 10^{-8}$ $B = 0$
   b. Between adhesive and steel sealing surface: $A = 1.7 \times 10^{-4}$ to 5.2×10^{-6} $B = 0$
   c. Total: $A = 1.7 \times 10^{-4}$ to 5.2×10^{-6} $B = 0$
2. Dutch Brand
   a. Cloth paper backing: $A = 8.0 \times 10^{-8}$ $B = 0$
   b. Between adhesive and steel sealing surface: $A = 1.2 \times 10^{-6}$ $B = 0$
   c. Total: $A = 1.2 \times 10^{-6}$ $B = 0$

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3. Arno Pipe Wrap Tape
   a. Through polyethylene backing:
      $A = < 10^{-9}$ (no detectable leakage)
   b. Between adhesive and steel sealing surface:
      $A = -0.75 \times 10^{-4}$ $B = 6.0 \times 10^{-4}$
   c. Total: $A = -0.74 \times 10^{-4}$ $B = 6.0 \times 10^{-4}$

Applicable Pressure Range: The test pressures are not above 10-in., and in each case the pressure tends to force the tape against the sealing surface. (See Limitations.)

Extrapolations: The tape covered an opening 1/4 by 15-1/4 in., using steel as the sealing surface. The data can be extrapolated to any length.

LIMITATIONS

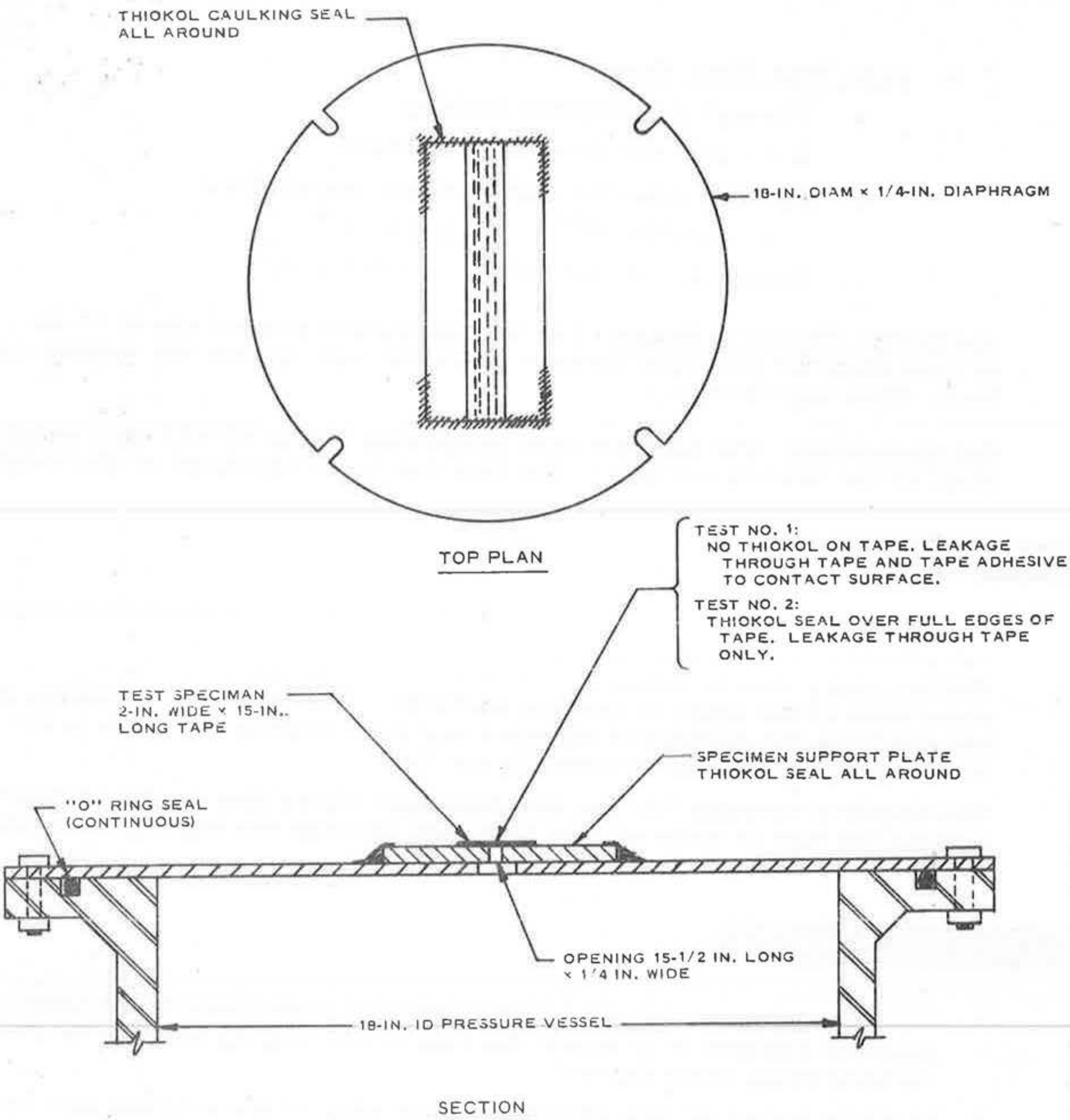
The deterioration of the backing and adhesive due to moisture, sunlight, and weather is unknown. The resistance to crack, peel, dry out, becoming brittle, tear, etc. is unknown. Another unknown factor is the adhesive properties of the tapes to various surfaces. The difference between the two readings for Al-backed adhesive and steel sealing surfaces is due to the "ironing out" of the wrinkles in the tape.

The negative constant "A" for the Arno tape shows that as the pressure against the tape is reduced, the leak path between the adhesive and sealing surface becomes greater.

RECOMMENDATIONS

1. Since the greatest variable is the adhesive properties of the tape, a possible solution is to attach the tape to the sealing surface by use of a thermosetting resin (epoxy).
2. Multiple layers of tape placed over the edge of the original tape could effectively reduce leakage. Series leakage would occur through the ends and thus reduce leakage by one-half for each tape added.

LEAKAGE DATA SHEET	Figure D-6	Page 3 of 3



SEALING TAPES

GENERAL TEST ARRANGEMENT

LEAKAGE DATA SHEET	No. D-7	Page 1 of 2

COMPONENT

Orifice, Capillary, and Concrete – Relation to Critical Flow

PURPOSE

To establish the limits of the pressure range for which the empirical coefficients A and B are valid in the equations

$$q_c = AP \quad ,$$

and

$$q_o = BP^{1/2}$$

where

q_c = volumetric leak rate of capillary,

q_o = volumetric leak rate of orifice, and

P = pressure differential across specimen.

TEST SPECIMEN DESCRIPTION

A number of experiments are performed using capillary, orifice, and porous types of leak paths. The upstream and downstream pressure differences are increased so that the ratio of downstream (P_o) to upstream (P_i) pressure exceeds the critical pressure ratio. The experiments are conducted in the small test cell by either leaving the upstream at a constant barometric pressure and evacuating the downstream portion of the cell or by increasing the upstream pressure and keeping the downstream pressure constant. Observations of the variation of pressure differential with time are then made and recorded.

LEAK TEST DATA

The change of pressure differential with time was computed as a function of pressure differential, and the empirical constants A and B were again computed. The results show that the equations are valid when $P_o/P_i \geq 0.7$

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for both the capillary and orifice. When $P_o/P_i \leq 0.53$ for the capillary and orifice, the flow is critical and the leak rates are directly proportional to the upstream pressure. No relationship has been found for the turbulent region ($0.53 < P_o/P_i < 0.7$).

Cracks in concrete have flow characteristics similar to the capillary and crack combination leak paths and enters the turbulent region at nearly the same pressure ratios. Maximum air pressure experiments with 3-1/2-in. thick concrete show that the following equation is valid for internal pressures up to at least 4 atmospheres.

$$q = \frac{am(P_i - P_o)}{\mu} \times \frac{\overline{P}}{P_i} ,$$

where

q = volumetric leak rate,

a = area of specimen under test,

m = permeability coefficient,

P_i = inside pressure (upstream),

P_o = outside pressure (downstream),

$\overline{P} = 1/2(P_i + P_o)$,

$\overline{P}/P_i$ = compressibility factor, and

μ = viscosity of air.

LEAKAGE DATA SHEET	No. D-8	Page 1 of 3

COMPONENT

Water Vapor and Concrete

PURPOSE

To determine the flow rate of water vapor through concrete at various temperatures

TEST SPECIMEN DESCRIPTION

Test and Mounting Design: See Figure D-8a.

Description of Specimen: The specimen is 2 ft by 4 ft by 6 in. reinforced concrete of the mix described in LDS B-1.

Installation Procedure: The concrete block is painted around the edge with several coats of epoxy. Polybutene sealant is used to seal the concrete to the pressure vessel. Fill and drain lines are included in order to periodically weigh the loss of water in the system. Heater lines are installed to vary the temperature of the vessel. Temperature measurements are determined by four temperature sensors located in the vessel.

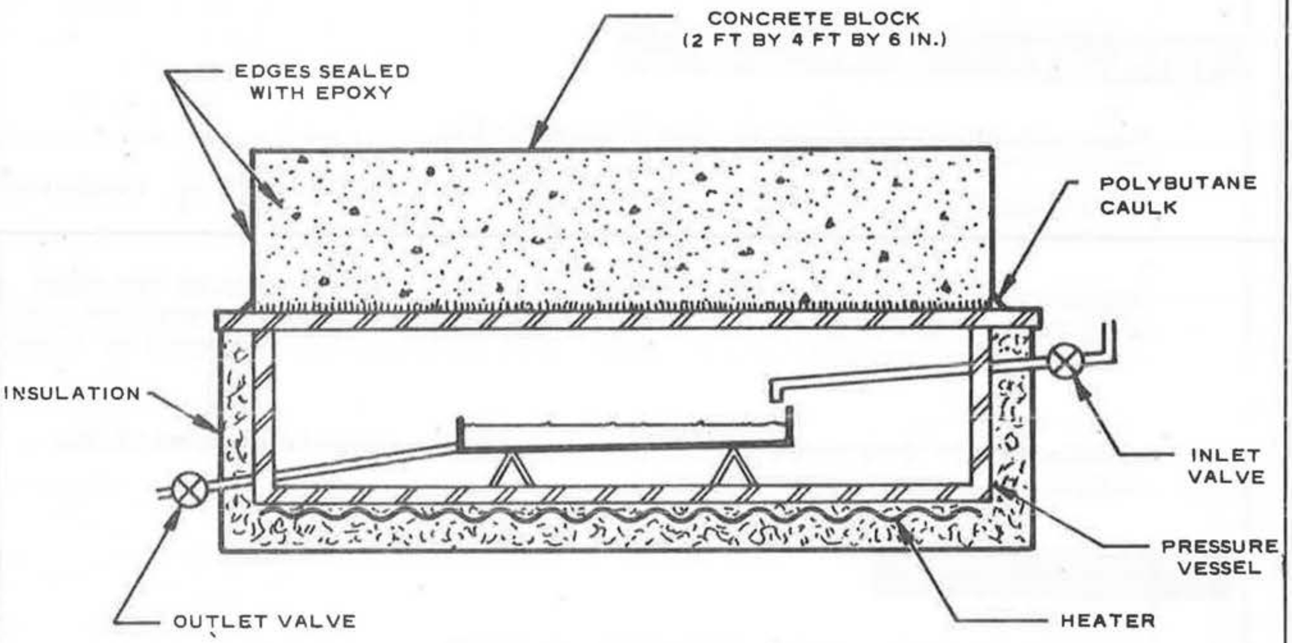
LEAK TEST DATA

See Figure D-8b, vapor transmission curve.

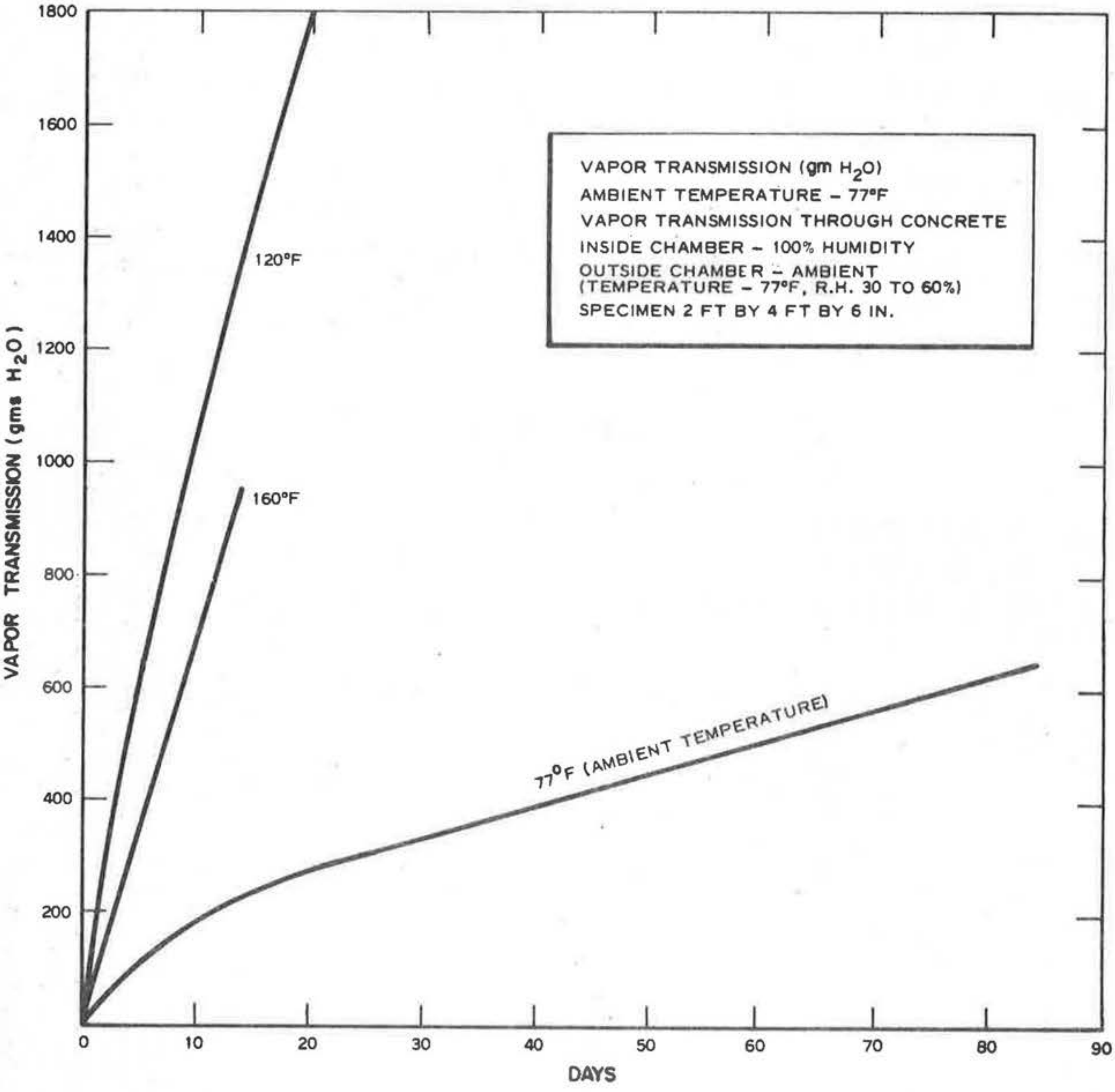
Conditions of Test				cfm/ft^2 (1-in. thick)
Inside Vessel		Outside Vessel		
Humidity (%)	Temperature (°F)	Humidity (%)	Temperature (°F)	
100	77	40	77	2.5×10^{-5}
100	120	40	77	5.6×10^{-5}
100	160	40	77	1.7×10^{-5}
40	77	40	77	1.6×10^{-5}*
100	77	40	77	6.6×10^{-6}†

*Air leakage through concrete at beginning of test.
†Air leakage through concrete at end of test.

LEAKAGE DATA SHEET	Figure D-8a	Page 2 of 3



LEAKAGE DATA SHEET	Figure D-8b	Page 3 of 3



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APPLICATION DATA

APPLICATION DATA SHEETS

IV. APPLICATION DATA

A. PURPOSE OF APPLICATION DATA

In the planning stages of any facility, numerous considerations enter into the establishment of basic facility parameters. Factors such as site location, size of structure, soil conditions, availability of materials, etc., influence the choice of the type of structure and method of construction. When a reactor housing facility is under consideration, these same factors as well as radiological safety considerations must be evaluated. This section contains building component design details together with their applicable leak rates for use in overall reactor housing planning and design. It also includes comments concerning precautions to be observed in designing, constructing, inspecting, and testing buildings. The data presented are intended for use by facility planners and designers when considering a conventional structure for low-leakage reactor housing purposes. Typical details for a variety of structural components are presented with appropriate coefficients to enable the designer to calculate anticipated leakage or to design a structure for some specified leakage. All coefficients are based on experimental results and are directly extrapolated from information included on the Leakage Data Sheets (Section III).

Quite often, in the planning of a facility, evaluation of structural and economic considerations establishes one or two types of structures as the most feasible for the project in question. Factors such as structure size, interior clear-span consideration, and soil characteristics dictate the use of a particular structural design. Information is provided in this section which will permit the planner to determine which basic structure type (of those feasible) satisfies the requirements relative to building leakage. An economic analysis of various types of reactor building structures is given in Section V.

Once a low-leakage facility is authorized for construction, an architect-engineer normally has the responsibility for designing a structure which satisfies the pressure requirements and the leakage restrictions established during the planning stages. The basic information has been provided on Application Data Sheets to enable the architect-engineer to design a structure and calculate estimated leakage with a degree of accuracy that heretofore has not been possible. The Application Data Sheets are not intended as a "building code" or some other rigid set of design requirements. The architect-engineer still has the responsibility of developing and preparing a set of plans and specifications with sufficient detail for use by a conventional construction contractor.

Since the construction contractor works to the plans and specifications prepared by the architect-engineer, it is not envisioned that this manual will be used by the contractor to any great extent. However, the manual can be used to indicate to the construction regulatory agency and the individual field inspectors the significance of leak-tight construction and thus create an awareness of leak paths and methods for leakage reduction. One fact remains uppermost: regardless of how thorough the planning and how complete the plans and specifications, the leak integrity of any structure is completely dependent upon the actual construction. Adequate contractual requirements and clearly defined plans and specifications can make the construction contractor legally responsible for fulfilling the leak requirements, but this legal responsibility is of little comfort after a structure is built and the overall schedule suffers while corrections are being made. Therefore, it is imperative that initial construction be as accurate as possible. It should be the responsibility of the inspecting agency to ensure that such is the case by having qualified inspectors available who are familiar with leakage characteristics to communicate to the contractor and, more importantly, the workers the importance of this aspect of construction.

In summary, it is believed that the Application Data Sheets will be primarily used during the following stages of any project:

1) Planning: where the basic type of structure is selected and engineering-economic considerations are evaluated.

2) Final Design: preparation of detailed plans and specifications by the architect-engineer.

3) Construction: inspection of construction to ensure compliance with the plans and specifications.

B. DESIGNING AND CONSTRUCTING LOW-LEAKAGE STRUCTURES

1. General Precautions and Limitations

The design and construction of low-leakage structures presents some unusual problems. These problems are related to the unique characteristics of the structures and to the leakage requirements. Some of the problems of most concern are: utilization of component leak test data; variation of building leakage with age; pressure variations due to the environment; and inspection and compliance with specifications. Other problems such as cracking of concrete panels and pressure limitations of metal panel buildings are specific to the concrete and metal panel buildings.

a. Utilization of Component Leak Test Data

The detailed data included on the Application Data Sheets present air-leakage characteristics only and are not to be construed as structurally and architecturally complete. The designer must determine design details such as member sizes, amount of reinforcement, etc., in accordance with design loadings and applicable codes and specifications. Furthermore, the details presented are not a complete record of all possible construction configurations; nor are they intended to limit the designer when an alternate method may be more suitable for the specific purpose. However, certain commonly used details are presented, with leakage coefficients being developed from the test program previously described. Since it was not possible to physically test all possible situations which may be encountered in conventional construction, a majority of the leakage coefficients were extrapolated from small-scale tests or were estimated based on results obtained from tests of similar configurations. The leakage coefficients provided for each suggested detail must be applied only within the limiting dimensional and environmental parameters indicated with each detail.

It is recommended that a safety factor of at least two be used in the design of structures to meet a specific leakage requirement. This factor is based on statistical component-reproducibility tests and the final results of the comparison between the summation of component tests and the model buildings. It is important to note that the component tests were made under laboratory conditions; the model tests were specified, designed, and inspected by the same individuals who conducted the component testing program. Even under these controlled conditions, it was necessary to test the models in phases in order to evaluate the leakage of components of the model as actually constructed. In many cases the construction was different from that specified, or different from construction used in the test cell studies. In those cases it was necessary to make appropriate corrections to the calculations or to modify or alter the component as installed.

b. Variation of Building with Age

Many of the Application Data Sheets for particular components utilize various caulking compounds for sealing certain leak paths. Some of these compounds are particularly sensitive to deterioration by ozone. Furthermore, some of the buildings are subject to other variances with age such as warping, cracking, etc. Many of the caulking compounds which are subject to deterioration with age have been identified, and, where possible, the less sensitive compounds and sealants should be used.

To minimize the effect of increased leakage with age, it is desirable that weak points be located so as to be readily maintainable. Unfortunately, this is not possible with the metal panel buildings which utilize caulking compounds in the joints. It is expensive to disassemble and recaulk these joints after the building has been in service. For that reason, metal panel buildings are not recommended for applications where leakage less than 10%/day at 1 in. water pressure is desirable.

It will be noted in the Application Data Sheets that all joints in the concrete building are readily accessible for maintenance. Long-lasting caulking compounds are used and in the event these compounds deteriorate with age, they can be replaced. Furthermore, for very low leakage requirements (less than 1%/day at 1 in. water pressure) long-lasting vinyl paints are recommended on inside surfaces. These paints are not subject to deterioration with age and should show good service throughout the building lifetime.

c. Pressure Variations Due to the Environment

If a low-leakage building is sealed by closing heating and ventilating ducts during a reactor accident, and if the heating and cooling system is inoperative, it is possible that temperatures and pressure changes induced between the building and outside from atmosphere environmental forces will produce significant pressure changes in the building. These would include effects of weather fronts, large diurnal temperature swings, and wind forces. The resulting pressure changes may be sufficient to exceed the design pressure of the building.

Consider a building of one million cubic feet internal volume designed to a leakage specification of 1% volume leakage per day at 1-in. internal water pressure. If an ambient air temperature change causes the internal building temperature to increase at the rate of 5°F/hr, this will result in an internally generated pressure increase of 4-in. water pressure/hour. An equilibrium pressure of 24 in. of water will be reached in the building when the building leakage will exactly compensate for the internally generated pressure increase. During the first 20-hr period, the building will reach an internal pressure of 23 in. of water and will have relieved by leakage what otherwise would have resulted in an internal pressure of 80 in. of water. In relieving this excess pressure, the building will have leaked 138,000 ft^3 of air, or approximately 14%.

If the building design pressure were 15 in. of water, the building would be equipped with a pressure-sensitive relief valve set to relieve at an internal building pressure of 15 in. of water. The pressure would increase in the building as before for approximately seven hours, at which time the relief valve would open and hold the pressure constant at 15 in. of water. During the 7-hr period, the building will have leaked approximately 4% by volume. In the first 20 hr, the building will have leaked approximately 16% by volume. When the internal pressure generation ceases, the relief valve would close and building leakage would be reduced accordingly.

These examples illustrate one of the peculiarities of low-leakage building design. As normally constructed, when subjected to a slight pressure difference, conventional buildings will leak many complete volume changes of air per day. These buildings easily adjust weather-induced pressure differences by leakage in and out. This is obviously undesirable for reactor containment purposes. A large conventional building can be designed and constructed to leak 1% of its volume or less in a 24-hr period with 1 in. of water pressure differential. With the building heating and ventilation system in operation, pressure differentials induced by weather extremes are equalized and no damage results. However, if following a nuclear incident the building is sealed with the heating and ventilation system inoperative, certain weather extremes could cause damage to the structure if the building complex were not designed to accommodate these extremes.

Aside from tornados, the most severe weather extreme from the point of view of low-leakage structures appears to be a condition called "Chinook." This condition exists in the United States east of the Rockies in the states of Montana, North and South Dakota, Nebraska, Colorado, New Mexico, and West Texas, and is characterized by rapid temperature variations. Under Chinook conditions a temperature increase of 50°F in four or five hours is not uncommon.

More extreme conditions than this occasionally occur. Two or three times per season, temperature increases on the order of 50°F in two hours are encountered. Under the latter extreme conditions, the maximum rate of internal building pressure rise could be as high as 20 in. of water pressure per hr. Fortunately, this rate of temperature change does not persist. However, the designer should be aware of the unusual design characteristics of low-leakage structures, and should provide means to accommodate possible internal pressure swings.

Some of the precautions which can be taken to preclude over-stressing low-leakage buildings in severe weather conditions are:

1) Design the building to leak sufficiently during expected weather extremes so that allowable pressures are not exceeded.

2) Design the building to include an auxiliary fan which discharges the air through a high-efficiency filtering system and out the stack.

3) Include a reliable internal air conditioning system.

Other methods can, of course, be utilized by the designer. In any event, the designer should consider the problems which are unique to low-leakage structures.

d. Inspection and Compliance with Specifications

The subject of field inspection is primarily a practical rather than a theoretical one, with the result that inspectors, field engineers, and others are often unaware of the pitfalls that they may encounter. This is particularly true in the case of low-leakage building facilities. There is no general formula for avoidance of these pitfalls other than to follow good field practices and to provide construction supervision and inspection personnel adequately skilled in their trade. As an aid to the builder of low-leakage reactor facilities, a few notes of advice and caution are outlined below. These notes are general comments concerning the proper philosophic approach to the construction and inspection of low-leakage facilities. In many cases, two references accepted by the building trade have been quoted directly: "Field Inspection of Building Construction," Thomas H. McKaig, F.W. Dodge Corp., N. Y. (1958); and "Field Inspector's Check List for Building Construction," NBS Bldg., Materials and Structure's Report BMS-81, Catalog C13:29:81.

During the construction process, it is essential that a superior program of construction supervision should be effected if conventional structures are to be made leak tight and within the allotted budget. Typical of the practices which should be followed in the supervision of construction are the following:

1) Adherence to the standards of materials and craftsmanship approved by the material manufacturer, designer, or user of the final working drawings and specifications.

2) Avoidance of extra construction costs beyond the approved construction contracts.

3) Checking of building processes and evaluation of materials to ensure conformity with the specifications.

4) Elimination of unacceptable substitutions.

5) Frequent conferences with the contractor to assist in the interpretation of the contractual documents (both before and during construction).

6) Prevention of error which might result in unnecessary and costly maintenance and upkeep costs.

7) Review of guaranteed materials or workmanship at the time of installation.

8) Skillful coordination of the work of the various crafts.

9) Discovery of error or elements overlooked in the final drawings of specifications, and their early correction.

10) Periodic reporting on the progress of the project so that the owner and users are kept informed.

11) Protection of the mutuality of interest of owner, architect, and contractor, and producing the desired integration of interests.

12) Prevention of unfair practices and procedures or attempts at avoidance of contractual obligations.

Obviously, both good specifications and alert field and building inspection are necessary for the execution of a satisfactory building project with a new purpose. A brief general requirement in the specifications for "workmanlike manner" is not stringent enough, but under this provision the inspector can, at least, try to extract from the contractor something more than bare compliance. However, if the specifications permit the contractor free scope, or if, worse yet, they actually call for improper procedures, the inspector is virtually helpless. Many specifications embody the "General Conditions of the Contract for the Construction of Buildings" of the American Institute of Architects as part of the Specifications, or "Metal Curtain Wall Manual" by the National Association of Architectual Metal Manufacturers (1960), or "Manual of Concrete Inspection of the American Concrete Institute." While these documents contain many of the ingredients required for good specification preparation, they are not sufficient for specifying low-leakage structures. One of the purposes of this manual is to provide information which will permit the leakage requirements of buildings to be appropriately specified.

On a construction project, it is normal practice for the architect-engineer to endeavor by general supervision to guard the owner against defects and deficiencies in the work of contactors, but he does not guarantee the performance of their contracts. The general supervision of the architect-engineer is to be distinguished from the continuous on-site inspection by a clerk of the works. When authorized by the owner, a clerk of the works acceptable to both the owner and architect shall be engaged. Thus the architect-engineer still retains general supervision of the work, and the field inspector has no authority to change the plans or specifications, to make his own interpretations, or to usurp in any way the authority of the architect-engineer as defined by the architect-owner contract.

Depending on the contract, the field inspector may be employed by the owner or the architect-engineer. If friction is to be avoided, he must be acceptable to both the owner and the designer. The architect-engineer is usually the captain of a team of designers, but he may be assisted and represented in certain aspects of the work by his field engineer, the landscape architect, or some other building inspector. The field inspector should be permitted to deal directly with any of these specialists on pertinent matters of interpretation of detail. All problems dealt with in this manner, and the decisions reached, should be recorded so that the architect-engineer and any other interested member of the team may be kept informed regarding the status of the work at all times.

Unreasonably severe requirements established by the inspector occasionally damage the reputation of the architect to the extent that contractors who have been harassed by inspectors may raise their estimates when bidding on subsequent work. This is a particularly sensitive area in the case of nuclear and/or low-leakage structures. Contractors are often frightened into increasing their bid price by the very word "Nuclear" on specifications or drawings. Therefore, the field inspector should exercise care not to place unreasonable demands upon the contractor, but at the same time, should not permit essential requirements to be compromised. Obviously, occasional controversial or questionable areas will arise which should be brought to the attention of the architect-engineer or nuclear designer by the inspector for arbitration.

In the case of low-leakage reactor housing structures, an additional requirement to the normal inspection during construction for compliance with specifications should be a final proof-test of the building leak tightness. The field inspector should be charged with the responsibility of determining that test procedures are adequate and that the specified leak tightness is achieved.

In summary, the ingredients for success in the construction of low-leakage reactor building enclosures are:

1) Clearly defined and complete plans and specifications

2) Good construction supervision

3) Adequate inspection during construction

4) A proof-test of the leak-tightness characteristics of the building.

2. Concrete Structures

Reinforced concrete building structures can be designed and constructed with low leakage to house nuclear reactors. Leakage of a typical concrete structure occurs at joints and through pores and cracks in the concrete. The leakage coefficients in the Application Data Sheets permit the computation of leakage from each of these leak paths. However, before the leakage through cracks can be determined, it is necessary to calculate the spacing and size of the cracks as a function of the building loading stresses.

The major reason for cracking in concrete is its relatively low tensile strength. Tensile stresses can be introduced into concrete in a number of ways, including:

a) Loading stresses from externally applied forces

b) Loading stresses from the weight of the concrete

c) Thermal expansion and contraction of a fixed member

d) Differential shrinkage during the curing process.

e) Differential expansion between the reinforcing steel and the concrete.

f) Stresses from internally applied pressure loads.

Cracking from all of these causes can be minimized by proper specification and by proper control during construction.

The spacing and size of cracks produced by flexure in elastically stressed panels can be computed by use of a technique developed by Chi and Kirstein.*
The method results in a conservative prediction of cracking and leakage.

When a concrete panel attempts to expand or contract due to temperature changes but is restrained from doing so by fixed attachment to beams or columns, stresses occur which can cause cracking. Uneven heating or cooling in a given portion of the panel can also cause thermal stresses in the panel. These stresses can be minimized by providing joints at points of attachments to columns which allow for movement of the panel. Specially designed joints are required in low-leakage structures to minimize leakage, allow movement of the panel to accommodate thermal expansion, and to permit maintenance.

The ultimate strength of concrete is a function of many variables including water/cement ratio; type, size, and amount of admixtures; placement; curing method and time. During the curing process, moisture evaporates from the concrete. If this occurs too rapidly, the concrete strength can be reduced by as much as 50%. Furthermore, uneven drying can result in differential shrinkage and local regions of weakness. Even well-cured concrete has built-in shrinkage stresses near the surface. If the concrete strength is low, considerable cracking can result. Fortunately, these cracks do not normally penetrate deeply into the concrete. However, they should be minimized in low-leakage structures by proper mixture and curing control. The newer methods of vacuum treating concrete after pouring offer an excellent means of reducing shrinkage cracks and water capillaries.

Improper placement of reinforcing steel too near the surface of the concrete frequently results in cracks which penetrate to the steel. These can be avoided by care in specifying and placing the steel. Precaution must be used

*See References, Conventional Housing and Components, 78 in such areas as joinery in precast concrete to prevent cracking. For example, when joining methods require welding of plates and inserts, heat causes expansion of the metal plates and anchors. The expansion weakens the bond between the steel and concrete and eventually may cause a major leak path if cracking occurs at the end of the anchor. It is important that the right type of steel plate and anchors be used and approved welding procedures be followed.

Cracks in concrete will have a leakage rate according to their number, spacing, width, and penetration into the concrete. The computation methods of Chi and Kirstein are used to determine crack width and spacing based on loading stresses. The depth of the cracks is determined from the computed depth of the neutral axis. Complete penetration of the cracks results only where stress reversal of the panels occurs. When cracks penetrate completely through the concrete, the leakage rate through the cracks can be computed.* Leakage of concrete through cracks which do not completely penetrate the slab can be computed by assuming that the leakage is only that which results from the thickness of the uncracked concrete. Special care should be exercised if credit is taken for the uncracked thickness of concrete since the cracked thickness may extend to a joint where leakage can occur. If the joint is properly designed with caulking below the cracks, then leakage is correctly controlled.

In low-leakage reinforced concrete building structures, constructed in accordance with techniques shown to be effective, the major source of leakage is through concrete cracks and capillaries. Concrete crack and capillary leakage can be controlled so that leakage is predictable. These structures can be constructed to leak less than 3 volume % per day at 14 in. of water pressure (1/2 psi). With properly prepared and painted surfaces, they can be constructed to leak less than 0.1% per day at 14 in. water pressure. As with any well-designed concrete structure, the loading stresses produced on the reinforced concrete should be in accordance with the ACI code and, thus, well below the yield point of the steel (in tension) or concrete (in compression). This is especially true in low-leakage reactor structures where the minimization of cracking is important.

3. Steel Structures

Metal-panel building structures can be designed and constructed with low leakage to house nuclear reactors. Leakage of a typical metal-panel structure

*A method of estimating concrete cracking and leakage is given in the Appendix.

occurs primarily at the joints. The leakage coefficients in the Application Data Sheets permit the computation of leakage through the joints.

For a single-layer 18-gage steel panel with lapped joints at 2-ft intervals, with girts at 5-ft centers perpendicular to the direction of the lapped joints, and with self-tapping screws at 6-in. centers on the girt lines, calculations show that the maximum pressure difference which can be resisted by the panel is approximately 2 in. of water.

For a double-layer 18-gage steel wall, a flat panel, and the outer layer a fluted 18-gage panel fastened directly to this inner panel and thence to girts located at 10-ft centers, it is estimated that the maximum allowable internal pressure is between 10 and 15 in. of water. The maximum allowable external pressure (if the ribbed external panel is leak tight), is approximately 45 in. of water.

If the ribbed external panel is adopted as the leakage barrier, the leakage rate will greatly increase since the eave and curb joints of a fluted panel are very difficult to seal.

Consideration must be given to the roof construction for the type of building. Normally a 5-ply built-up roofing over a steel decking is employed. The internal pressure limit for this type of roof is 5 in. of water (or less), when the 5-ply roofing is used as the leakage barrier. Except for low pressures, the steel decking must be considered the leakage barrier. For this case, the area between the decking and 5-ply roofing must be allowed to breathe to the atmosphere.

Metal-panel buildings of the Robertson type (a representative type) can be designed for a maximum internal pressure of between 10 and 15 in. of water. At leakage rates of less than 10%/day at 1 in. water, normal ambient air temperature and pressure changes may cause the internal pressure to exceed this design limit. By air temperature and/or pressure control devices, the leakage rate can be reduced to 5%/day without exceeding the allowable design stresses. There is little incentive for designing a building of this type for leak rates lower than 100%/day at the building design capability pressure (10 to 15 in. water). Section V of this report shows that concrete buildings (designed for 1/2 psig) are less expensive and easier to seal against leakage.

4. Leakage of Gases and Vapors

The majority of tests conducted have been performed with components in which the leakage of air has been studied. This type of leakage is characterized by a flow proportional to the pressure differential or the square root of the pressure differential. This successfully represents the mass flow of gases through cracks, orifices, joints, etc.

Gases other than air should behave in a somewhat similar manner for mass flow in the turbulent or viscous flow regions with different coefficients applied to the basic flow equations. If, instead of crack and orifice flow, the flow is through a porous membrane such as an uncracked concrete wall or through an unviolated paint surface, then the mechanism of flow is more nearly represented by diffusion equations. In this case, the rate of flow through the membrane is dependent on the partial pressure of the gas or vapor being considered on the one side of the membrane compared to the other side. In such a case, it is possible for the flow of two different gases through a membrane to be in opposite directions if the partial pressure gradients are of opposite sign. Various combinations of diffusion and mass flow are possible.

Fortunately, in most building designs of the type required for reactor containment, the major contribution of leakage is from cracks and orifices with mass flow predominating. However, when considering a porous membrane, designers should remember that if the partial pressure of a particular gas constituent is higher on one side of the membrane than the other and the total pressure is in the opposite direction, it is possible that the gas in question may migrate by diffusion in the opposite direction to the mass flow leakage. This could occur, for example, through a concrete wall in which the inside of the building is maintained at a negative pressure and the majority of the leakage is taking place by mass flow through cracks and orifices from the outside of the building, yet the partial pressure of a particular constituent is higher on the inside and diffusion through uncracked portions of the concrete occurs to the outside of the building.

Tests on the leakage of water vapor through concrete indicate that water vapor can be considered as another gas and obeys the same physical laws of transport including diffusion proportional to the partial pressure differential. These tests also indicate, however, that water vapor tends to condense in the pores of the concrete as it penetrates the concrete and can form pools of moisture through which gases and vapors cannot readily penetrate because of the low liquid diffusion coefficient.

C. APPLICATION DATA SHEET DESCRIPTION

The format of the Application Data Sheets facilitates accessibility and use of building design details by the working designer. The data sheets are grouped in three basic construction categories: I. Concrete Structures, II. Steel Structures, and III. Building Components. The latter are components common to any type structure, such as doors, louvers, roof hatches, paints, caulking, piping penetrations, etc. A listing of all components within a basic construction category precedes each category group. Typical details, leakage coefficients, and controlling parameters are indicated on individual Application Data Sheets. The Leakage Data Sheet (Section III), which contains the experimental basis for the leakage coefficient, is referenced where applicable.

Each Application Data Sheet is assigned a code number to permit reference and identification. Application Data Sheets are designated ADS, followed by a Roman numeral which represents the basic construction category. The category numeral is followed by a letter which indicates the group of components within the category. Specific components are identified by sequential numbers following the component-group letter. Since more than one commonly used configuration exists for many of the specific components, multiple suggested designs for the same component are treated as separate cases on the same Application Data Sheet. For example: ADS III-A-2 Case 2 is an Application Data Sheet, Category III (Building Components), Group A (Doors), Data Sheet 2 (Personnel Access), Case 2 (Marine).

Incorporated into each Application Data Sheet, when applicable and available, is the following information:

1) Title

2) Description

3) Case number

   a. Design details

   b. Leakage coefficients

   c. Notes

D. LEAKAGE CALCULATION PROCEDURES

1. Leak Rate Formula

The basic formulae for leakage are defined in Section II. The leak rate per unit leak path of a specific component or structural configuration is

$$q = AP + BP^{1/2} \quad , \qquad \ldots(11)$$

where P is the pressure difference across the component. A and B are the empirically measured leakage coefficients presented in Section III.

On Application Data Sheets, the units of the coefficients are:

A = cfm per unit leak path – in. water pressure

B = cfm per unit leak path – in.$^{1/2}$ water pressure

The total leak rate through a component is

$$q_T = qD \quad , \qquad \ldots(12)$$

where D is the number of units or total dimension of the component. The total leak rate of a building or structure is the sum of all component leakages:

$$Q = \Sigma q_T \quad . \qquad \ldots(13)$$

2. Method of Calculating Total Building Leakage

The following steps are followed for calculating the total estimated leakage of an existing building or a proposed structure for which construction details have been specified:

a) Identify the various component leak paths in the structure

b) Itemize each leak path component

1. Unit leak path
2. Number of leak path units

c) Review Application Data Sheets for an appropriate possible detail for each component

d) Itemize the leakage coefficients for each component

e) Calculate the estimated leakage per unit leak path for each component at the specified pressure difference

f) Compute the total leakage through each component by use of the number of leak path units

g) Sum the total component leakages to obtain the total building leakage.

It is believed that the calculated leakage of a large-scale structure based on the data presented will be within ±50% of the actual leakage.

An example for a typical structure (metal panel), with the leakage components identified, is given in Figure IV-1. A sample leakage calculation is shown in Table IV-1. Each component which can contribute to the total leakage of the building (Figure IV-1) is itemized in the first two columns of the table. The unit leak path and the number of units of each component is entered into the next two columns. The leakage coefficients are determined from the Application Data Sheet corresponding to the component construction detail and both are itemized in the table. The leakage per unit path of each component at 3 inches of water is estimated, using Equation 11, and then tabulated. The last column of the table, the total leakage through each component, is computed by use of Equation 12. The total leak rate of the building, obtained from the sum of all component leakages (Equation 13), is 37,000 cfm or about 5000% per day.

3. Determination of Structural Components for Specified Leakage

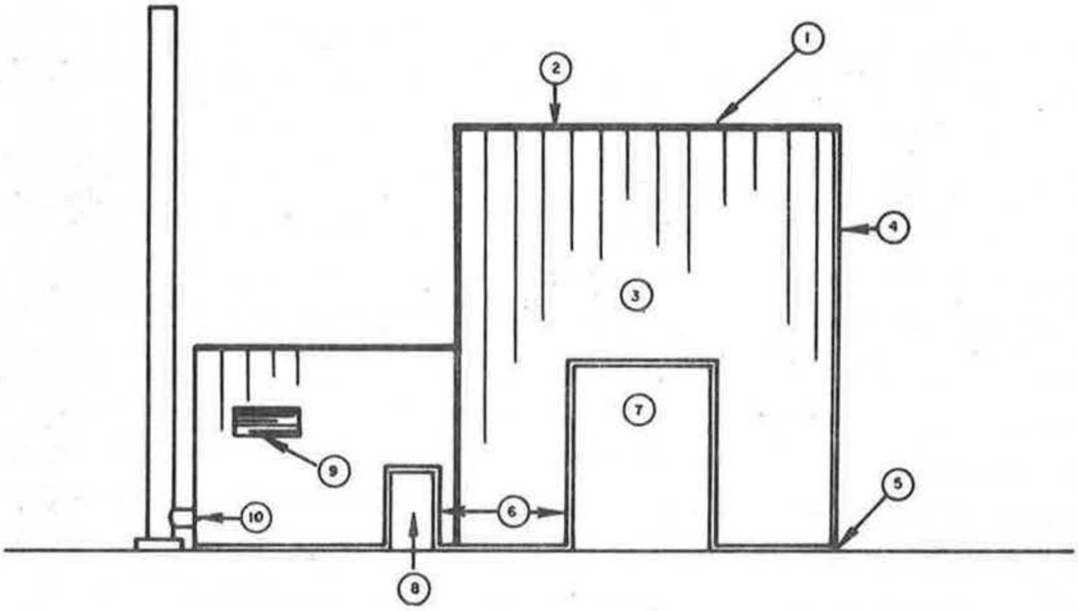
The following basic steps should be followed to determine the most economical construction arrangement when the allowable leakage has been established (also see discussion in Section V, Economics):

a) Identify possible leak paths for the proposed structure configuration.

b) Review the Application Data Sheets for leakage of the various construction details for each possible leak path. (If the basic structure type such as cast-in-place concrete or insulated metal siding has not been determined, leak paths should be tabulated for each type of structure considered economically feasible for the proposed application.)

c) Determine which construction detail is fixed by engineering and economic considerations other than leakage.

d) Select the most economical appropriate combination of details for the remaining leak paths.



1. Roof
2. Eave
3. Wall
4. Corner
5. Curb
6. Framed Door Opening
7. Door
8. Door
9. Louver
10. Stack Penetration

Figure IV-1. Typical Metal Panel Building with Leakage Components Identified

e) Tabulate leak paths and estimated leakage coefficients for the various possible details.

f) Calculate the total building leakage.

g) This process should be repeated for each feasible structure type; final selection to be based on local estimated cost of the final configurations of each possible structure type which meets the leakage specifications.

The first leakage calculation sheet should include only the most economical method of construction. If the leakage is greater than allowed, the sheet should be examined for components which contribute an excessive leakage. An alternative component or building detail is selected and the calculation repeated until the desired leakage results. In a few cases, a component must be eliminated if no adequate substitution is found. By using the fundamental data presented, a facility designer, well versed in leak-path characteristics, should be able to estimate leakage (including details not specifically described) so that a typical large building can be designed to leak within ±50% of the design leak rate. The accuracy of tabulated component leakage data, the reliability of materials used, and the quality of methods of component subassembly by the manufacturer are probably sufficient to select components to achieve a specified leakage. It is recommended that a minimum safety factor of 2 be used in the design of low-leakage buildings to accommodate the various uncertainties.

Suppose an insulated metal panel building is required to leak less than 15% per day at 3 inches water pressure. Table IV-1 is an example of the first work sheet which might be calculated. It is apparent that the major leakage is through Item No. 2, the eaves, when constructed by standard construction. If the improved construction of ADS II-A-5 Case 2 were employed, the total leakage of the building would be reduced to 5800 cfm, or about 900% per day. Table IV-2 is an example of the leakage calculation sheet for a structure which meets the leakage specifications with a safety factor of 3.6. Note that Item No. 9, the louver, must be eliminated to meet the leakage specification. Also note that the use of a hollow-metal gasketed door for Item No. 8 would not result in a sufficient factor of safety.

Leakage of components which are designed with minor variations from the Application Data Sheet specifications can be predicted without significantly affecting the desired leakage result. This is true provided that the structure is assembled by experienced workmen under knowledgeable supervision and that there is careful inspection of the work. The facility planner and designer must use these data as a complement of, rather than a substitute for, good engineering practices. He must depend on his ingenuity and experience to develop the final design best suited to the particular application being considered. Extrapolations to larger or more complex structures and any relationship between tests at ambient conditions to leakage under accident conditions should be assessed and taken into consideration when establishing a safety factor for the application. There are a number of reasons why a larger safety factor may be necessary. For example, it may be essential to meet the leakage specification, there may be major variations in design, quality of workmanship, or experience in inspection, or there may be abnormally large, environmentally induced stresses in the structure. Thus, a safety factor as large as 4 or 5 may be required under some conditions.

TABLE IV-1

LEAKAGE CALCULATION SHEET

Facility: A.B.C. Power Co. Lewisberg, Ohio	Gross Volume: 1,000,000 cu ft	Allowable Leakage:	Pressure Difference 3 in. water	Existing Structure: Insulated Metal Siding Steel Frame

Leak Item No.	Component	Unit	Estimated No. of Units	Possible Detail	Leakage Coefficient A	Leakage Coefficient B	Estimated Leakage Per Unit (cfm)	Total Component Leakage (cfm)
1	Roof	ft^2	25,000	II-A-4	6×10^{-5}	0	1.8×10^{-4}	4.5
2	Eave	ft	1,470	II-A-5 Case 1	>7	0	21	30,800
3	Wall	ft^2	37,500	II-A-3 Case 1	2.2×10^{-3}	5.0×10^{-4}	7.5×10^{-3}	280
4	Corner	ft	200	II-A-6 Case 1	0.4	0.1	1.4	280
5	Curb	ft	810	II-A-2 Case 1	0.62	1.27	4.06	3300
6	Framed Door Openings	ft	78	II-A-7	$<10^{-6}$	0	$<10^{-6}$	0
7	Door, 15 ft x 20 ft Std Sliding or Roll up	each	1	III-A-3 Case 1	600	0	1800	1800
8	Door, Hollow Metal Gasketed	each	1	III-A-2 Case 1	0	35	61	61
9	Louver, 2 x 2 ft	each	1	III-B-1	30	0	90	90
10	12 in. diameter Stack Penetration	in.	38	III-D-1 Case 1	$<10^{-8}$	-	10^{-8}	0
							Estimated Total Leakage	36,600 cfm

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TABLE IV-2

LEAKAGE CALCULATION SHEET

Facility: A. B. C. Power Co. Lewisberg, Ohio		Gross Volume: 1,000,000 cu ft		Allowable Leakage 15%/24 hr. (100 cfm)	Design Pressure 3 in. water			Proposed Structure: Insulated Metal Siding Steel Frame
Leak Item No.	Component	Unit	Estimated No. of Units	Possible Detail	Leakage Coefficient A	Leakage Coefficient B	Estimated Leakage Per Unit (cfm)	Total Component Leakage (cfm)
1	Roof	ft^2	25,000	II-A-4	6×10^{-5}	0	1.8×10^{-4}	4.5
2	Eave	ft	1,470	II-A-5 Case 2	$<6 \times 10^{-5}$	0	1.8×10^{-4}	0.7
3	Wall	ft^2	37,500	II-A-3 Case 2	2×10^{-4}	5×10^{-7}	6×10^{-4}	22.5
4	Corner	ft	200	II-A-6 Case 2	$<10^{-8}$	$<10^{-8}$	10^{-8}	-
5	Curb	ft	800	II-A-2 Case 3	$<3 \times 10^{-8}$	0	$<9 \times 10^{-8}$	-
6	Framed Door Openings	ft	78	II-A-7	$<10^{-6}$	0	$<10^{-6}$	-
7	Door, 15 ft x 20 ft W/Infl. Seals	in.	1,200	III-A-3 Case 2	Negligible	0	Negligible	-
8	Door, Marine, Quick Acting	each	1	III-A-2 Case 2	0.0012	0.0014	0.006	-
9	Louver - Do not use louver for vent air-excessive leakage							
10	12 in. diameter Stack Penetration	in.	38	III-D-1 Case 1	$<10^{-8}$	-	10^{-8}	-
						Estimated Total Leakage		27.7 cfm

CONTENTS
APPLICATION DATA SHEETS

I. CONCRETE STRUCTURES

APPLICATION DATA SHEET	No. I-A-1	Page 1 of 3

TITLE

Concrete Structure; Leak Path Key Drawing

DESCRIPTION

Reinforced concrete structure, cast-in-place or precast

Notes

1. Caulking compound called out in subsequent data sheets is to be a polysulfide base polymer, with bonding qualities to concrete. Caulking is to be applied per manufacturer's directions.

