WCAP-13711

INTEGRITY EVALUATION OF INDICATIONS IN THE SAFETY INJECTION ACCUMULATOR TANKS FOR DIABLO CANYON UNITS 1 AND 2

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TABLE OF CONTENTS

1. INTRODUCTION

The safety injection accumulator tanks for Diablo Canyon are 138 inches in outside diameter, made of SA516 Grade 70 steel with SA240 Type 304 stainless steel roll bonded cladding. The design drawings specify Type 304L for Unit 1 [1] and Type 304 for Unit 2 [2]. Their specified design temperature is 300°F, and the design pressure is 708 psi [1,2].

As a result of recent PG and E non-destructive examination (NDE) findings, an engineering evaluation has been carried out to establish the integrity of the tanks. The evaluation has been structured to be applicable to all eight accumulator tanks in both Unit 1 and Unit 2.

These tanks were designed to the ASME Code Section III, 1968 edition. For the evaluations discussed in this report, the most recent published edition of Section XI (1992) was used. Although the Section XI paragraph references are from this edition,the analytical criteria for acceptance of indications have remained unchanged since their original publication in 1974.

The evaluation which follows provides a technical justification for not repairing the shallow cracks which have been found in the cladding in the cylindrical shell and the spherical heads.

2. BACKGROUND AND HISTORY OF CRACKS

During Diablo Canyon's fifth refueling outage for Unit 2, cracks were discovered in the Accumulator Tanks 2-2 and 2-3 stainless steel roll-bonded cladding which lines the inside of the accumulators. The cladding cracks were discovered during dye-penetrant (PT) examination of the seam welds and the heat affected zone adjacent to these welds. These cracks initiate at the toe of the clad-to-clad or seam welds of the tanks and extend into the cladding material.

Thirty-two (32) rejectable PT indications were found in the seam welds of Accumulator 2-3 and twenty-seven (27) rejectable indications were found in the seam welds of Accumulator 2-2. The seam welds in Accumulators 2-1 and 2-4 were also examined using dye-penetrant. Indications were found in these

Accumulators but these indications were mechanical discontinuities in the vicinity of the weld seams and are not associated with the cracking in the cladding found in Accumulators 2-2 and 2-3. These indications are also covered by this report.

Further examination of these clad cracks has been performed. Most of the cracks as identified by PT were examined using Eddy-Current (ET) techniques from the inside of the tank. Additionally, representative cracks were examined using Ultrasonic (UT) techniques from the inside and outside of the tank. Both the UT and ET data confirmed that some of the cladding cracks extend through the entire thickness of the cladding to the base metal interface. The UT and ET data also indicate that the cladding cracks stop at the carbon steel base metal.

The same dye-penetrant examination was performed on the seam welds on one accumulator tank in the fifth refueling outage for Unit 1 (Accumulator 1-4). This examination discovered only one rounded indication which was buffed clean. No other Unit 1 accumulators had this examination performed.

Numerous 304 stainless steel nozzles in the Unit 1 and 2 Accumulators have been replaced due to cracking from Intergranular Stress Corrosion Cracking (IGSCC). This condition has been documented in PG and E Diablo Canyon Power Plant LER 87-023 and its subsequent revision.

The accumulators were manufactured by Delta Southern of Baton Rouge, Louisiana, under Westinghouse Specifications No. 676441 and 677022 and supplied as part of the NSSS contract scope for the Diablo Canyon Power Plant.

The eddy current data taken from the inside of the tank indicates that some of the cracks go to a depth just beyond 150 mils from the inside of the tank. The thickness of the cladding material is a minimum of 5/32" (156 mils) throughout [1,2]. The 150 mil readings are at the upper band of the capability of the Eddy Current testing equipment. However, this does indicate that some of the cracks have gone through the cladding to the base metal.

The ultrasonic (UT) testing of these same cracks from both the inside and outside of the tank correlates very well with these readings. The UT shows that the deepest crack depth is approximately 150 mils, which would extend up to the base metal interface but not into the base metal.

Additionally, a clad crack next to the nozzle bore of removed nozzle B in Accumulator 2-4 was chased to the base metal where the crack was observed to stop. The crack was discovered by a dye-penetrant examination around the bore of the nozzle. This crack was ground out due to design requirements for an acceptable PT examined surface around the nozzle bore prior to welding in a new nozzle. This grind-out provides additional field data which correlate to the data taken by UT, ET and confirmed by analysis.

3. FLAW GEOMETRY

The evaluation was performed for surface flaws in both the cladding and the base metal in the accumulator tanks. The surface flaws were postulated to be oriented normal to the maximum principle stress in the tank, the hoop stress, and to have a range of lengths and depths.

4. CRITERIA FOR FLAW ACCEPTABILITY: SECTION XI

Section XI of the ASME Code provides acceptance criteria for flaw indications found during inservice inspection and operation. There are presently no criteria in Section XI for class 2 components, so this evaluation has employed the class 1 criteria. This adds additional conservatism to the results.

Paragraph IWB 3610 states that "a flaw which lies entirely within the clad need not be evaluated". From this viewpoint the flaws found in the clad material in the accumulator tank could be considered acceptable in their present condition. It is important to mention that the cladding thickness was used in the design report as part of the design thickness of the tank in demonstrating compliance with Section III.

To provide additional assurance of the integrity of the tank in the presence of these indications, a fracture evaluation using the flaw acceptance criteria of Section XI was carried out.

Two criteria for flaw acceptability are required by Section XI and they are:

1) Acceptance Criteria based on Stress Intensity Factor (Section XI, IWB-3612).

2) Acceptance Criteria based on Primary Stress Limits (Section XI, IWB-3610, which requires meeting the limits of Section III, NB 3000).

These criteria are explained in the following sections, and will be used to establish the flaw acceptability sizes for both the head and shell regions.

4.1 Criteria Based on Stress Intensity Factor

These criteria are from IWB-3612 of Section XI. The term stress intensity factor (K_I) is defined as the driving force on a crack. It is a function of the size of the crack and the applied stresses, as well as the overall geometry of the structure. In contrast, the fracture toughness (K_{Ia}, K_{Ic}) is a measure of the resistance of the material to propagation of a crack. It is a material property, and a function of temperature.

The criteria are:

$$K_I \leq \frac{K_{Ia}}{\sqrt{10}}$$ for normal conditions (upset and test conditions inclusive)

$$K_I \leq \frac{K_{Ic}}{\sqrt{2}}$$ for faulted conditions (emergency conditions inclusive)

where

K_I = The maximum applied stress intensity factor for the flaw size a_f to which a detected flaw will grow, during the condition under consideration, at the end of design life, or to the next inspection.

K_{Ia} = Fracture toughness based on crack arrest for the corresponding crack tip temperature.

K_{Ic} = Fracture toughness based on fracture initiation for the corresponding crack tip temperature.

