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APR 16 1993

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Gentlemen:

In the Matter of the Application of	)	Docket Nos. 50-390
Tennessee Valley Authority	)	50-391

WATTS BAR NUCLEAR PLANT (WBN) - 10 CFR 50.55a(a)(3)(ii) - PROPOSED ALTERNATIVE TO THE INSERVICE REQUIREMENTS OF SECTION XI OF AMERICAN SOCIETY OF MECHANICAL ENGINEERS (ASME) BOILER AND PRESSURE VESSEL CODE

During the replacement of a sample line nozzle in Accumulator Tank No. 3, TVA identified several linear indications in the tank cladding. Pursuant to 10 CFR 50.55a(a)(3)(ii), as discussed in our March 25, 1993 meeting, TVA is requesting NRC authorization to apply the fracture mechanics methodology of ASME Section XI, "Rules for Inservice Inspection of Nuclear Power Plant Components," to these linear indications. TVA has determined that reverting to the specified requirements of ASME Section III would result in hardship and unusual difficulty without a compensating increase in the level of quality and safety.

The attached enclosure is a description of the proposed alternative, including the justification.

If you have any questions, please telephone P. L. Pace at (615) 365-1824.

Very truly yours,

W. J. Museler

William J. Museler

Enclosure
cc: See page 2

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ENCLOSURE
PROPOSED ALTERNATIVE TO THE FLAW
ACCEPTANCE REQUIREMENTS OF SECTION III
AND THE SECTION XI INSERVICE REQUIREMENTS

The safety injection accumulator tanks (4 per unit) for Watts Bar are 10 feet in diameter and approximately 23 feet high. Each tank is constructed of SA516 Grade 70 carbon steel with SA240 Type 304 stainless steel roll bonded cladding. The subject tanks were designed by Westinghouse to the ASME Code Section III, 1971 Edition, Winter 71 Addenda, and fabricated by Delta Southern. Each tank during plant operation will contain diluted boric acid with a pressurized nonreactive cover gas (nitrogen) over it. The specified design temperature is 300°F, with a design pressure of 700 psi. The operating temperature ranges from 60-150°F with an operating pressure of 626-660 psig. The borated water in each tank is forced into the appropriate cold leg once the reactor coolant system pressure drops below that in the accumulator tank. For medium to large loss of coolant accidents (LOCA), the contents of three of the four tanks are needed to meet initial core cooling requirements.

During the replacement of the sample line nozzle to the Unit 1 Accumulator Tank No. 3, linear indications in the cladding were identified. When the nozzle to the tank weld preparation was penetrant inspected, the examination revealed linear indications approximately one and one-half inches away from the periphery of the weld on the inside of the tank. The indications were identified only in the cladding material; the new weld joining the nozzle to the tank was clear of any indications. Penetrant inspection to determine extent of condition revealed additional indications near the nozzle, and adjacent to the welds joining the lower head sections. (The lower head is fabricated from six orange peel sections). One of the areas containing indications was further examined by in-situ metallography which revealed a severely sensitized grain structure in the stainless cladding. Fabrication records indicate that the cladding material had been exposed to as many as four heating operations; hot roll bonding, plate stress relief, and two post weld heat treatments.

Initial penetrant testing revealed that the indications were only present in two of the six orange peel sections, and predominantly in the section containing the sample line nozzle and the one adjacent section.

Grinding on the indications as well as ultrasonic inspection from the inside surface of the tank revealed that the indications extended to the cladding - carbon steel interface, but not beyond. The ultrasonic inspection as well as measurements of the excavation depths both confirmed the actual cladding thickness to be approximately .156 inches nominal.

TVA began to repair these initial indications in an effort to meet ASME Section III requirements. The technique used was to remove the cladding material containing the indications and replace it with weld metal. Several of the areas were excavated. The excavations, from removing the indications, only extended down to the carbon steel, but they extended horizonal beyond the original detected areas. Excavation and welding seemed to produce additional indications in adjacent cladded areas previously free of indications. Therefore, the

excavations covered a larger area than expected before they finally passed a penetrant inspection within the cavity and on the cladding material surrounding the cavity. Weld repairs then commenced on these areas.

After the first layer of weld material had been deposited, a penetrant examination was performed. This examination revealed new indications on the cladding surface adjacent to the excavation. It was obvious that new indications were being initiated in the sensitized cladding as a result of the shrinkage stresses from the welding operation. In some cases indications appeared after excavating an adjacent area.

At this point, TVA elected to complete the weld repair of the excavated areas by adding at least one layer of stainless steel weld material and pursue resolution of the remaining indications by means of a fracture mechanics analysis in accordance with of Section XI of the ASME Boiler and Pressure Vessel Code. A schematic map of the indications by area which remain in tank No. 3 of Unit 1 is shown in Figure 2-1.

TVA, in conjunction with Westinghouse, developed the following analysis:

1. Flaw Geometry

   An evaluation was performed for surface flaws in both the cladding and the base metal of 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.

2. Criteria for Flaw Acceptability: Section XI

   Section XI of the ASME Code provides acceptance criteria for flaw indications found during inservice inspection and operation. Since the accumulator tanks met the requirements of the Construction Code and received their N-stamp, Section XI criteria has been employed. There are presently no criteria in Section XI for Class 2 components, so this evaluation used the Class 1 criteria. This added 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 of the accumulator tank could be considered acceptable in their present condition. However, originally the cladding thickness was used by Westinghouse as part of the design thickness of the tank in demonstrating compliance with Section III. Additional analysis based on the minimum measured carbon steel thickness and the operating parameters at WBN indicate the carbon steel wall thickness alone is sufficient for safe operation.

