#2 CCI Report No. 593-110

ODH ANALYSIS FOR A LIQUID ARGON SPILL FROM THE UNIVERSITY OF ROCHESTER LAC CRYOSTAT

PREPARED UNDER P.O. NO. 94362, TASK ORDER NO. 002

CRYOGENIC CONSULTANTS, INC.
ALLENTOWN, PA

FOR

FERMI NATIONAL ACCELERATOR LABATORY
BATAVIA, IL

December 6, 1984

INDEX

LIST OF FIGURES

ODH ANALYSIS FOR A LIQUID ARGON SPILL FROM THE UNIVERSITY OF ROCHESTER LAC CRYOSTAT

I. INTRODUCTION

The effect upon the surrounding environment of a large liquid argon (LAr) spill from a cryostat has been studied by CCI previously (Ref. 1-3). These studies differ from the current work in that two of them deal with a spill at the D-0 Detector and the third, although it addresses a spill at the LAC cryostat, was less specific than the current work. However, these reports provide relevant information concerning the handling of a LAr spill and should be considered in conjunction with this report. Conclusions and calculations relative to the current work presented in these reports were not repeated herein. Suggestions for minimizing LAr vapor generation and for recovering spilled vapor and liquid presented in these earlier works are applicable and should be considered.

This study addresses the specific situation of the LAC cryostat as it will be installed and operated at Fermi Lab. The physical configuration is as presented in CCI Drawing 7405-E and Fermi Lab Drawings 8-1-45, A-4 and A-5 (the later two undated but received at CCI on October 24, 1984). The study objective was to predict the probable failure(s) and subsequent hazards created by the liquid spilled and the vapor generated from it, and to recommend measures to minimize the resulting hazards.

II. DISCUSSION

A plan view of the LAC Dewar in the on-line position is shown in Figure 1. The trough depth is 3 feet below the level of the MW Experimental Hall floor. The pit depth is 21.8 feet below the trough floor. The trough is sloped towards the pit. Both the trough and pit provide collection volume for LAr and gaseous argon following a LAr spill, thus initially containing the spill and localizing the hazard. During this initial containment period there will be sufficient time for personnel to be evacuated from the area.