2. Membrane barrier under slabs, etc. is to be as follows:
   a) Hot tar: 50 lb/100 ft^2
   b) Dry ply: 15 lb tarred felt, lap 4 in.

3. Nonshrink grout is to be Portland cement grout with expanding aggregate admixture, mixed and placed in accordance with manufacturer's instructions.

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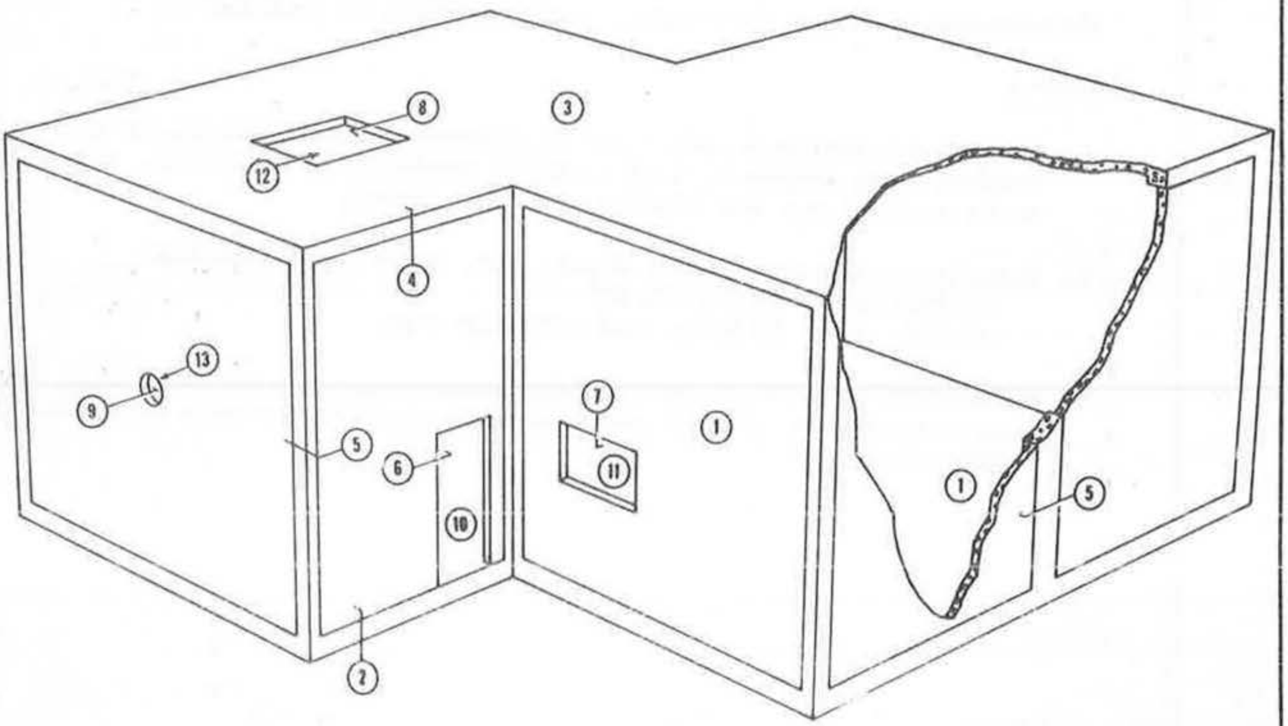
APPLICATION DATA SHEET	No. I-A-1	Page 2 of 3



APPLICATION DATA SHEET	No. I-A-1	Page 3 of 3

LEAK PATH LEGEND

Path No.	Description	ADS No.
(1)	Concrete slabs or panels	I-A-2
(2)	Juncture of floor slab, footing, and wall	I-A-3
(3)	Roof slab	I-A-4
(4)	Eave	I-A-5
(5)	Corners and column and wall joints	I-A-6
(6)	Framed door opening	I-A-7
(7)	Framed louver opening	I-A-9
(8)	Framed roof opening	I-A-10
(9)	Inserts through wall	I-A-8
(10)	Doors	III-A
(11)	Louvers	III-B
(12)	Roof hatches	III-C
(13)	Piping penetrations	III-D

APPLICATION DATA SHEET	No. I-A-2(1)	Page 1 of 3

TITLE

Concrete Structure; Cast-in-Place Concrete Slabs or Panels

DESCRIPTION

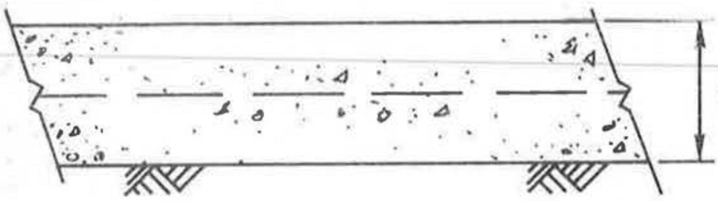
Reinforced concrete floor slab
Leakage through slab surface area
Leakage through joints at intersection of slab and walls or footings (ADS I-A-3)
Concrete specifications

Cement (sacks/yd^3)	7.75
Cement (lb)	729
Sand (lb)	1196
No. 3 gravel (lb)	1832
Water (lb)	264
Total Weight (lb)	4021
Water (gal)	31.7
Water (gal/sack)	4.23
Slump, calculated (in.)	2 to 4
Plastiment admixture per sack, Sika Chem. Co. (oz)	2
Maximum allowable water (gal)	33

Water-cement ratio: 0.43 ± 0.03

CASE 1

Plain slab on wall area; no visible or known cracks; size and location of reinforcement per design requirement (LDS B-13 and LDS B-15).



TYPICAL DETAIL

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APPLICATION DATA SHEET	No. I-A-2 (1)	Page 2 of 3

Leakage Coefficient per ft^2 of concrete surface
Pressure range: 0 to 100 in. water

x(in.)	A	B	Remarks
4	3×10^{-6}	0	See Note 2
8	1.5×10^{-6}	0	
12	1×10^{-6}	0	

Notes
1. Above coefficients do not give any consideration to leakage resistance of soil for slabs on grade. Therefore, calculated leakage values will be conservative if slab is constructed on compacted base.
2. An increase in water-cement ratio of 18% can cause an increase of leak rate by a factor of 10 [LDS B-1 (3)].
3. A 12-mil crack in 4-in.-thick concrete leaks 0.17 cfm/ft length at 1-in. water pressure (LDS B-7).

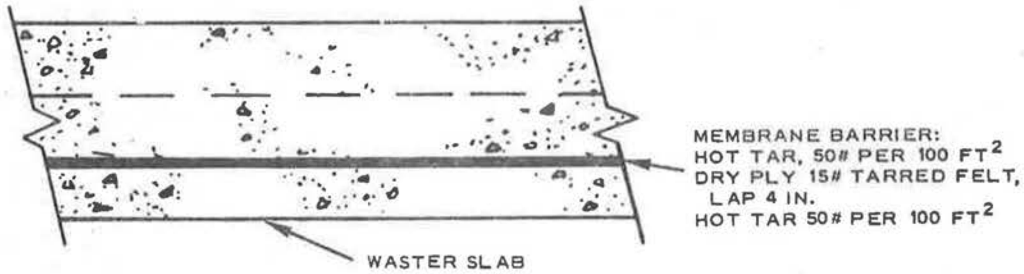
$$cfm = 3.9 \times 10^4 \frac{b^3 L}{x} P \text{ (LDS D-3)},$$

where

b = crack width in in.
x = wall thickness in in.
L = crack length in in.
P = pressure difference in in. of water

CASE 2

Floor slab cast on waster slab; membrane barrier between waster slab and floor slab (LDS A-8).



TYPICAL DETAIL

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APPLICATION DATA SHEET	No. I-A-2(1)	Page 3 of 3

Leakage Coefficient per ft^2 of concrete surface
pressure range 0 to 10 in. water

A	B	Remarks
6×10^{-5}	0	membrane only
2.8×10^{-6}	0	membrane + 4-in. thickness of uncracked concrete

Notes

1. With adequate membrane barrier, leakage is independent of slab thickness and contraction joint spacing since leakage is assumed to be through cracks along the contraction joints. (See note 4.)
2. Membrane barrier must adhere to sides of footings, equipment bases, etc., that pierce floor slab. Apply membrane minimum of 3 in. up sides of footings, etc.
3. Care must be taken to maintain integrity of membrane barrier during construction.
4. The total leak in cfm through uncracked 4-in.-thick concrete and the membrane is obtained by treating the two coefficients in series:

$$q_T = \frac{P(6 \times 10^{-5} \times 3 \times 10^{-6})}{(6 \times 10^{-5} + 3 \times 10^{-6})} = 2.85 \times 10^{-6} P$$

while the leak estimation procedure for 1 ft^2 equivalent crack area in a 10^4 ft^2 concrete floor slab is

$$q_T = P(10^4 \times 2.85 \times 10^{-6} + 1 \times 6 \times 10^{-5}) = 2.85 \times 10^{-2} P$$

Thus the leak is 2.85×10^{-6} cfm P/ft^2 which is less than the membrane only.

APPLICATION DATA SHEET	No. I-A-2 (2)	Page 1 of 2

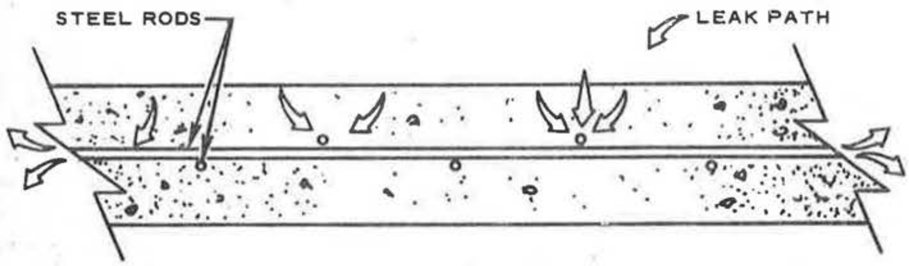
TITLE

Concrete Structure; Prestressed Concrete Panel

DESCRIPTION

Prestressed concrete panel (LDS B-2).
Leakage through panel surface area.
Leakage through joints at intersection of panel or footings (ADS I-A-3).
Concrete specification and mix proportion (compression strength may vary from 5,500 to 8,400 psi - 28 day):

Cement	1 sack
Sand	141 lb
Aggregate	235 lb
Water	47 lb
Plastiment	3 oz



PRESTRESSED CONCRETE PANEL

Jacking force	20,600 lb per rod
Final force	19,600 lb per rod

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Leakage Coefficient per ft² of concrete surface

Thickness	A	B	Remarks
5-1/2 in.	1.1×10^{-5}	0	edges of panel sealed and painted
5-1/2 in.	2.2×10^{-5}	0	edges of panel not sealed and painted

Notes

1. The above coefficients depend on the location of the steel rods which determine the effective thickness of the concrete. The air passes through the concrete to the wrapped steel rods and follow along the rod to the atmosphere.
2. A variation of mix or water-cement ratio can change the leakage rate by a factor of 10.

APPLICATION DATA SHEET	No. I-A-3	Page 1 of 2

TITLE

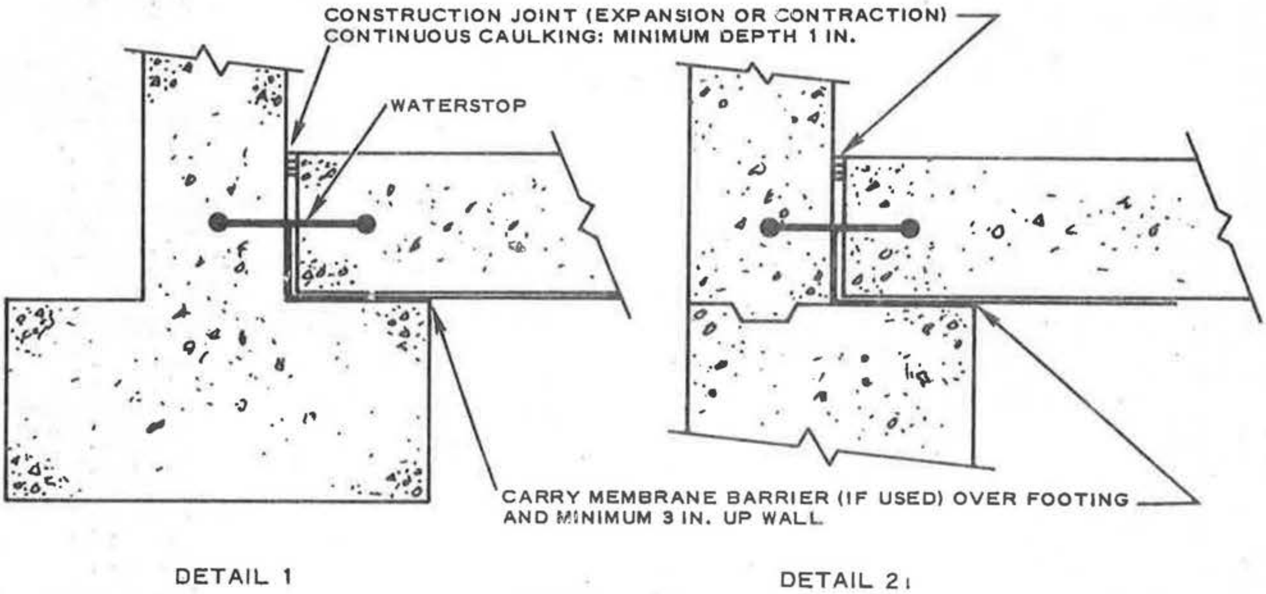
Concrete Structure; Juncture of Floor Slab, Footing, and Wall

DESCRIPTION

Reinforced concrete floor slab, footing, and wall
Leakage through construction joint between slab and footing or wall

CASE 1

Cast-in-Place



TYPICAL DETAILS

Leakage Coefficient per lineal ft of joint
pressure range 0 to 25 in. water (LDS-B-16)

No Waterstop With Caulking		With Waterstop No Caulking		With Waterstop and Caulking	
A	B	A	B	A	B
8×10^{-6} (LDS B-8)	0	1.6×10^{-3} (LDS B-16)	0	8×10^{-6} (LDS B-8 and B-16)	0

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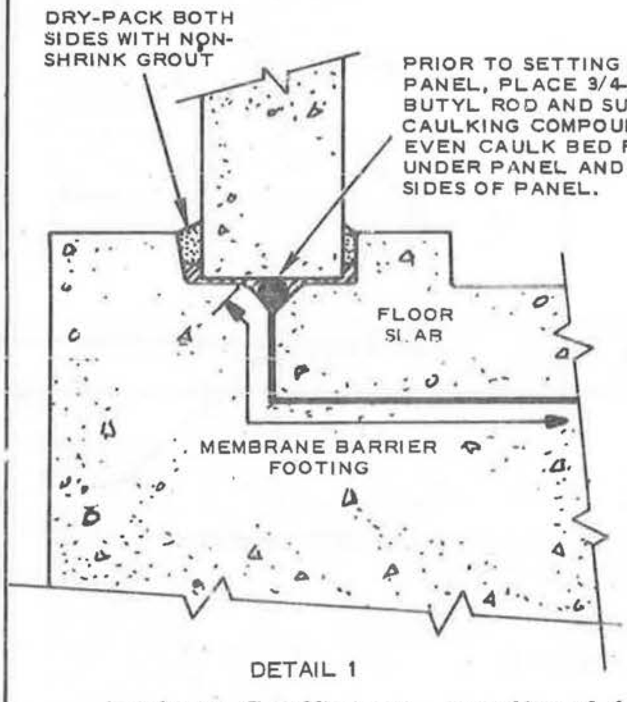
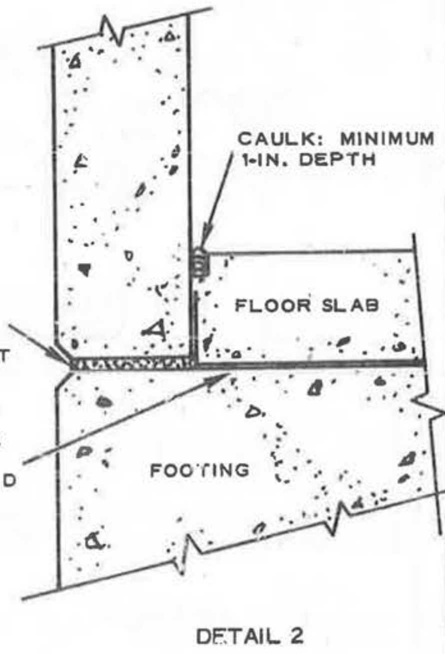
APPLICATION DATA SHEET	No. I-A-3	Page 2 of 2

Notes 1. All joints and corners of waterstops (if used) must be leak tight. All intersections of waterstops at wall and slab construction joints must be leak tight. Refer to ADS I-A-2 (1) for leakage of membrane barrier.
2. Care must be taken to maintain integrity of waterstops during construction.
3. Rubber or neoprene seals to concrete have not been suitable for air-leakage reduction when the concrete was poured into a horizontal form.

CASE 2

Precast Wall Panels





Leakage Coefficient per lineal ft of joint
pressure range 0 to 100 in. water (LDS B-8)

Detail	A	B	Remarks
1	1×10^{-6}	0	
2	8×10^{-6}	0	

Notes 1. Leak rate value for Detail 1 reflects limit of leak detection sensivity.

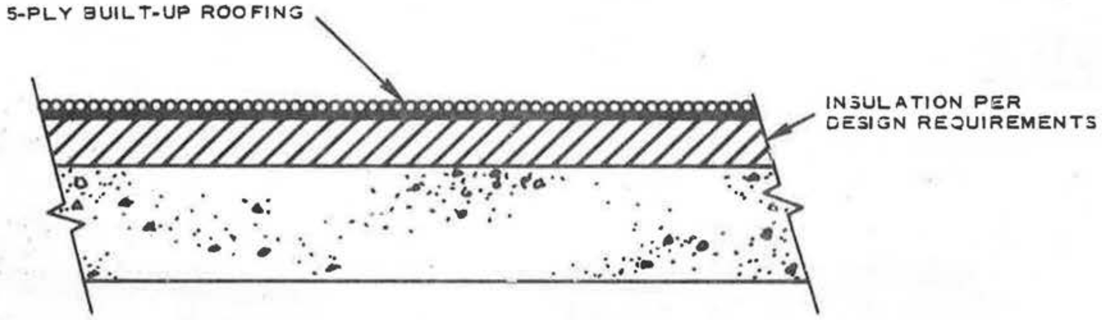
APPLICATION DATA SHEET	No. I-A-4	Page 1 of 1

TITLE

Concrete Structure; Roof Slab

DESCRIPTION

Reinforced concrete roof slab
Five-ply built-up roofing over slab
Leakage through slab surface area
Leakage through eave joint (ADS I-A-5)



TYPICAL DETAIL

Leakage Coefficient — per sq ft of roof slab surface, pressure range 0 to 5 in. water (LDS A-8)

A	B	Remarks
6×10^{-5}	0	—

Notes

1. Built-up roofing to be applied in accordance with best roofing practices. Method of application should be clearly defined in project specifications.
2. With proper roofing, the leakage coefficient is relatively independent of slab thickness and number and location of construction joints (and cracks), provided the eave is sealed.
3. Larger pressures may lift 5-ply roofing when tar membrane is used as the leakage barrier.

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APPLICATION DATA SHEET	No. I-A-5	Page 1 of 3

TITLE

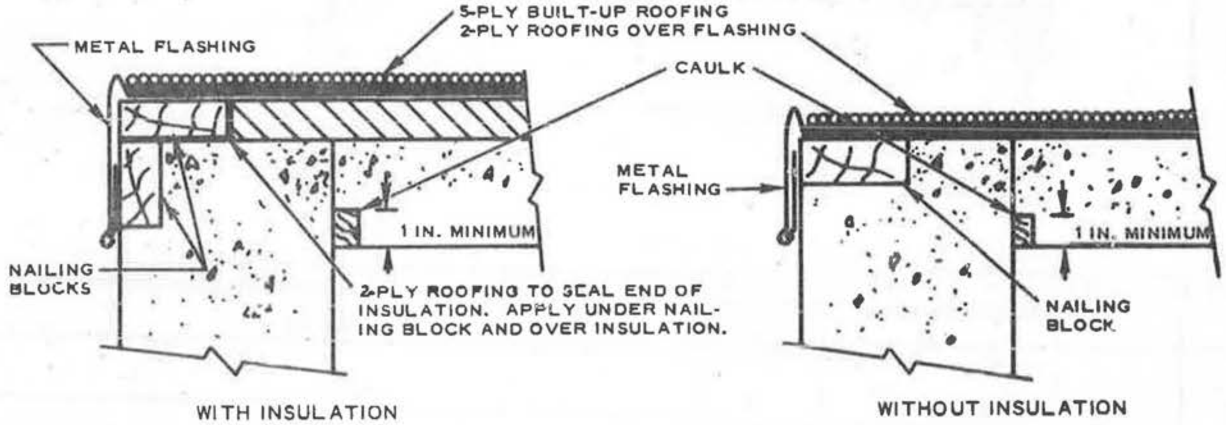
Concrete Structure; Eave

DESCRIPTION

Reinforced concrete roof slab and wall
Five-ply built-up roofing over roof slab
Leakage through construction joint at eave (between roof slab and wall)

CASE 1

Concrete roof deck, cast-in-place, no parapet



TYPICAL DETAILS

Leakage Coefficient per lineal ft of eave
pressure range 0 to 5 in. of water

A	B	Remarks
2×10^{-6}	0	—

Notes
1. Built-up roofing to be applied in accordance with best roofing practices. Method of application should be clearly defined in project specifications.
2. Two-ply roofing to seal end of insulation must be continuous full length of eave, and a minimum of 2 in. wide.
3. Walls are minimum of 4 in. thick; nailing blocks are ~2 in. wide.
4. See Note 3, ADS I-A-4.

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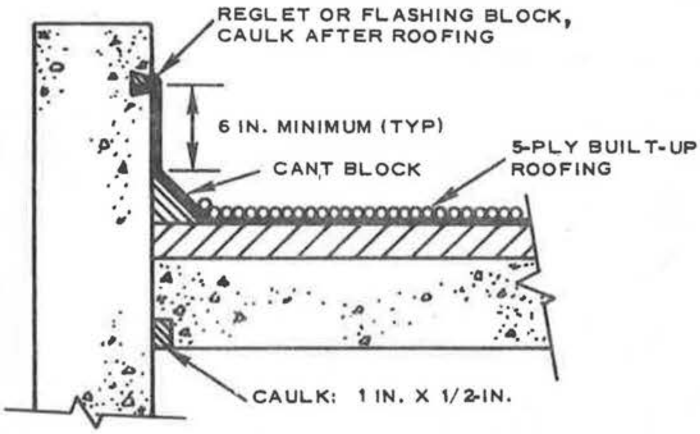
APPLICATION DATA SHEET	No. I-A-5	Page 2 of 3

CASE 2

Concrete roof deck, cast-in-place, with parapet



DETAIL 1
PARAPET AND WALL MONOLITHIC
SLAB PLACED SEPARATELY

TYPICAL DETAIL

Leakage Coefficient per lineal ft of eave
pressure range 0 to 10 in. water

Detail	No Waterstop		With Caulking		Remarks
	A	B	A	B	
1	$<6 \times 10^{-5}$		0	0	

Notes
1. Above coefficients are suitable for firewall parapets if roofing details are followed on both sides of parapet.
2. See Note 3, ADS I-A-4.

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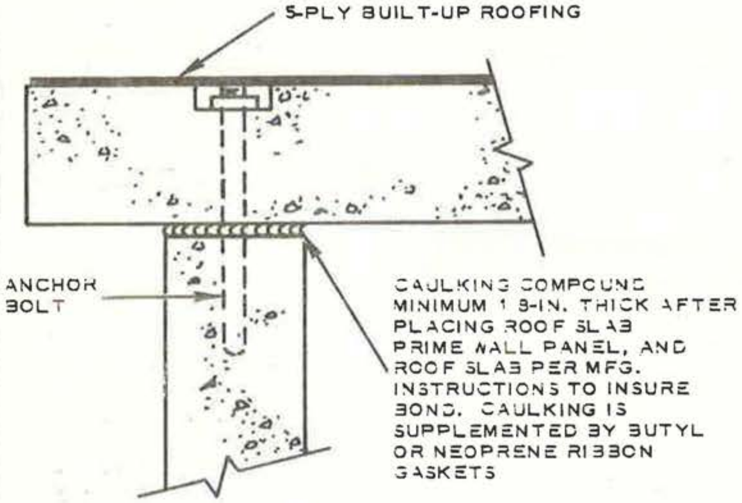
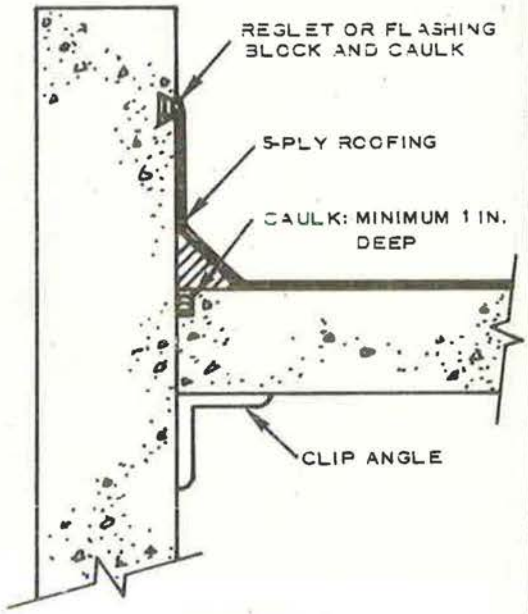
APPLICATION DATA SHEET	No. I-A-5	Page 3 of 3

CASE 3

Precast concrete roof deck



DETAIL 1
NO PARAPET



DETAIL 2
WITH PARAPET

Leakage Coefficient per lineal ft of eave
pressure range 0 to 14 in. water (LDS A-8)

Detail	A	B	Remarks
1	6×10^{-5}		at 20 in. - min detectable
2	6×10^{-5}		

Notes
1. Level of roof deck and wall determines effectiveness of seal.
2. Bonding strength of 5-ply roofing to concrete unknown.

APPLICATION DATA SHEET	No. I-A-6	Page 1 of 2

TITLE

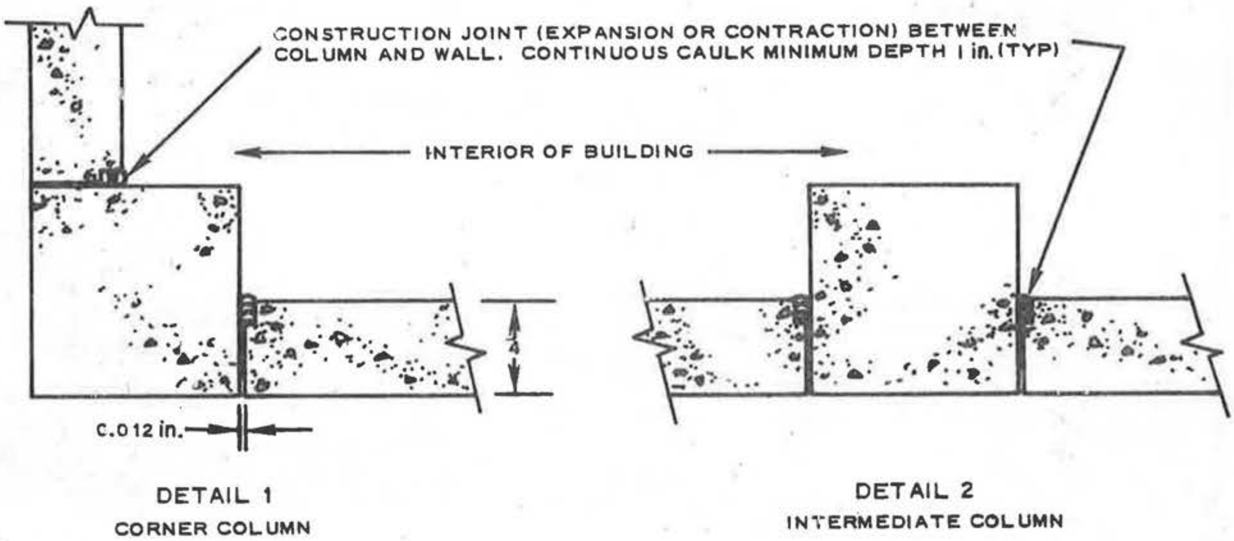
Concrete Structure; Corners and Column-Wall Joints

DESCRIPTION

Reinforced concrete structure
Leakage through construction joints between columns and walls

CASE 1

Column cast-in-place; wall precast or cast-in-place



Leakage Coefficient — per lineal ft of both joints, pressure range 0 to 100 in. water (LDS B-8)

Detail	No Caulking		With Caulking	
	A	B	A	B
1	0.34	0	1.6×10^{-5}	0
2	0.34	0	1.6×10^{-5}	0

Notes 1. The crack dimension assumed for "no caulking" leak data is 12 mils x 4 in. thick.

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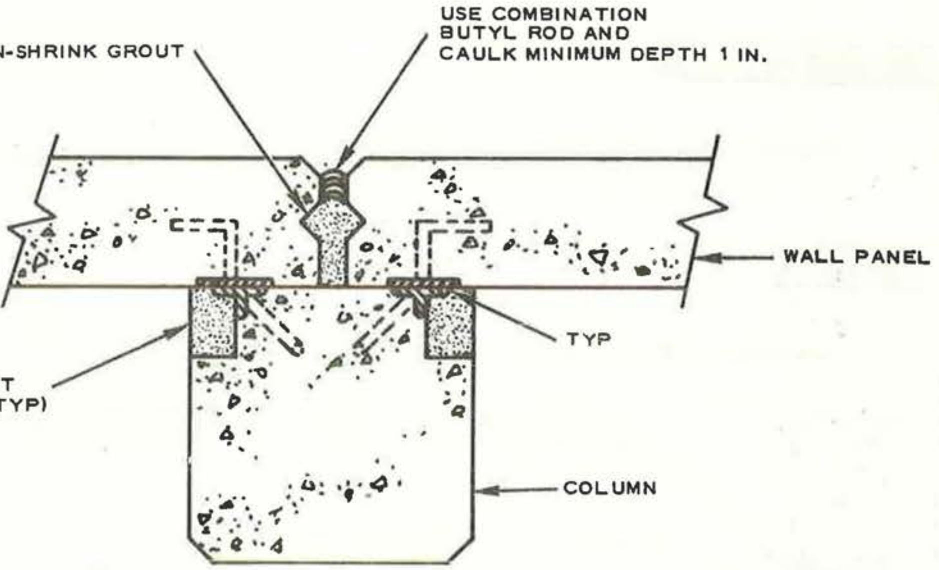
APPLICATION DATA SHEET	No. I-A-6	Page 2 of 2

CASE 2

Precast column and precast wall



SECTION

Leakage Coefficient per lineal ft of joint
pressure range 0 to 20 in. water (LDS B-8)

A	B	Remarks
8×10^{-6}	0	Assuming imperfect bond between grout and concrete

APPLICATION DATA SHEET	No. I-A-7	Page 1 of 2

TITLE

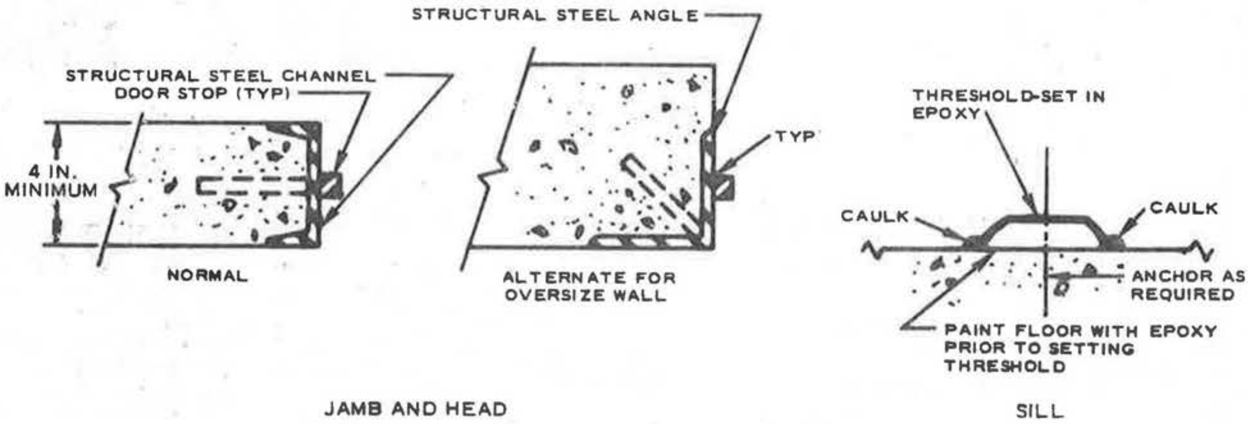
Concrete Structure; Framed Opening in Wall and Roof for Doors and Louvers

DESCRIPTION

Prefabricated metal door frames
Leakage between concrete wall and door frame
Leakage between frame and door, or through door (ADS III-A)

CASE 1

Structural steel frame cast with concrete wall



TYPICAL DETAILS

Leakage Coefficient per lineal ft
pressure range 0 to 100 in. water (LDS B-9)

	A	B	Remarks
Jamb and head	1.3×10^{-4}	0	4-in. concrete and metal contacts required
Sill	4×10^{-6}	0	score and caulk all around inside face of channel or angle

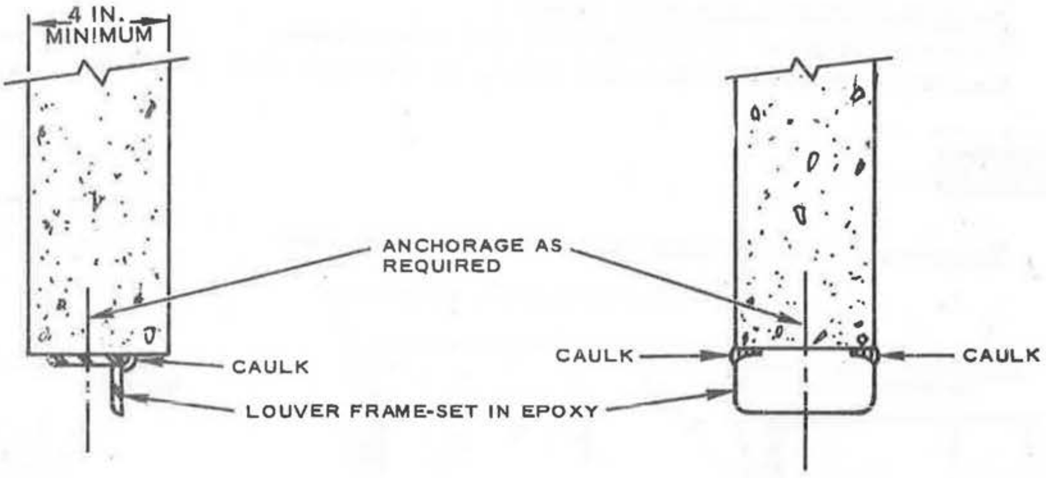
Notes 1. Paint floor surface under threshold with epoxy and set threshold in wet epoxy. Use manufacturer's recommendations for preparing floor surface. Caulking required to minimize metal-epoxy-concrete expansion problems. A flexible epoxy is recommended.

APPLICATION DATA SHEET	No. I-A-7	Page 2 of 2

2. All welding must be completed prior to casting-in place.

CASE 2

Prefabricated frame fastened to existing concrete surface



ALTERNATE JAMB, HEAD, AND SILL DETAILS

Leakage Coefficient per lineal ft of frame
pressure range 0 to 100 in. of water

A	B	Remarks
$<4 \times 10^{-6}$	0	(LDS B-9)

Notes
1. Frame to be continuous, with all joints and corners to be welded gas-tight.
2. Paint exposed face of concrete opening with epoxy and set frame in wet epoxy, sealing anchor leak path in frame to concrete contact.

APPLICATION DATA SHEET	No. I-A-8	Page 1 of 2

TITLE

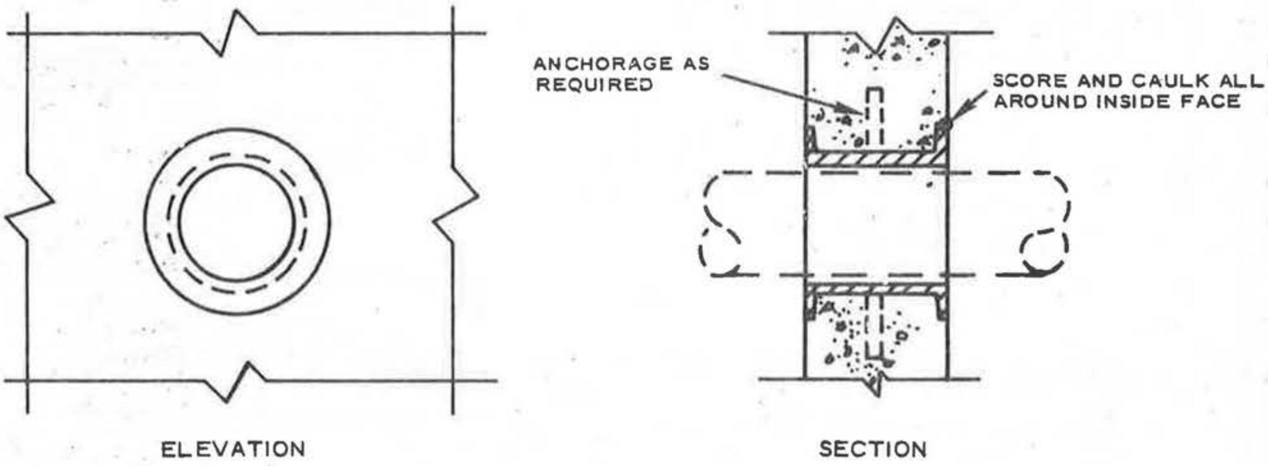
Concrete Structure; Inserts Through Wall

DESCRIPTION

Prefabricated metal inserts for pipes, ducts, conduit, etc.
Leakage between concrete and insert
Leakage between insert and pipe or duct (ADS III-D)

CASE 1

Single insert, flanged, cast with wall



TYPICAL DETAIL

Leakage Coefficient — per in. of insert circumference
pressure range 0 to 100 in. water

No Caulking		With Caulking		Remarks
A*	B	A	B	
1.3×10^{-5}	0	10^{-6}	0	(LDS B-9)

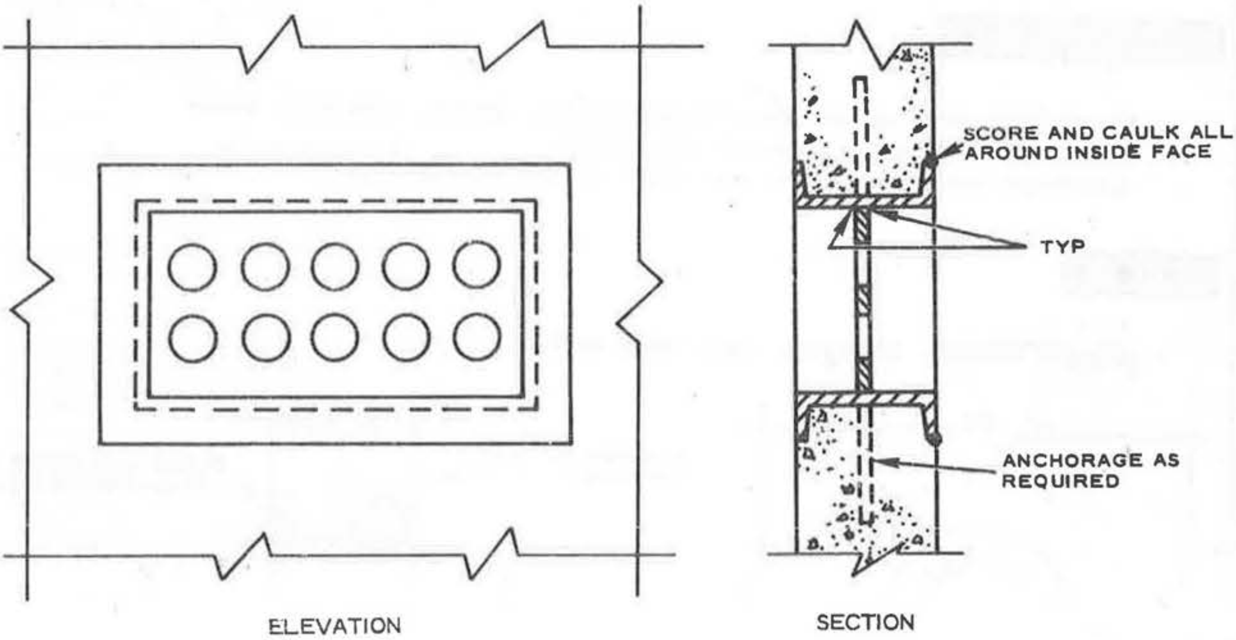
Notes
1. Insert to be solid joint, either casting or welded.
2. Surface of insert to be clean and free of grease, loose scale, etc., prior to placing concrete to ensure good bond.
3. Caulking to be used if imperfect bond between concrete and insert is obtained.

*Assuming metal-to-concrete bond remains intact

APPLICATION DATA SHEET	No. I-A-8	Page 2 of 2

CASE 2

Multiple insert, flanged, cast with wall



TYPICAL DETAIL

Leakage Coefficient per lineal ft of insert frame circumference pressure range 0 to 100 in. water

No Caulking		With Caulking		Remarks
A	B	A	B	
1.3×10^{-4}	0	10^{-6}		(LDS B-9)

Notes
1. Insert to be solid joint, either casting or welded.
2. Surface of insert to be clean and free of grease, loose scale, etc., prior to placing concrete to ensure good bond.
3. Caulking to be used if imperfect bond between concrete and insert is obtained.

APPLICATION DATA SHEET	No. I-A-9	Page 1 of 3

TITLE

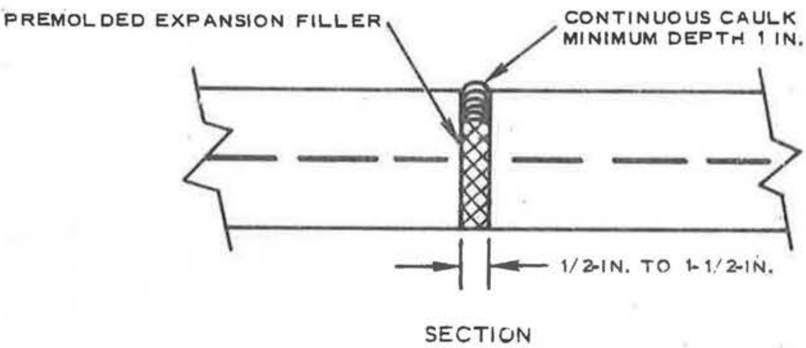
Concrete Structure; Joints and Cracks

DESCRIPTION

Reinforced concrete structure
Joints and cracks in walls and floor slabs

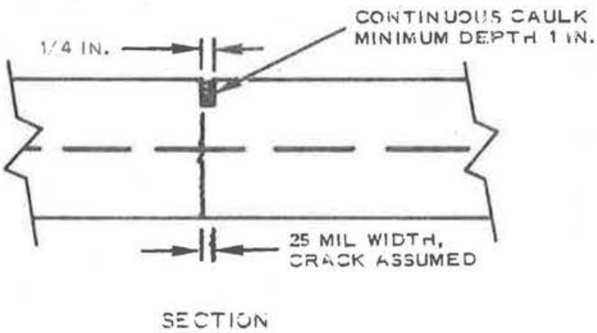
CASE 1

Expansion joint



CASE 2

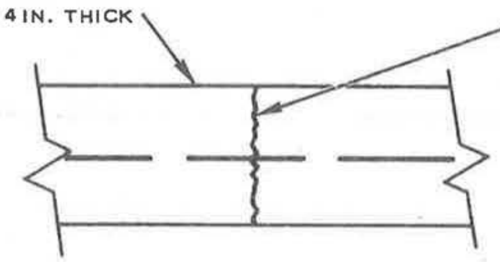
Contraction (weakened plane) joint



APPLICATION DATA SHEET	No. I-A-9	Page 2 of 3

CASE 3

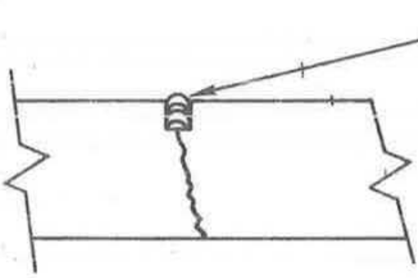
Cold joint



SECTION

CASE 4

Crack



SECTION

APPLICATION DATA SHEET	No. I-A-9	Page 3 of 3

Leakage Coefficient   per lineal ft of joint or crack
pressure range 0 to 50 in. water

Case	Without Caulking		With Caulking		Remarks
	A	B	A	B	
1	12.3	0	8×10^{-6}	0	LDS B-8
2	1.5	0	8×10^{-6}	0	LDS B-8
3	$<2.4 \times 10^{-4}$	0	Not Applicable		LDS B-5
4	Note 3		8×10^{-6}	0	LDS B-8

Notes

1. For maximum bond between concrete and caulking
   a) Avoid using oil or wax-coated premolded strips which may contaminate joint surface.
   b) Avoid etching joint surface (side walls).
   c) Use wire brush to clean joint side walls.
   d) Use primer on both side walls before applying caulk.
2. See LDS B-8, page 2 of 2, for further comments.
3. The leakage through a crack depends on the wall thickness, width of crack, length of crack, as well as on pressure. When these parameters are known, the leakage can be determined by the theoretical crack equation as given on LDS D-3, page 2 of 3.

CONTENTS
APPLICATION DATA SHEETS

II. STEEL STRUCTURES

APPLICATION DATA SHEET	No. II-A-1	Page 1 of 3

TITLE

Steel Structure, Insulated Metal Panels;
Leak Path Key Drawing

DESCRIPTION

Steel frame structure, footings and floor slab of reinforced concrete

Siding composed of field assembled insulated metal panels fastened to steel frame

Notes

1. The suggested details in the following Application Data Sheets concentrate on the problem of sealing the inner panels, and the outer panels have been omitted for clarity in most instances. However, the designer must ensure that the method specified for fastening the insulation and outer panel does not violate the integrity of the inner panel in manners other than those recommended.
2. Tests have indicated that the inner panel provides virtually all of the leak resistance of the wall system. Not only are edge and end laps in the exterior panel more difficult to seal, the fluted configuration is virtually impossible to close and seal at the curb and eave lines. Rubber closure strips provided for sealing ends of the flutes are effective in keeping out foreign objects, but due to irregularity of panel surface these closure strips offer little resistance to passage of air under pressure.
3. Many commercial wall panel sections are produced in 1 to 2-ft widths, and selection of the maximum suitable width naturally reduces the amount of joint in a given wall surface. This concept may be carried one step further by specifying shop fabrication and joining of multiple widths of the inner panels, with insulation and outer panels being installed per normal field assembly methods. This concept would reduce the amount of edge and/or end laps which are made in the field, with an attendant reduction in leakage due to the lower quality field joints.
4. It has been determined that the normal factory-installed caulking for edge laps is inadequate for maximum resistance to air leakage, and supplementary measures should be taken by addition of extra caulking compound to female portion of edge lap prior to fastening or crimping sections together.
5. Caulking mastics to meet specifications of Presstite Eng. Co., Series No. 579, gun grade, tapes, or knife grade consistency per installation requirements. Caulking to be mixed and applied per manufacturer's instructions when two-part polysulphide sealing compound is recommended.