   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:

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.

2.1 Criteria Based on Stress Intensity Factor

These criteria are from IWB-3612 of Section XI. The term stress intensity factor (K_1) 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_{1a}, K_{1c}) 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:

$K_1 \leq \frac{K_{1a}}{\sqrt{10}}$ for normal conditions (upset and test conditions inclusive)

$K_1 \leq \frac{K_{1c}}{\sqrt{2}}$ for faulted conditions (emergency conditions inclusive)

where

K_1 = The maximum applied stress intensity factor for the flaw size to which a detected flaw will grow, during the condition under consideration, at the end of design life, or to the next inspection.

K_{1a} = Fracture toughness based on crack arrest for the corresponding crack tip temperature.

K_{1c} = Fracture toughness based on fracture initiation for the corresponding crack tip temperature.

2.2 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 local area reduction of the pressure retaining membrane was used, equal to the area of the indication, and the

stresses were increased to reflect the smaller cross section. Using this criterion, the allowable flaw depth is 0.84 inches for the head, and 1.74 inches in the cylindrical shell. The allowable depths calculated based on the criteria of Section 2.1 are more restrictive, and therefore the criteria of Section 2.1 were used in finding the allowable flaw depths. This calculation was included to ensure that integrity would be maintained from the standpoint of ductile failure.

3. LOADS

The design transients are listed in Table 1. This is a Class 2 tank which only functions during safety injection. The loads considered in the analysis are the pressure loads, which are the only operational transients [2]. The pressure goes from 650 psig to 0 psig during the governing transient of Table 1 [2,3]. Further details of this transient are given in the section of this report which discusses the fatigue crack growth evaluation. The conservative design pressure of 700 psig was used in the fracture analysis.

4. 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 [5] was used to evaluate the surface flaw. The following expression is used for calculating K_1:

$$K_1 = \left[\frac{a}{Q}\right]^{0.5} \left[G_0A_0 + G_1A_1a + G_2A_2a^2 + G_3A_3a^3\right]$$

where G_0, G_1, G_2, and G_3 are magnification factors [5]

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

ϕ = parametric angle of ellipse
a = flaw depth
c = one-half flaw length

5. 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. In the transition temperature region, these curves can be represented by the following equations:

$$K_{1c} = 33.2 + 2.806 \exp.[0.02(T-RT_{NDT} + 100°F)]$$

$$K_{1a} = 26.8 + 1.223 \exp. [0.0145 (T-RT_{NDT} + 160°F)]$$

where K_{1c} and K_{1a} 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. This value is consistent with general practice in such evaluations, as shown for example in Reference 6, which provides the background and technical basis for Appendix A of Section XI.

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. For this analysis, it was assumed that the RT_{NDT} was 10°F for the weld material in the accumulator tanks. This is considered to be an upper bound for welds of this type based on earlier work on accumulator tanks and the guarantees which are available from fabricators on vessels of this size. The tank material (SA 516 Grade 70) was required to have a Charpy energy of 20 ft. lb. or greater, when tested at 0°F, as specified in the equipment data sheet. The value of RT_{NDT} for the vessel shell material was determined from the Charpy results shown on the material test certificates, through use of the NRC Standard Review Plan [7]. These results are shown in Table 2. The analysis used a value of RT_{NDT} = 20°F, which is the governing value from Table 2.

6. FATIGUE CRACK GROWTH

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_1, which depends on crack and structure geometry and the range of applied stresses in the area where the crack exists. Once ΔK_1 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. Crack growth calculations were carried out for a range of surface indications.

6.1 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. The water environment in the accumulator tanks is basically the same as primary water, with a boron concentration of nominally 2000 ppm. Therefore, the reference crack growth curves of Section XI will be directly applicable.

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

$$(\Delta K_1 < 19 \text{ ksi } \sqrt{\text{in}}) \quad \frac{da}{dN} = (1.02 \times 10^{-6}) \ \Delta K_1^{5.95}$$

$$(\Delta K_1 > 19 \text{ ksi } \sqrt{\text{in}}) \quad \frac{da}{dN} = (1.01 \times 10^{-1}) \ \Delta K_1^{1.95}$$

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

For R > 0.65

$$(\Delta K_1 < 12 \text{ ksi } \sqrt{\text{in}}) \quad \frac{da}{dN} = (1.20 \times 10^{-5}) \ \Delta K_1^{5.95}$$

$$(\Delta K_1 > 12 \text{ ksi } \sqrt{\text{in}}) \quad \frac{da}{dN} = (2.52 \times 10^{-1}) \ \Delta K_1^{1.95}$$

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

6.2 Fatigue Crack Growth Results

Table 4 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, a fracture analysis to determine the largest acceptable flaw sizes was carried out without consideration of fatigue crack growth.

7. 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 that show the largest flaw of a given shape which meets the Section XI acceptance criteria for evaluation, as contained in paragraph IWB 3600.

7.1 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. Results are shown for a range of tank temperatures, from 60°F to 150°F. The nominal operating temperature of the tank is 110°F. 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.