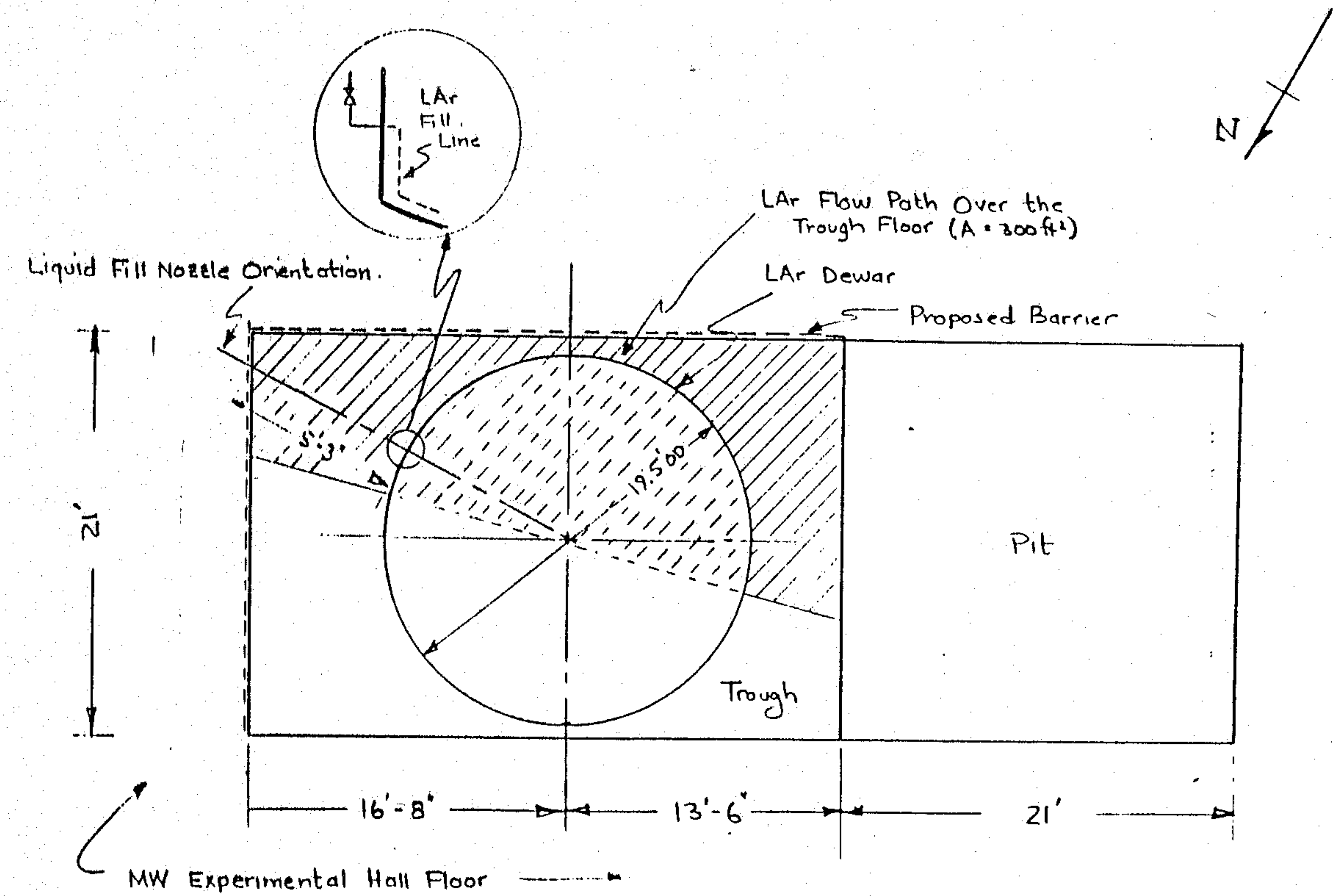


FIGURE 1

PLAN VIEW OF LAC DEWAR IN THE ON-LINE POSITION

There are two occurrences which would result in a LAr spill of sufficient magnitude within the MW Experimental Hall to warrant consideration, namely

1. Dewar rupture, and

2. LAr fill line break.

Of these two possibilities, a dewar rupture resulting from a physical blow is not a likely occurrence. The dewar shell is fabricated from 9/16" stainless steel plate without "windows", thin-skinned areas or other vulnerable components. A force of sufficient magnitude to cause a rupture of this 9/16" plate is not likely to occur. Reasonable precautions will preclude this from occurring. A more likely possibility is that a crack would develop from a thermal stress which would occur during cooldown or warmup when the cryostat would be empty or nearly empty. Consequently, a dewar rupture occurrence was eliminated from further consideration as a source of a major LAr spill.

The second occurrence, namely a liquid fill line break, is a more likely possibility. The line into the dewar is 3" IPS Sch 40 pipe with a shutoff valve near the dewar. When the dewar is filled with LAr, a rupture between the valve and the dewar shell would result in a serious LAr spill. This occurrence was considered to be the most likely source of a serious LAr spill and as such, was chosen as the subject for this study.

Consider the following situation. The LAr cryostat is in the on-line position and is filled with LAr. The fill line to the dewar lies approximately along the east-west axis and extends in an easterly direction from the dewar (Figure 1). Assume the line suffers a complete break between the valve and the dewar and LAr begins to escape from the dewar. The cumulative mass discharge of LAr from the break as a function of time is shown in (Figure 2). The fill line extends into the dewar (CCI Dwg 7405-E) creating an impedence to the discharge of LAr. The LAr leaving the break does so with a velocity such that it