4.2 Criteria Based on Primary Stress Limits

In addition to satisfying the fracture criteria, Section XI requires that the primary stress limits of Section III, paragraph NB 3000 must be satisfied. [

]^{a,c,e} This calculation was included to ensure that integrity would be maintained from the standpoint of ductile failure.

5. LOADS

All the design transients considered in the analysis are listed in Table 1 and they were obtained from reference 3. This is a Class 2 tank which only functions during safety injection. [

]^{a,c,e} The pressure goes from 650 psig to 0 psig during the governing transient of Table 1. Further details of this transient are given in Section 8 of this report which discusses the fatigue crack growth evaluation. The design pressure of 708 psig was used in the fracture analysis. Thermal stresses and seismic loads are negligible.

6. STRESS INTENSITY FACTOR CALCULATIONS

One of the key elements of the critical flaw size calculations is the determination of the driving force or stress intensity factor (K_I). This was done for each of the regions using expressions available from the literature. In all cases the stress intensity factor for the critical flaw size calculations utilized a representation of the actual stress profile rather than a linearization. This was necessary to provide the most accurate determination possible of the critical flaw size and is particularly important for consideration of emergency and faulted conditions, where the stress profile is generally nonlinear and often very steep. The stress profile was represented by a cubic polynomial:

$$\sigma(x) = A_0 + A_1 x + A_2 x^2 + A_3 x^3$$

where

A_0, A_1, A_2, and A_3 are stress profile curve fitting coefficients

x is the coordinate distance into the wall

σ is the stress perpendicular to the plane of the crack

The stress intensity factor of Raju and Newman [4] was used to evaluate the surface flaw. The following expression is used for calculating K_I:

$$K_I = \left[\frac{a}{Q}\right]^{0.5}\left[G_0A_0 + G_1A_1a + G_2A_2a^2 + G_3A_3a^3\right]$$

where G_0, G_1, G_2, and G_3 are magnification factors [4]

$$Q^{1/2} = \int_0^{\pi/2} \left[\cos^2\phi + \frac{a^2}{c^2}\sin^2\phi \right]^{0.5} d\phi$$

ϕ = parametric angle of ellipse

a = flaw depth

c = one-half flaw length

7. FRACTURE TOUGHNESS

An essential element in the determination of critical flaw sizes is the fracture toughness of the material. The fracture toughness has been taken directly from the reference curves of Appendix A, Section XI of the ASME Code [7]. In the transition temperature region, these curves can be represented by the following equations:

$$K_{Ic} = 33.2 + 2.806 \text{ exp. } [0.02 \ (T\text{-}RT_{NDT} + 100°F)]$$
$$K_{Ia} = 26.8 + 1.223 \text{ exp. } [0.0145 \ (T\text{-}RT_{NDT} + 160°F)]$$

where K_{Ic} and K_{Ia} are in ksi$\sqrt{\text{in.}}$.

The upper shelf temperature regime requires utilization of a shelf toughness which is not specified in the ASME Code. A value of 200 ksi$\sqrt{\text{in}}$ has been used here. [

]a,c,e

The other key element on the determination of the fracture toughness is the value of RT_{NDT} which is a parameter determined from Charpy V-notch and drop-weight tests. [

]a,c,e The tank material (SA 516 Grade 70) was not required to have Charpy tests, so no direct Charpy information is available. [ ]a,c,e

[

]a,c,e

[

]a,c,e

8. FATIGUE CRACK GROWTH

The accumulator tank environment is basically the same as that of the primary coolant system, with a nitrogen blanket to ensure low oxygen levels, as discussed further in Section 10.1. [

]a,c,e

The fatigue crack growth analysis procedure involves postulating an initial flaw at specific regions and predicting the growth of that flaw due to an imposed series of loading transients. The input required for a fatigue crack growth analysis is basically the information necessary to calculate the parameter ΔK_I which depends on crack and structure geometry and the range of applied stresses in the area where the crack exists. Once ΔK_I is calculated, the growth due to that particular stress cycle can be calculated by equations given in the following section and in Figure 8-1. This increment of growth is then added to the original crack size, and the analysis proceeds to the next transient. The procedure is continued in this manner until all the transients known to occur in the period of evaluation have been analyzed.

The transients considered in the analysis are listed in Table 1, and they were obtained from reference 3. [

]^{a,c,e} Crack growth calculations were carried out for a range of surface indications, using the stresses in Table 2.

8.1 Crack Growth Rate Reference Curves

The crack growth rate curves used in the analyses were taken directly from Appendix A of Section XI of the ASME Code. Water environment curves were used for the postulated inside surface flaws. [

]^{a,c,e}

For water environments the reference crack growth curves are shown in Figure 8-1, and growth rate is a function of both the applied stress intensity factor range, and the R ratio (K_{min}/K_{max}) for the transient.

For R < 0.25

$$\left(\Delta K_I < 19\ \text{ksi}\sqrt{\text{in}}\right)\ \frac{da}{dN} = \left(1.02 \times 10^{-6}\right) \Delta K_I^{5.95}$$

$$\left(\Delta K_I > 19\ \text{ksi}\sqrt{\text{in}}\right)\ \frac{da}{dN} = \left(1.01 \times 10^{-1}\right) \Delta K_I^{1.95}$$

where $\frac{da}{dN}$ = crack growth rate, micro-inches/cycle.

For R > 0.65

$$\left(\Delta K_I < 12\ \text{ksi}\sqrt{\text{in}}\right)\ \frac{da}{dN} = \left(1.20 \times 10^{-5}\right) \Delta K_I^{5.95}$$

$$\left(\Delta K_I > 12\ \text{ksi}\sqrt{\text{in}}\right)\ \frac{da}{dN} = \left(2.52 \times 10^{-1}\right) \Delta K_I^{1.95}$$

For R ratio between these two extremes, interpolation is recommended.

8.2 Fatigue Crack Growth Results

Table 3 gives the fatigue crack growth results for a range of surface flaws. This table shows that the crack growth is small enough to be neglected in the fracture analysis. Therefore, the fracture analysis in Section 9 to determine the largest acceptable flaw sizes was carried out without consideration of fatigue crack growth.

9. FRACTURE RESULTS: ACCEPTABLE FLAW SIZE

To determine the largest acceptable flaw sizes for the safety injection accumulator tanks, two sets of calculations were carried out, one for the cylindrical shell region, and a second for the hemispherical head region. The results for each region have been presented in the form of charts which show the largest flaw of a given shape which meets the Section XI acceptance criteria for evaluation, as contained in paragraph IWB 3600.

9.1 Description of the Flaw Evaluation Charts

The charts are shown in Figures 9-1 through 9-3, for the cylindrical shell and hemispherical head regions, respectively. [

]a,c,e Each chart is developed with two dimensionless parameters, which together describe the complete range of possible flaw shapes. They are:

- Flaw Shape Parameter a/l
- Flaw Depth Parameter a/t

where:

t = wall thickness of tank, including carbon and stainless steel
a = flaw depth, in.
l = flaw length, in.