The cladding has been included in the fracture mechanics calculations, and for ease of use, the allowable flaw depths are presented in the flaw evaluation charts with the depth of the flaw measured from the inside surface of the tank, that is the clad surface.

It is helpful to describe the flaw evaluation charts and their construction steps:

- The flaw shape parameter a/l was plotted as the abscissa, from a value of 0 (continuously long flaw) to 0.5 (semicircular flaw).

- The flaw depth parameter a/t was plotted as the ordinate.

- The curves show the maximum acceptable flaw depth for each of a range of flaw shapes. The most restrictive shape is a continuously long flaw.

- Results are presented for a range of operating temperatures to cover the range of temperatures which could exist in the tanks.

- The charts have been developed for both flaw orientations in the cylindrical shell, circumferential and longitudinal flaws. The stresses in the hemispherical head are equal in both directions, so results for the two directions are equal.

- Any surface indication which is plotted below the curves is acceptable for further operation, having satisfied the criteria of Section XI, IWB 3600.

7.2 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. The length of the longest indication is approximately one inch, while its depth is no greater than the total thickness of the roll bonded clad, or 0.156 inches. The tank thickness in the region is 1.189 inches, so the flaw parameters are:

$a/l = 0.156$
$a/t = 0.131$

The indication was located in the bottom head region, so plotting this point on Figure 9-3 shows this flaw is acceptable for further service. The plotted point demonstrating acceptance is shown as a circle in Figure 9-4.

Even if the indications were to be close enough to each other as to require consideration as a continuous flaw ($a/l = 0.0$), Figure 9-4 shows that this case would also be acceptable. The plotted point is shown as a triangle in the figure.

8. OTHER CONSIDERATIONS

8.1 Corrosion of Exposed Carbon Steel

It has been confirmed that many of the flaws discovered in the stainless steel extend completely through, exposing the carbon steel to the borated water environment. Service experience has shown that 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.

The water in the accumulator tanks contains boron in the range of 1900 to 2100 ppm, with the nominal concentration specified as 2000 ppm. The proof and review technical specification, March 30, 1993, limits the concentration to 2100 ppm. The accumulators operate with a nitrogen blanket, which controls the oxygen to very low levels. There is no mechanism for the borated water to become concentrated inside the tank. Therefore, the water in the tank is basically the same chemistry as the primary coolant.

There are a number of cases where carbon steel has been exposed to primary coolant environments for long periods of time with no detrimental effects. Crack-like indications have been found along the boundaries of adjacent weld-deposited cladding strips in the primary side of steam generators in at least five plants and in a pressurizer in another plant. One reactor vessel has operated for over 20 years with some areas of cladding removed, with no detrimental effects.

Also, at least 20 boiling water reactors have operated for periods in excess of 10 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.

8.2 Code Compliance With Respect to Wall Thickness

The design of these accumulator tanks 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 must be restored in areas where grinding has occurred. The answer is that the full thickness is not required.

The tank is classified as Class 2, and the ASME Code Section III has special rules, 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)

This criterion applies in "local" areas, the size of which is undefined, but the areas of grinding could be considered local for this case. The size of a local region is defined for Class 1 components as a region where the stress exceeds 1.1 S, and this region is limited to a diameter equal to $\sqrt{Rt}$, where R = the tank mean radius, and t = tank thickness. In using these criteria, we will use the 1.5 S limit for the small region whose diameter is $\sqrt{Rt}$, and the 1.1 S limit for the larger local region. The required thicknesses are shown in Table 5.

Referring to Table 5, it may be seen that the required minimum thickness for these local regions is about equal to the original design thickness of the carbon steel, both in the head and cylindrical region. Therefore, the stainless steel need not be returned to its original thickness. However, for cleanliness reasons no carbon steel regions will be left exposed to the water environment.

9. Summary

The engineering evaluation has been completed to consider the effect of the subject indications identified in the stainless steel on the integrity of the tanks. Both fatigue crack growth and fracture mechanics calculations have been completed and the results presented in terms of allowable flaw size charts for a wide range of operating temperatures.

As a separate consideration, calculations were made to determine the required wall thickness in the regions which have been ground to remove the indications. Results show that the criteria of Section III are satisfied with only the carbon steel thickness. Ultrasonic tests also confirmed that the existing wall thickness is adequate to meet Section III requirements.

The existing indications in the stainless steel can be left as is without grinding or repair. The carbon steel areas that were exposed during the repair process have been reclad with one layer of stainless steel to prevent carbon steel regions from being directly exposed to borated water. These reclad areas were visually and liquid penetrant inspected to ASME III requirements.

The tanks meet the ASME Section III requirements for structural integrity, but cannot meet the acceptance criteria for flaw acceptance. Since the accumulator tanks were code stamped and met original fabrication requirements, TVA requests to use the criteria for flaw acceptability from ASME Section XI. Section XI is normally applied to the inspection of components and systems once the requirements of the Construction Code have been satisfied and the item placed in service. The accumulator tanks at WBN met the Construction Code requirements, but have not yet been placed in service. Reverting to the specified requirements of Section III would result in hardship and unusual difficulty without a compensating increase in the level of quality and safety. Accessibility to the tank and the possibility of further damage to the tank during any recladding process presents potential difficulties that would not increase the level of quality and safety of WBN.