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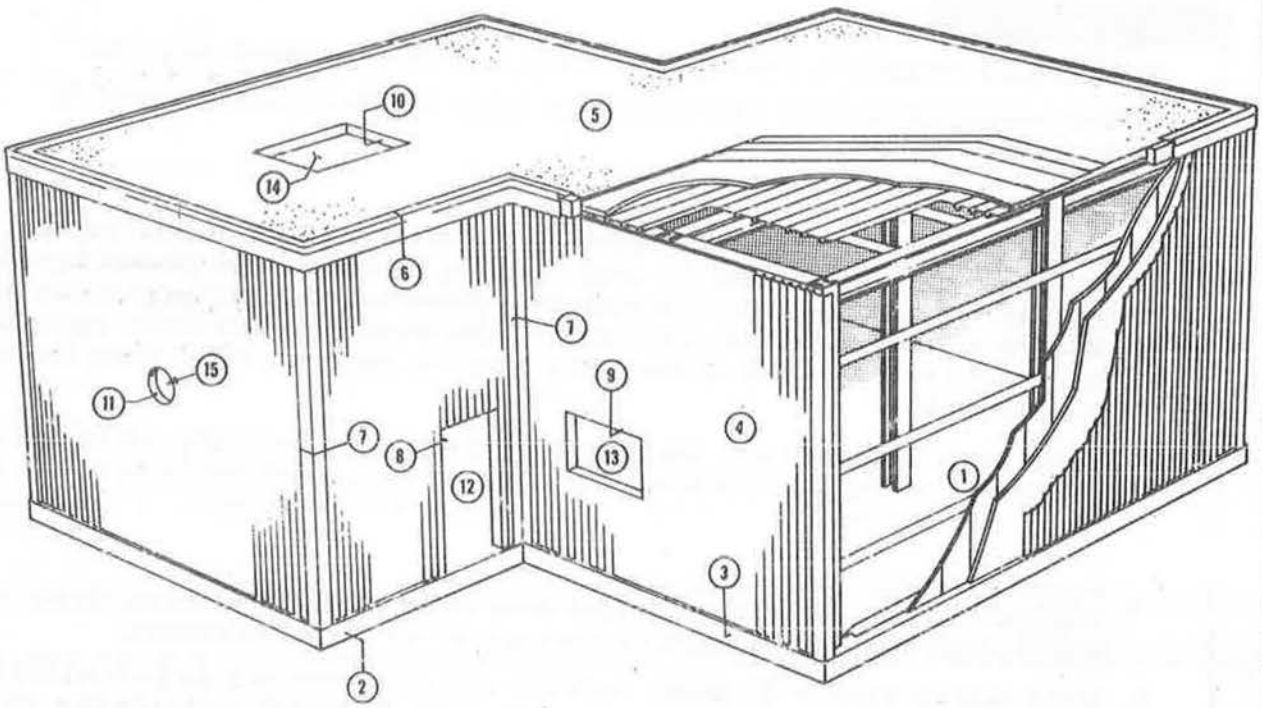
APPLICATION DATA SHEET	Figure II-A-1	Page 2 of 3



APPLICATION DATA SHEET	No. II-A-1	Page 3 of 3

LEAK PATH LEGEND

Path No.	Description	ADS No.
(1)	Floor Slab	I-A-2
(2)	Juncture of Floor Slab, Footing, and Curb	I-A-3
(3)	Curb Detail	II-A-2
(4)	Wall	II-A-3
(5)	Roof	II-A-4
(6)	Eave	II-A-5
(7)	Corners	II-A-6
(8)	Framed Door Opening in Wall	II-A-7
(9)	Framed Louver Opening in Wall	II-A-8
(10)	Framed Roof Opening	II-A-9
(11)	Inserts Through Wall	II-A-10
(12)	Doors	III-A
(13)	Louvers	III-B
(14)	Roof Hatches	III-C
(15)	Piping Penetrations	III-D

APPLICATION DATA SHEET	No. II-A-2	Page 1 of 3

TITLE

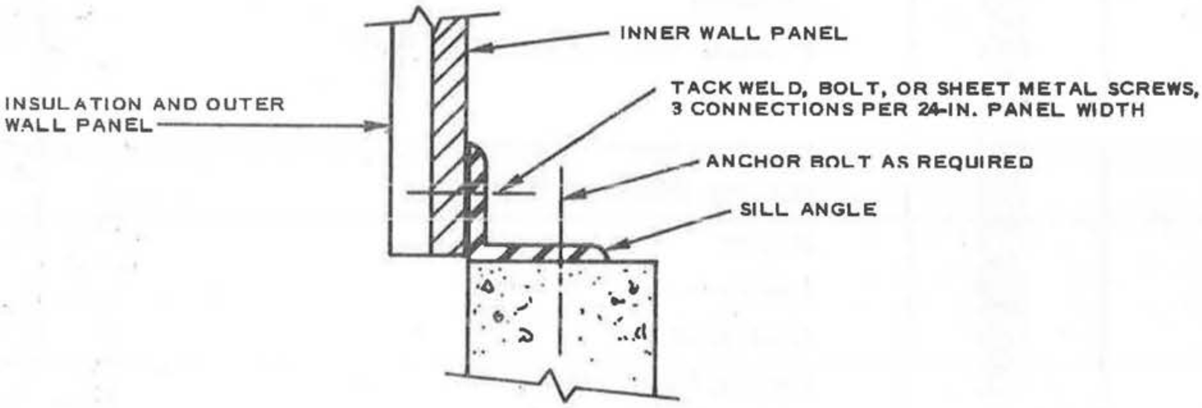
Steel Structure, Insulated Metal Panels; Curb detail

DESCRIPTION

Intersection of insulated metal wall panels with concrete curb
Leakage between sill angle and curb and between sill angle and wall panel

CASE 1

Standard construction; sill angle bolted to curb; wall panel welded, bolted or screwed to sill angle; no protection between bearing surfaces



TYPICAL DETAIL

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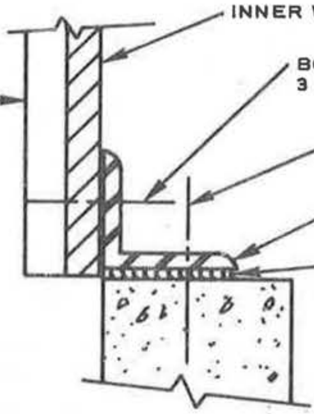
APPLICATION DATA SHEET	No. II-A-2	Page 2 of 3

CASE 2

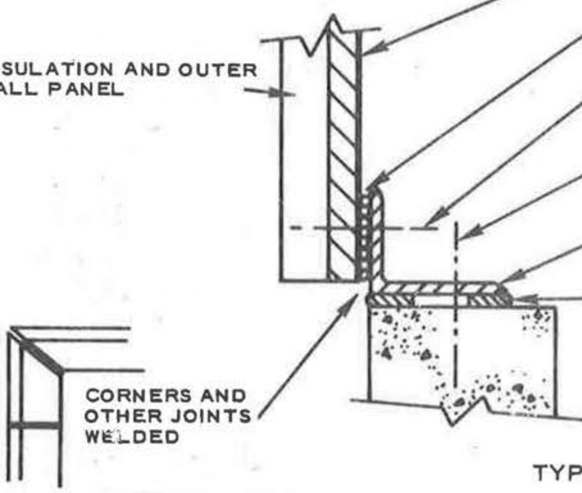
Standard construction; sill angle bolted to curb; wall panel bolted or screwed to sill angle; mastic protection between sill angle and curb



TYPICAL DETAIL

CASE 3

Improved construction; sill angle bolted to curb; wall panel bolted or screwed to sill angle; neoprene gasket between sill angle and curb; mastic between concrete, wall panel, and sill angle



TYPICAL DETAIL

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APPLICATION DATA SHEET	No. II-A-2	Page 3 of 3

Leakage Coefficient per lineal ft of curb
pressure range 0 to 20 in. water

Case	A	B	Remarks
1. Std construction	0.62	1.27	Developed from test configuration shown in LDS C-8
2. Std construction	0.4	0.1	
3. Std construction	$<3 \times 10^{-8}$	0	Mastic (continuous) between wall panel and sill angle
4. Improved construction	$<3 \times 10^{-8}$	0	

Notes

1. Sill angle to be continuous around structure, with all joints and corners to be welded before caulk and gasket is applied.
2. Drill holes in wall panel and sill angle prior to fastening; caulk hole for minimum leakage.
3. Gasket to be neoprene or butyl rubber.
   Concrete surface to be clean or treated as recommended by polysulphide manufacturer.
   Various Epoxy-thiokol mixtures are available also.
   Waviness of concrete, sill angle, and inner wall panel limit effectiveness of seal.
   Edge lap at curb (sill angle) must be fully caulked.

APPLICATION DATA SHEET	No. II-A-3	Page 1 of 4

TITLE

Steel Structure, Insulated Metal Panels; Wall

DESCRIPTION

Insulated wall panels fastened to steel frame
Wall panels joined by overlapping end laps and male-female edge laps
Leakage through joints between wall panels and through screw penetrations at structural attachment

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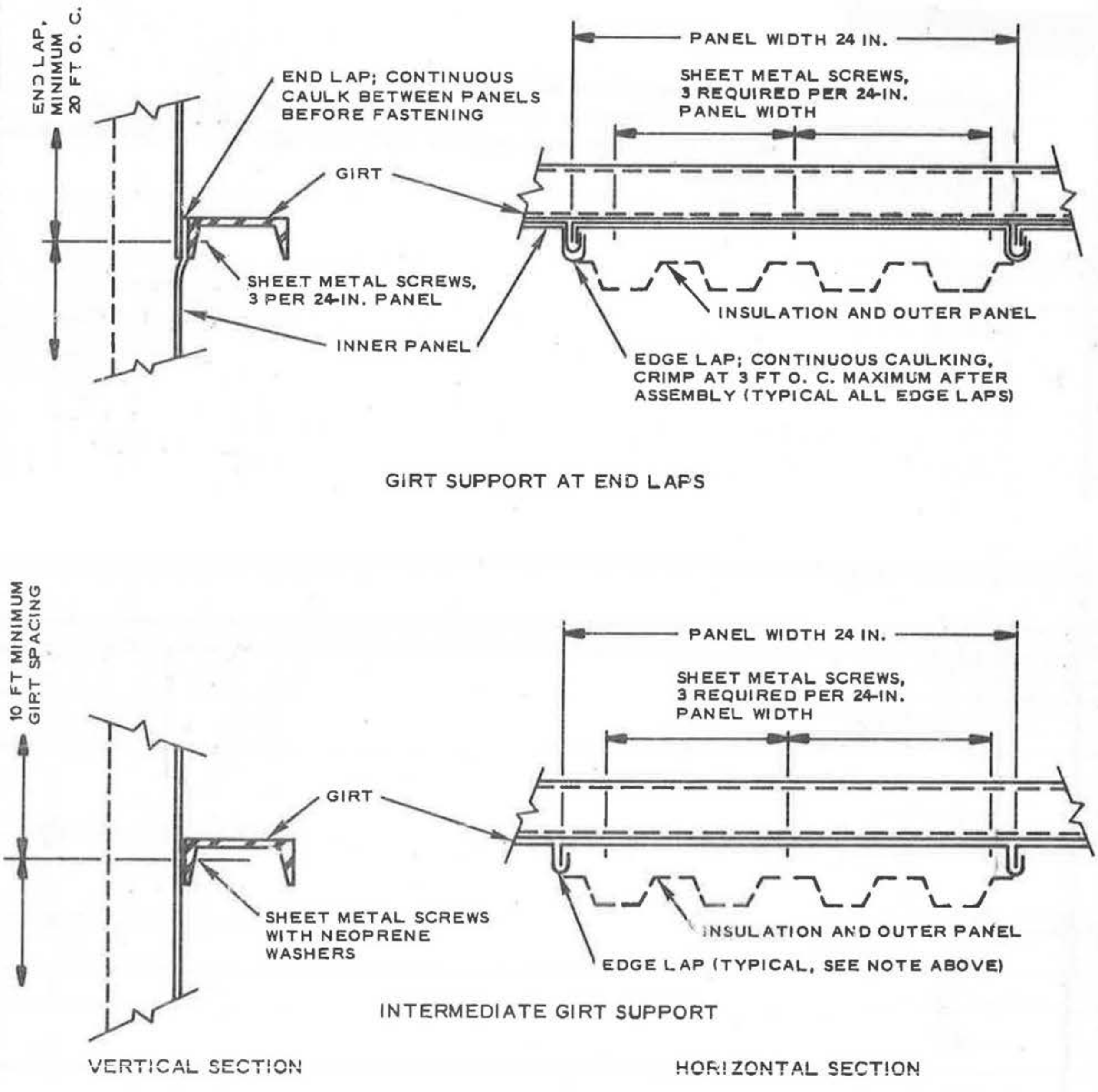
APPLICATION DATA SHEET	No. II-A-3	Page 2 of 4

CASE 1

Standard construction



TYPICAL DETAIL

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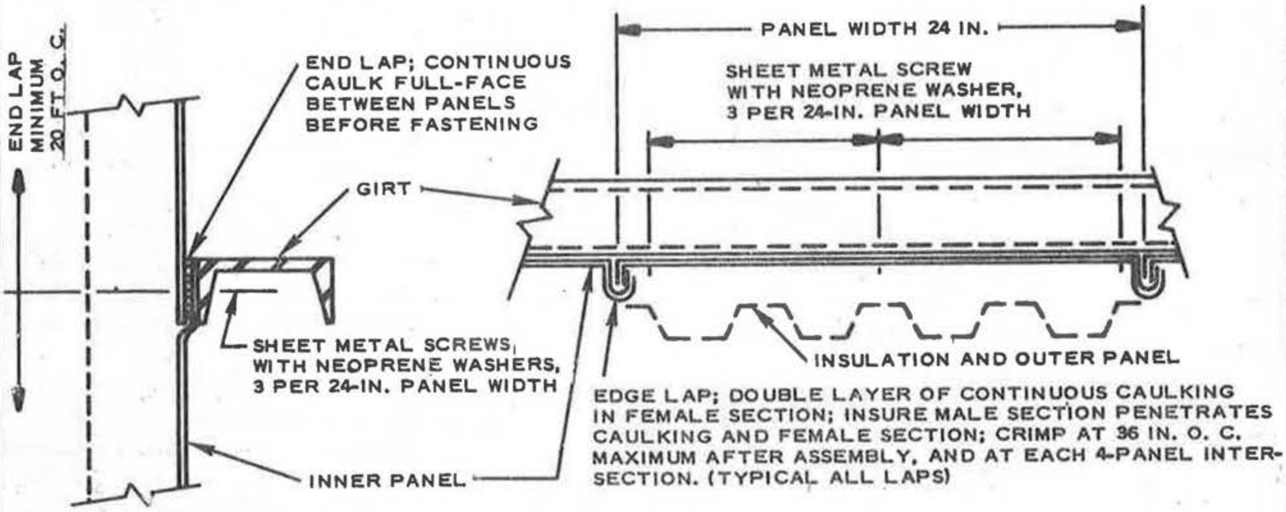
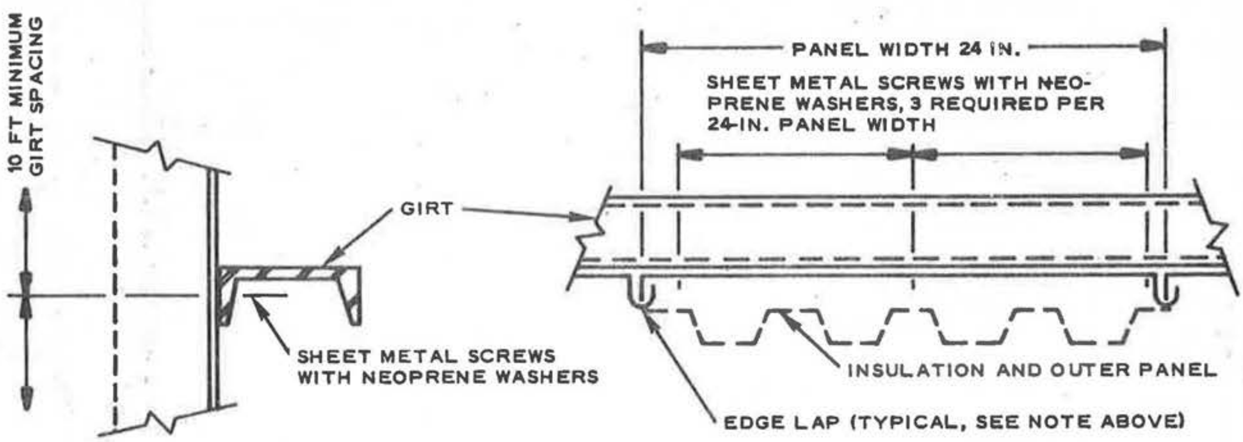
APPLICATION DATA SHEET	No. II-A-3	Page 3 of 4

CASE 2

Improved construction



GIRT SUPPORT AT END LAPS



INTERMEDIATE GIRT SUPPORT

VERTICAL SECTION — HORIZONTAL SECTION

TYPICAL DETAIL

Leakage Coefficient per sq ft of wall surface
pressure range 0 to 8 in. water
Computed from a 2 ft by 20 ft module

Case	A	B	Remarks
1. Std construction	2.2×10^{-3}	5×10^{-4}	LDS C-5
2. Improved construction	2×10^{-4}	5×10^{-7}	

Notes

1. For improved construction (Case 2), care must be taken at edge laps to ensure penetration of male lip into female portion of lap prior to crimping. Second layer of caulking in female section is required to ensure filling of lap with caulking compound. Crimp at intersection of four panels.
2. Continuous layer of caulking is required between panels at end laps.
3. Sheet-metal screws at girts must be tight enough to seal gasket (washer) to panel. However, excess tightening must be prevented to avoid mechanical destruction of the washer.
4. Installation of insulation and outer panel to be per manufacturer's recommendations. Care must be taken not to violate inner panel seal.
5. Inner panel and girt must be drilled for fasteners. Punching not permitted. Caulk hole for minimum leakage.
6. For wall heights utilizing one length of inner panel (where end laps and girts between inner panels are eliminated), leakage is reduced (see LDS C-3 through C-7).
7. Leak paths involved in the above estimations:
   a) sheet metal screws: 3
   b) crimps: 6
   c) end-laps: 2 ft
   d) edge lap: 20 ft
   e) end-edge lap intersection: 1

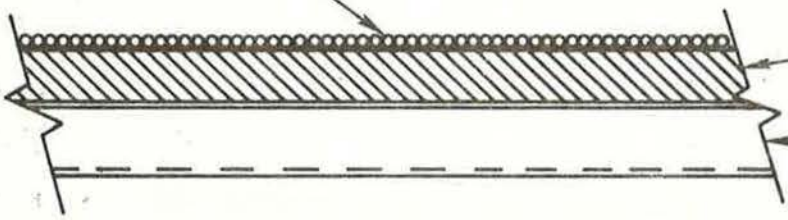
APPLICATION DATA SHEET	No. II-A-4	Page 1 of 1

TITLE

Steel structure, Insulated Metal Panels; Roof

DESCRIPTION

Steel roof deck
Five-ply built-up roofing over decking
Leakage through roof surface area
Leakage through eave (ADS II-A-5)



TYPICAL DETAIL

Leakage Coefficient — per sq ft of roof slab surface
pressure range 0 to 5 in. water (LDS A-8)

A	B	Remarks
6×10^{-5}	0	Coefficients valid if eave is sealed as shown in ADS II-A-5

Notes

1. Built-up roofing to be applied in accordance with best roofing practices. Method of application should be clearly defined in project specifications.

APPLICATION DATA SHEET	No. II-A-5	Page 1 of 2

TITLE

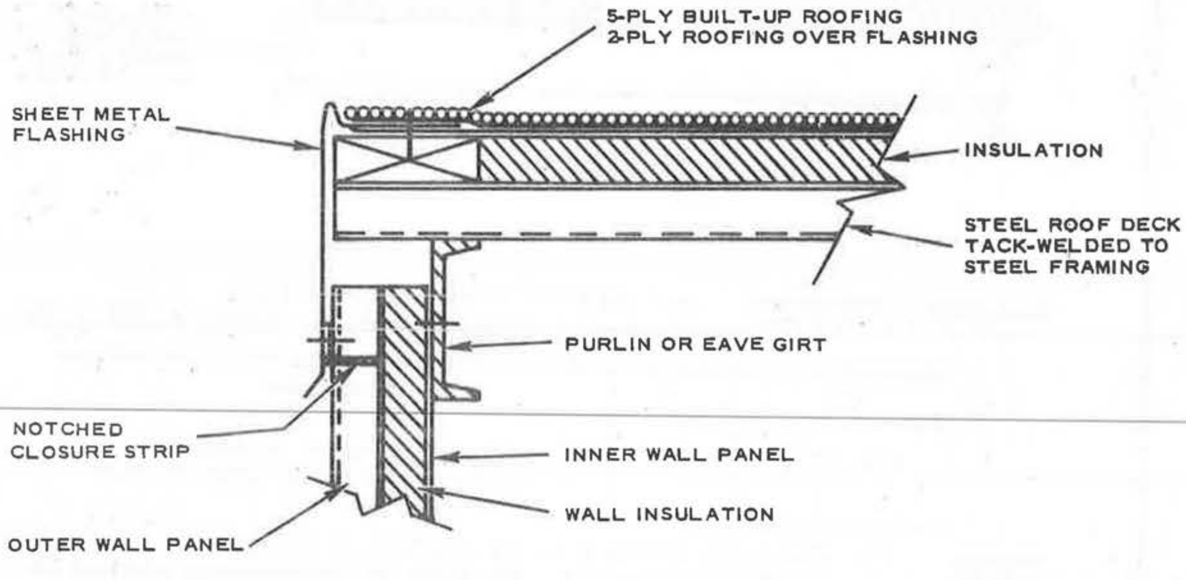
Steel Structure, Insulated Metal Panels; Eave

DESCRIPTION

Insulated metal panel wall
Steel roof deck with 5-ply built-up roofing
Leakage through eave joint

CASE 1

No parapet, standard construction



TYPICAL DETAIL

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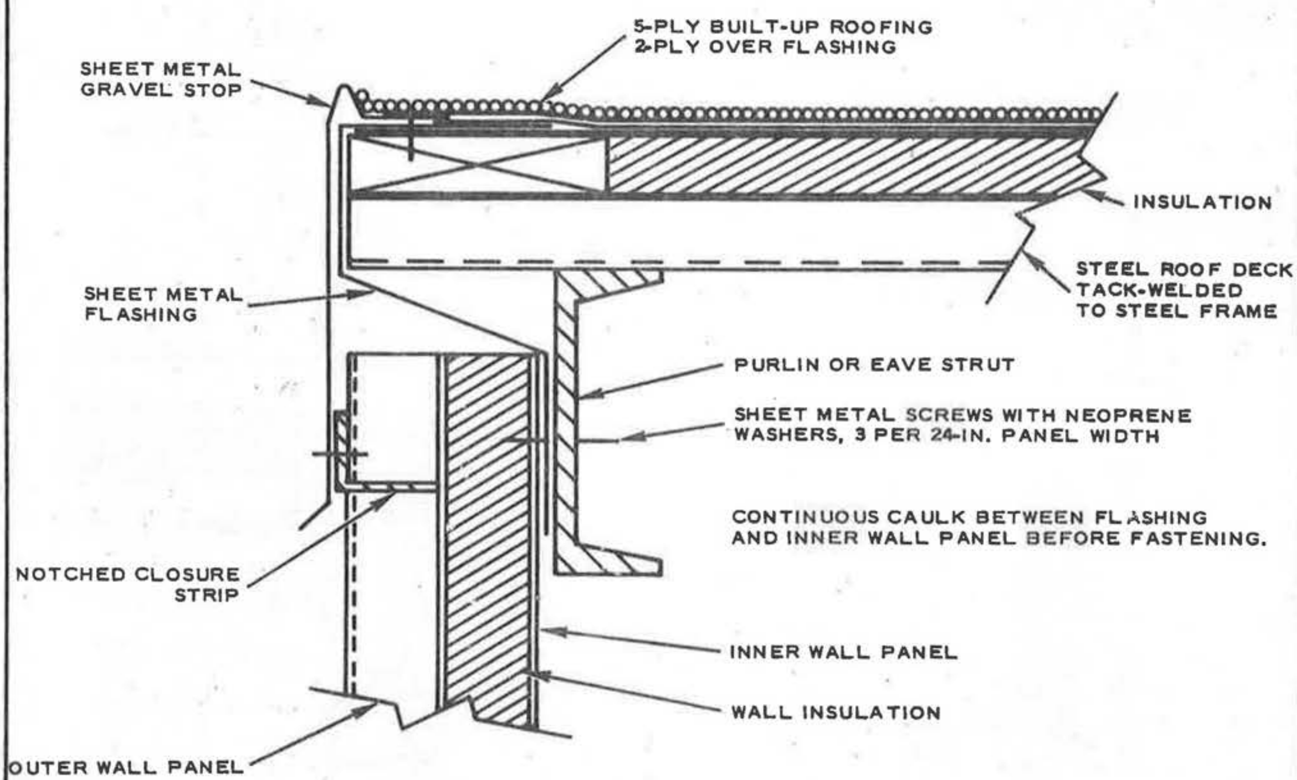
APPLICATION DATA SHEET	No. II-A-5	Page 2 of 2

CASE 2

No parapet; improved construction



TYPICAL DETAIL

Leakage Coefficient per lineal ft of eave
pressure range 0 to 4 in. water

Case	A	B	Remarks
1. Std construction	> 7	-	LDS C-2
2. Improved construction	$< 6 \times 10^{-5}$	0	majority of leakage through 5-ply

Notes
1. All joints and corners of flashing must be soldered and leak tight for improved construction (Case 2).
2. Edge lap should be fully caulked at end of flashing.
3. Preformed caulk as tape is effective.

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APPLICATION DATA SHEET	No. II-A-6	Page 1 of 3

TITLE

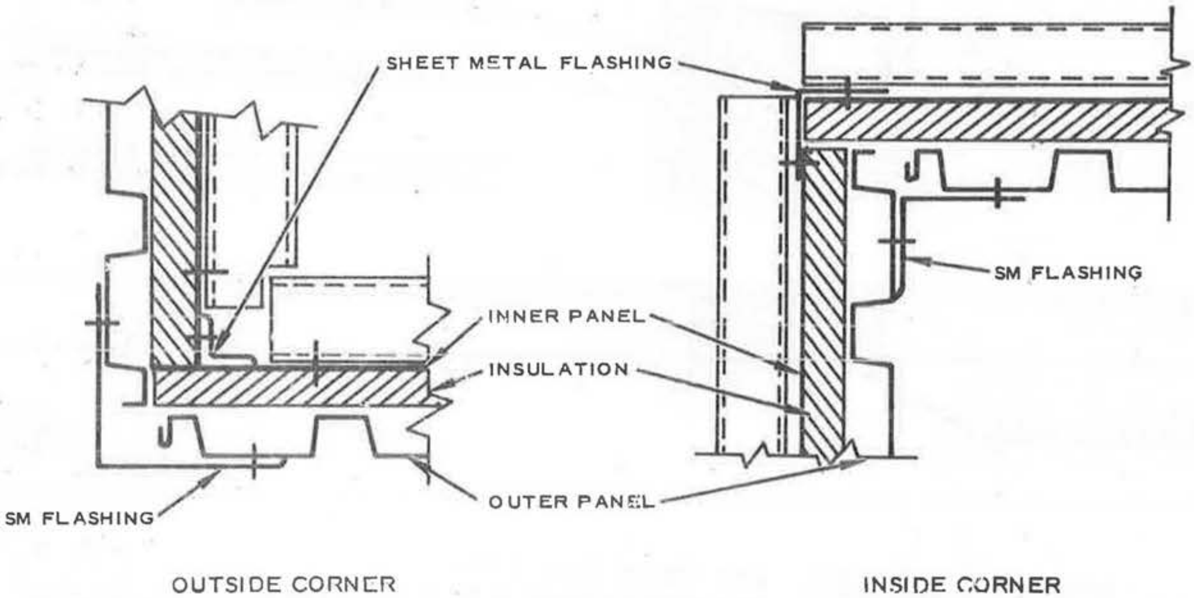
Steel Structure, Insulated Metal Panels; Corners

DESCRIPTION

Corner intersections of insulated metal wall panels
Leakage through corners

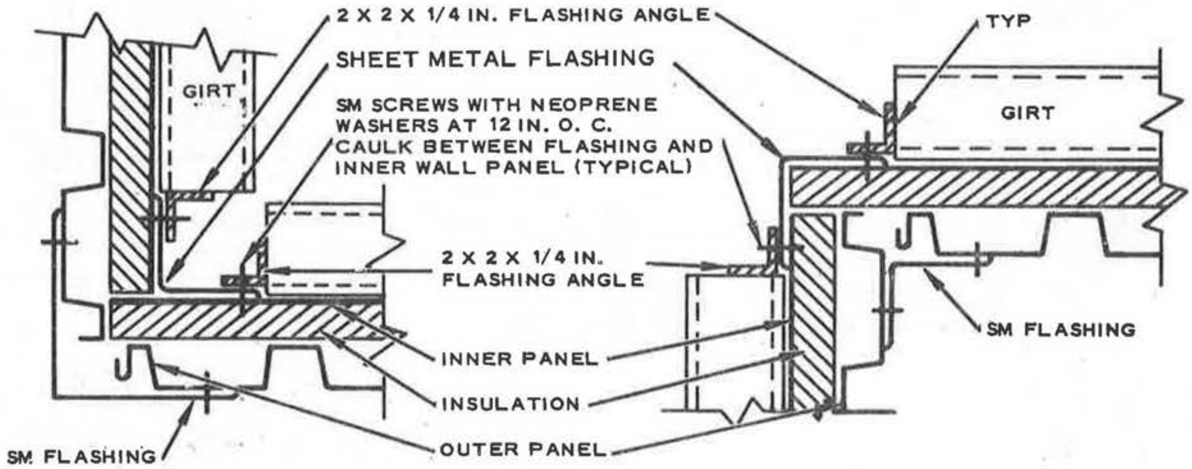
CASE 1

Standard Construction



CASE 2

Improved construction

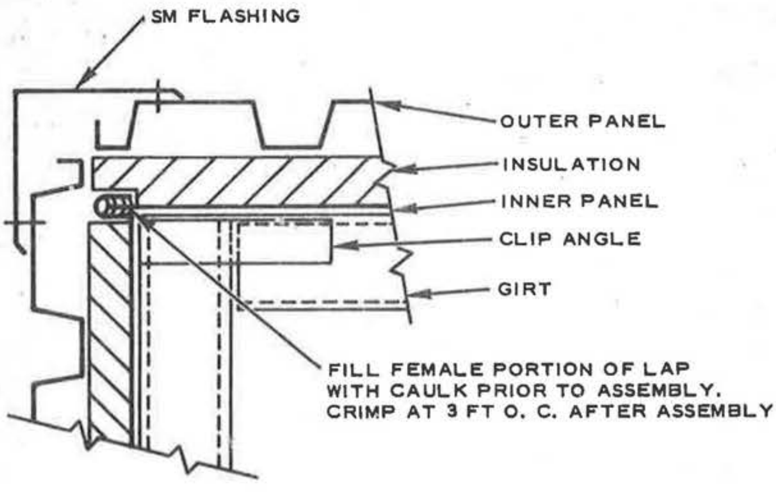


OUTSIDE CORNER

INSIDE CORNER

CASE 3

Improved construction



OUTSIDE CORNER

APPLICATION DATA SHEET	No. II-A-6	Page 3 of 3

Leakage Coefficient   per lineal ft of corner
pressure range 0 to 5 in. water

Case	A	B	Remarks
1. Std construction	0.4	0.1	(LDS C-8 Test 2)
2. Improved construction	$<10^{-8}$	$<10^{-8}$	(LDS C-6) (LDS C-7)
3. Improved construction	$<1.5 \times 10^{-4}$	$<1 \times 10^{-4}$	Outside corners only

Notes
1. Exterior flashing to be same material and finish as outside wall panel. Interior flashing to be same as inner panel.
2. For improved construction, corner flashing must join and form seal with eave flashing.

APPLICATION DATA SHEET	No. II-A-7	Page 1 of 3

TITLE

Steel Structure, Insulated Metal Panels; Framed Door Opening in Wall

DESCRIPTION

Prefabricated metal door frames
Leakage between metal panel wall and door frame
Leakage between frame and door, or through door (ADS III-A)

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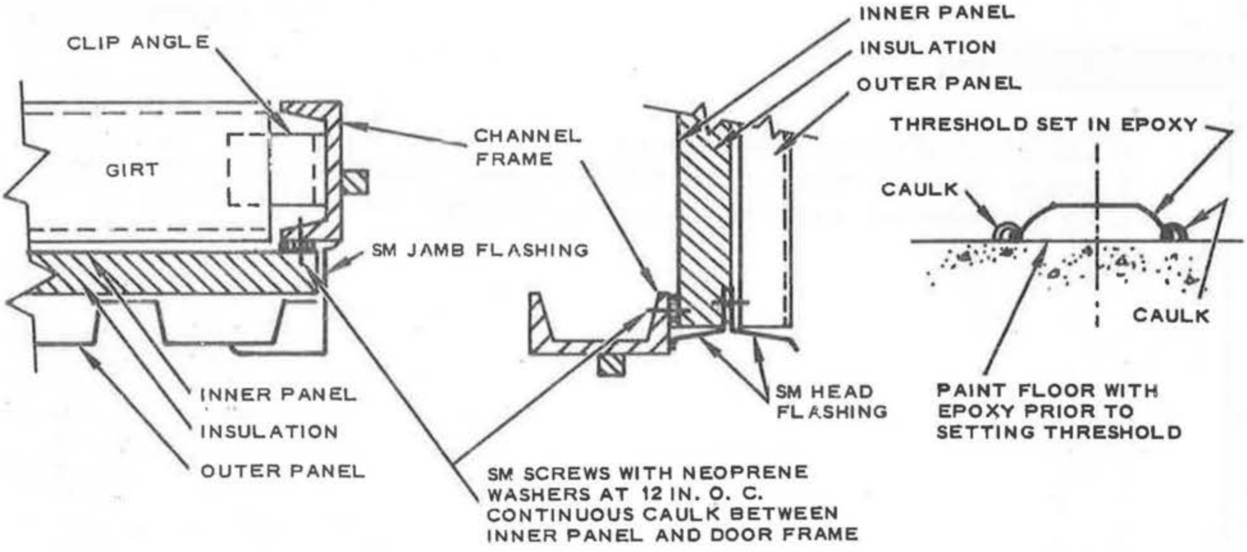
APPLICATION DATA SHEET	No. II-A-7	Page 2 of 3

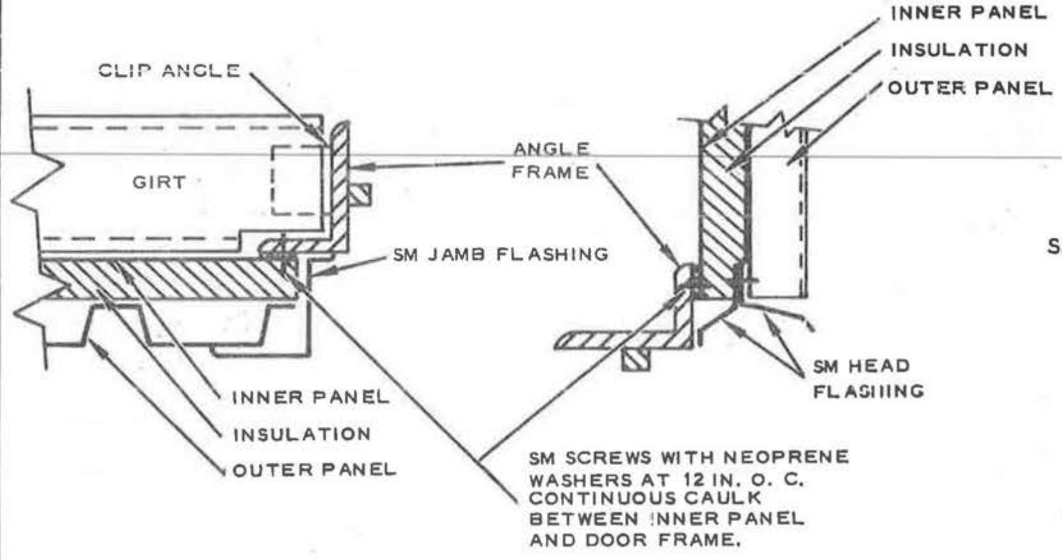
CASE 1

Structural steel frame



JAMB HEAD SILL

STEEL CHANNEL FRAME



SILL
SAME AS ABOVE

JAMB HEAD

STEEL ANGLE FRAME

300<

APPLICATION DATA SHEET	No. II-A-7	Page 3 of 3

Leakage Coefficient — per lineal ft of door frame including sill pressure range 0 to 20 in. water

A	B	Remarks
$< 10^{-6}$	0	No detectable leak at 20 in. of water except through sill

Notes
1. Steel frame to be welded at corners.
2. Paint floor surface under threshold with Epoxy and set threshold in wet Epoxy (see ADS I-A-7, Case 1, for leakage at sill).

APPLICATION DATA SHEET	No. II-A-8	Page 1 of 1

TITLE

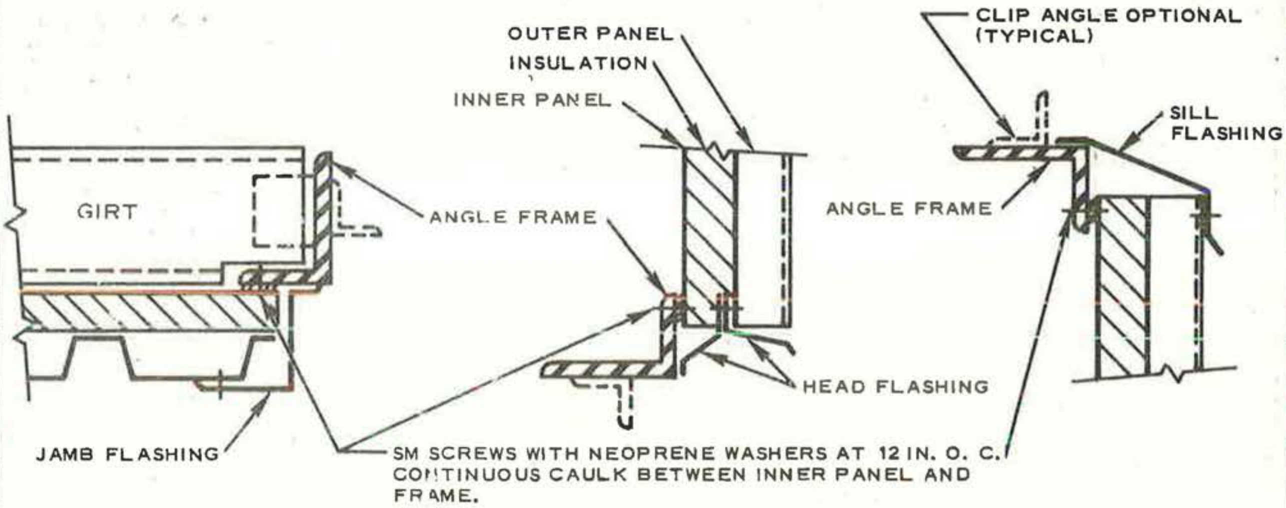
Steel Structure, Insulated Metal Panels; Framed Louver Opening in Wall

DESCRIPTION

Prefabricated metal louver frame
Leakage between metal panel wall and louver frame
Leakage between frame and louver, or through louver
(ADS III-B)

CASE I

Steel angle frame



Leakage Coefficient: per lineal ft of frame
pressure range 0 to 20 in. of water

A	B	Remarks
$<10^{-9}$	0	No detectable leak at 20 in.

Notes
1. Steel frame to be welded at corners before caulking.
2. Preformed tapes recommended.

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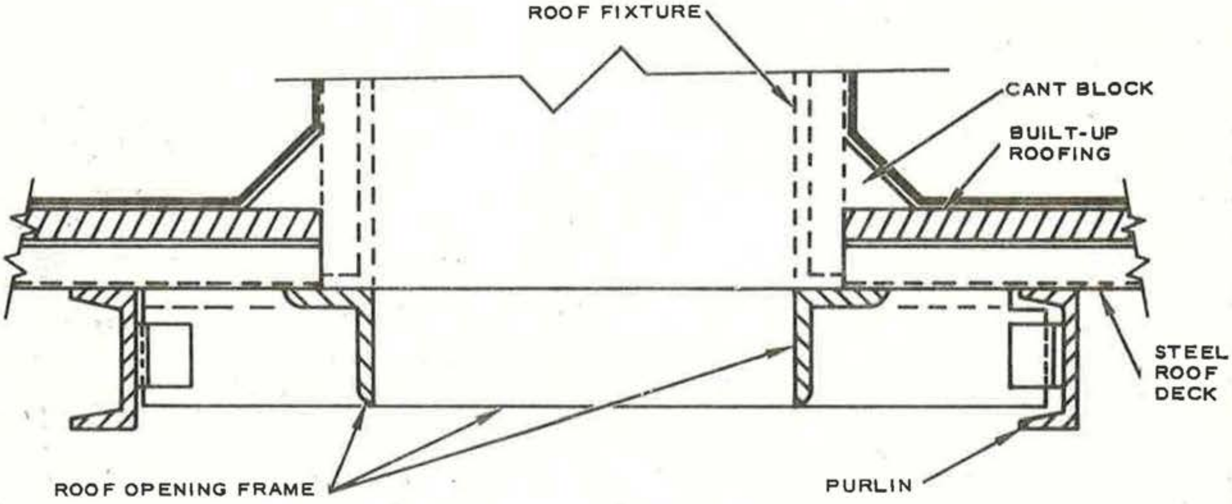
APPLICATION DATA SHEET	No. II-A-9	Page 1 of 1

TITLE

Steel Structure, Insulated Metal Panels; Framed Roof Opening

DESCRIPTION

Steel framed roof opening
Leakage between frame and roof system
Leakage frame and fixture, or through roof fixture (ADS III-C)



SECTION

Leakage Coefficient per lineal ft of frame
pressure range 0 to 5 in. water

A	B	Remarks
$< 10^{-8}$	-	see Note 2

Notes
1. Built-up roofing must be properly integrated and flashed to roof fixture. See ADS IV-C for installation details of fixture.
2. Leakage can be disregarded if 5-ply roofing is properly applied and flashed to roof fixture (LDS A-8).

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APPLICATION DATA SHEET	No. II-A-10	Page 1 of 3

TITLE

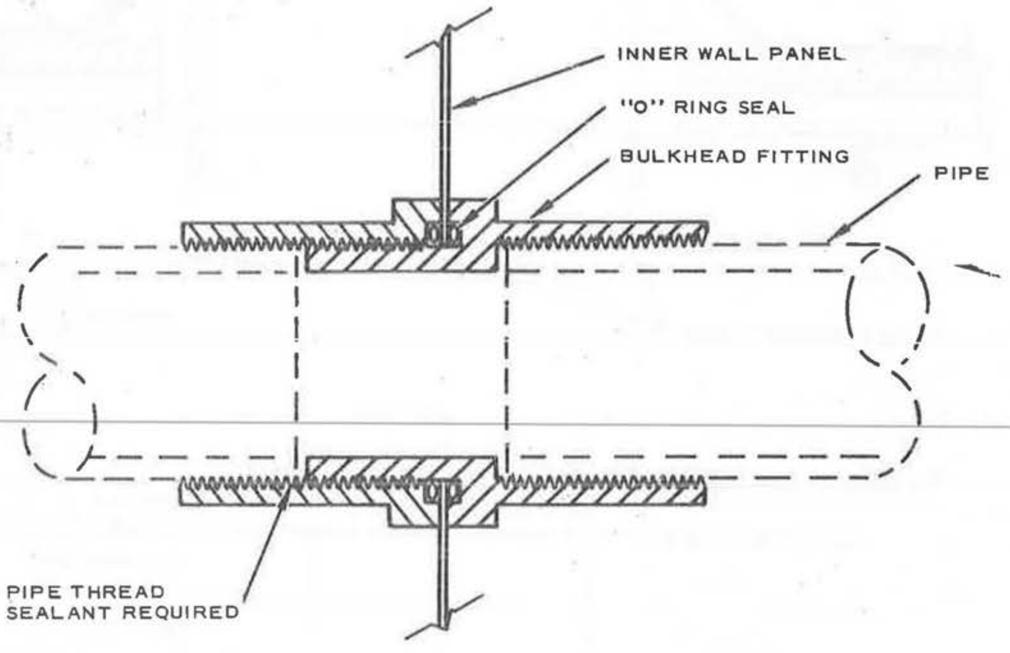
Steel Structure, Insulated Metal Panels; Inserts Through Wall

DESCRIPTION

Prefabricated metal inserts for pipe, conduit, etc.
Leakage between wall and insert
Leakage between insert and pipe or duct (ADS III-D)

CASE 1

Pipe bulkhead fitting



SECTION

Leakage Coefficient — see Notes
pressure range: limit of inner wall panel (LDS A-1)

Notes — Bulkhead fittings in metal panel walls not recommended for pipes without good support.

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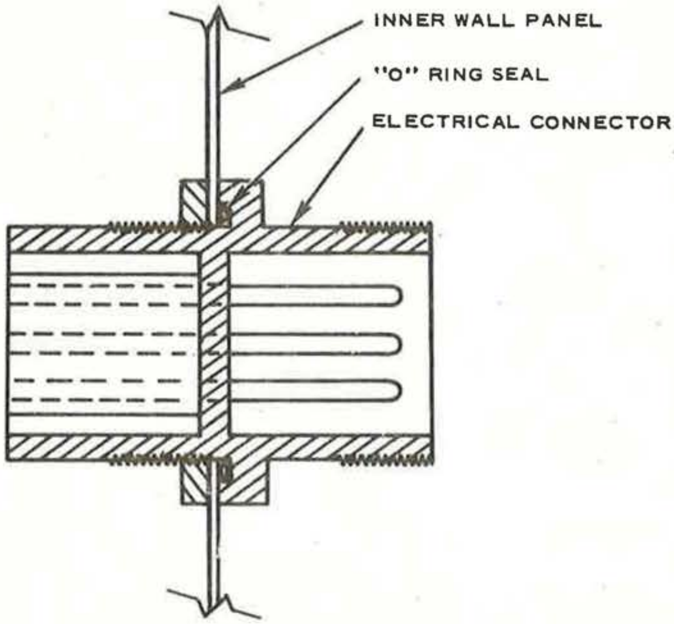
APPLICATION DATA SHEET	No. II-A-10	Page 2 of 3

CASE 2

Electrical connector



Leakage Coefficient — see Notes
pressure range 0 to 20 in. water
(LDS A-5)

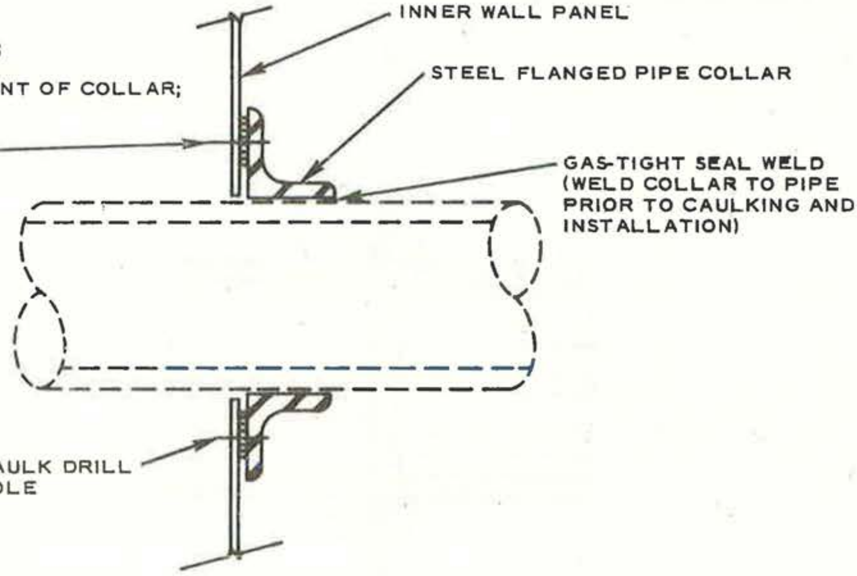
Notes

1. Refer to Cannon Electric Co. Reliability Test Report No. 13 (6-7-61) for additional leak data. The report states leak values for their KDT-receptacle connector is $<24 \times 10^{-9}$ ft^3/min at 30 psi.
2. Pressure limit is that of wall.