[

]a,c,e

9.2 Use of the Charts

When an indication is discovered, it must be characterized as to its length (l) and depth (a). The following two parameters are then calculated:

- Flaw Shape Parameter a/l
- Flaw Depth Parameter a/t

Once these parameters have been determined, a point is determined and simply plotted on the appropriate chart. Let us illustrate with an example from the indications found by the recent examinations. [

]a,c,e

10. OTHER CONCERNS

10.1 Corrosion of Exposed Carbon Steel

It has been confirmed that some of the flaws discovered in the stainless steel do extend to the base metal, exposing the carbon steel to the borated water environment. Service experience has shown that very high concentrations of boron in water can erode carbon steel. This has happened in boron injection tanks, and at the outside of reactor vessel top head regions where the reactor coolant boiled and concentrated itself.

[

]a,c,e

[

]^{a,c,e}

Also, at least twenty boiling water reactors have operated for periods in excess of ten years with the cladding removed from their feedwater nozzle regions, with no detrimental effects.

From this extensive service experience it may be concluded that there is no cause for concern even for cracks which have extended to the clad-base metal interface.

10.2 Code Compliance With Respect to Wall Thickness

The design of these accumulator tanks has included the thickness of the roll-bonded stainless steel as part of the structural portion of the tank, to satisfy the thickness requirements of the design. The question which may be asked is whether the full thickness of the stainless steel is actually required to meet the code design rules. [

]^{a,c,e}

The tank is classified as Class 2, and the ASME Code Section III has special rules for localized regions, in Table NC 3321-1. Specifically the requirement is

$$\sigma_L + \sigma_b < 1.5\ S$$

where

σ_L = local membrane stress

σ_b = local bending stress

S = allowable stress (17,500 psi for the carbon steel at 300°F)

[

]a,c,e

11. SUMMARY AND CONCLUSIONS

As a result of recent inspection findings, an engineering evaluation has been completed to consider the effect of the small cracks in the stainless steel on the integrity of the tanks. Both fatigue crack growth and fracture calculations have been completed for the tanks, and the results are presented in terms of allowable flaw size charts for a range of operating temperatures. The criteria of ASME Section XI were used to construct these charts, which show that the cracks which remain in the tank need not be repaired.

As a separate consideration, calculations were made to determine the required carbon steel wall thickness in the tanks. Results showed that the criteria of Section III could be satisfied with the original base metal thickness.

In conclusion, it is recommended that the existing indications in the stainless steel be left as is without grinding or repair. There is no need for further action.

12. REFERENCES

1. Tank-Accumulator - 138" OD x 8'-1.75", Westinghouse Drawings D-41048, Rev. 4 and D-41049, Rev. 3.

2. Tank-Accumulator - 138" OD x 8'-1.75", Westinghouse Drawings D-41058, D-41059, Rev. 2, June 1970.

3. Auxiliary Pressure Vessel Equipment Data Sheet #EDS-AT-012, June 1974.

4. Newman, J. C. Jr. and Raju, I. S., "Stress Intensity Factors for Internal Surface Cracks in Cylindrical Pressure Vessels," ASME Trans. Journal of Pressure Vessel Technology, Vol. 102, 1980, pp. 342-346.

5. Marston, T. U. et. "Flaw Evaluation Procedures: ASME Section XI", Electric Power Research Institute Report EPRI-NP-719-SR, August 1978.

6. USNRC Standard Review Plan, NUREG 0800, July 1981.

7. ASME Code Section XI, "Rules for Inservice Inspection of Nuclear Power Plant Components, 1992 Edition.

8. E. Nelson, Pacific Gas and Electric, personal communication to W. Bamford, April 6, 1993.

TABLE 1

ACCUMULATOR TANK NORMAL CONDITION TRANSIENTS [3]
(UPSET AND TEST CONDITIONS INCLUSIVE)

TRANSIENT TITLE	PRESSURE TRANSIENT (PSIG)	NUMBER OF CYCLES
I. Test Condition		a,c,e
A. Inservice Pressure Test		
II. Operating Conditions		
A. Pressure Variations		
B. Accumulator Discharge		

TABLE 2

STRESS PROFILES USED IN FRACTURE ANALYSIS

DISTANCE FROM THE INSIDE SURFACE (a/t)	AXIAL STRESS (KSI)	HOOP STRESS (KSI)
	SPHERICAL HEAD	a,c,e
0		
0.2		
0.4		
0.6		
0.8		
1.0		
	CYLINDRICAL SHELL	a,c,e
0		
0.2		
0.4		
0.6		
0.8		
1.0		

TABLE 3

FATIGUE CRACK GROWTH RESULTS FOR SURFACE FLAWS

INITIAL CRACK DEPTH (IN.)	CRACK DEPTH (IN.) AFTER YEAR 10	20	30	40
				a,c,e
0.2				
0.3				
0.4				

TABLE 4
REQUIRED MINIMUM THICKNESS FOR LOCAL REGIONS

REGION	MINIMUM THICKNESS		DESIGN THICKNESS* (BASE METAL ONLY)
	$\sqrt{Rt}$ REGION (1.5 S LIMIT)	LARGER LOCAL REGION (1.1 S LIMIT)	
CYLINDRICAL SHELL	[ ] [a,c,e]	[ ] [a,c,e]	2.59 IN.
HEMISPHERICAL HEAD	[ ] [a,c,e]	[ ] [a,c,e]	1.254 IN.

* This thickness is the original design tank minimum thickness for the carbon steel, to which was added a minimum thickness of 0.156 inches for the cladding.

