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SECTION 1

EVALUATION OF D.C. COOK CONTAINMENT TO DETERMINE LIMITING INTERNAL UNIFORM PRESSURE CAPACITY

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1.0 INTRODUCTION

1.1 PURPOSE AND SCOPE OF REPORT

The object of this report is to determine a best estimate of the limiting uniform equivalent static internal pressure capacity of the containment structures for the D.C. Cook Nuclear Generating Units No. 1 and 2. The evaluation reported is limited to the reinforced concrete base mat, the reinforced concrete right circular cylinder and hemispherical dome as well as major containment penetrations including the equipment and personnel hatches. This report completes Phase I of a three phase effort which will include as Phase II an upper and lower bound estimate of the internal uniform equivalent static pressure capacity of the "as built" containment structures and Phase III which will consider potential time dependent localized non-uniform pressure load effects.

1.2 EVALUATION CRITERIA

The evaluation to determining the limiting best estimate uniform static pressure capacity of the containment structures is based on a linear elastic analysis of critical portions of the structure up to stress levels limited by "as built" mean value samples of the yield in steel and ultimate strength of the concrete. It should be understood that the structural and leak tight integrity of a steel lined concrete containment shell and slab structure should be maintained well beyond actual yield of the steel reinforcement. This is due primarily to the relative high ductility of the steel liner, (ie. 20-23 percent uniform ultimate strain at rupture) compared to the 40 ksi steel reinforcement (ie. 8-11 percent uniform ultimate strain at rupture) and strain hardening in the reinforcement. Hence the liner in general would be able to accomodate relatively large nonlinear deformation of the concrete structure before significant leakage would occur. However, since deformations beyond the yield range are difficult to predict and localized deformations in the structure can significantly exceed those calculated globally, the limiting internal pressure has been determined conservatively considering only assumed elastic response up to the initial yield of the materials used.

It is the author's opinion based on the observed results of model tests that significant leakage (> 1.0 percent of containment volume) of the containment would not occur until pressures exceeded the limiting pressures calculated in this study by at least 20 percent. Assuming a composite coefficient of variation of 10 percent and a log normal distribution of material properties the probability of significant leakage at the pressure level defined in this study would be approximately 0.01. The probability of significant leakage and upper and lower bounds on pressure will be evaluated in more detail in Phase II.

1.3 CONTAINMENT DESCRIPTION AND DESIGN BASIS

The reactor containment structure is a reinforced concrete vertical cylinder with a flat base and a hemispherical dome as shown in Figure 1. A ductile welded steel liner with a thickness of 1/4-inch on the containment base and 3/8-inch on the Cylinder is stud attached to the inside face of the concrete shell to insure a high degree of leak-tightness. The design objective of the containment structure is to contain all radioactive material which might be released from the reactor coolant system following a postulated loss of coolant accident. The structure serves as both a biological shield and a pressure container.

The structure consists of side walls measuring 113-feet from the liner on the base to the springline of the dome, and has an inside diameter of 115-feet. The side wall thickness of the cylinder at the base is 4.5 ft. tapering to 3 .5 ft., seven feet above the base mat and continuing at 3.5 ft. to the springline. The reinforced concrete thickness of the dome varies uniformly from 3.5 ft. at the springline to 2.5 ft at the apex of the dome. The inside radius of the dome is equal to the inside radius of the cylinder. The flat concrete base mat is 10-ft. thick with an outside diameter of 140'-0" and with the bottom liner plate 1/4" thick located on top of this mat. The bottom liner plate is covered with a 2-ft. structural slab of concrete which serves to carry internal equipment loads and forms the floor of the containment. The base mat is supported directly by relatively stiff soil.

The basic structural elements considered in the design of the containment structure is the base slab, side walls and dome acting as one structure under all loading conditions. The liner is anchored to the concrete shell walls by means of stud anchors so that it forms an integral part of the entire composite structure under all membrane loadings. The reinforcing in the structure has an elastic response to all primary design loads.

The base mat is 10'-0" thick and 140'-0" in diameter. The reinforcement in the top of the base slab consists primarily of one layer of #18S bars at 12" c/c in the hoop and 2 layers of #18S bars at 9" c/c in the radial directions. The bottom reinforcement consists of 2 layers of #18S bars at 12" c/c in the hoop and 3 layers of alternate #18S and #11 bars at 9" c/c in the radial directions. The base slab was poured in two five foot lifts which are tied together in order to transmit horizontal shear induced by bending moments by shear keys and vertical #11 bars at 6'-0" c/c spacing.

The membrane hoop (horizontal) reinforcement in the cyclinder walls is generally in two rows, one on each face consisting of #18S at 18" c/c circumferentially extending to 20' above the base mat reduced to 9" c/c spacing between 20' and 57' above the base and then increased to 12" c/c spacing between 57' and 113' (springline) above the base mat.

The membrane meridional, (vertical) reinforcement in the containment shell consists primarily of two layers one on each face of #18S bars on 18" c/c. In the region of discontinuity at the base mat the amount of vertical reinforcement is doubled to 4 layers of #18 bars at 18" c/c and at the cylinder dome intersection one vertical staggerd row of #11 bars at 18" c/c is added to the existing membrane vertical reinforcement to provide discontinuity bending moment resistance.

In addition to the vertical and horizontal membrane and bending reinforcing steel, in plane diagonal reinforcement has been provided to carry seismically·induced membrane shear. The 45 degree diagonal bars consist of #11 bars spaced 3'-0" on the horizontal c/c placed in two rows in each face and in each direction. The diagonal reinforcement is embedded in and extends from the base mat to 4-3" above the springline into the dome for alternate bars and 7'-0" for the rest of the diagonals.

The dome reinforcement consists of #18 bars at 18" c/c in each face in each direction.

The containment structure encloses an ice condenser containment system which is designed to limit pressurization of the containment under design basis accident conditions to 12.0 psi. Other significant design load parameters are the equivalent safe shutdown earthquake loading of 0.2g zero period ground acceleration and a design basis tornado of 360 mph. wind and and 3.0 psi differential pressure. Hot process pipe penetrating the containment are anchored in the containment shell with the anchors designed to resist the postulated rupture of the process line without loss of containment leak tight integrity.

A load factor of 1.5 (additional safety factor) is used with the internal pressure component of design load while a load factor of 1.0 is used with both the SSE and Tornado loading.

1.4 MATERIAL PROPERTIES

The particular specified minimum materials properties used in the construction of the containments are summarized as follows:

(a) concrete - f'_c = 3,500 psi at 28 day (ACI - 308-63, 301,66, and 214-65)

(b) reinforcing rod - f_y = 40,000 psi (ASTM A 15)

(c) liner plate - f_y = 32,000 psi; f_u = 60,000 psi
(ASTM SA 442-Gr.60)

(d) equipment hatch - f_y = 38,000 psi; f_u = 70,000 psi
(ASTM SA 516-Gr.70)

(e) personnel hatch - f_y = 38,000 psi; f_u = 70,000 psi
(ASTM SA 516-Gr.60)

(f) hatch bolts - f_y = 105,000 psi; f_u = 125,000 psi
(ASTM SA 193-Gr.B7)

In Table 1 can be found a summary of the "as built" strengths as well as a measure of the dispersion associated with the materials used in the containment construction, based on a limited sample of existing test record data. As part of Phase II of this evaluation a more detailed evaluation of "as built" material property data will be developed.

2.0 IDENTIFICATION OF LIMITING FAILURE MODES ASSOCIATED WITH UNIFORM STATIC INTERNAL PRESSURE

In selecting the potential limiting failure modes associated with equivalent static uniform internal over pressurization of a PWR reinforced concrete ice containment a number of existing analyses have been reviewed. These include the following references:

(1) Harstead, G.A. "D.C. Cook Nuclear Power Plant, American Electric Power, Estimate of Ultimate Pressure Capacity of Containment Structure", Harstead Engineering Associates, Report prepared for the NRC Staff, September, 1980. (See Attachment A)

(2) Von Riesemann, W.A. et.al. "Structural Response of Indian Point 2 and 3 Containment Buildings" Summary of Draft Report results presented to NRC Staff, Technology-Exchange Meeting 5, 17 June 1980.

(3) United Engineers and Constructors "Evaluation of Capability of Indian Point Containment Vessels Units 2 and 3" presented to NRC Staff, Technology Exchange Meeting 5, 17 June 1980.

(4) American Electric Power Service Corp., "D.C. Containment Design Calculations, AEP, 1969.

(5) S. Barnes et.al. Indian Point Nuclear Generating Unit No. 2 Containment Design Report, Westinghouse Nuclear Energy Systems, United Engineers and Constructors, March, 1969.

(6) Shulman, J. "Analysis of TVA Sequoyah Containment Shell to Determine Response of a Critical Panel to Uniform Internal Pressure", Offshore Power Systems, September, 1980.

Based on this review the following areas have been identified as potentially limiting the containment capacity to carry uniform internal pressure load.

(1) Bending shear in the reinforced concrete containment base mat adjacent to reinforced concrete cylinder walls.

(2) Membrane tension in hoop direction in the reinforced concrete cylinder adjacent to the base mat (assuming no rotational or shear restraint by the cylinder).

(3) Bending moment in equipment hatch end plate.

(4) Bending moment in personnel hatch end plate.

3.0 POTENTIAL FAILURE MODE ANALYSIS

3.1 SHEAR FAILURE IN BASE MAT

The program used to determine net shear and tensile forces in the base slab is "GENSHL" which was developed by the Franklin Institute Research Laboratory of Philadelphia. The program consists of a multi-layered static shell formulation where each shell layer may have different stiffness properties and can consider elastic foundation support conditions. This is the same program that was used in the original design and analysis of the base slab for design basis loadings. A uniform soil reaction distribution is used for dead load plus internal uniform pressure case.

Results of the analysis are summarized as follows:

1.	Specified minimum design strength of concrete at 28 days	= 3,500 psi
2.	Mean Sample Value at 28 days	= 4,950 psi
3.	Minimum Sample Value at 28 days	= 4,156 psi

Foundation Slab:

T = 120 inches

d = 114 inches

From computer output as shown in Tables 2 and 3 at sections indicated in Figure 2:

Evaluation for lowest measured concrete strength value:

	N_{11} k/in	Q_{13} k/in	Comp. Run
Case			
12.0 psi, internal pressure	1.898	- 2.948	Soil Par. 1
Assume			
49.5 psi, internal pressure	7.829	-12.160	Soil Par. 1
Dead Load	1.300	- 0.193	Soil Par. 5
DL + 49.5 psi pressure	9.129	-12.353	

$$v = \frac{Q_{13}}{d} = \frac{12.353 \times 1000}{1 \times 114} = 108.36 \text{ psi}$$

where:

N_{11} = membrane tension in base slab

Q_{13} = maximum vertical shear in base slab

v = maximum shear stress in base slab

From ASME Section III - Division 2 and ACI-359-80 Code for Concrete Reactor Vessels and Containments CC 3421.4.1

Using lowest measured mean value of concrete strength:

$$v_c = 2.0 \sqrt{f'_c} \left\{1 + [0.002\ Nu/Ag]\right\}$$

$$v_c = 2.0 \sqrt{4156} \left\{1 + \left[0.002 \left(\frac{-9.129 \times 1000}{1 \times 120}\right)\right]\right\}$$

$$v_c = 2(64.46)[1 - 0.152] = 108.59 \text{ psi}$$

Note: Internal Pressure Capacity wherever noted as "Psi" means "Psig"

Evaluate for mean of measured concrete strength values

	N_{11} k/in	Q_{13} k/in	Comp. Run
Assume			
53.8 psi, internal pressure	8.509	-13.217	Soil Par. 1
Dead Load	1.300	- 0.193	Soil Par. 5
DL + 53.8 psi pressure	9.809	-13.410	

$$v = \frac{13.410}{1 \times 114}(10^3) \qquad v_c = 2\sqrt{4950}\left\{1 + \left[0.002\left(-\frac{9.809 \times 1000}{1 \times 120}\right)\right]\right\}$$

$$v = 117.63 \text{ psi} \qquad v_c = 2\ (70.356)\ [1 - 0.1635]$$

$$v_c = 117.71 \text{ psi}$$

In like manner it can be shown for a specified minimum concrete strength f'_c = 3500 psi that the internal pressure capacity is 46.4 psi.

In this evaluation no credit is taken for the vertical #11 bar at 6' c/c in the base mat nor is any credit taken for shear capacity of the fill slab above the base mat.

In table 4 can be found the limiting pressure capacity adjusted for the assumption of minimum specified and minimum sampled material properties as defined in Table 1.

In Reference 1 the Harstead report Pg. 5-1-1 identified a failure mode based on the assumed pull out of the vertical membrane steel in the cylinder wall from the base mat as having a containment internal pressure capacity of 46 psi. The pull out failure mode capacity of 46 psi internal pressure capacity of the containment was determined without consideration of the radial shear (diagonal tension) capacity of the concrete which is permitted by the ACI-359 code even in presence of membrane tension. To ignore the shear capacity of the concrete is not in accordance with normal design nor analysis procedures. Hence the failure pressure in the concrete containment of 53.8 psi as defined by the calculations performed in this section is limiting.

3.2 MEMBRANE HOOP TENSION FAILURE OF CONCRETE CYLINDER

Membrane load due to containment pressurization in the horizontal (hoop) direction

$$P = p\ R \qquad (1)$$

where:

P = membrane load in lbs/in of wall

p = uniform internal pressure

R = mean radius of wall (57.5 x 12 = 690 inches)

Membrane load capacity of reinforced concrete cylinder at its base neglecting discontinuity moment transfer:

Available Reinforcement

1) 2 Layers #18 bar hoop reinforcement at 18" c/c =

$$\frac{8\ in^2}{1.5\ ft} = 5.33\ in^2/ft \text{ of wall}$$

2) 3/8" Liner plate = 3/8" x 12 = 4.50 in^2/ft of wall

3) 2 Layers #11 bar diagonal reinforcement at 36" c/c considering only those bars acting in tension

$$2 \times \frac{1.56}{3.0\ ft} \times \sqrt{2} = 1.47\ in^2/ft \text{ of wall}$$

From Table 1 of this report the mean value of the reinforcement yield = 49.8 ksi and liner plate ≃ 48.3 ksi

$$P = (5.33\ in^2 \times 49.8\ ksi) + (4.50\ in^2 \times 48.3\ ksi)$$

$$+ (1.47\ in^2 \times 49.8\ ksi)$$

$$= 265.4\ k + 217.4\ k + 73.2\ k$$

$$= 556.0\ kips/ft = 46.33\ kips/in$$

From Eq. 1

$$p = \frac{46{,}330\ lbs/in}{690\ in} = 67.1\ psi$$

In Table 4 can be found the limiting pressure capacity adjusted for the assumption of minimum specified and minimum sampled material properties as defined in Table 1.

3.3 PRESSURE CAPACITY OF THE EQUIPMENT HATCH CLOSURE

The equipment hatch closures used on the D.C Cook Containments have been identified (Ref.1) as potentially limiting the capacity of the containment to carry internal pressure loads. The reasons for this limitation are identified as follows:

1. The end closure is in the form of a flat plate hence pressure induced loading must be carried by bending rather than membrane shell action.

2. A bolted splice is used in a region of high bending moment which may limit the capacity of the hatch cover to carry pressure load.

3. The far spaced bolt pattern and the relatively low rotational stiffness of the equipment hatch barrel result in little rotational stiffness or fixed end moment capacity of the equipment hatch cover-barrel attachment. This requires that the hatch be analyzed essentially as pin connected (allowed to rotate) rather than fixed (moment resistant) at its supports thereby significantly increasing center span moments in the hatch cover.

Because of the presence of the unsymmetric splice and the unsymmetric insertion of the personnel hatch into the equipment hatch cover as shown in Figure 3 the evaluation of the equipment hatch uniform pressure capacity cannot be performed with a high degree of accuracy without recourse to a finite element formulation. Two such analyses were performed, one of the cover plate splice and the other of the equipment hatch cover plate including the effect of the splice and the inserted personnelhatch to determine their maximum internal pressure carrying capacities.

3.3.1 <u>Splice Plate Moment Capacity</u>

3.3.1.1 Hand Calculation - considering 1" full penetration weld detail as shown in Figure 4[(1)]

Before proceeding to a review of the finite element analysis of the splice plate shown in Figure 4, a hand calculation was performed in order to have a basis of comparison with the more detailed finite element calculation

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(1) Note the Harstead report neglected the weld geometry in its calculation of stresses.

Given: Splice as shown in Figure 4 - check section at top of weld

(a) 95 - 1" A-193 Gr B7 bolts on a 224" length of splice = 2.38" spacing between bolts on tension side of splice

Limiting capacity of splice at top of weld is assumed at mean yield in outermost fiber of 2 inch splice plate on tension bolt side of splice

$M_{2"}$ PL = sZ = (53.2 ksi) $\frac{1}{6}$ (2.38)(4) = 84.41 k-in/2.38 in. of splice

Limited tensile capacity of splice plate

Tx = M; x = 1.5 in.

T = M/1.5 = 84.41/1.5 = 56.27 kips/bolt

M_{Joint} = T x jd = (56.27) x (2.5 + 4.0 + 1.875) = 471.26 k-in/2.38 in. of splice

Moment capacity /in of splice

471.26/2.38 = 198.01 k-in/in

Moment capacity of 4" plate without splice

$M_{4"PL}$ = sZ = 53.2 ksi$\left(\frac{1}{6}\right)$(1) 16 = 141.87 k-in/in < 198.01

∴4" plate governs design

Capacity of Splice = $\frac{198.01}{141.87}$ = 139.6 of 4" plate

Check section at base of weld

Limiting capacity of splice at base of weld is assumed at mean yield in outermost fiber of 2 inch splice plate plus 1" weld.
(Minimum Specified F_y of the Weld material = 60.0 Ksi)

$M_{2\text{" PL + 1" weld}} = s\,Z = (53.2\text{ Ksi})\,\frac{1}{6}\,(2.38)\,9 = 189.92\text{ K - in}/2.38$ in. of splice

Limited tensile capacity of section

$Tx = M;\ x = 2.5$ in.

$T = M/2.5 = 189.92/2.5 = 75.97$ Kips/bolt

Since 75.97 > 56.27 Kips
top of weld limits design

Check capacity of bolt

From Table 1 Mean Yield of 1" bolt = 121.3 Ksi

Tensile area 1" bolt = 0.605 sq. in.

$P_{yield} = 121.3 \times 0.606 = 73.51$ Kips/bolt > 56.27 ∴ OK.

3.3.1.2 Finite Element Analysis

In Figure 5 is the finite element model of the equipment hatch splice joint showing plate elements. Using the computer program ANSYS for an applied moment to the 4 inch hatch cover plate equal to a reference containment internal pressure of 40 psi, the maximum outer most fiber stress in the 2 inch splice plate is 27.82 ksi in element 76. The maximum outer most fiber stress in the four inch plate is determined as 46.27 ksi in element 145. It appears therefore that the 4 inch rather than 2 inch plate at the joint controls design. This is due primarily to the weld which significantly increases the effective thickness of the splice plate at its connection to the four inch plate.

3.3.2 Equipment Hatch Cover Plate Pressure Capacity

In reference 1 Harstead determined the equipment hatch capacity of 53.0 psi uniform pressure loading based on simple support boundary conditions of the cover as a uniform 4" thick circular plate having a diameter of 19'-10". Because of the effect of the unsymmetric splice and personnel hatch insert a finite element analysis of the plate is performed.

A finite element modeling of the plate which included the splice is shown in Figure 6. The personnel hatch because of its rigid equivalent 12" thick support ring connection to the equipment hatch is assumed to transmit only reaction loads due to pressure to the equipment hatch. The splice is modeled as an equivalent 12" x 4" beam parallel to the splice and equal to the stiffness of the four inch plate across the splice. Using the computer program ANSYS the maximum stress intensity in the cover plate is determined in element 95 as shown in Figure 7 adjacent to the splice. The resultant limiting internal pressure load at element 95 is 45.1 psi for an "as built" mean yield stress of 53.2 ksi in the plate. From Sections 3.3.1.1 and 3.3.1.2 of this report it is determined that the splice plate has a greater moment capacity than the four inch plate.

The limiting internal pressure capacity of the Equipment Hatch Cover Plate is therefore limited by the capacity of the four inch plate at 45.1 psi. In Table 4 can be found the limiting pressure capacity adjusted for the assumption of minimum specified and minimum sampled material properties.

3.4 PRESSURE CAPACITY OF PERSONNEL HATCH

3.4.1 End Plate Closure

Because of the unsymmetric stiffening of the personnel hatch cover plate as shown in Figure 8, a finite element analysis of the plate is performed to determine its internal pressure retaining capacity. As in the case of the equipment hatch the loading from the personnel hatch door is transmitted to the personnel hatch closure plate as a reaction line load at the point of support. Also the plate is conservatively assumed simply supported rather than fixed end supported at its connection to the personnel hatch barrel because of the relative low rotational stiffness of the barrel.

In Figure 9 is found the finite element model of the hatch showing all elements. The plate and stiffner system is analyzed using the computer program ANSYS. The maximum outermost fiber stress is determined in the door stiffner at element 87 as 79.3 ksi for a reference 70 psi internal pressure load. The pressure capacity p of the personnel hatch closure is determined:

$$p = 70 \times \frac{53.2}{79.3} = 47.0 \text{ psi}$$

3.4.2 Door

The personnel hatch door is shown in Figure 8. It acts essentially as a one way spaning simply supported stiffened plate. The total span of the 1/2" thick plate is 42". The plate is stiffened by 3" x 1-1/4" solid plate stiffners on approximately 15 inch centers. Assuming a composite T section with the effective outstanding flange leg of tee equal to 8 times the flange thickness, the moment of inertia of the T section is 6.93 in^4 and distances to the outermost fibers of the section are 1.03 and 2.47 inches respectively.

Maximum applied bending moment:

$$M = \frac{1}{8} b\, p\, l^2 = \frac{1}{8} (15)(p)(42^2) = 3307.5$$

Moment Capacity of Stiffen Door Section:

$$M = sZ = (53,200) \frac{I}{c} = (53,200) \frac{6.93}{2.47} = 149,261$$

Limiting internal pressure

$$p = \frac{149,261}{3307.5} = 45.1 \text{ psi}$$

In Table 4 can be found the limiting pressure capacity adjusted for the assumption of minimum specified and minimum sampled material properties.

4.0 SUMMARY AND CONCLUSION

From the summary results of the analysis presented in Table 4 it can be seen that the current limiting internal pressure capacity of the D.C. Cook Containments are the equipment hatch closure plate and the equipment hatch door at 45.1 psi based on the use of mean "as built" material properties. It should also be pointed out that even if specified minimum material properties had been used as was the case reported in Ref. 1 by Harstead the minimum capacity of the D.C. Cook Containment is 32.3 psi based on the more detailed analyses reported herein rather than the 23.5 psi reported in Ref. 1 which were based on more approximate hand calculations.

It should also be emphasized that the analytical assumption used in the more rigorous analyses reported in this study of the equipment and personnel hatches whose limiting failure modes were in bending still considered only elastic behavior and section properties. It has long been established in the behavior of plate elements during test and as the basis for the 1.5 increase in allowable bending versus membrane stress limits of the ASME Boiler and Pressure Vessel Code that plate and shell bending elements behave essentially elastic (small deformations) until the plastic section modulus is reached. Since the plastic section modulus for rectangular shapes associated with the hatch plates is 1.5 times the elastic section modulus there is significant additional safety margin in the hatch analysis which is not applicable to the membrane or shear type failure modes identified in the containment concrete shell and base mat.

To quantify the effect of the plastic section modulus of the equipment hatch on the internal pressure capacity of the containment a non-linear elastic-plastic finite element analysis of the hatch cover plate using the computer Program ANSYS was performed for the assumed fy = 50.3 Ksi material property. Evaluation at 70 psi internal pressure or 1.64 times the elastic capacity of the cover plate indicated that the maximum deflection of the plate is still linear and the maximum plastic strain was 1.8 times the elastic strain at yield.

Therefore it is our conclusion that the D.C. Cook Containments as presently designed and constructed constitute a balanced design. That is, the true pressure retaining capacity of the hatches when the 1.5 factor discussed previously is applied is approximately the same as that of the concrete limiting portion of the containment, approximately 54.5 psi. On this basis we do not recommend any modification of the existing D.C. Cook Containment hatches.