10. References

1. Tank-Accumulator - 1350 Cubic Feet, Westinghouse Drawing #1097E08, Revision 8, April 1985.

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

3. Westinghouse System Standard Design Criteria 1.3.X, "Nuclear Steam Supply System Design Transients," Revision 0, September 1978.

4. Wichman, K. R., Hopper, A. G., and Mershon, J. L., "Local Stresses in Spherical and Cylindrical Shells due to External Loadings, "Welding Research Council Bulletin No. 107, August 1965, Revised Printing December 1968.

5. 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.

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

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

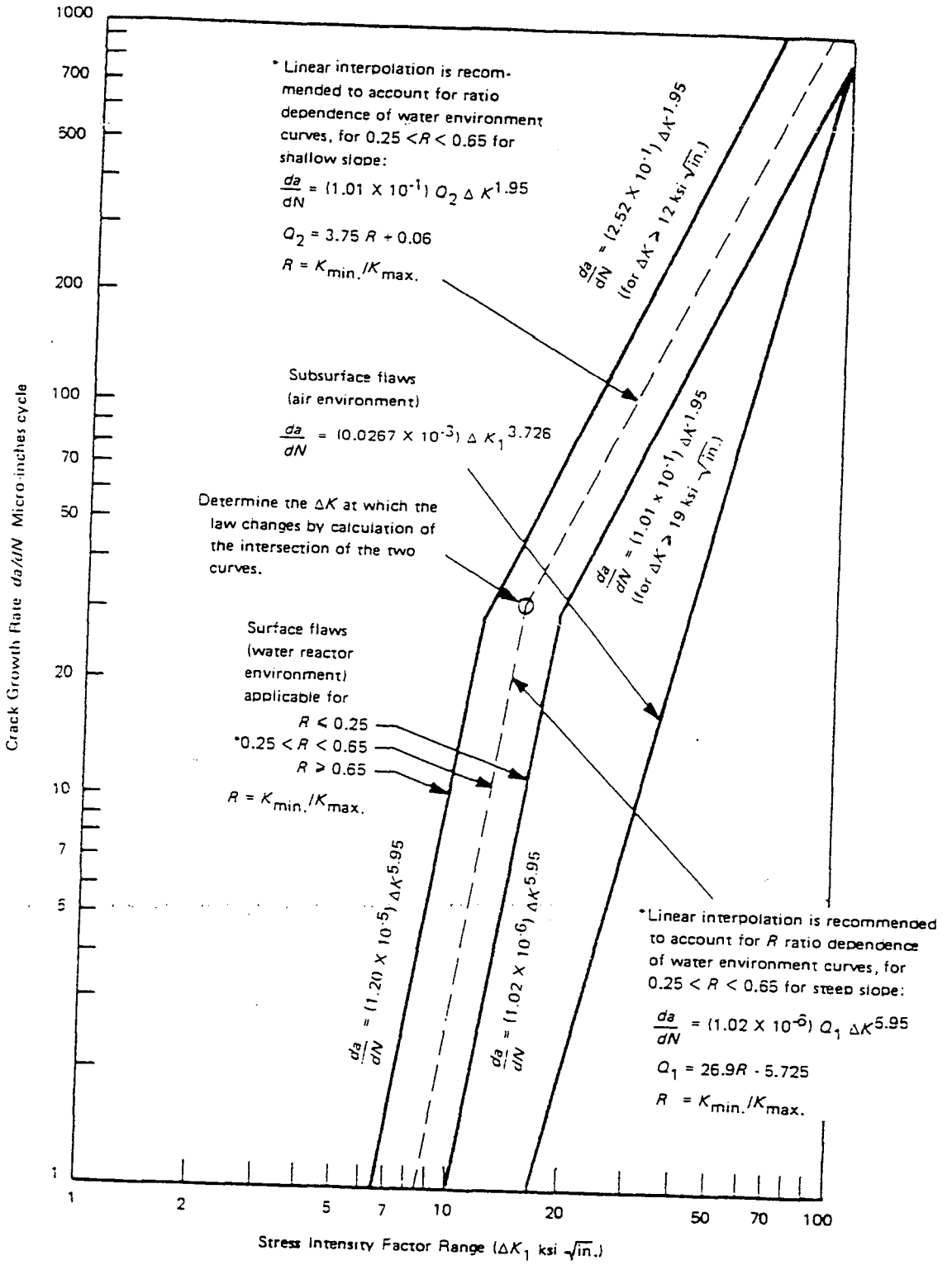

Figure 8-1. Reference Fatigue Crack Growth Curves for Carbon and Low Alloy Ferritic Steels