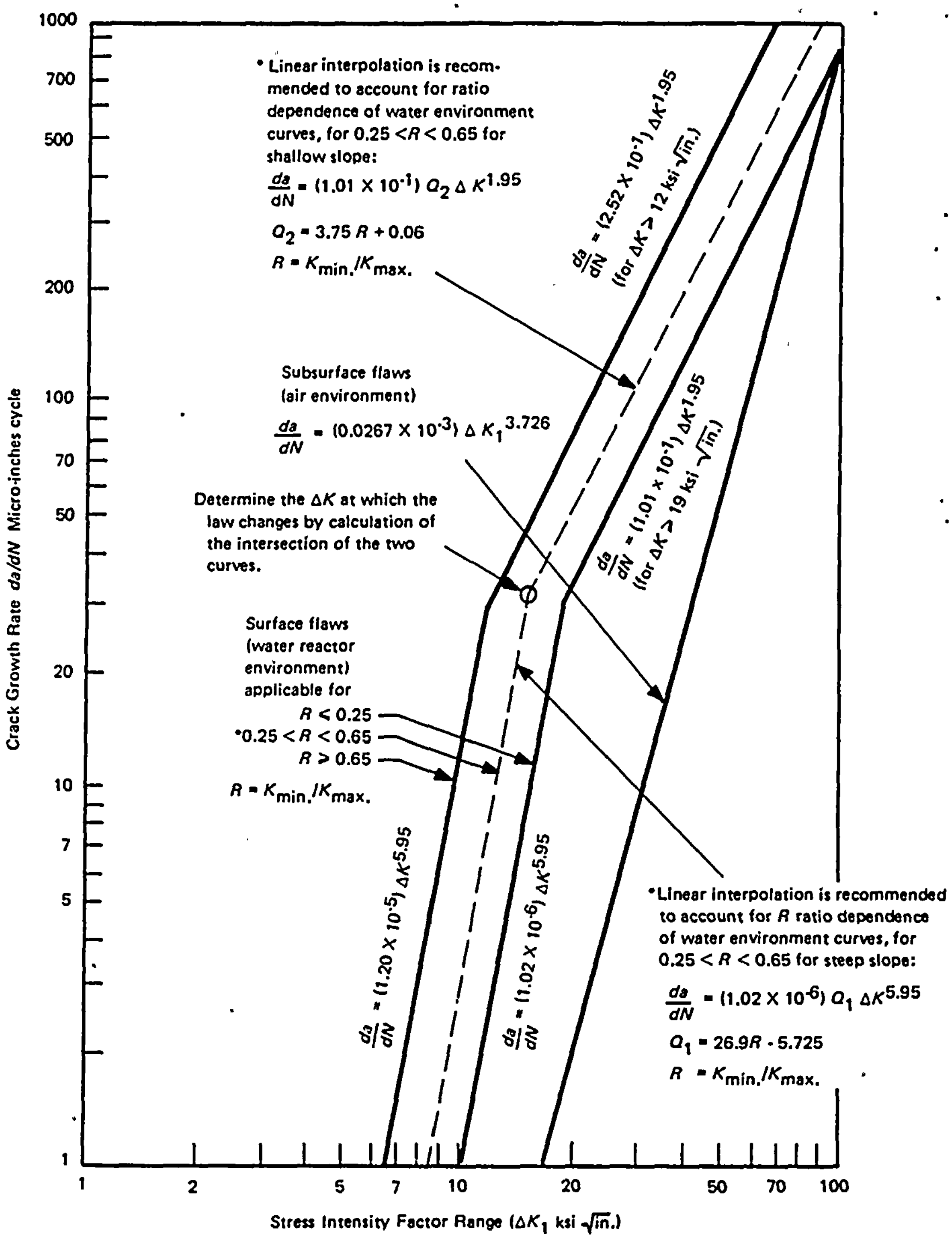

Figure 8-1. Reference Fatigue Crack Growth Curves for Carbon and Low Alloy Ferritic Steels

a,c,e

Figure 9-1. Results for Largest Allowable Flaw Depth: Accumulator Tank Cylindrical Shell Region — Longitudinal Flaws

a,c,e

[ ]

Figure 9-2. Results for Largest Allowable Flaw Depth: Accumulator Tank Cylindrical Shell Region — Circumferential Flaws

a,c,e

Figure 9-3. Results for Largest Allowable Flaw Depth: Accumulator Tank Hemispherical Head Region — Circumferential and Longitudinal Flaws

a,c,e

Figure 9-4. Flaw Evaluation Results for An Existing Indication in the Head Region

APPENDIX A: SUMMARY OF CHARPY INFORMATION FOR SI ACCUMULATORS

The Diablo Canyon accumulator tanks were not ordered to a Charpy requirement, but tanks ordered only a short time later had required Charpy tests. The results should be directly applicable to Diablo Canyon, and therefore have been used to establish the value of RT_{NDT} for the accumulator materials. Results are summarized here for five plants, ordered between 1971 and 1974, a total of 17 accumulator tanks.

The first series of eight tanks belong to two units ordered in 1971, with a required minimum Charpy energy of 20 ft.-lb at 0°F. Three tests were done at 0°F for each heat of A516 Grade 70 in the tank, and the results are shown in Table A-1. From these results, and using the NRC standard review plan [6], the RT_{NDT} can be estimated as no higher than 20°F. These results are considered directly applicable to Diablo Canyon, so RT_{NDT} has been estimated as 20°F.

Another series of Charpy results are available from plants ordered in the 1972-74 time frame, and these results are presented in Table A-2. These tests were done at 60°F, and confirm the high Charpy values expected at that temperature, but unfortunately cannot be used to further verify that RT_{NDT} is equal to 20°F or lower. These additional results are provided for further information.

TABLE A-1

CHARPY RESULTS FOR TANK MATERIALS TESTED AT 0°F

COMPONENT	HEAT NUMBER	CHARPY VALUES* (ft. lb.)	RT_{NDT} (°F)
	UNIT 1 ACCUMULATOR #1		a,c,e
Shell Ring No. 1	C2715-66		
Shell Ring No. 2	C8720-73		
Bottom Head No. 3	B6426-63		
Top Head No. 4	C8692-61		
Heads No. 5	C8692-68		
	UNIT 1 ACCUMULATOR #2		a,c,e
Shell Ring No. 1	C8720-69		
Shell Ring No. 2	A1362-66		
Bottom Head No. 2	B6412-74		
Bottom Head No. 3	B6426-63		
Top Head No. 4	C8692-64		
	UNIT 1 ACCUMULATOR #3		a,c,e
Shell Ring No. 1	A1362-64		
Shell Ring No. 2	C2715-74		
Bottom Head No. 2	B6412-80		
Bottom Head No. 3	B6426-63		
Top Head No. 4	C8692-65		
	UNIT 1 ACCUMULATOR #4		a,c,e
Shell Ring No. 1	C3110-70		
Shell Ring No. 2	A1542-66		
Bottom Head No. 2	B6412-86		
Bottom Head No. 3	B6426-64		
Top Head No. 4	C8692-68		

* Values at 0°F

TABLE A-1 (cont.)

CHARPY RESULTS FOR TANK MATERIALS TESTED AT 0°F

COMPONENT	HEAT NUMBER	CHARPY VALUES* (ft. lb.)	RT_{NDT} (°F)
UNIT 2 ACCUMULATOR #1			a,c,e
Shell Ring No. 1	B6426-70		
Shell Ring No. 2	C2715-80		
Bottom Head No. 2	B6412-81		
Bottom Head No. 3	B6426-64		
Top Head No. 4	C8692-69		
UNIT 2 ACCUMULATOR #2			a,c,e
Shell Ring No. 1	B6426-80		
Shell Ring No. 2	C2715-64		
Bottom Head No. 2	B6678-66		
Bottom Head No. 3	B6426-64		
Top Head No. 4	C8692-60		
UNIT 2 ACCUMULATOR #3			a,c,e
Shell Ring No. 1	C2747-60		
Shell Ring No. 2	B6479-66		
Bottom Head No. 2	B6412-75		
Bottom Head No. 3	B6426-64		
Top Head No. 4	B2670-61		
UNIT 2 ACCUMULATOR #4			a,c,e
Shell Ring No. 1	C8727-80		
Shell Ring No. 2	B6871-70		

TABLE A-1 (cont.)