TABLE 1 SUMMARY OF MINIMUM SPECIFIED AND AS BUILT MATERIAL PROPERTIES

			YIELD (ksi)	ULTIMATE (ksi)
1.	LINER PLATE - SA442	GRADE 60		
	SAMPLE SIZE = 6	SPECIFIED MINIMUM	32.0	60.0
	S = 2.27	MEAN SAMPLE VALUES	48.3	64.7
	Cov. = 0.047	MINIMUM SAMPLE VALUES	45.8	62.4
2.	EQUIPMENT HATCH - SA516	GRADE 70		
	SAMPLE SIZE = 5	SPECIFIED MINIMUM	38.0	70.0
	S = 2.74	MEAN SAMPLE VALUES	53.2	81.2
	Cov. = 0.051	MINIMUM SAMPLE VALUES	50.3	80.2
3.	BOLTING - SA193	GRADE 87		
	SAMPLE SIZE - 2 ea.			
	1/2" x 2-1/2"	SPECIFIED MINIMUM	105.0	125.0
		MEAN SAMPLE VALUES	119.0	137.0
	1" x 5-1/2" (SPLICE)	SPECIFIED MINIMUM	105.0	125.0
		MEAN SAMPLE VALUES	121.3	141.0
	1-1/4" x 10" (COVER)	SPECIFIED MINIMUM	105.0	125.0
		MEAN SAMPLE VALUES	120.1	140.3
4.	REINFORCING ROD A15	GRADE 40		
	18S	SPECIFIED MINIMUM	40.0	70.0
	SAMPLE SIZE 9	MEAN SAMPLE VALUES	49.8	81.8
	S = 3.34	MINIMUM SAMPLE VALUES	44.3	75.5
	Cov. = 0.067			
5.	CONCRETE - 28 DAY STRENGTH -	UNIT 1 and 2		
		SPECIFIED MINIMUM		3.5
	SAMPLE SIZE 29	MEAN SAMPLE VALUES		4.956
	S = 0.508	MINIMUM SAMPLE VALUE		4.112
	Cov. = 0.103			

Table 2 Computer Calculated Resultants [illegible]ces in the Containment Base Slab Due to Dead Weight

SOLUTION FUNCTIONS IN SYSTEM REFERENCE FRAME

1	0.207258E 04	0.0	0.179783E 04	0.834138E 05	-0.120054E-02	0.0	-0.719304E-02	0.163832E-03
2	0.220710E 04	0.0	0.181662E 04	0.548537E 05	0.148695E-02	0.0	-0.704790E-02	0.162184E-03
3	0.234638E 04	0.0	0.183450E 04	0.243167E 05	0.414161E-02	0.0	-0.685249E-02	0.159843E-03
4	0.249031E 04	0.0	0.185155E 04	-0.824924E 04	0.675165E-02	0.0	-0.663427E-02	0.156762E-03
5	0.263875E 04	0.0	0.186704E 04	-0.420949E 05	0.930451E-02	0.0	-0.636066E-02	0.152896E-03
6	0.279153E 04	0.0	0.188343E 04	-0.796689E 05	0.117869E-01	0.0	-0.603897E-02	0.148198E-03
7	0.294845E 04	0.0	0.189336E 04	-0.118619E 06	0.141846E-01	0.0	-0.566649E-02	0.142618E-03
8	0.310929E 04	0.0	0.191265E 04	-0.159789E 06	0.164827E-01	0.0	-0.524038E-02	0.135108E-03
9	0.327378E 04	0.0	0.192634E 04	-0.203221E 06	0.186656E-01	0.0	-0.475782E-02	0.128616E-03
10	0.344161E 04	0.0	0.193942E 04	-0.248953E 06	0.207165E-01	0.0	-0.421597E-02	0.120092E-03
11	0.361263E 04	0.0	0.195193E 04	-0.297069E 06	0.226201E-01	0.0	-0.361094E-02	0.110472E-03

ACTUAL STRESS RESULTANTS-SHELL REFERENCE FRAME-BODY 7
%AT CENTROID<

STATION NO.	CENTROIDS MERID.	CENTROIDS HOOP	N11 LB/IN	Q12 LB/IN	N22 LB/IN	Q13 LB/IN	Q23 LB/IN	M11 IN-LB/IN	M12 IN-LB/IN	M22 IN-LB/IN
1	62.862	62.811	0.179783E 04	0.0	0.216753E 04	-0.207258E 04	0.0	-0.192634E 05	0.0	0.189855E 06
2	62.862	62.811	0.181662E 04	0.0	0.216602E 04	-0.220710E 04	0.0	-0.488963E 05	0.0	0.177062E 06
3	62.862	62.811	0.183450E 04	0.0	0.216593E 04	-0.234638E 04	0.0	-0.804544E 05	0.0	0.163588E 06
4	62.862	62.811	0.185155E 04	0.0	0.216720E 04	-0.249031E 04	0.0	-0.113994E 06	0.0	0.149402E 06
5	62.862	62.811	0.186784E 04	0.0	0.216971E 04	-0.263875E 04	0.0	-0.149570E 06	0.0	0.134474E 06
6	62.862	62.811	0.188343E 04	0.0	0.217339E 04	-0.279153E 04	0.0	-0.167235E 06	0.0	0.118778E 06
7	62.862	62.811	0.189836E 04	0.0	0.217818E 04	-0.294845E 04	0.0	-0.227037E 06	0.0	0.102286E 06
8	62.862	62.811	0.191265E 04	0.0	0.218402E 04	-0.310929E 04	0.0	-0.269024E 06	0.0	0.849739E 05
9	62.862	62.811	0.192634E 04	0.0	0.219084E 04	-0.327378E 04	0.0	-0.313230E 06	0.0	0.668169E 05
10	62.862	62.811	0.193942E 04	0.0	0.219860E 04	-0.344161E 04	0.0	-0.359717E 06	0.0	0.477931E 05
11	62.862	62.811	0.195193E 04	0.0	0.220726E 04	-0.361263E 04	0.0	-0.408547E 06	0.0	0.278602E 05

RESULTANT STRESSES-PSI BODY 8

STATION NO.	LAYER NO.	STRESS S11 INSIDE	STRESS S11 OUTSIDE	STRESS S12 INSIDE	STRESS S12 OUTSIDE	STRESS S22 INSIDE	STRESS S22 OUTSIDE
1	1	0.14413E 01	0.13126E 01	0.0	0.0	0.36946E 02	0.33971E 02
	2	-0.46754E 02	-0.46667E 02	0.0	0.0	0.99142E-05	0.98951E-05
	3	-0.16092E-05	-0.16044E-05	0.0	0.0	0.28696E 03	0.28607E 03
	4	-0.46527E 02	-0.46276E 02	0.0	0.0	0.98645E-05	0.98099E-05
	5	0.12971E 01	0.11138E 01	0.0	0.0	0.33613E 02	0.29374E 02
	6	-0.40609E 02	-0.40359E 02	0.0	0.0	0.85740E-05	0.85194E-05
	7	-0.13917E-05	-0.13820E-05	0.0	0.0	0.24706E 03	0.24529E 03

Computer Calculated Resultant Forces i[illegible]e Containment Base Slab Due to a Referen[illegible]2.0 psi Internal Pressure

COOK PLANT SOIL PARAMETER STUDY NO. 1   12-30-80
LOADING 3 DEAD WEIGHT

SOLUTION FUNCTIONS IN SYSTEM REFERENCE FRAME

1	0.362819E 04	0.0	0.124021E 04	0.197442E 06	-0.181325E 01	0.0	-0.936208E-02	0.193628E-03
2	0.300629E 04	0.0	0.125189E 04	0.147726E 06	-0.181004E 01	0.0	-0.940639E-02	0.195016E-03
3	0.240632E 04	0.0	0.126290E 04	0.108824E 06	-0.180683E 01	0.0	-0.939061E-02	0.195358E-03
4	0.182652E 04	0.0	0.127325E 04	0.800810E 05	-0.180361E 01	0.0	-0.932920E-02	0.194910E-03
5	0.126535E 04	0.0	0.128295E 04	0.609194E 05	-0.180040E 01	0.0	-0.923599E-02	0.193908E-03
6	0.721415E 03	0.0	0.129201E 04	0.503248E 05	-0.179722E 01	0.0	-0.912352E-02	0.192576E-03
7	0.193453E 03	0.0	0.130045E 04	0.493393E 05	-0.179405E 01	0.0	-0.900394E-02	0.191125E-03
8	-0.319680E 03	0.0	0.130826E 04	0.560519E 05	-0.179091E 01	0.0	-0.888067E-02	0.189754E-03
9	-0.818996E 03	0.0	0.131547E 04	0.705932E 05	-0.178780E 01	0.0	-0.878856E-02	0.188653E-03
10	-0.130542E 04	0.0	0.132209E 04	0.926286E 05	-0.178469E 01	0.0	-0.871393E-02	0.188003E-03
11	-0.178029E 04	0.0	0.132812E 04	0.121891E 06	-0.178159E 01	0.0	-0.867464E-02	0.187975E-03

ACTUAL STRESS RESULTANTS-SHELL REFERENCE FRAME-BODY 7
%AT CENTROID<

STATION NO.	CENTROIDS MERID.	HOOP	N11 LB/IN	Q12 LB/IN	N22 LB/IN	Q13 LB/IN	Q23 LB/IN	M11 IN-LB/IN	M12 IN-LB/IN	M22 IN-LB/IN
1	62.862	62.811	0.124021E 04	0.0	0.163855E 04	-0.362819E 04	0.0	0.126612E 06	0.0	0.250910E 06
2	62.862	62.811	0.125189E 04	0.0	0.163914E 04	-0.300629E 04	0.0	0.762289E 05	0.0	0.236913E 06
3	62.862	62.811	0.126290E 04	0.0	0.163207E 04	-0.240632E 04	0.0	0.366978E 05	0.0	0.223955E 06
4	62.862	62.811	0.127325E 04	0.0	0.163539E 04	-0.182652E 04	0.0	0.736369E 04	0.0	0.212269E 06
5	62.862	62.811	0.128295E 04	0.0	0.163115E 04	-0.126535E 04	0.0	-0.123520E 05	0.0	0.202044E 06
6	62.862	62.811	0.129201E 04	0.0	0.162541E 04	-0.721415E 03	0.0	-0.229642E 05	0.0	0.193441E 06
7	62.862	62.811	0.130045E 04	0.0	0.161821E 04	-0.193453E 03	0.0	-0.249314E 05	0.0	0.186585E 06
8	62.862	62.811	0.130826E 04	0.0	0.160957E 04	0.319680E 03	0.0	-0.186653E 05	0.0	0.181583E 06
9	62.862	62.811	0.131547E 04	0.0	0.159956E 04	0.818996E 03	0.0	-0.453569E 04	0.0	0.178522E 06
10	62.862	62.811	0.132209E 04	0.0	0.158820E 04	0.130542E 04	0.0	0.171221E 05	0.0	0.177468E 06
11	62.862	62.811	0.132812E 04	0.0	0.157549E 04	0.178029E 04	0.0	0.460396E 05	0.0	0.178482E 06

RESULTANT STRESSES-PSI   BODY 8

STATION NO.	LAYER NO.	STRESS S11 INSIDE	STRESS S11 OUTSIDE	STRESS S12 INSIDE	STRESS S12 OUTSIDE	STRESS S22 INSIDE	STRESS S22 OUTSIDE
1	1	0.24416E 01	0.22035E 01	0.0	0.0	0.60108E 02	0.54197E 02
	2	-0.73659E 02	-0.73481E 02	0.0	0.0	0.15811E-04	0.15773E-04
	3	-0.25338E-05	-0.25241E-05	0.0	0.0	0.45741E 03	0.45564E 03
	4	-0.73193E 02	-0.72691E 02	0.0	0.0	0.15712E-04	0.15603E-04
	5	0.21749E 01	0.18357E 01	0.0	0.0	0.53486E 02	0.45064E 02
	6	-0.61216E 02	-0.60709E 02	0.0	0.0	0.13146E-04	0.13037E-04
	7	-0.20934E-05	-0.20738E-05	0.0	0.0	0.37809E 03	0.37456E 03

TABLE 4 SUMMARY OF LIMITING INTERNAL UNIFORM PRESSURE CAPACITY OF

D.C. COOK CONTAINMENT

INTERNAL PRESSURE CAPACITY (ELASTIC ANALYSIS)
(See Subsection 4.0 for Plastic Analysis)

CRITICAL FAILURE MODE	SPECIFIED MINIMUM PROPERTIES	LOWEST MEASURED SAMPLE PROPERTY	MEAN SAMPLE PROPERTY
1. Bending Shearing Concrete Base Mat	f_c = 3500 psi; f_c = 59.16 Limiting internal pressure = 45.8 psi	f_c = 4100 psi; f_c = 64.03 Limiting internal pressure = 49.6 psi	f_c = 4950 psi; f_c = 70.36 Limiting internal pressure = 54.5 psi
2. Membrane Hoop Tension in Concrete Cylinder	f_y = 40,000 psi Limiting internal pressure = 50.2 psi	f_y = 44,300 psi Limiting internal pressure = 61.2 psi	f_y = 49,800 psi Limiting internal pressure = 67.1 psi
3. Bending Capacity of Equipment Hatch	f_y = 38,000 psi Limiting internal pressure = 32.3 psi	f_y = 50,300 psi Limiting internal pressure = 42.6	f_y = 53,200 psi Limiting internal pressure 45.1
4. Bending Capacity of Personnel Hatch	f_y = 38.000 psi	f_y = 50,300 psi	f_y = 53,200 psi
(a) Closure Plate	Limiting internal pressure = 33.6 psi	Limiting internal pressure = 44.4 psi	Limiting internal pressure = 47.0 psi
(b) Door	Limiting internal pressure = 32.3 psi	Limiting internal pressure = 42.6 psi	Limiting internal pressure = 45.1 psi

Note: Internal Pressure Capacity wherever noted as "Psi" means "Psig"

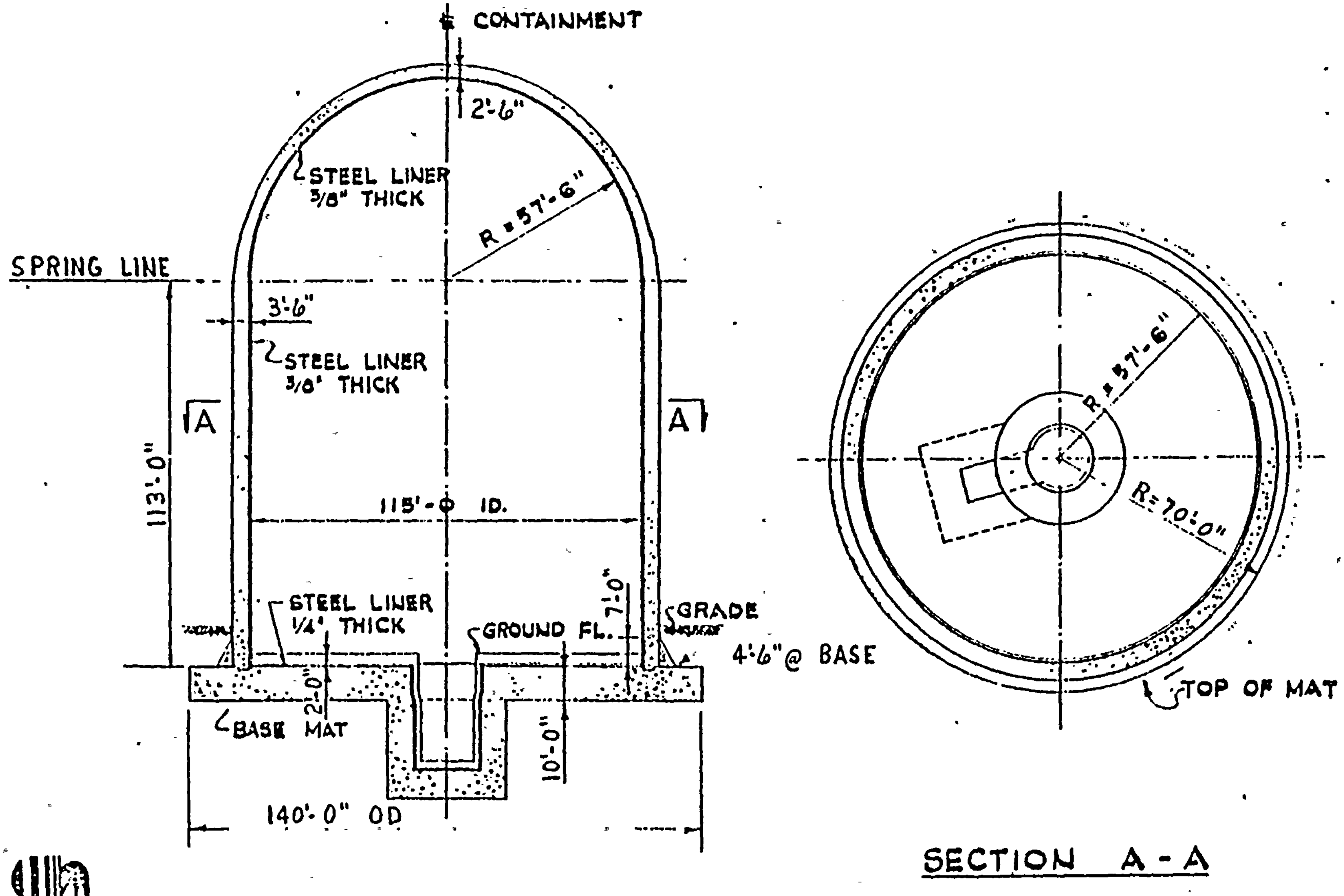


Figure 1 D.C. Cook Containment Dimensions and General Arrangment

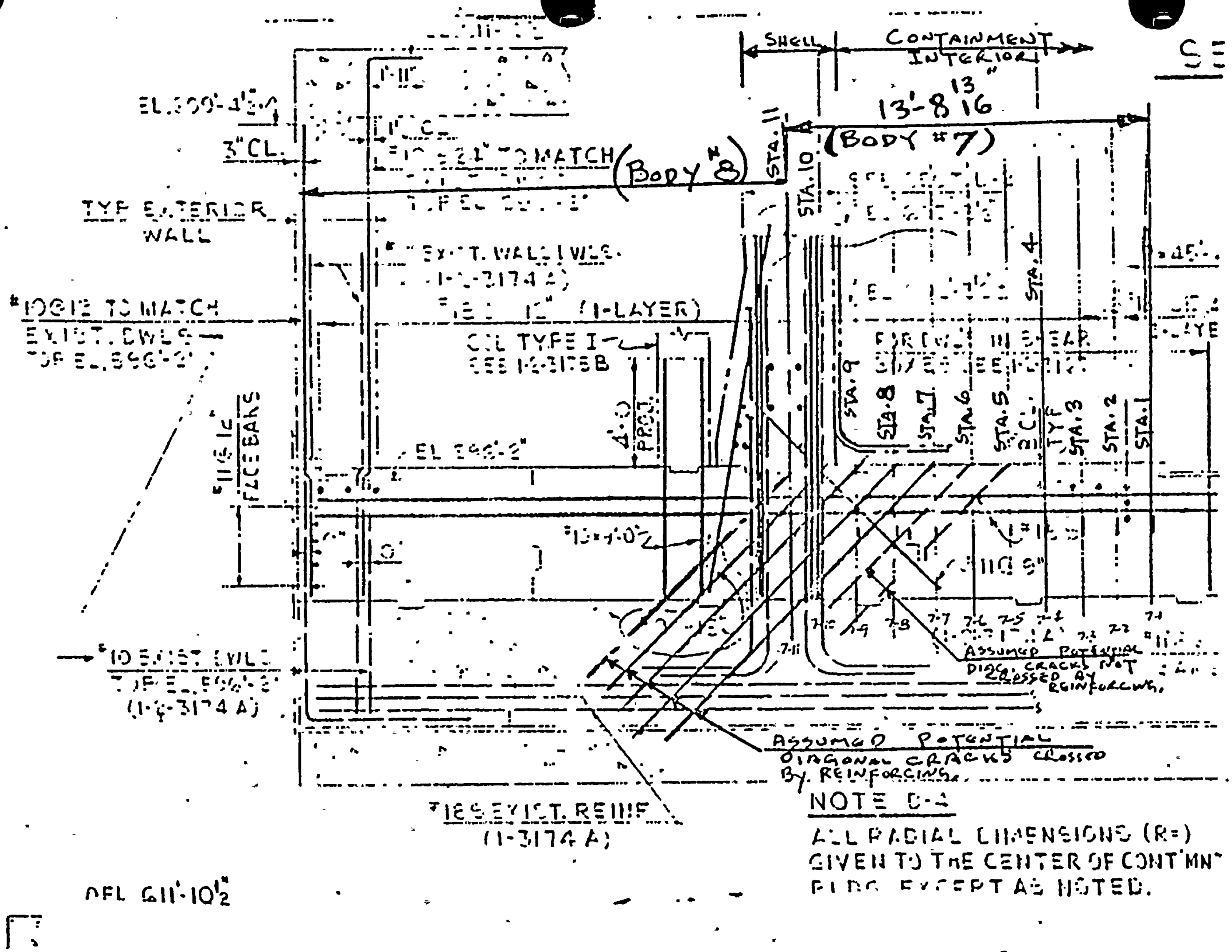


Figure 2 Shear Failure Planes and General Arrangement of Reinforcement in the Containment Base Mat