APPLICATION DATA SHEET	No. II-A-10	Page 3 of 3

CASE 3

Single insert, flanged



SECTION

Leakage Coefficient per in. of insert circumference pressure range 0 to 20 in. water

A	B	Remarks
$<10^{-9}$	-	(LDS C-7)

Notes 1. Insert and wall not to support any pipe load. Adequate hangers or supports attached to structural frame must be provided.

CASE 4

Framed insert
Details and coefficients same as found in ADS II-A-8, Case 1, "Framed louver opening in wall."

Notes 1. Framed insert can be used for single or multiple pipe penetrations.

Source unable to furnish pages IV-234 through IV-302. Document is being released in interest of making as much information available as possible.

NTIS

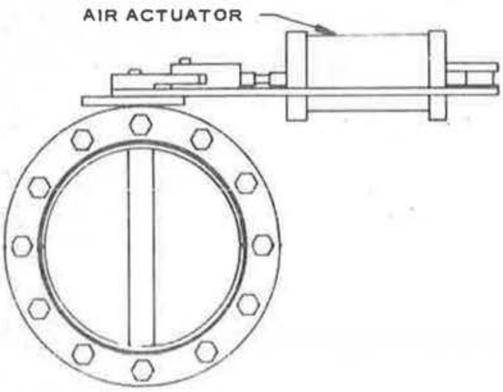
APPLICATION DATA SHEET	No. III-A-1	Page 1 of 1

TITLE

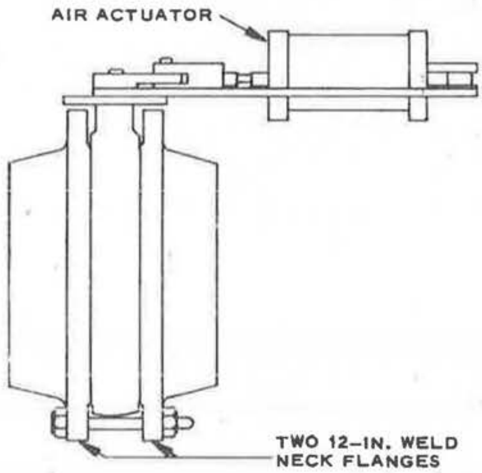
Building Components, Butterfly Valve

DESCRIPTION

The 12-in. valve is bolted between two flanges by means of 12 bolts. A continuous neoprene gasket is used as the seat for the steel valve. Leakage around (1) valve and gasket, and (2) valve shaft (ADS A-2).



FRONT ELEVATION



SIDE ELEVATION

Leakage Coefficient

No detectable leak at 13.8 psig

APPLICATION DATA SHEET	No. III-A-2	Page 1 of 4

TITLE

Building Components, Doors; Personnel Access Doors

DESCRIPTION

Personnel access doors
Leakage between door and frame and through door

CASE 1

Hollow metal doors [LDS A-4(1), -4(2)]

Leakage Coefficients

Per 3 x 7-ft door
Pressure range 0 to 7 in. water

Type of Door and Weatherstripping	Leakage Coefficient		Door Opening
	A	B	
Hollow metal door, metal interlocking weatherstripping	12	34	Out In
Hollow metal door, metal interlocking and gasketed weatherstripping	5 4	27 22	Out In
Hollow metal door, sound insulating weatherstripping	23 0	41 35	Out In

Notes

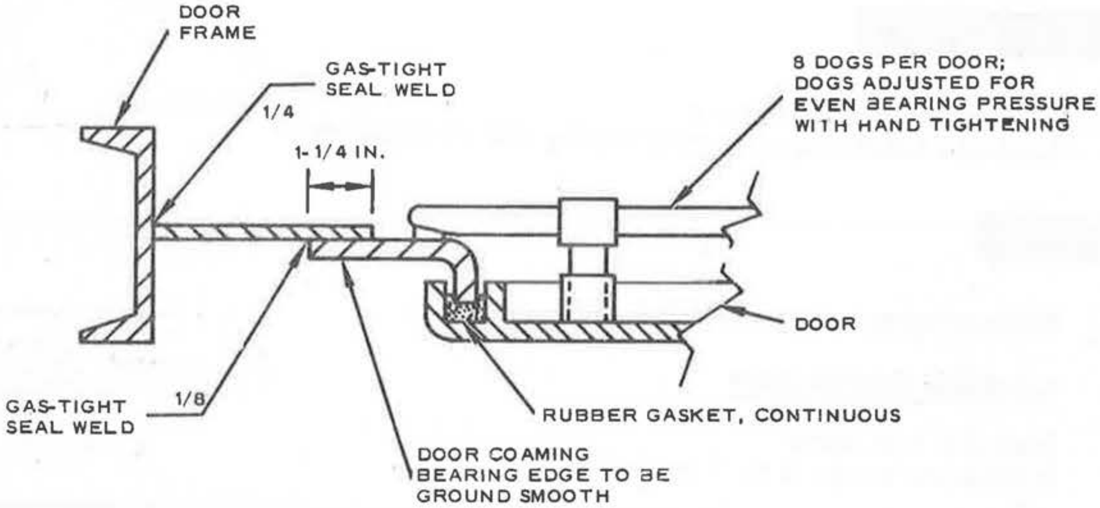
1. Refer to LDS A-4 (1 through 4) for additional information regarding description, limitations, extrapolations, etc.

2. At higher pressures, turbulent flow exists and linear extrapolations are not permissible.

APPLICATION DATA SHEET	No. III-A-2	Page 2 of 4

CASE 2

Marine doors [LDS A-4(3), -4(4)]



JAMB, HEAD, AND SILL DETAIL

Leakage Coefficients

Per 3 by 7-ft door
Pressure range 0 to 50 in. water

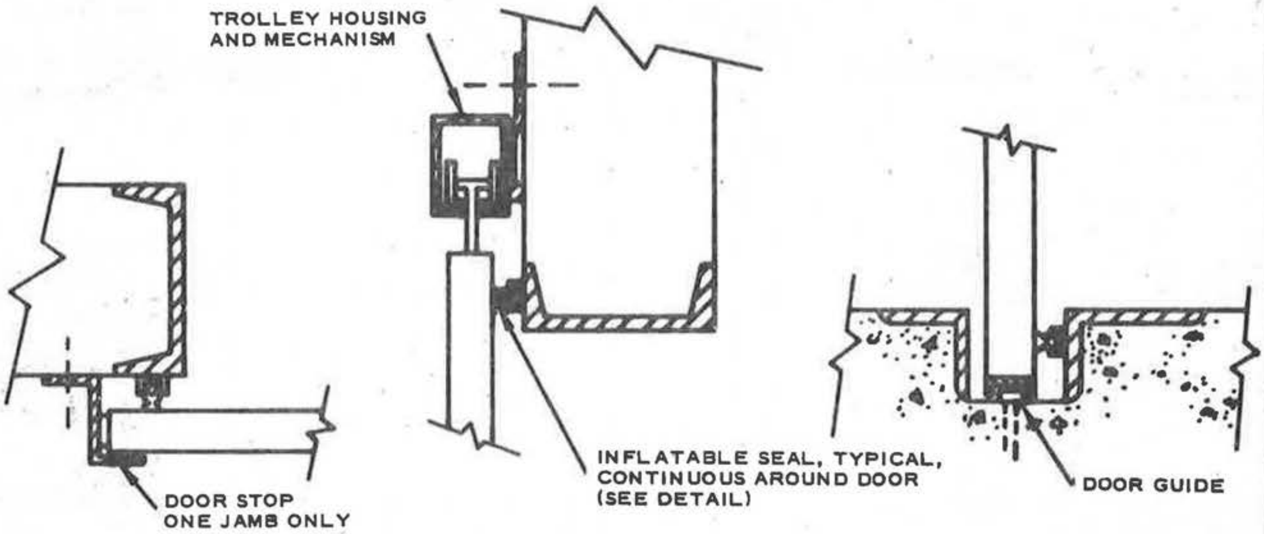
Door Type	Leakage Coefficient		Door Opening
	A	B	
Individual dogging door — hand tight	0.02 0.023	0.17 0.24	Out In
Quick acting door	0.003 0.0012	0.015 0.0014	Out In

Notes

Refer to LDS A-4 (1 through 4) and LDS D-1 for additional information regarding description, limitations, extrapolations, etc.

CASE 3

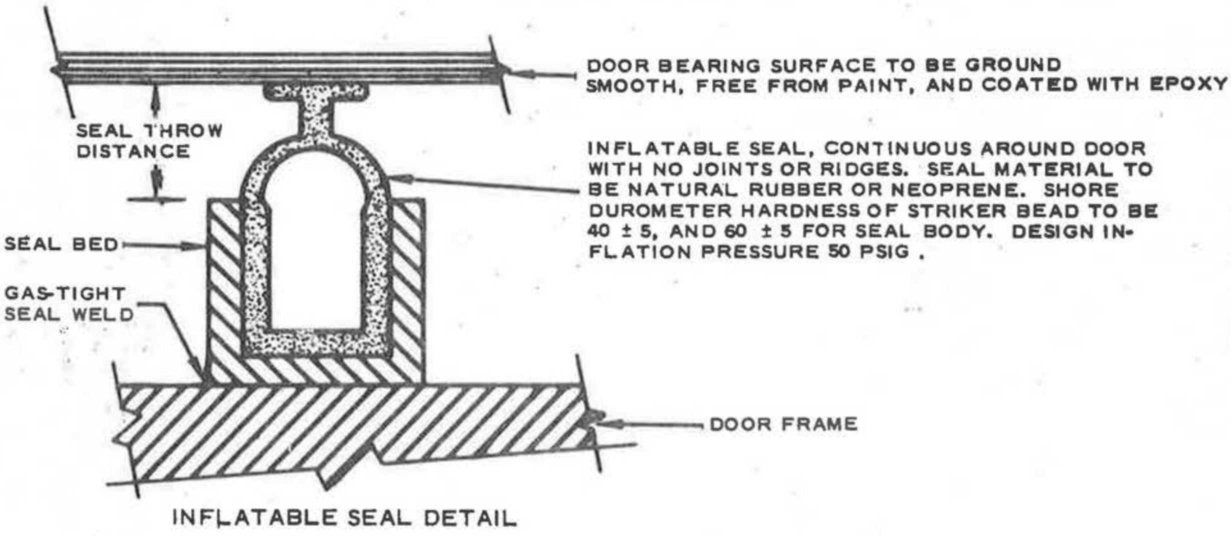
Sliding metal door with inflatable seals



JAMB

HEAD

TYPICAL DETAIL



INFLATABLE SEAL DETAIL

(TEE BEAD SHOWN)

APPLICATION DATA SHEET	No. III-A-2	Page 4 of 4

Leakage Coefficients

Per inch of inflatable seal
Pressure range: 15 psig

Type of Bead	Seal Throw Distance (in.)	Leakage in ft^3 per 24 hr at 15 psig	Remarks
1/8-in. round	5/16	10^{-2}	—
1/8-in. round	3/8	6×10^{-4}	—
1/8-in. round	1/2	—	—
1/4-in. square	5/16	—	—
1/4-in. square	3/8	1.6×10^{-4}	—
1/4-in. square	1/2	—	—
1/2-in. tee	5/16	—	—
1/2-in. tee	3/8	6×10^{-5}	—
1/2-in. tee	1/2	—	—

Notes

1. Data are from NAA-SR-2544.
2. Inflatable seal pressure is ~50 psig.
3. May be used on hinged doors effectively.
4. Epoxy minimizes stickiness tendency of inflated rubber.

APPLICATION DATA SHEET	No. III-A-3	Page 1 of 2

[illegible]

Building Components, Doors; Equipment Access Doors

DESCRIPTION

Equipment access doors
Leakage between door and frame and through door

CASE 1

Standard rolling doors

Notes

1. Standard rolling doors are not recommended for low-leakage applications due to the numerous leak paths through door section joints and around door. Although no tests were performed on this type of door, it is estimated that leakage under 1-in. of water pressure would exceed 600 cfm.

CASE 2

Sliding metal door with inflatable seals

Notes

1. Details and leakage coefficients are the same as for ADS III-A-2, Case 3.

[illegible]

Leakage Coefficient per door with no rubber seal and crack 1/64 by 1/8 by 840 in.

A (estimated) = 90

Notes

1. Manufactured by Peele Door Co.

APPLICATION DATA SHEET	No. III-A-3	Page 2 of 2

CASE 4

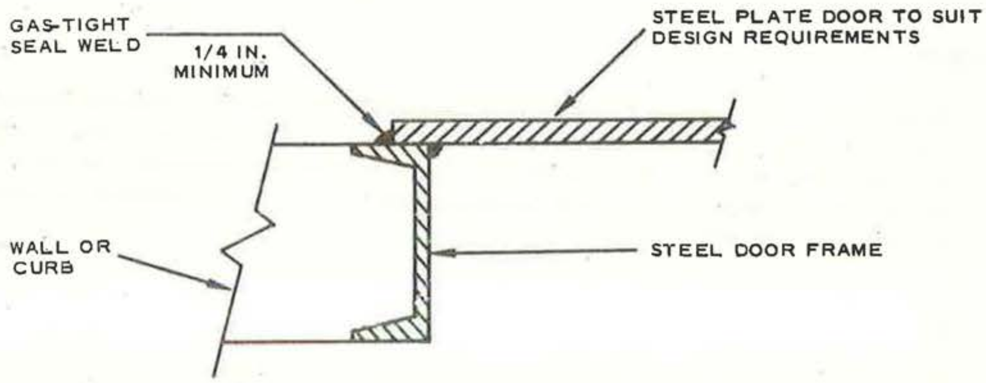
Box car refrigeration doors

Notes

1. Design is applicable for low pressure.

CASE 5

Steel access plate



JAMB, HEAD, AND SILL DETAIL

Leakage Coefficient per lineal ft of opening

A	B	Remarks
9×10^{-4}	0	Value will vary according to welding technique (see Note 3)

Notes

1. This type of door is suitable only for equipment openings subject to infrequent access since plate door must be completely removed, then rewelded after each use.

2. Portable ramps must be provided to permit movement of equipment over raised sill curb.

3. Welding of plate ruptures steel to concrete bond.

APPLICATION DATA SHEET	No. III-B-1	Page 1 of 1

TITLE

Building Components, Louvers; Metal Louver Adjustable, Gasketed

DESCRIPTION

Adjustable wall louvers
Leakage between louver and frame, and through louver

CASE 1

Adjustable metal louver, gasketed (LDS A-7)

Notes

1. As noted from review of leak test results (LDS A-7), a high rate of leakage can be expected through conventional louvers. The sample tested is representative of a quality "air tight" louver which is commercially available, yet the 20- by 21-in. louver showed leakage in excess of 30 cfm under differential pressure of 1 in. of water.

2. Due to the number and complexity of leak paths in an adjustable louver, it is considered that leakage reduction modifications would be difficult, if not impossible, to perform.

3. Use of wall louvers are not recommended in low-leakage applications. It is considered that some form of contained ventilating systems, where proven leak control techniques can be utilized, will be made appropriate in cases where leakage must satisfy stringent criteria.

APPLICATION DATA SHEET	No. III-C-1	Page 1 of 3

TITLE

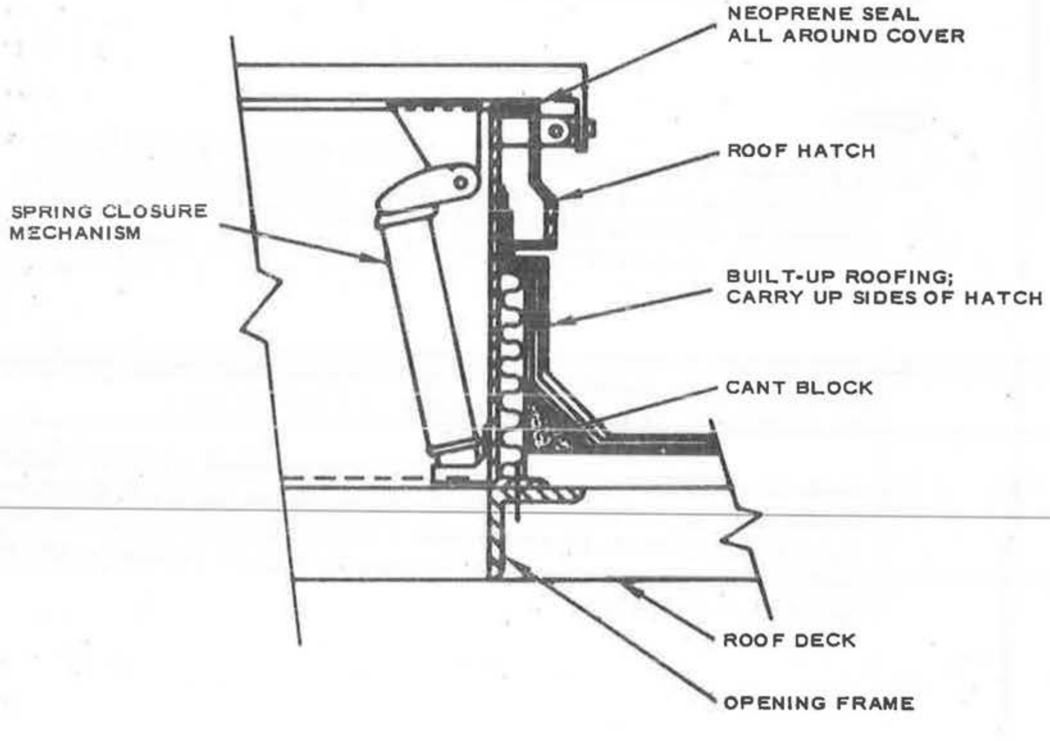
Building Components, Roof Hatches; Prefabricated Metal Hatch

DESCRIPTION

Prefabricated metal hatch through roof leakage through hatch

CASE 1

Metal hatch, spring closure



SECTION THROUGH HATCH

Leakage Coefficient

Per lineal ft of hatch opening circumference pressure range 0 to 5 in. water

APPLICATION DATA SHEET	No. III-C-1	Page 2 of 3

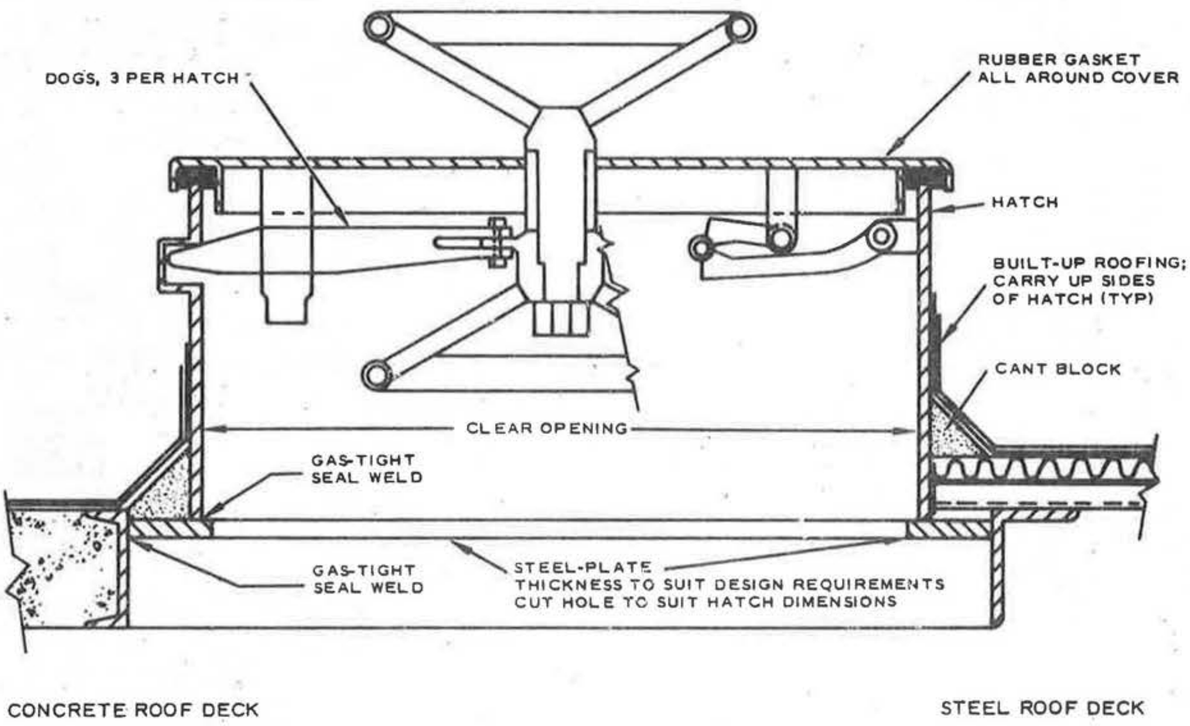
A	B	Remarks
9.3	13	Hatch opening OUT

Notes

1. Because of high leak rates, this type of hatch is not suitable for low-leakage applications unless modified.

CASE 2

Marine hatch, quick acting



SECTION THROUGH CIRCULAR HATCH

APPLICATION DATA SHEET	No. III-C-1	Page 3 of 3

Leakage Coefficients

Per lineal ft of hatch opening circumference. Pressure range 0 to 50 in. water

A	B	Remarks
1.5×10^{-4}	7×10^{-4}	Hatch opening OUT

Notes

1. Refer to ADS III-A-2.

APPLICATION DATA SHEET	No. III-D-1	Page 1 of 3

TITLE

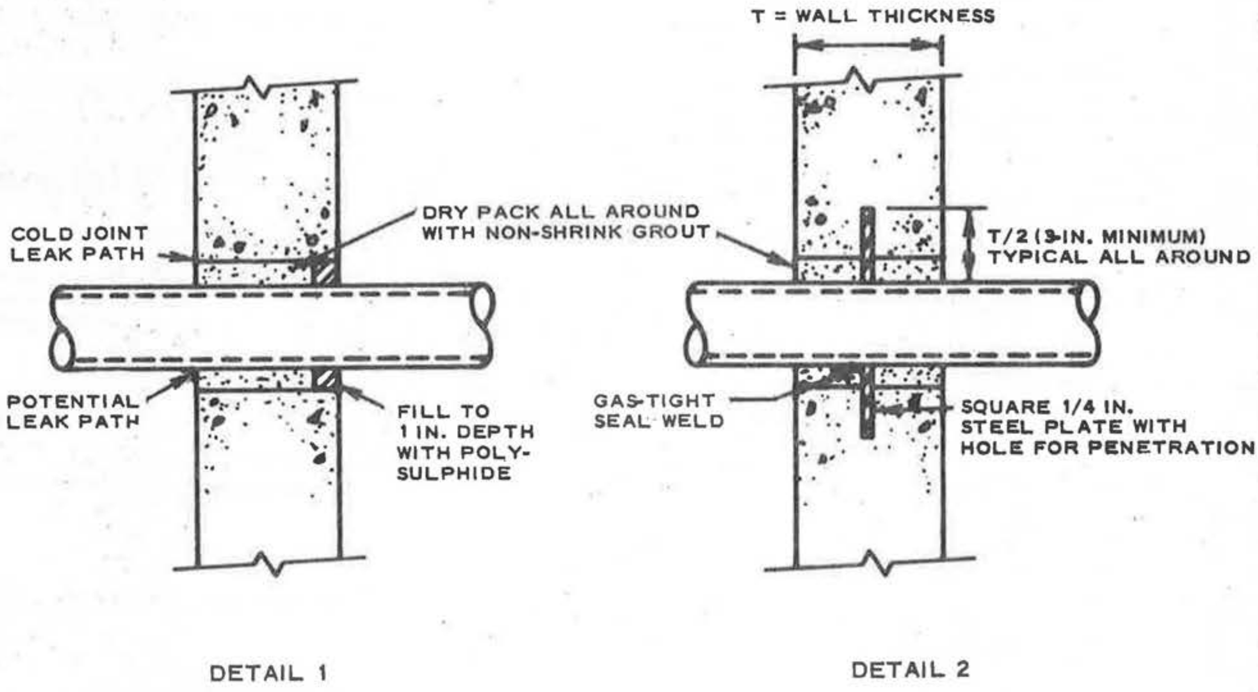
Building Components; Piping Penetrations Through Walls

DESCRIPTION

Penetrations through walls
Leakage between insert and pipe or duct
Leakage between wall and insert to be found in appropriate building section

CASE 1

Single penetrations cast in concrete wall



Leakage Coefficients

Per lineal in. of penetration circumference. Pressure range 0 to 50 in. water

APPLICATION DATA SHEET	No. III-D-1	Page 2 of 3

Detail	A	B	Remarks
1	3.3×10^{-7}	0	Similar to LDS B-9, -12
2	$<7 \times 10^{-5}$	0	ADS I-A-8 (can be reduced by caulking)

Notes

1. Nonshrink grout is as good as concrete for leak reduction, but intersection with cured concrete and pipe is difficult to make perfect in a horizontal plane. Above values assume imperfect bond between grout and pipe, and between concrete and steel.

CASE 2

Penetrations through insert in wall

Leakage Coefficients

Per lineal in. of penetration circumference. Pressure range (see remarks below).

Detail	A	B	Remarks
1. Concrete wall	1.3×10^{-5}	0	Pressure range up to 100 in. water
1. Concrete wall	10^{-6}	0	When scored and caulked
1. Metal panel wall	$<10^{-9}$	0	Pressure ranges up to 20 in. water
2. Concrete wall	1.3×10^{-5}	0	Pressure ranges up to 100 in. water
2. Concrete wall	10^{-6}	0	When scored and caulked
2. Metal panel wall	$<10^{-9}$	0	Pressure ranges up to 20 in. water
3. Concrete wall	8×10^{-6}	0	NAA-SR-4850 (see Note 3)

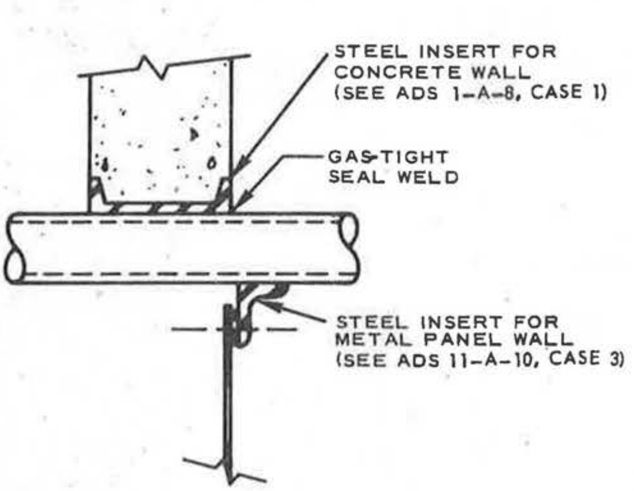
Notes

1. Use standard expansion bellows, etc., to relieve pipe stresses should pipe design require.

2. Any pipe insulation should be carried as close to the point of penetration as possible.

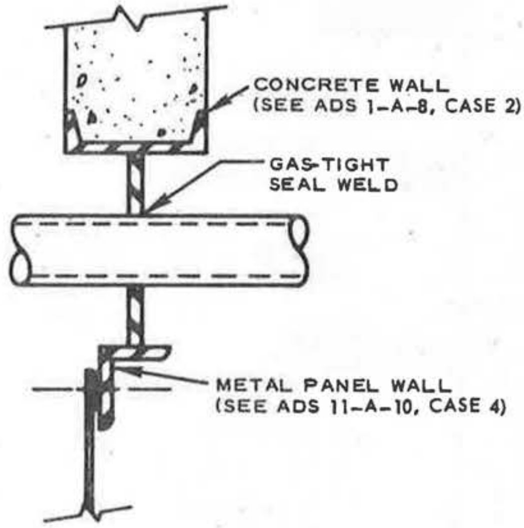
3. Conduit packing tested to 20 psig.

APPLICATION DATA SHEET	No. III-D-1	Page 3 of 3



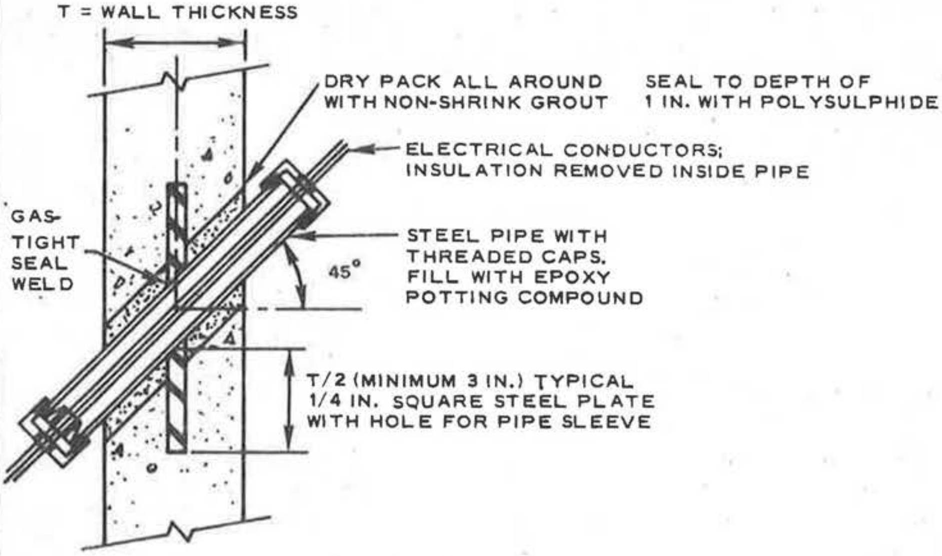
DETAIL 1

SINGLE STEEL FRAME INSERT



DETAIL 2

MULTIPLE STEEL FRAME INSERT



DETAIL 3

ELECTRICAL PENETRATION - CONCRETE WALL

APPLICATION DATA SHEET	No. III-D-2	Page 1 of 4

TITLE

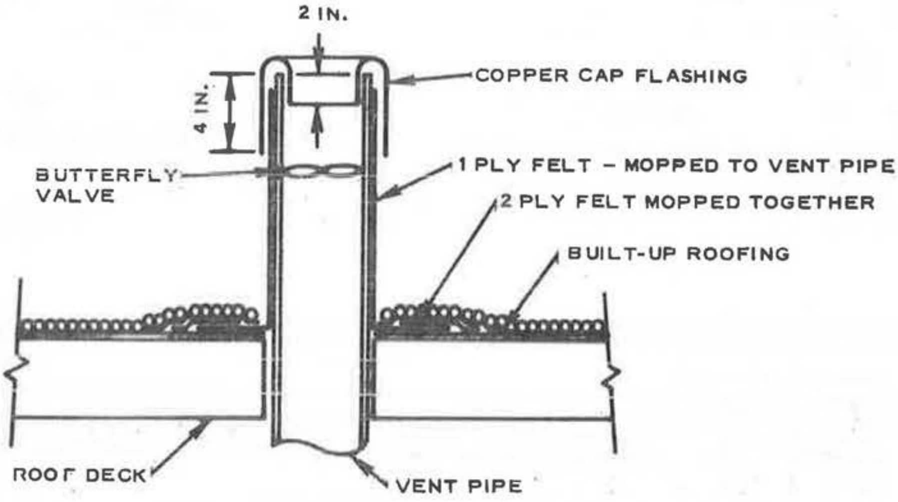
Building Components; Piping Penetrations Through Roof

DESCRIPTION

Piping, vent, and roof drain penetrations
Leakage between roof and penetration

CASE 1

Vent pipe



SECTION

CASE 2

Pipe through concrete roof

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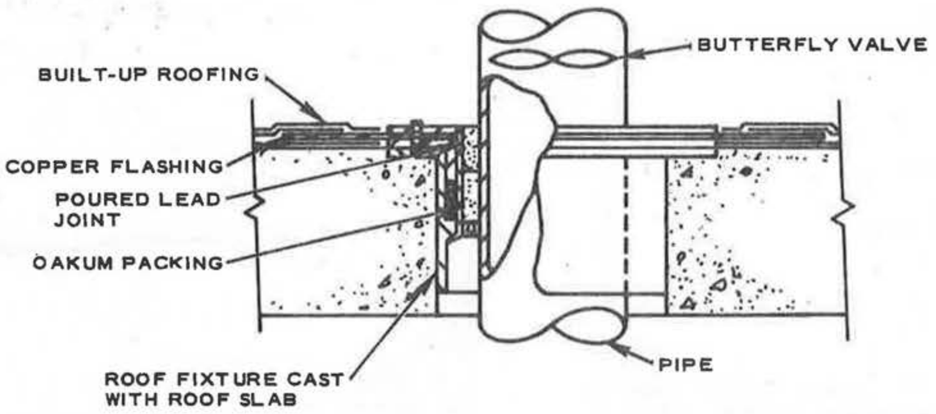
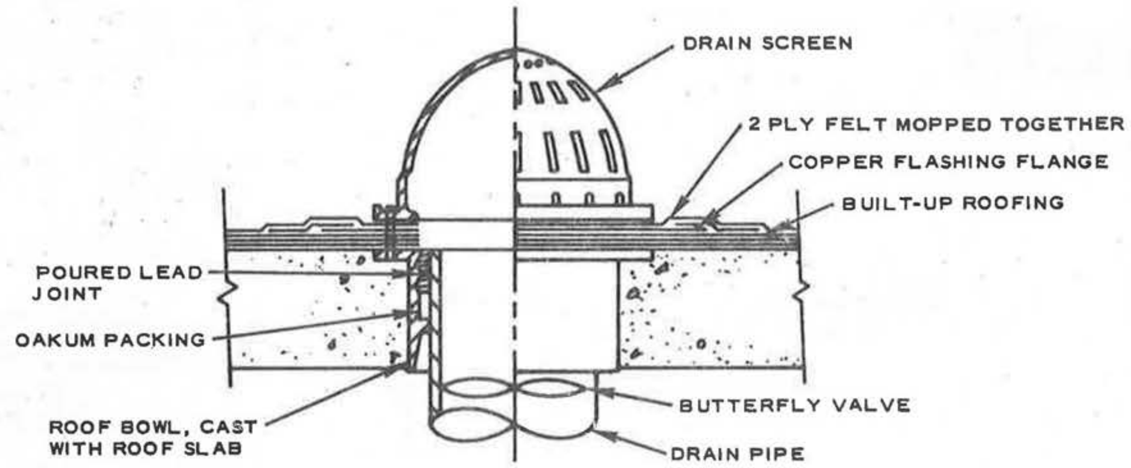


SECTION

CASE 3

Drain in concrete roof



SECTION

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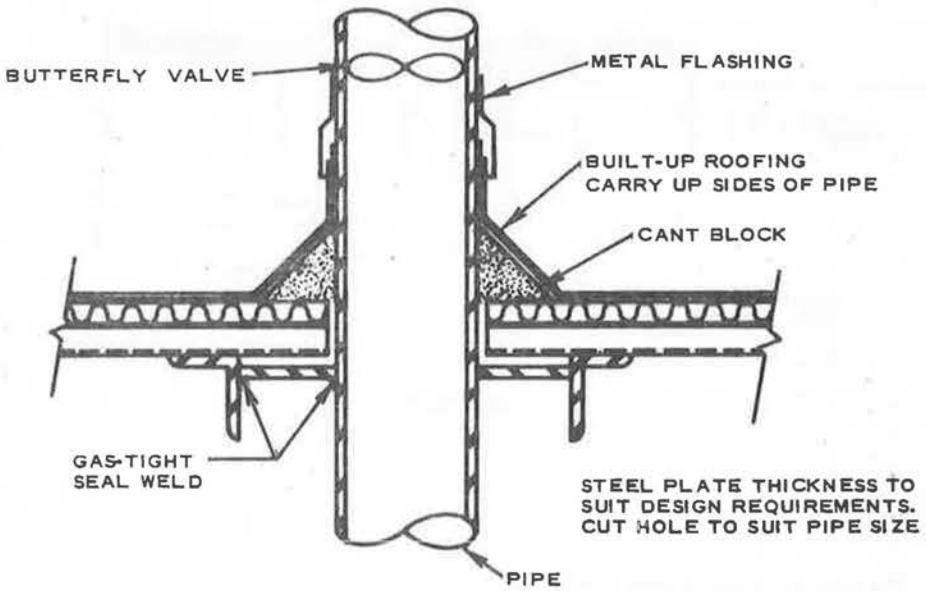
CASE 4

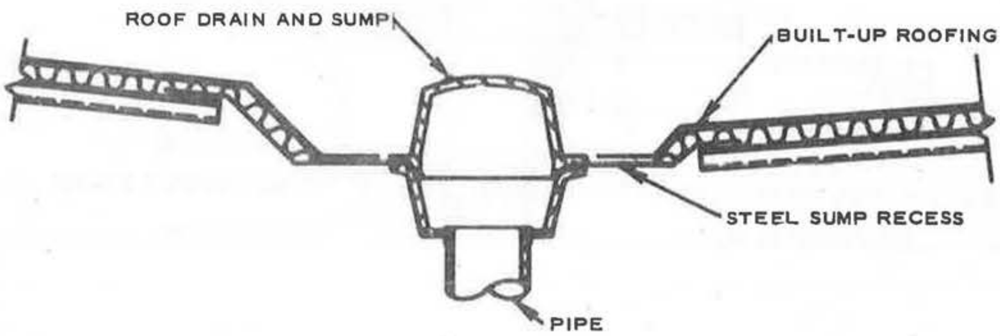
Pipe through metal deck roof



SECTION

CASE 5

Drain in metal deck roof



SECTION

APPLICATION DATA SHEET	No. III-D-2	Page 4 of 4

Leakage Coefficients

Per lineal in. of penetration circumference. Pressure range 0 to 20 in. water.

Detail	A	B	Remarks
Case 1	$<10^{-8}$	0	ADS II-A-9
Case 2	$<2 \times 10^{-8}$	0	See Note 3
Case 3	$<2 \times 10^{-8}$	0	See Note 3
Case 4	$<10^{-8}$	0	ADS II-A-9
Case 5	-	-	Undetermined

Notes

1. All leakage between penetration walls and properly applied roofing materials can be disregarded.
2. Safety precautions
    a) Flashing to pipe and deck before applying roofing
    b) Caulk between flashing and pipe
    c) Flashing welded continuous at joints
3. A void of 0.1 mil is assumed between head and pipe for Case 2 and 3.

APPLICATION DATA SHEET	No. III-E-1	Page 1 of 4

TITLE

Building Components; Caulking Compounds

DESCRIPTION

Categorization and manufacturers of caulking compounds and joint sealers

	Bulk Compounds					
			Two Part		One Part Elastic	
	Oil Base Caulking	Nonskinning	Rubber Base	Thermosetting	Solvent-Release Type	Curing Type
Chief Ingredients	Oils 1) Hydrocarbon 2) Vegetable 3) Synthetic drying Asbestos fibers Other inert fillers	Polybutenes or blends of polybutenes and polyisobutenes Asbestos fibers Other inert fillers Synthetic resins	Polysulfide Resins	Epoxides	Polyisobutenes Acrylics Vinyls or hypalons Mitrites Fillers	Polysulfides Silicones or polyurethanes Fillers Curing agents
Solids (%)	75 to 95	85 to 100	95 to 100	100	80 to 90	95 to 100
Maximum Effective Elongation (%)	10	100	100	0 to 100	25 to 100	75 to 100
Adhesion	Poor to fair	Fair to good	Good to excellent	Good to excellent	Fair to excellent	Fair to excellent
Weathering Effects	Dries gradually	Nondrying	Some increase in hardness Maximum 90 Shore A durometer	Excellent	Increase in hardness Maximum 50 to 60 Shore A durometer	Increase in hardness Maximum 35 Shore A durometer
Life Expectancy (yr)	5 to 10	15 to 20	Up to 20 (estimated)	20 (estimated)	15 to 20 (estimated)	15 to 20 (estimated)
Limitations	Oil separates % elongation poor	Tendency to pick up dirt	Requires controlled mixing and application May require primer on concrete	Requires controlled mixing and application	Long curing time Shrinkage >10% May need primer	Long curing time Special handling and storage required May require primer
Recommended Uses	Caulking in short joints between masonry	Sealing of joints where movement is limited Nondrying	Horizontal and vertical joints for metal and concrete	Seal joints and cracks Patches Bonds	-	-
Maximum Pressure Range for Minimum Leakage	2- to 5-in. H_2O	25- to 50-in. H_2O	5 to 50 psig (estimated)	5 to 100 psig (estimated)	-	-
Manufacturer (see p 4 of 4 for code)	15, 17, 21, 22, 32, 33	2, 21, 26, 33	2, 10, 11, 13, 15, 16, 17, 18, 21, 22, 26, 27, 29, 32, 33	1, 2, 4, 6, 7, 10, 13, 16, 23, 26, 28, 29, 30, 31, 32, 34	10, 18, 19, 20, 27	8, 9, 26, 34

	Bulk Compounds					
	Hot Melt		Cold Applied		Nonresilient	
	Coal Tar Derivative	Rubberized	Coal Tar Derivative	Rubberized	Elastomeric Uncured	Elastomeric Partially Cured
Chief Ingredients	Asphalt	-	Asphalt		Polybutene asbestos fibers Asphalt Other inert fillers	-
Solids (%)	100	100	100	100	100	100
Maximum Effective Elongation (%)	to 160		to 100		Very high unless reinforced	Up to 300
Adhesion	-	-	-	-	-	-
Weathering Effects	Excellent	-	Excellent	-	Good	Good to excellent
Life Expectancy (yr)	>20	-	>20	-	15 to 20 (estimated)	15 to 20 (estimated)
Limitations	Do not overheat	Do not overheat	Keep from freezing	Flammable	Tendency to pick up dirt	Tendency to pick up dirt
Recommended Uses	Horizontal cracks and joints Minimum working	-	Concrete joints	Horizontal and inclined working joints	-	-
Maximum Pressure Range for Minimum Leakage	-	-	-	-	-	-
Manufacturer (see p 4 of 4 for code)	10, 26	10	2, 10, 26	10, 26	26	-

APPLICATION DATA SHEET	No. III-E-1	Page 3 of 4

Preformed Compounds

	Resilient (Elastomers)						
	Vinyl	Neoprene	Butyl	Rubber Natural	Blended	Hypalon	Adiprene
Chief Ingredients	Vinyl-chloride polymers	Polychloroprene	Isobutylene isoprene copolymers	Basic polymer	Asphalt Resins Plasticizing compounds	Chlorosulfonated polyethylene (hypalon)	Polyurethane (foam-impregnated throughout with asphalt bitumen)
Solids (%)	100	100	100	100	100	100	100
Maximum Effective Elongation (%)	250 to 375	250 to 500	200 to 800	to 650	100	-	Used under compressed condition (200)
Adhesion	-	Good	Good	Good	Good	-	Varies for each material
Weathering Effects	Good	Excellent	Good	Poor to fair	Excellent	Excellent	Excellent to outstanding
Life Expectancy (yr)	-	>25	25	Poor	Good	>30	20 to 25
Limitations	Affected by extreme temperatures	Not field sealable	Not field sealable Must be under compression	Not field sealable	Not field sealable Width 6 times expected movement	-	Needs to be compressed to 1/5 original size for air leakage May require primer
Recommended Uses	Masonry joints (good re-expansion properties)	Precast concrete wall panels	Used as a gasket and with a two-part base sealer		Concrete and metal joints	-	Sealing joints of metal, concrete, and other seating flashing (excellent memory)
Maximum Pressure Range for Minimum Leakage	400 psig	300 psig	-	400 psig	-	-	-
Manufacturer (see p 4 of 4 for code)	24, 35	5, 24, 35	-	5, 12, 14, 25	31	9, 14, 26	3, 9

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LIST OF MANUFACTURERS

1. Adhesive Engineering (Division of Hiller A-C); 1411 Industrial Road, San Carlos, California
2. Armstrong Cork Company, Industrial Division Lancaster, Pennsylvania
3. Asbiten (Canada) Limited; 1200 W. Pender Vancouver 1, British Columbia
4. Carl H. Biggs Company, Inc.; 1547 14th Street, Santa Monica, California
5. Bridgeport Fabrics, Inc.; Bridgeport 9, Connecticut
6. Carboline Company; 32 Hanley Industrial Court, St. Louis 17, Missouri
7. CIBA Products Corporation; Fairlawn, New Jersey
8. Dow Corning Corporation; Midland, Michigan
9. E. I. duPont de Nemours & Company, Elastomeric Chemical Department; Wilmington 98, Delaware
10. EDOCO Technical Products; 2370 E. Artesia Boulevard, Long Beach, California
11. Electro Cote Company; 5220 Main Street, N. E., Minneapolis 21, Minnesota
12. Faultless Rubber Company; Ashland, Ohio
13. Flintkote Industrial Products Division; 55th and Alameda Street, Los Angeles, California
14. Geauga Industrial Company; Middlefield, Ohio
15. A. C. Horn Co., Division Sun Chemical Co.; 7237 E. Gage Bell Gardens, California
16. International Epoxy Corporation; 501 N. E. 33 Street, Fort Lauderdale, Florida
17. H. B. Fred Kuhls; 3rd Avenue and 65th Street, Brooklyn 20, New York
18. Magichemical Company; Brockton, Massachusetts
19. Marsh Wall Products, Inc.; Dover, Ohio
20. Masury-Young Company; 76 Roland Street, Boston, Massachusetts
21. Minnesota Mining and Manufacturing Company; 900 Bush Avenue, St. Paul, Minnesota
22. Pecora, Incorporated; 300-400 W. Sedgley Avenue, Philadelphia, Pennsylvania
23. D. J. Peterson Company; P.O. Box 181, Sheboygan, Wisconsin
24. Poloran Products; 165 Huguenot, New Rochelle, New York
25. Presray Corporation; Pawling, New York
26. Presstite Division, American Marietta Company; 139th and Chouteau, St. Louis 10, Missouri
27. Prod. Res. Company; 2919 Empire Avenue, Burbank, California
28. Revere Chemical Corporation; 2010 E. 102 Street Cleveland, Ohio
29. Rubber and Asbestos Corporation; 225 Belleville, Bloomfield, New Jersey
30. Shield Chemical Corporation; 251 Grove Avenue, Verona, New Jersey
31. Sika Chemical Corporation; 35 Gregory Avenue, Passaic, New Jersey
32. Sonneborn Chemical and Refining Corp.; 4821 S. Vermont Los Angeles, California
33. Tremco Manufacturing; 8701 Kinsman Road, Cleveland, Ohio
34. Wilbur and Williams Company, Inc.; 650 Pleasant, Norwood, Massachusetts
35. Williams Seals and Gasket Division, Williams Equipment and Supply Company; 486 W. Eight Nile Road, Hazel Park, Michigan

APPLICATION DATA SHEET	No. III-F-1	Page 1 of 2

TITLE

Building Components; Concrete Surface Treatments

DESCRIPTION

Surface coating systems for concrete
Leakage through coating system, including pin holes
Leakage Coefficient: per sq ft of coating area
pressure range 0 to 10 psi

Manufacturing Name and No.	Recommended Coating System	Leakage Coefficient A
Carboline Co. Phenoline No. 305	Primer: 6 mils at 200 ft^2/gal Membrane coat: 2- to 4-mil coats at 280 ft^2/gal Total system: 14 mils thickness	8.0×10^{-9}
Pittsburgh Coke and Chemical Co. Insul-Mastic No. 3911	Total system: 5.0 mils	2.7×10^{-8}
Soc-Co Plastic Coating Co. Soc-Co Plastic No. V-500	Total system: 10 mils	2.9×10^{-8}
Keratin, Inc. Coverseal Vinyl	Primer: 1 mil at 200 ft^2/gal Intermediate coat: 40 mils at 25 ft^2/gal Top coat: 5 mils at 60 ft^2/gal Total system: 46 mils thickness	5.1×10^{-8}
Carl H. Biggs Co., Inc. PC-621	Total system: 4 mils	6.3×10^{-8}
Pittsburgh Coke and Chemical Co. Insul-Mastic No. 4010	Total system: 67 mils	1.0×10^{-7}
Products Research Co. PRC-402	Primer: 4 mils at 350 ft^2/gal Coating: 20 mils at 60 ft^2/gal Total system: 24 mils thickness	3.6×10^{-7}
Surface Engineering Co. Perma Skin No. 2980	Primer: 0.3 mils at 200 ft^2/gal Intermediate coat: 2 mils at 100 ft^2/gal Top coat: two 2-mil coats at 100 ft^2/gal per coat Total system: 6 mils thickness	6.0×10^{-7}
Carboline Co. Epoxy 150	Primer: 2 mils at 320 ft^2/gal Top coat: two 2-mil coats at 320 ft^2/gal per coat Total system: 6 mils thickness	1.0×10^{-6}
Soc-Co Plastic Coating Co. Soc-Co Plastic No. 7-AT	Primer: 7 mils at 150 ft^2/gal Membrane coat: 10 mils at 150 ft^2/gal Total system: 17 mils thickness	1.7×10^{-6}
Surface Engineering Co. Secoton No. 2860	Primer: 1 mil at 150 ft^2/gal Membrane coat: 20 mils at 20 ft^2/gal Total system: 21 mils thickness	2.6×10^{-6}
Surface Engineering Co. Secoton No. 2810	Primer: 1 mil at 150 ft^2/gal Membrane coat: 20 mils at 25 ft^2/gal Total system: 21 mils thickness	7.0×10^{-6}

APPLICATION DATA SHEET	No. III-F-1	Page 2 of 2

Notes

1. Additional information regarding properties, methods of application, limitations, etc. to be found in LDS-B-11
2. Coating system recommended by manufacturer.