CHARPY RESULTS FOR TANK MATERIALS TESTED AT 0°F

COMPONENT	HEAT NUMBER	CHARPY VALUES* (ft. lb.)	RT_{NDT} (°F)
			a,c,e
Bottom Head No. 2	B6842-67		
	B6412-86		
	B6412-75		
	B6412-81		
	B6678-66		
	B6412-80		
Bottom Head No. 3	B6426-63		
Top Head No. 4	B2670-60		

* Values at 0°F

TABLE A-2

COMPONENT	HEAT NUMBER	CHARPY VALUES* (ft. lb.)
	UNIT 3 ACCUMULATOR #1	a,c,e
Shell Ring	C4899	[ ]
Top Head	D0758	
Bottom Head	A3514	
	UNIT 3 ACCUMULATOR #2	a,c,e
Shell Ring	C4899	[ ]
Top Head	A3661	
Bottom Head	A3490	
	UNIT 3 ACCUMULATOR #3	a,c,e
Shell Ring	C4940	[ ]
Top Head	D0758	
Bottom Head	A3490	
	UNIT 4 ACCUMULATOR #1	a,c,e
Shell Ring	C4899	[ ]
Top Head	A3306	
Bottom Head	A3306	
	UNIT 4 ACCUMULATOR #2	a,c,e
Shell Ring	B8866	[ ]
Top Head	A3490	
Bottom Head	A3306	

* Values at 60°F

TABLE A-2 (cont)

COMPONENT	HEAT NUMBER	CHARPY VALUES* (ft. lb.)
	UNIT 4 ACCUMULATOR #3	a,c,e
Shell Ring	C4940	
Top Head	D0758	
Bottom Head	A3490	
	UNIT 5 ACCUMULATOR #1	a,c,e
Shell Ring	C4715	
Top Head	D0759	
Bottom Head	D0758	
	UNIT 5 ACCUMULATOR #2	a,c,e
Shell Ring	D0759	
Top Head	D0758	
Bottom Head	D0758	
	UNIT 5 ACCUMULATOR #3	a,c,e
Shell Ring	B8748	
Top Head	A3306	
Bottom Head	D0758	

* Values at 60°F

APPENDIX B: DELTA SOUTHERN DESIGN CALCULATIONS FOR THE DIABLO CANYON ACCUMULATOR TANKS

This series of calculation pages was retrieved from the microfiche records at Westinghouse for the Diablo Canyon tanks. These calculations are provided for reference.

DELTA SOUTHERN CO.

PRESSURE VESSEL CALCULATIONS

S.O. 41143	JGC-1
SHT. 1 OF ___	
BY [illegible]	
DATE [illegible]	

215/5

CUSTOMER Westinghouse A.P.D.

P.O. NO. 54-E-70616-E ITEM [illegible]

DESCRIPTION 138" O.D. x 97 1/4" S.M.-S.M. Accumulator

DESIGN COND. 700 PSIG @ 300 °F. W/ 0 C.A.

SPECIFICATIONS ASME Code Sec. III and E-679122

PGE-215-A-8

SUMMARY { MAWP 700 PSIG @ 300 °F. LIMITED BY Heads
HYDRO (1.5)(707.9) = 1062 PSIG LIMITED BY Design

ASA FLANGES 400 # FF MAT'L. A-181-1 — ASA B16.5

RATINGS: 910 PSIG @ 300 °F. 960 PSIG @ 100 °F.

___ SHELL-JT. EFF. [illegible] MAT'L. A-516-70 with 3/32" 304L clad

$t = \frac{PR_o}{SE + .4P} = \frac{700\ (69.0)}{17,500 + 280} = \frac{}{17,780} = 2.7165$

$+ .0131$ C.A.

2.7299

USE $\boxed{2\ 3/4\text{" TOTAL THK.}}$ — UG-27B UA-1

$P_D = \frac{SEt}{R_o - .4t} = \frac{17,500\ (2.7366)}{69 - 1.0946} = \frac{}{67.9054} = 705$ PSI

$P_{NC} = \frac{SEt}{R_o - .4t} = \frac{17,500\ (2.75)}{69 - 1.1} = \frac{}{67.9} = 708$ PSI

___ HEAD-TYPE Hemi 100% MAT'L. A-516-70 with 3/32" 304L clad

$t = \frac{PR_o}{2SE + 1.8P} = \frac{700\ (68.33)}{35,000 + 560} = \frac{}{35560} = 1.3451$

$+ .01$ C.A.

1.4099

USE $\boxed{1.41\text{ TOT. NOM. THK}}$ — UG-32B UA-4

$P_D = \frac{2SEt}{R_o - .8t} = \frac{35000\ (1.3466)}{68.33 - .8(1.3466)} = \frac{}{67.2527} = 700$ PSI

$P_{NC} = \frac{2SEt}{R_o - .8t} = \frac{35000\ (1.36)}{68.33 - 1.088} = \frac{}{67.242} = 707.9$ PSI

CODE F&D HEADS ONLY — L = ______ r = ______

$M_D = 1/4\,(3 + \sqrt{(L+C)/(r+C)}) = 1/4\,(3 + \_\_\_\_) = \_\_\_\_$

$M_{NC} = 1/4\,(3 + \sqrt{L/r}) = 1/4\,(3 + \_\_\_\_) = \_\_\_\_$

5/32 (17,000/17,500) = .1428 ... = 5/32 - .1428 = .0138 ... effective

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BATON ROUGE, LOUISIANA, U.S.A.

SO 41248
SHT. 2 OF

DIMENSIONS OF VESSEL

TOTAL CAPACITY = 1350 FT^3

CAPACITY OF HEMI HEADS

$$VOL = \frac{1/3\,\pi\,(57.4825)^2\,[3(66.92) - 57.4825]}{1728}$$

VOL = 286.9 FT^3 EACH

CAPACITY OF SHELL/FT.