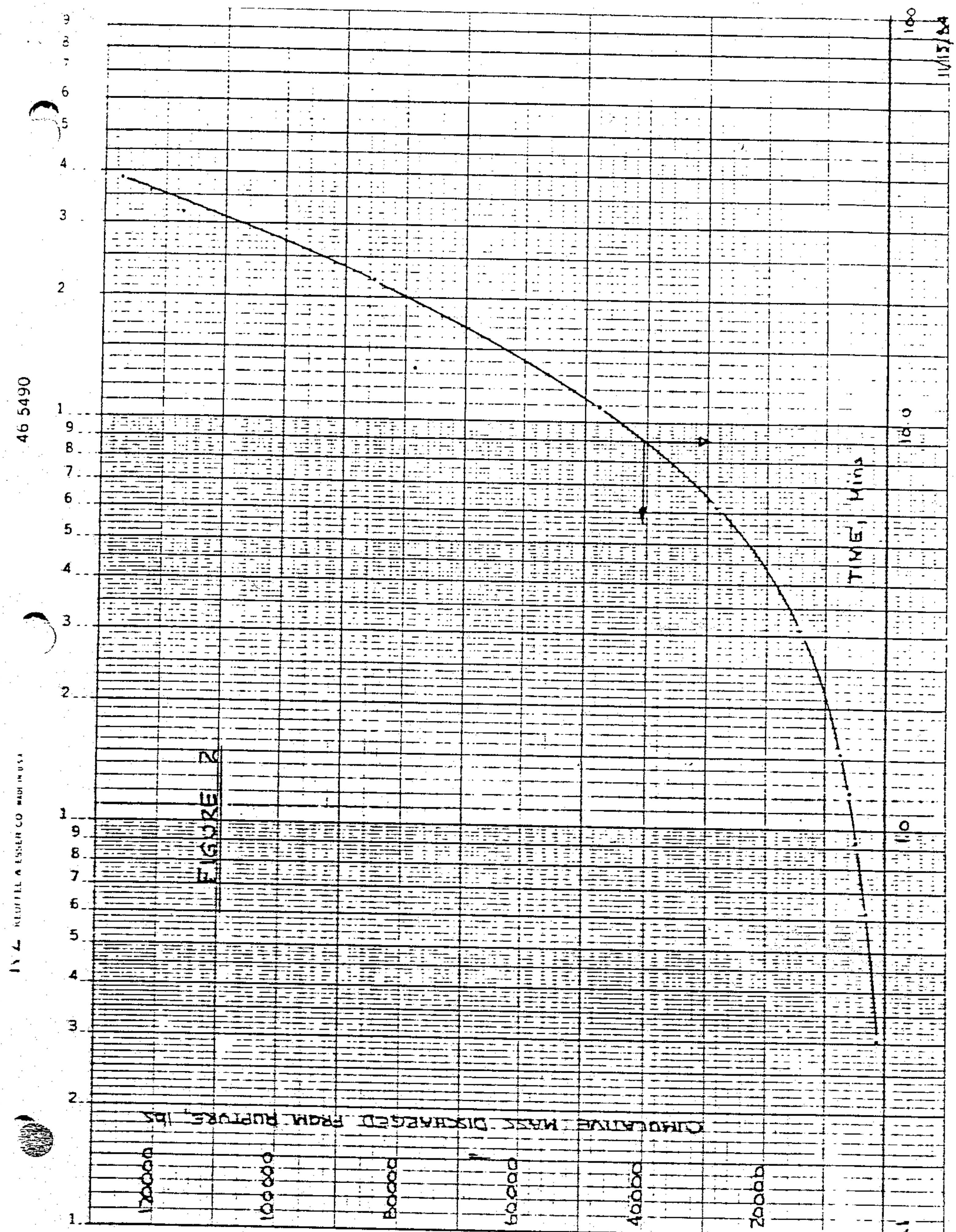


FIGURE 2
TIME, Mins
CUMULATIVE MASS DISCHARGED FROM RUPTURE, lbs
120000
100000
80000
60000
40000
20000
0.1
1.0
10.0
100
11/15/84
46 5490
KEUFFEL & ESSER CO. MADE IN U.S.A.

will travel some distance from the point of break to the point of impact. Figure 3 is a plot of the horizontal distance "X" traveled from the point of break to the point of impact as a function of time. At t=+0, the exit velocity is 18 ft/sec and the horizontal distance to impact is 8.8 ft, which exceeds the 5.25 ft horizontal distance from point of rupture to the edge of the trough (see Figure 1). The LAr will then impact on the floor of the MW Experimental Hall creating an extensive hazard area. This will continue for approximately 22 minutes into the event. To prevent this and thus contain the spill, a barrier should be erected along the edge of the trough opposite the dewar fill line to deflect the LAr into the trough. This barrier will contain the spilled LAr to the trough and the pit for the entire duration of the spill. The following discussion assumes such a barrier is in place.

