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May 19, 2000

**EVALUATION OF THE POTENTIAL FOR LEAKAGE FROM THE HI-STAR/HI-STORM MULTI-PURPOSE CANISTER**
**DOCKET NO. 72-22 / TAC NO. L22462**
**PRIVATE FUEL STORAGE FACILITY**
**PRIVATE FUEL STORAGE L.L.C.**

Reference: May 10, 2000 telephone call between the NRC and Stone and Webster

The purpose of this letter is to submit the enclosed report entitled "A DETERMINISTIC EVALUATION OF POTENTIAL FOR LEAKAGE FROM A HI-STAR/HI-STORM MULTI-PURPOSE CANISTER". Holtec International, the vendor for the HI-STORM storage cask system, prepared the report for the Private Fuel Storage Facility (PFSF). The evaluation demonstrates that leakage from the canister confinement boundary is not credible over the design life of the storage system under normal conditions of storage.

Amendment 13 of the PFSF Safety Analysis Report (SAR) will revise SAR Chapter 7 to include a summary discussion of this report as well as a formal reference to the report. It is currently anticipated that Amendment 13 will be submitted to the NRC during the week of May 22, 2000. If you have any questions regarding this response, please contact me at 303-741-7009.

Sincerely

JL Cooper for

John L. Donnell
Project Director
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NMSS01 Public

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# A DETERMINISTIC EVALUATION OF POTENTIAL FOR LEAKAGE FROM A HI-STAR/HI-STORM MULTI-PURPOSE CANISTER

FOR

**PRIVATE FUEL STORAGE, LLC**

Holtec Report No. HI-2002424

Holtec Project No. 70651

Report Category: A

Report Class: Safety Related



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# EXECUTIVE SUMMARY

The HI-STAR/HI-STORM MPCs are manufactured from an ASME Code austenitic stainless steel alloy. The MPC consists of two principal components, namely, the "Fuel Basket" and the "Enclosure Vessel". The Fuel Baskets, which are available in a number of cavity opening sizes to store various fuel types, are installed inside the Enclosure Vessel. The Fuel Baskets are open structures; they do not contain any pressure. The Enclosure Vessel, on the other hand, is a pressure containment device. Its sole function is to provide a complete confinement to its contents, which are both particulate and gaseous. The gaseous content is normally in the form of the helium (inert) gas with which the canister is filled prior to the welding of its final closure welds. Upon completion of the closure welding operation, the MPC is placed inside the overpack (HI-STAR or HI-STORM) for long-term storage or transport in HI-STAR 100.

The object of the study summarized in this report is to determine whether it is credible for a Holtec MPC to develop a leak while it is stored in an overpack for a period of up to forty years.

It should be noted that the prior practice in the canister Enclosure Vessel design was to invoke the requirements of the ASME nuclear code (Section III), Class 2. In designing the HI-STAR/HI-STORM MPCs, Holtec upgraded the reference ASME Code to the highest category (Class 1) available, which is the same category to which the most critical nuclear components (viz., the reactor vessel) are engineered. To provide for additional margin in the ability of the canister to maintain absolute leak tightness, the wall thicknesses of the Enclosure Vessel were set to be much greater than those required by the ASME Code. For example, while the Code would have called for an approximately 2.25 inch thick top cover, the actual cover thickness used in the Holtec MPCs varies from 9.5 inch (PWR MPCs) to 10" (BWR MPCs). Likewise, the shell is over 100% thicker than that required by the ASME Code.

Further, as required by the Class 1 of the ASME Nuclear code, the material of the Enclosure Vessel is subjected to volumetric examinations to check for internal flaws and the weld are subjected to multiple surface NDEs to ensure that any welding flaw buried within the weld mass will be minimal and so small that it will remain unconditionally stable under normal storage conditions.

The analyses based on classical fracture mechanics, presented in this report, show that, even if the largest possible material non-homogeneity is postulated to exist in the Enclosure Vessel, it is not possible for a leak path to develop from the inside of the vessel to the outside. In mathematical terms, the minimum factor-of-safety against flaw propagation implying through-boundary leakage is 4.25. This factor of safety translates into a virtually unbreachable boundary in normal storage because the material strength (yield strength, for example) will have to be 1/20 of its standard ASME Code required strength for the MPC, to reduce the fracture toughness to a value that reduces the safety factor to 1.0 and implies a vulnerability to leakage. No austenitic stainless steel material has ever been provided by any mill to any user, commercial or nuclear, which had such reduced yield strength.