$$= \pi\,(66.25)^2/144 = 95.75\ FT^3/FT$$

LENGTH OF SHELL REQUIRED FOR 1350 FT^3

$$= \frac{1350 - 2(286.9)}{95.75} = 8.1065\ FT.$$

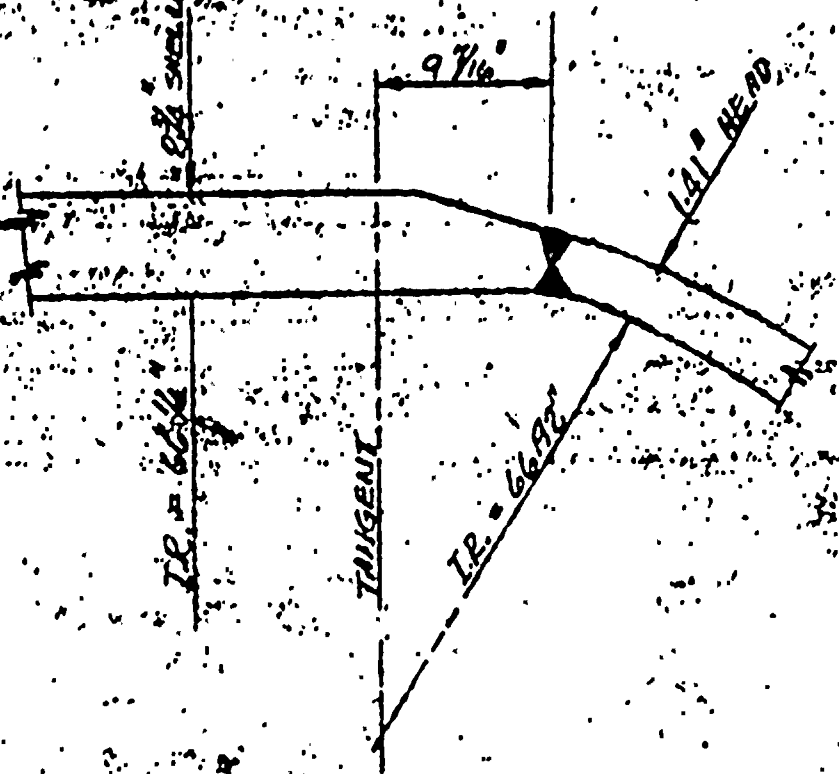
SAY 8 FT. 1¼ IN.

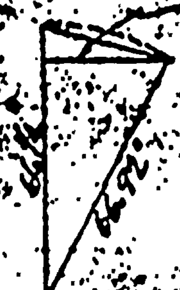
OAL = 97¼ + 2(57.5) + 2(1.41) = 215.07 IN.

SAY 17 FT. 11 1/16 IN.

PG-E-25

HEAD TO SHELL PREP.





$d = \sqrt{(66.92)^2 - (66.25)^2} = 9.4458$

Use $d = 9\frac{7}{16}''$

PGE-215

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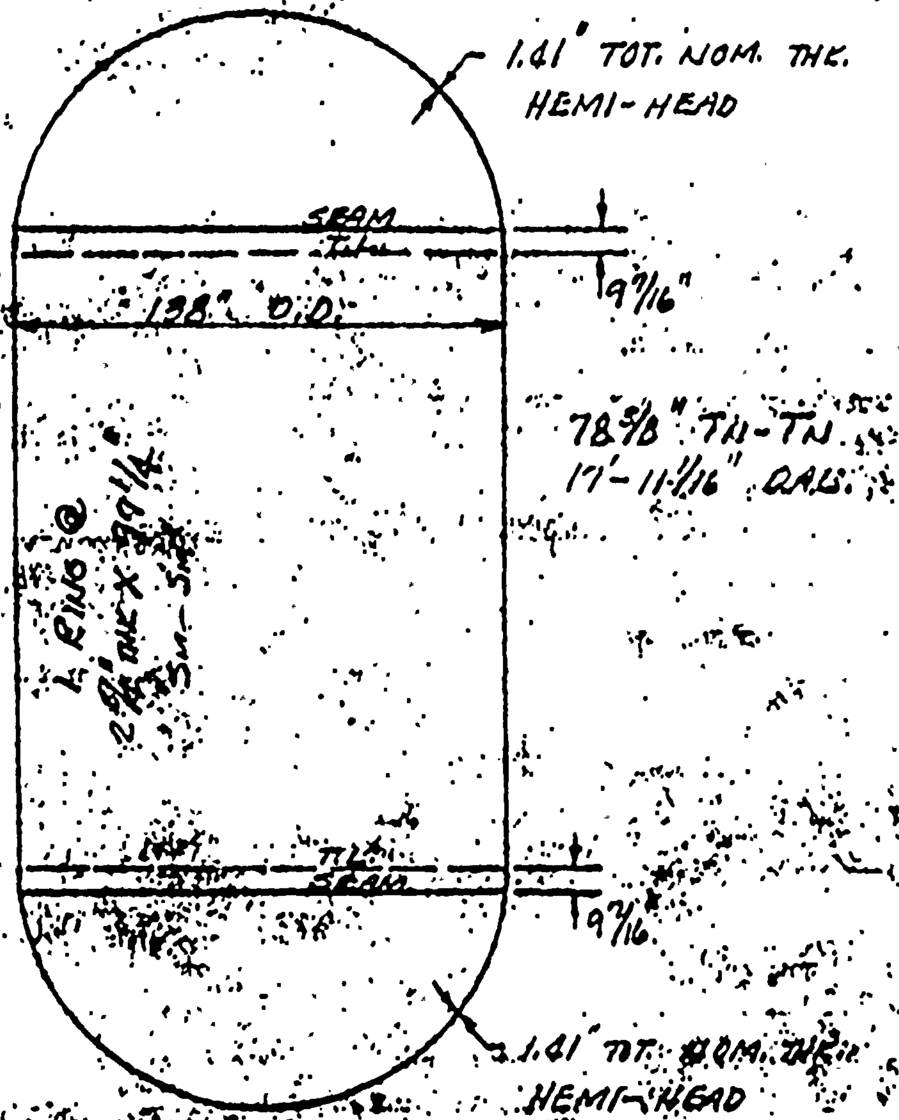
SQ 41048
SHT. 4 OF

WESTINGHOUSE A.P.D.
OCT. 1968



PGB-215

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BATON ROUGE, LOUISIANA, U.S.A.

S.O. 41648
SHT. 1 OF

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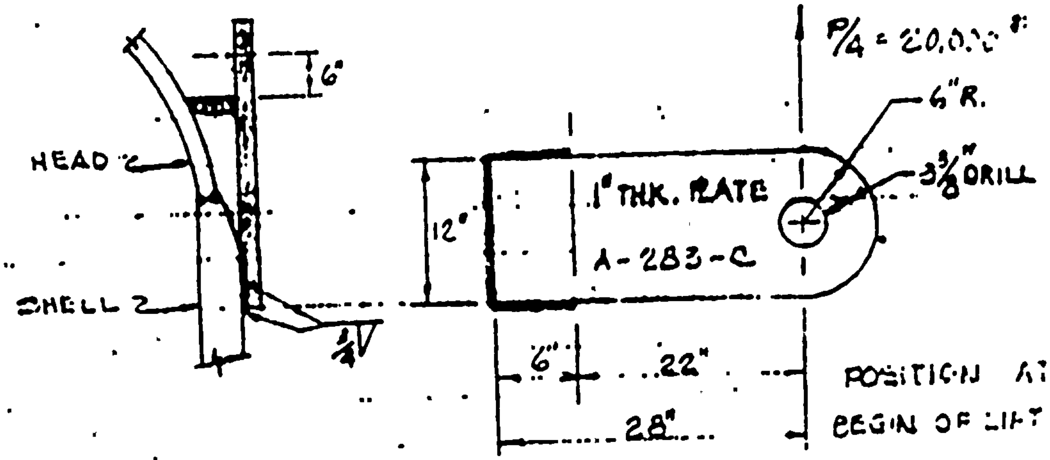
OCT. 1968

LIFTING LUG DESIGN

REF: A.I.S.C. (ECCENTRIC LOADS ON WELD GROUPS)



DESIGN WT. = $P/4 = 80{,}000/4 = 20{,}000$ #
ACTING ON EACH LUG AT BEGIN OF LIFT.