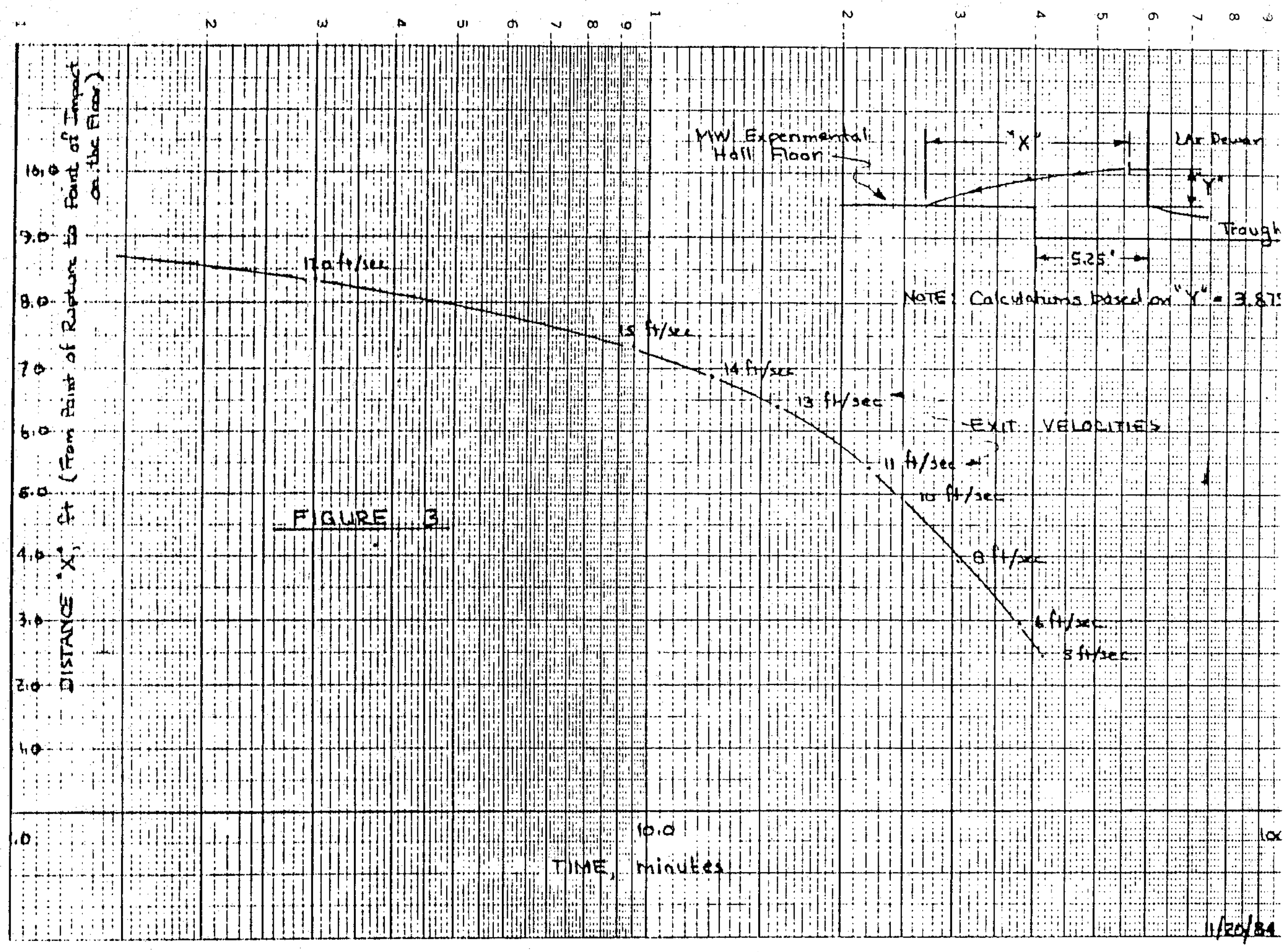
Estimating the dispersement of the LAr in the trough, the subsequent generation of vapor and the dispersement of this vapor to create ODH areas is a complicated problem. To render the analysis manageable, finite time segments from moment of rupture were defined and static conditions assumed during these time segments. The LAr would first contact the trough floor opposite the break point and begin to vaporize.