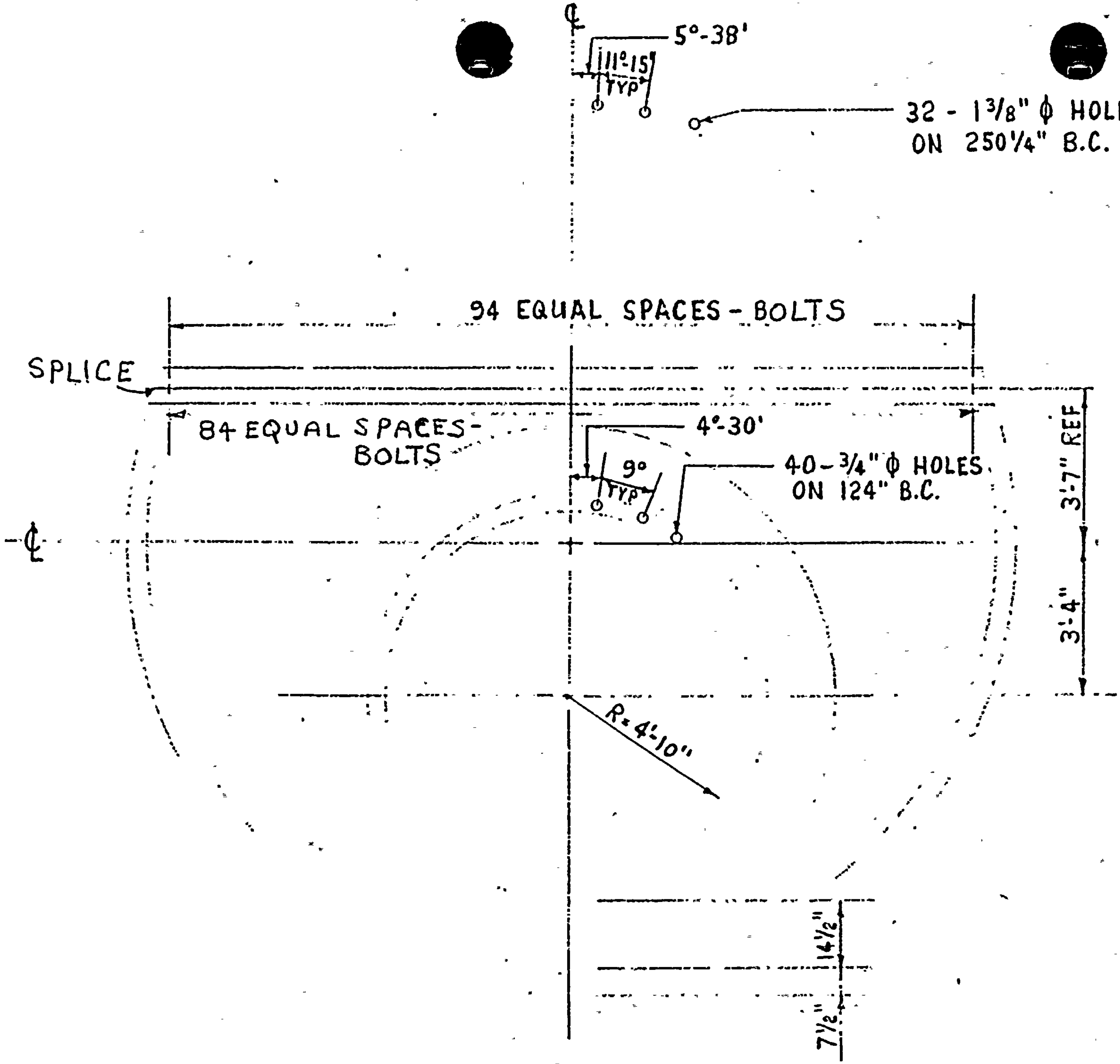


Figure 3 General Arrangment of the Equipment Hatch Closure Plate

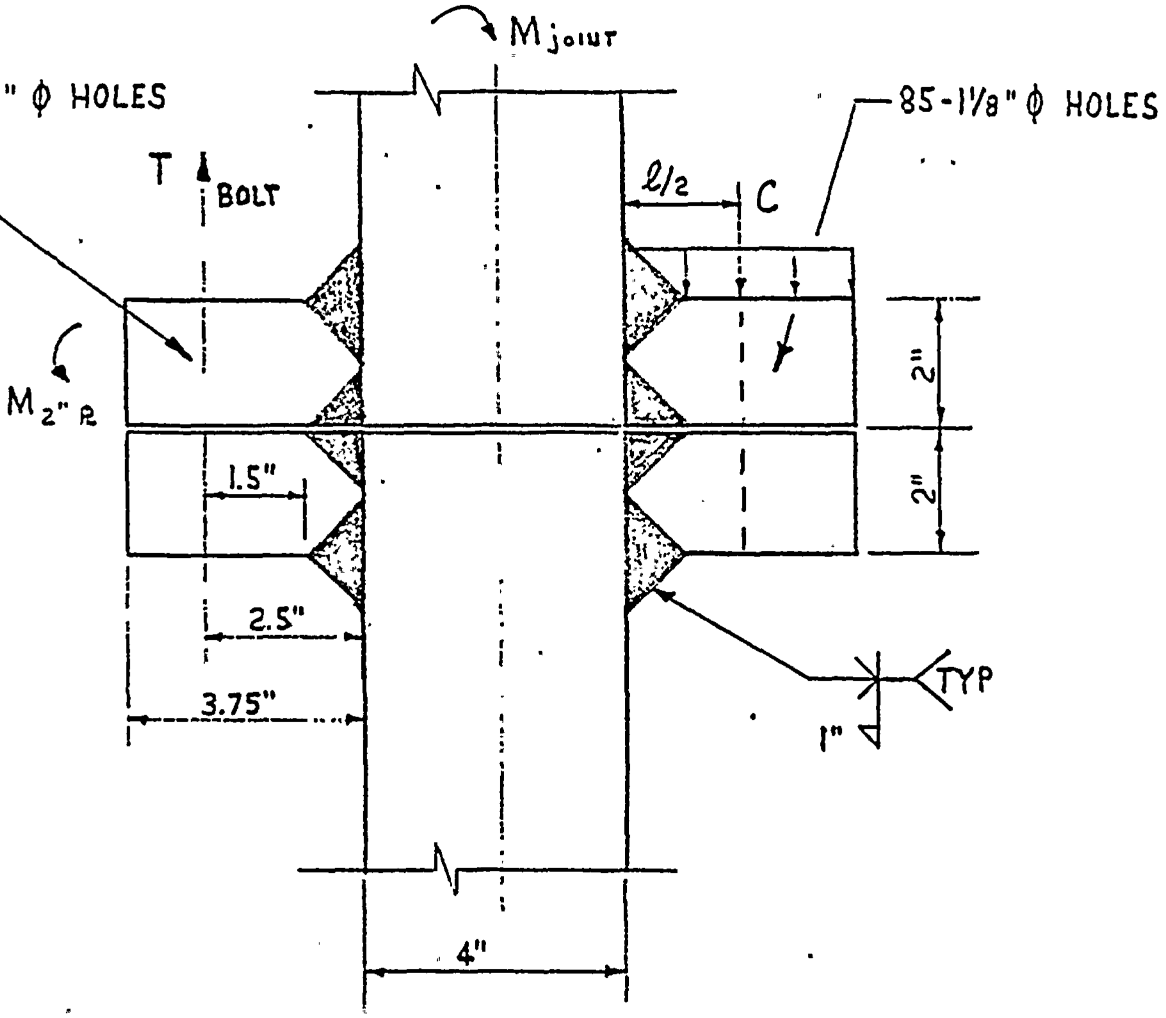


Figure 4 General Arrangment of the Equipment Hatch Closure Plate Splice

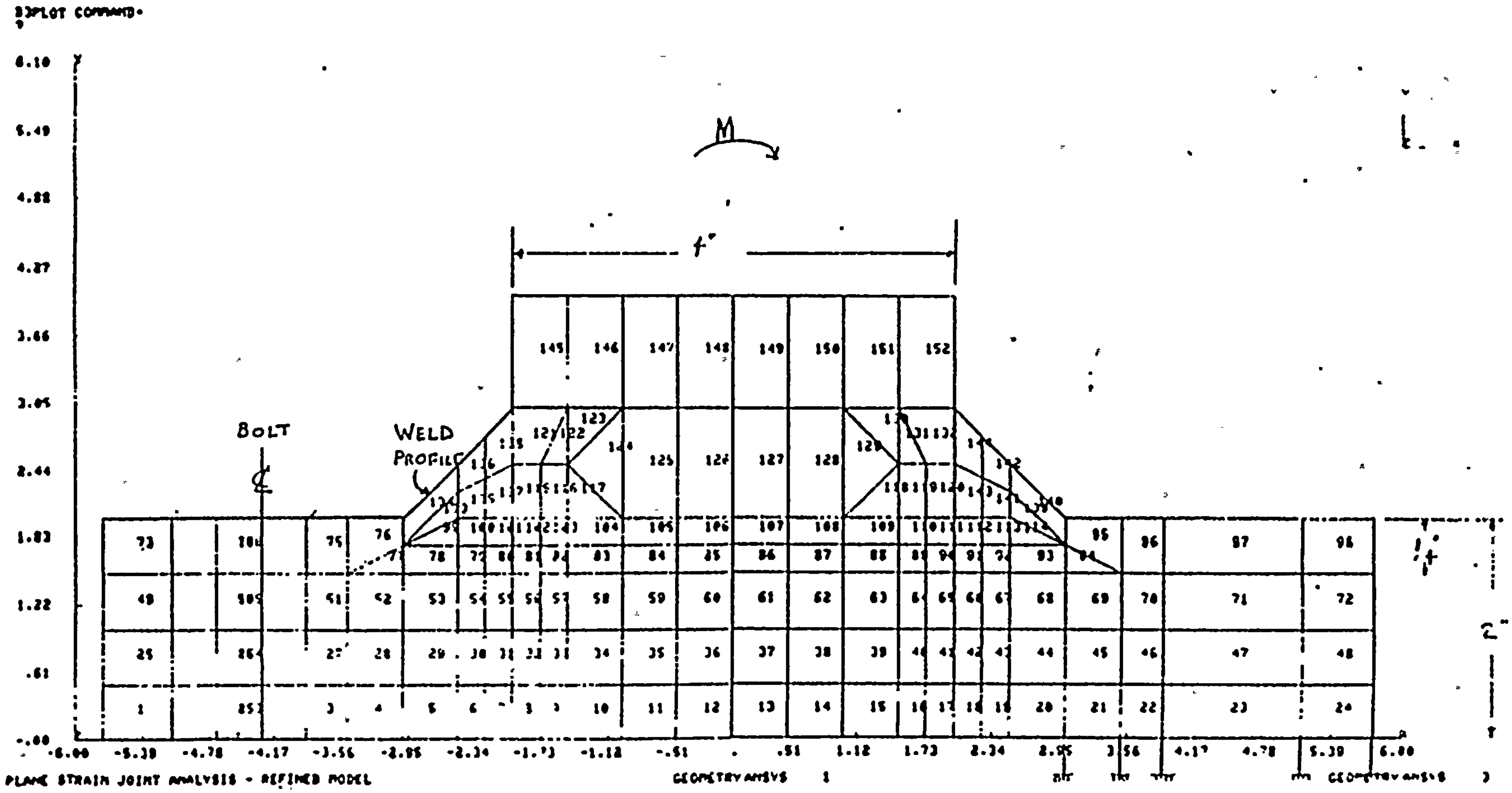


Figure 5 Finite Element Model of Equipment Hatch Closure Plate Splice

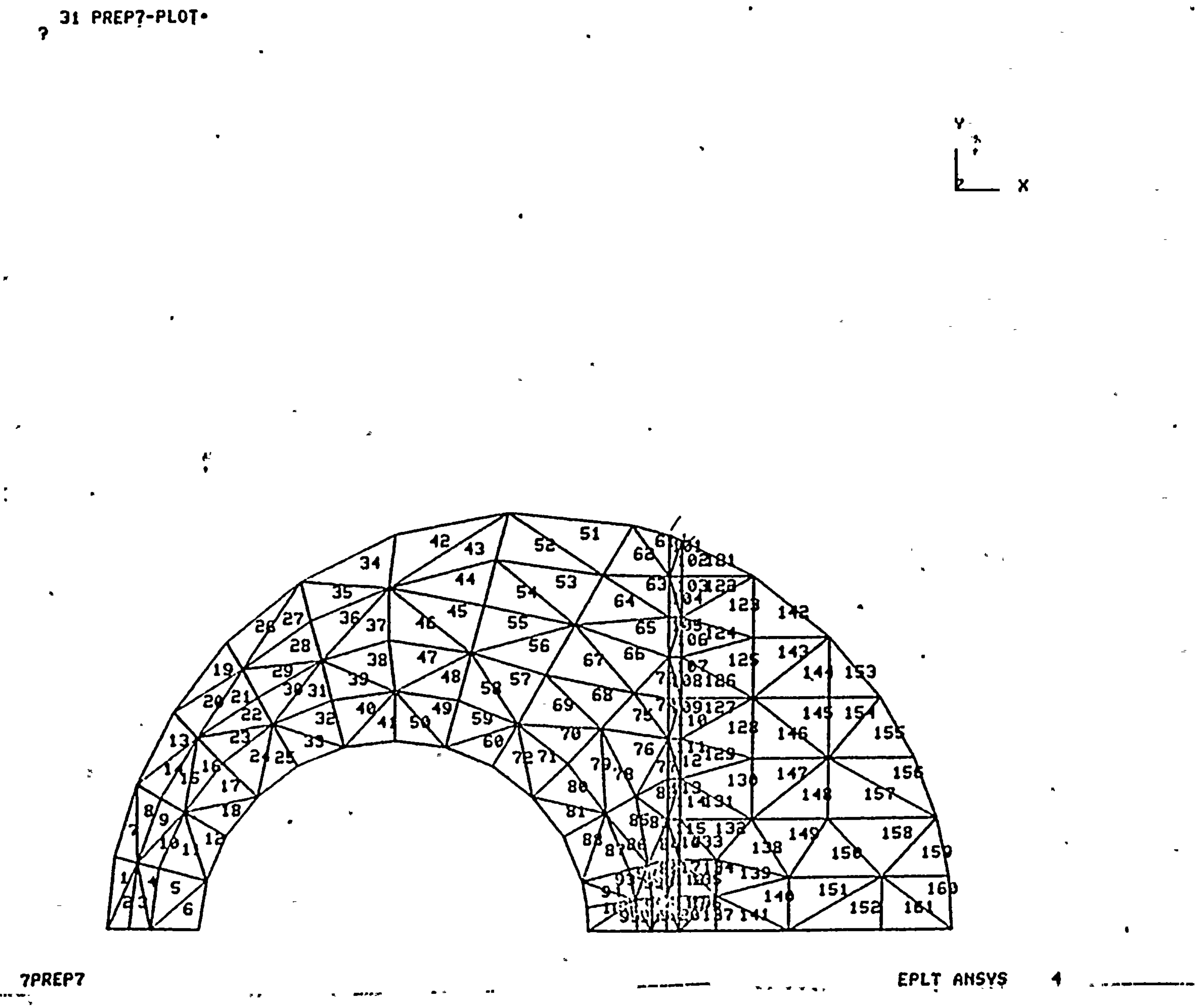


Figure 6 Finite Element Model of the Equipment Hatch Closure Plate

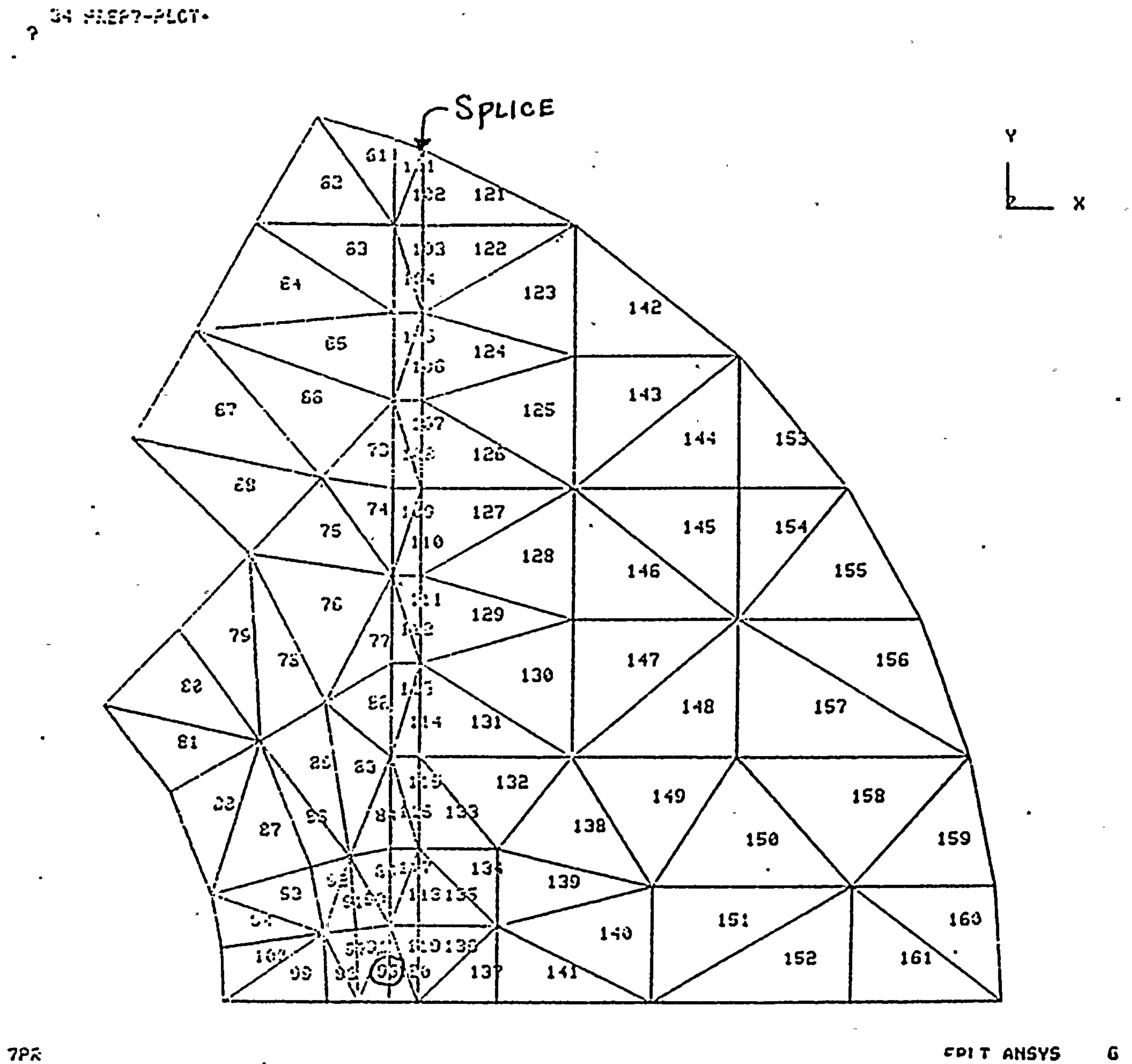


Figure 7 Detailed Finite Element Model of the Equipment Hatch Closure Plate

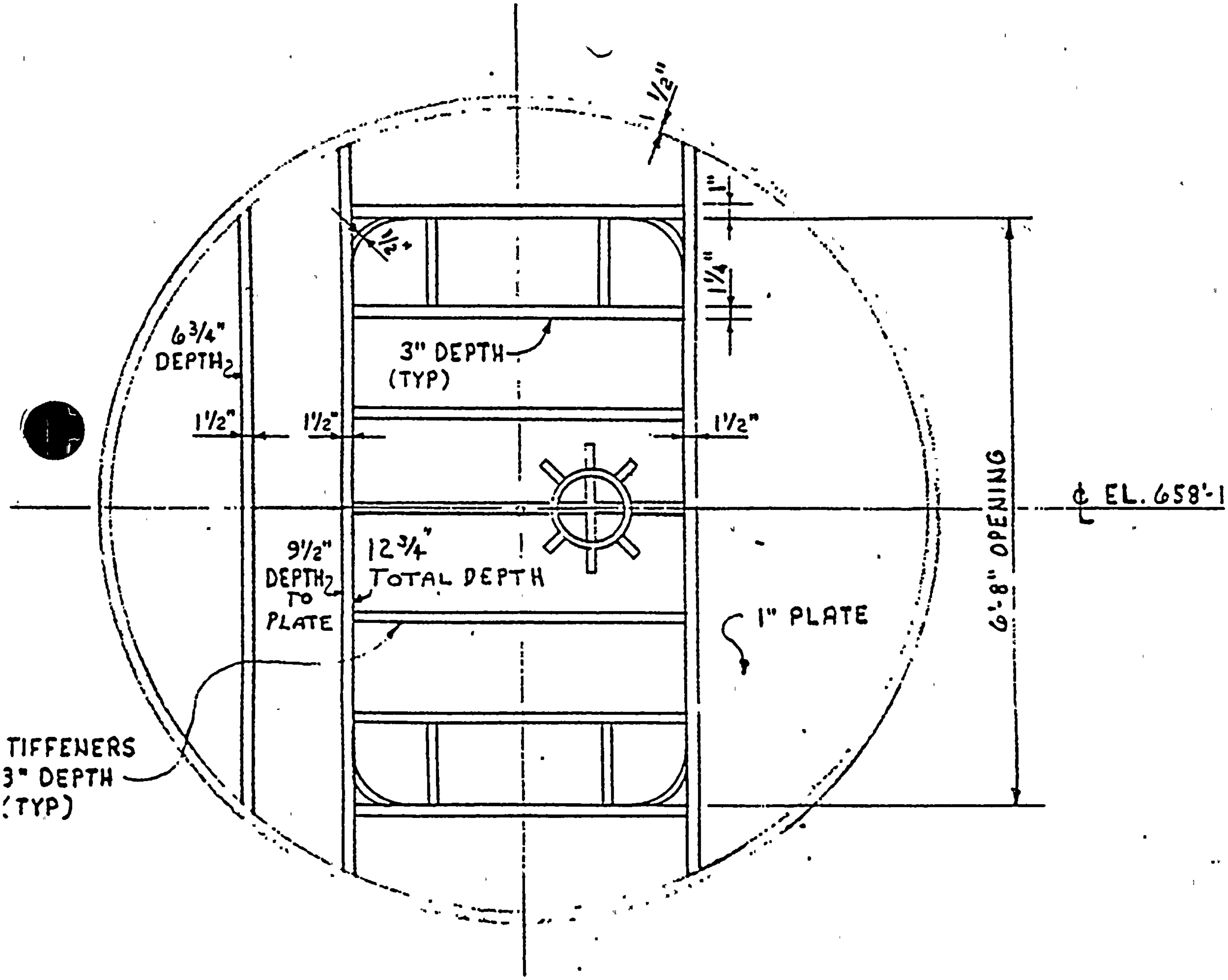


Figure 8 General Arrangement of the Personnel Hatch Closure Plate

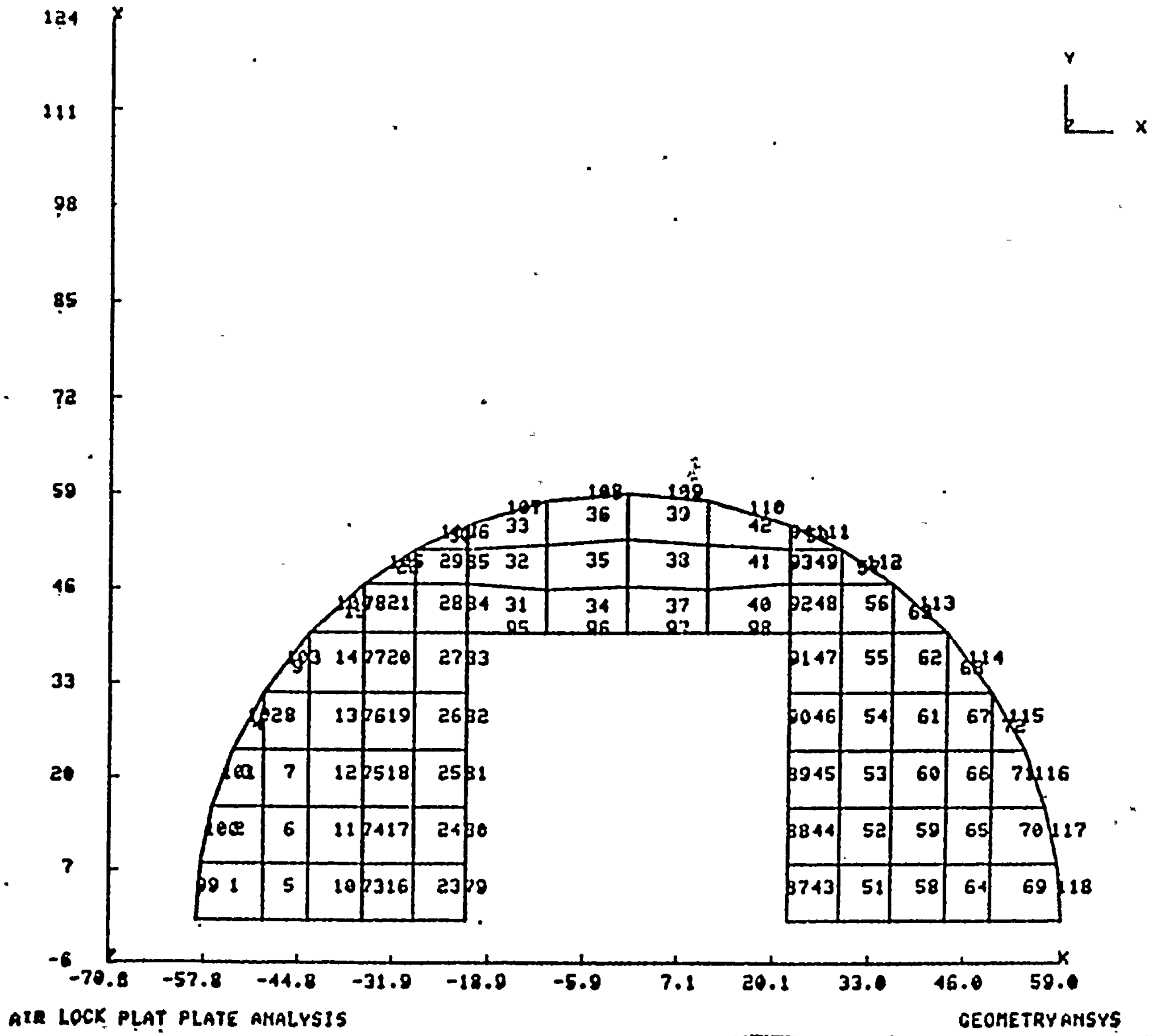


Figure 9 Finite Element Model of the Personnel Hatch Closure Plate

SECTION 2

Phase II of the D.C. Cook Internal Pressure Containment Analysis - Probabilistic Analysis

In this effort the variability of the "as-built" material parameters on the best estimate capacity of the containment to carry static uniform internal pressure is being evaluated. Four potential limiting failure modes have been identified by deterministic analysis. Two of the modes involve potential failure by plate bending of the equipment and personnel hatch closure plates. The other two potentially limiting failure modes are by membrane tension failure of the main steel hoop reinforcement at the base of the containment shell and shear (diagonal tension) failure of the concrete base met. The ACI-359 Code equation governing diagonal tension failure is based on test results hence it is also being evaluated in a probabilistic manner.