$t_{SHELL} = 2\,3/4$ IN.

CLAIM 3/4" WELD (LUG TO SHELL WELD)

l = LUG WIDTH = 12 IN.

D = NO. OF 16^{THS} IN. OF WELD. = 12.

kl = HORIZONTAL WELD ON END OF LUG = 6 IN.

$k = 6/l = 6/12 = 1/2$

PGE-215-A-8

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S.O. 41048
SHT. 2 OF

L = TOTAL LENGTH OF WELD.

$k = k^2 l / L = .25 (12) / 24 = .125$

$kl = 1.5$

$al = A - kl = 28 - 1.5 = 26.5$

$a = 26.5 / 12 = 2.2083$

C = .152 (FROM TABLE IN A.I.S.C)

$P/4 = C D L = .152 (12) 12 = 21.888$ KIPS

$P/4 = 21,888\# > 20,000\#$ OK

CHECK SHEAR THRU WELD

WELD LENGTH = 24 IN.

$AREA_{WELD} = 3/4 (24) .707 (47) = 6.23 \ IN^2$

LOAD = $P/2 = 40,000\#$ (EACH LUG)

$S = F/A = 40,000 / 6.23$

PGE-215

S = 6421 PSI < 12,650 PSI OK

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S.O. 41048
SHT. 3 OF ___

CHECK TEARING THRU HOLE

$1.0 \times \left[6 - \frac{3\frac{3}{8}}{2}\right] = 4.3125 \text{ IN}^2$

(AREA ABOVE HOLE)

$S = F/A = 40{,}000/4.3125$

$S = 9{,}275 \text{ PSI} < 12{,}650 \text{ PSI}$ OK

USE 1 IN. THK. PL. FOR LUG A-[illegible] USE 3/4 IN. WELD AROUND LUG

PG E-215

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NOTE: ONLY THOSE OPENINGS HAVING "LIMITS OF REINFORCEMENT" LOCATED WITHIN THE PRESCRIBED BOUNDARIES OF THE FORMULAE (PAR. UG-37) AND NOT REQUIRING CONSIDERATION AS "MULTIPLE OPENINGS" (PAR. UG-42) MAY BE INVESTIGATED ON THIS FORM. ADJUSTMENT SHALL BE MADE IF THE "ALLOWABLE STRESS" OF THE SHELL OR HEAD MATERIAL EXCEEDS THAT OF THE REINFORCEMENT (PAR. UG-41).

A_x = AREA OF REINFORCEMENT REQUIRED OTHER THAN FROM THE SHELL OR HEAD.

t_a = THK @ AMBIENT TEMP.
t_d = THK @ DESIGN TEMP.

C.A. = 0		SHELL – t_a = 2.75 t_d = 2.7366	HEAD – t_a = 1.36 t_d = 1.3466
INTERNAL PRESSURE	DESIGN 700 PSIG @ 300 °F	$t_r = \frac{PR_o}{S+.4P} = \frac{700(69)}{17,500+.4(700)}$ = $\frac{}{17,780}$ = 2.7162 $A_x = (2t_r - t_d)d_c$ = (2.6964) d_c	$t_r = \frac{PR_o}{2S+.8P} = \frac{700(68.33)}{35,000+.8(700)}$ = $\frac{}{35,560}$ = 1.3450 $A_x = (2t_r - t_d)d_c$ = (1.3434) d_c
	NEW & COLD 707.9 PSIG @ 100 °F	$t_r = \frac{PR_o}{S+.4P} = \frac{707.9(69)}{17,500+.4(707.9)}$ = $\frac{}{17,783.16}$ = 2.7467 $A_x = (2t_r - t_a)d_n$ = (2.7434) d_n	$t_r = \frac{PR_o}{2S+.8P} = \frac{707.9(68.33)}{35,000+.8(707.9)}$ = $\frac{}{35,566.32}$ = 1.3600 $A_x = (2t_r - t_a)d_n$ = (1.3600) d_n
EXT PRESSURE	DESIGN 60 PSI @ 300 °F	L = D_o = t_r = < t_d B = $\frac{L}{D_o}$ = $\frac{D_o}{t_r}$ = $P_a = \frac{B}{D_o/t_r}$ = PSI $A_x = (1/2 t_r - t_c)d_c$ = (—) d_c	L = t_r = < t_d B = $P_a = \frac{B}{L/t_r}$ = PSI $A_x = (1/2 t_r - t_c)d_c$ = (—) d_c

OPEN'G	HD/SH	SIZE	NECK	DESIGN d_c	DESIGN A_x	NEW & COLD d_n	NEW & COLD A_x	REINFORCEMENT OD = $A_x/t_p + d_o$
A	HEAD	1"	2000# CPLG.		No Pad Required			—
B	HEAD	1"	2000# CPLG.		No Pad Required			—
C, C	SHELL	2"	2000# CPLG.		No Pad Required			—
D	HEAD	3/4"	2000# CPLG.		No Pad Required			—
E	HEAD	10"	SS FORGING SCH 80 [illegible]				See SHT. B & C	
[illegible]	HEAD	[illegible]	2000# CPLG.		No Pad Required			—
F	SHELL	16"	[illegible] OUTLETS				See SHT. D	

REMARKS:

PGE-275-A-8

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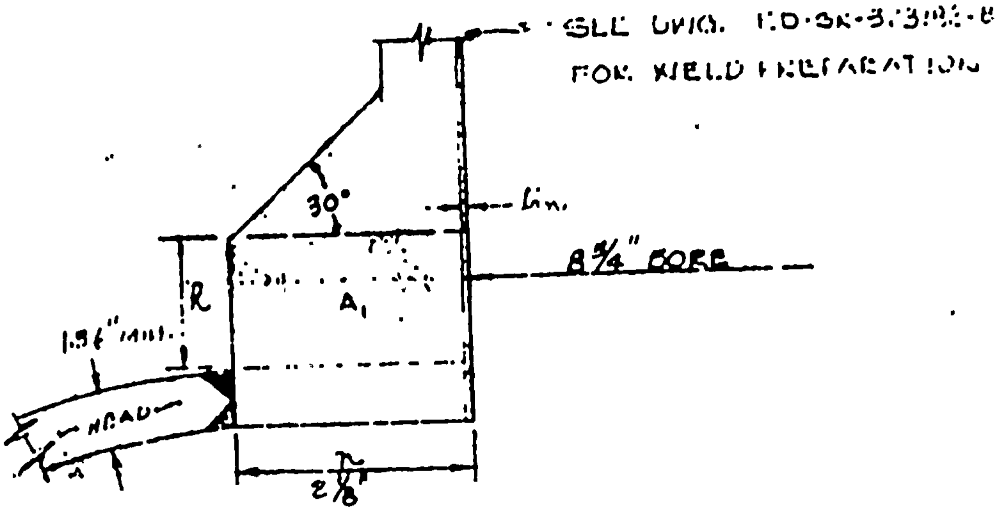
SO 41048
SHT. 8 OF

NOZZLE "E" - 10" SCH. [illegible]
A-182 TYPE 304 L
FORGING

WESTINGHOUSE AHM.
OCT. 1969



S_{ALLOW} @ 300°F = 15,400 PSI

$A_{REQD} = 8\,3/4\ (1.3434) = 11.7547\ IN^2$ MIN $\qquad A_1$

$t_{rn} = \frac{708\ (8.75)}{30,800 - 1.2(708)} = .2068$ IN.