In procuring the material for the MPCs, Holtec employs the highest standards of quality assurance, which have been reviewed and approved by the USNRC. The manufacturer of the MPCs is required to hold the ASME Code stamp for Class 1 nuclear components.

In view of the design margins engineered into the Enclosure Vessel, the stringent quality control measures implemented in its manufacturing and use of proven stainless steel alloy materials, it is concluded that the potential for a through-wall leak from a Holtec MPC can be, deterministically speaking, precluded as a credible event.

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# 1. INTRODUCTION

## *1.1 Scope*

The multi-purpose canister (MPC) provides the confinement boundary for the stored spent nuclear fuel in the HI-STAR 100 and HI-STORM 100 dry storage systems. This document provides an assessment of the leak-tightness of the multi-purpose canister (MPC) under long-term storage normal conditions. This assessment is considers the MPC component in the context of ASME Code requirements, fabrication and welding methodology, material inspection procedures, applied structural loads, structural evaluations and design margins, and fracture mechanics evaluations design margins. The intent of this document is to provide the necessary substantiating information to provide support to the conclusion that leakage from the MPC confinement boundary is not credible over the design life of the storage system under normal conditions of storage.

## *1.2 Description of MPC Confinement Boundary*

The confinement boundary of the MPC is a welded enclosure consisting of a closure ring, a thick top closure lid, a cylindrical shell, and a base plate. All multi-purpose canisters submitted for certification under HI-STAR 100 and HI-STORM 100 dockets are constructed from austenitic stainless alloy. The nominal outer diameter of the MPC is 68-3/8 inches, the overall length is approximately 190-1/2 inches, and the canister shell thickness is 0.5-inch. The closure lid is a 9.5-inch thick circular plate in the PWR MPC and a 10-inch thick circular plate in the BWR MPC. The baseplate is a 2.5-inch thick circular plate. The closure ring provides an additional independent barrier against leakage through the closure lid-to-shell welded connection. Detailed drawings are provided in Section 1.5 of the HI-STAR and HI-STORM TSARs [1,2].

The closure lid-to-canister shell welding is effected by an automated MIG or TIG process that requires approximately 16 to 20 passes to make a ¾ inch groove weld. Any MPC used for failed fuel has a larger weld, namely a 1.25" deep J-groove weld and an increased enclosure shell thickness in the lid/shell junction region. The closure lid-to-canister shell welding is performed in the horizontal face-down configuration, which is known to be the orientation most conducive to a sound, void and inclusion-free welds deposition. Figures 1, 1A illustrate the weld detail.

The canister shell-to-baseplate weld is a full penetration weld joining the thinner canister shell to the baseplate.

The drawing notes, together with tables in Chapter 9 of the TSAR, provide inspection requirements for the base metal and for the welds.

# 2. METHODOLOGY

A comprehensive assessment of the confinement boundary long-term resistance to leakage is performed by reviewing the documented features of the MPC in the docketed TSARs that affect and enhance the leak-tightness of the unit. An evaluation of long-term leak tightness requires consideration of the robustness of the confinement boundary to resist the normal structural loads applied over the component storage life and parallel consideration of the fabrication and inspection requirements that insure robust margins against flaw propagation. To achieve the intent of this report, a review and summary of all code requirements is presented. This review is based on the documented material in the TSAR (no new structural analyses are performed) and is presented to demonstrate the conservative design approach and to provide lower bounds for the applicable stresses that can cause propagation of a pre-existing flaw. The presence of a flaw, coupled with an applied nominal state of stress that could cause the flaw to propagate, is the only mechanistic means whereby the leak-tightness of the MPC, under normal conditions of storage, can be adversely affected.

Since all materials have microscopic flaws, documentation of the robustness of the MPC structure to resist design basis normal storage loads must be supplemented by demonstrating that the interaction between stress levels, flaw characterization, and material fracture toughness provides a large safety margin against any microscopic flaw growth, with passage of time, degrading the leak-tightness of the MPC. To this end, analysis is performed to determine the fracture mechanics safety factors of the major confinement boundary components and their joining welds

The following sections of this report separately consider the MPC confinement boundary with respect to structural (stress) safety factors and with respect to flaw propagation safety factors. The totality of results forms the basis for the assessment of long-term leak tightness of the MPC confinement boundary.