Results of this statistical analysis will be probability density function of containment resistance defined for the two different containment "as-built" material properties and in the case of shear in the base mat the statistical nature of the code defined failure equation. This evaluation should be completed by May 15, 1981.

SECTION 3

Phase III of the D.C. Cook Internal Pressure Containment Analysis - Localize Dynamic Loads

In this evaluation dynamic analytical models of the containment structure assuming localize dynamic pressure loading input are being prepared. The containment areas where the dynamic models are being developed include the equipment and personnel hatch closure plates, the shell portion of the containment shell adjacent to the base mat and the base mat adjacent to the cylinder shell juncture.

The development of the dynamic models should be complete by May 30, 1981. Then using the internal pressure time history forcing functions, a dynamic analysis will be done to determine the forces and moments at the critical sections of the containment.

DONALD C. COOK NUCLEAR PLANT UNIT NOS. 1 AND 2

ATTACHMENT NO. 2 TO AEP:NRC:00500A

SECOND QUARTERLY REPORT ON HYDROGEN MITIGATION AND CONTROL

2.0 Distributed Ignition System

2.1 Introduction

Indiana & Michigan Electric Company (I&MECo.) has decided to install a Distributed Ignition System (DIS) in Unit Nos. 1 and 2 of the Donald C. Cook Nuclear Plant. The DIS utilizes thermal resistance heating elements (glow plugs) located throughout the containment building. Operation of the DIS will be accomplished by means of manual control switches located in the main control room.

2.2 Distributed Ignition System Design

The DIS is a two-train system employing sixty eight (68) igniter assemblies located throughout the containment building. Each train of thirty four (34) igniter assemblies is further divided into two groups; one group of sixteen (16) assemblies in the general lower volume area and a second group of eighteen (18) assemblies in the general upper volume area - including the ice condenser upper plenum volume.

Each igniter assembly consists of a General Motors type 7G AC glow plug and a Dongan Electric control power transformer (model 52-20-435) mounted in a sealed box housing as shown in Figure 2. The igniter box is a water tight enclosure meeting NEMA-4 specifications. A copper plate is employed as a heat shield to minimize temperature rise inside the igniter box and a drip shield is utilized to minimize direct water impingement on the thermal element. The transformer is seismically mounted to the igniter box using unistrut. The entire igniter assembly is seismically mounted so as to prevent any possible interferences with safety-related equipment during/after a design basis seismic event.

The normal and emergency power sources for each train of igniters meets Electrical Class 1E specifications and the electrical train separation criteria commensurate with a Class 1E system are maintained in the DIS design. The DIS will be a manual system controllable from the main control room. Two control switches per train will be located on auxiliary relay panels A7 and A8 in the main control room. The control switches are of the two-position type, 'off' and 'on', and red and green indicating lights are provided above each switch. Control room annunciation will be provided to indicate loss of power and failure to operate due to hypothetical control circuit equipment malfunctions.

2.3 Igniter Assembly

The igniter assembly is a 16" x 12" x 8" enclosure meeting NEMA-4 specifications. The igniter is protected from direct water impingement by a 1/8" steel plate (10" x 18" galvanized steel) drip shield welded to the top of the enclosure. The igniter is mounted to the enclosure through a 6" x 4" x 1/4" copper plate to reduce the temperature rise inside the enclosure during periods of combustion. All electrical connections inside the igniter assembly, its associated condulet box, and the two splice boxes per train utilized in the DIS are protected with heat shrink tubing to enhance system performance in an adverse environment. In addition, all DIS cables inside containment are routed in conduit and hence are protected from the environment associated with hydrogen combustion. Access to the interior of the igniter assembly is through a hinged cover plate secured with screws. A bead of silicone rubber will be placed around all bolt holes in the igniter assembly. Details of the igniter assembly and its condulet box are given in Figure Nos. 1 and 2.

2.4 Igniter Assembly Locations

Igniter assemblies are distributed throughout the containment to promote combustion of lean hydrogen/air/steam mixtures. The DIS will minimize the potential for hydrogen accumulation and preclude detonations in the unlikely event of a degraded core cooling event similar in nature to the TMI-2 accident involving substantive hydrogen generation. The containment air recirculation/hydrogen skimmer system, in conjunction with upper and lower volume containment sprays, provides sufficient mixing so as to prevent the stratification or pocketing of hydrogen in the various compartments of the containment building.

Approximate igniter assembly locations are listed in Table 2-1. A general view of the containment structure is provided in Figure 3 and approximate igniter locations shown in Figure Nos. 4, 5 and 6. The locations given are for D. C. Cook Unit No. 2 and are typical for Unit No. 1. Minor variations in igniter locations may be required in Unit No. 1 in consideration of physical interferences with existing equipment. A schematic representation of the DIS electrical network inside containment is provided in Figure Nos. 7 and 8.

One of the questions raised by members of the NRC staff during our meeting of March 18, 1981 dealt with the need, or lack thereof, to install igniter assemblies in the instrument room. The results of our reviews performed to date indicate that except for potential in-leakage there is no communication between the instrument room and either the general lower volume or the pipe tunnel (annulus region) with the exception of the flow path through the hydrogen skimmer ductwork.

The above notwithstanding, it should be noted that any leakage into the instrument room would, in all probability, be significantly less than the hydrogen skimmer flow (100 CFM per train) out of the room, thus preventing the accumulation of hydrogen to combustible levels. It should also be noted, that the effects of hydrogen combustion on 'required' equipment located in the instrument room, pressurizer pressure and pressurizer level transmitters, is, for all intents and purposes, bounded by the calculations contained in Attachment No. 4 of this submittal.

TABLE 2-1

IGNITER ASSEMBLY LOCATIONS*

TRAIN 'A'			TRAIN 'B'		
No.	Compartment/Area	Elevation	No.	Compartment/Area	Elevation
A-1	Ice Cond. Upper Plenum	- 708'	B-1	Ice Cond. Upper Plenum	- 709'
A-2	Ice Cond. Upper Plunum	- 709'	B-2	Ice Cond. Upper Plenum	- 709'
A-3	Ice Cond. Upper Plenum	- 709'	B-3	Ice Cond. Upper Plenum	- 709'
A-4	Ice Cond. Upper Plenum	- 709'	B-4	Ice Cond. Upper Plenum	- 709'
A-5	Ice Cond. Upper Plenum	- 709'	B-5	Ice Cond. Upper Plenum	- 709'
A-6	Ice Cond. Upper Plenum	- 710'	B-6	Ice Cond. Upper Plenum	- 709'
A-7	Ice Cond. Upper Plenum	- 709'	B-7	Ice Cond. Upper Plenum	- 709'
A-8	Inside #1 SG Enclosure	- 686'	B-8	Inside #1 SG Enclosure	- 686'
A-9	Inside #2 SG Enclosure	- 686'	B-9	Inside #2 SG Enclosure	- 686'
A-10	Inside #3 SG Enclosure	- 686'	B-10	Inside #3 SG Enclosure	- 686'
A-11	Inside #4 SG Enclosure	- 686'	B-11	Inside #4 SG Enclosure	- 685'
A-12	Inside PZR Enclosure	- 686'	B-12	Inside PZR Enclosure	- 682'
[illegible]	Outside #1 SG Enclosure	- 659'	B-13	Outside #1 SG Enclosure	- 662'
A-14	Outside #2 SG Enclosure	- 662'	B-14	Outside #2 SG Enclosure	- 659'
A-15	Outside #3 SG Enclosure	- 662'	B-15	Outside #3 SG Enclosure	- 659'
A-16	Outside #4 SG Enclosure	- 662'	B-16	Outside #4 SG Enclosure	- 659'
A-17	Outside PZR Enclosure	- 662'	B-17	Outside PZR Enclosure	- 659'
A-18	Primary Shield Wall	- 647'	B-18	Primary Shield Wall	- 642'
A-19	Primary Shield Wall	- 648'	B-19	Primary Shield Wall	- 637'
A-20	Primary Shield Wall	- 648'	B-20	Primary Shield Wall	- 636'
A-21	Primary Shield Wall	- 648'	B-21	Primary Shield Wall	- 636'
A-22	Primary Shield Wall	- 641'	B-22	Primary Shield Wall	- 637'
A-23	Primary Shield Wall	- 648'	B-23	Primary Shield Wall	- 645'
A-24	East Fan/Accumulator Room	- 631'	B-24	East Fan/Accumulator Room	- 630'
A-25	East Fan/Accumulator Room	- 629'	B-25	East Fan/Accumulator Room	- 629'
A-26	West Fan/Accumulator Room	- 629'	B-26	West Fan/Accumulator Room	- 623'
A-27	West Fan/Accumulator Room	- 634'	B-27	West Fan/Accumulator Room	- 634'
A-28	Vicinity of PRT	- 618'	B-28	Vicinity of PRT	- 618'
A-29	Upper Volume Dome Area	- 760'	B-29	Upper Volume Dome Area	- 760'
[illegible]	Upper Volume Dome Area	- 760'	B-30	Upper Volume Dome Area	- 760'

TRAIN 'A' No.	TRAIN 'A' Compartment/Area-Elevation	TRAIN 'B' No.	TRAIN 'B' Compartment/Area-Elevation
A-31	Upper Volume Dome Area - 760'	B-31	Upper Volume Dome Area - 760'
A-32	Upper Volume Dome Area - 748'	B-32	Upper Volume Dome Area - 748'
A-33	Upper Volume Dome Area - 748'	B-33	Upper Volume Dome Area - 748'
A-34	Upper Volume Dome Area - 748'	B-34	Upper Volume Dome Area - 748'

KEY:
- SG - Steam Generator
- PZR - Pressurizer
- PRT - Pressurizer Relief Tank

e locations given are for Donald C. Cook Unit No. 2 and are typical for nit No. 1.

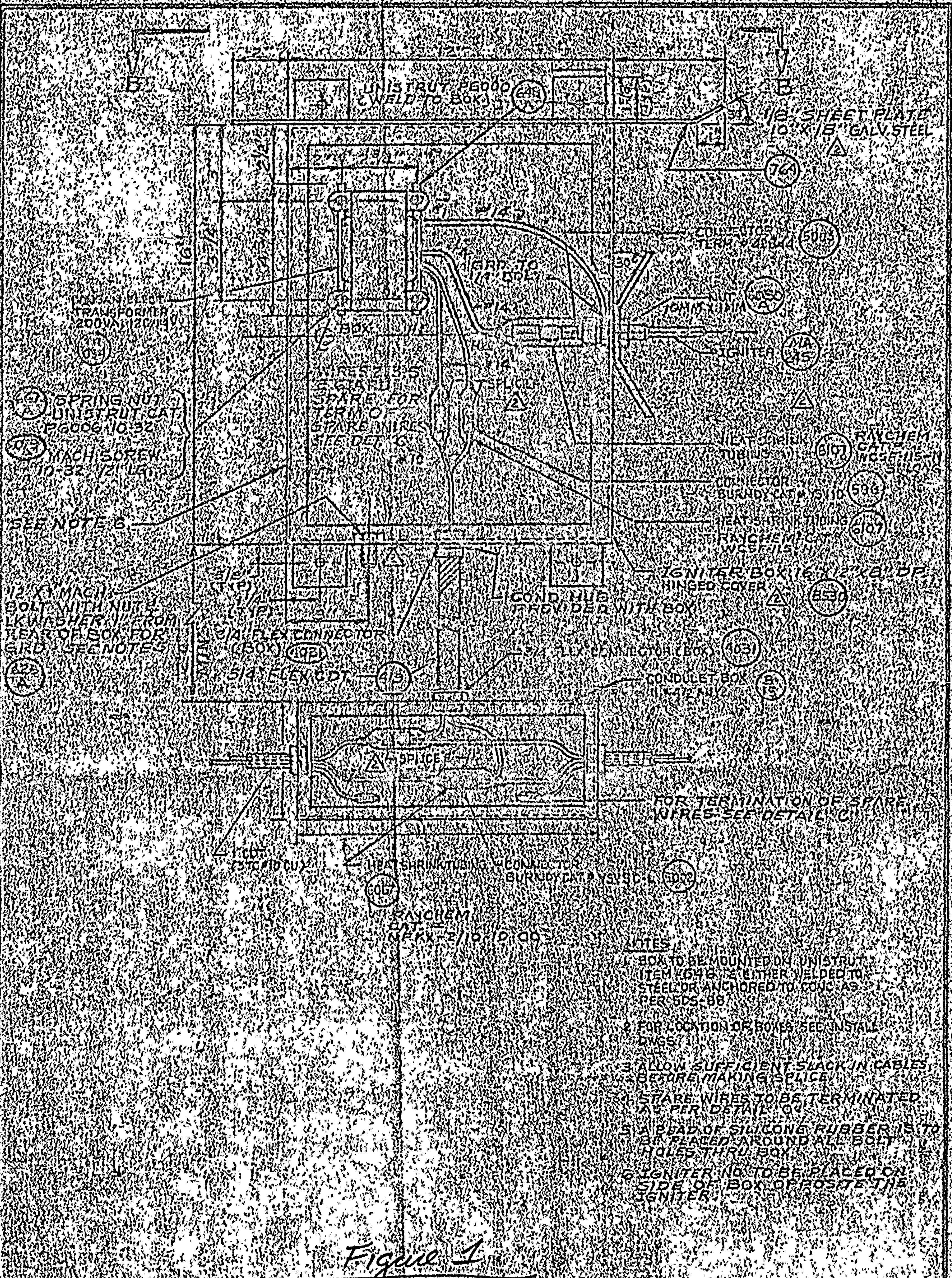


Figure 1

NUMBERS IN ◯ REFER TO B/M #1798

RFC-DC-12-2522

INDIANA & MICHIGAN ELECTRIC CO. — DONALD C. COOK NUCLEAR PLANT
REVISION #2 3/20/81 — REVISED AS INDICATED △
DIST. IGNITION SYSTEM — DETAILS OF IGNITER BOX & TERM. BOX
APP'D BY — DR. BY JR — CH. BY GME — DATE 3-25-81
AMERICAN ELECTRIC POWER SERVICE CORP. 2 BROADWAY, N.Y.
EDS-12-309-2 SH. 1 OF 4

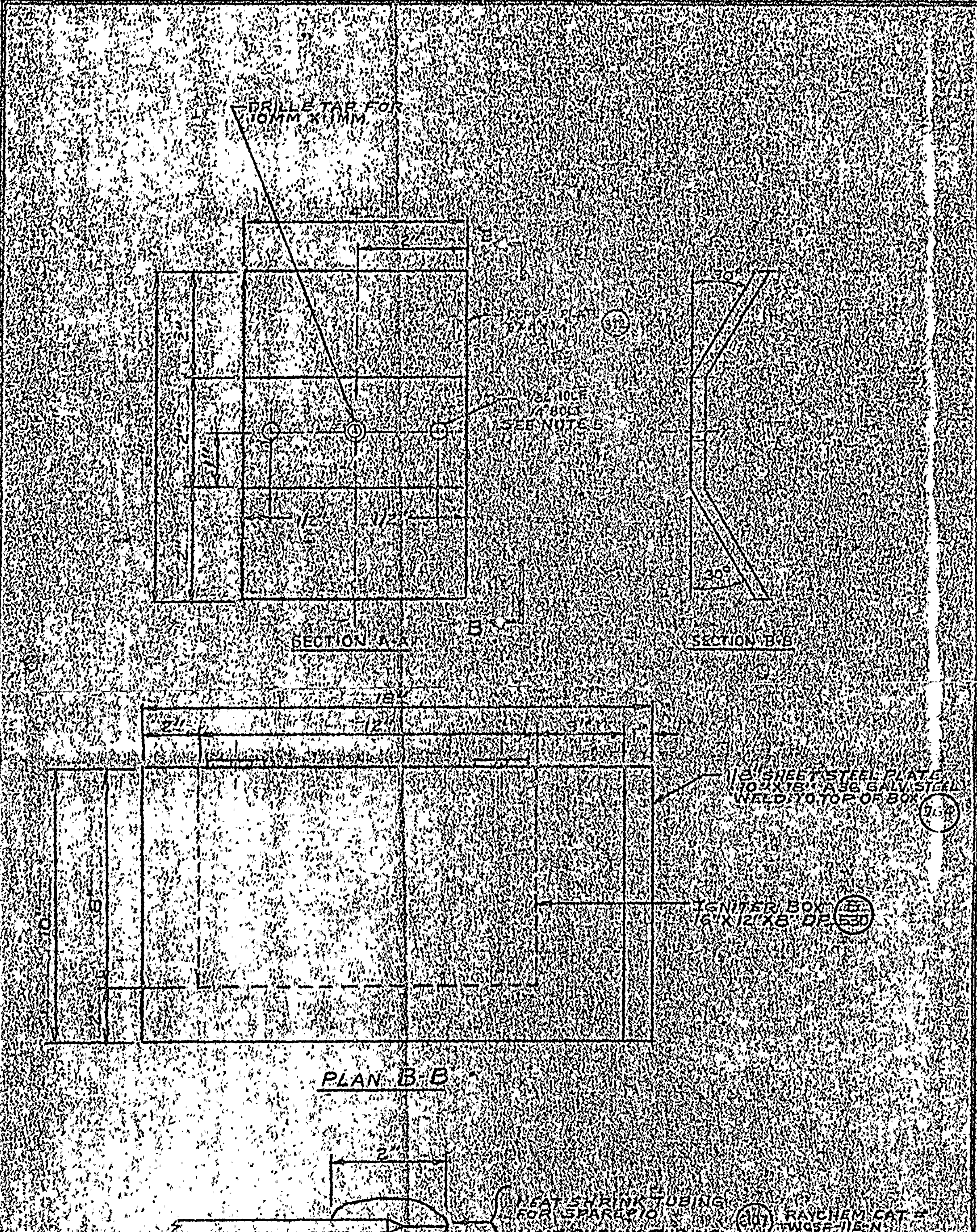


Figure 2

RFC-DC-12-2522

NUMBERS IN ◯ REFER TO B/M #1788

INDIANA & MICHIGAN ELECTRIC CO. DONALD C. COOK NUCLEAR PLANT	REVISION #2 4/20/81	DIST. IGNITION SYSTEM DETAILS OF IGNITER BOX & TERM. BOX
APP'D BY	DR. BY JP	CH. BY GMB	DATE 3-26-81
AMERICAN ELECTRIC POWER SERVICE CORP. 2 BROADWAY, N.Y.	EDS-12-539-2	SH. 2 OF 4

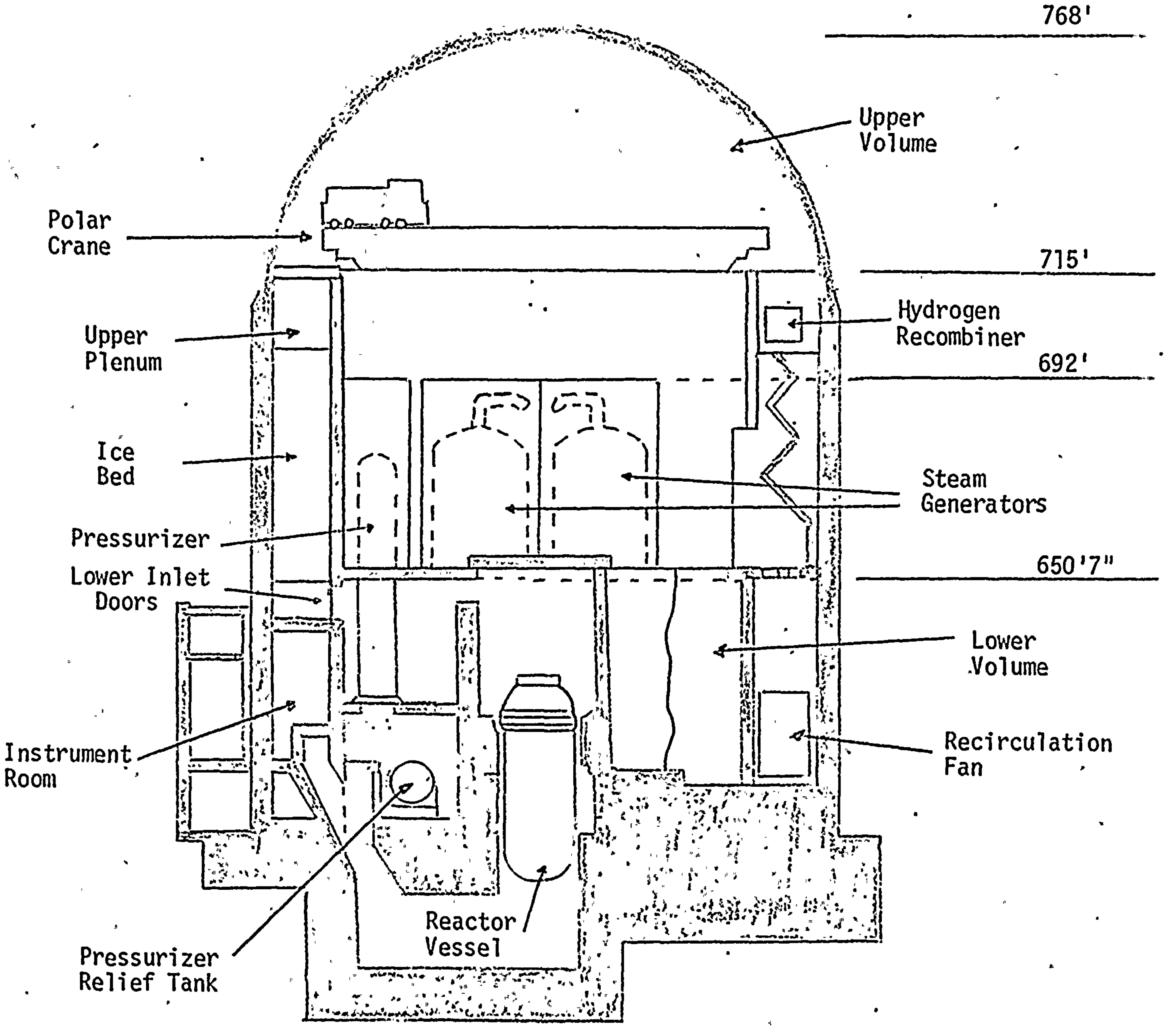
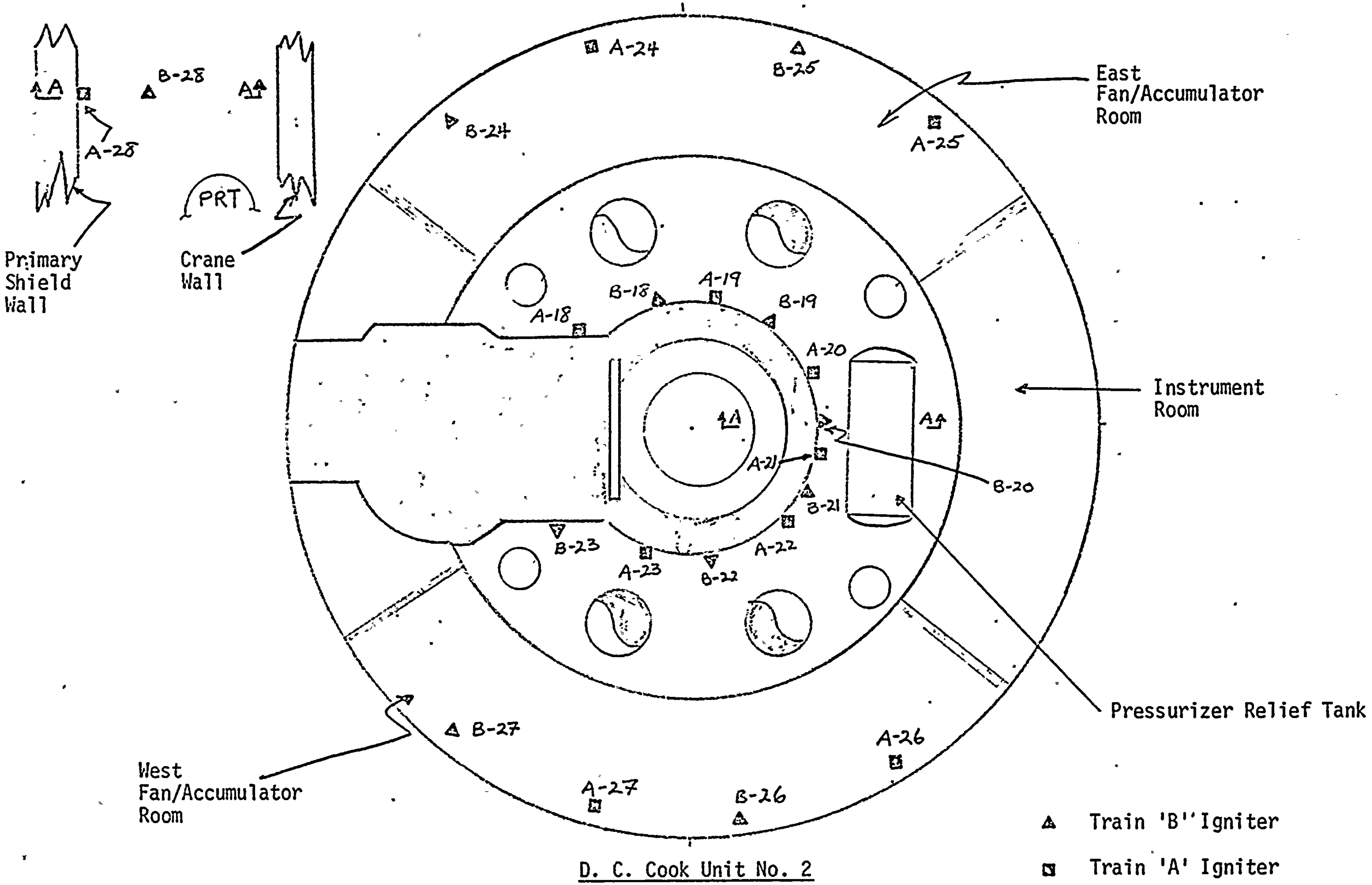

