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August 7, 1986

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Subject: Fermilab Subcontract 94362, Task Order 002 (#593)

Dear Kelly:

I am submitting herewith CCI Report 593-120 entitled "ODH Analysis of the MW Faraday Cage". This completes our work on this Task Order. Please call with any questions or comments regarding this report.

Very truly yours,

CRYOGENIC CONSULTANTS, INC.

Jerry

Jerry B. Gibbs
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Encls: CCI Report 593-120
Dwg. No. 7437-D (1)
Dwg. No. 7432-D (1)

CCI Report 593-120

ODH ANALYSIS OF THE MW FARADAY CAGE

Prepared Under Subcontract No. SC-94362

By

Cryogenic Consultants, Inc.
Allentown, PA

For

Fermilab
Batavia, IL

July 30, 1986

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ODH ANALYSIS OF MW FARADAY ROOM

I. INTRODUCTION

The MW Faraday Room, or Faraday Cage as it is commonly referred to, encloses the LAr dewar Rabbit Hutches and the vessel flange which joins the dewar upper and lower shell. The Cage is totally enclosed and is air conditioned so it is reasonably air tight. As such, argon leakage from the dewar which is at a positive pressure, through the Rabbit Hutch feed-through plates and the dewar flange into the Cage presents a potential ODH hazard to personnel in the Cage. The purpose of this study was to determine if such leakage could create an ODH condition in the Faraday Cage, and if so, recommend actions to prevent this occurrence.

II. DISCUSSION OF CALCULATIONS

There are two sources for leakage of argon vapor into the Faraday Cage:

1.) The Rabbit Hutches, and
2.) The dewar flange joining the upper and lower dewar shells.

The Cage is a totally enclosed structure as shown on Fermi Drawing No. 2802.150 - SE-770051. There are two air conditioning units for the Cage each rated at 7.5 tons of refrigeration. Argon vapor could possibly infiltrate into the Faraday Cage from the dewar through "joints" or "cracks" connecting the two volumes. During normal operation, the dewar will be at an elevated pressure relative to the Cage. The desired dewar operating pressure is 1.136 ata (2.0 psig) or less. However, the pressure could rise to as high as 7.0 psig in the dewar before the relief valve is activated. The pressure differential between the dewar and the Faraday Cage provides the driving force for argon infiltration into the Cage. The model as described herein was developed to be able to estimate argon leakage rates into the Faraday Cage for various size leak channels. From these calculated leak rates and assumed Cage air change rates, equilibrium oxygen concentrations were determined.

The physical descriptions contained in this report represent our current understanding of the Rabbit Hutches and flange assemblies. It is on this basis that the estimated leakage rates were calculated. In addition, it is our understanding that each Rabbit Hutch junction box (ie, signal feed-through assembly) is presently or soon will be helium leak tested to an acceptable leakage rate of 3×10^{-4} cc-atm/sec (Ref. 1). This testing will include all of the epoxy joints. The dewar flange joint, we assume, will also be checked for gross leaks, and any found repaired. Therefore, any subsequent leakage of argon vapor from the dewar into the Faraday Cage through the Rabbit Hutches or dewar flange will be via small, capillary-like openings, or "leak channels".

For the purpose of this study, all leak channels were assumed to be rectangular with the flow area being the product of the height and width of the leak channel. The height was a variable; width was the distance between hold-down bolts on the dewar flange, hold-down bolts on the Rabbit Hutch cover plates, and the length of the electrical feed-throughs on the Rabbit Hutches. The bolt hole spacings are shown on CCI Drawings 7437-D and 7432-D; the electrical feed-through's are shown on Figure 1 (which was excerpted from Reference 1). The distance between any two bolt holes and a single feed-through each represent a potential leak channel. The total possible number of leak channels is the sum of all the individual electrical feed-through's, the number of hold-down bolts on the Rabbit Hutch feed-through's and the number of dewar flange bolts.