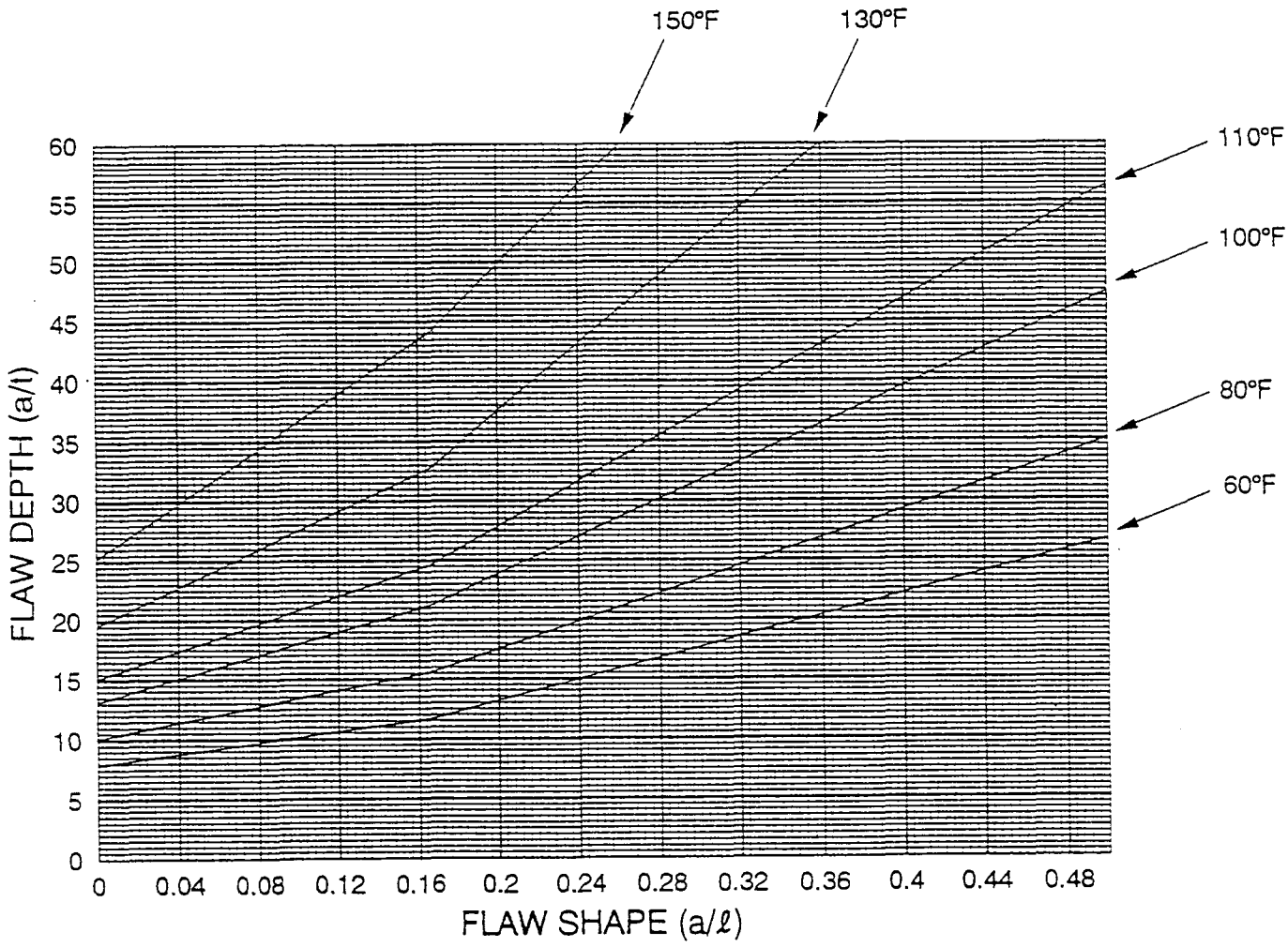

Figure 9-1. Results for Largest Allowable Flaw Depth: Accumulator Tank Cylindrical Shell Region — Longitudinal Flaws