The unvaporized LAr then flows via a preferred liquid flow path over the sloped trough floor towards the pit. This preferred flow path was assured to remain constant for the duration of the spill (Figure 1). The LAr vaporization rate is controlled by film pool boiling (Ref 4) which occurs on the concrete surface rather than by the heat flux through the concrete (Figure 4). The cold vapor generated on the trough floor will flow into the pit rather than spill onto the MW Experimental Hall floor until such time when both the trough and pit are filled with vapor and liquid.

[redacted], or 0.95%. A LAr droplet will accelerate down this slope at a rate of 0.54 ft/sec,

K•E SEMI-LOGARITHMIC 2 CYCLES x 140 DIVISIONS
KEUFFEL & ESSER CO. MADE IN U.S.A.

46 5130



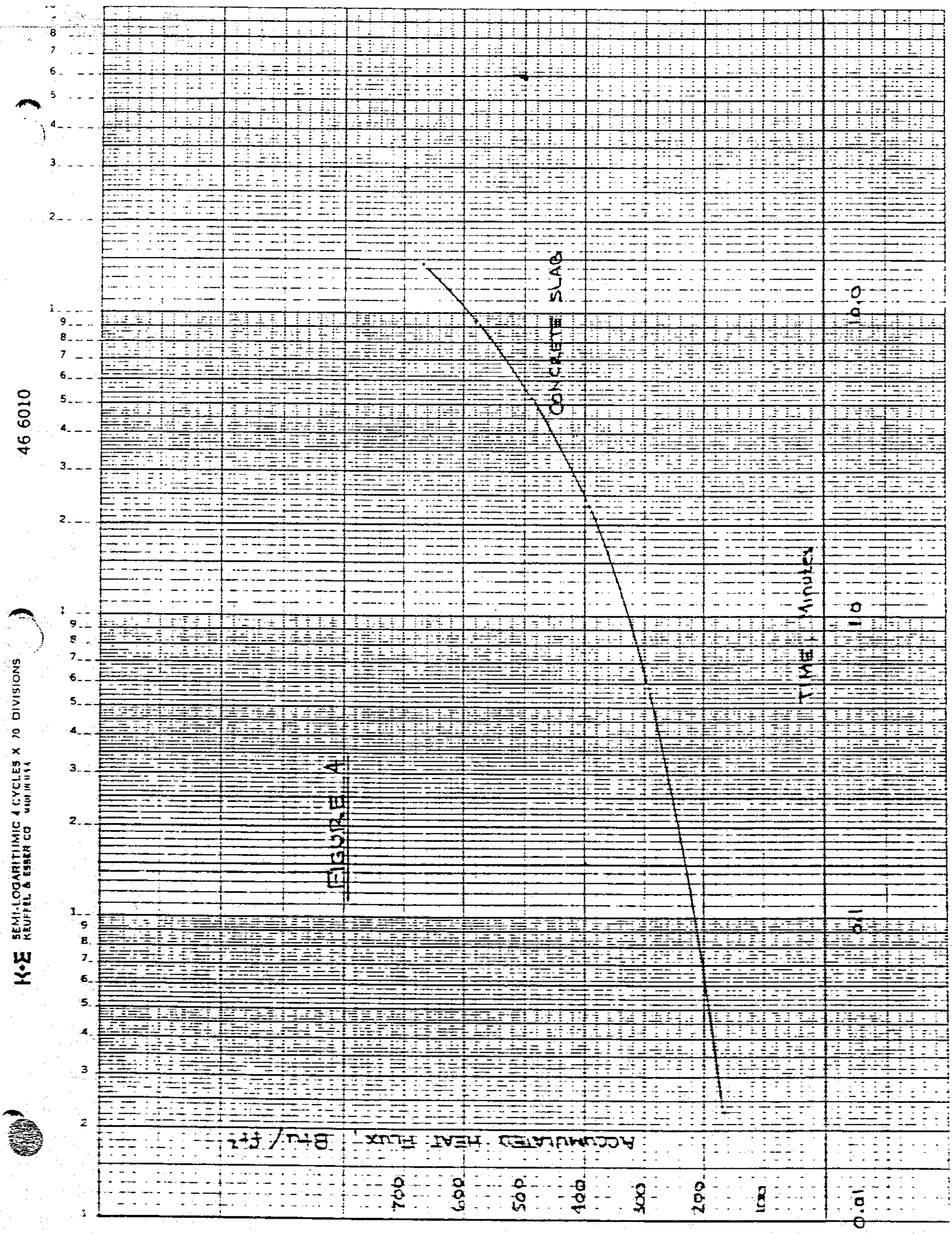


FIGURE 4
CONCRETE SLAB
TIME, Minutes
ACCUMULATED HEAT FLUX Btu/ft²
700
600
500
400
300
200
100
0.01
0.1
1.0
10.0
46 6010
K+E SEMI-LOGARITHMIC 4 CYCLES X 70 DIVISIONS
KEUFFEL & ESSER CO. MADE IN U.S.A.