Laminair flow through fine porous material or capillary passages can be calculated using Darcy's Law of Permeability (Reference 3):

$$\frac{\Delta P}{L} = \frac{(9.645 \times 10^{-6})(\mu)(V)}{g_c \, (\varepsilon^3)(D^2)} \qquad \text{(Eq. 1)}$$

RABBIT HUTCH JUNCTION BOX

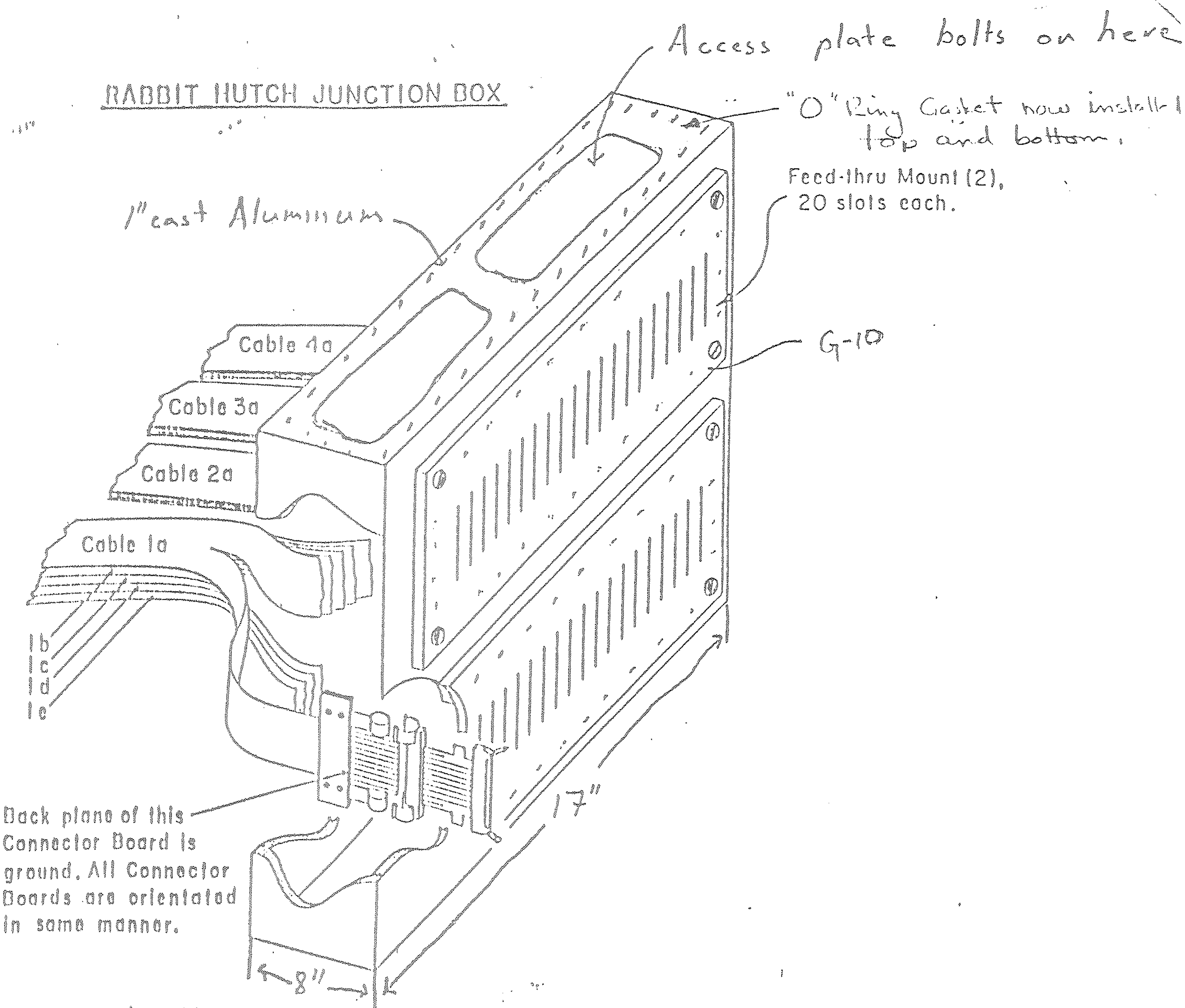

Fig 1

where:

ΔP = pressure driving force, psi

L = length of leak path, ft

μ = gas viscosity, lbs/ft.hr

V = gas velocity, ft/sec

D = equivalent diameter of the leak channel, ft

ε = material porosity, dimensionless

g_c = acceleration of gravity, 32.2 $\frac{\text{lbmass}}{\text{lbforce}}\ \frac{\text{ft}}{\text{sec}^2}$

The leak rate is then calculated by multiplying the velocity, V, by the cross sectional area of the leak channel.

A second correlation which defines theoretical flow through a capillary (or pipe) is the Poiseuille-Hagen equation (Reference 2):

$$F = \frac{g_c\, \Pi\, a^4\, M\, \bar{P}\, \Delta P}{8\, \mu R\, T\, \ell} \qquad \text{(Eq. 2)}$$

which can be reduced to:

$$F = \frac{12.645\, a^4\, M\, \bar{P}\, \Delta P}{\mu\, R\, T\, \ell}$$

where:

F = gas flow rate, lbs/sec

g_c = acceleration of gravity, ft/sec²

a = radius of the leak path, inches

M = molecular weight of the gas, lbs/lbmole

$\bar{P}$ = average of upstream and downstream pressures, psia

ΔP = differential pressure across leak channel, psi

μ = gas viscosity, lbs/ft.sec

R = ideal gas constant, 10.73 ft.lbs/lbmole.°R

T = temperature, °R

ℓ = length of the leak channel, ft

This latter equation was used to check the results of the Darcy Equation.

A. RABBIT HUTCHES LEAKAGE

The Rabbit Hutch junction box connections to the dewar are shown on CCI Drawing 7437-D. The junction box itself is attached to the dewar and sealed with an "O" ring. The two access ports on the top and bottoms of the box are also sealed with "O" rings (not shown on drawing). Leakage from these two sources can be assumed to be non-existent or negligible. The other connection is where the two G-10 feed-through plates bolt to the box. Here an epoxy material is used as a sealant. In addition there are 20 feed-through paddle connections per plate, and two plates per junction box. These feed-throughs are also sealed with epoxy. The most likely source of argon infiltration into the Faraday Cage is through these epoxyed connections.

The total number of possible leakage channels for the Rabbit Hutches (epoxy connections) was calculated as follows:

Number of Rabbit Hutches: 30

Number of feed-through plates per Rabbit Hutch: 2

Number of feed-through paddle connections per Plate: 20

Number of spaces between hold-down bolts per plate: 20

Length per paddle connection feed-through: ~1.25 inches

Distance between hold-down bolts on plate: ~2.10 inches

Therefore, the number of bolt hole leakage paths, each 2.10 inches in width, is:

$$N_B = (20)(2)(30) = 1200$$

and the number of feed-through leakage paths, each 1.25 inches in width, is:

$$N_T = (20)(2)(30) = 1200$$

Each of these leakage channels was assumed rectangular in shape, being either 1.25 inches or 2.10 inches wide. If an opening height is assumed, a leakage rate can be calculated by solving either Equation 1 or 2. Table I presents results using the Darcy Equation. The following is a sample calculation for the Rabbit Hutches using the Darcy Equation:

Let leak path height, $h = 0.001$ inches
and the pressure driving force, $\Delta P = 7.0$ psig
The material porosity, $\varepsilon = 1.0$
and the equivalent diameter, $D = \frac{2(h)(w)}{(h+w)}$
For the bolt hole leak path, $w = 2.10$ inches
then:

$$D = \frac{2(0.001)(2.10)}{(2.10 + 0.001)} = 0.0019999 \text{ in} = 0.000167 \text{ ft}^{1}$$

$$L = 0.75 \text{ inches} = 0.0625 \text{ ft}$$

$$\frac{\Delta P}{L} = \frac{(9.645\text{x}10^{-6})(\mu)(V)}{g_c(\varepsilon^3)(D^2)}$$

[1]. For the feed-through path, D = 0.001998 inches or essentially the same for both leak paths.