REINF LIMIT = 2.5 (1.41) = 3.5250 IN.

AVAILABLE AREA:

$11.7547 = 2R\,(t_n - t_{rn})\ \frac{15,400}{17,500}$ — nozzle allowable / head allowable

USE t_n = 2 1/8 IN.

THEN:

$R = 11.7547 \,/\, 2\left(2\tfrac{1}{8} - .2068\right)\frac{15,400}{17,500} = 3.4818$ IN.

PG-E-215

USE R = [illegible]

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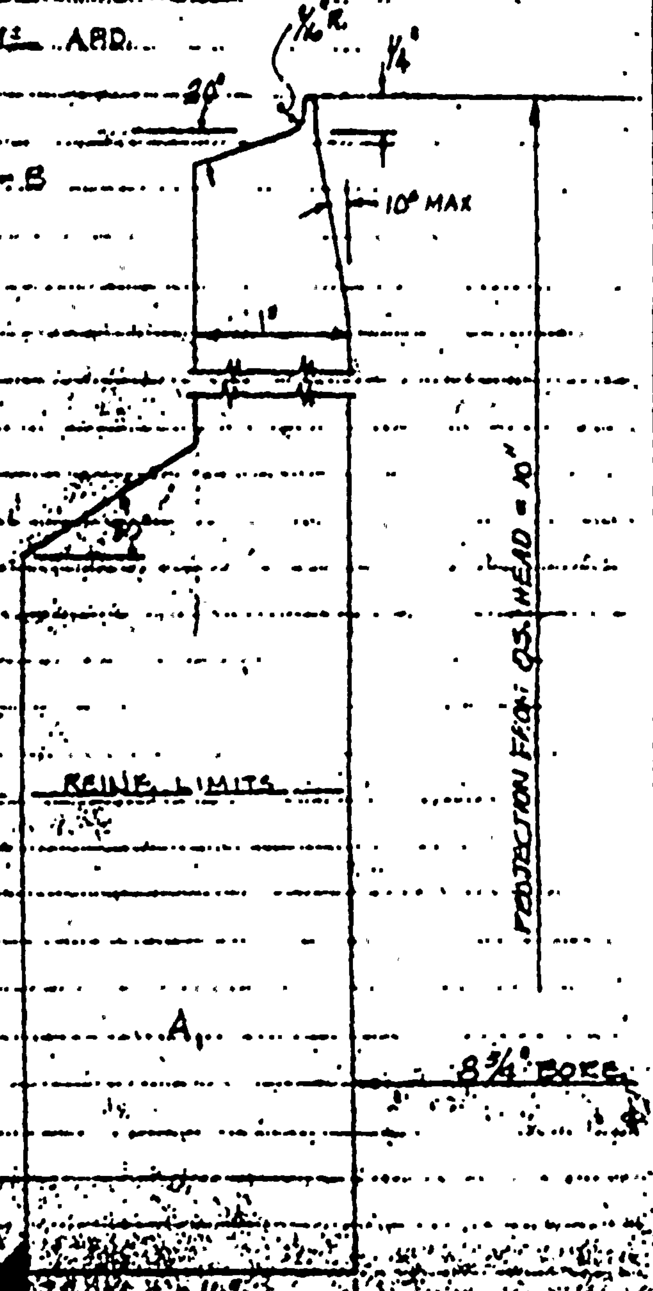
SO 41048
SHT. c OF

NOZZLE "E" - 10" SCH. 160 CONE
FOR: WESTINGHOUSE ARD.

END WELD PREP.
PER ED-SK-323182-B

PROJECTION = 10"
HEAD = 1.41
DROP-OFF = .372
11.785

ORDER: A-182 TYPE
304L FORGING
8¾" I.D. X 13" O.D. X
11 13/16" MIN. LG.



AGE-225

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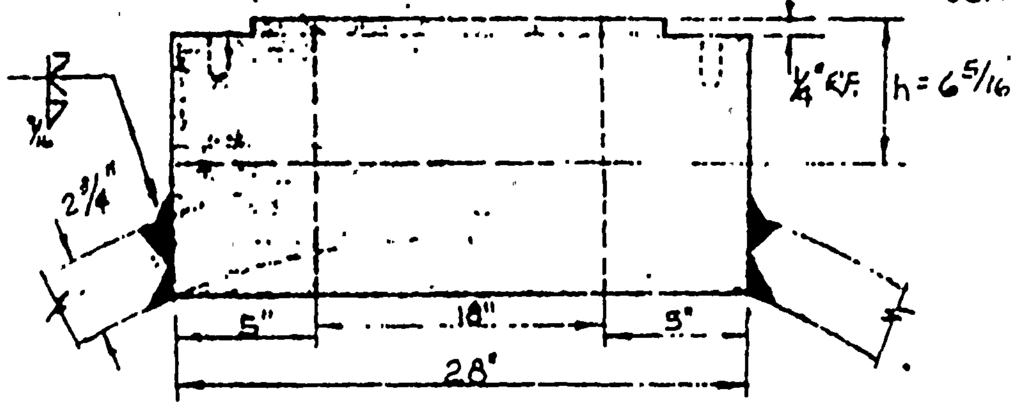
SO. 41048
SHT. D OF

NOZZLE "F" - 40J* LENAPE STUDDING OUTLET
A-105-2 w/304 L CLAD
WESTINGHOUSE A.P.D.



DESIGN

$t_m = \frac{700(18)}{35000 - 1.2(700)} = .3688$

$d t_r = 18(2.7165) = 48.8970$
STUD AREA (2) = 6.20
AREA TO REPLACE: 55.0970

[28-18-2(.3688)] h = 55.0970

h = 5.9434 IN. + RF

NEW & COLD

$t_m = \frac{705(18)}{35000 - 1.2(708)} = .3731$

$d t_r = 18(2.7467) = 49.4406$
6.20
55.6406

[28-18-2(.3731)] h = 55.6406

h = 6.0127 IN. + RF

PGE-215

NOTE TO DRAFTSMAN:
ORDER LENGTH OF 10 9/16" TO
INCLUDE 1/4" R.F. & 1 1/2" DROP.

USE h = 6 5/16 IN.
1/4" R.F. IS INCLUDED IN "h"
FINISHED I.D. = 17 11/16"