# 3. STRUCTURAL EVALUATIONS

### *3.1 ASME Code Rules*

The MPC is classified as important-to-safety. The enclosure vessel (confinement boundary) is designed and fabricated as a Class 1 component pressure vessel in accordance with ASME Code Section III, Subsection NB to the maximum extent practicable. Table 3.1, abstracted from [2], lists the exceptions to Subsection NB, and the justifications and compensatory measures applied to provide equivalent assurance of safety.

### *3.2 Analyses*

In the ASME Code, plant and system operating conditions are commonly referred to as normal, upset, emergency, and faulted. Consistent with the terminology in NRC documents, the TSAR [1,2] utilizes the terms normal, off-normal, and accident conditions.

The ASME Code defines four service conditions in addition to the Design Limits for nuclear components. They are referred to as Level A, Level B, Level C, and Level D, service levels, respectively. Their definitions are provided in Paragraph NCA-2142.4 of the ASME Code. Only Level A service conditions are applicable to the long-term storage condition of interest here. Allowable stresses and stress intensities for structural analyses appropriate to Level A service conditions of the MPC confinement boundary are tabulated in Chapter 3 of the TSAR documents [1,2].

The structural analyses undertaken in the TSAR documents having direct influence on the assessment of the long-term leak tightness of the MPC confinement boundary are only those associated with pressure confinement; these are:

Internal Pressure – Evaluate primary membrane and bending stress intensity (in closure lid, and baseplate) and primary plus secondary stress intensity in the shell.
Internal Pressure plus Temperature –Evaluate primary plus secondary stress intensity (in closure lid, shell, and baseplate).

The TSAR documents for HI-STAR and for HI-STORM provide a complete description of the formulation and results for each analysis to demonstrate safety factors in excess of 1.0 for the components of the MPC confinement boundary.

### *3.3 Summary of Key Safety Factors*

To assess the continued leak-tightness of the MPC confinement boundary for long-term storage, we need only consider the calculated stress intensity, the allowable stress intensity, and the resulting safety factors, SF, defined as (Allowable value/Calculated value). Table 2 presents a compendium of the limiting results from the TSAR analyses for the normal conditions of storage that directly affect the leak tightness of the all-welded MPC confinement boundary during long-term storage conditions.

# 4. FRACTURE MECHANICS EVALUATIONS

### *4.1 Characterization of Maximum Flaws by Inspection Requirements*

The following fabrication controls and required inspections are performed on the MPC confinement boundary to assure compliance with the TSAR and the Certificate of Compliance:

The plate and the lid forging for are UT inspected, per the requirements of ASME Section III [3], Article NB-2500, prior to receipt by the fabricator. Materials are receipt inspected by the fabricator for visual and dimensional acceptability, material conformance to specification requirements, and traceability markings. Table 3 summarizes the NDE test requirements for the MPC confinement boundary welds. From the applicable ASME Code sections, a maximum flaw size that may exist (either because it is permitted by the Code rules if detected or is undetectable by the NDE methodology specified by the Code rules) at various locations in the confinement boundary can be postulated. To conservatively quantify the safety factors relating to long-term leak-tightness of the MPC confinement boundary, the following maximum flaw sizes (that are equal to or bound from above the values inferred from the Code rules) are used for fracture mechanics evaluations of flaw propagation under Level A service conditions.

Closure lid-to-canister shell weld – 0.375" (.625" for MPC-68F), complete circumferential extent
Canister shell-to-baseplate weld – 0.25", complete circumferential extent
Top closure lid – 1" long, circumferential, 0.5" depth, near surface
Baseplate – 1" long, circumferential, 0.5" depth, near surface