TABLE I

ARGON INFILTRATION RATES INTO THE FARADAY CAGE USING DARCY EQUATION

		Leak Rates, CFM		
		Rabbit Hutches		Flange
Argon Dewar Pressure, psig	Height of Leak Path, in	Per Bolt Hole Path	Per Feed Through Path	
2.0	0.001	4.77×10^{-2}	2.83×10^{-2}	2.59×10^{-2}
2.0	0.0005	5.92×10^{-3}	3.52×10^{-3}	3.23×10^{-3}
2.0	0.0001	4.77×10^{-5}	2.83×10^{-5}	2.59×10^{-5}
7.0	0.001	1.67×10^{-1}	9.90×10^{-2}	9.08×10^{-2}
7.0	0.0005	2.07×10^{-2}	1.23×10^{-2}	1.13×10^{-2}
7.0	0.0001	1.67×10^{-4}	9.90×10^{-5}	9.08×10^{-5}

Solving for V,

$$V = \left(\frac{\Delta P}{L}\right) g_c \frac{(\varepsilon^3)(D)^2}{(9.645x10^{-6})(\mu)}$$

and substituting

$$V = \left(\frac{7.0}{0.0625}\right) \frac{(32.2)(1.67x10^{-4})^2(1.0)^3}{(9.645x10^{-6})(0.0548)}$$

$$V = 190.3 \text{ ft/sec}$$

The leak rate, R in CFM can then be calculated for,

. The bolt hole paths,

$$R_B = \frac{(190.3)(0.001)(2.10)(60)}{144} = 0.167 \text{ CFM/path}$$

. The feed-through paths,

$$R_T = \frac{(190.3)(0.001)(1.25)(60)}{144} = 0.099 \text{ CFM/path}$$

B. <u>DEWAR FLANGE JOINT LEAKAGE</u>

The design of the flange connecting the dewar upper and lower shells is shown on CCI Drawing 7432-D. The flange is sealed with an "O" ring and the upper and lower halves bolted together with 108 bolts, equally spaced around the circumference of the flange. The distance between bolt holes is 6.10 inches. Therefore, the number of potential leak paths for argon infiltration from the dewar into the Faraday Cages via the flange is 108, each 6.10 inches long.

The Darcy and Poiseuille-Hagen Equations were again used to estimate leakage rates for various opening sizes as described previously. These results are also presented in Table I.

III. DISCUSSION OF RESULTS

The likelihood of an ODH condition developing in the Faraday Cage is remote. Such an occurrence would depend on a number of factors, including leakage rate through the Rabbit Hutches and dewar flange and the number of Faraday Cage air changes per minute, all of which are subject to probabilities of occurrence. However, given (1) the maximum acceptable tested leakage rate of 3×10^{-4} cc-atm/sec for the Rabbit Hutches, (2) the "O" ring seal on the dewar flange, (3) a Faraday Cage air change rate of 3-5 changes per hour, and (4) an air conditioning unit which promotes air flow and mixing in the Cage, the oxygen level in the Faraday Cage should remain well above 17.8% at all times. For example, assume the following:

(a) Air leak rate/Rabbit Hutch = 3×10^{-4} cc-atm/sec
= 6.36×10^{-7} CFM,

(b) 30 Rabbit Hutches,

(c) Faraday Cage air changes = 3-5/hr for air conditioned room,

(d) Faraday Cage volume = 3300 ft^3,

(e) Flange leakage rate at 2.0 psig dewar pressure,
= 2.59×10^{-2} CFM/path

(f) 10% of the potential leak paths leak at this rate,

(g) Then, flange leakage = $(2.59 \times 10^{-2})(.01)(108)$
= 0.28 CFM

The Rabbit Hutch leakage is insignificant compared to the flange leakage. Assuming total mixing in the Faraday Cage, the minimum oxygen content for three (3) Cage air changes/hrs would be:

$$0.2095\ (9900 - 17) = 9900\ (X)$$

$$X = .2091 \text{ or } 20.91\%\ O_2$$

If the dewar pressure rises to 7.0 psig and all other parameters remain unchanged, the new equilibrium oxygen concentration in the Faraday Cage would be,

$$0.2095\ (9900 - 59) = 9900\ (X)$$

$$X = 0.0283 \text{ or } 20.83\%\ O_2$$

Although it is difficult to postulate a realistic worst case condition, consider the following as approaching that situation:

(a) 10% of all possible leak paths leak,

(b) Leak path height = 0.001 inches,

(c) Faraday Cage volume = 3300 ft^3, and

(d) Faraday Cage air change = 3 per hour

For this situation, argon leakage into the dewar, L is

$$L = (0.1)(60)\left[(4.75+2.83)(10^{-2})(2400)+(2.59)(10^{-2})(108)\right]$$

$$= 1108\ ft^3/hr$$

The equilibrium oxygen concentration would be,

$$\%O_2 = \frac{0.295(9900 - 1108)}{9900} \times 100 = 18.61\%$$

If the number of air changes increased from 3 to 5 per hour, the equilibrium oxygen concentration would increase from 18.61% to 19.54%.

The assumed rectangular cross-sectional configuration of the leak path as described in the previous section represents a "worst case" assumption. Any leak channels, or paths, which develop between bolts will have an irregular cross-sectional area smaller than the assumed rectangular area. The leak channel height will be zero nearest the bolt holes and increase to a maximum near the mid-point between adjacent bolts for a leak caused by a warping or buckling of the plates. For leaks which develop as a result of cracks in, or other failure of, the epoxy, the maximum leak channel height will be simply the thickness of the epoxy layer between mating plates and the leak channel width the thickness of the crack or failure. This latter dimension would be a small fraction of that assumed for the calculations in this study. Leaks due to porosity of the epoxy (Rabbit Hutches) or "O" rings will also be small relative to the quantities calculated herein. For instance, each capillary-type leak through a 0.001 inch diameter opening would leak at a rate equal to 0.04% of that which would leak through a rectangular opening, 0.001"x2.10".

As an added precaution, oxygen monitors should be located inside the Faraday Cage. It is difficult to imagine a situation where a catastrophic leak could occur, but should such a leak occur, the monitors would provide immediate warning. A more likely occurrence would be a gradual argon leak of sufficient magnitude to cause the oxygen content in the Cage to deteriorate <u>gradually</u> and essentially unnoticed by the personnel in the Cage. To protect against this occurrence, the oxygen monitors would be set to alarm at perhaps 19% O_2 which would allow sufficient time to evacuate or take corrective action before a hazardous condition was reached.

The blower on the air conditioning units provides a useful function (in addition, of course, to its design purpose) in preventing localized low-oxygen pockets from developing. The forced circulation of air promotes mixing to maintain a uniform oxygen content in the Cage. The blower also promotes a higher air change rate than would be achievable in a stagnant, or passive, environment.

IV. CONCLUSIONS

A quantitative definition of the probability of an ODH condition (ie, O_2 <17.8%) developing in the Faraday Cage as a result of argon vapor infiltration from the LAC dewar is beyond the scope of this study. However, the results presented herein clearly show that such an occurrence is extremely unlikely, and in the event it should occur, it would do so gradually and uniformily, and would be detected by the oxygen monitors at an early stage. The creation of an instananeous ODH condition in the Cage could only occur as a result of a catastrophic failure of the dewar upper or lower shell. This study assumes such an occurrence has a zero probability of occurrence, and as such was not considered.