reaching the edge of the pit in approximately eleven (11) seconds after it is spilled onto the trough floor. The velocity at the point the LAr spills into the pit is 5.9 ft/sec. During this time increment of 11 seconds, 950 lbs of LAr will have discharged from the rupture and 42 lbs will have vaporized on the trough. The assumed LAr flow path from spill point to the edge of the pit as shown on Figure 1 was assumed to remain unchanged and to cover 300 ft^2 of trough floor. The heat transferred from the floor to the LAr is limited by the film pool boiling flux of 6340 Btu/hr. ft^2 of surface area (Reference 4), for a temperature difference of 400F. The vapor generated in the trough is heavy relative to air (0.36 lbs/ft^3 vs. 0.075 lbs/ft^3) and will flow into the pit rather than overflow the trough walls.

During the second time increment, from t=11 seconds to t=20 seconds, an additional 700 lbs of LAr are spilled. At t=11 seconds, LAr begins to spill into the pit and at t=17 seconds the pit floor is completely covered with liquid. At t=20 seconds, an additional 68 lbs of vapor has been generated on the trough plus 89 lbs in the pit, bring the total LAr vaporized after 20 seconds to 199 lbs, or 533 ft^3 of cold vapor. The unvaporized LAr is 1451 lbs, 908 lbs of which is on the trough and 543 lbs in the pit. The analysis was repeated at 10 second intervals until the unvaporized liquid and vapor generated combined volume totaled approximately 12,500 ft^3, the combined volume of the trough and the pit. The time elapsed to reach this volume is 240 seconds assuming no change in temperature of the vapor generated (i.e., - 303°F In reality the vapor will warm as a result of heat transfer between it and the pit wall. Assuming a heat transfer coefficient of 2.0 Btu/hr. ft^2°F, a temperature driving force of 400°F, an average contact area of 1030 ft^2 and a uniform enthalpy increase for the vapor, the gas will warm to -204 °F and occupy a combined volume with the unvaporized liquid of approximately 12,500 ft^2 at t = 160 seconds. Therefore, the containment of LAr and argon vapor resulting from the spill as described previously will last for 160 seconds following the rupture.

The vapor generation rate at the time cold vapor begins to flow onto the MW Experimental Hall floor (t = 160 second is 3120 ft^3 of cold gas per minute (52 ft^3/sec.). The cold gas flows onto the floor at a velocity of 5.1 ft per second assuming a height of cold vapor in the trough and pit of 0.5 ft. above the MW Experimental Hall floor. As the cold gas travels across the floor it is warmed, becomes less dense, and hence creates a larger ODH area. The rate of warming of this vapor is limited by the heat transfer coefficient between the vapor and the floor, assumed to be 2.0 Btu/hr. ft^2°F. Therefore little turbulence will be generated and little mixing of argon vapor with the surrounding air occurs. The ODH boundries remain distinct.

As an example, consider what occurs during the first second after argon vapor begins to spill over onto the MW Experimental Hall floor. The following conditions exist:

Vapor generation rate	=	96 ft^3/sec.
Vapor velocity	=	5.1 ft/sec.
Temperature difference	=	400°F
Heat transfer coefficient	=	2.0 Btu/hr ft^2°F
Surface area in contact with vapor	=	388 ft^2

The resulting heat transfer rate of 86 Btu/sec is distributed over 35lbs of argon vapor resulting in an enthalpy rise of 2.5 Btu/lb.sec. The temperature of the gas increases by 20°F and the density deceases from 0.36lbs/ft^3 to 0.25 lbs/ft^3. This rate of change decreases with time as the ΔT between the gas and the flow decreases.