### *4.2 Potential for Flaw Propagation*

#### 4.2.1 CLOSURE LID-TO-MPC CANISTER SHELL WELD (LTMS)

The ASME Code Section XI (1998 issue) provides explicit quantitative criteria for acceptable flaw size determination in ferritic steel weldments and in austenitic stainless steel pressurized piping. Similar criteria for welds of the LTMS genre have not yet been developed and adopted in the Code. The reason for this obvious omission is the universally recognized excellent fracture toughness of austenitic stainless alloys that is hardly affected at even cryogenic temperatures. The crack propagation mechanism in austenitic stainless steel is principally connected with stress corrosion cracking (SCC) (both transgranular and intergranular) and requires that both stress (tensile) and an inimical environment (oxygen and halides) be present. Since the environment around the LTMS weld is entirely inert (helium filled container), and the normal operating stresses are extremely modest, SCC is not a credible vehicle for crack propagation in the LTMS weld. Likewise, other classical flaw propagation mechanisms, namely hydrogen embrittlement and cyclic fatigue, do not have credible underlying actuators in the LTMS welds. Therefore, the sole potential candidate mechanism is classical void propagation in the presence of a tensile or a shear stress field. Herein, concepts from fracture mechanics theory (which also underline ASME Code rules in this matter) are used to determine the safety factor for flaw propagation based on a conservatively postulated maximum undetected flaw size in the LTMS weld. All calculations performed herein use very conservative assumptions on stress magnitude and on flaw size.

The modified J-groove closure lid-to-canister shell weld illustrated in Figures 1 and 2 has a cross sectional area of approximately 0.59 square inch. Under the normal condition of storage, the LTMS weld experiences little stress. The only loads acting on the LTMS weld under normal storage conditions are the internal pressure p and dead weight of the lid, $W_L$ (Table 4).

The shear stress, $\tau$, in the lid weld under normal storage conditions follows from force equilibrium

$$\tau = \frac{pD}{4b} - \frac{W_L}{\pi D b}$$

where b = axial length of the weld (= 0.75").

and D = lid O.D. = 68.375"

Substituting numerical values from Table 4, we have

$\tau$ = 2,215 psi

Recognizing that the lid is quite thick, it is readily deduced that the most likely fracture failure mode for the LTMS weld is through shear failure, formally known as the Mode II crack propagation in the fracture mechanics literature. Therefore, a flaw shape and configuration which would synergize with the Mode II failure model is chosen. The shape of the weld joint and the nature of the applied loading (axial) indicates that the flaw should be assumed to be rectangular with sharp corners, oriented with its long side parallel to the MPC shell axis (Figure 2). Further, we assume that the flaw extends 360 degrees circumferentially, i.e., it is seamless. Such an adversely oriented cylindrical flaw, albeit entirely hypothetical, helps maximize the potential for crack growth. Finally, we assume that the flaw is 50% of the height of the weld, i.e., a = 0.375" in Figure 2.

For an MPC carrying damaged fuel, the weld section (1.25" J-groove per Figure 1A), shear stress, $\tau$, in the lid weld under normal storage conditions follows from force equilibrium

$$\tau = \frac{pD}{4b} - \frac{W_L}{\pi D b}$$

where b = axial length of the weld (= 1.25").
and D = lid OD =67.375"

$$\tau = 1{,}308 \text{ psi}$$

For the Mode II failure model in this larger weld, we will continue to assume that the flaw is 50% of the height of the weld, i.e., a = 0.625".

For conservatism, we will analyze the consequences of $\tau$ on crack propagation for the two weld sizes. Moreover, we will further assume the nominal $\tau$ to be increased by the ratio (b/a), even though classical fracture mechanics principles do not require the nominal shear stress to be magnified for reason of the flaw. Therefore, the applicable shear stresses for fracture analysis are $\tau$ = 4,430 psi (for the 0.75" weld) and $\tau$ = 2,616 psi (for the 1.25" weld).

We will now proceed to utilize concepts from linear elastic fracture mechanics to determine the consequences of $\tau$ on the assumed flaw. An alternate confirmatory analysis, using an elastic-plastic J-integral formulation, is presented in Appendix A.

Analysis for 0.75" Groove Weld

A critical flaw size is assumed to exist if the Stress Intensity Factor (SIF) equals the materials' fracture toughness.

Fracture toughness of austenitic stainless steel is known to be quite high. According to [4, p. 20-9], the value of Charpy energy, C, at -50°C is well in excess of 130 lb-ft. Therefore, a Charpy impact energy value of 130 ft-lb at -40°F is a most conservative lower bound value.