APPLICATION DATA SHEET	No. III-G-1	Page 1 of 4

TITLE

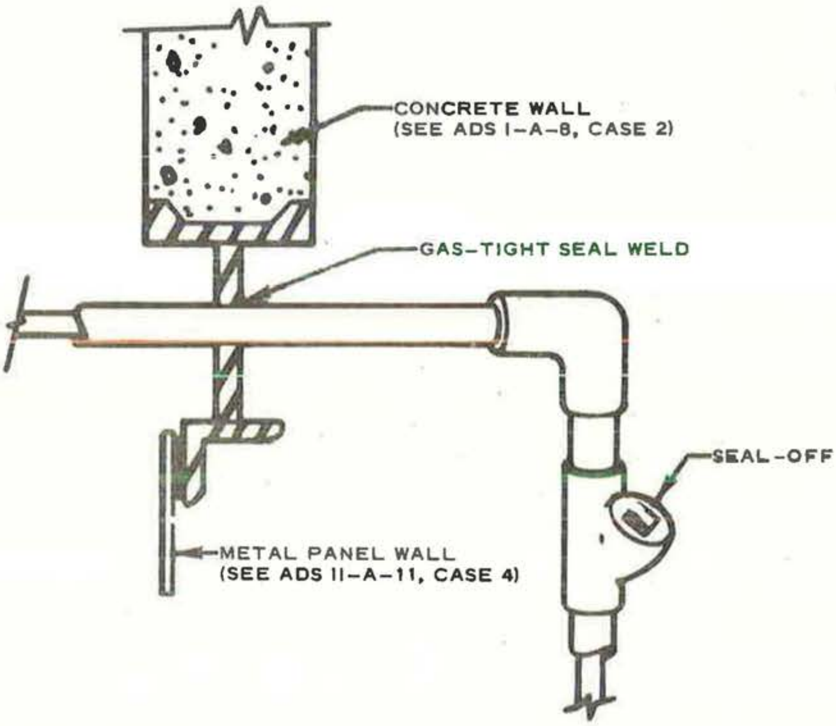
Building Components, Electrical Penetration Through Walls

DESCRIPTION

Conduit, pipe, and trough-type seals

CASE 1

Conduit sealoffs.



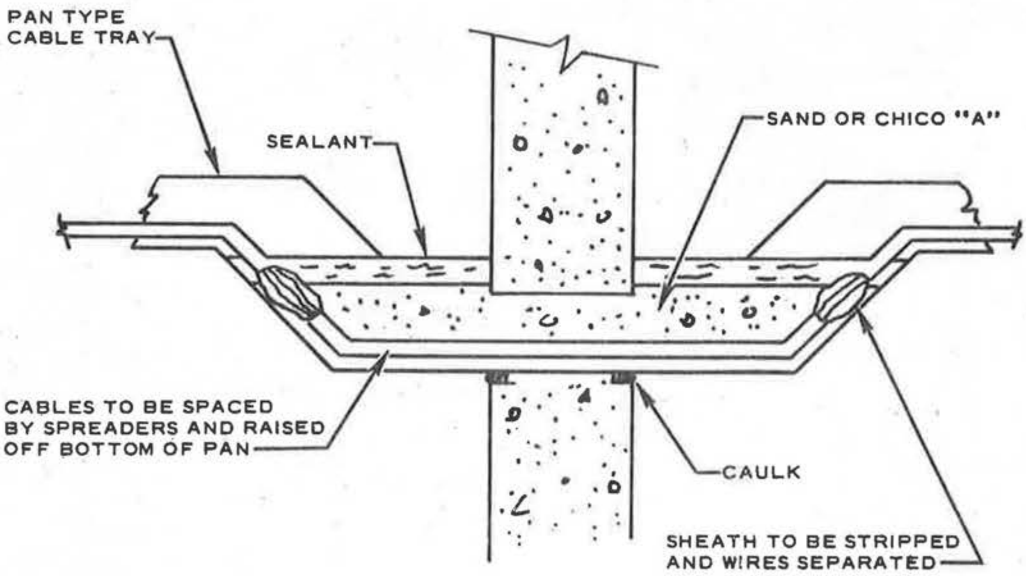
Leakage Coefficients

Leakage value for one conduit seal. Pressure range at least 5 psi.

A	B	Remarks
10^{-9}	10^{-9}	LDS A-3(2), Case 1

CASE 2

Trough-type seal.



Leakage Coefficients

No detectable leakage around seal as reported in HW-64972. Pressure range 18 psi. See LDS A-3(2), Case 2.

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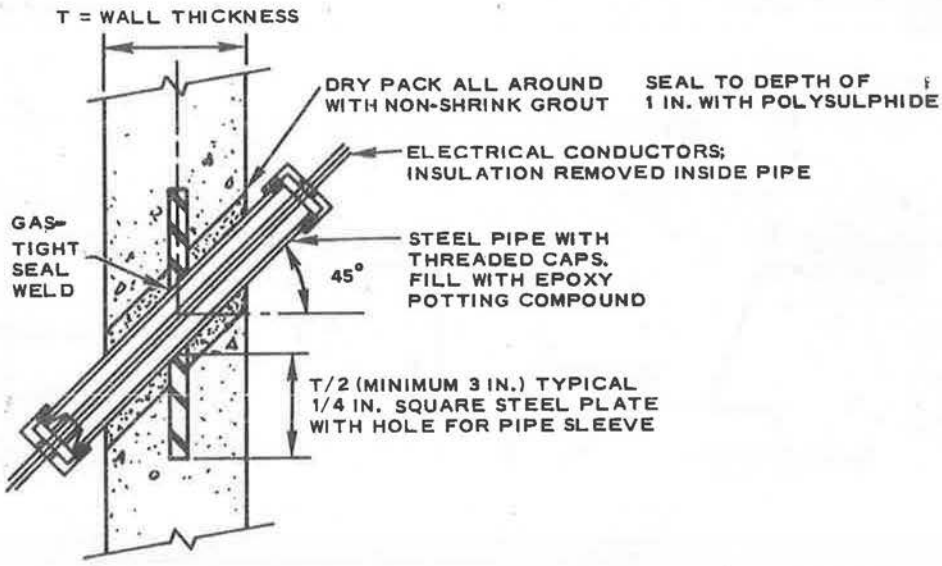
CASE 3

Pipe Seal



ELECTRICAL PENETRATION – CONCRETE WALL

Leakage Coefficients

No detectable leakage through seal at pressures up to 20 psi (NAA-SR-4850).

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CASE 4

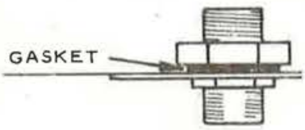
Wall mounting receptacle

Leakage Coefficients

Leakage value for 1-in.-diameter seal

A	B	Remarks
5.1×10^{-4}	0.6×10^{-4}	LDS – A-5

Bulkhead Receptacle



CASE 5

Leakage Coefficients

No detectable leakage around seal (LDS – A-5)

CONTENTS

APPLICATION DATA SHEETS

III. BUILDING COMPONENTS

CONTENTS
ECONOMICS

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FIGURES

V. ECONOMICS

A. INTRODUCTION

1. Objective

The major objective of the economic analysis was to examine various types of reactor building structures and to determine their relative costs. Specifically, the study attempted to determine the importance of leakage reducing techniques and building design pressure on costs. Since, for certain accident criteria, it was desirable to have cylindrically arranged buildings, a further objective was to determine the effect of arrangement on costs. A final objective was to determine cost differences between conventionally constructed buildings used for reactor containment, and steel dome containment.

2. Scope of Study

Two basic reactor types were selected as a basis for designing the reactor buildings and containment. These types were a 200-Mwe sodium graphite reactor and a 180-Mwe boiling water reactor. The sodium graphite reactor was selected since postulated accidents involving this kind of reactor system normally do not involve high building pressures and are therefore amenable to conventionally constructed buildings. The boiling water reactor was selected because it represents the type of system which, under postulated accident conditions, normally results in high building pressures. Furthermore, it was possible to use the results of a recent boiling water reactor containment study by Sargent and Lundy.*

For the sodium graphite reactor, two basic plant arrangements were made; both were for a 200-Mwe generating plant. One arrangement included a rectangular building enclosure, and the other included a cylindrical enclosure. The arrangement of the steam generating equipment, turbine generator, and associated auxiliary equipment were identical for both the rectangular and cylindrical plants.

Since many components have been investigated and tested for both fluted metal panel construction and concrete construction, these two types of building structures were selected for cost analysis in the sodium graphite reactor. The metal panel structures were designed only in the rectangular arrangement. The

*See References, Reactor Housing, 23

concrete structures were designed for both the cylindrical and rectangular arrangements.

To determine the effect of pressure on building costs, three design pressures were used for the rectangular arrangement: 4 in. water, 1/2 psig, and 2 psig. For the cylindrical arrangement, a design pressure of 1/2 psig was selected. Different degrees of leak tightness were used in the various building designs to determine the effect of leakage improvement on building costs.

Although the plant arrangement was complete in every respect in that it included site development, turbine facilities, and other factors not directly associated with reactor containment, cost estimates were prepared for only those items which were believed to have a significant effect on cost differences between designs. For example, since the turbine-generator facilities were arranged in an identical manner for all sodium graphite reactor designs considered, no cost differences existed for the turbine-generator facilities. On the other hand, it was obvious from the arrangement drawings that although the reactor shielding per se was not associated with reactor containment, it did differ between designs and contributed to cost differences. For this reason, the substructure concrete was included as part of the cost estimate. However, estimates were not made for such items as steam and feed water piping, circulating water system piping, accessory electrical equipment, and other items which may contribute to minor cost differences between designs.

In the case of the completed boiling water reactor designs, such systems as feed water piping, circulating water system piping, and accessory electrical equipment were included in the Sargent and Lundy cost estimates. Additionally, the boiling water reactor site included cost provision for rock removal and dewatering. To make the boiling water reactor cost estimates compatible with those of the sodium graphite reactor, adjustments were made to the Sargent and Lundy estimate. These adjustments included modification of the siting costs to remove dewatering and rock removal requirements. They also included removal from the estimate of all items which were not included in the sodium graphite reactor estimate, such as auxiliary electrical equipment, circulating water system piping, etc.

The direct costs of the various boiling water and sodium graphite reactor arrangement designs were thus obtained on a similar basis. These direct costs were further adjusted by suitable factors to account for general and administrative expense, miscellaneous construction costs, engineering design and inspection costs, contingency costs, and interest during construction. Identical factors were used for all the building designs considered.

The two types of containment included for comparison from the Sargent and Lundy study were the steel dome and the pressure suppression containment arrangements. These were selected since they represent the most common type of containment currently being used by water reactor designers.

3. Accident Philosophy

The buildings for the sodium graphite reactor were not designed for any specific accident or site, but were selected so that a variety of accident and site conditions could be used. In every case a heating and ventilating system was included in the design and cost estimate. This system was designed so that under accident conditions it could be used to direct building air and fission products through a filtering system and up a stack. Under accident conditions in which the ventilating system is used, it is likely that the building will be maintained under a negative pressure and all leakage will be into the building, through the ventilating and filtering systems, and thence out the stack. Expanded gas resulting from any heat sources will also be vented from the building by the ventilating system. Alternatively, it can be assumed that the accident philosophy will require no dependence on ventilating or filtering systems. In this event, it may be desirable to completely close off the building. Under this condition, any leakage is directly from the building to the atmosphere. As a result of heat sources, the accident can result in a building pressure rise, and the building should be designed to accommodate this rise. For various conditions of siting population density, the leakage requirements of the building may be high or low for the two accident design philosophies described above.

The building designs were selected so that various combinations of these alternative possibilities can be made. For example, at a densely populated site in which it is assumed that the air-conditioning and filtering systems can be used, it might be desirable to select a low-pressure building design (4 in. of water to

1/2 psig) with a low leakage requirement (1 to 0.1% per day). At another site located in a sparsely populated region, it may be desirable to select a high-leakage, low-pressure building. Various other combinations are possible.

In all cases involving the sodium graphite reactor, the cost estimate includes money for a completely enclosed primary system as well as the reactor building enclosure. This primary system enclosure consists of steel-lined concrete cells maintained under an inert atmosphere. In the detailed cost breakdown, the cost of the cell liner is separately designated.

In the case of the water reactor systems, the accident philosophy designated by Sargent and Lundy was that which is most commonly accepted for water reactor systems, namely the failure of a main coolant line. The resulting pressure from the fluid flashing into steam is the design pressure of the building. A similar accident in the sodium-cooled reactor system results in the release of sodium to the inert-gas-filled cells.

B. GENERAL PLANT ARRANGEMENT

1. Site Assumptions

The site is located near a river, and, in general, the land contours provide for natural drainage. The soil profile is such that the bedrock and water-bearing shale strata are below excavation requirements of 20 ft. The above shale strata is suitable for machine excavation, so that the entire plant operations can be accomplished with normal earth moving equipment and minimum pumping requirements.

2. Sodium Graphite Reactor

a. General Design Features

The plant is located near the river bank to minimize the length of condenser cooling water lines. The plot plan, plant arrangement, and superstructure for the rectangular and cylindrical buildings are shown at the end of this section (see page V-23).

The turbine area shown in the drawings includes the outdoor design turbine-generator and auxiliary equipment, condenser, extraction heaters, boiler feed and condensate pumps, instrument and service air compressors, and the closed-loop cooling water heat exchangers and pumps. The main and auxiliary transformers and transmission switchyard are located to the east of the main power plant building complex.

A base case design was selected for both the rectangular and the cylindrical arrangements. Complete arrangement drawings were made for these base cases. The base case rectangular reactor enclosure is designed for a 200-Mwe plant with a 1% volume per day leak rate at 1/2 psig pressure. The enclosure above grade is divided into three sections. The high bay is 180 ft long, 60 ft wide, and 80 ft high. The low bay is 180 ft long, 26 ft wide, and 30 ft high. The portion of the main and auxiliary loop intermediate heat exchanger cells exterior to the low-bay structure are 72 ft long, 41 ft wide, and 30 ft high. The substructure dimensions are approximately the same as the superstructure except that a major portion of the excavation is approximately 50 ft deep, with the reactor excavation (approximately 65 ft deep) being the lowest point.

The base case cylindrical reactor enclosure is designed for a 200-Mwe plant with a 1% volume per day leak rate at 1/2 psig pressure. The enclosure above grade is 161 ft in diameter and 80 ft high. It is a right-circular cylinder with a flat top. The substructure dimensions are approximately the same as the superstructure.

The rectangular building requires an external radioactive waste facility which is designed as a two-level unit. The area below ground is constructed of cast-in-place concrete and provides tankage storage space. The above-ground area is of tilt-up design and is divided into three areas: an operating area and two compressor cells. Each compressor cell contains a low-volume and high-volume compressor. The operating area contains the valve and gage boards, heating and ventilating equipment, and switch gear for operation of the facility.

The cylindrical enclosure concept has the radioactive waste facilities built into the cylindrical enclosure. The external access or fuel shipping transfer area is provided with sealable access plugs. The access way is of cast-in-place concrete extending beyond and into the enclosure perimeter to permit handling of the cask with a crane.

As noted previously, the primary sodium system equipment for the sodium graphite reactor is located in individual cells such as the intermediate heat exchanger (IHX cells). The cells are filled with an inert gas during plant operation, and most of them are lined with 1/4-in. carbon steel plate welded to "T" bars embedded in the concrete. The maintenance cell is lined with 1/2-in. plate since, in this cell, the plate serves the dual function of structural support for equipment as well as a leakage barrier. In addition to the IHX and maintenance cells, the two primary sodium service cells and connecting pipeway, the reactor enclosure cell, fuel pick-up cell, fuel storage cell, component storage cell, and the component work cell are steel-lined.

The cells are designed for 6-psig pressure and a leak rate of 3/4% of cell volume per day with a differential pressure of 2 psig. Access plugs to the majority of the equipment cells are sealed by means of a knife edge in restrained rubber technique at the shielding step, with a secondary closure of Thiokol and oakum at the floor level as a secondary seal and dust stop. In the IHX cells, a gas-tight seal is obtained at the plugs by welding a cover plate beneath the plugs, over the opening, and connecting to the wall and ceiling liner plates.

The above-grade superstructure for both arrangements consists of tilt-up, precast concrete panels fastened to building columns and girts. Attachment to the columns is accomplished by 1-in. Nelson studs extending through the wall panels from the column. Bolt holes are oversized to allow for thermal expansion. The panels are also welded to the horizontal midpoint support girts from a plate precast in the panel. The joint details are shown on the plant plans. The roof for both high and low bay is of precast concrete panels (prestressed for the cylindrical structure) covered by insulation and a built-up tar and gravel roof. A cast-in-place closure at the wall panel junction is provided to assure a leak-tight strength joint. Roof girders are tapered from 5 ft 4 in. at mid-span to 2 ft 4 in. at column connections. The roof structure purlins are 14WF. The roof panels are stitch-welded to the girders from cast-in-plates in the panels.

The above-grade superstructures for two variations from the base case building designs are shown at the end of this section.

b. Leakage Design

A caulked joint is provided at the junction between the wall panel and the substructure concrete and at all other joints where leakage is possible. The design of the caulked joints (using Thiokol) is such that there is a readily accessible area to every joint to make necessary repairs. Since the concrete panels are free to expand and crack (under certain conditions), the panels are painted with a vinyl paint such as Surface Engineering Co. vinyl coating No. 2980. This paint can be elongated up to 400% to compensate for any normal cracking. Its bond strength is estimated to be 40 psi, and its maximum recommended service temperature is 180°F.

There are personnel and equipment accesses provided through the enclosure in addition to the process penetrations. The leakage calculation sheets for both of the base case building designs is shown in Tables V-1 and V-2. The column labled "Possible Detail" in the tables refers to the applicable leakage or application data sheet in this document. The tables also show various recommended component details and their leakage coefficients. Total leakage from components of a given type is determined by multiplying the leakage coefficient per in. water-unit by the appropriate number of units and the design pressure; e. g., 14 in. water x 15,500 ft^2 x 2 x 10^{-7} cfm/ft^2-in. water = 0.04 cfm.

A major fraction of the leakage occurs through the concrete cracks. Cracking of concrete can be accounted for by methods described in the Appendix. By use of these methods, a computed maximum crack width of 4 mils is obtained for the panels in the base case structures. This 4-mil crack width occurs at the tensile surface of the concrete during the lifting of the concrete panel. These cracks do not completely penetrate the panels, however. After installation and assumed pressurization of the panels, stress reversal occurs on a portion of the panel, and new cracks are formed on the opposite side of the panel from the lifting cracks. A portion of these cracks may intersect those produced during lift, thus generating a leakage path through a completely penetrating crack. However, these pressure-stress generated cracks average only about 1/2 mil in size. The maximum total crack length of these 1/2-mil cracks can be calculated. Since leakage through cracks varies with the cube of the crack thickness, it is desirable to also estimate the maximum number and spacing of large cracks. This was done in the case of the buildings in question, and the following conservative assumptions were then made:

1) Each crack produced in the reverse stress region of the panel intersects a lifting crack on the opposite side of the panel.
2) The average width throughout the total depth of these cracks is 1 mil.

TABLE V-1

LEAKAGE CALCULATION SHEET

Facility:	Gross Volume:	Allowable Leakage:	Design Pressure:	Proposed Structure:
200-Mwe Sodium Graphite Reactor	1,000,000 ft^3	1%/ day (7 cfm)	1/2 psig	Rectangular Building, Concrete Construction

Leak Item No.	Component	Unit	Estimated No. of Units	Possible Detail	Leakage Coefficient		Estimated Leakage per unit (cfm)	Total Component Leakage (cfm)
					A	B		
1	Roof							
	Paint (18 mil)	ft^2	15,500	ADS III-F-1	2×10^{-7}	–	28×10^{-7}	0.04
	Cracks (1 mil)	in.	256	ADS I-A-9	6.6×10^{-6}	–	9.2×10^{-5}	0.024
2	Wall							
	Paint (18 mil)	ft^2	47,000	ADS III-F-1	2×10^{-7}	–	28×10^{-7}	0.14
	Cracks (1 mil)	in.	12,800	ADS I-A-9	6.6×10^{-6}	–	9.2×10^{-5}	1.18
3	Joints – Leakage reduced to an insignificant level when coated with paint							
4	Doors							
	Personnel	each	1	ADS III-A-2	(Used in series with bulkhead door listed below)			
	Personnel	each	2	ADS III-A-2	8.6×15^{-4}	1.1×10^{-3}	30×10^{-3}	–
	Equipment	ft of seal	60	ADS III-A-3 Case 2	4×10^{-10}	–	56×10^{-10}	–
5	Process penetration							
	H & V ducts	in. of seal	360	ADS III-D-1 Case 2	10^{-6}	–	14×10^{-6}	0.016
	Cold water piping	in. of seal	120	ADS III-D-1 Case 2	10^{-6}	–	14×10^{-6}	0.0044
	Sodium service piping	in. of seal	135	ADS III-D-1 Case 2	10^{-6}	–	14×10^{-6}	0.0058
	Main heat transfer piping	in. of seal	500	ADS III-D-1 Case 2	10^{-6}	–	14×10^{-6}	0.019
	NaK cooling piping	in. of seal	72	ADS III-D-1 Case 2	10^{-6}	–	14×10^{-6}	0.003
	Cold gas piping	in. of seal	120	ADS III-D-1 Case 2	10^{-6}	–	14×10^{-6}	0.0031
	Liquid waste piping	in. of seal	60	ADS III-D-1 Case 2	10^{-6}	–	14×10^{-6}	0.0024
	Pneumatic signal piping	each	100	ADS III-D-1 Case 2	2×10^{-8}	–	28×10^{-8}	–
6	Electrical Penetration							
	Instrument cable	each (multi-insert)	15	ADS III-G-1 Case 2	–	–	–	–
	4160-v cable	each (multi-insert)	12	ADS III-G-1 Case 1	10^{-9}	–	4×10^{-9}	–
	480-v cable	each (multi-insert)	7	ADS III-G-1 Case 1, 2, 3	10^{-9}	–	4×10^{-9}	–
	110-v cable	each (multi-insert)	4	ADS III-G-2 Case 2	–	–	–	–
							TOTAL	1.43

TABLE V-2

LEAKAGE CALCULATION SHEET

Facility:	Gross Volume:	Allowable Leakage:	Design Pressure:	Proposed Structure:
200-Mwe Sodium Graphite Reactor	1,000,000 ft^3	1%/day (7 cfm)	1/2 psig	Cylindrical Building, Concrete Construction

Leak Item No.	Component	Unit	Estimated No. of Units	Possible Detail	Leakage Coefficient A	Leakage Coefficient B	Estimated Leakage per unit (cfm)	Total Component Leakage (cfm)
1	Roof							
	Paint (18 mil)	ft^2	20,000	ADS III-F-1	2×10^{-7}	–	28×10^{-7}	0.056
2	Wall							
	Paint (18 mil)	ft^2	40,000	ADS III-F-1	2×10^{-7}	–	28×10^{-7}	0.112
	Cracks (1 mil)	in.	10,900	ADS I-A-9	6.6×10^{-6}	–	9.2×10^{-5}	1.00
3	Joints – Leakage reduced to an insignificant level when coated with paint							
4	Doors							
	Personnel	each	1	ADS III-A-2	(used in series with bulkhead door listed below)			
	Personnel	each	2	ADS III-A-2	8.6×10^{-4}	1.1×10^{-3}	30×10^{-3}	–
	Equipment	ft of seal	60	ADS III-A-3 Case 2	4×10^{-10}	–	56×10^{-10}	–
5	Process Penetration							
	H & V ducts	in. of seal	360	ADS III-D-1 Case 2	10^{-6}	–	14×10^{-6}	0.016
	Cold water piping	in. of seal	120	ADS III-D-1 Case 2	10^{-6}	–	14×10^{-6}	0.0044
	Sodium service piping	in. of seal	135	ADS III-D-1 Case 2	10^{-6}	–	14×10^{-6}	0.0058
	Main heat transfer piping	in. of seal	500	ADS III-D-1 Case 2	10^{-6}	–	14×10^{-6}	0.019
	NaK cooling piping	in. of seal	72	ADS III-D-1 Case 2	10^{-6}	–	14×10^{-6}	0.003
	Cold gas piping	in. of seal	120	ADS III-D-1 Case 2	10^{-6}	–	14×10^{-6}	0.0031
	Liquid waste piping	in. of seal	60	ADS III-D-1 Case 2	10^{-6}	–	14×10^{-6}	0.0024
	Pneumatic signal - piping	each	100	ADS III-D-1 Case 2	2×10^{-8}	–	28×10^{-8}	–
6	Electrical penetration							
	Instrument cable	each (multi-insert)	15	ADS III-G-1 Case 2	–	–	–	–
	4160-v cable	each (multi-insert)	12	ADS III-G-1 Case 1	10^{-9}	–	4×10^{-9}	–
	480-v cable	each (multi-insert)	7	ADS III-G-1 Case 1, 2, 3	10^{-9}	–	4×10^{-9}	–
	110-v cable	each (multi-insert)	4	ADS III-G-2 Case 2	–	–	–	–
							TOTAL	1.22

3) Although the buildings are painted with 18 mils of vinyl paint which will span these cracks, 4% of all cracks will have paint violations which permit free leakage throughout the total of the crack.

Leakage calculation sheets for the two variations from the base case building designs are shown in Tables V-3 and V-4.

In designing to a warranted leak rate on a concrete structure of the type considered in the base cases, it is desirable to use considerable conservatism in the selection of safety factors. It is possible to do this, since the cost increase of the structure by introducing more stringent leakage requirements is not a significant fraction of the total building cost. For example, the total of all leakage components computed in Table V-1 for the base rectangular case was 1.65 cfm at 1/2 psi. This corresponds to a leakage rate of 0.239%/day, or a safety factor of approximately 4 when compared with the design leak rate of 1% per day. Since the minimum recommended safety factor is 2, the building is considered adequately designed. Similar leakage analysis was performed for all of the building designs considered.

Leakage control was also provided in the equipment cells since penetrations from these cells also occur. These penetrations are not included in the tables since leakage from the cells is into the building and does not contribute to building leakage. Nevertheless, the type of penetrations were determined and cost estimates provided because the cells are a part of the containment of the sodium graphite reactor. The cells are isolated, one from the other, by bulkheads or diaphragm seals. Penetrations through these cells vary with applications. For hot pipes, bellows expansion joints are provided from the bulkhead to the pipe; cold pipes are seal-welded to the bulkheads. Pneumatic instrument lines utilize standard tubing bulkhead fittings. Electrical penetrations are made through potted bulkhead fittings. Thermocouple multicontact fittings are also used. Rupture discs set for 4 psig are furnished for pressure protection by providing expansion area to adjoining cells.

3. Boiling Water Reactor

The details of the general arrangement of boiling water reactors are included in the Sargent and Lundy study. Complete arrangement drawings, piping and instrument diagrams, cost estimates, and design descriptions are included in this reference. Briefly, the containment arrangements for the boiling water reactors are as follows.

The steel dome containment method consists of a welded steel shell, 190 ft in diameter, enclosing the reactor and its auxiliaries. The vessel design pressure at 23 psig is such that it will be equal to or greater than the maximum pressure which will develop due to an instantaneous release of the reactor coolant (including the addition of chemical energy which may result from the accident). The steel shell is designed in accordance with the ASME code for unfired pressure vessels. No credit is taken for the absorption of the released energy by the structural material of the containment building.

Included within the containment dome are the reactor, steam generators, circulating water pumps, decay heat exchanger, fuel handling system, fuel handling canal, primary steam drum, emergency condenser, surge tank, purification system, primary system shielding, and the reactor service crane. Air locks provide for access into the containment sphere. A separate turbine building is provided for the turbine generator and its auxiliaries.

In the case of the pressure suppression system, the basis for the design is the Humboldt Bay Nuclear Plant. This system utilizes an energy heat sink for pressure suppression. The reactor and primary system are housed in a steel containment vessel or dry well. The dry well is vented by large pipes into a pool of water which serves to condense and cool the steam released from an accidental rupture. The dry well is designed for the maximum overpressure which occurs at the time of the accident. The suppression chamber is designed for the maximum pressure which results primarily from compression of the air contained in the dry well and suppression chamber. One hundred percent carryover of primary system fluid is assumed. The resultant pressure in the containment chamber is relatively low (10 psig) so that this structure is made of reinforced concrete. The steel lining is provided to prevent leakage from the suppression chamber.

In the pressure suppression arrangement, all primary system pipes penetrating the dry well vessel are provided with isolating valves for automatic closing on loss of primary system pressure. Thus, in the event of a pipe rupture

TABLE V-3

LEAKAGE CALCULATION SHEET

Facility:	Gross Volume:	Allowable Leakage:	Design Pressure:	Proposed Structure:
200-Mwe Sodium Graphite Reactor	1,000,000 ft^3	100%/day (700 cfm)	4 in. water	Rectangular Building, Concrete Construction

Leak Item No.	Component	Unit	Estimated No. of Units	Possible Detail	Leakage Coefficient A	Leakage Coefficient B	Estimated Leakage per unit (cfm)	Total Component Leakage (cfm)
1	Roof							
	Metal panel	ft^2	15,500	ADS-II-A-3	2×10^{-4}	5×10^{-5}	9×10^{-4}	14.0
	Eave	ft	880	ADS-II-A-5	6×10^{-5}	-	2.4×10^{-4}	0.2
2	Wall							
	Concrete (6-in. thick)	ft^2	47,000	ADS-I-A-2	2×10^{-6}	-	8×10^{-6}	0.4
	Cracks (1 mil)	in.	320,000	ADS-I-A-9	6.6×10^{-6}	-	2.6×10^{-5}	8.5
3	Joints	ft	4,500	ADS-I-A-6	1.6×10^{-5}	-	6.4×10^{-4}	2.9
4	Doors							
	Personnel	each	2	ADS-III-A-2	-	35	70	140.0
	Equipment	ft of seal	60	ADS-A-3 Case 2	4×10^{-10}	-	16×10^{-10}	-
5	Process Penetration							
	H & V ducts	in. of seal	360	ADS-III-D-1 Case 2	10^{-6}	-	4×10^{-6}	-
	Cold water piping	in. of seal	120	ADS-III-D-1 Case 2	10^{-6}	-	4×10^{-6}	-
	Sodium service piping	in. of seal	135	ADS-III-D-1 Case 2	10^{-6}	-	4×10^{-6}	-
	Main heat transfer piping	in. of seal	500	ADS-III-D-1 Case 2	10^{-6}	-	4×10^{-6}	-
	NaK cooling piping	in. of seal	72	ADS-III-D-1 Case 2	10^{-6}	-	4×10^{-6}	-
	Cold gas piping	in. of seal	120	ADS-III-D-1 Case 2	10^{-6}	-	4×10^{-6}	-
	Liquid waste piping	in. of seal	60	ADS-III-D-1 Case 2	10^{-6}	-	4×10^{-8}	-
	Pneumatic signal piping	each	100	ADS-III-D-1 Case 2	2×10^{-8}	-	8×10^{-8}	-
6	Electrical penetration							
	Instrument cable	each (multi-insert)	15	ADS-III-G-1 Case 2	-	-	-	-
	4160-v cable	each (single insert)	12	ADS-III-G-1 Case 1	10^{-9}	-	-	-
	480-v cable	each (multi-insert)	7	ADS-III-G-1 Case 1, 2, 3	10^{-9}	-	-	-
	110-v cable	each (multi-insert)	4	ADS-III-G-2 Case 2	-	-	-	-
							TOTAL	166

TABLE V-4

LEAKAGE CALCULATION SHEET

Facility:	Gross Volume:	Allowable Leakage	Design Pressure:	Proposed Structure:
200-Mwe Sodium Graphite Reactor	1,000,000 ft^3	0.1%/day (0.7 cfm)	1/2 psig	Cylindrical Building, Concrete Construction

Leak Item No.	Component	Unit	Estimated No. of Units	Possible Detail	Leakage Coefficient		Estimated Leakage per unit (cfm)	Total Component Leakage (cfm)
					A	B		
1	Roof					-		
	Paint (18 mil)	ft^2	20,000	ADS-III-F-1	2×10^{-7}	-	28×10^{-7}	0.056
2	Wall							
	Paint (18 mil)	ft^2	40,000	ADS-III-F-1	2×10^{-7}	-	28×10^{-7}	0.113
	Concrete	ft^2	1,200	ADS-I-A-2	6×10^{-6}	-	8.4×10^{-5}	0.10
3	Joints - Leakage reduced to an insignificant level when coated with paint.							
4	Doors							
	Personnel	each	1	ADS-III-A-2 (used in series with bulkhead door listed below)				
	Personnel	each	2	ADS-III-A-2	8.6×10^{-4}	1.1×10^{-3}	30×10^{-3}	-
	Equipment	ft of seal	60	ADS-III-A-3 Case 2	4×10^{-10}	-	56×10^{-10}	-
5	Process Penetration							
	H & V ducts	in. of seal	360	ADS-III-D-1 Case 2	10^{-6}	-	14×10^{-6}	0.005
	Cold water piping	in. of seal	120	ADS-III-D-1 Case 2	10^{-6}	-	14×10^{-6}	0.004
	Sodium service piping	in. of seal	135	ADS-III-D-1 Case 2	10^{-6}	-	14×10^{-6}	0.006
	Main heat transfer piping	in. of seal	500	ADS-III-D-1 Case 2	10^{-6}	-	14×10^{-6}	0.019
	NaK cooling piping	in. of seal	72	ADS-III-D-1 Case 2	10^{-6}	-	14×10^{-6}	0.003
	Cold gas piping	in. of seal	120	ADS-III-D-1	10^{-6}	-	14×10^{-6}	0.003
	Liquid waste piping	in. of seal	60	ADS-III-D-1 Case 2	10^{-6}	-	14×10^{-6}	0.002
	Pneumatic signal piping	each	100	ADS-III-D-1 Case 2	2×10^{-8}	-	18×10^{-8}	-
6	Electrical penetration							
	Instrument cable	each (multi-insert)	15	ADS-III-G-1 Case 2	-	-	-	-
	4160-v cable	each (multi-insert)	12	ADS-III-G-1 Case 1	10^{-9}	-	4×10^{-9}	-
	480-v cable	each (multi-insert)	7	ADS-III-G-1 Case 1, 2, 3	10^{-9}	-	4×10^{-9}	-
	110-v cable	each (multi-insert)	4	ADS-III-G-2 Case 2	-	-	-	-
							TOTAL	0.31

inside the dry well, all of the released coolant and fission product activity are effectively retained. After the initial transient, the pressure is reduced to a low value so that leakage is minimized. Loss of coolant from a pipe rupture outside the dry well is limited by the automatic closing of the isolating valves. As with the steel dome type of arrangement, the dry well is a steel sphere 190 ft in diameter. In addition to the primary system which includes the steam generator and steam generator pumps, the fuel handling system, primary steam drum, emergency condenser, and reactor crane are located inside the dry well. An air lock provides for entrance to this facility. A separate turbine building is provided for the turbine generator and its auxiliaries.

Since the Sargent and Lundy study provided designs at 180 Mwe and 300 Mwe, it was necessary to adjust the boiling water study to make it compatible with the 200-Mwe sodium graphite reactor study. The adjustment was accomplished by a straight-line extrapolation between the direct costs of the 180-Mwe and 300-Mwe reactors.

C. COSTS

The cost estimating methods for the boiling water reactor containment arrangements are described in detail in the Sargent and Lundy study. Briefly, they consisted of completing preliminary designs of the various plant arrangements and making quantity take-offs of materials. Equipment items, such as heating and ventilating equipment, which contributed to cost differences between arrangements were also itemized and estimated. The various estimated items were separated into cost accounts according to the Atomic Energy Commission's "Qualification of Construction Accounts for Nuclear Power Plants." These various accounts were totalled to obtain the total direct costs, and the following factors were applied against the direct costs:

1) Engineering design and inspection
2) General and administrative expense
3) Contingency
4) Interest during construction.

A similar procedure was followed for the conventional buildings used to house the SGR. As noted previously, two basic sets of drawings were completed covering site development and plant arrangement for the rectangular and the cylindrical schemes. Following completion of the arrangement drawings, the specific type of building was selected (metal panelling or concrete construction) and the leakage and pressure requirements were specified. The detailed structural design was then continued for the particular building under construction. The structural work included analysis of penetrations, cells joints, and other factors affecting leakage. Itemized quantity take-offs were made of most materials such as structural steel, concrete, special painting, etc. Special items of equipment such as marine doors, special cells, penetrations, etc. were estimated by obtaining preliminary quotations from manufacturers or referring to previous cost data where significant costs were involved. If the costs were less significant (as, for example, some of the electrical penetrations) these costs were estimated based upon the estimator's judgement and from experience on other plants.

A complete estimate was not made of certain piping and electrical systems which may have contributed in a minor way to cost differences between plants. Some of these systems were included in the Sargent and Lundy boiling water reactor containment study. To make the two studies comparable, the cost for these systems were removed from the Sargent and Lundy estimate. Other adjustments to the boiling water reactor study included an adjustment to the siting costs to remove dewatering requirements and rock removal. On the SGR study, it was assumed that the site required no dewatering nor rock removal.

Table V-5 shows a cost breakdown of the more significant building arrangements which were prepared. Those items which contribute directly to leakage improvement have been separately itemized. For example, doors which are specially constructed to reduce leakage have been separated from standard doors. Similarly, special vinyl painting for the treatment of concrete buildings has been separated from standard wall and ceiling finishes.

The direct costs of the various equipment and material items were summarized and totalled, as shown in Table V-5. The following factors were then applied to these direct costs:

1) General and administrative expense: 8.6%
2) Miscellaneous construction costs: 1.2%
3) Engineering design and inspection: 13%
4) Contingency: 10%
5) Interest during construction: 11.2%

With regard to the sodium graphite reactor plants, it should be noted that a dual containment system is provided. This system consists of the individual equipment cells which are steel lined and filled with inert gas, and the reactor building enclosure. The cost of these special cells, the cell liner, and the cell penetrations have been itemized separately. It is not possible to separate the concrete into different categories such as shielding, cell, and foundation, since more often than not the concrete performs multiple functions.

The total building costs were determined by adding the direct costs to the costs determined by applying the aforementioned factors.

For purposes of comparing the building costs with the total plant costs, it was assumed that in every case the plant costs were $200/kw.

D. SUMMARY

The major features of all the evaluated building designs are shown in Table V-6. Also, the leakage criteria for each of the designs and the total costs are presented. Figures V-1 and V-2 show the effect of design pressure and leakage rate on total differential costs.

As shown by the figures, the most important parameters affecting costs are: (1) design pressure; (2) building arrangement, rectangular or cylindrical; and (3) type of building construction used. Leakage characteristics of a given type of building are seen to be less important in determining costs than the previously mentioned factors.

It is apparent from the figures that concrete construction is less costly than fluted metal panel construction. Since properly designed concrete buildings are easier to maintain at a given leakage value (see Section IV), they are the preferable type of construction.

It is also shown in Figure V-1 that a cylindrical building is considerably more expensive than a rectangular structure at low pressures. The point at which the cylindrical arrangement becomes less expensive than the rectangular building depends upon the type of design. In the present study, the cylindrical building utilized tilt-up panels on structural steel. The slope of the cost vs pressure curves for the cylindrical structure, as shown in Figure V-1, is based upon this type of design. It is believed that the slope would be reduced if the stresses of the building walls were absorbed in hoop stress through the use of pre- or post-tensioned concrete rather than in bending stress. The point of intersection of equal cost for the cylindrical or rectangular buildings is estimated to lie between 4 or 5 psi for the hoop stress design and 7 to 9 psi for the bending stress design. The point of cost equality for the bending stress arrangement would be higher than that of the hoop stress building.

The major purpose of this cost evaluation was to indicate the probable parameters most important in affecting costs, with some indication of comparative cost trends. The costs should not be presumed to apply to reactor systems other than those studied. The results should not be extrapolated literally since they may be dependent on the particular sizes, designs, conditions, or arrangements selected for study. For example, unfavorable geological or subsoil conditions were not considered. Thus the costs do not include possible changes in substructure which might be required to ensure the integrity of low-leakage structures.

Differences between the cost of the vapor suppression arrangement and the steel containment dome for the boiling water reactor and other building arrangements are obvious from the figures. Containment dome costs, as a function of size and pressure, should be presumed to change differently than conventional buildings designed for reactor containment.

It is not always possible to unequivocally associate costs with a single factor such as leak rate, pressure, design, or arrangement. For example, painting costs more in high-pressure structures than it does in low-pressure structures due to interference from structural features. However, it is impractical to differentiate whether this is a pressure or a leakage cost. Furthermore, in low-leakage construction, the cost of work such as caulking and painting is relatively small. Consequently, the highest possible quality of workmanship and materials is always utilized, regardless of the desired leakage. This means that as far as cost is concerned, quality is not a significant factor in meeting a leakage specification. Rather, the reduction of leak paths and changes in design have far greater effects on cost.

The additional comparative costs which might be associated with certain contingencies, such as inspection and repair due to aging or usage, were not evaluated. Thus, if concrete were presumed to crack too much for a given application, a better paint or a better concrete would be called for rather than more frequent inspection and repair. It is impossible to estimate the extent of cracking of concrete due to poor workmanship or the amount of paint integrity violation as a result of careless operation. Consequently, in order to put costs on a comparable basis, it was assumed that leakage due to failures of components, structures, joints, and caulking did not occur. Cracks in concrete unbridged by paint was arbitrarily selected as the complete loss of paint integrity below 5 ft in elevation on the reactor structure.