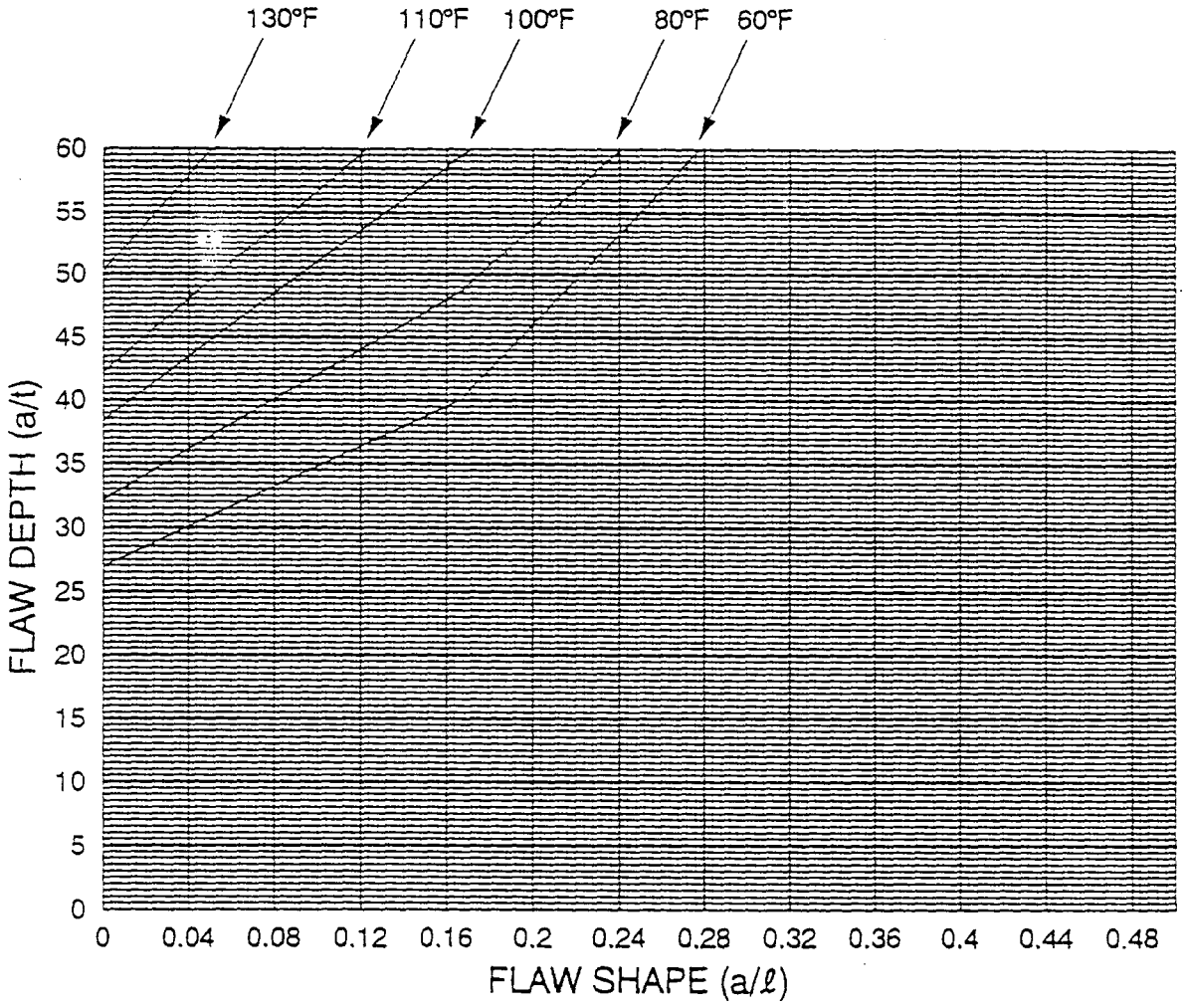

Figure 9-2. Results for Largest Allowable Flaw Depth: Accumulator Tank Cylindrical Shell Region — Circumferential Flaws

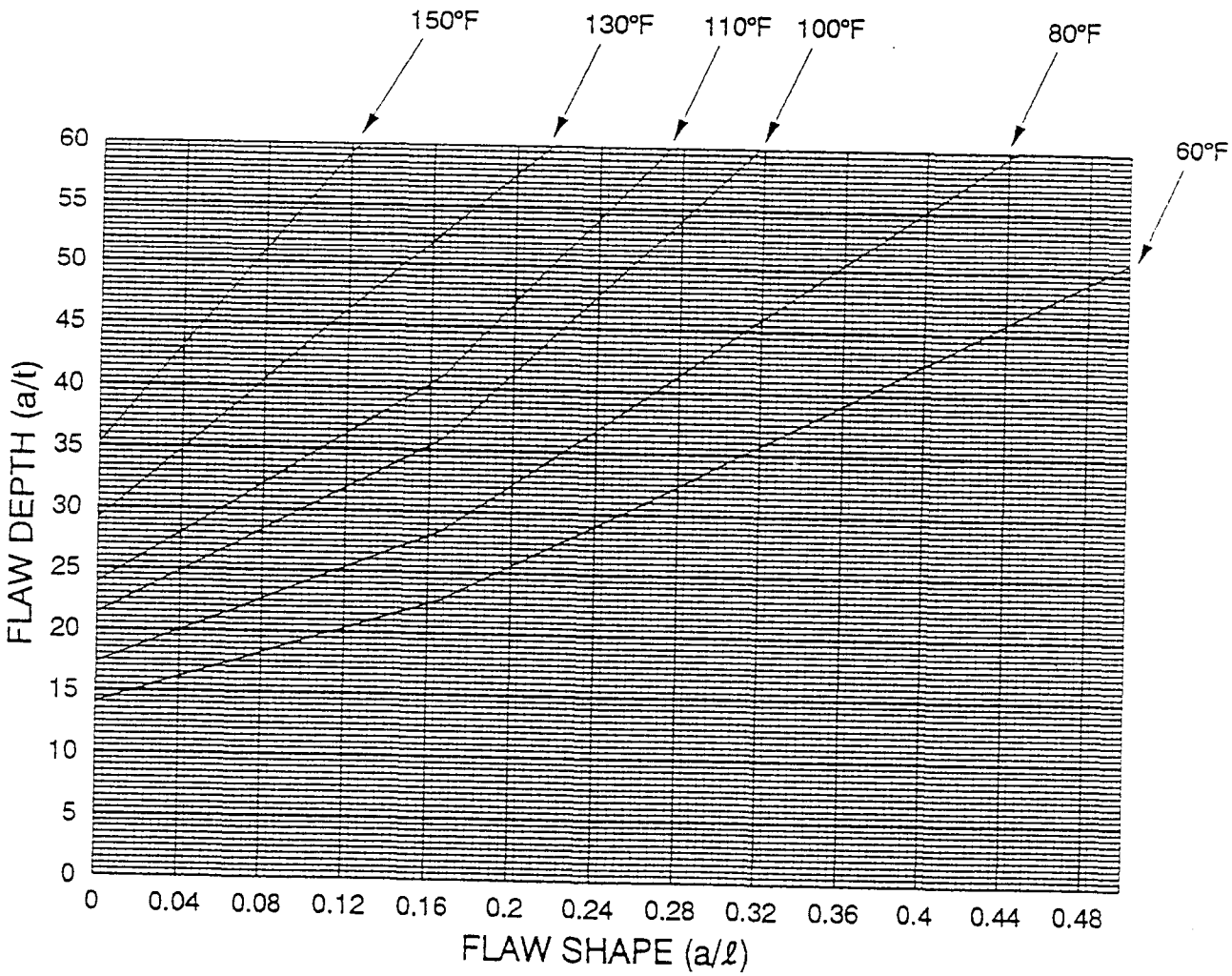

Figure 9-3. Results for Largest Allowable Flaw Depth: Accumulator Tank Hemispherical Head Region — Circumferential and Longitudinal Flaws