The preceding analysis assumes the LAr dewar is in the on line position and that the rupture occurs in the liquid fill line between the dewar and the shutoff valve. It also assumed a barrier is erected along the edge of the trough opposite the rupture to deflect the spilled LAr into the trough. If the dewar is being moved towards the pit or is in the off-line position when the line rupture occurs, the LAr will continue to discharge onto the trough floor and subsequently accumulate in the pit. The vapor generation rate will be slower if the entire trough is not completely covered with liquid and hence the creation of an ODH will be delayed beyond the 160 seconds determined previously.

In addition to the ODH created during a LAr spill, there exists the possibility that structured damage can occur to the gantry and support members. The structural integrity of the walls of the trough and pit are essential to the support of the gantry. The walls should be lined with an insulating material such as plywood or foam, to prevent cold shock cracking of the walls. A 3/4" - 1" thickness will be adequate. The lower members of the gantry should also be protected against cold shock. One possibility is insulation, such as a spray-on foam of the type used for fire protection. The LAr deflection barrier recommended to contain the spill could be designed in such a manner as to perform the dual function of containing a spill and protecting the gantry structural members. Particular attention should be paid to protecting the lower horizontal member of the gantry. A failure of this member could result in separation of the vertical legs followed by collapse of the gantry.

III. CONCLUSIONS

1. A rupture of the LAr cryostat shell resulting in a catastrophic spill of LAr is an extremely remote possibility and does not warrant consideration. The dewar shell is fabricated of 9/16" steel plate and such a rupture could only result from a massive physical blow to the shell. A scenario wherein such a blow could occur could not be envisioned at this time.

2. The most likely failure is the rupture of the LAr fill line between the dewar shell and the shut-off valve. Such a failure would result in a spill which would be contained in the trough and the pit. The time lapse between rupture and the occurrence of an ODH condition on the MW Experimental Hall floor is of the order of 160 seconds.

3. Personnel on the MW Experimental Hall floor will have ample time to evacuate. The immediate hazard will be to individuals in the trough or pit as they will

be immediately subjected to cold "burns", followed by an asphixiation hazard as vapor is generated in these areas.

4. The ODH boundaries will be distinct. LAr vapor is much heavier than air and will concentrate near the floor and will flow much like a liquid. There will be little turbulence created and hence little mixing with air resulting in a distinct boundry between the argon vapor and the air.

5. As the argon vapor warms as a result of contact with the floor, the ODH volume height will increase but again no appreciable mixing with the air will occur.

6. Personnel injured or otherwise in the prone position will be vulnerable. Immediate attention will be required by these individuals.

IV. RECOMMENDATIONS

1. Erect a barrier along the edge of the trough (Figure 1) opposite the LAr fill line to the dewar. If possible, the barrier should extend the entire lengths of the east edge and the south edge of the trough. As a minimum, the barrier must be of sufficient length to protect against rupture other than a clean break (i.e., rupture where the LAr would be discharged at an angle to the center line axis of the fill line). The barrier must be able to withstand cold shock.

2. The walls of the trough and the pit should be lined with 3/4" - 1" thick insulating material to protect against cold shock cracking. These walls provide foundational support for the gantry.

3. Although no immediate ODH hazard will be created from a fill line rupture, the ODH occurrence can be further delayed and reduced in magnitude by:

   a. Lining the trough and pit floors and pit walls with a low conductivity material such as plywood or insulating foam.

   b. Provide means to recover both the LAr and Argon vapor from the pit.

   Both of these subjects are described in further detail in References 2 and 3, and will not be repeated here.

4. The lower structural steel members of the gantry should be protected from cold shock with insulating material. Of particular concern is the lower horizontal structural members.

V. REFERENCES

1. Failure Mode Analysis/LAC Cryostat, prepared for the University of Rochester (PO U-17288), dated March 30, 1984. Pg. 3 and Pg. 10.

2. CCI Report No. 593-104, Analysis of the Effects of a Large Liquid Argon Spill at the D.O. Detector, July 2, 1984.

3. CCI Report No. 593-105, Updated Analysis of the Effects of a Large Liquid Argon Spill at the D.O. Detector, July 31, 1984.

4. International Advances In Cryogenic Engineering, 1964 Vol. 10, Pg. 325, article entitled Nucleate and Film Pool Boiling Design Correlations of O_2, N_2, H_2 and He.