TABLE V-5

COST BREAKDOWN OF VARIOUS REACTOR CONTAINMENT ARRANGEMENTS

	Sodium Graphite Reactor					Boiling Water Reactor	
General Description							
Building leakage category	High	Moderate	Low	Low	Very Low	Very Low	Very Low
Building pressure category	Low	Low	Low	Low	Low	High	Moderate
Containment type	Cells & Bldg	Cells & Bldg	Cells & Bldg	Cells & Bldg	Cells & Bldg	Steel dome	Pressure suppresion
Reactor building shape	Rectangular	Rectangular	Rectangular	Cylindrical	Cylindrical	Spherical	Spherical
Building superstructure	Tilt-up concrete	Tilt-up concrete	Tilt-up concrete	Tilt-up concrete	Prestress concrete	Steel Shell	Steel Shell
Building substructure	Reinforced concrete	Reinforced concrete	Reinforced concrete	Reinforced concrete	Reinforced concrete	Steel & concrete	Steel & concrete
Special treatment	None	None	Vinyl paint inside	Vinyl paint inside	Vinyl paint inside	None	None
Plant electrical output (Mwe)	200	200	200	200	200	180	180
Leakage Criteria							
Volume leakage at design pressure (%/day)	10,000+	100	1	1	0.1	0.1	0.1
Design pressure	4 in. water	4 in. water	1/2 psig	1/2 psig	1/2 psig	23 psig	15 psig
Costs ($)							
Superstructure							
Structural steel & misc iron	156,600	156,600	222,400	288,200	288,200	220,600	159,100
Exterior walls	70,000	80,500	82,700	85,700	121,300	–	–
Containment shell steel	–	–	–	–	–	2,000,000	1,864,000
Temporary columns	–	–	–	–	–	64,000	64,000
Doors or air locks (leakage hardware)	–	8,860	10,860	10,860	17,460	109,000	108,000
Doors or windows (Standard)	9,940	6,940	6,340	6,340	6,340	–	–
Insulation, exterior	–	–	–	–	–	288,000	288,000
Roof deck, roofing, floors & partitions	45,000	53,000	69,300	94,500	94,500	348,000	348,000
Wall and ceiling finish	31,300	31,300	10,500	13,400	13,400	83,400	83,400
Building penetrations	5,000	21,600	27,000	27,300	31,600	(In containment)	(In containment)
Cell penetrations	46,400	46,400	47,000	47,000	48,000	–	–
Special painting	–	–	55,000	59,000	59,000	–	–
Substructure							
Excavation & back fill	98,800	98,800	98,800	119,300	119,300	48,700	139,200
Concrete (including embedments & waterproofing)	1,000,200	1,000,200	1,000,200	1,629,100	1,629,100	1,314,000	1,836,500
Cell Liners, suppression C. S. plate liner, P. V. C. liner	502,200	502,200	502,200	528,000	528,000	–	375,000
Building Services							
Heating, ventilating & service water	192,000	192,000	165,000	257,000	257,000	48,500	48,500
Lighting and service wiring	32,000	32,000	32,000	45,000	45,000	32,000	32,000
Leak testing building	–	5,000	10,000	10,000	15,000	(In contain. cost)	10,000
Subtotals	2,189,440	2,235,400	2,339,300	3,221,400	3,273,600	4,556,200	5,355,700
General and Administrative (8.6%)	188,300	192,200	201,000	277,000	286,000	391,800	460,600
Subtotals	2,377,740	2,427,600	2,540,000	3,498,400	3,559,600	4,948,000	5,816,300
Misc Construction Costs (1.2%)	28,500	29,200	30,500	42,000	42,700	59,400	69,800
Subtotals	2,406,240	2,456,800	2,570,800	3,540,400	3,602,300	5,007,400	5,886,100
Engineering, Design & Inspection (13%)	312,800	318,200	334,200	460,000	468,000	651,000	765,200
Subtotals	2,719,040	2,775,000	2,905,000	4,000,400	4,070,300	5,658,400	6,651,300
Contingency (10%)	271,900	277,500	290,500	400,000	407,000	565,800	665,100
Subtotals	2,990,940	3,052,500	3,195,500	4,400,400	4,477,300	6,224,200	7,316,400
Interest During Construction (52 mo; 11.2%)	335,000	342,000	358,000	493,000	502,000	697,100	819,400
Total building costs ($)	3,325,940	3,394,500	3,553,500	4,893,400	4,979,300	6,921,300	8,135,800
Total building costs, adjusted to 200 Mwe	–	–	–	–	–	7,061,300	8,244,800
Total building costs ($/kw)	16.6	17.0	17.8	24.5	24.9	35.3	41.2
Total plant costs, assumed ($/kw)	200	200	200	200	200	200	200
Building costs as % of total plant costs	8.30	8.48	8.88	12.2	12.5	17.6	20.6
Total differential costs from datum	Datum	68,560	227,560	1,567,460	1,653,360	3,735,360	4,918,850
Differential costs as % of datum cost	0	2.06	6.83	47.2	49.7	112	148

TABLE V-6

SUMMARY OF COSTS FOR VARIOUS REACTOR CONTAINMENT ARRANGEMENTS

	Sodium Graphite Reactor										Boiling Water Reactor	
General Description												
Building leakage category	High	Moderate	Low	Low	Low	Very low	High	Moderate	High	Moderate	Very low	Very low
Building pressure category	Low	Low	Low	Moderate	Low	Low	Low	Low	Low	Low	High	Moderate
Containment type	Cells & bldg	Cells & bldg	Cells & bldg	Cells & bldg	Cells & bldg	Cells & bldg	Cells & bldg	Cells & bldg	Cells & bldg	Cells & bldg	Steel dome	Pressure Suppression
Reactor building shape	Rectangular	Rectangular	Rectangular	Rectangular	Cylindrical	Cylindrical	Rectangular	Rectangular	Rectangular	Rectangular	Spherical	Spherical
Building superstructure	Tilt-up concrete	Tilt-up concrete	Tilt-up concrete	Tilt-up concrete	Tilt-up concrete	Prestress concrete	Metal panel	Metal panel	Metal panel	Metal panel	Steel shell	Steel shell
Building substructure	Reinforced concrete	Reinforced concrete	Reinforced concrete	Reinforced concrete	Reinforced concrete	Reinforced concrete	Reinforced concrete	Reinforced concrete	Reinforced concrete	Reinforced concrete	Steel and concrete	Steel and concrete
Special treatment	None	None	Vinyl paint	Vinyl paint	Vinyl paint	Vinyl paint	None	Vinyl paint	None	Vinyl paint	None	None
Plant electrical output (Mwe)	200	200	200	200	200	200	200	200	200	200	180	180
Leakage Criteria												
Volume leakage at design pressure (%/day)	10,000+	100	1	5	1	0.1	100,000+	100	1,000,000	1,000	0.1	0.1
Design pressure	4 in. water	4 in. water	1/2 psig	2 psig	1/2 psig	1/2 psig	4 in. water	4 in. water	1/2 psig	1/2 psig	23 psig	15 psig
Costs												
Total building costs ($)	3,325,940	3,394,500	3,553,500	4,173,700*	4,893,400	4,979,300	3,459,800*	3,516,600*	3,522,700*	3,640,400*	7,061,300*	8,244,800*
Total building costs ($/kw)	16.6	17.0	17.8	20.9	24.5	24.9	17.3	17.6	17.6	18.2	35.3	41.2
Differential costs from datum	Datum	68,560	227,560	847,760	1,567,460	1,653,360	133,860	190,660	196,760	314,460	3,735,360	4,918,860
Differential costs as % of datum cost	0	2.06	6.83	25.5	47.2	49.7	4.02	5.73	5.91	9.46	112	148

*These costs are adjusted or normalized from different designs to put on similar basis to other costs

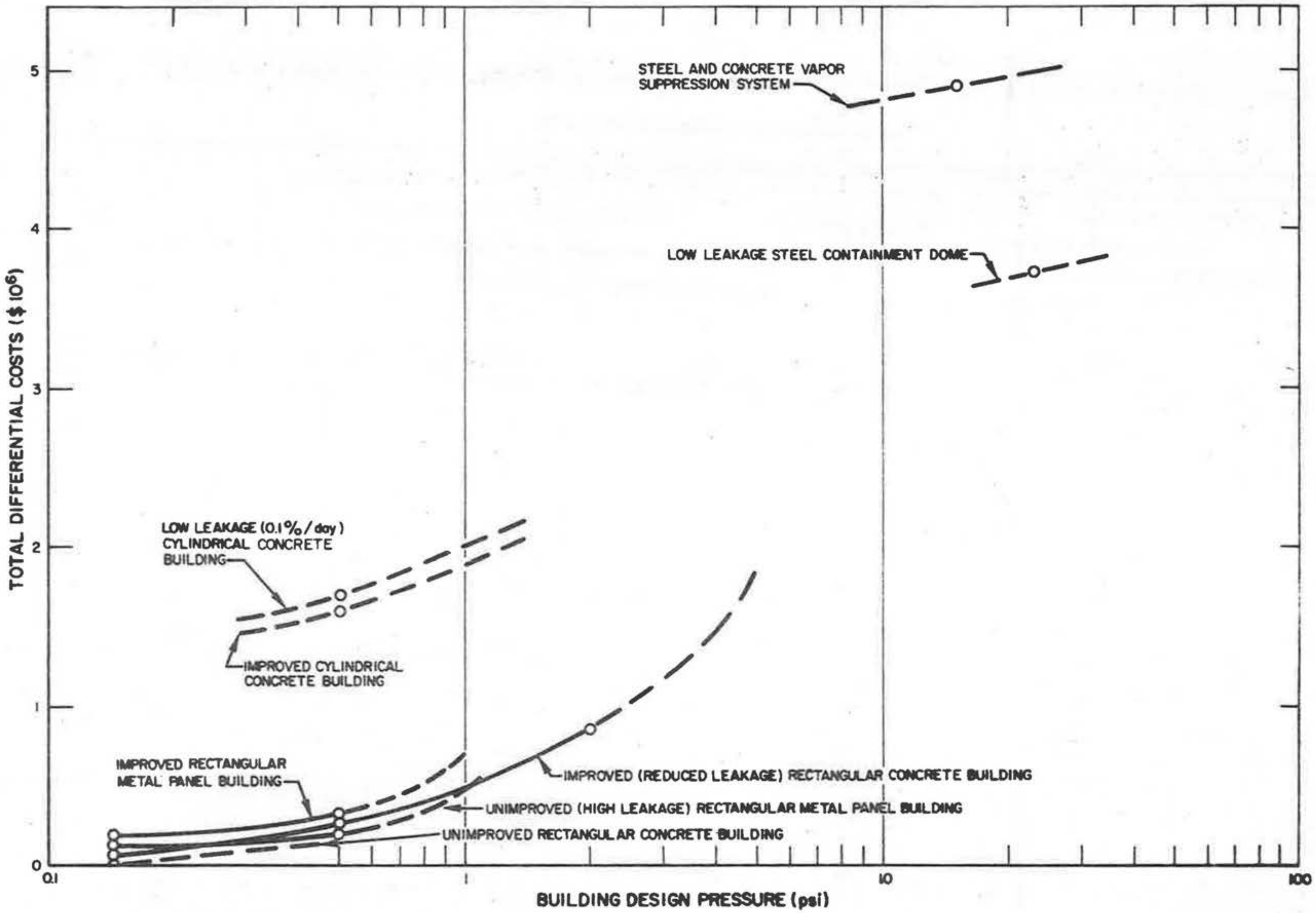

Figure V-1. The Effect of Design Pressure on Reactor Containment Building Differential Costs

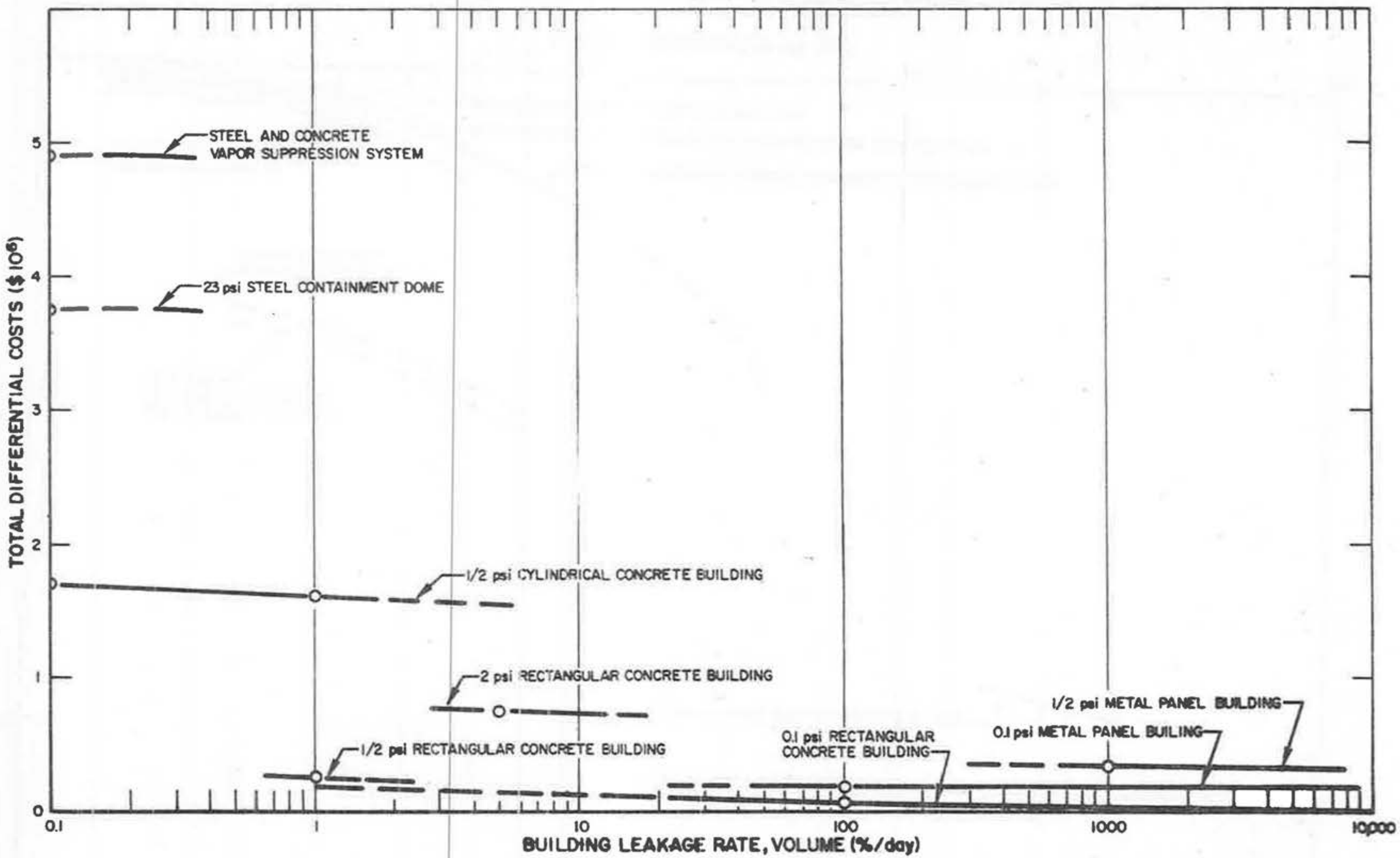

Figure V-2. The Effect of Leakage Rate on Reactor Containment Building Differential Costs

PLANT DRAWINGS

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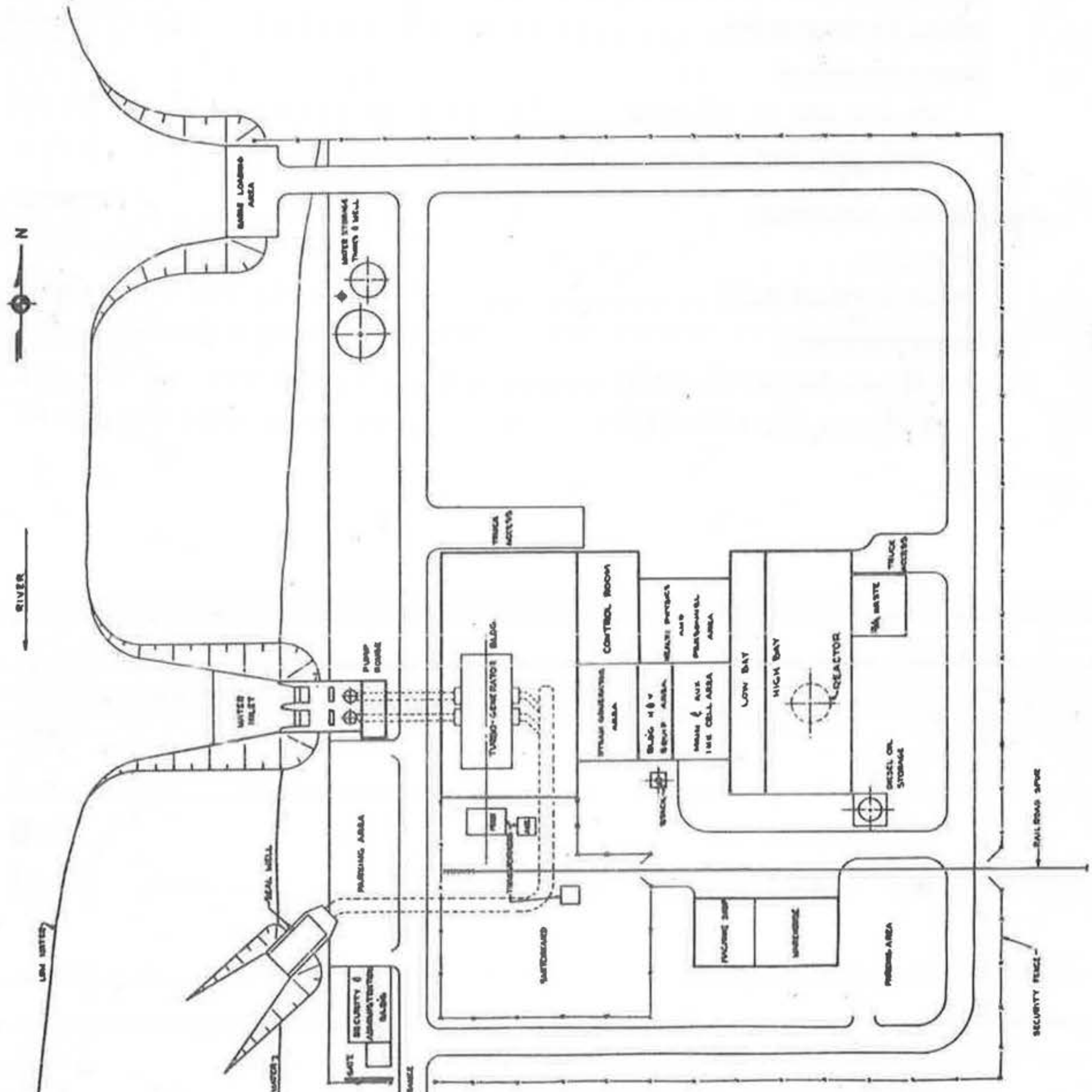

Rectangular Building
(7603-FA001)

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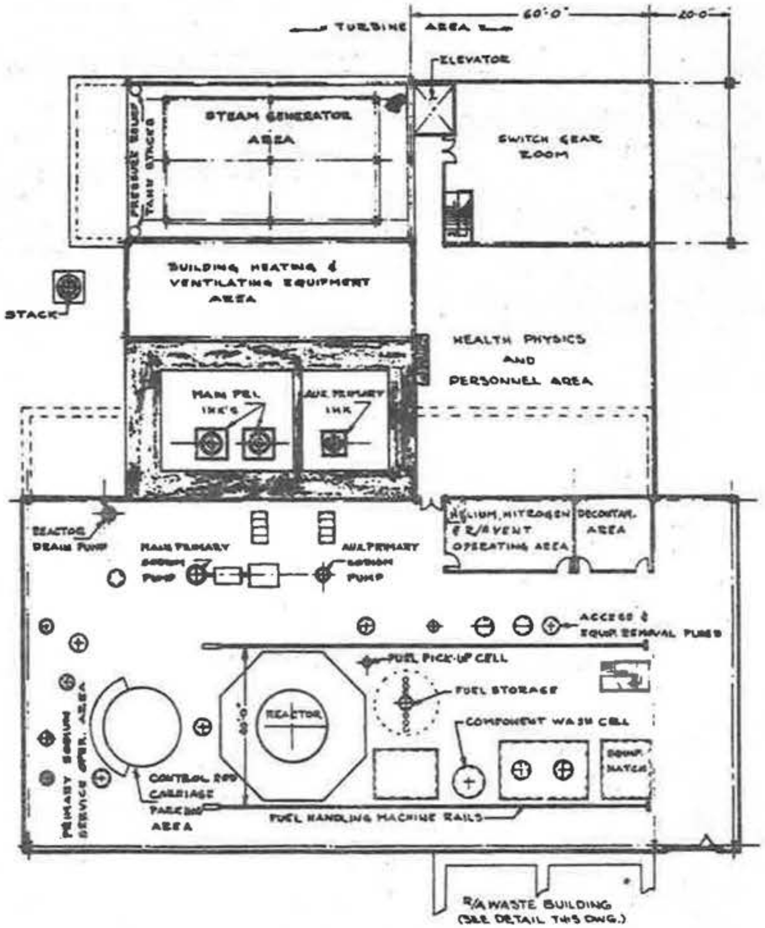
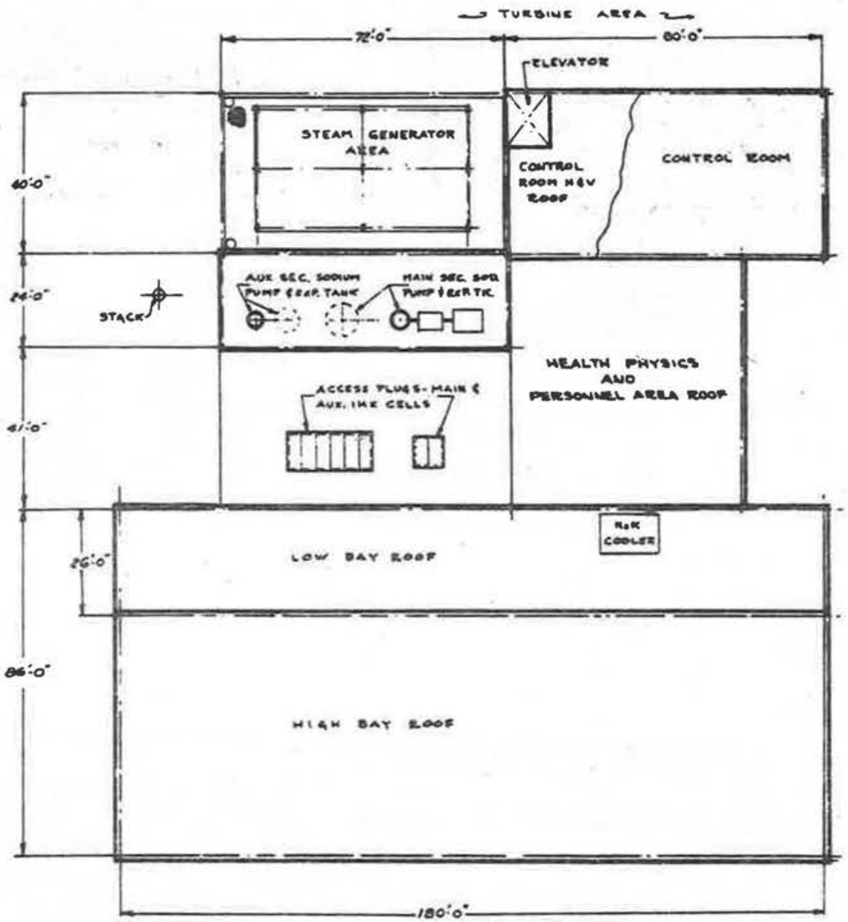
360<

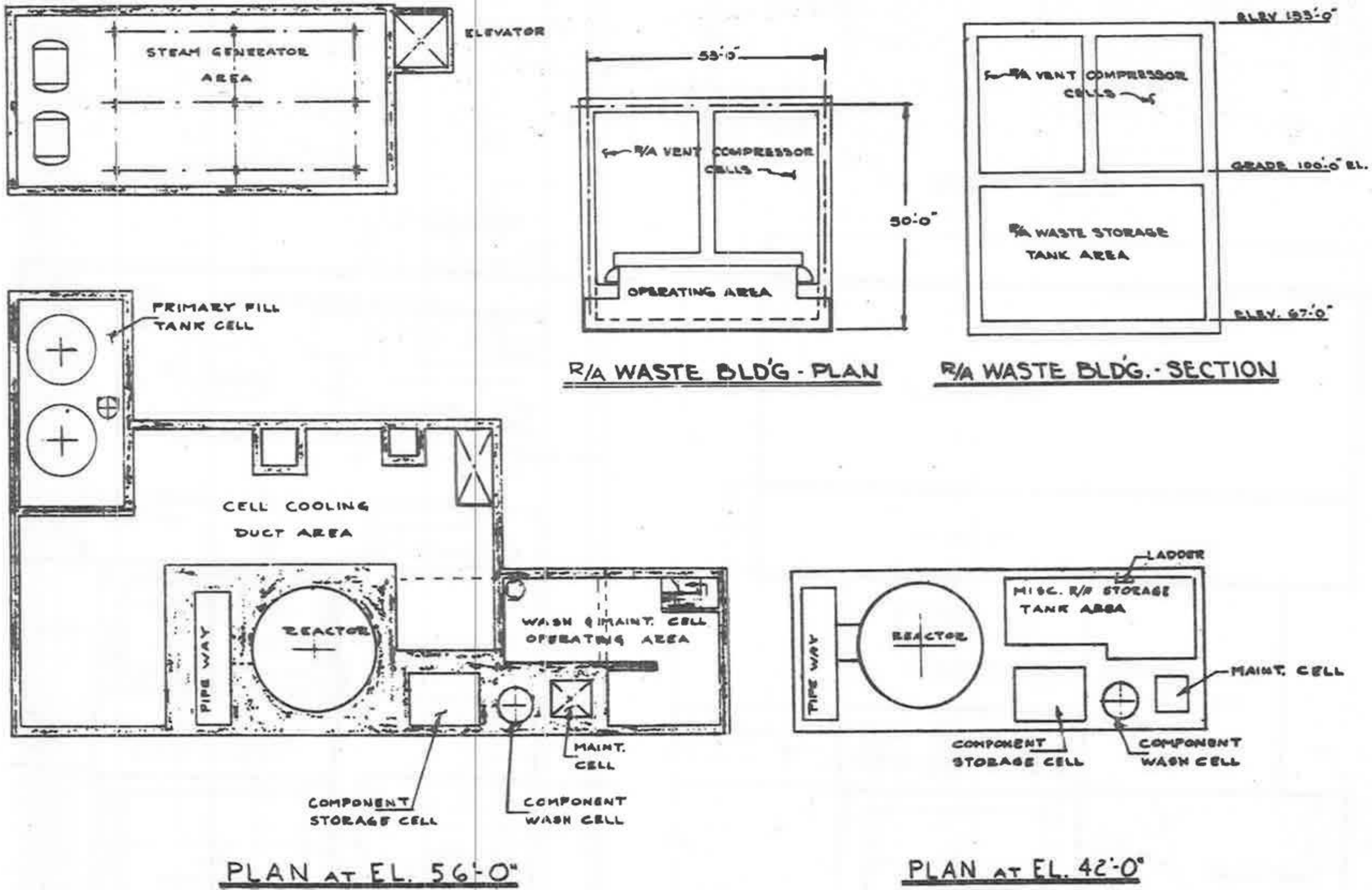


PLAN AT EL. 102'-0"

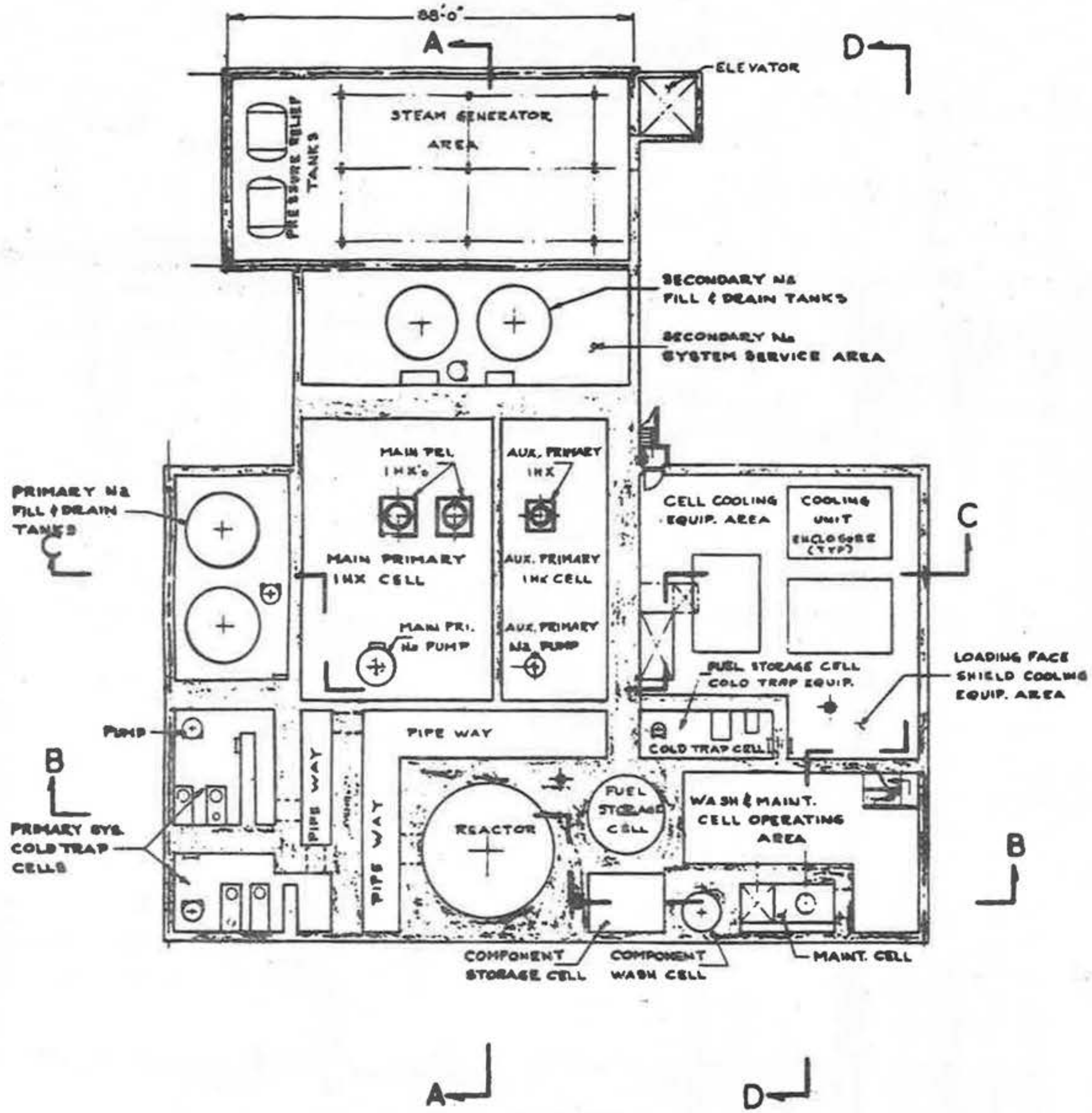


PLAN AT EL. 180'-0"

Rectangular Building
(7603-GA001a)

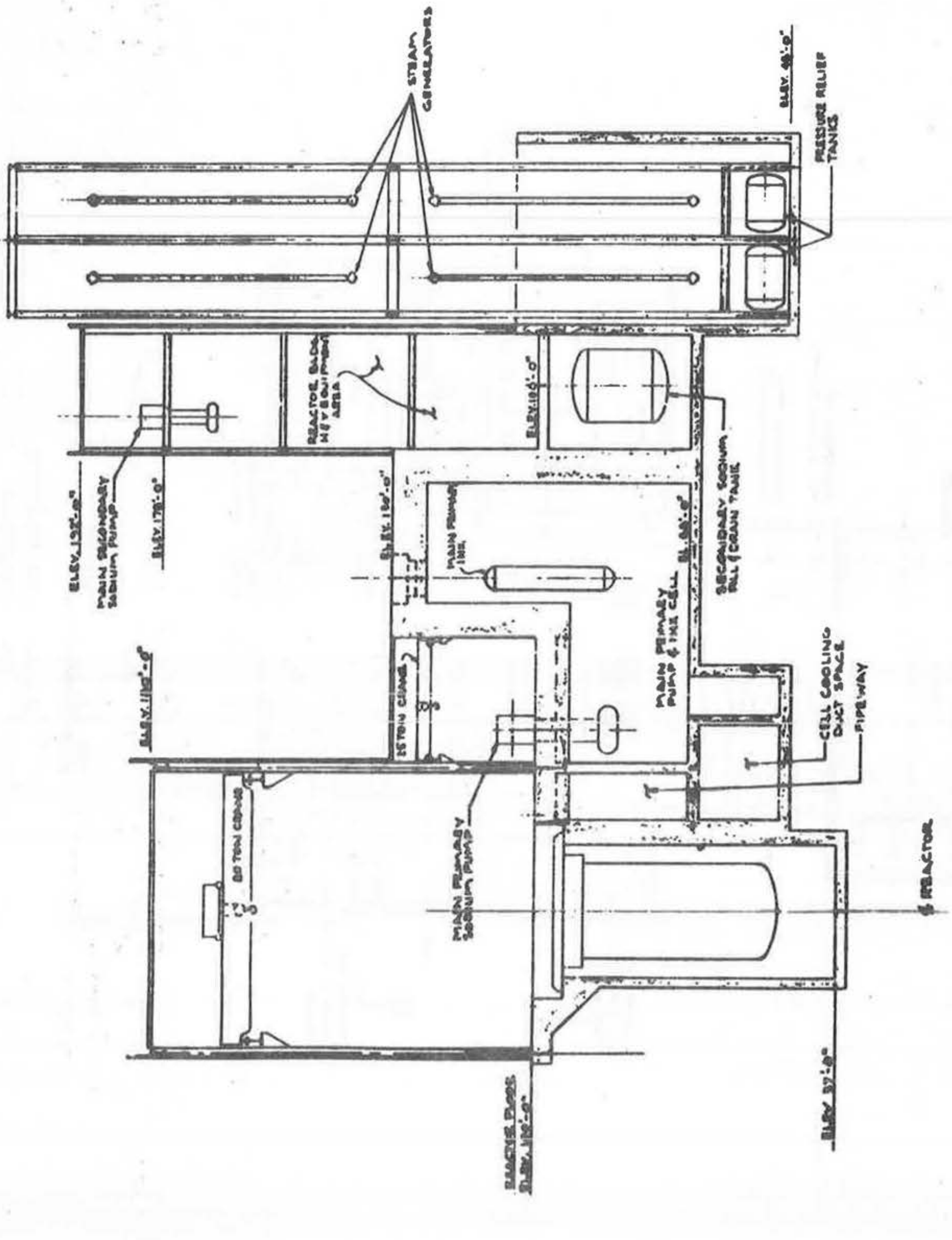


Rectangular Building
(7603-GA001b)



PLAN AT EL. 84'-0"

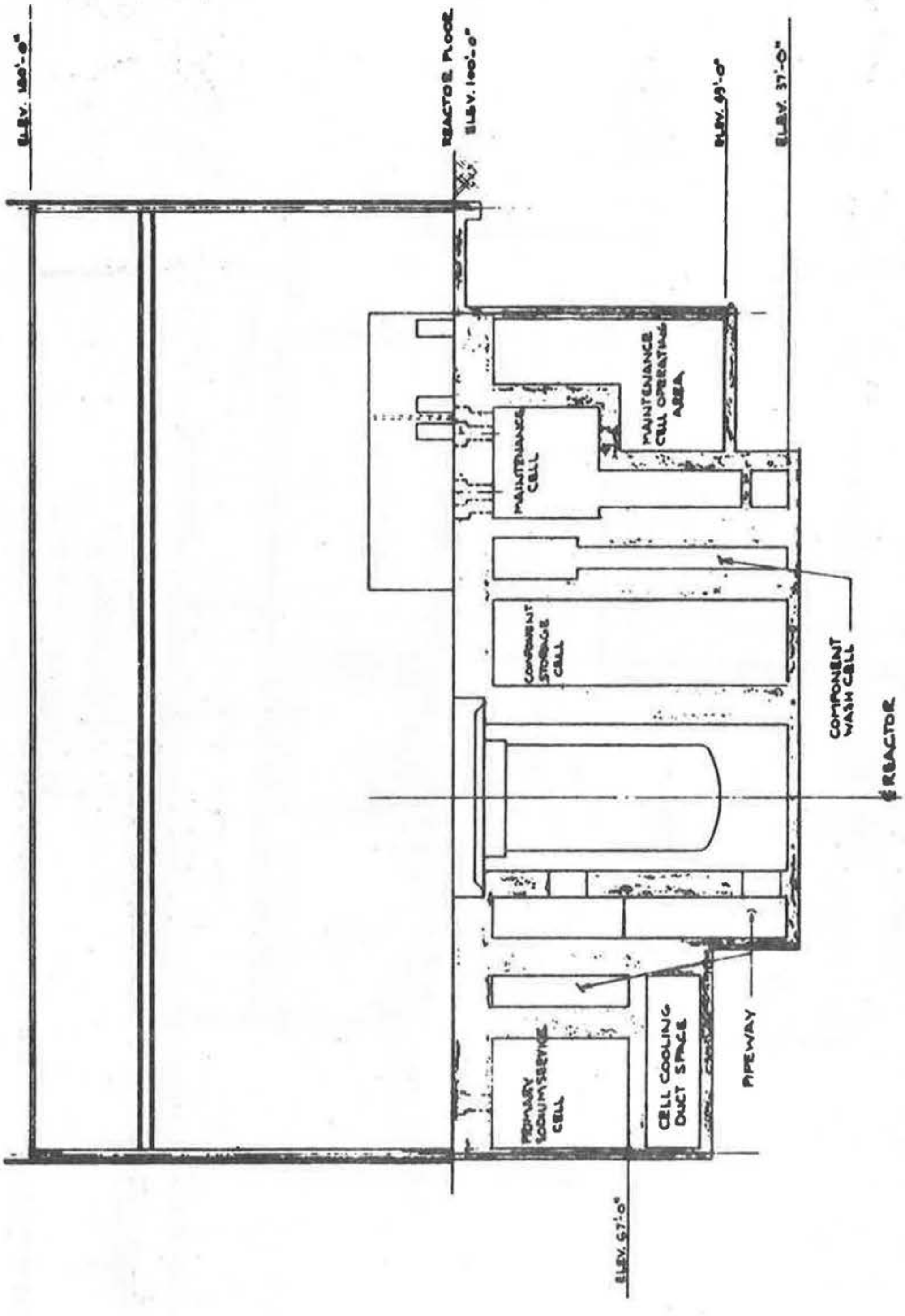
Rectangular Building
(7603-GA001c)



SECTION A-A

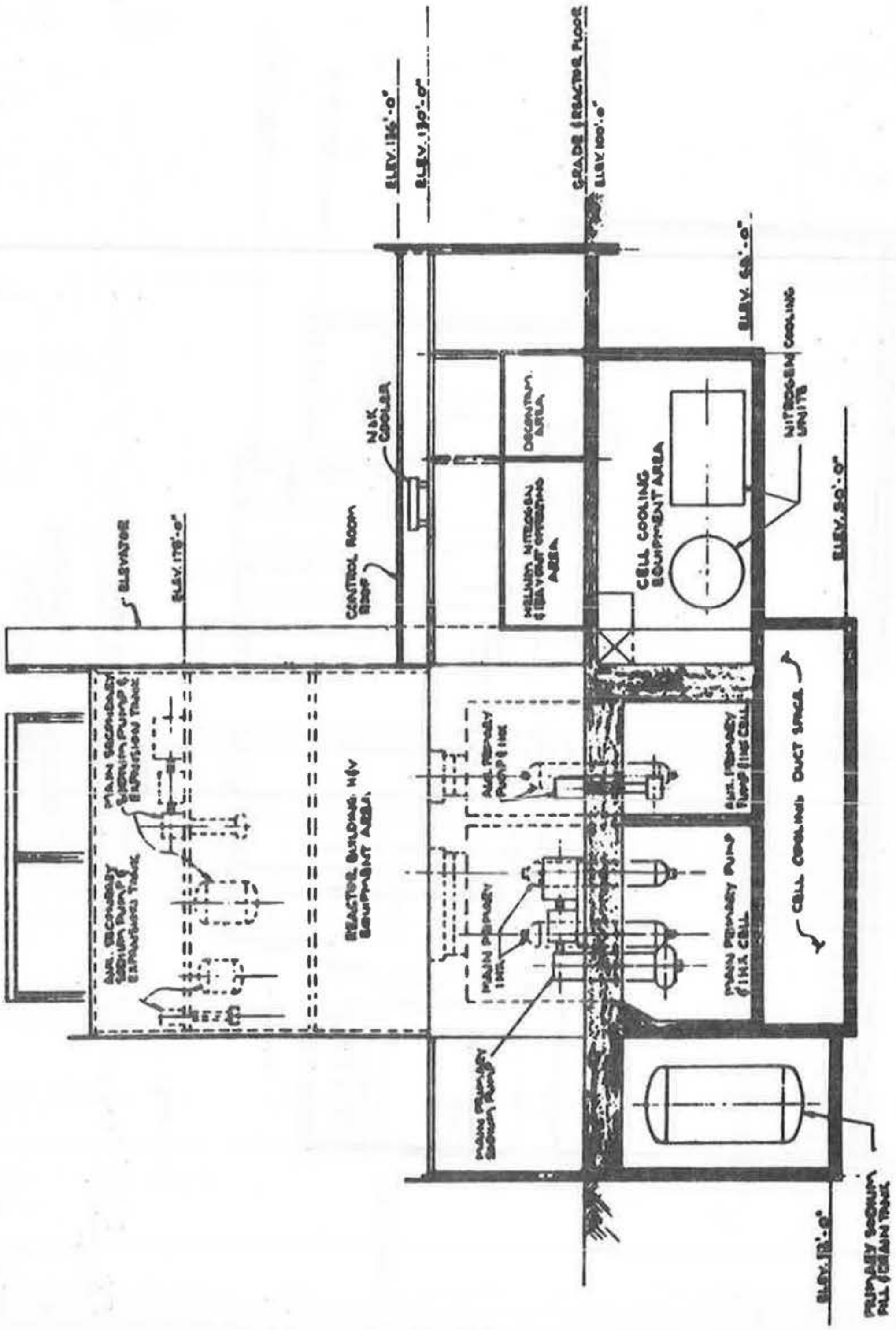
Rectangular Building
(7603-GA002a)

364<



SECTION B-B

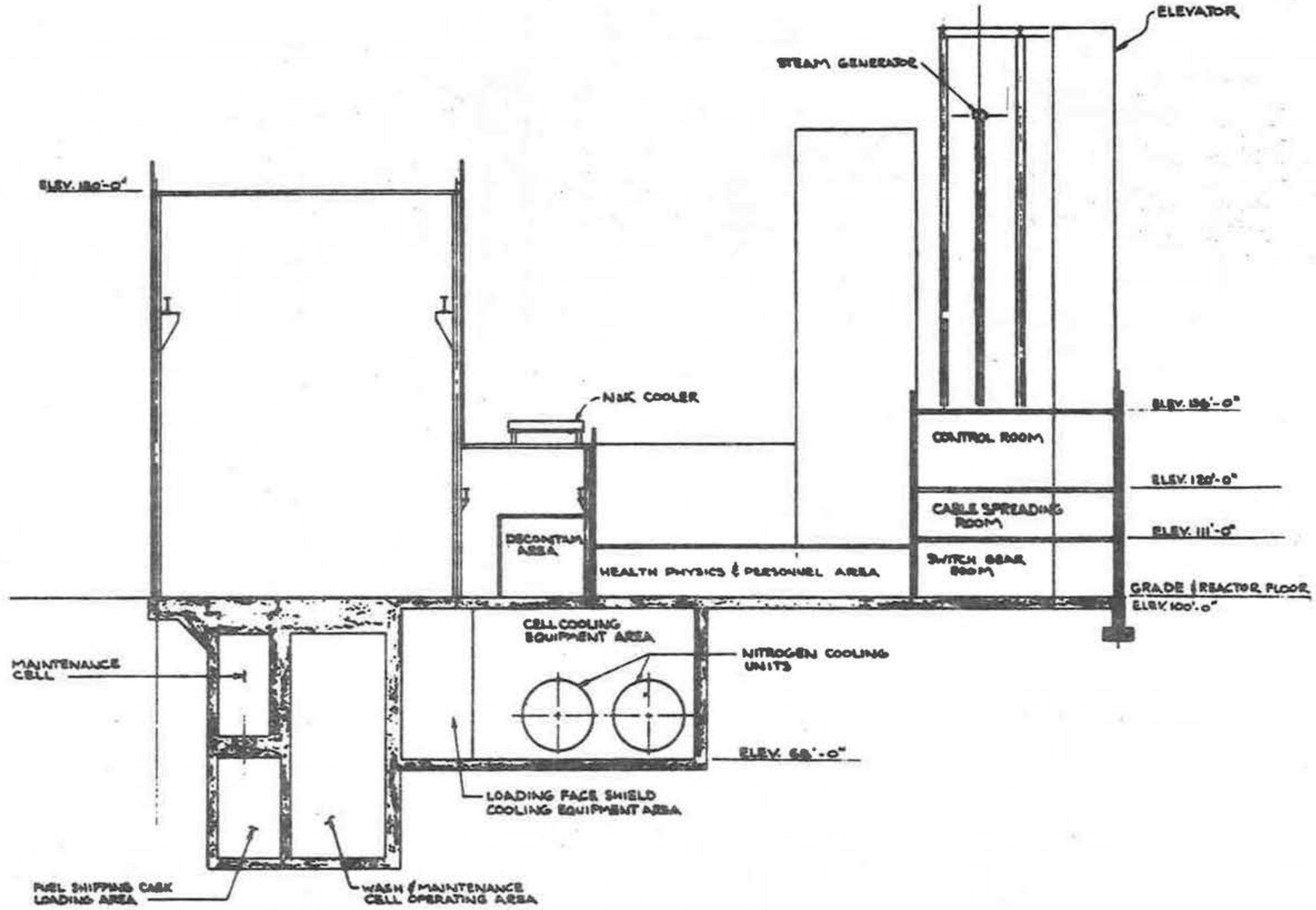
Rectangular Building
(7603-GA002b)



SECTION G-G

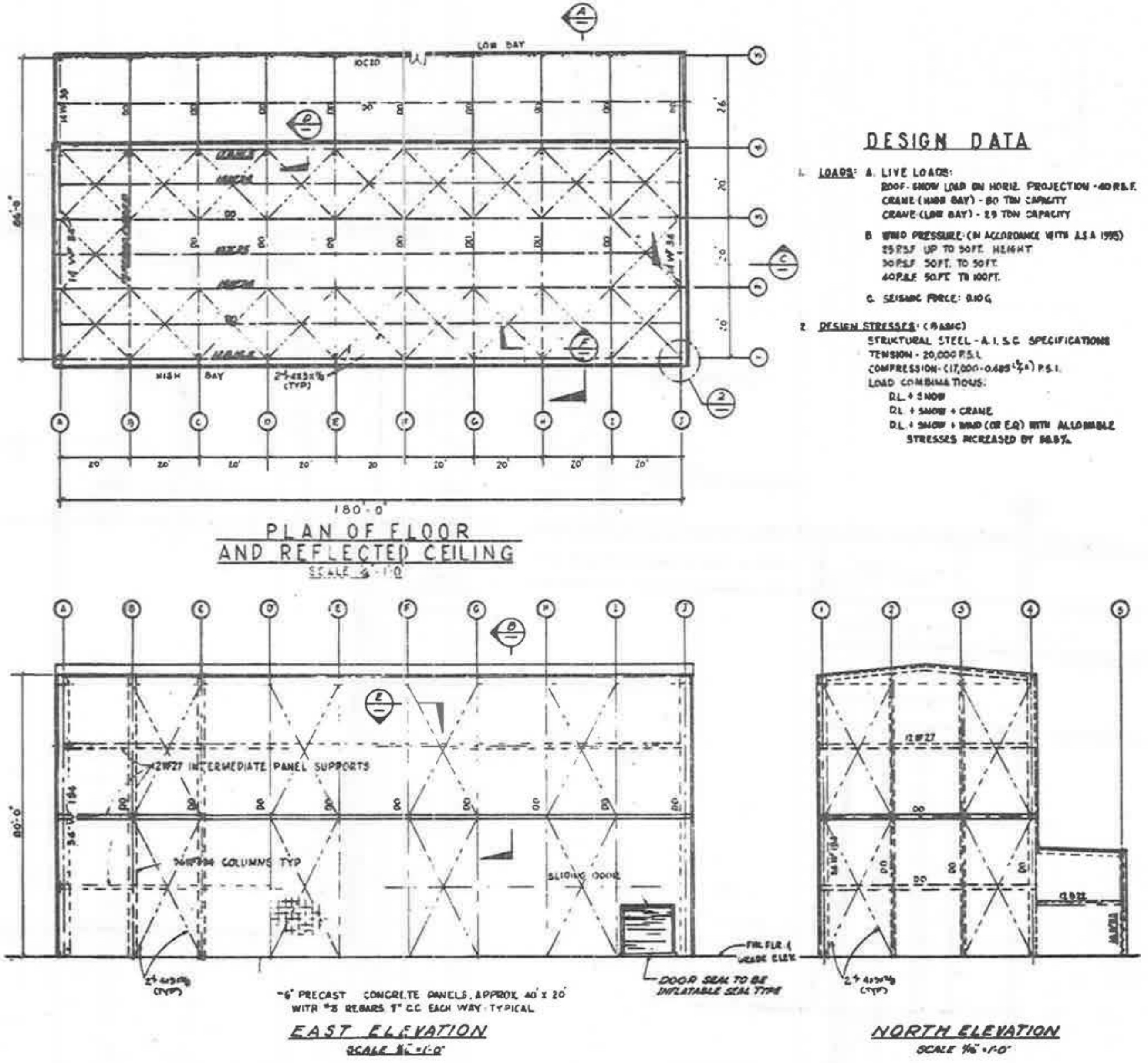
Rectangular Building
(7603-GA002c)

366<

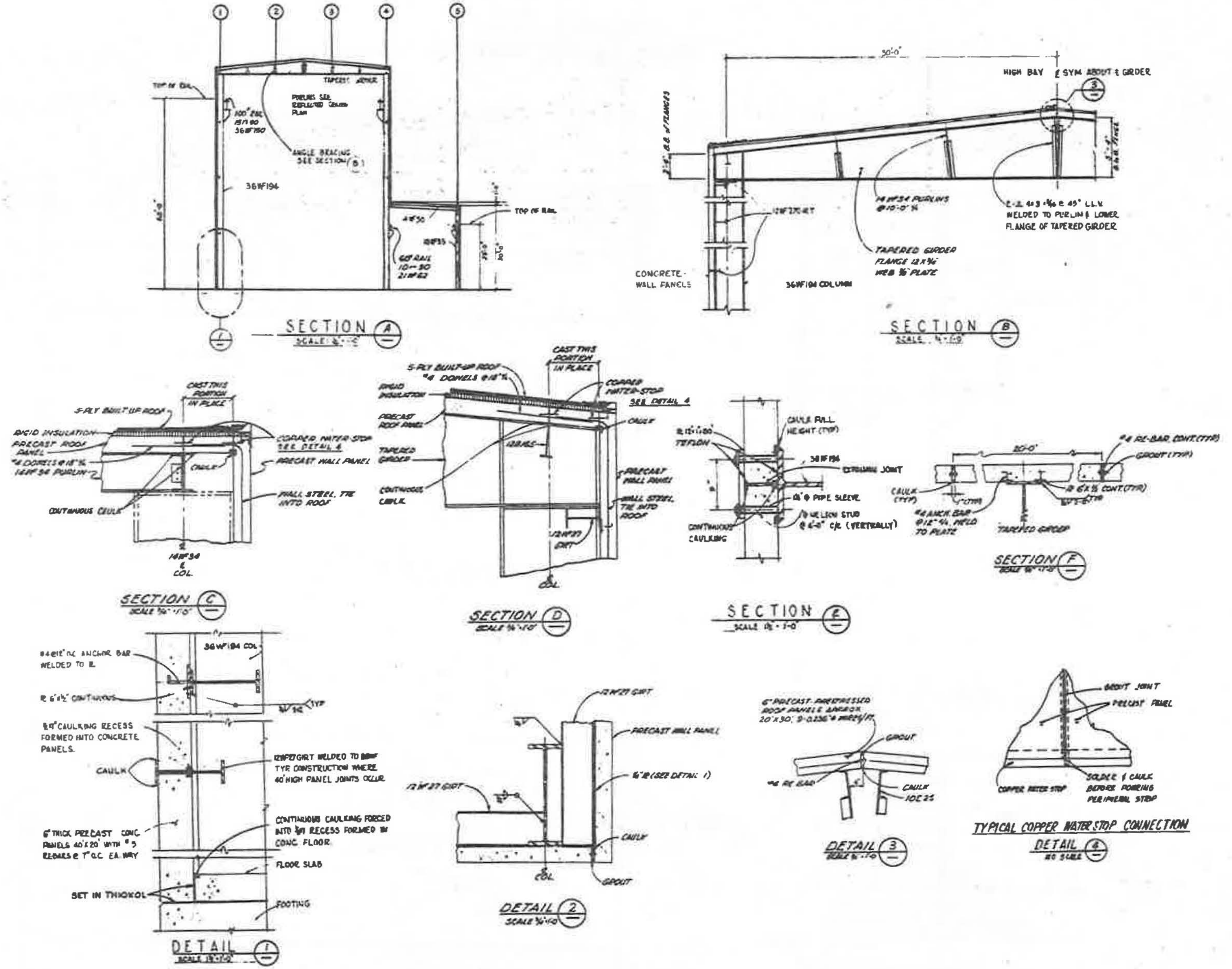


SECTION D-D

Rectangular Building
(7603-GA002d)



Rectangular Building
(7603-FS001a)