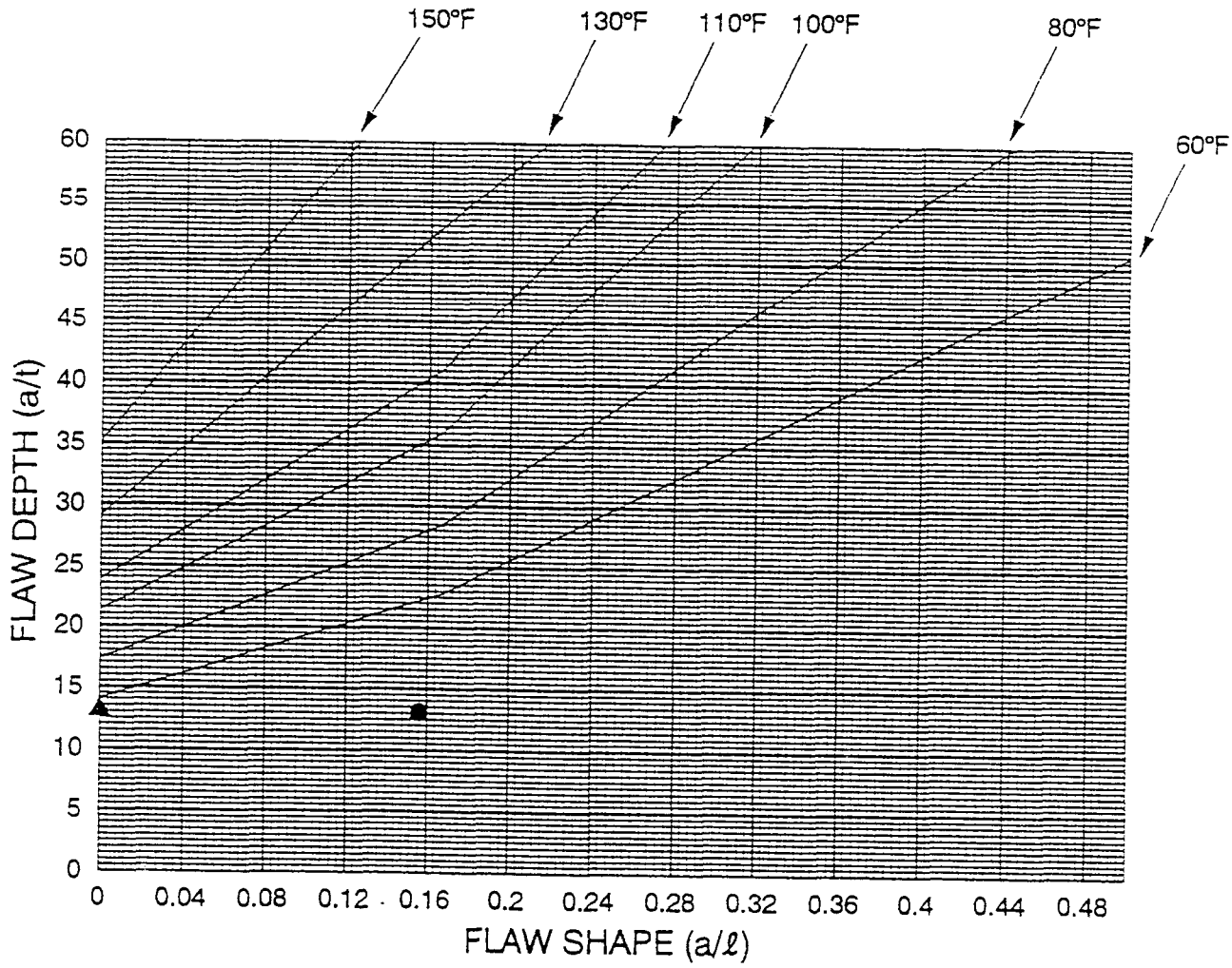

Figure 9-4. Flaw Evaluation Results for An Existing Indication in the Head Region

TABLE 1

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

TRANSIENT TITLE	PRESSURE TRANSIENT (PSIG)	NUMBER OF CYCLES
I. Test Condition		
A. Inservice Pressure Test	0-650-0	40
II. Operating Conditions		
A. Pressure Variations	650-600-650	480
B. Accumulator Discharge	650-O	30