768'
Upper Volume
Polar Crane
715'
Hydrogen Recombiner
Upper Plenum
692'
Ice Bed
Steam Generators
Pressurizer
650'7"
Lower Inlet Doors
Lower Volume
Instrument Room
Recirculation Fan
Reactor Vessel
Pressurizer Relief Tank

FIGURE 3

FIGURE 4

Section 'A-A'

Elevation 618

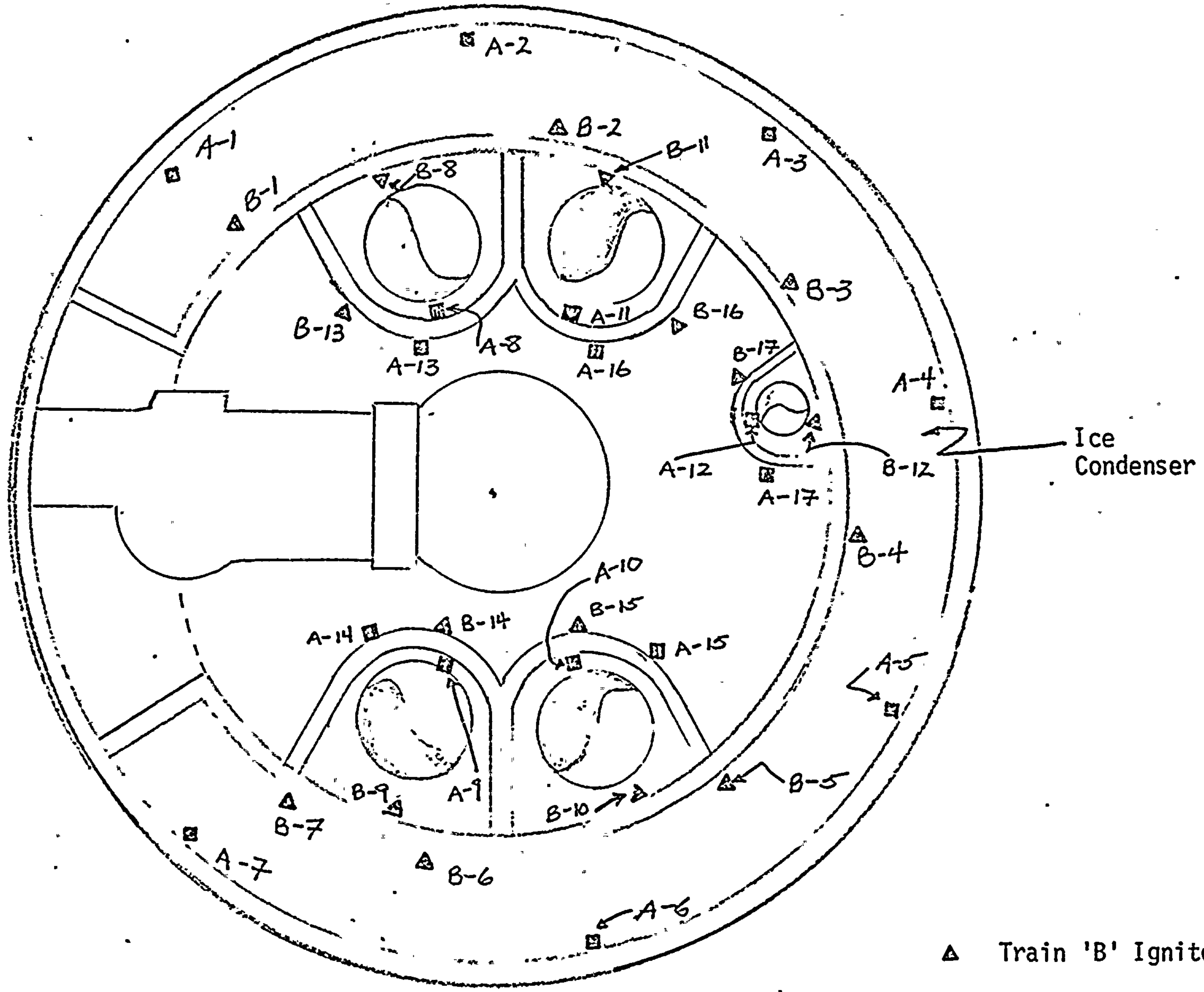


D. C. Cook Unit No. 2

Containment Plan Below

Elevation 652'7"

FIG[illegible]5



Δ Train 'B' Igniter

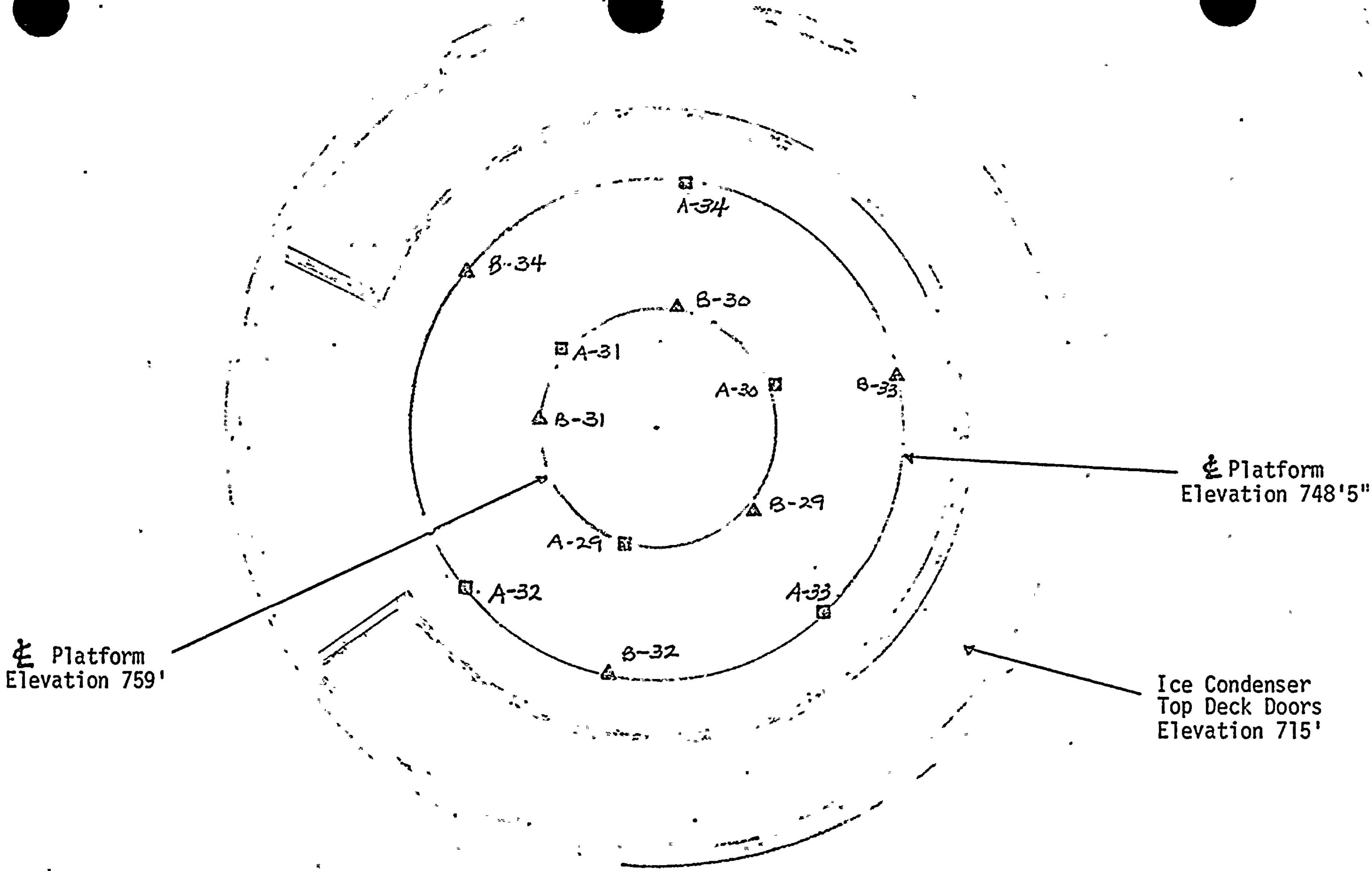
⊠ Train 'A' Igniter

D. C. Cook Unit No. 2

Containment Plan Above

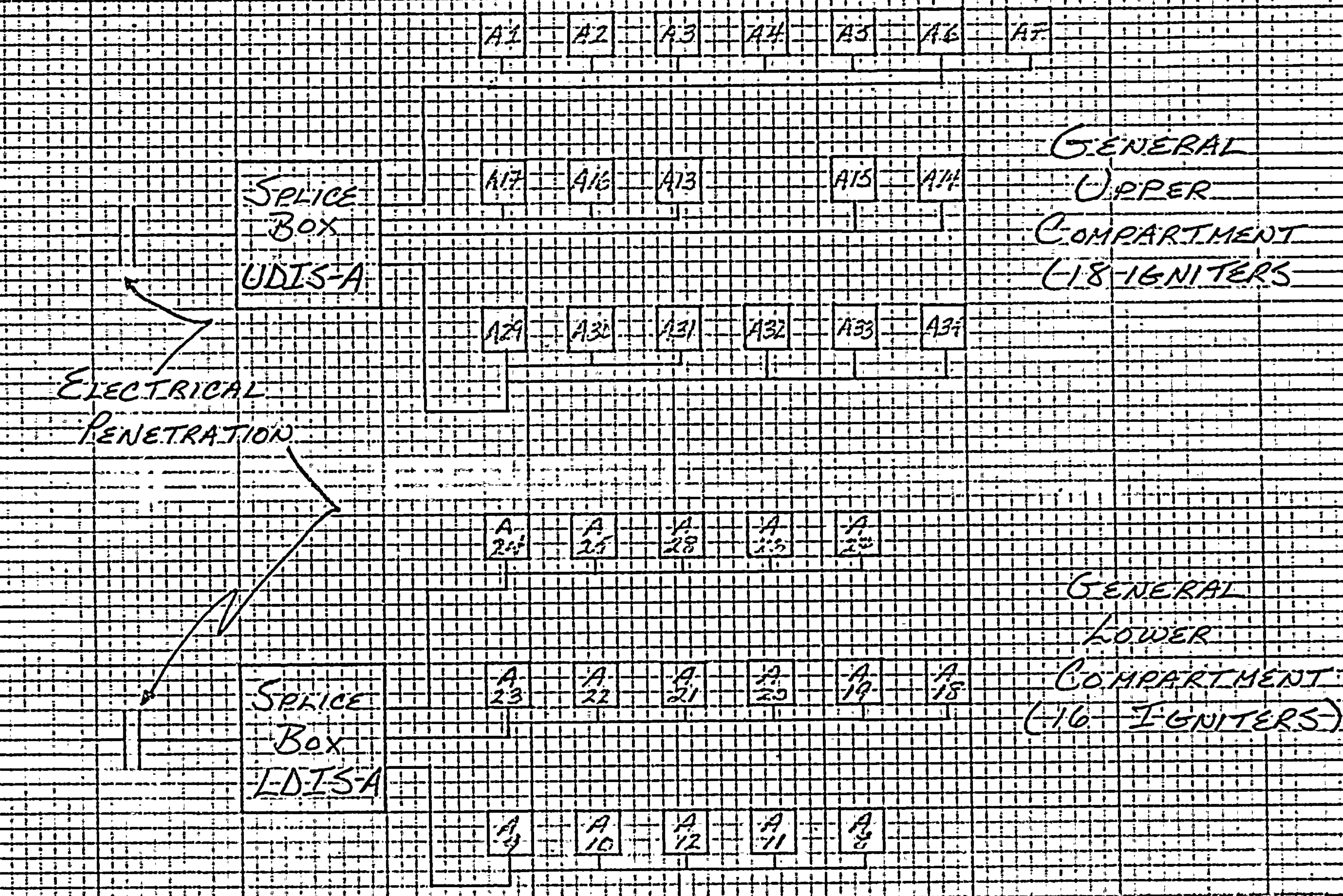
Elevation 652'7"

FIGURE 6



D. C. Cook Unit No. 2
Containment Plan Above
Elevation 715'

CABLE FOR D.I[illegible] INSIDE CONTAINMENT*
TRAIN "A"

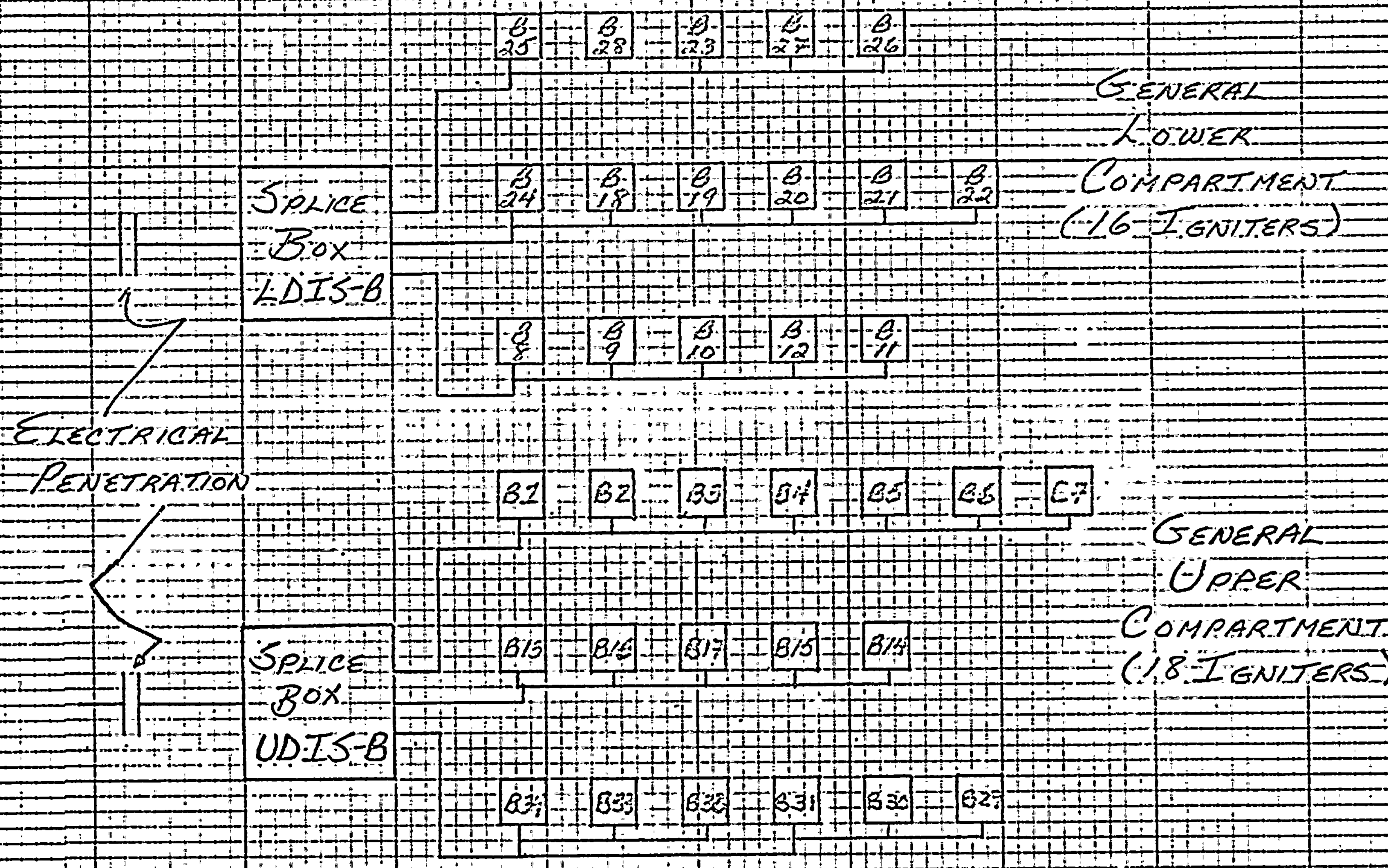


*SCHEMATIC SHOWN IS FOR D.C. COOK UNIT No. 2 BUT IS TYPICAL OF THE UNIT No. 1 CABLE SCHEME

FIGURE 7

CABLE FOR DIS INSIDE CONTAINMENT *

TRAIN 'B'



*SCHEMATIC SHOWN IS FOR D.C. COOK UNIT NO. 2 BUT IS TYPICAL OF THE UNIT NO. 1 CABLE SCHEME

FIGURE 8

09 april 81

DONALD C. COOK NUCLEAR PLANT UNIT NOS. 1 AND 2

ATTACHMENT NO. 3 TO AEP:NRC:00500A

SECOND QUARTERLY REPORT ON HYDROGEN MITIGATION AND CONTROL

3.0 Inadequate Core Cooling/Hydrogen Control Equipment

3.1 Introduction

There are two primary concerns associated with an inadequate core cooling (ICC) event similar to the TMI-2 accident involving the release of substantive amounts of hydrogen and subsequent combustion utilizing the Distributed Ignition System (DIS). These concerns involve, (1) the ability to achieve and maintain the reactor coolant system in a safe shutdown condition and (2) maintenance of containment integrity through adequate hydrogen control. The equipment located inside reactor containment required to perform the above functions is identified in this section. The survivability of the equipment discussed herein during periods of hydrogen combustion is addressed in Attachment No. 4 of this submittal. The containment response to hydrogen combustion is contained in Offshore Power System (OPS) Report No. 36A05 previously transmitted to the Commission as Attachment No. 2 to our first quarterly report on hydrogen issues (AEP:NRC:00500 dated 12 January 1981). The analyses performed by OPS utilizing the CLASIX computer code clearly indicate that the peak pressure resulting from hydrogen combustion is well below the ultimate strength of the Cook Plant containments.

3.2 Equipment List

Table 3-1 lists the active components inside containment required to function during and (or) after periods of hydrogen combustion. The location of these components and their susceptibility to hydrogen combustion effects are addressed below.

(1) Steam Generator Narrow-Range Level Monitors

Three safety-grade differential pressure transmitters (ΔP) are employed on each steam generator to monitor narrow-range steam generator water level. The ΔP transmitters, manufactured by ITT Barton, are fully qualified for post-accident use inside containment (LOCA/MSLB qualification). These transmitters are located in the general lower volume, with two transmitters per steam generator mounted nearly eleven feet below the maximum containment flood level of 614' elevation.

Clasix run JVAC4 (see Attachment No. 2 to our AEP:NRC:00500 submittal - OPS Report No. 36A05) represents the minimum time to combustion for the S_2D cases run to date and hence represents the case for which the minimum containment water level would exist at the time of initial combustion. Figure No. 32 of the OPS report shows the initial combustion to occur in the lower compartment approximately 4,600 seconds into the S_2D event sequence. Assuming that water is transferred to the containment from the refueling water storage tank (RWST) solely via two containment spray pumps, it is clear that the minimum usable RWST volume specified in the Plant Technical Specifications (350,000 gallons) would have effectively been delivered to the containment pump long before the onset of combustion. In addition, the OPS report shows that approximately 22.4% of the initial ice inventory has been melted during the LOTIC portion of the analysis; up to a time of 3480 seconds. Assuming the initial ice inventory to be the Technical Specification minimum value of 2.37 million pounds;

it is thus shown that in excess of 530,000 pounds of ice has been melted prior to combustion. This ice melt is equivalent to approximately 80,000 gallons of additional water in the containment. Combining the ice melt with the RWST water yields a total containment water inventory of 430,000 gallons, well in excess of the water inventory which would result in submergence of two level transmitters per steam generator. Thus, it is clear that the steam generator narrow-range level monitoring function would not be susceptible to the effects of a hydrogen combustion environment.

(2) Pressurizer Pressure and Pressurizer Level Monitors

The pressure transmitters and the ΔP transmitters utilized for the pressurizer (PZR) pressure and level monitoring functions, respectively are located in the instrument room. These transmitters, manufactured by ITT Barton, are fully qualified for post-accident use inside containment (LOCA/MSLB qualification). As stated in Section 2.4 of Attachment No. 2 of this submittal, our reviews performed to date indicate that there is no communication between the instrument room and either lower compartment or the pipe tunnel (annulus region) other than the hydrogen skimmer ductwork. In addition, the CLASIX analyses do not predict combustion in the dead-ended volume, of which the instrument room is a part. Hence, the information available at this time indicates that the PZR pressure and level transmitters would not be exposed to a hydrogen combustion environment in the unlikely event of a degraded core cooling event involving the generation of substantive amounts of hydrogen.

(3) RCS Wide-Range Pressure Transmitters

The RCS wide-range pressure transmitters are located in the lower compartment nearly eleven feet below maximum containment floodup level. The transmitters, manufactured by ITT Barton, are fully qualified for post-accident use inside containment (LOCA/MSLB qualification). For reasons set forth in Item (1) above, these transmitters would be submerged prior to initiation of combustion and hence would not be exposed to a hydrogen combustion environment in the unlikely event of a degraded core cooling event involving the generation of substantive amounts of hydrogen.

(4) Core Exit Thermocouples

The effects of a hydrogen combustion environment on the core exit thermocouple cable is addressed in Attachment No. 4 to this submittal.

(5) RCS Loop RTDs

The hot leg and cold leg RTDs, located in the lower compartment, are fully qualified for post-accident use (LOCA/MSLB qualification). The cable associated with the RTDs is addressed in Attachment No. 4 to this submittal.

(6) Air Recirculation/Hydrogen Skimmer Fans

The air recirculation/hydrogen skimmer fans are located in the upper compartment and the fan motors are fully qualified for post-accident use (LOCA/MSLB qualification).

(7). Distributed Ignition System (DIS) Components

The DIS components inside containment are the igniter assemblies; splice boxes and condulet boxes, and the ancillary cable. All DIS cable inside containment is routed in conduit and thus is protected

from a hydrogen burn. All electrical connections inside the igniter assembly, its associated condulet box, and the two splice boxes per train utilized in the DIS are protected with heat shrink tubing to enhance system performance in an adverse environment. The igniter assembly itself is a sealed enclosure meeting NEMA-4 specifications.