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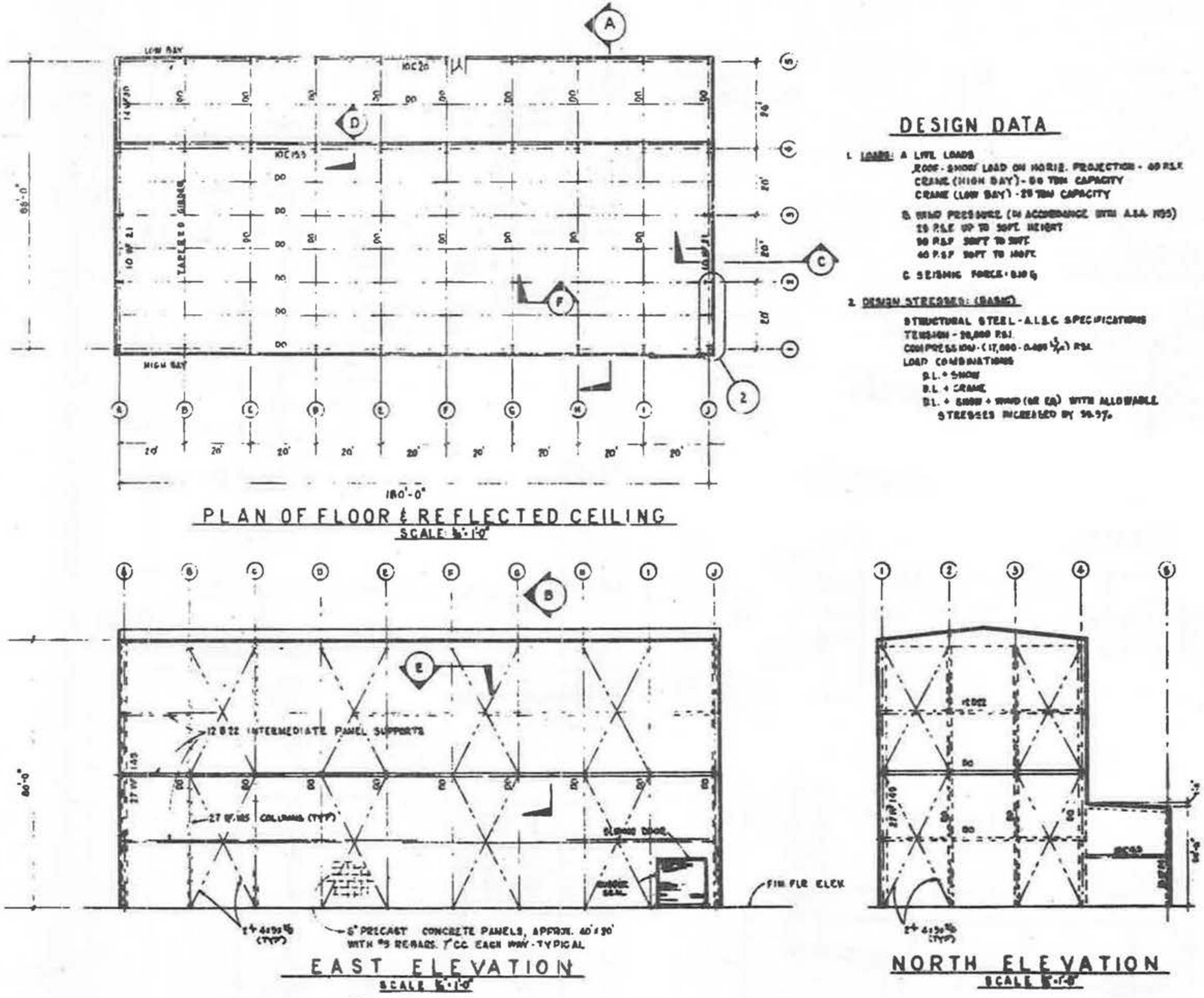

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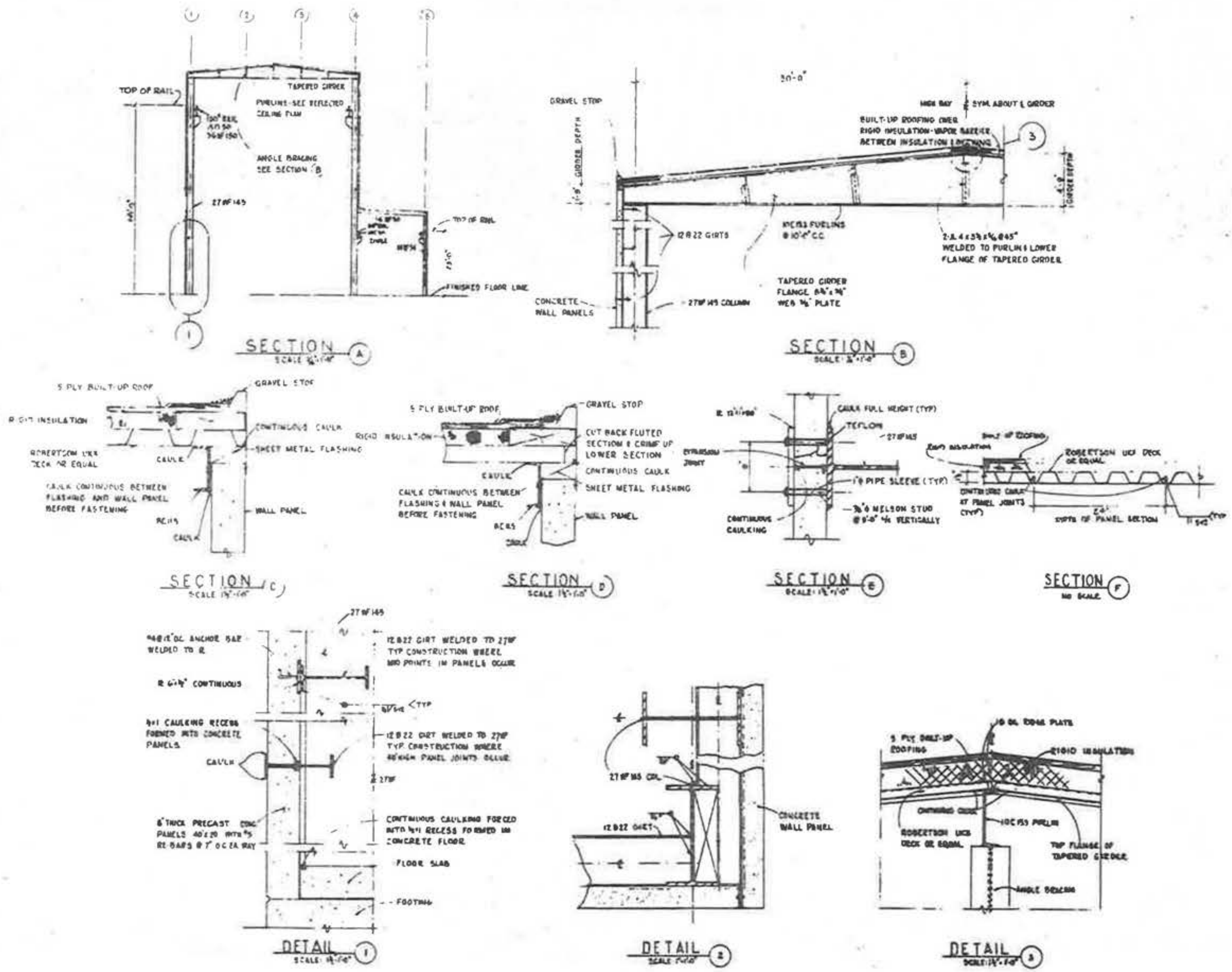
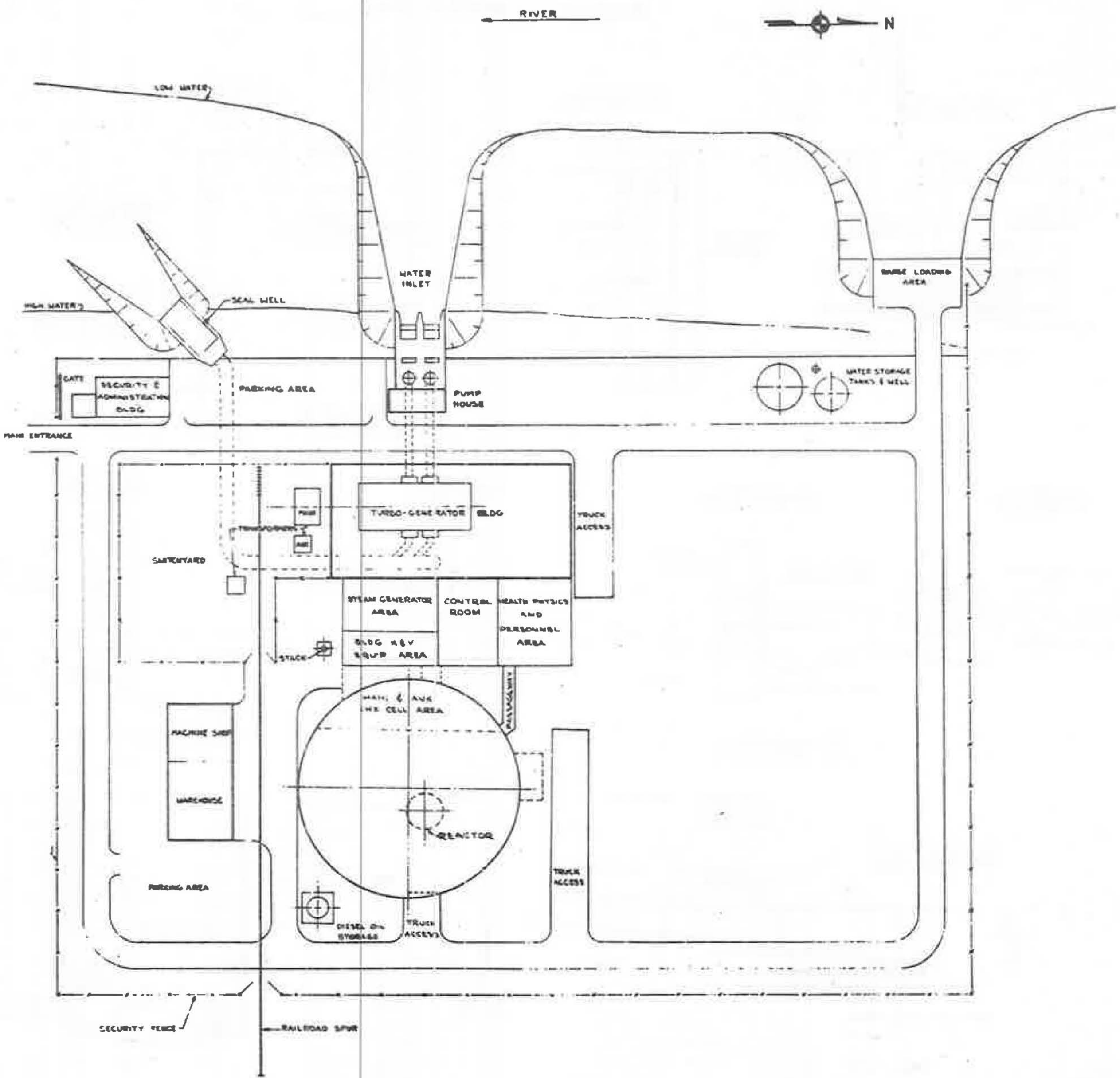
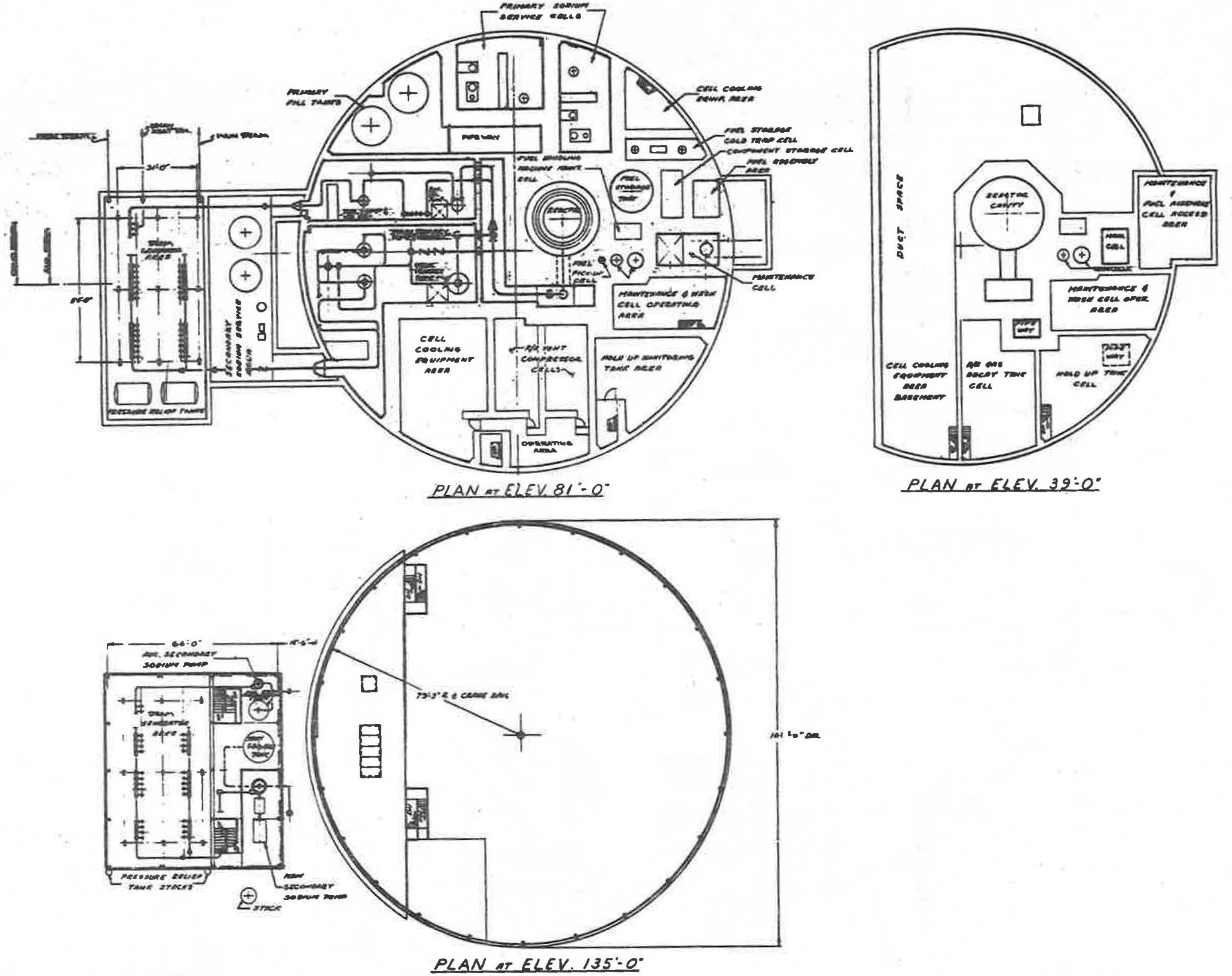


Rectangular Building
(7603-FS002b)

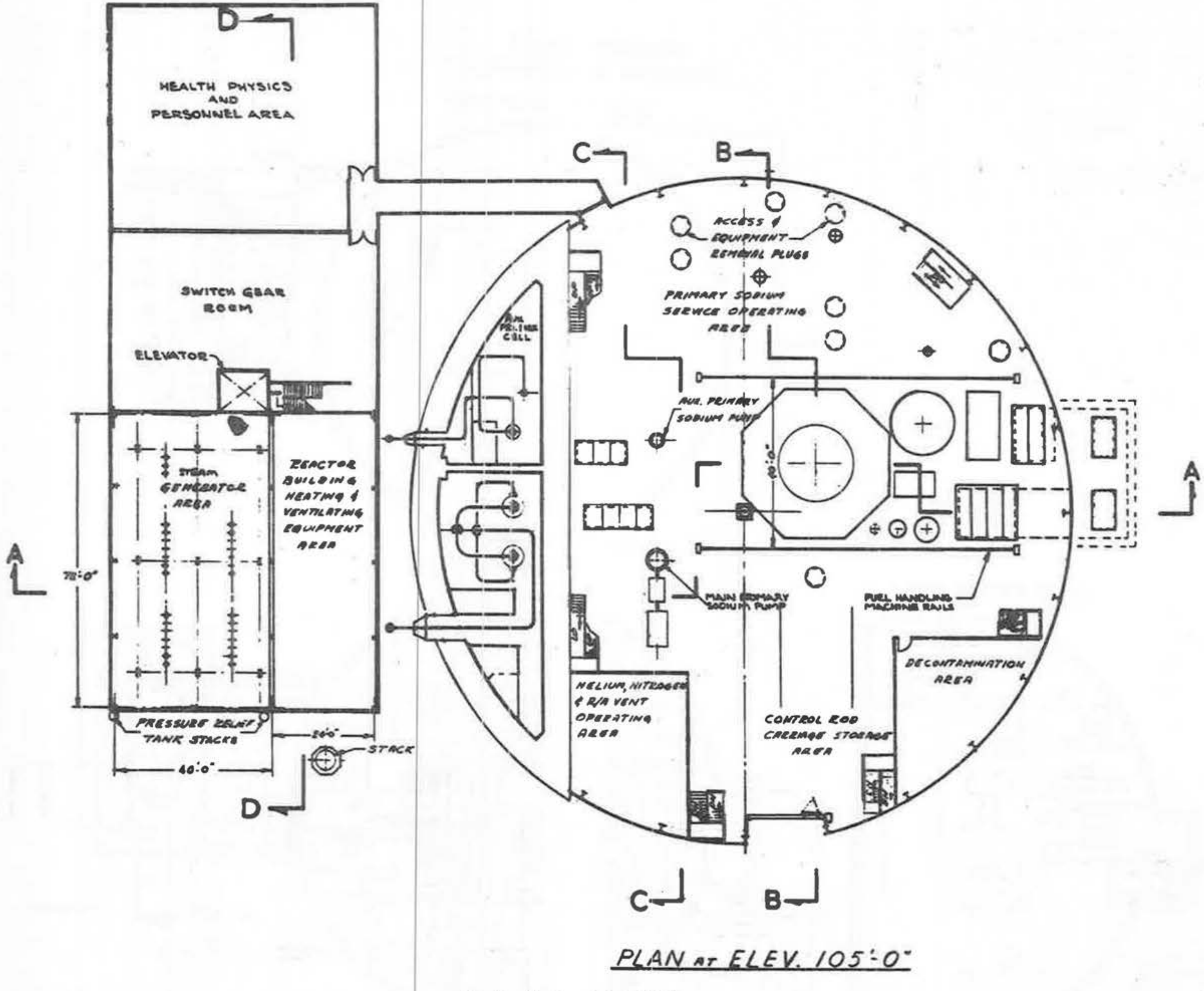


Cylindrical Building
(7603-FA002)



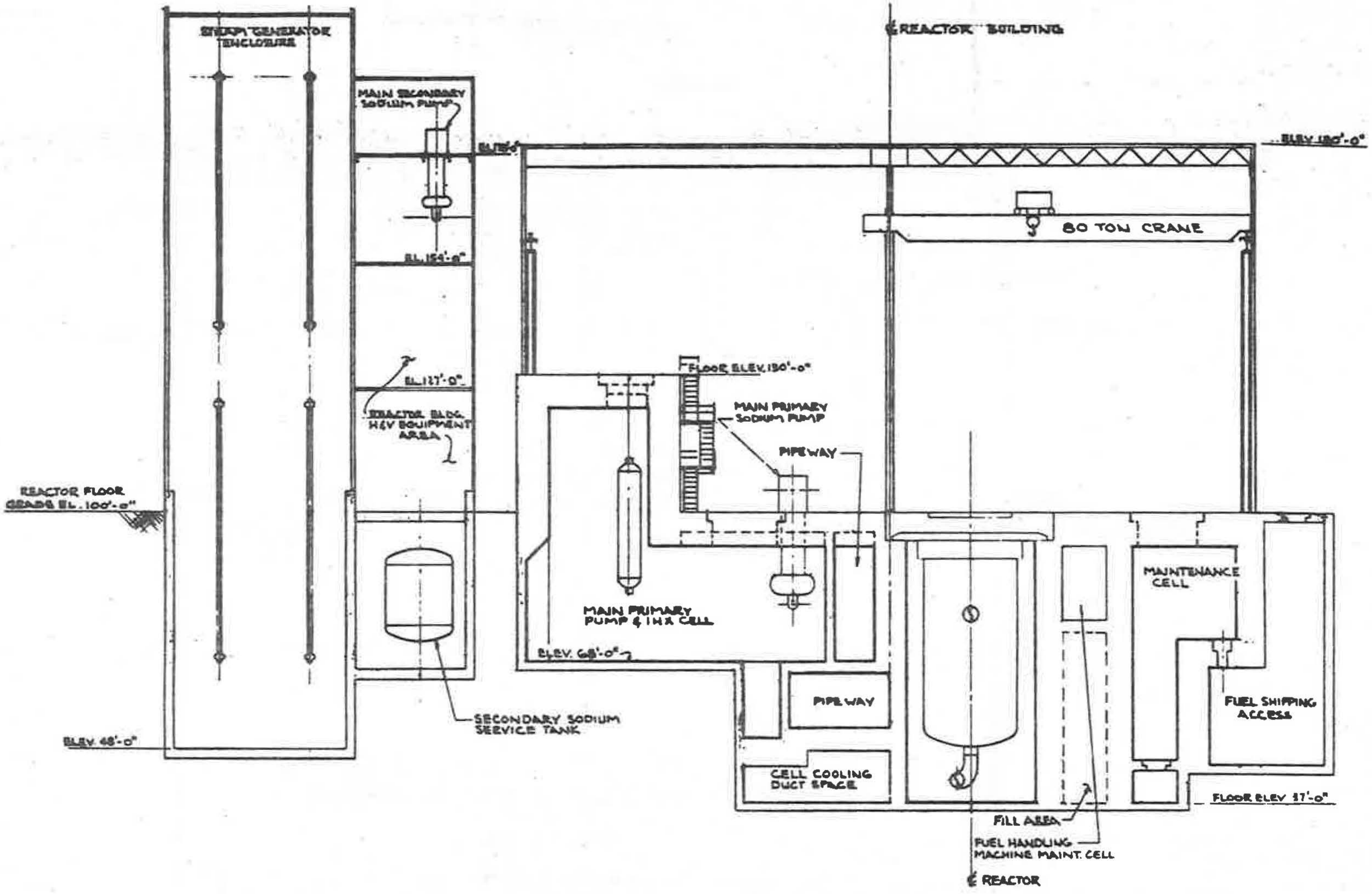
Cylindrical Building
(7603-GA003a)

373



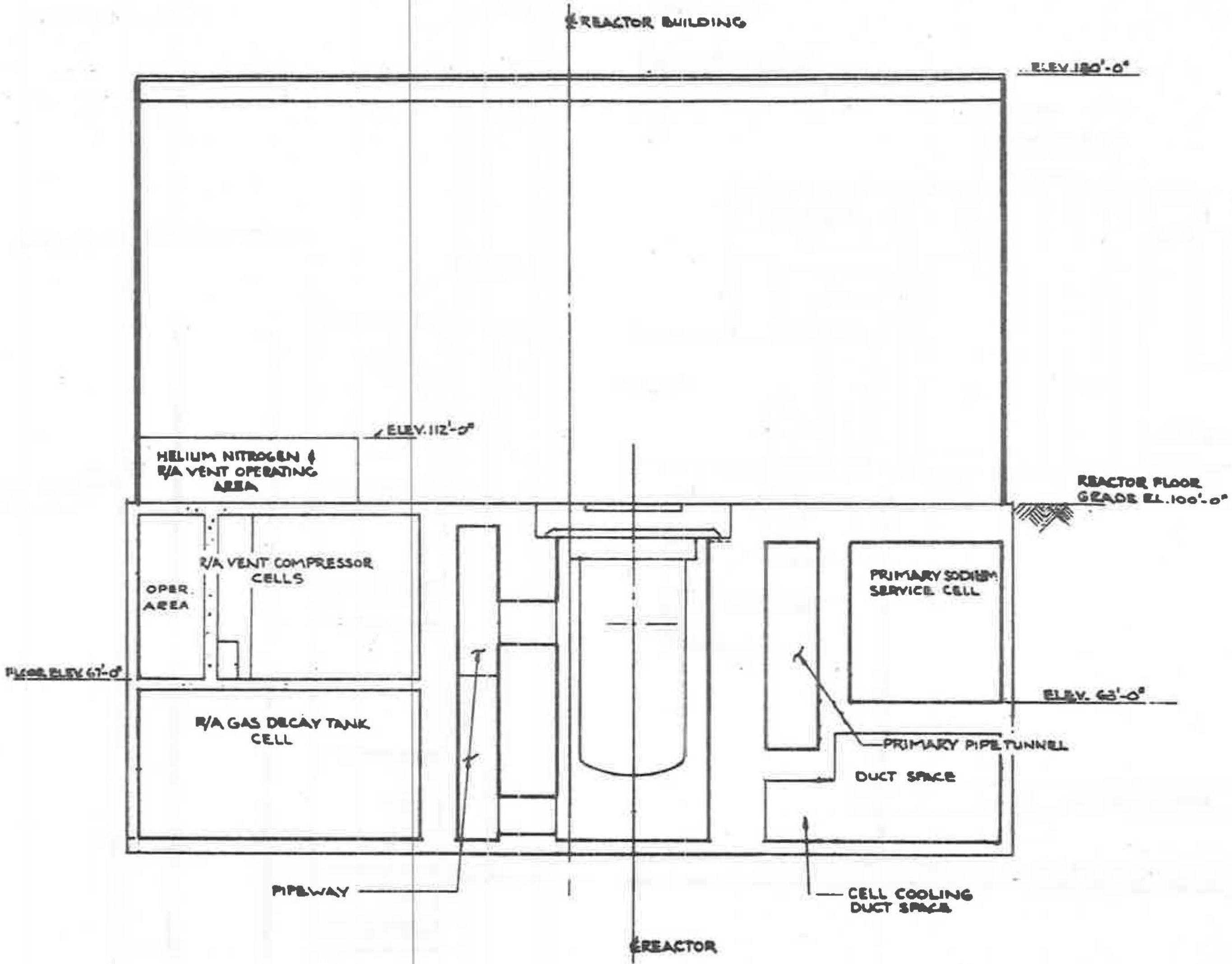
PLAN AT ELEV. 105'-0"

Cylindrical Building
(7603-GA003b)



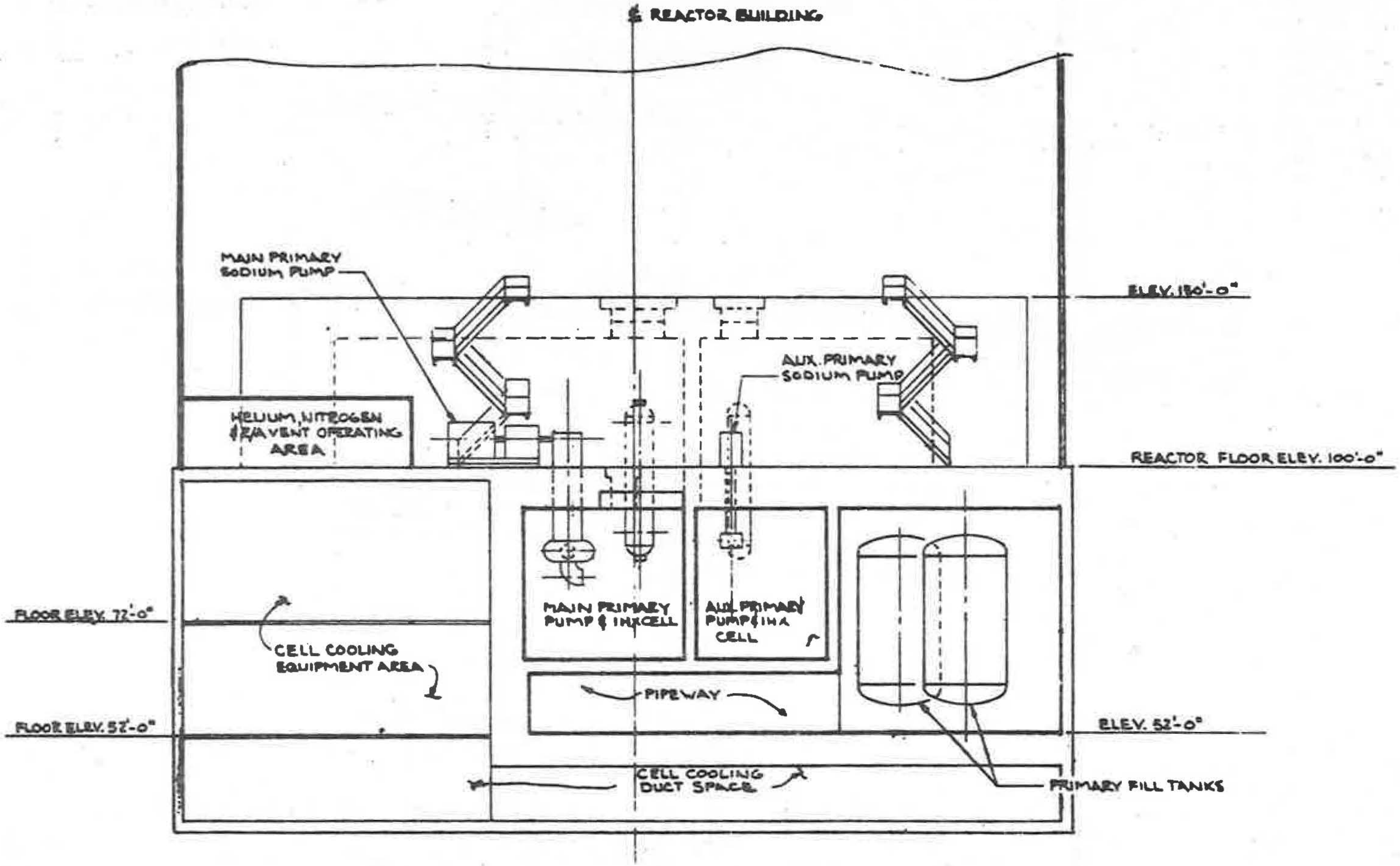
SECTION A-A

Cylindrical Building
(7603-GA004a)



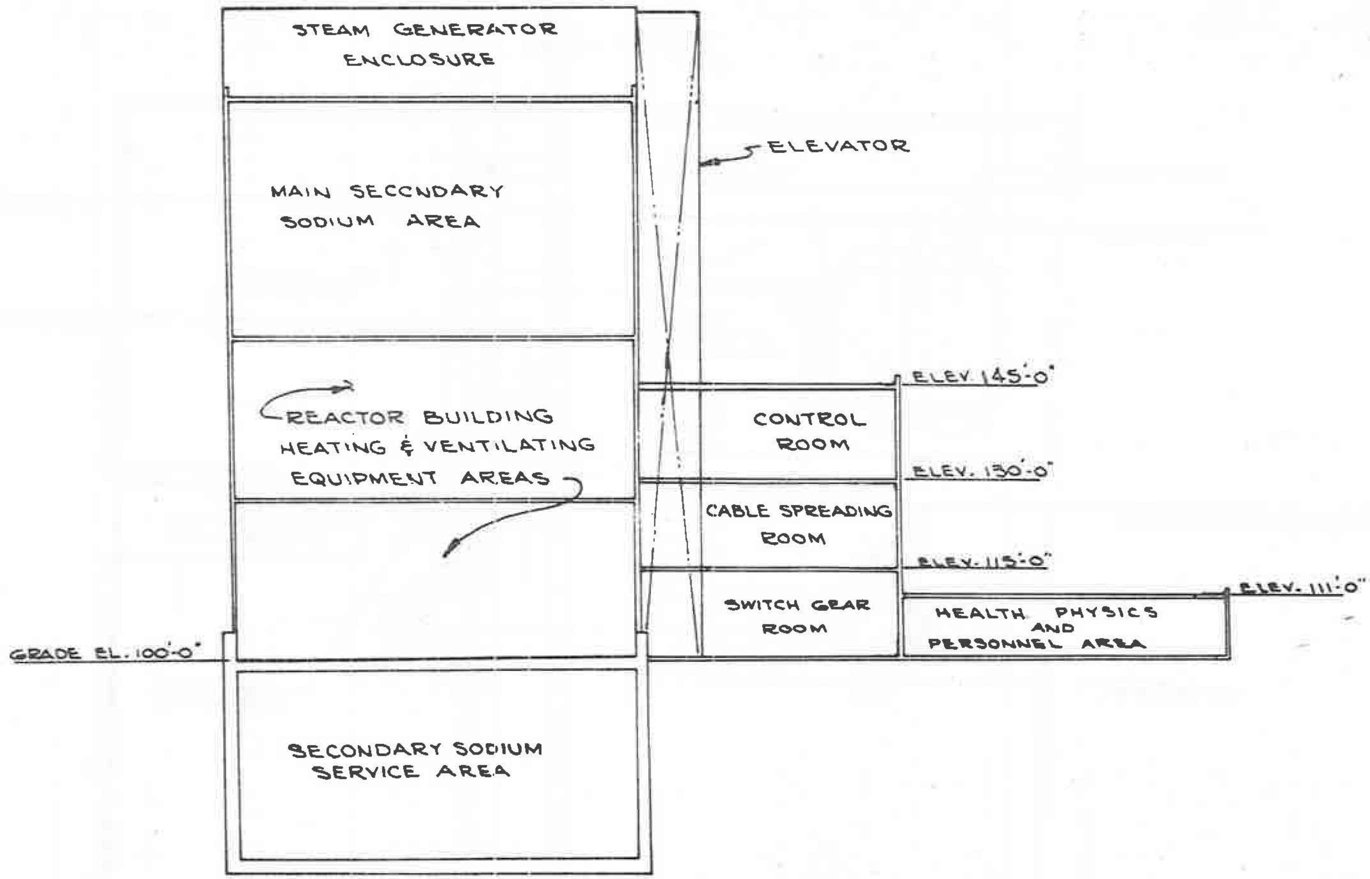
SECTION B-B

Cylindrical Building
(7603-GA004b)



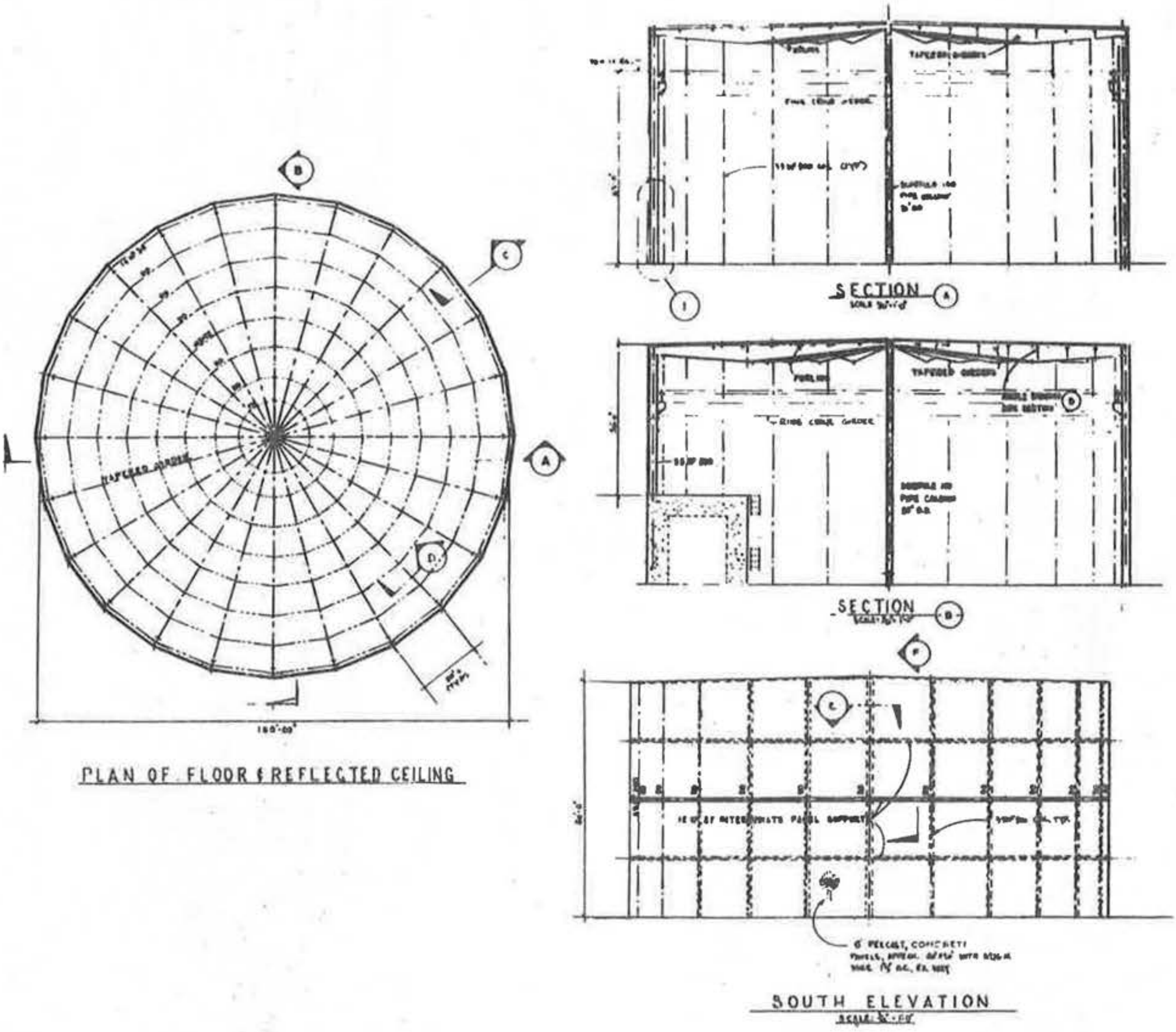
SECTION - C-C

Cylindrical Building
(7603-GA004c)



SECTION D-D

Cylindrical Building
(7603-GA004d)

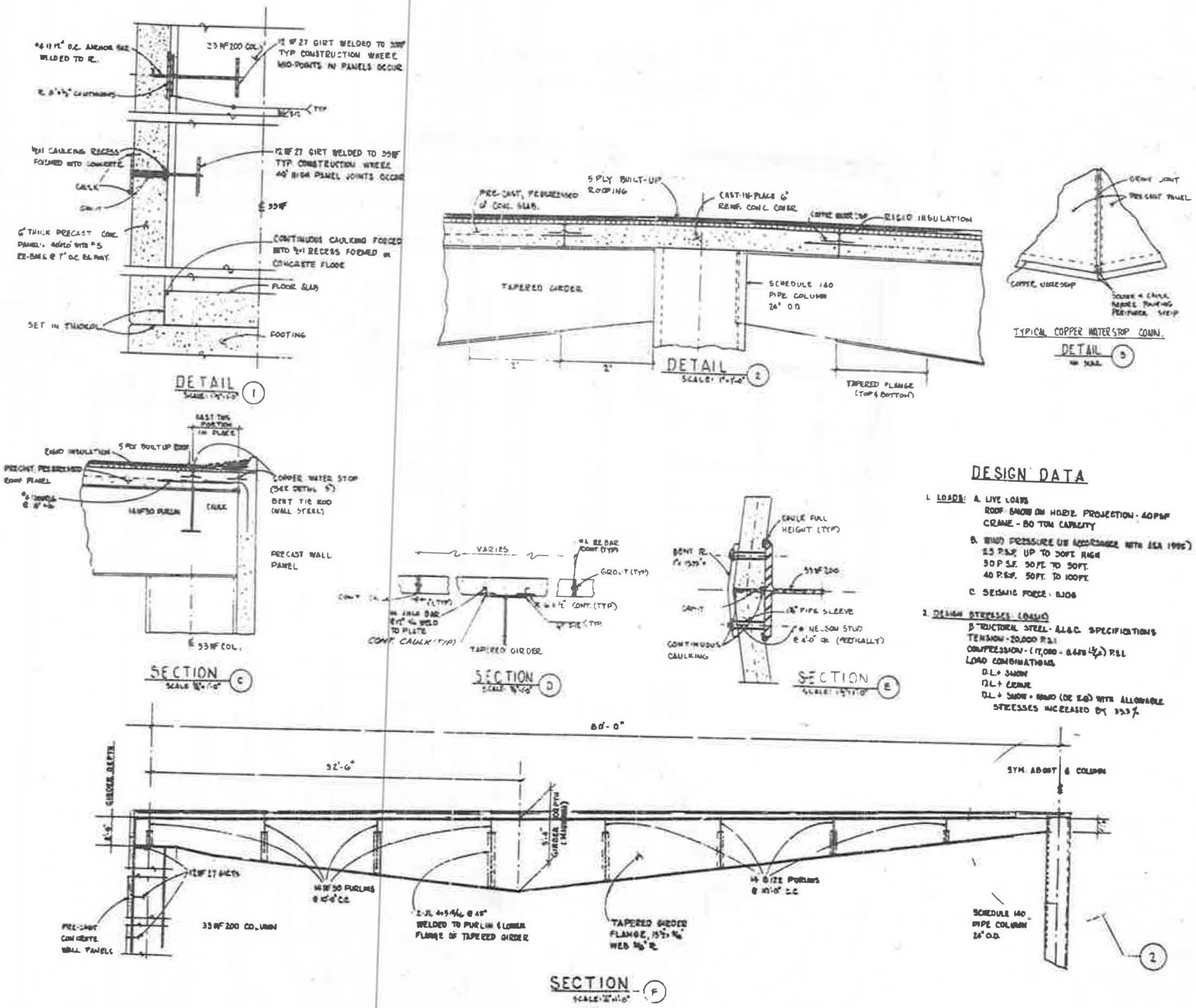


Cylindrical Building
(7603-FS004a)

NAA-SR-10100

V-45

380<



Cylindrical Building
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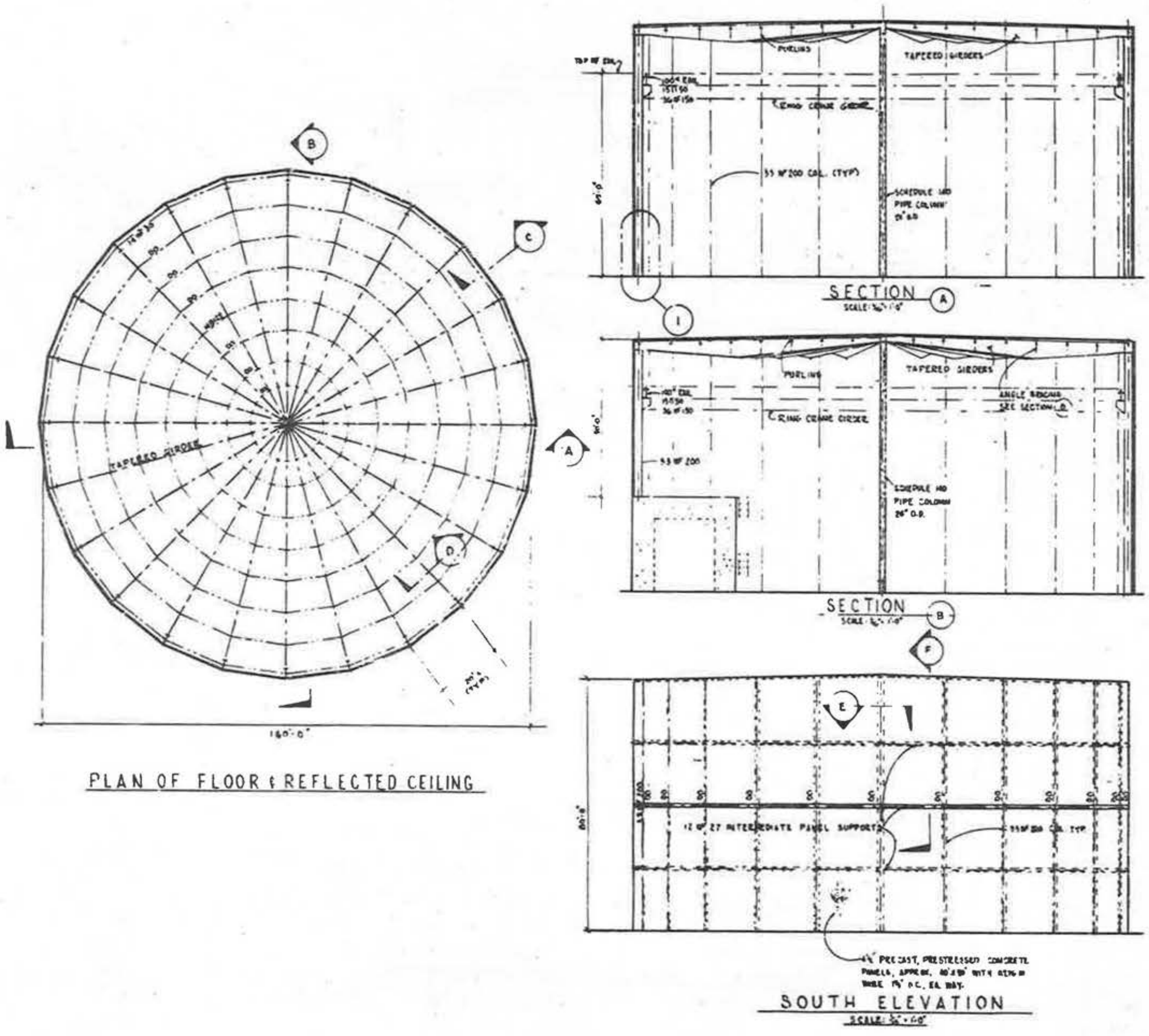

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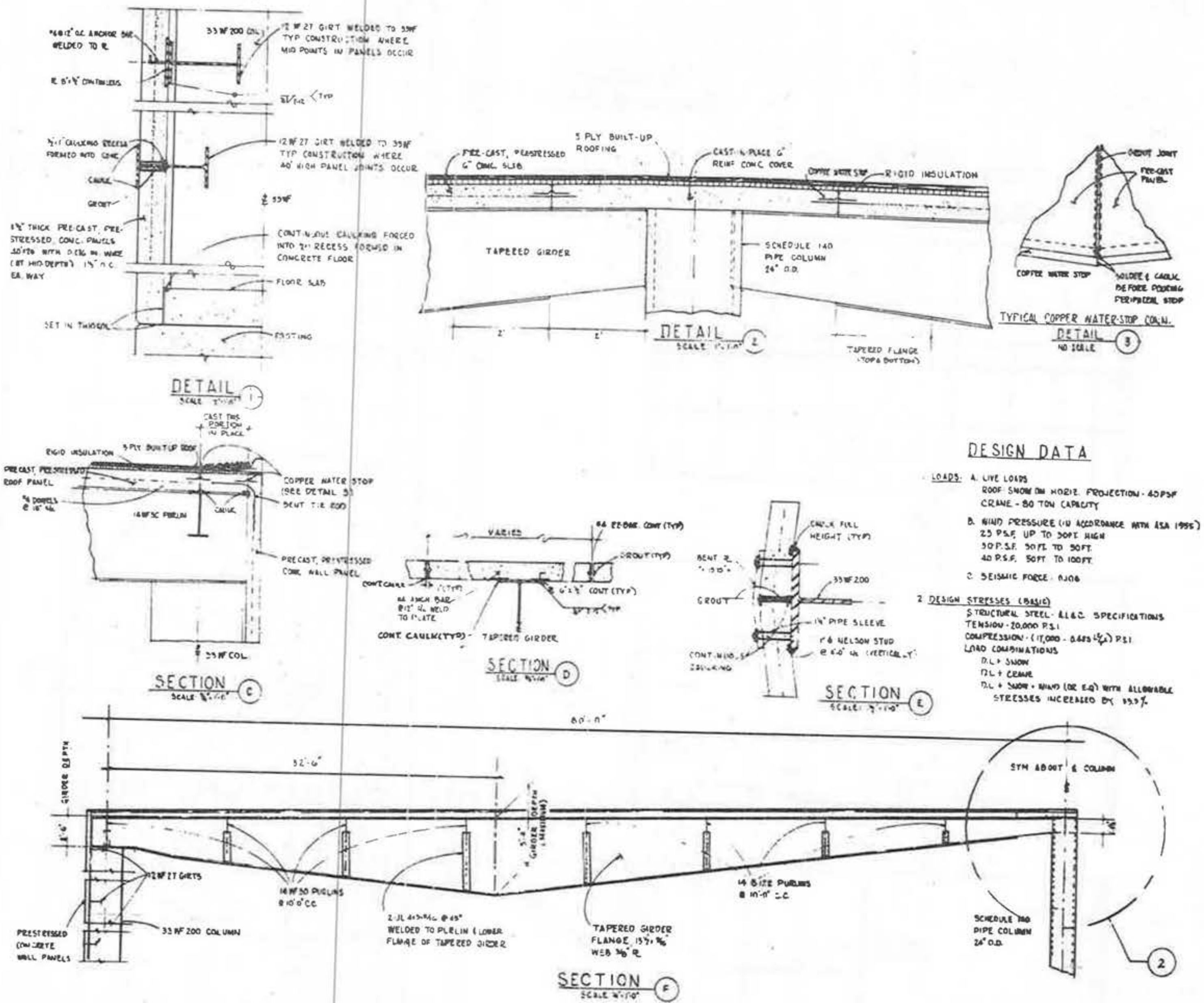

Cylindrical Building
(7603-FS003b)

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APPENDIX

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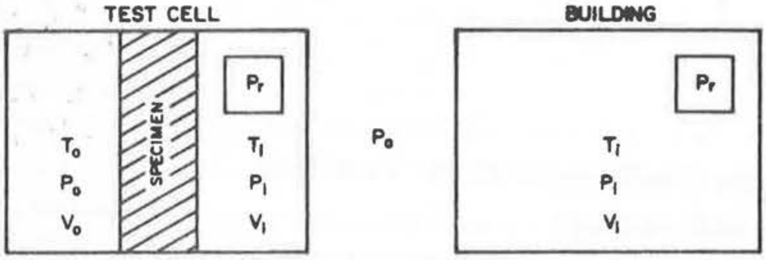
NOMENCLATURE



b = crack width

q = leak rate per unit leak path

q_T = leak rate of a component

t = time

x = thickness of specimen or crack depth

A = leak rate per unit leak path-in. H_2O

B = leak rate per unit leak path-in.$^{1/2}$ H_2O

C_1 = leak rate per component-in. H_2O

C_2 = leak rate per component-in. H_2O

D = total dimension or number of leak path units

L = crack length

P = pressure difference across component or structure

P_a = atmospheric pressure

P_i = pressure in building or test cell (upstream side)

P_o = pressure in test cell (downstream side)

P_r = pressure in reference system

P_s = standard pressure

Q = total leakage of a structure

T_i = temperature in building or test cell (upstream side)

T_o = temperature in test cell (downstream side)

T_s = standard temperature

V_i = volume of building or test cell (upstream side)

V_o = volume of test cell (downstream side)

V_s = volume of building air or test cell air (upstream side) at standard conditions

DETERMINING LEAKAGE COEFFICIENTS FROM TEST DATA

The procedure for determining leakage coefficients is described in Section II. In order to illustrate the method of calculation, an example is taken from typical component data measured in a test cell. The majority of components were tested and calculated in this way.