TABLE 2

CHARPY RESULTS FOR TANK MATERIALS

COMPONENT	HEAT NUMBER	CHARPY VALUES* (ft. lb.)	RT_{NDT} (°F)
UNIT 1 ACCUMULATOR #1, (SPIN NO. WAT-SIATAT-01)			
Shell Ring No. 1	C2715-66	46, 48, 60	0
Shell Ring No. 2	C8720-73	53, 54, 49	0
Bottom Head No. 3	B6426-63	71, 79, 68	0
Top Head No. 4	C8692-61	52, 52, 48	0
Heads No. 5	C8692-68	24, 25, 22	20
UNIT 1 ACCUMULATOR #2, (SPIN NO. WAT-SIATAT-02)			
Shell Ring No. 1	C8720-69	42, 39, 37	20
Shell Ring No. 2	A1362-66	68, 60, 64	0
Bottom Head No. 2	B6412-74	65, 63, 61	0
Bottom Head No. 3	B6426-63	71, 79, 68	0
Top Head No. 4	C8692-64	44, 50, 51	20
UNIT 1 ACCUMULATOR #3, (SPIN NO. WAT-SIATAT-03)			
Shell Ring No. 1	A1362-64	49, 52, 50	0
Shell Ring No. 2	C2715-74	30, 31, 29	20
Bottom Head No. 2	B6412-80	47, 57, 49	0
Bottom Head No. 3	B6426-63	71, 79, 68	0
Top Head No. 4	C8692-65	23, 23, 22	20
UNIT 1 ACCUMULATOR #4, (SPIN NO. WAT-SIATAT-04)			
Shell Ring No. 1	C3110-70	33, 42, 37	20
Shell Ring No. 2	A1542-66	39, 44, 38	20
Bottom Head No. 2	B6412-86	64, 44, 53	0
Bottom Head No. 3	B6426-64	64, 60, 51	0
Top Head No. 4	C8692-68	24, 25, 22	20

TABLE 2 (contd.)

CHARPY RESULTS FOR TANK MATERIALS

COMPONENT	HEAT NUMBER	CHARPY VALUES* (ft. lb.)	RT_{NDT} (°F)
UNIT 2 ACCUMULATOR #1, (SPIN NO. WBT-SIATAT-01)			
Shell Ring No. 1	B6426-70	33, 28, 25	20
Shell Ring No. 2	C2715-80	45, 38, 57	20
Bottom Head No. 2	B6412-81	73, 65, 60	Bottom
Head No. 3	B6426-64	64, 60, 51	0
Top Head No. 4	C8692-69	23, 24, 22	20
UNIT 2 ACCUMULATOR #2, (SPIN NO. WBT-SIATAT-02)			
Shell Ring No. 1	B6426-80	39, 46, 48	20
Shell Ring No. 2	C2715-64	45, 42, 48	20
Bottom Head No. 2	B6678-66	35, 31, 38	20
Bottom Head No. 3	B6426-64	64, 60, 51	0
Top Head No. 4	C8692-60	23, 22, 23	20
UNIT 2 ACCUMULATOR #3, (SPIN NO. WBT-SIATAT-03)			
Shell Ring No. 1	C2747-60	48, 49, 42	20
Shell Ring No. 2	B6479-66	36, 36, 51	20
Bottom Head No. 2	B6412-75	56, 41, 41	20
Bottom Head No. 3	B6426-64	64, 60, 51	0
Top Head No. 4	B2670-61	23, 23, 24	20
UNIT 2 ACCUMULATOR #4, (SPIN NO. WBT-SIATAT-04)			
Shell Ring No. 1	C8727-80	46, 45, 51	0
Shell Ring No. 2	B6871-70	39, 55, 41	20
Bottom Head No. 2	B6842-67	50, 43, 34	20
	B6412-86	64, 44, 53	20
	B6412-75	56, 41, 41	20
	B6412-81	73, 65, 60	0
	B6678-66	35, 31, 38	20
	B6412-80	47, 57, 49	0
Bottom Head No. 3	B6426-63	71, 79, 68	0
Top Head No. 4	B2670-60	23, 24, 20	20

* Values at 0°F

TABLE 3

STRESS PROFILES USED IN FRACTURE ANALYSIS

DISTANCE FROM THE INSIDE SURFACE (IN.)	AXIAL STRESS (KSI)	HOOPSTRESS (KSI)
	SPHERICAL HEAD	
0	19.08	19.08
0.214	19.0	19.0
0.428	18.94	18.94
0.642	18.87	18.87
0.856	18.8	18.8
1.07	18.73	18.73
	CYLINDRICAL SHELL	
0	8.42	17.55
0.475	8.42	17.4
0.950	8.42	17.26
1.425	8.42	17.12
1.900	8.42	16.98
2.375	8.42	16.85

TABLE 4

FATIGUE CRACK GROWTH RESULTS FOR SURFACE FLAWS

INITIAL CRACK DEPTH (IN.)	CRACK DEPTH (IN.) AFTER YEAR			
	10	20	30	40
0.2	.20005	.20011	.20016	.20022
0.3	.30020	.30050	.30072	.30079
0.4	.40052	.40114	.40166	.40228

TABLE 5

REQUIRED MINIMUM THICKNESS FOR LOCAL REGIONS

REGION	MINIMUM THICKNESS		DESIGN THICKNESS* (BASE METAL ONLY)
	RT REGION** (1.5 S LIMIT)	LARGER LOCAL REGION (1.1 S LIMIT)	
CYLINDER SHELL	1.58 IN.	2.16 IN.	2.06 IN.
HEMISPHERICAL HEAD	0.78 IN.	1.06 IN.	1.03 IN.

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

** RT = 8.5" for head, 12" for cylindrical shell