Table 3-1

Donald C. Cook Nuclear Plant Unit Nos. 1 and 2

Inadequate Core Cooling/Hydrogen Control Equipment*

(1) Narrow-range Steam Generator Level Monitors

(2) Pressurizer Level Monitors

(3) Pressurizer Pressure Monitors

(4) RCS Wide-Range Pressure Monitors

(5) Core Exit Thermocouples

(6) RCS Loops RTDs

(7) Air Recirculation/Hydrogen Skimmer Fans

(8) Distributed Ignition System Components

*inside reactor containment

DONALD C. COOK NUCLEAR PLANT UNIT NOS. 1 AND 2

ATTACHMENT NO. 4 TO AEP:NRC:00500A

SECOND QUARTERLY REPORT ON HYDROGEN MITIGATION AND CONTROL

4.0 Equipment Survivability

This attachment to the quarterly report addresses the issue of the survivability of equipment exposed to a hydrogen combustion atmosphere inside containment. Heat-transfer models have been developed to determine the effects of hydrogen burns on critical components (see Table 3-1 in Attachment 3). The models are presented in this attachment followed by a calculation made for a representative piece of equipment. Particular attention has been devoted to a number of individual pieces of equipment, each of which is discussed separately.

4.1 General Analysis

In order to characterize the environment to which a piece of critical equipment is subjected during and subsequent to a hydrogen burn, two heat-transfer models have been developed. The first heat-transfer model is a time dependent heat-transfer analysis which calculates the lower compartment environment as a result of a hydrogen burn. This model takes into account the presence of structural heat sinks and sprays in the lower compartment and assumes that during a hydrogen burn energy is removed by the ice condenser. The burn itself is modelled by an energy input rate to the compartment.

At the onset of the combustion, the lower compartment is assumed to be isothermal; energy is then introduced into the compartment for a duration of 20 seconds, comparable to the time of a hydrogen burn in the containment. As a result of the burn, the temperature of the compartment atmosphere begins to rise rapidly; concurrently, heat is being transferred to the structural heat sinks and removed by the ice condenser and by the lower compartment sprays. Heat transfer to the containment sinks is characterized by both convection and

radiation. Conservative assumptions have been made in the calculation with regard to parameters such as gas emissivity and configuration factors. After 20 seconds, the atmosphere temperature is observed to decrease exponentially, whereas the containment wall temperature continues to rise over the next twenty seconds (see Figure 4-1) until the time when the atmosphere temperature falls below the wall temperature. The maximum atmosphere temperature calculated does not exceed 500°F.

Sensitivity studies of various parameters used in the analysis are presented in Figures 4-2 and 4-3. Figure 4-2 depicts the results obtained when the heat transfer coefficient,"h", from atmosphere to wall is varied; as "h" vanishes, the peak atmosphere temperature approaches the CLASIX results. It can also be noted that, in general, the peak temperature is fairly insensitive to small variations in the values of the heat transfer coefficient chosen. Perturbations in the spray flow rate also reveal small increases ($\sim$15%) in the peak temperature, see Figure 4-3. These analyses clearly show that if containment structural heat sinks are considered, the containment environment is not expected to experience temperatures in excess of 500°F. The equipment included in the critical list of components (Table 3-1) is qualified for LOCA and MSLB events, which includes exposure to 340°F for a period in excess of one hour. Comparison between the MSLB conditions and the data presented in Figure 4-1 indicates that equipment, which is subjected to a hydrogen burn of the magnitude predicted by CLASIX, will experience environmental conditions no more severe than those of a MSLB event.

The second heat-transfer model attempts to describe and define the environmental conditions for equipment which is located in the path traversed by the hydrogen flame. A Barton pressure transmitter has been selected as a representative piece of equipment to be investigated.

Prior to hydrogen ignition, the transmitter casing and its internals are assumed to be in thermal equilibrium with the containment environment. At the onset of a hydrogen burn, it is postulated that ignition occurs in the vicinity of the transmitter and the casing is subjected to a very high hydrogen flame temperature ($\sim$2000^{o}F) initially as the flame front moves away from the component. The temperature to which the transmitter surface is exposed will then decrease gradually and will eventually approach long-time results calculated by the previous heat-transfer model. This temperature profile will provide the outside boundary condition needed to evaluate the temperature rise on the inside surface of the transmitter. The one-dimension time-dependent conduction heat transfer equation is evaluated assuming that the inside surface is an adiabatic boundary. This model treats the transmitter casing as a one-dimensional slab. The time dependent temperature profile to be used on the outside surface is imposed as a convective boundary condition.

Two different temperature profiles, which reflect the environment temperature to which the transmitter is exposed, have been employed in this calculation. The first profile represents a hydrogen flame temperature of 2000^{o}F for a duration of one second at the onset prior to a linear decay to 1000^{o}F in the next second; temperature continues to decrease to 300^{o}F from two to six seconds and eventually approaches 150^{o}F after 10 seconds (see Figure 4-4), curve A. This temperature profile is similar to the one used by TVA in its equipment survivability calculations. The other profile, see Figure 4-4, curve B, decays exponentially from 2000^{o}F to 150^{o}F over a period of 18 seconds and is similar to the one used in the Duke analysis. A computer code was used to analyze the temperature rise in a 1/4" carbon steel casing given the aforementioned boundary conditions. The heat transfer coefficient assumed in the code includes both convective and radiative transport.

The temperature transients at the inside surface calculated from the two temperature profiles are depicted in Figure 4-5. Curve (A) of Figure 4-5, which corresponds to the curve A of Figure 4-4, showed that the initial temperature rise is very abrupt during the first few seconds; later on the inside surface reaches a maximum temperature of 171°F at 10 seconds prior to a gradual decrease. The temperature response depicted by curve (B) of Figure 4-5 indicates that there is a more gradual rise over the initial 15 seconds and that the temperature reaches its maximum of 175°F at about 30 seconds before a slow decay begins.

Based on this analysis, one can assume that for a single hydrogen burn, the inside casing temperature will rise no more than 30°F. Additionally, if one assumes that there is a total of eight consecutive burns and that between each burn the inside casing surface temperature is held constant, the temperature profile will be a stepwise function similar to the one presented in Figure 4-6. Each temperature increase (30°F) can be interpreted as the heatup of the casing resulting from one hydrogen burn. Between each burn, the temperature at the inside casing is assumed to be constant which implies that no credit is given to the cooling of the component subsequent to any burn. In addition, the time interval between combustions is assumed to be substantially shorter than what is predicted by CLASIX; only 100 second intervals are used in this calculation. Based on the stepwise curve, a conservative linear heatup temperature profile at the inside surface of the casing is used, see Figure 4-6.

Utilizing this linear temperature response at the inside of the transmitter casing, a heat transfer analysis has been performed to evaluate the heatup rate of the air and the subcomponents inside the casing. Results

indicate that the heatup rate of the air inside is slightly below the temperature of the casing and that the heatup rate of the subcomponents is estimated to be approximately 50^{o}F over seven burns, or 7^{o}F per burn. It is important to bear in mind that conservative assumptions have been used in obtaining the above results.

The heat transfer analysis clearly indicates that for most equipment which is environmentally qualified for LOCA or MSLB events, elevated temperatures resulted from hydrogen burns of the magnitude and duration discussed do not appear to pose any threat to its ability to survive in a S_2D-type event.

4.2 Survivability of Particular Pieces of Equipment

This section of Attachment 4 discusses the survivability of particular pieces of equipment needed for the mitigation and control of a S_2D-type sequence. These pieces of equipment require either particular evaluations or, else, the analysis presented in Section 4.1 does not apply to them.

a) Cables

The burning of hydrogen inside containment by use of a Distributed Ignition System (DIS) results in very short duration exposure fires and may involve cables which are exposed in trays.

Inside the Cook containment buildings power and control cables are either installed in conduits or in cable trays.

Cables installed in conduits are not likely to burn as a result of exposure to short-duration exposure fires. These cables cannot propagate a fire even if they burn since the flame resulting from the combustion is entirely confined to the conduit and cannot cause failure of cables in adjacent enclosures.

In the case of the control cables where the current carried by the conductors is small relative to the thermal rating of the conductors, the cables are installed in trays with solid steel sides, bottoms and covers. Hence, it is not likely for a hydrogen burn inside containment to ignite any control cables installed in trays. However, upon exiting a tray, either mid-span through a hole in the tray cover or at the end of the tray span, a portion of the cable becomes exposed for a very short length until the cables either enter a conduit which facilitates entry into terminal devices or until the cables are connected to the device or containment penetration (below flood level).

All control cables inside containment needed for inadequate core cooling mitigation equipment are qualified for flame resistance in accordance with either IPCEA Standard S-19-81 or IEEE-383. Hence, for the exposed portions of the control cables and cables entirely contained in trays or conduits, it is extremely likely that the cables will survive hydrogen burns inside containment. Furthermore, the cable will be wet due to the actuation of containment sprays making the possibility of ignition from a short duration exposure to fire even more remote.

For the case of power cables, they are installed in conduits or in expanded metal trays without covers and are sized to accommodate the full load current of connected equipment without exceeding their continuous rated temperature. When installed in expanded metal cable trays, the cables are laid typically one layer deep with spaces between adjacent cables and secured to the bottom of the tray to maintain this spacing. The power cables for ICC equipment may be exposed to hydrogen burning inside containment but they are

qualified for flame resistance in accordance with IEEE-383 or S-19-81. Further, since the power cables are exposed (open trays) they will be wet due to the effect of containment sprays.

Testing results have been reported by L. J. Klamerus of Sandia on IEEE-383 cables [1]. Private communication with Mr. Klamerus [2] revealed that the cables used in the experiment were X-link polyethylene cables. They were selected for the test because they were believed to be most susceptible to exposure fire failure. Reported results indicate that the time to electrical short for these cables ranges from five to nine minutes. Review of ICC equipment power cables at Cook confirms the fact that they are either insulated by Hypalon or a synthetic compound made by Kerite. Both types of materials are believed to exhibit superior fire resisting capability than those tested by Sandia Laboratory.

Therefore, despite the fact that power cables at Cook might be exposed to a two to three minutes total duration of hydrogen burns experimental evidence support the contention that it is very likely that they will be able to survive hydrogen burns typical of those discussed for a S_2D-type event.

b) <u>Air Recirculation Fans</u>

There are two air recirculation fans at Cook and both of them are located in the upper compartment. These two centrifugal fans have a total capacity of 80,000 cfm and discharge the flow into the two fan/accumulator rooms. At the exit of each fan there is a backdrop damper which opens as a result of flow through the fan. The damper is gravity loaded and is expected to close if there is an overpressure in the fan/accumulator room. The CLASIX results predict burns in the upper compartment with pressure differentials

unaccounted for in the design of the system. Fan integrity is being evaluated both from the point of view of casing damage and overspeeding of the wheel and motor.

c) <u>Steam Inerting and Polyurethane Insulation Burn</u>

In a S_2D-type event, hydrogen release begins approximately 3800 seconds after the onset of a small break. Results obtained from the March code for Sequoyah indicate that during the initial 700 seconds, the steam concentration at the lower compartment reaches a maximum of 78% prior to decaying to 45%, see Figure 4-7. Subsequently, the steam concentration continues to decrease to approximately 25% at onset of the hydrogen release. Data reported by the U.S. Bureau of Mines [(3)] indicate that little change to the lower flammability limit of hydrogen is noted when steam concentration in the mixture is kept below 30%. Therefore, with a 25% steam concentration in the lower compartment, the effects of steam upon hydrogen combustion should be minimal. Moreover, lower compartment sprays at Cook would further serve to enhance condensation of steam and to promote rapid temperature reduction in the lower compartment. Thus, it is expected that the steam concentration in the Cook lower compartment will be substantially lower than what has been presented in Figure 4-7. Therefore, it is unlikely that Cook will experience steam inerting in a S_2D-like event except possibly during the initial 1000 seconds.

In addition, data presented by Lawrence Livermore Laboratory[(4)] in their igniter test program clearly show that steam concentrations up to 40% do not inhibit the ignition of hydrogen by the glow plugs nor the ability of the igniters to function as designed. In spite of the fact that there would be a higher steam concentration in the lower compartment, evidence indicates

that the glow plug igniters will perform their intended functions as required.

It is conceivable that at the upper plenum of ice condenser, a higher hydrogen concentration may be present as a result of steam stripping by the ice condenser. It has also been postulated that combustion may first occur at that location and that it may even burn in a continuous manner. However, it must be pointed out that the likelihood of the above scenario diminishes if the assumption on steam inerting at the lower compartment is considered unrealistic.

Given the complexity of this issue, the question of burning in the upper plenum of the ice condenser will continue to be investigated by AEP. Moreover, upcoming results from the modified version of CLASIX should be able to provide additional information on this subject. If hydrogen combustion is assumed to occur at the upper plenum for an extended period of time, it has been postulated that the integrity of the polyurethane insulation may be threatened by the presence of hot gases. This question is being addressed at AEP simultaneously with the upper plenum burn issue. The results of our evaluations will be transmitted to the NRC in the next quarterly report.