The following example shows the results from two tests in the large test cell with a specimen 4 ft long. A pressure reference system was used. The pressure difference across the closed cell was measured. The method of calculation is shown in tabulated form on page VI-4.

The first three columns are experimental data: time (t); pressure difference across the specimen (P); and the pressure difference between the reference system and the upstream side of the test cell ($P_r - P_i$). The remaining columns are calculated from the experimental data. The difference notation, Δ, is the change from the previous value in the table.

The standard leak rate is plotted against the average specimen pressure difference in Figure VI-1. Values of the standard leak rate and the average specimen pressure difference are selected from a smooth curve drawn through the data. The leakage coefficients are calculated from the leakage equation

$$q = AP + BP^{1/2} \quad .$$

For this example, the values selected from the curve were:

Standard leak rate (cfm)	0.0050	0.051
Average specimen pressure difference (in. H_2O)	0.040	1.0

and thus the leakage coefficients are

$A = 8.0 \times 10^{-3}$ cfm/ft-in. H_2O

$B = 4.8 \times 10^{-3}$ cfm/ft-in.$^{1/2}H_2O$.

The last three columns of the table are used to calculate the leakage coefficients by the least squares method. In this example, the leakage coefficients are

$A = 7.5 \times 10^{-3}$ cfm/ft-in. H_2O

$B = 4.9 \times 10^{-3}$ cfm/ft-in.$^{1/2}H_2O$.

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LEAST SQUARES CALCULATION OF LEAKAGE COEFFICIENTS

t Time (min)	P Specimen Pressure Difference (in. H_2O)	$P_r - P_i$ Reference Pressure Difference (in. H_2O)	$\Delta(P_r - P_i)$ Pressure Loss (in. H_2O)	$\frac{\Delta(P_r - P_i)}{\Delta t}$ Pressure Loss Rate (in. H_2O/min)	$\frac{\Delta(P_r - P_i)}{\Delta t} \frac{V_i T_s}{P_s T_i}$ Standard Leak Rate (cfm)	$P - \frac{\Delta P}{2}$ Average Specimen Pressure Difference (in. H_2O)	$\left(P - \frac{\Delta P}{2}\right)^{1/2}$ (in.$^{1/2}$ H_2O)
0	4.452	0					
3	2.728	0.535	0.535	0.1783	0.1121	3.590	1.894
6	1.792	0.953	0.423	0.1410	0.0886	2.260	1.503
9	1.139	1.279	0.321	0.1070	0.0672	1.465	1.210
10	0.676	1.516	0.237	0.0790	0.0496	0.907	0.952
15	0.372	1.679	0.163	0.0543	0.0341	0.524	0.724
18	0.186	1.786	0.107	0.0356	0.0224	0.279	0.528
21	0.079	1.853	0.067	0.0223	0.0140	0.132	0.363
24	0.011	1.893	0.040	0.0133	0.0084	0.045	0.212
0	4.620	0					
3	3.065	0.969	0.969	0.3230	0.2031	3.842	1.960
6	2.058	1.437	0.468	0.1560	0.0981	2.561	1.600
9	1.370	1.758	0.321	0.1070	0.0672	1.714	1.309
12	0.850	1.989	0.231	0.0770	0.0484	1.110	1.054
15	0.518	2.153	0.164	0.0546	0.0343	0.684	0.827
18	0.287	2.272	0.119	0.0396	0.0249	0.402	0.634
21	0.141	2.350	0.078	0.0260	0.0164	0.214	0.463
24	0.056	2.383	0.033	0.0110	0.0069	0.098	0.313

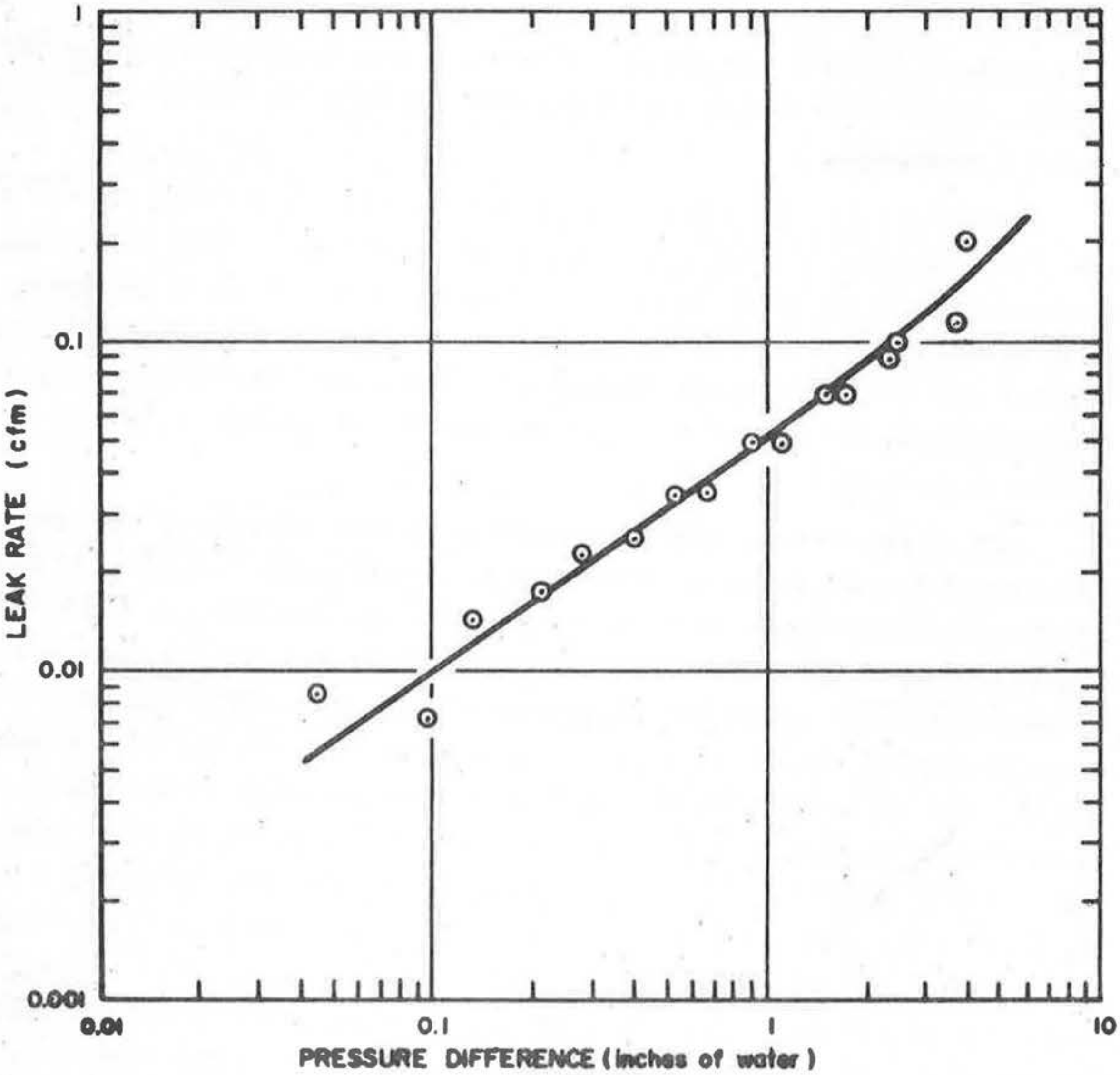

Figure VI-1. Graphical Calculation of Leakage Coefficients

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CONCRETE CRACKING AND LEAKAGE

A. LOADING STRESSES AND CRACK DEPTH DEPENDENCE

Most reactor enclosures must be designed to accommodate certain accident situations. Frequently these accident situations result in an internal pressure rise of the enclosure. As the pressure increases, the building panels must resist the applied load in flexure if the panels are flat, or in hoop stress if the building is circular.

A typical flat panel under internal pressure is shown in Figure VI-1a. Figure VI-1b is a moment diagram of the panel, and Figure VI-1c is an exaggerated picture of the flexed slab showing the cracks. In the center of the spans, the slab is subjected to the maximum positive bending moment, and at the center support it is subjected to the maximum negative moment. Figure VI-1d is a representation of the deflections and stresses in a cross section of the slab at the center of the span.

Figure VI-1d shows that the portion of the slab adjacent to the applied load is in compression and the opposite side is in tension (at the center of the spans). As the load is gradually applied, the concrete and steel deform elastically, the compressive stress region being deformed compressively and the tensile stress region expanding. When the ultimate tensile strength of the concrete is reached (tensile strength ≅ 0,1 x compressive strength), the concrete cracks perpendicularly to the applied tensile stress. The cracks propagate in the tensile region almost to the neutral axis. After cracking occurs, the tensile load is shifted from both the concrete and steel to only the steel reinforcing bars. If the elastic limit of steel (in tension) or the concrete (in compression) is not exceeded, release of the load results in the slab assuming its original shape. When this occurs, the cracks close (with some variances since concrete does not behave completely elastically). If the elastic limit is not exceeded, the cracks penetrate only in the tension region of the slab as shown in Figure VI-1d; they stop slightly short of the neutral axis. If the elastic limit of the steel is exceeded, then the neutral axis of the slab shifts, the concrete is subjected almost entirely to tensile stresses, and the cracks completely penetrate the slab. The most severe cracking obviously occurs when the steel is stressed beyond its yield point.

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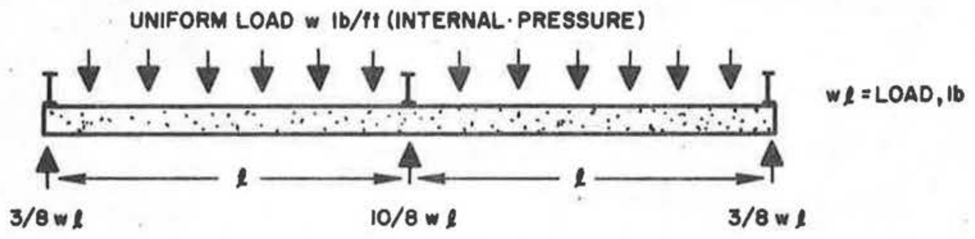

Figure VI-1a. Loading Diagram, Typical Panel Under Pressure

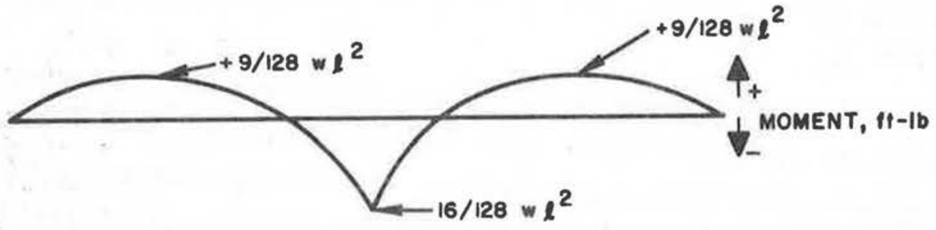

Figure VI-1b. Moment Diagram, Typical Panel

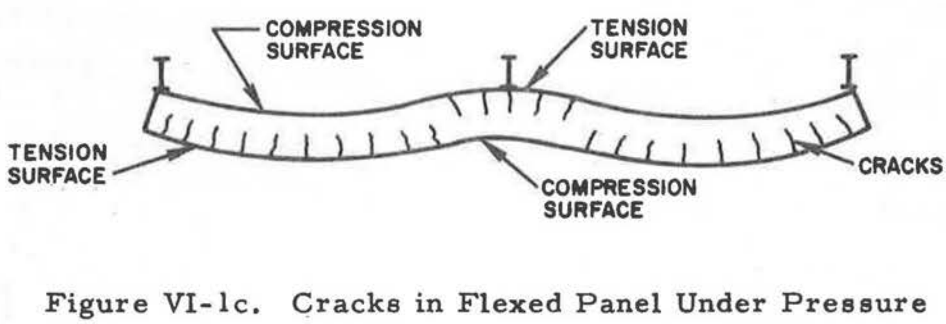

Figure VI-1c. Cracks in Flexed Panel Under Pressure

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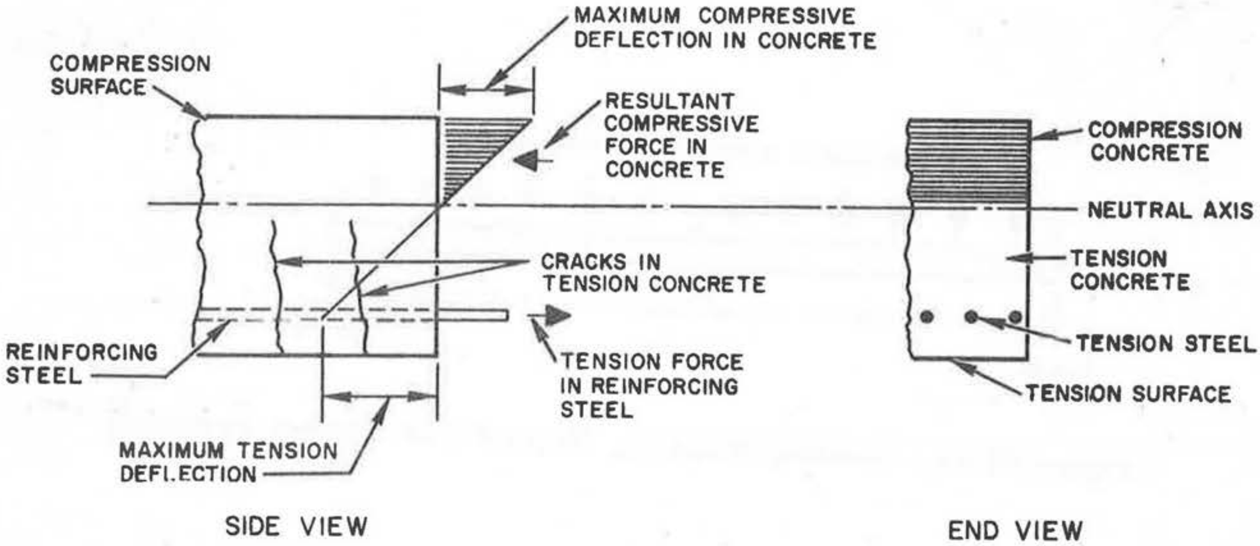

Figure VI-1d. Deflection and Stress Diagram in Flexed Panel

B. COMPUTATION OF CRACK WIDTH AND SPACING FROM LOADING STRESSES

Crack width and spacing in elastically stressed panels may be computed based on a technique developed by Michael Chi and Arthur Kirstein.* A combination theoretical-empirical approach was used which permits prediction of the size and spacing of the cracks in a member in flexure. The basic assumptions of their analysis are:

1) Concrete is homogeneous and elastic.

2) Cracked portions of beams are subjected to pure bending.

3) Reinforcing steel does not exceed the proportional limit.

4) After cracks have occurred in the tensile zone, tensile strains due to flexure are negligible. Any measurable strains in that portion of the concrete are attributed to shear deformation developed through the bond by extension of the steel.

The Chi and Kirstein formulas for computing crack width and spacing are as follows:

$$e = \frac{f_t'}{w_o} m^2 \Phi D \quad , \qquad \ldots(1)$$

*See References, Conventional Housing and Components, 78

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$$\Phi = \frac{A_t}{m^2 A_s} \quad , \qquad \ldots(2)$$

$$w_s = \frac{f_t'}{w_o} m^2 \; \Phi D \frac{(f_s - f_{so})}{E_s} \quad , \qquad \ldots(3)$$

where:

w_s = average width of crack at reinforcing steel

e = average minimum spacing of cracks

f_t' = tensile strength of concrete

A_t = area of concrete affected by the extension of the steel

m = factor determining the diameter of the concrete area affected by the extension of the reinforcing steel

A_s = area of reinforcing steel

D = diameter of reinforcing bars

f_s = computed steel stress (by linear theory)

f_{so} = steel stress just prior to crack formation in concrete

E_s = modulus of elasticity of steel

w_o = bond strength of concrete

The investigators empirically fitted the data to the above equations to obtain:

$$e = 5\Phi D$$

$$w_s = \frac{5\Phi D}{E_s}\left(f_s - \frac{2500}{\Phi D}\right) \quad , \qquad \ldots(4)$$

For concrete panels up to 20-in. thick, the value of Φ is equal to approximately 1.0 for compressive strength between 2000 and 6000 psi.

C. LEAKAGE THROUGH CRACKS AND CAPILLARIES IN CONCRETE

Cracks in concrete will have a leakage rate according to their number, spacing, width, and penetration into the concrete. When cracks penetrate completely through the concrete, the leakage rate through the cracks can be computed as follows:

$$q_T = \frac{g_c b^3 L(P_i - P_o)}{12\mu x} , \qquad \text{...(5)}$$

where:

q_T = volumetric leak rate

g_c = gravitational conversion factor

b = crack width

L = crack length

P_o = outside pressure

P_i = internal pressure

μ = viscosity of gas

x = depth of crack

This can be simplified to

$$q_T = 3.9 \times 10^4 \frac{b^3 LP}{x} , \qquad \text{...(6)}$$

where:

q_T = volumetric leak rate (cfm)

b = crack width (in.)

L = crack length (in.)

x = crack depth (in.)

P = pressure differential (in. H_2O)

Leakage of concrete through cracks which do not completely penetrate the slab can be computed by determining the leakage contributions of the cracks and of the uncracked concrete. Figure VI-2 shows the leakage paths when the cracks penetrate completely, and when they only partially penetrate. Special care should be exercised if credit is taken for the uncracked thickness of concrete since the cracked thickness may extend to a joint where leakage can occur. If the joint is properly designed with caulking below the cracks, then leakage is correctly controlled.

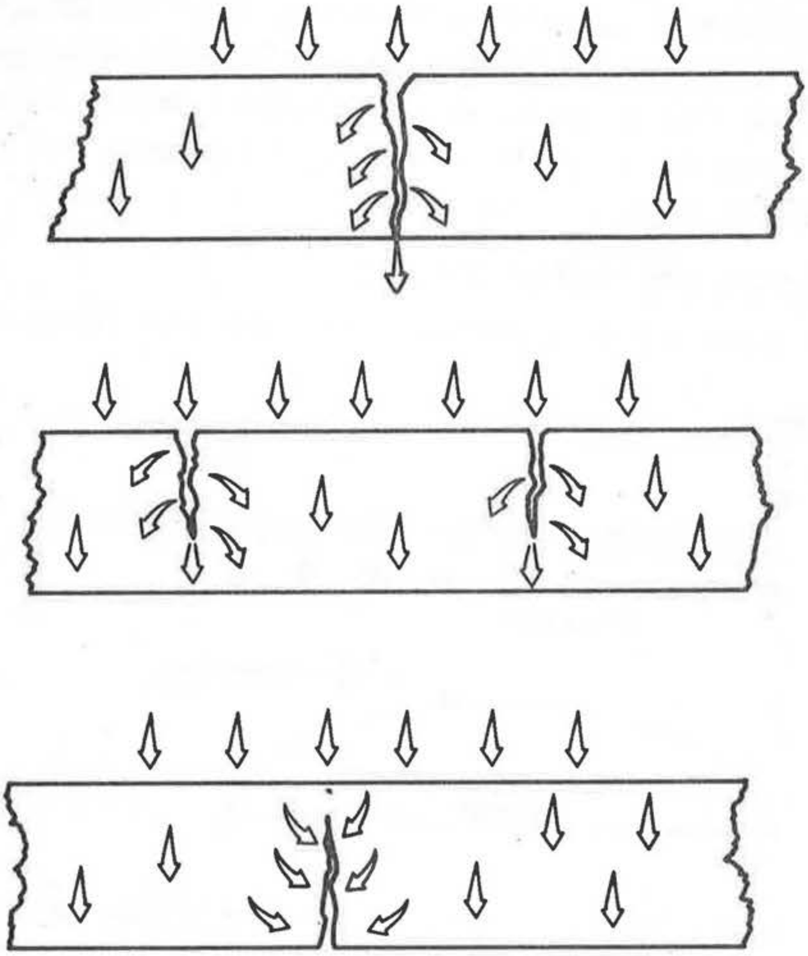

Figure VI-2. Leakage Paths Through Cracked Concrete

D. APPLICATION OF CRACK ANALYSIS TO TYPICAL BUILDING DESIGN

1. Objective and Basis of Design

To indicate the manner in which the leakage and stress data can be applied to a low-leakage structure, a leakage and stress analysis of typical building superstructure panels is presented below.

The Hallam Reactor superstructure has been selected for general sizing purposes. This superstructure is 178 ft long by 84 ft wide by 71 ft high. Major column centerlines are at 25-ft centers. Columns and beams in the hypothetical building have been designed to withstand the transmitted loads from an internal pressure of 14 in. water (1/2 psi).

Two types of building wall reinforced panels have been designed. One is a cast-in-place reinforced concrete panel, and the other is a tilt-up reinforced concrete panel. The panels are 25 ft square with supports at all outside edges and intermediate supports transversing the horizontal center. Joints are continuously caulked from the inside of the building at all edges, and provision is made for thermal expansion of the panels.

2. Stress, Crack, and Leakage Analysis

Loading and moment diagrams are shown in Figure VI-3a and VI-3b. As

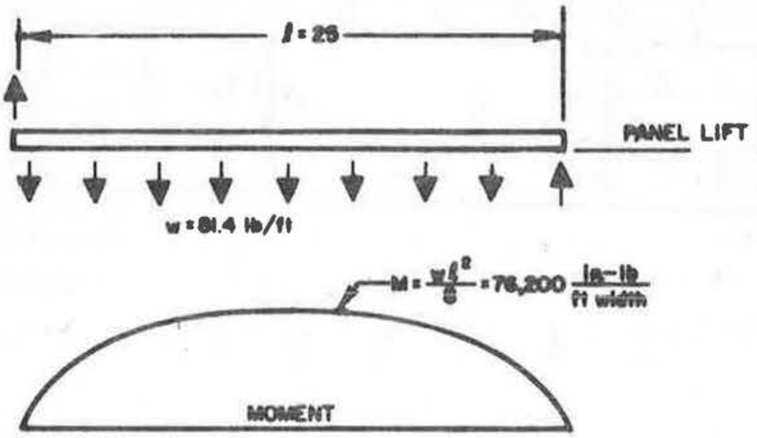

Figure VI-3a. Loading and Moment During Lift

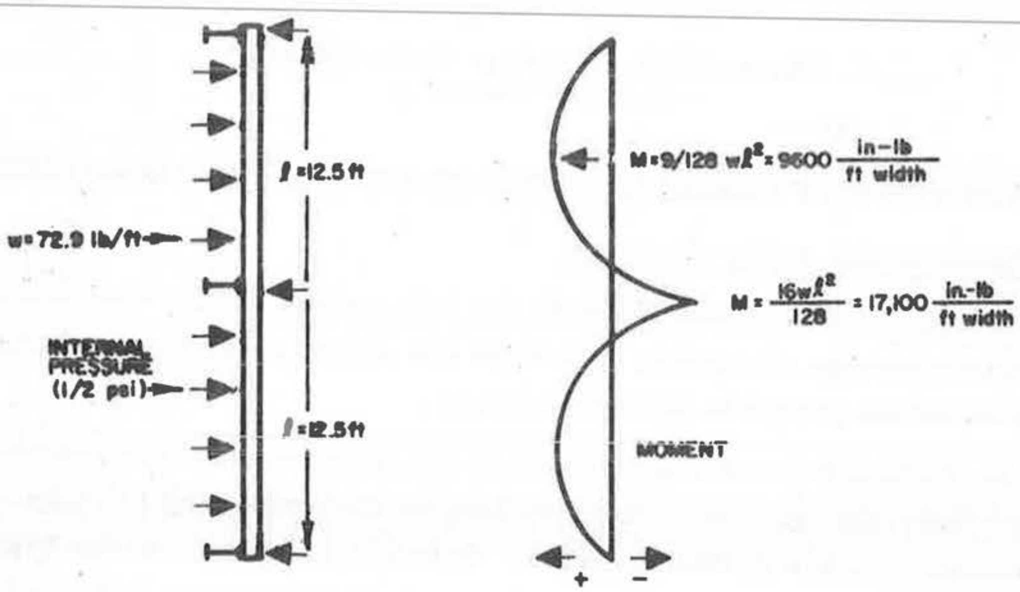

Figure VI-3b. Loading and Moment During Lift and Pressurization can be seen, maximum moment occurs during lifting of the tilt-up panel. Therefore, the tilt-up panel is thicker and requires more reinforcing steel than does the cast-in-place panel. A summary of the results of the stress and cracks analysis is shown in Table VI-1.

TABLE VI-1

SUMMARY OF STRESS ANALYSIS - TYPICAL BUILDING DESIGN

	Cast-in-Place Panel	Tilt-Up Panel
Panel thickness (in.)	5-5/8	6-1/2
Reinforcing steel	No. 5 @ 11-1/2 in. centers	No. 7 @ 6.6 in. centers No. 3 @ 9.6 in. centers
Maximum moment (in.-lb/ft width)		
From internal Pressure	-17,000* + 9,600†	-17,100* + 9,600†
From lift	-	76,200
Tensile stress in concrete	Negligible	Negligible
Maximum tensile stress in steel (psi)		
From internal pressure	16,800	4,050* 18,000†
From lift	-	18,000
Maximum compressive stress in concrete (psi)		
From internal pressure	880	380* 212†
From lift	-	1,690
Depth to neutral axis, from compression face (in.)	1.03	1.94
Tension crack spacing (in.)	3.1	4.3
Maximum crack width at tension face (mils)		
From internal pressure	2.46	0.35* 1.23†
From lift	-	3.88
Estimated average crack width in panel at tension face (mils)	1.4	3.0§
Total length of cracks in building walls (ft)	145×10^3	105×10^3

*At negative moment
†At positive moment
§During lift

Under no circumstances does the panel approach the yield stress of the steel (40,000 to 55,000 psi) or the compressive strength of the concrete (3750 psi). The computation methods described above are used to determine crack width and spacing. The maximum crack width is 3.9 mils. A crack spacing of 3.1 in. is obtained for the cast-in-place panel, and 4.3 in. for the tilt-up panel. The total lineal feet of crack is obtained as follows:

$$\text{No. of cracks per panel} = \frac{25 \text{ ft/panel} \times 12 \text{ in./ft}}{4.3 \text{ in. spacing/crack}} = 70$$

$$\text{Total lineal ft of cracks} = 70 \frac{\text{cracks}}{\text{panel}} \times 25 \frac{\text{ft}}{\text{crack}} \times 60 \frac{\text{panels}}{\text{bldg}} = 105{,}000$$

Estimates of average crack width are made (based on the loading stresses), and these average crack widths are used to compute leakage. The depth of the cracks is determined from the computed depth of the neutral axis. Complete penetration of the cracks results only where stress reversal of the panels occurs, as in the positive portion of the installed tilt-up panel (Figure VI-3b). Prior to installation, the moment of this portion of the panel is in the opposite direction (Figure VI-3a).

Leakage of the panels is determined by summing the crack leakages, using the crack leakage formula presented, and by computing the leakage through the uncracked portion of the concrete. Where cracks do not penetrate completely, leakage is computed by assuming that the depth of the concrete through which the concrete leakage formula applies is the uncracked depth.

In addition to computing leakages through the untreated concrete panels, leakage through specially painted panels is computed. The painting specification for the panels is:

a) Wash surface with 10% solution of muriatic acid, and rinse.

b) Caulk all major cracks with vinyl filler.

c) Prime coat 1-mil thick (200 ft^3/gal).

d) Coat to 40 mils thick with Surface Engineering Co. vinyl coating No. 2980 or 810 (25 ft^3/gal).

e) Top with color selected material different from previous color to 5 mils thick (60 ft^3/gal). The total thickness applied is thus 46 mils.

Since the 40 mils of vinyl paint is applied in several layers, the likelihood of a pin-hole finish is very small, and since the paint is elastic and can be elongated up to 400%, it is unlikely that cracking of the concrete will affect the integrity of the paint. When the paint is properly applied, leakage through the paint membrane becomes negligible. However, violation of the integrity of the paint membrane in certain locations during operation of the plant is inevitable. These violations lead to an increase in leakage. To obtain an estimate of the leakage through a practical painted structure, it is assumed that 500 ft of crack are exposed.

A complete description of the stress and leakage analysis for the building is given in NAA-SR Memo 9429, "Prediction and Control of Leakage Through Cracks and Capillaries in Reinforced Concrete Buildings used to House Reactors." Table VI-2 is a summary of the total leakage from the painted and unpainted concrete panel buildings. In addition, it shows representative leakage values for other components so that the relative importance of each component can be determined. The stress, crack, and leakage analysis of the building demonstrates that properly designed and constructed reinforced concrete building structures can be used to house reactors.

TABLE VI-2

LEAKAGE FROM TYPICAL CONCRETE BUILDING
(10^6 ft^3)

Component	Leakage (ft^3/day at 14-in. H_2O)	
	Cast-in-Place Panels	Tilt-Up Panels
Unpainted Building		
Unpainted walls	17,400	24,100
Joints	800	800
Penetrations	400	400
Roof	7,000	9,800
Doors	50	50
Total	25,650	35,150
Total (%/day)	2.6	3.5
Painted Building		
Painted walls	67	91
Joints	100	100
Penetrations	400	400
Roof	27	36
Doors	50	50
Total	644	677
Total (%/day)	0.064	0.068

STANDARDS AND SPECIFICATIONS

A. ADHESIVES

ASTM: American Society for Testing Materials

D 429	Methods of Test for Adhesion of Vulcanized Rubber to Metal (tentative)
D 816	Methods of Testing Rubber Cements (tentative)
D 897	Method of Test for Tensile Properties of Adhesives
D 898	Method of Test for Applied Weight Per Unit Area of Dried Adhesive Solids
D 899	Method of Test for Applied Weight Per Unit Area of Liquid Adhesive Solids
D 903	Method of Test for Peel or Stripping Strength of Adhesives
D 904	Recommended Practice for Determining the Effect of Artificial (Carbon-Arc Type) and Natural Light on the Permanence of Adhesives (tentative)
D 905	Method of Test for Strength Properties of Adhesives in Shear by Compression Loading
D 907	Definitions of Terms Relating to Adhesives
D 950	Method of Test for Impact Strength of Adhesives
D 1002	Method of Test for Strength Properties of Adhesives in Shear by Tension Loading (Metal-to-Metal) (tentative)
D 1062	Method of Test for Cleavage Strength of Metal-to-Metal Adhesives
D 1084	Method of Test for Consistency of Adhesives (tentative)
D 1144	Recommended Practice for Determining Strength Development of Adhesive Bonds (tentative)
D 1151	Recommended Practice for Determining the Effect of Moisture and Temperature on Adhesive Bonds (tentative)
D 1184	Method of Test for Strength of Adhesives on Flexural Loading (tentative)
D 1337	Method of Test for Storage Life of Adhesives by Consistency and Bond Strength (tentative)
D 1338	Method of Test for Working Life of Liquid or Paste Adhesives by Consistency and Bond Strength (tentative)
D 1344	Method of Testing Cross-Lap Specimens for Tensile Properties of Adhesives (tentative)

B. CONCRETE AND RELATED MATERIALS

ACI: American Concrete Institute

ACI 315	Manual of Standard Practice for Detailing Reinforced Concrete Structures
ACI 318	Building Code Requirements for Reinforced Concrete
ACI 319	Recommended Practice for Use of Metal Supports for Reinforcement
ACI 604	Recommended Practice for Winter Concreting
ACI 613	Recommended Practice for the Design of Concrete Mixes
ACI 614	Recommended Practice for Measuring, Mixing, and Placing Concrete

ASTM: American Society for Testing Materials

ASTM A15	Billet Steel Reinforcement Bars
ASTM A16	Rail Steel Reinforcement Bars
ASTM A82	Cold Drawn Steel Wire for Concrete Reinforcement
ASTM A160	Axle Steel Reinforcement Bars
ASTM A184	Fabricated Steel Rod Mats for Concrete Reinforcement
ASTM A185	Welded Wire Fabric Reinforcement
ASTM C10	Natural Cement
ASTM C30	Concrete Aggregate Test for Voids
ASTM C31	Method of Test for Concrete Compression and Flexure Test Specimens, Making and Curing in the Field
ASTM C33	Coarse and Fine Aggregate for Concrete
ASTM C39	Compression Test of Molded Concrete Cylinders
ASTM C40	Test for Organic Impurities in Sand for Concrete
ASTM C42	Method of Test for Securing, Preparing, and Testing Specimens from Hardened Concrete for Compressive and Flexural Strength
ASTM C58	Definition of Terms Relating to Aggregate
ASTM C70	Fine Aggregate Test for Surface Moisture
ASTM C78	Method of Test for Flexural Strength of Concrete (Using Simple Beam with Third Point Loading)
ASTM C85	Cement Content of Hardened Cement Concrete
ASTM C87	Method of Test for Measuring Mortar-Making Properties of Fine Aggregate
ASTM C88	Test for Soundness of Aggregate by Use of Sodium Sulfate or Magnesium Sulfate

ASTM C91	Masonry Cement
ASTM C94	Specification for Ready-Mixed Concrete
ASTM C114	Chemical Analysis of Portland Cement
ASTM C116	Method of Test for Compressive Strength Using Portions of Beams Broken in Flexure
ASTM C117	Test for Amount of Material Finer than No. 200 Sieve in Aggregate
ASTM C123	Test for Lightweight Pieces in Aggregate
ASTM C124	Method of Test for Flow of Portland Cement Concrete by Use of the Flow Table
ASTM C125	Definition ofTerms Relating to Concrete and Concrete Aggregates
ASTM C127	Coarse Aggregate Test for Specific Gravity and Absorption
ASTM C128	Fine Aggregate Test for Specific Gravity and Absorption
ASTM C136	Coarse and Fine Aggregate Test for Sieve Analysis
ASTM C138	Method of Test for Air Content, Weight, and Yield of Concrete
ASTM C142	Test for Clay Lumps in Natural Aggregates
ASTM C143	Slump Test of Concrete for Consistency
ASTM C150	Portland Cement
ASTM C157	Method of Test for Volume Change of Concrete
ASTM C171	Specification for Waterproof Paper for Curing Concrete
ASTM C172	Method of Test for Sampling Fresh Concrete
ASTM C173	Method of Test for Air Content of Freshly Mixed Concrete by the Volumetric Method
ASTM C174	Method of Test for Measuring Length of Drilled Concrete Cones
ASTM C175	Air Entraining Portland Cement
ASTM C205	Air Entraining Blast Furnace Slag Portland Cement
ASTM C215	Method of Test for Fundamental Transverse, Longitudinal, and Torsional Frequencies of Concrete Specimens
ASTM C226	Air Entraining Additives
ASTM C227	Potential Alkali Reaction of Cement Aggregate Combinations
ASTM C231	Method of Test for Air Content of Freshly Mixed Concrete by the Pressure Method
ASTM C233	Method of Test for Air Entraining Admixtures for Concrete
ASTM C234	Method of Test for Bleeding of Concrete
ASTM C235	Coarse Aggregate Test for Soft Particles
ASTM C243	Bleeding of Cement Pastes and Mortars

ASTM C260	Specification for Air Entraining Admixtures for Concrete
ASTM C290	Method of Test for Resistance of Concrete Specimens to Rapid Freezing and Thawing in Water
ASTM C291	Method of Test for Resistance of Concrete Specimens to Rapid Freezing in Air and Thawing Water
ASTM C295	Method of Test for Flexural Strength of Concrete (Using Simple Beam with Center Point Loading)
ASTM C309	Specification for Liquid Membrane-Forming Compounds for Curing Concrete
ASTM C310	Method of Test for Resistance of Concrete Specimens to Slow Freezing in Air and Thawing in Water
ASTM C311	Method of Test for Fly Ash for Use as an Admixture in Portland Cement Concrete
ASTM C330	Lightweight Aggregates for Structural Concrete
ASTM C340	Portland-Pozzolan Cement
ASTM C342	Test for Potential Volume Change of Cement Aggregate Combinations
ASTM C350	Specification for Fly Ash for Use as an Admixture in Portland Cement Concrete
ASTM C358	Slag Cement
ASTM C360	Method of Test for Ball Penetration in Fresh Concrete
ASTM D98	Specification for Calcium Chloride
ASTM D544	Specification for Preformed Expansion Joint Filler for Concrete (Nonextruding and Resilient Types)
ASTM D994	Specification for Preformed Expansion Joint Filler for Concrete (Bituminous Type)
ASTM E11	Specification for Sieves for Testing Purposes
C 1	Compilation of Standards on Cement (May 1954)
A 305	Specification for Minimum Requirements for the Deformations of Deformed Steel Bars for Concrete Reinforcement (tentative)
CRSI	Manual of Standard Practice for Reinforced Concrete Construction
PCA	Concrete Information Bulletin
SPR R26	Steel Reinforcing Bars
SPR R53	Reinforcing Steel Spirals
SPR R234	Welded Wire Fabric Reinforcement

ASA: American Standards Association

A 1.1	Specifications for Portland Cement (ASTM C150)
A 1.16	Specifications for Air Entraining Portland Cement (ASTM C175)

A 37.7	**Method of Test for Abrasion of Coarse Aggregate by Use of the Los Angeles Machine (ASTM C131)**
A 37.16	**Method of Test for Unit Weight of Aggregate (ASTM C29)**
A 37.62	**American Standard for Quality of Water to be Used in Concrete**
A 37.69	**Specifications for Ready-Mixed Concrete (ASTM C49)**
A 37.75	**Methods of Sampling Stone, Slag, Gravel, Sand, and Stone Block for Use as Highway Materials (ASTM D75)**
A 80. 1	**Specifications for Hollow Nonloadbearing Concrete Masonry Units (ASTM C129)**
A 84.1	**Methods of Sampling and Testing Concrete Masonry Units (ASTM C140)**
CS 53	**Colors and Finishes for Cast Stone**
SS-C-614	**Concrete Units: Masonry, Hollow**
32-38 SPR	**Concrete Building Units**

C. SEAL AND GASKET STANDARDS

ASTM: American Society for Testing Materials

D-15-58T	Methods of Sample Preparation for Physical Testing of Rubber Products
D 314-52T	Test for Hardness of Rubber
D 395-55T	Test for Compression Set of Vulcanized Elastomers
D 471-57T	Test for Change in Properties of Elastomeric Vulcanizates Resulting from Immersion in Liquids
D 531-56T	Method of Test for Indentation of Rubber by Means of the Pusey and Jones Plastometer
D 573-53	Test for Accelerated Aging of Vulcanized Rubber by the Oven Method
D 575-46T	Test for Compression-Deflection Characteristics of Vulcanized Rubber
D 623-58	Compression Fatigue of Vulcanized Rubber
D 676-58T	Test for Indentation of Rubber by Means of a Durometer
D 733-57T	Methods of Testing Compressed Asbestos Sheet Packing
D 735-58T	Specification for Elastomer Compounds for Automotive Applications
D 865-57	Method of Heat Aging of Vulcanized Natural or Synthetic Rubber by Test Tube Method
D 926-56	Test for Plasticity and Recovery of Rubber and Rubber-like Materials by the Parallel Plate Plastometer

D 945-55	Test for Mechanical Properties of Elastomeric Vulcanizates Under Compressive or Shear Strains by the Mechanical Oscillograph
D 1129-55	Test for Low-Temperature Compression Set of Vulcanized Elastomers
D 1147-56T	Compressibility and Recovery of Gasket Materials
D 1149-55T	Test for Accelerated Ozone Cracking of Vulcanized Rubber
D 1170-58T	Specification for Nonmetallic Gasket Materials for General Automotive and Aeronautical Purposes
D 1171-57T	Test for Weather Resistance Exposure of Automotive Rubber Compounds
D 1330-55T	Specification for Sheet-Rubber Packing
D 1415-56T	Test for International Standard Hardness of Vulcanized Natural and Synthetic Rubbers
D 11	Compilation of Standards on Rubber and Rubber-Like Materials (1955)
D 5	Method of Test for Penetration of Bituminous Materials
D 297	Methods for Chemical Analysis of Rubber Products (tentative)
D 394	Methods of Test for Abrasion Resistance of Rubber Compounds
D 429	Methods of Test for Adhesion of Vulcanized Rubber to Metal (tentative)
D 430	Methods of Dynamic Testing for Ply Separation and Cracking of Rubber Products (tentative)
D 518	Method of Test for Resistance to Light Checking and Cracking of Rubber Compounds
D 570	Method of Test for Water Absorption of Plastics (tentative)
D 624	Methods of Test for Tear Resistance of Vulcanized Rubber
D 638	Method of Test for Tensile Properties of Plastics (tentative)
D 729	Specification for Vinylidene Chloride Molding Compounds (tentative)
D 736	Method of Test for Low-Temperature Brittleness of Rubber and Rubber-Like Materials (tentative)
D 746	Method of Test for Brittleness Temperature of Plastics and Elastomers by Impact (tentative)
D 794	Recommended Practice for Determining Permanent Effect of Heat on Plastics
D 795	Recommended Practice for Accelerated Weathering of Plastics Using S-1 Bulb and Fog Chamber
D 797	Method of Test for Young's Modulus in Flexure of Natural and Synthetic Elastomers at Normal and Subnormal Temperatures

D 813	Method of Test for Resistance of Vulcanized Rubber or Synthetic Elastomers to Crack Growth (tentative)
D 927	Method of Test for Viscosity of Rubber and Rubber-Like Materials by the Shearing Disk Viscometer (tentative)
D 1203	Method of Test for Volatile Loss from Plastic Materials (tentative)
D 1207	Method of Test for Resistance to Aging of Vulcanized Rubber by Measurement of Creep (tentative)
D 1229	Method of Test for Low-Temperature Compression Set of Vulcanized Elastomers (tentative)

D. PAINTS

ASTM: American Society for Testing Materials

D 1	Compilation of Standards on Paint, Varnish, and Related Products (January 1955)
D 15	Methods of Sample Preparation for Physical Testing of Rubber Products (tentative)
D 658	Method of Test for Abrasion Resistance of Coatings of Paint, Varnish, Lacquer, and Related Products with the Air Blast Abrasion Tester
D 822	Recommended Practice for Operating Light and Water Exposure Apparatus (Carbon-Arc Type) for Testing Paint, Varnish, Lacquer, and Related Products (tentative)
D 870	Method of Water Immersion Test of Organic Coatings on Steel
D 968	Method of Test for Abrasion Resistance of Coatings of Paint, Varnish, Lacquer, and Related Products by the Falling Sand Method
D 1005	Method for Measurement of Dry Film Thickness of Paint, Varnish, Lacquer, and Related Products
D 1212	Methods for Measurement of Wet Film Thickness of Paint, Varnish, Lacquer, and Related Products

E. ROOFING

ASTM: American Society for Testing Materials

ASTM D226	Asphalt Saturated Roofing Felt for Use in Constructing Built-up Roofs
ASTM D227	Coal Tar Saturated Roofing Felt for Use in Constructing Built-up Roofs
ASTM D228	Testing of Asphalt Roll Roofing, Cap Sheets, and Shingles
ASTM D249	Asphalt Roofing Surfaced with Mineral Granules

ASTM D250	Asphalt Saturated Asbestos Filts for Built-up Roofs
ASTM D312	Asphalt for Use in Constructing Built-up Roof Coverings
ASTM D317	Pure Linseed Oil Putting for Glazing
ASTM D371	Asphalt Roofing, Wide Selvage, Surfaced with Mineral Gravels
ASTM D517	Asphalt Plank
ASTM D654	Coal Tar Pitch for Roofing Steep, Built-up Roofs
ASTM D655	Asphalt Saturated and Coated Asbestos Felts for Constructing Built-up Roofs

F. SEALING COMPOUNDS

ASA: American Standards Association

ASA 116.1	Proposed Specification for Sealing Compounds (Polysulfide Base or Equivalent)

Bureau of Reclamation Specifications

"Cold-Applied, Internal Set-up, Mastic Filler for Sealing Joints in Concrete, and Instructions Governing Its Use"

"Sealing Compound Rubberized, Cold-Application, Ready Mixed, for Joints in Concrete Canal Linings"

Federal Specifications

HH-F-341a Type 1 - Class B	"Filler, Expansion, Joint, Performed, Nonextruding and Resilient Types (for Concrete)"
SS-A-701	"Asphalt-Primer: (for) Roofing and Waterproofing"
SS-C-153	"Cement: Bituminous Plastic" - Type 1
SS-R-451	"Roof Coating: Asphalt, Brushing Consistency"
SS-S-156	"Sealer, Cold-Application Emulsion Type, for Joints in Concrete"
SS-S-158a	"Sealing Compound: Cold-Application Ready-Mixed Liquifier Type for Joints in Concrete"
SS-S-159b	"Sealer: Cold-Application Mastic Type, for Joints in Concrete"
SS-S-164- (Superseding Fed. Spec. SS-F-336a)	"Sealer, Hot Pour Type, for Concrete Joints"
SS-S-00167b	"Sealer, Hot Pour - Jet Fuel Resistant Type"
SS-S-00170a	"Sealing Compound, Two Components, Jet-Fuel-Resistant Cold-Applied, Concrete Paving"
SS-S-00200a (Army-CE)	"Sealing Compound, Two-Component Elastomeric-Type, Jet-Fuel-Resistant, Cold-Applied, Concrete Paving"

Military Specifications

MIL-S-7124 (QPL-7124-1)	"Sealing Compound, Pressure-Cabin"
MIL-S-7126a (QPL-7126)	"Sealing Compound, Synthetic Glass," Type I and II
MIL-S-7502C (ASG)	"Sealing Compound, Integral Fuel, Tanks, and Fuel Cell Cavities, High Adhesion, Accelerator Required"
MIL-S-8516B	"Sealing Compound, Synthetic Rubber, Accelerator (for Electric Connectors and Systems)
MIL-S-11030B (28 July 1954)	"Sealing Compound: Noncuring (Polysulfide Base)" Type 1, Class 1
MIL-S-12158A (ORD)' QPL-12158	"Sealing Compound, Noncuring, Polybutene"
MIL-C-15705A (Amendment 1, 13 Oct. 1953)	Minimum amounts required 5,000 lb "Caulking Compound (Liquid Polymer, Polysulfide Synthetic Rubber, Formula 112, for Metal Encls)"

Ordnance Department Specifications

PXS-910	"Compound, Luting (for Sealing Metal Lined Boxes)"

U.S. Army Specifications

2-87	"Compound, Sealing, Aircraft Instrument"

U.S. Navy Specifications

46Yc, Number 46 (See SS-S-00170A)	"Navy Department Bureau of Yards and Docks Spec. for Joints, Reinforcement and Mooring Eyes in Concrete Pavement"
52P69	"Putting, Sealing (for Bolted Steel Petroleum Tanks)"

G. JOINT SEALERS

Federal: Specifications

SS-A-696

SS-S-158a

SS-S-159b

SS-S-164

SS-S-167b

SS-S-00170a

SS-S-00170a (with added resilience requirement)

SS-S-00200 (latest amendment)

Corps of Engineers: Specifications

CRD-C 504-53

CRD-C 527-58

CRD-C 532-56

CRD-C 546-56

ASTM: American Society for Testing Materials

D1190-52T

AASHO: American Association of State Highway Officials

M18-42, Grades A & B

City of Los Angeles: Specification

Standard Specification No. 158, Section 25-3

Bureau of Reclamation: Specifications

Proposed Specification, 1959, for Sealing Compound, Rubberized, Cold Application, Ready-Mixed

Spec'n, May 1954, for Cold Applied Inernal Setup Mastic Filler

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