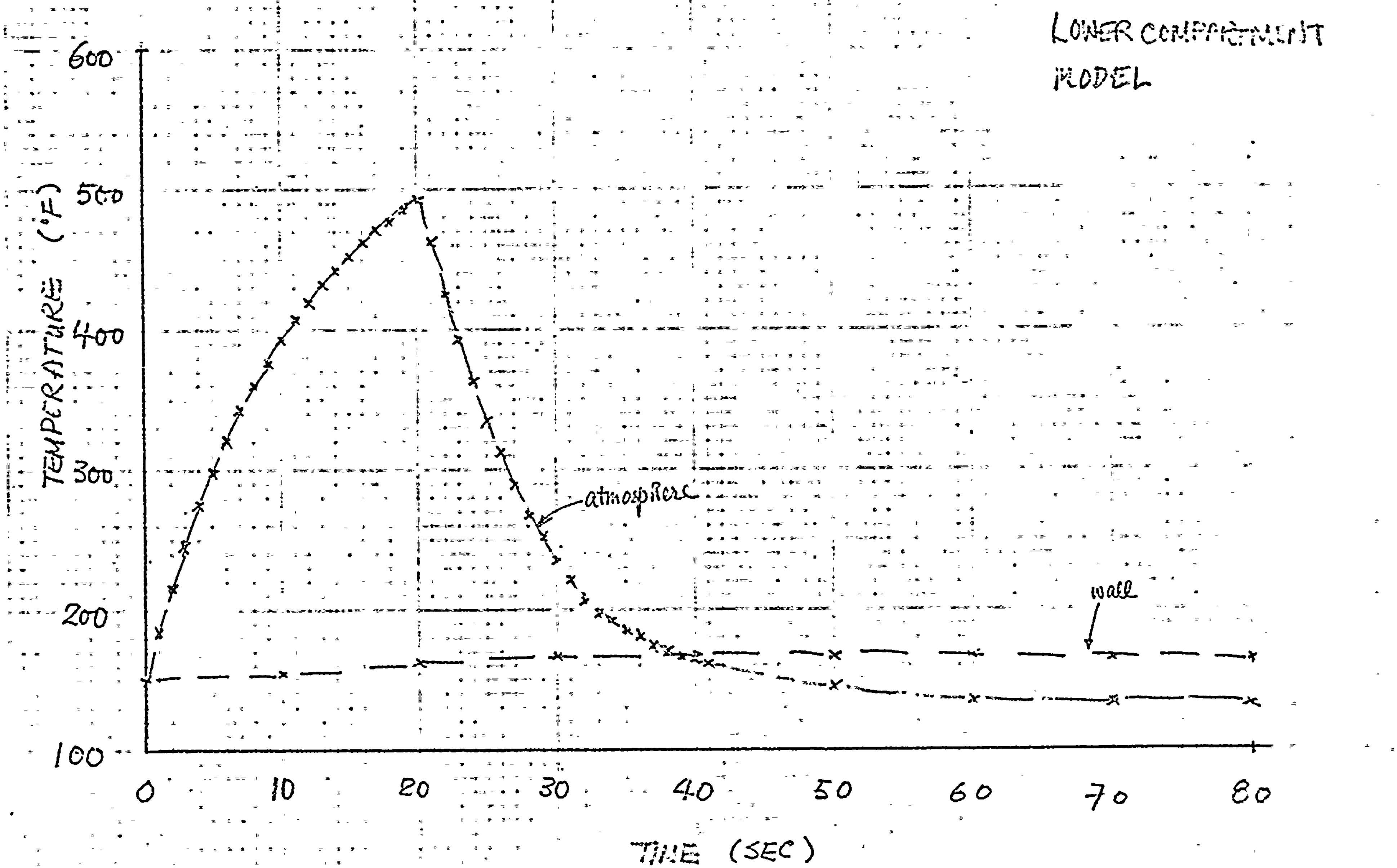


FIGURE 4-1 TEMPERATURE RESPONSES OF LOWER COMPARTMENT ATMOSPHERE AND WALL

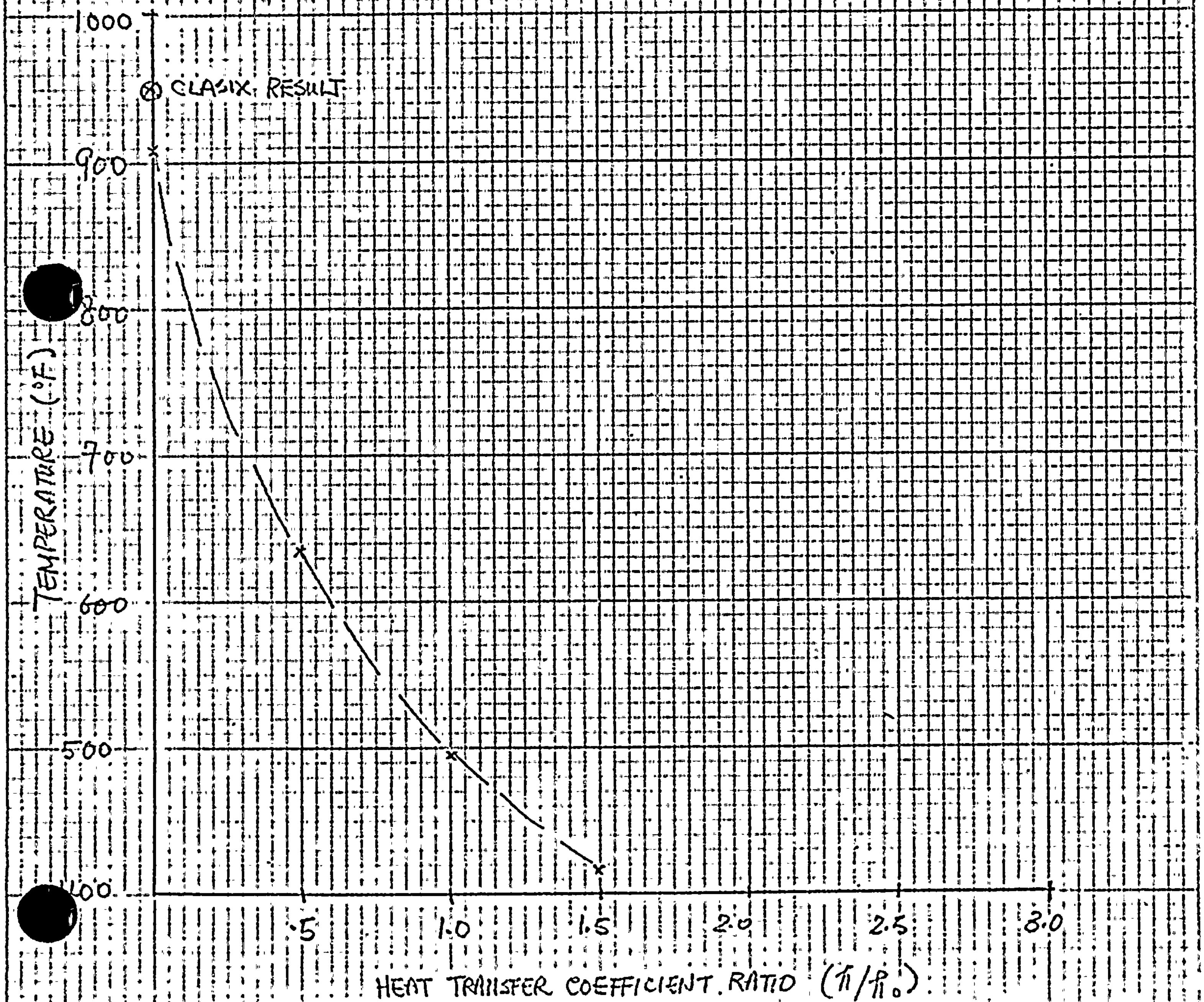


FIGURE 4-2 EFFECTS OF HEAT TRANSFER COEFFICIENT VARIATIONS ON MAXIMUM ATMOSPHERE TEMPERATURE IN LOWER COMPARTMENT

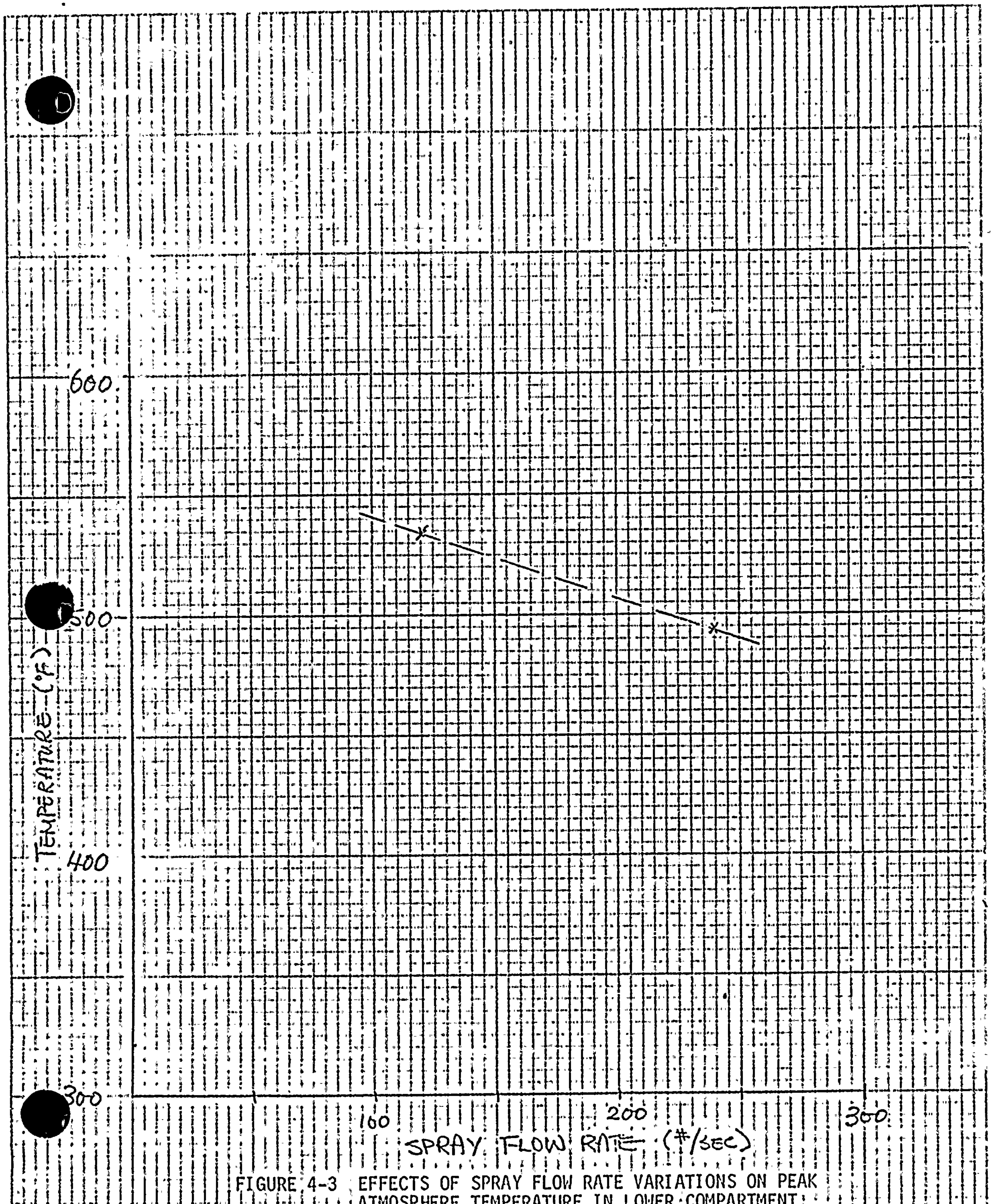


FIGURE 4-3 EFFECTS OF SPRAY FLOW RATE VARIATIONS ON PEAK ATMOSPHERE TEMPERATURE IN LOWER COMPARTMENT

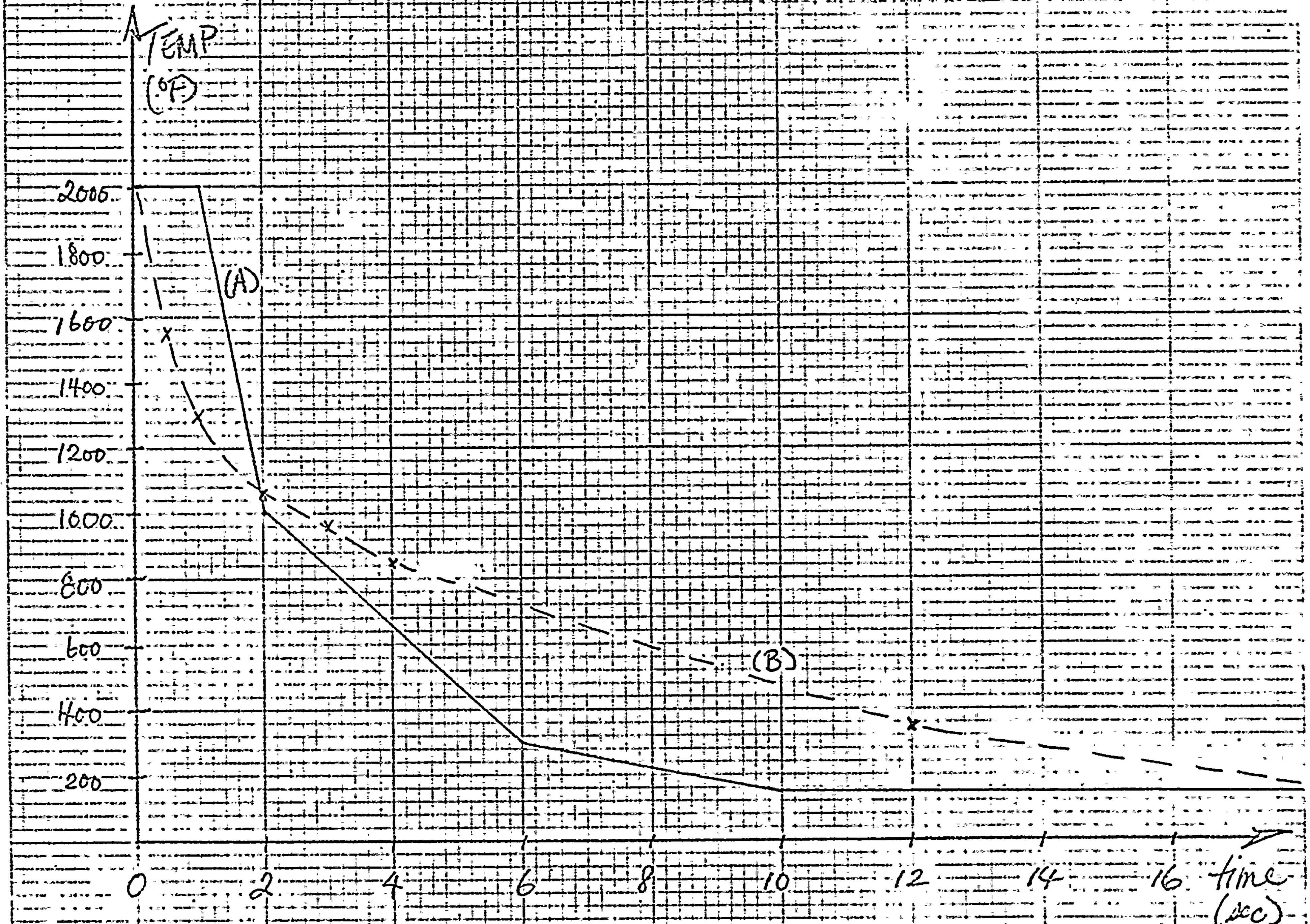


FIGURE 4-4 TEMPERATURE PROFILES USED AS CONVECTIVE BOUNDARY CONDITIONS

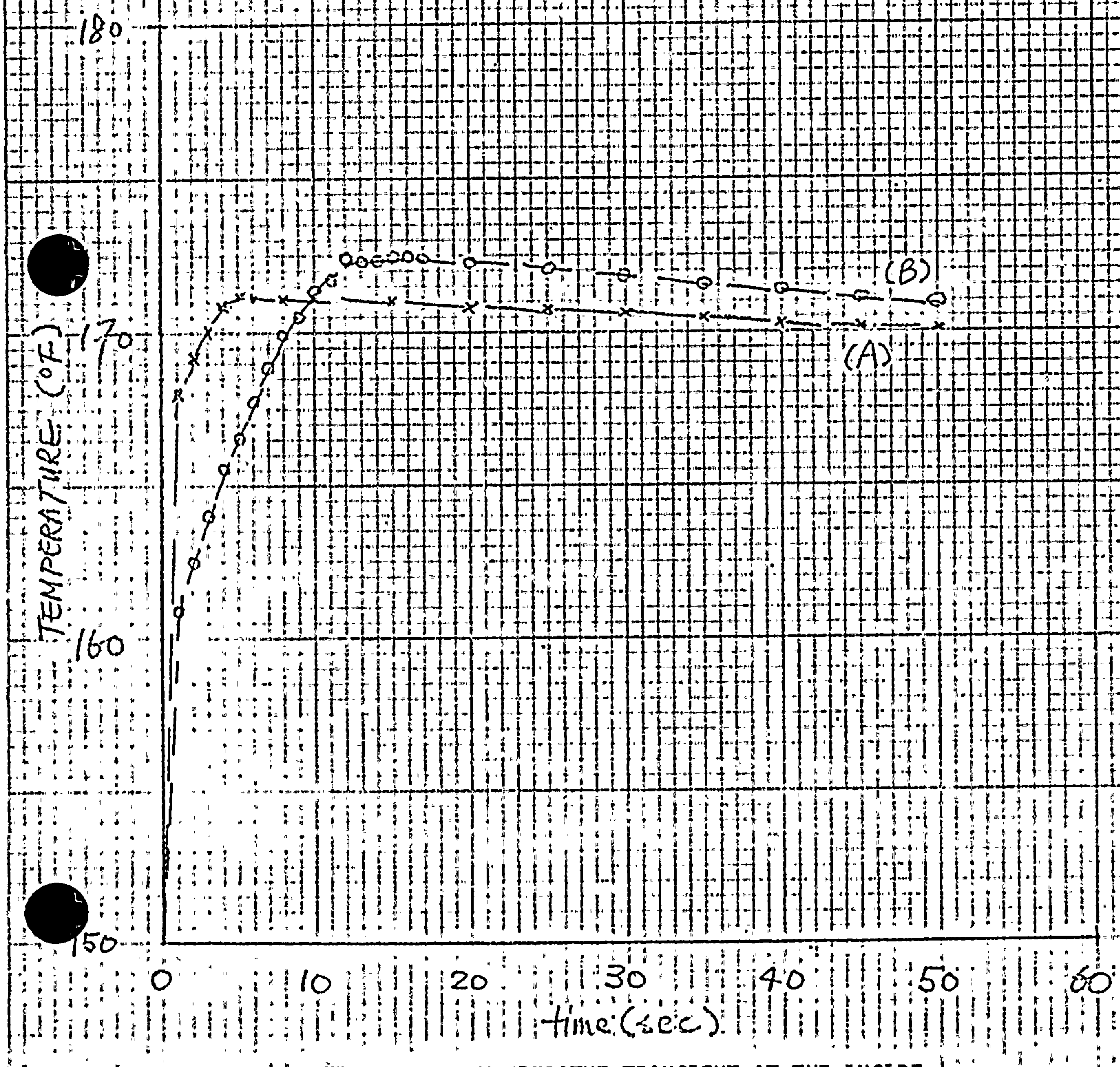


FIGURE 4-5 TEMPERATUE TRANSIENT AT THE INSIDE SURFACE OF 1/4" SLAB

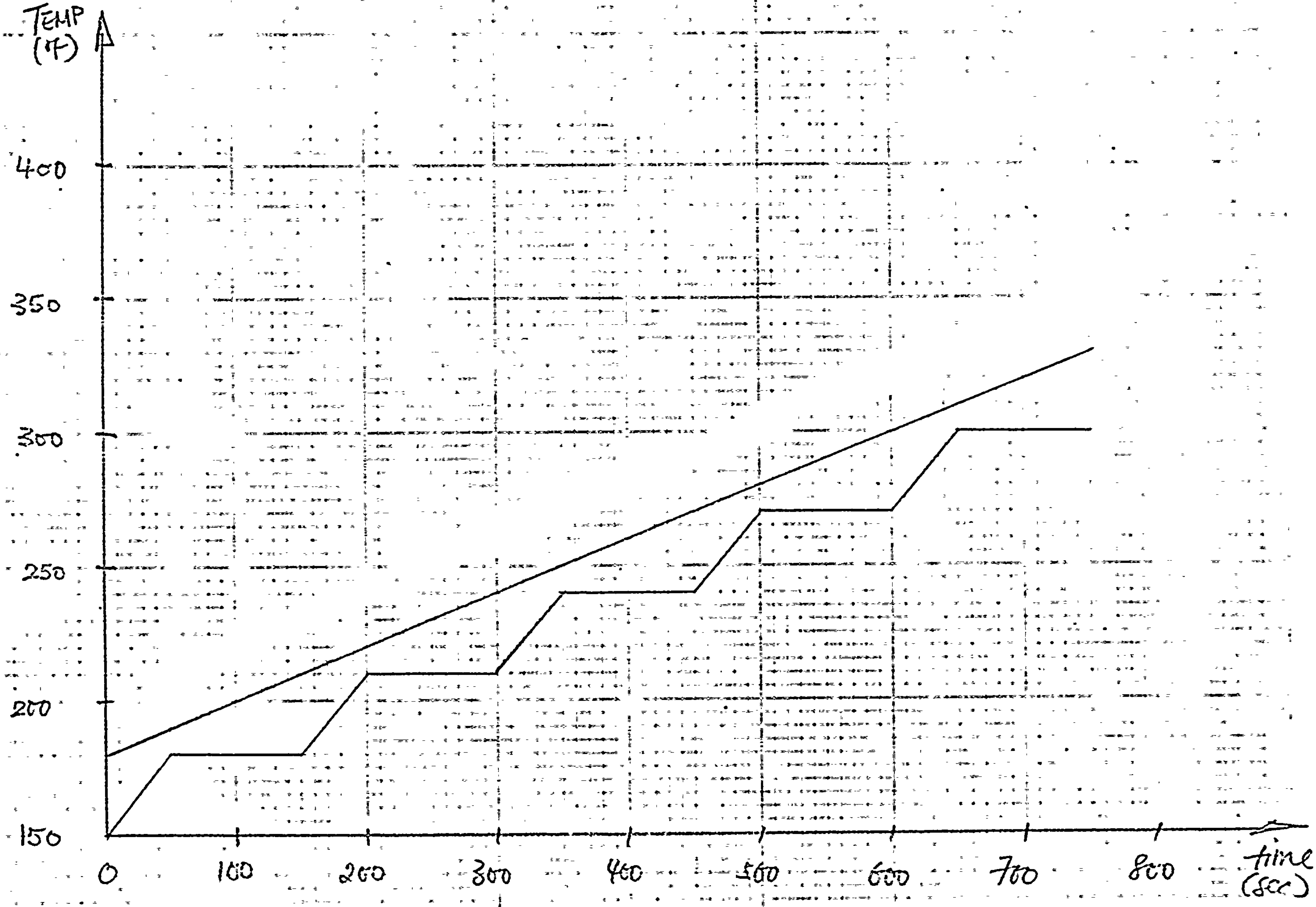


FIGURE 4-6 ASSUMED INSIDE SURFACE TEMPERATURE PROFILES

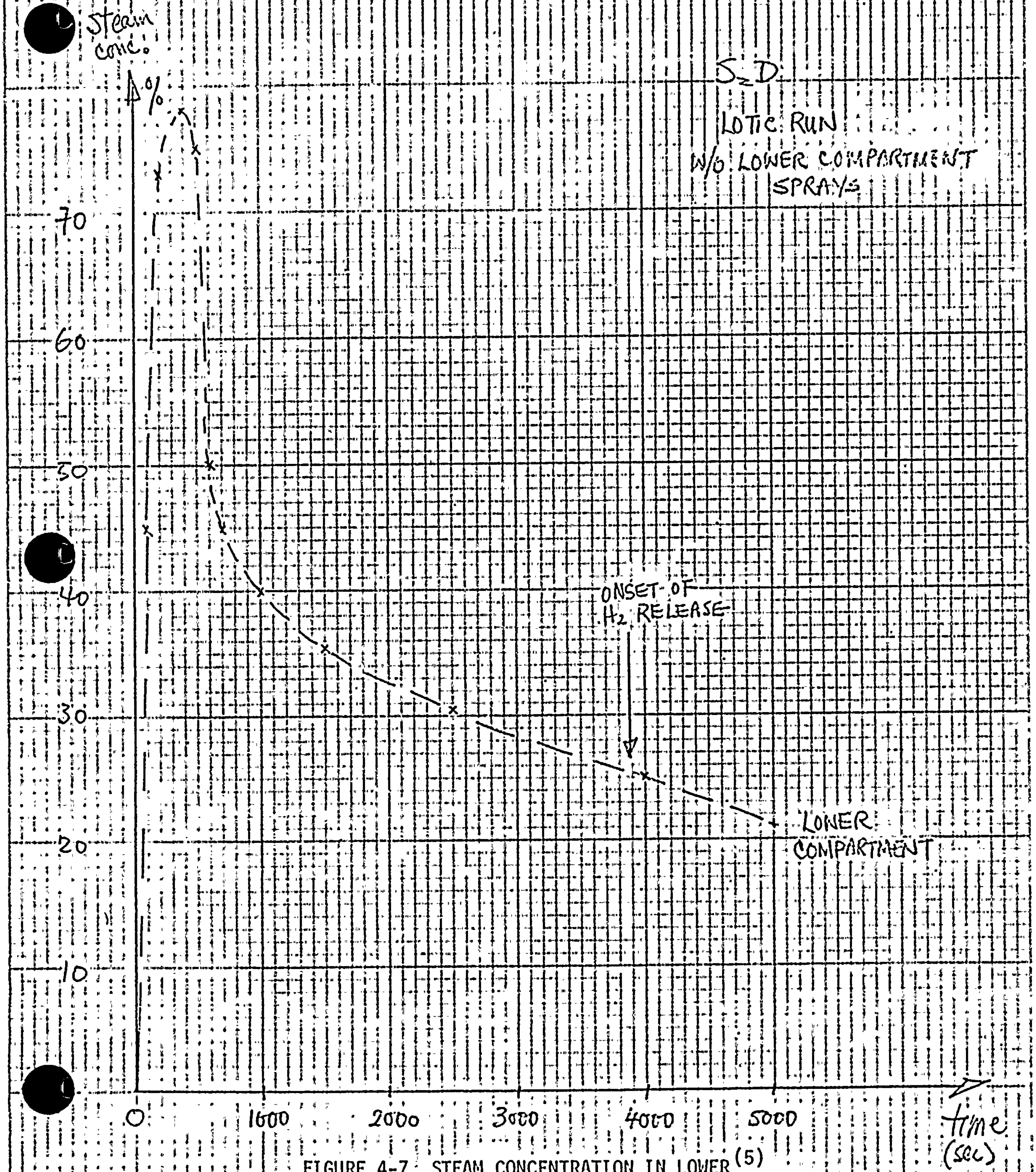


FIGURE 4-7 STEAM CONCENTRATION IN LOWER[5] COMPARTMENT AS A FUNCTION OF TIME

References:

(1) Klamerus, L. J., "Fire Protection Research," Quarterly Progress Report, October - December 1977, NUREG/CR-0366.

(2) Private Communication, L. J. Klamerus to K. K. Shiu, March 1981.

(3) Hertzberg, M., "Flammability Limits and Pressure Development in H_2-Air Mixtures," U.S. Bureau of Mines, PRC Report No. 4305, January 1981.

(4) Lowry, W., "Preliminary Results of Thermal Igniter Experiments in H_2-Air Steam Environments," Paper presented at the workshop on the impact of Hydrogen on Water Reactor Safety, Albuquerque, New Mexico, January 1981.

(5) Sequoyah Nuclear Plant, Core Degradation Program, Volume 2, Report on the Safety Evaluation of the IDIS, December 15, 1980.

DONALD C. COOK NUCLEAR PLANT UNIT NOS. 1 AND 2

ATTACHMENT NO. 5 TO AEP:NRC:00500A

SECOND QUARTERLY REPORT ON HYDROGEN MITIGATION AND CONTROL

5.0 Current Research Programs

Several research programs have been undertaken by AEP to investigate hydrogen control related phenomena; some of these programs were discussed in the last quarterly report. In this section a number of the current research programs will be reviewed; program status, revised test plan and program schedule of each effort will be discussed individually.

5.1 EPRI Programs

AEP, along with Duke and TVA, are co-sponsors of four EPRI research programs in which fundamental flame studies will be made; research and development on various igniter types will be pursued; mixing and distribution of hydrogen in prototypic containment environments will be investigated and additional glow plug testing will be performed.

a) Whiteshell Nuclear Research Establishment

This research facility is operated by Atomic Energy of Canada Limited. Two research programs will be pursued independently at this facility; namely, the hydrogen combustion phenomena study and the research and development of different igniter types. Both of these programs will be undertaken with the collaboration of Ontario Hydro as an additional financial contributor to the work.

The first experimental program is designed to investigate various hydrogen combustion phenomena and can be divided into four parts. The first part of this experimental effort entails performing nineteen ignition tests on lean hydrogen mixtures. The hydrogen concentration to be examined in these tests will vary from 5.0% to 30% by volume. A spark ignition source which is

in the order of 0.5 joule will be used to ignite the mixture. Details of the experimental set up and test vessel dimensions have been presented in the previous quarterly submittal. Fast response pressure transducers, thermocouples and ionization probes will be employed to monitor and record various important test parameters. Of the nineteen tests planned the majority of them will be conducted with the ignition spark located near the bottom of the spherical test vessel. Two tests are planned in which the ignition source will be located at the center of the vessel and one test is planned with the ignition source near the top of the vessel. These three tests will be used to assess the effect of igniter location.

These tests are anticipated to require approximately three weeks to complete. According to the latest estimate provided by WNRE, system shakedown is being performed on the test vessel and on the data acquisition system; it is expected that data collection will begin by early May.

Part II of the hydrogen combustion program includes a total of eighteen tests which are intended to study spherical deflagrations of a hydrogen flame. The hydrogen concentrations that will be investigated range from 10% to 42% whereas the steam concentrations will vary from 0 to 30%. With the exception of two tests in which ignition will be initiated at the bottom of the test vessel all tests will be performed using center ignition. The time required to complete these tests is approximately one month.

Subsequent to these tests the test vessel will be modified for the study of turbulent effects on hydrogen combustion. Two weeks have been scheduled in the program plan to accomplish these modifications.

The primary objective of the Part III tests is to investigate turbulent effects upon completeness of hydrogen burns, and upon pressure and temperature responses. Turbulence in these tests will be created by two different means: 1) two 16" diameter variable speed fans and, 2) gratings. The fans are rated at 1500 cfm each and consequently are capable of creating a very turbulent environment. The gratings are made of 1/4" perforated plate with 50% porosity and they are used to simulate obstacle-induced turbulence. Six tests will be devoted to examining lean hydrogen combustion under turbulent conditions; ignition will be initiated at the bottom of the vessel. Four additional tests will be conducted using 14% and 20% hydrogen-air mixtures when the ignition source will be placed at the center of the test vessel. The time needed to complete these tests is expected to be about one month.

Part IV of the hydrogen combustion program entails a total of six tests. Prior to performing these tests, a week's time is needed to set up the test rig which includes a sphere used in the previous tests. Ignition for these tests will be initiated at either the center of the sphere or at the end of the pipe for hydrogen mixtures of either 8% or 20%. In addition to collecting the temperature and pressure data, ionization probes will be used to record flame propagation from one compartment to another. The final two tests using this test geometry include studying hydrogen combustion characteristics from a 8% or a 10% mixture to a 6% mixture. In these tests the pipe will be filled with a 8% or 10% mixture, while the sphere is filled with a 6% mixture. Ignition will be initiated in the pipe section. The duration of these tests is anticipated to be about three weeks.

The second experimental program that will be carried through at the Whiteshell facility involves research and development effort on various igniter types. The objective of this work is to perform extensive benchmark tests in a six cubic foot spherical test vessel to identify igniter types and to demonstrate their combustion capability in a prototypic environment. The testing program will begin in May and last about four months. Based on test data obtained, a selection of igniters will then be further tested in a larger scale test vessel (600 ft^3) at Acurex. Presently, besides the GMAC 7G glow plugs, a few resistance-heating glow plugs developed by Tayco will also be examined.

b) <u>Acurex</u>

In the Acurex program, the test plan can also be divided into two parts; the first part is designed to examine the effectiveness and the performance of glow plugs in igniting hydrogen under various prototypic containment conditions. In these experiments, hydrogen flow rate, steam flow rate, water sprays parameters and ignitor locations will be varied to provide parametric studies on the ability of glow plugs to ignite hydrogen mixtures. The effect of micro-fog on glow plug ignition and pressure transients will also be investigated. A number of the experiments will attempt to provide data to correlate fogging as a pressure suppressant with spray volume, spray drop size, and hydrogen concentrations. A strong ignition source, e.g., electric match, will be used in all the fogging-related tests.

A second part of the test plan calls for testing a selected number of igniters developed at the Whiteshell Nuclear Research Establishment. These will be large scale confirmatory tests for ignition devices which have demonstrated a superior potential in igniting lean hydrogen mixtures and in

replacing the existing glow plug designs in the future. Their effectiveness in a spray environment will be evaluated at Acurex's 600 ft^3 vessel.

Prior to carrying through the above described test plan, a series of shakedown tests will be performed to provide checks for consistency and accuracy of all instrumentation; specifically, results will be compared with those obtained at Whiteshell and from the available literature.

c) Hanford Engineering Development Laboratory (HEDL)

The objective of this effort is to experimentally investigate aspects of hydrogen mixing and distribution in a simulated ice condenser lower compartment geometry. Hydrogen release into the compartment will be modelled by two approaches. In the first approach, steam and hydrogen are introduced as a jet into the compartment simulating a pipe break; in the second approach, hydrogen and steam are added to the compartment as a diffuse source similar to pressurizer relief tank release. In order to extend the range of hydrogen concentration beyond 4%, helium will be used as a simulation fluid in place of hydrogen. Confirmatory tests will be performed to demonstrate that helium can indeed be used to substitute hydrogen in these mixing studies.

The first test is scheduled to begin some time in mid June and the whole test program is expected to last approximately two months. In the meantime, similitude and scaling calculations are being done so as to properly model the necessary parameters that are vital to the investigation of mixing and distribution. Some of the non-dimensional groups that are being examined are: the Richardson number, the Reynolds number, and the Grashof number.

d) Factory Mutual Research

AEP, Duke, TVA and EPRI recently came to the conclusion that in order to better understand fogging as a means of hydrogen control and to eventually

render a decision on its applicability as a viable solution to hydrogen mitigation, they would contract with Factory Mutual Research to undertake a research program to investigate fogging. The objective of this program is to determine the effects of micro-fog upon the lower flammability limit (LFL) of hydrogen, to provide a relationship between dropsize and fogging density on LFL and to correlate the concentrations of lean hydrogen air mixtures with various fogging parameters.

In order to ensure that the effects of fogging on LFL are properly reproduced, a strong ignition source has been proposed and is likely to be used to initiate ignition on all LFL tests. The range of droplet sizes that is of interest to the utilities varies from a few microns to hundreds of microns, whereas the fogging density varies from zero to a few percent. Test parameters that will be measured include temperature, pressure, dropsize distribution and fog density distribution. A schematic of the experimental set up is shown in Figure 5-1.

A detail test plan is being prepared by Factory Mutual Research with aid from AEP and the other participants. The test vessel is scheduled to become available for test in approximately three weeks. Finally, it is also the intent of this effort to provide the necessary and pertinent information to assist in the selection of test parameters in the Acurex fogging tests.

e) CLASIX

In the AEP-NRC meeting on March 18, 1981, the staff expressed interest in reviewing a number of additional CLASIX runs. The first concern centers around the unique lower containment spray capability at Cook and its possible effect upon other compartment responses during and subsequent to a hydrogen burn.

Reviews at AEP indicate that in the CLASIX sensitivity study submitted to the NRC, spray parameters such as spray flow rate, droplet size, heat transfer characteristics to the drop and spray temperature were varied; minimal effects on the containment pressure and temperature responses were noted. Thus, the available information from CLASIX, points out that variations in spray parameters would not significantly affect containment temperature and pressure response.

Another possible CLASIX run discussed in the above mentioned meeting involved initiating hydrogen combustion at 10% with 50% burn fraction. Experimental measurements on completeness of hydrogen combustion reported in the literature show that in spite of the large scattering in data around 5% to 7%, an initial 10% concentration consistently results in an almost 100% burn.(1) In addition, it has been shown that turbulence will further enhance completeness of combustion for lean hydrogen mixtures (2). Therefore, if the probability of incomplete combustion of 10% is indeed negligibly small, as it seems to be, its effects upon the containment need not be investigated.

It was suggested by the staff that a case with ignition initiated at 10% and then propagating to a 8% hydrogen concentration region should be studied. Both types of combustion would assume a 100% burn fraction. Close examination of the various cases presented in the CLASIX sensitivity studies reveals that there is one case (JVD15) which uses the exact input parameters requested by the staff. One burn was observed in the upper compartment with an estimated maximum pressure of 57 psia (only one air recirculation fan was assumed to be operational in the run). This maximum pressure is very close to the Cook containment elastic limit. However, since heat sinks have not been included in these sensitivity calculations, the results are likely to be overly conservative.

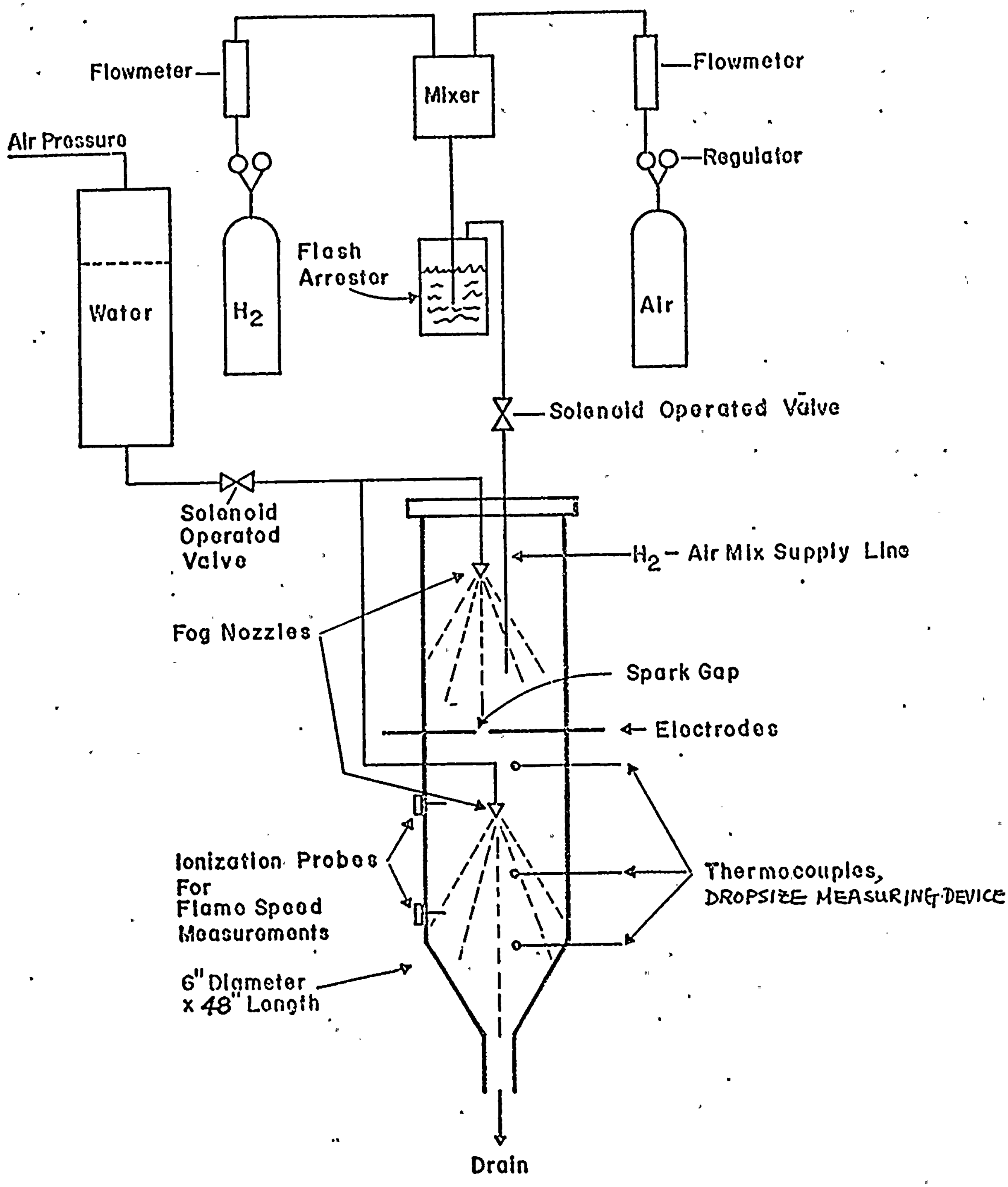


FIGURE 5-1 EXPERIMENTAL ARRANGEMENT OF FOGGING TESTS

References:

(1) Liu D. D. S., et al, "Some Results of WNRE Experiments on Hydrogen Combustion," Water Reactor Safety Workshop on the Impact of Hydrogen, Albuquerque, New Mexico, January 1981.

(2) Hertzbert, M., "Flammability Limits and Pressure Development in H_2-Air Mixtures," U. S. Bureau of Mines, PRC Report No. 4305, January 1981.

DONALD C. COOK NUCLEAR PLANT UNIT NOS. 1 AND 2

ATTACHMENT NO. 5 TO AEP:NRC:00500A

SECOND QUARTERLY REPORT ON HYDROGEN MITIGATION AND CONTROL

5.0 Current Research Programs

Several research programs have been undertaken by AEP to investigate hydrogen control related phenomena; some of these programs were discussed in the last quarterly report. In this section a number of the current research programs will be reviewed; program status, revised test plan and program schedule of each effort will be discussed individually.

5.1 EPRI Programs

AEP, along with Duke and TVA,are co-sponsors of four EPRI research programs in which fundamental flame studies will be made; research and development on various igniter types will be pursued; mixing and distribution of hydrogen in prototypic containment environments will be investigated and additional glow plug testing will be performed.

a) Whiteshell Nuclear Research Establishment

This research facility is operated by Atomic Energy of Canada Limited. Two research programs will be pursued independently at this facility; namely, the hydrogen combustion phenomena study and the research and development of different igniter types. Both of these programs will be undertaken with the collaboration of Ontario Hydro as an additional financial contributor to the work.

The first experimental program is designed to investigate various hydrogen combustion phenomena and can be divided into four parts. The first part of this experimental effort entails performing nineteen ignition tests on lean hydrogen mixtures. The hydrogen concentration to be examined in these tests will vary from 5.0% to 30% by volume. A spark ignition source which is

in the order of 0.5 joule will be used to ignite the mixture. Details of the experimental set up and test vessel dimensions have been presented in the previous quarterly submittal. Fast response pressure transducers, thermocouples and ionization probes will be employed to monitor and record various important test parameters. Of the nineteen tests planned the majority of them will be conducted with the ignition spark located near the bottom of the spherical test vessel. Two tests are planned in which the ignition source will be located at the center of the vessel and one test is planned with the ignition source near the top of the vessel. These three tests will be used to assess the effect of igniter location.

These tests are anticipated to require approximately three weeks to complete. According to the latest estimate provided by WNRE, system shakedown is being performed on the test vessel and on the data acquisition system; it is expected that data collection will begin by early May.

Part II of the hydrogen combustion program includes a total of eighteen tests which are intended to study spherical deflagrations of a hydrogen flame. The hydrogen concentrations that will be investigated range from 10% to 42% whereas the steam concentrations will vary from 0 to 30%. With the exception of two tests in which ignition will be initiated at the bottom of the test vessel all tests will be performed using center ignition. The time required to complete these tests is approximately one month.

Subsequent to these tests the test vessel will be modified for the study of turbulent effects on hydrogen combustion. Two weeks have been scheduled in the program plan to accomplish these modifications.

The primary objective of the Part III tests is to investigate turbulent effects upon completeness of hydrogen burns, and upon pressure and temperature responses. Turbulence in these tests will be created by two different means: 1) two 16" diameter variable speed fans and, 2) gratings. The fans are rated at 1500 cfm each and consequently are capable of creating a very turbulent environment. The gratings are made of 1/4" perforated plate with 50% porosity and they are used to simulate obstacle-induced turbulence. Six tests will be devoted to examining lean hydrogen combustion under turbulent conditions; ignition will be initiated at the bottom of the vessel. Four additional tests will be conducted using 14% and 20% hydrogen-air mixtures when the ignition source will be placed at the center of the test vessel. The time needed to complete these tests is expected to be about one month.

Part IV of the hydrogen combustion program entails a total of six tests. Prior to performing these tests, a week's time is needed to set up the test rig which includes a sphere used in the previous tests. Ignition for these tests will be initiated at either the center of the sphere or at the end of the pipe for hydrogen mixtures of either 8% or 20%. In addition to collecting the temperature and pressure data, ionization probes will be used to record flame propagation from one compartment to another. The final two tests using this test geometry include studying hydrogen combustion characteristics from a 8% or a 10% mixture to a 6% mixture. In these tests the pipe will be filled with a 8% or 10% mixture, while the sphere is filled with a 6% mixture. Ignition will be initiated in the pipe section. The duration of these tests is anticipated to be about three weeks.

The second experimental program that will be carried through at the Whiteshell facility involves research and development effort on various igniter types. The objective of this work is to perform extensive benchmark tests in a six cubic foot spherical test vessel to identify igniter types and to demonstrate their combustion capability in a prototypic environment. The testing program will begin in May and last about four months. Based on test data obtained, a selection of igniters will then be further tested in a larger scale test vessel (600 ft^3) at Acurex. Presently, besides the GMAC 7G glow plugs, a few resistance-heating glow plugs developed by Tayco will also be examined.

b) Acurex

In the Acurex program, the test plan can also be divided into two parts; the first part is designed to examine the effectiveness and the performance of glow plugs in igniting hydrogen under various prototypic containment conditions. In these experiments, hydrogen flow rate, steam flow rate, water sprays parameters and ignitor locations will be varied to provide parametric studies on the ability of glow plugs to ignite hydrogen mixtures. The effect of micro-fog on glow plug ignition and pressure transients will also be investigated. A number of the experiments will attempt to provide data to correlate fogging as a pressure suppressant with spray volume, spray drop size, and hydrogen concentrations. A strong ignition source, e.g., electric match, will be used in all the fogging-related tests.

A second part of the test plan calls for testing a selected number of igniters developed at the Whiteshell Nuclear Research Establishment. These will be large scale confirmatory tests for ignition devices which have demonstrated a superior potential in igniting lean hydrogen mixtures and in

replacing the existing glow plug designs in the future. Their effectiveness in a spray environment will be evaluated at Acurex's 600 ft^3 vessel.

Prior to carrying through the above described test plan, a series of shakedown tests will be performed to provide checks for consistency and accuracy of all instrumentation; specifically, results will be compared with those obtained at Whiteshell and from the available literature.

c) Hanford Engineering Development Laboratory (HEDL)

The objective of this effort is to experimentally investigate aspects of hydrogen mixing and distribution in a simulated ice condenser lower compartment geometry. Hydrogen release into the compartment will be modelled by two approaches. In the first approach, steam and hydrogen are introduced as a jet into the compartment simulating a pipe break; in the second approach, hydrogen and steam are added to the compartment as a diffuse source similar to pressurizer relief tank release. In order to extend the range of hydrogen concentration beyond 4%, helium will be used as a simulation fluid in place of hydrogen. Confirmatory tests will be performed to demonstrate that helium can indeed be used to substitute hydrogen in these mixing studies.

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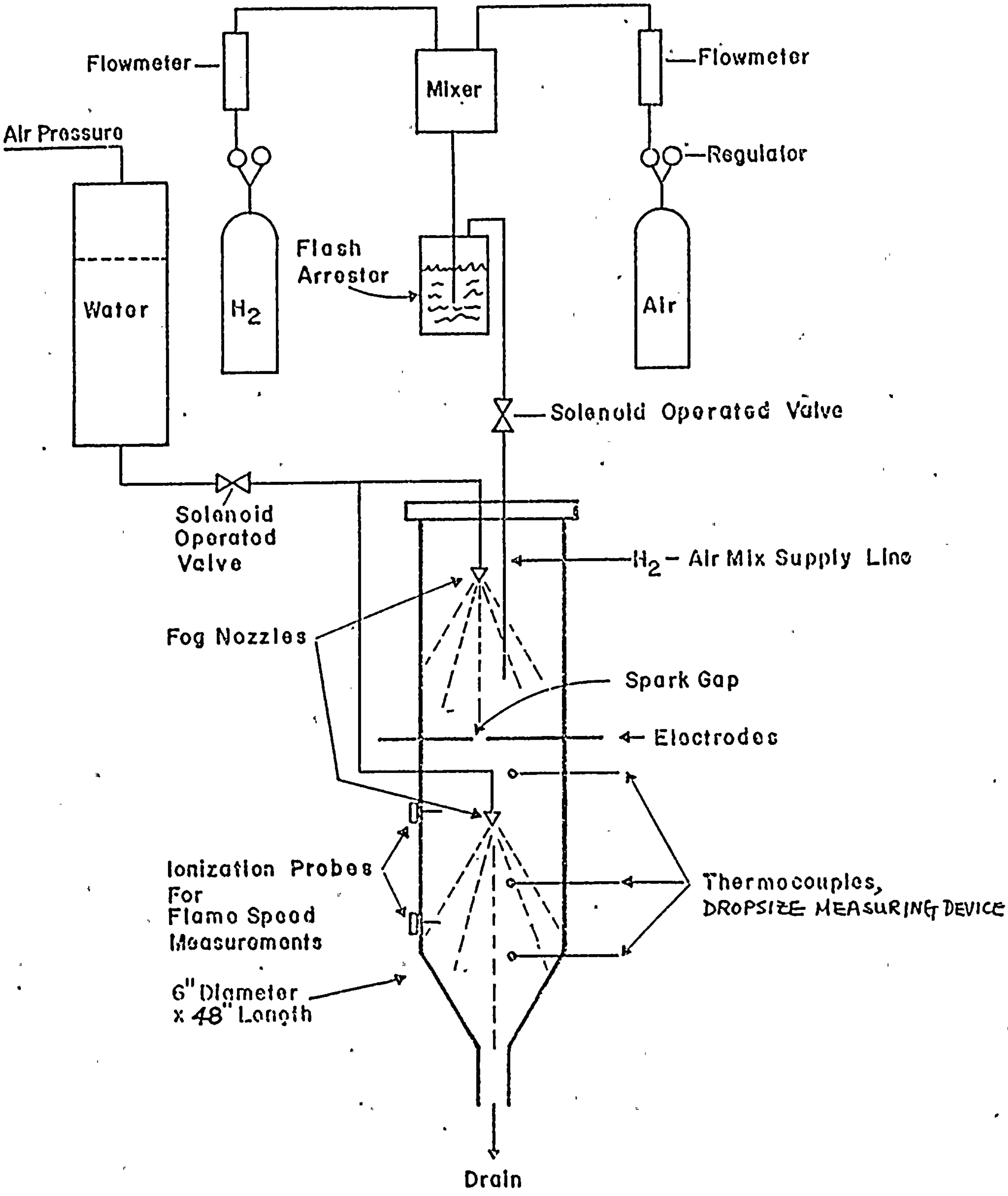

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DONALD C. COOK NUCLEAR PLANT UNIT NOS. 1 AND 2

ATTACHMENT NO. 6 TO AEP:NRC:00500A

SECOND QUARTERLY REPORT ON HYDROGEN MITIGATION AND CONTROL

6.0 Core Cooling Capability Subsequent to Hydrogen Combustion

6.1 Introduction

The write-up below addresses the existing components necessary to achieve and maintain a safe shutdown condition subsequent to a reactor trip and to maintain a safe shutdown condition and containment integrity via adequate hydrogen control during and after a hypothetical degraded core cooling event.

6.2 Safe Shutdown

The three primary functions to be performed in order to achieve and maintain a safe shutdown condition subsequent to a reactor trip are:

(1) circulation of reactor coolant

(2) residual heat removal

(3) control of RCS pressure

The methods by which each of these functions can be performed, and the necessary equipment located inside containment, are discussed below.

6.2.1 Circulation of Reactor Coolant

Circulation of reactor coolant is provided by natural circulation with the reactor core serving as the heat source and the steam generators serving as the heat sink. Water is provided to the steam generators via the safety-grade Auxiliary Feedwater System (AFS) or, if offsite power is available and sufficient steam is available, via the normal feedwater system. The AFS can be aligned to take suction from the Essential Service Water System, which itself takes suction from Lake

Michigan, thus assuring a virtually limitless supply of cooling water for the steam generators. Steam release paths include turbine bypass (if offsite power is available) using the main condenser, the main steam safety valves, and the main steam power operated relief valves.

Those portions of the reactor coolant system, main feedwater system, auxiliary feedwater system, and main steam system inside containment contain no active components required to operate to assure coolant circulation and operation of said systems would not be adversely affected by a hydrogen combustion environment.

The equipment located inside containment needed to assure adequate reactor coolant circulation is listed below. The susceptibility of this equipment to a hydrogen combustion environment and the effects of such an environment on equipment operation are addressed in Attachment Nos. 3 and 4 of this submittal, respectively.

1. Steam Generator Narrow-Range Level Monitors
2. Pressurizer Water Level Monitors
3. Pressurizer Pressure Monitors
4. Loop RTDs
5. Core Exit Thermocouples
6. RCS Wide Range Pressure Monitors

6.2.2 Residual Heat Removal

Residual heat is removed via the steam generators utilizing the methods and equipment described in 6.2.1 above. For the same reasons set forth in 6.2.1, this function is not adversely affected by a hydrogen combustion environment.

6.2.3 RCS Pressure Control

Subsequent to a reactor trip, RCS pressure is maintained utilizing the 'natural circulation' equipment described above, with the pressurizer (PZR) safety valves serving as high pressure protection. The PZR safety valves are self contained, spring loaded valves and would not be adversely affected by a hydrogen combustion environment.

A second aspect of RCS pressure maintenance deals with isolation of the various branch lines attached to the RCS. Each of these potential leakage paths, including the method of isolation, is discussed below.

(1) Pressurizer Power Operated Relief Valves (PORVs)

Each PORV is normally closed and is designed to fail closed upon loss of air or loss of power.

In addition, a block valve is located upstream of each PORV to assure RCS isolation in the event that PORV leakage were to develop.

(2) Letdown Line

Letdown isolation is provided by three parallel fail-closed air operated valves located inside containment and a fail-closed air operated valve outside containment. These valves will automatically close on a safety injection signal.

(3) Excess Letdown/Seal Water Injection

Flow from the excess letdown heat exchanger is directed to the reactor coolant pump seal water return line (connection inside containment) which is isolated by two motor operated valves in series, one inside reactor containment and one outside containment. These valves will automatically close on a safety injection signal.

(4) Residual Heat Removal (RHR) Letdown

The RHR letdown line is isolated by two normally closed motor operated valves in series located inside reactor containment. Both valves are interlocked with RCS wide-range pressure to automatically close on increasing pressure above 600 psig and cannot be opened until RCS pressure has decreased below 425 psig. In addition, the valve control switches are administratively key locked closed in the main control room during power operation.

(5) Reactor Vessel Head Vent

The reactor vessel head vent system consists of two redundant parallel paths, each path containing two normally closed, solenoid actuated valves in series for isolation. These valves are designed to fail closed upon loss of power.

6.3 Hydrogen Control Equipment

Operation of the containment air recirculation/hydrogen skimmer (CAR/HYS) fans and the DIS in conjunction with the containment spray system (CTS) further assures the combustion of lean hydrogen mixtures without posing a threat to the containment structure via overpressurization. The portion of the CTS inside containment contains no active components and hence CTS operation is not adversely affected by a hydrogen combustion environment. The active components inside containment used for hydrogen control are the CAR/HYS fans and the DIS. The electrical hydrogen recombiners would be used to remove residual hydrogen (less than 4 volume percent) from the containment subsequent to DIS operation.

6.4 ECCS Injection Subsequent to Combustion

An evaluation has been made to verify ECCS injection capability subsequent to hydrogen combustion inside containment. The results of this evaluation indicated that high-head safety injection (SI) (charging pumps) flow path via the BIT and the intermediate/low head SI (SI and RHR pumps) flow path to the RCS cold legs will be unaffected

by hydrogen combustion. These flow paths contain motor operated valves inside containment. These valves receive a signal to open on a SI signal despite the fact they are normally in the open position, thus providing further assurance of ECCS injection capability. No mechanism has been identified whereby the environment associated with hydrogen combustion would result in closure of these valves.

With the refueling water storage tank (RWST) available, twelve weight percent boric acid can be delivered to the RCS by aligning the suction of the charging pumps to the RWST and aligning the pump(s) discharge to the boron injection tank (BIT). A second flow path involves alignment of the charging pump suction to the discharge of the boric acid transfer pumps, which are themselves aligned to take suction from the boric acid tanks with the discharge of the charging pumps again aligned to the BIT. Neither of the above described flow paths utilize components (eg. valves) inside containment which are required to change position/function in a hydrogen burn environment. In the event that the contents of the RWST had already been injected coolant injection is achieved by aligning the charging pump(s) suction to the discharge of the residual heat removal (RHR) pump(s); with the RHR pump(s) taking suction from the containment recirculation sump. This third flow path does not utilize any active components inside containment which are susceptible to a hydrogen combustion environment.

The subject valves are fully qualified for post-accident use inside containment (LOCA/MSLB qualification). In addition, the analyses described in Attachment No. 4 to this report clearly show that the environmental conditions associated with hydrogen combustion are less severe than the environment to which they have been qualified; thus assuring maintenance of the aforementioned flow paths. The normally closed motor operated valves in the intermediate/low head SI flow path have also been qualified for use in a LOCA/MSLB environment and would be expected to remain in operation subsequent to hydrogen combustion; thus providing another ECCS injection path.

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ATTACHMENT NO. 7 TO AEP:NRC:00500A

SECOND QUARTERLY REPORT ON HYDROGEN MITIGATION AND CONTROL

7.0 Preliminary Safety Evaluation

Indiana & Michigan Electric Co. (I&MECo.) has decided to install a Distributed Ignition System (DIS) in the Donald C. Cook Nuclear Plant Unit Nos. 1 and 2. The DIS in conjunction with operation of existing safety-related equipment provides additional hydrogen control capability in the extremely unlikely event of a degraded core event similar in nature to the TMI-2 accident involving the generation of substantive amounts of hydrogen.

The DIS, described in detail in Attachment No. 2 of this report, is designed to assure combustion of lean hydrogen/air/steam mixtures and hence will minimize the pressure and temperature transients associated with hydrogen combustion. Conservative analyses of the containment response have previously been submitted via our first quarterly report (AEP:NRC:00500). The results of these analyses indicate that deliberate ignition of lean hydrogen mixtures using the DIS will result in pressures below the ultimate strength of the Cook Plant containments. The effects of a hydrogen combustion environment on necessary equipment located inside containment has been evaluated and the results of this evaluation presented in Attachment No. 4 of this report. It is clear from our evaluation that the temperature effects of deliberate hydrogen combustion are less severe than those to which most of the necessary equipment has been qualified (LOCA/MSLB qualification). It has also been shown that the ability to inject emergency core cooling water is not affected by hydrogen combustion.

The extensive plant modifications and enhanced operator training implemented subsequently to the TMI-2 accident have effectively reduced the already low probability of occurrence of events which could result in the generation of substantive amounts of hydrogen at the Cook Plant. The DIS, in conjunction with existing plant equipment, will provide an additional level of mitigation capability for hypothetical events well beyond the design basis of the Cook Units, further enhancing the defense-in-depth philosophy. Installation of the DIS provides further assurance that operation of the Cook Plant will in no way adversely effect the health and safety of the general public.