The Charpy value C is related to the fracture toughness K by a relationship of the form [5, p. 300].

$$\left(\frac{K}{\sigma_y}\right)^2 = 5\left(\frac{C}{\sigma_y} - 0.05\right)$$

where:

$K$ is $ksi\sqrt{inch}$

$\sigma_y$ is yield stress, ksi

C is Charpy energy in ft-lb

Using a conservative value of C = 130, $\sigma_y$ = 30 (yield strength), we obtain

$$K = 138.8\ ksi\sqrt{inch}$$

To determine the "Stress Intensity Factor", we utilize the solution for a Mode II cracking of a plate of width b [5, Table 7.1, case 2]. The value of b in our case is the longitudinal dimension of the weld, i.e., 0.75 inch.

Let us assume that the crack is 0.375 inch long, i.e., a = 0.375". The stress intensity factor $K_{II}$ under $\tau$ in this configuration is given by

$$K_{II} = \tau\sqrt{.5\pi a}F(x)$$

where:

$$F(x) = \{1 - 0.1x^2 + 0.96x^4\}\sqrt{\sec \pi x}$$

$$x = \frac{.5a}{b} = 0.25$$

$\tau = 4.033$ ksi

By substituting for x, we obtain F(x) = 1.186. Then, for $\tau = 4.43$ ksi, we have

$K_{II} = 4.033 << K$

The safety factor SF = $K/K_{II}$

SF = 34.42

Analysis for 1.25" Groove Weld

The preceding calculation is repeated here for the larger weld. The value of b is the longitudinal dimension of the weld, i.e., 1.25 inch.

Let us assume that the crack is 0.625 inch long, i.e., a = 0.625". The stress intensity factor $K_{II}$ under $\tau$ in this configuration is given by

$K_{II} = \tau\sqrt{.5\pi a}F(x)$

where:

$F(x) = \{1 - 0.1x^2 + 0.96x^4\}\sqrt{\sec \pi x}$

$x = \dfrac{.5a}{b} = 0.25$

$\tau = 2.616$ ksi

By substituting for x, we again obtain F(x) = 1.186. Then, for $\tau = 2.616$ ksi, we obtain $K_{II} = 3.075 << K$

The safety factor SF = $K/K_{II}$

SF = 45.14

It is concluded that for both weld sizes considered, the fracture toughness of austenitic stainless steel is considerably greater than the stress intensity factor corresponding to a 50% thru-thickness crack (360°) oriented to maximize the potential for Mode II (shear) failure.

### 4.2.2 CANISTER SHELL-BASEPLATE WELD

The full penetration weld between the canister shell and the baseplate is again modeled by the configuration described by Figure 2 except that now the loading is tensile in nature (a Mode I failure) with tensile stress equal to 43.986 ksi (Table 2). We conservatively use this calculated discontinuity stress value as a "remote" stress on the postulated flaw and use Reference [5 case 1] to evaluate the stress intensity factor to compare with the fracture toughness.

Let us assume that the crack is 0.25 inch long, i.e., in Figure 2, a = 0.25". The stress intensity factor $K_I$ under $\sigma$ in this configuration is given by (b = 0.5" for this weld)

$K_I = \sigma\sqrt{.5\pi a}F(x)$

where:

$$F(x) = \{1 - 0.1x^2 + 0.96x^4\}\sqrt{\sec \pi x}$$

$$x = \frac{.5a}{b} = 0.25$$

$\sigma = 43.986$ ksi

By substituting for x, we again obtain F(x) = 1.186. Then, for $\sigma$ ksi, we obtain

$K_{II} = 32.698 << K$

The safety factor SF = $K/K_{II}$

SF = 4.25

### 4.2.3 TOP CLOSURE LID

Because the depth of the top closure lid is much larger than any non-detectable flaw, we examine a single flaw, with semi-circular shape, that spans 1" at the center of the lid (considered as a semi infinite body) oriented so that it is exposed to the maximum bending stress generated by the internal pressure. The stress intensity factor is generated by considering case 16 in [5, Table 7.1], A semi-infinite body with semi-circular crack, subject to a flaw opening stress equal to 3.517 ksi (Table 2), is considered. Figure 3 shows the analyzed flaw configuration.

$$K_I = \frac{2}{\pi}\sigma\sqrt{\pi a}(1.211) \quad ; a=0.5"$$

The calculated stress intensity factor is

K=3.398

so that the safety factor, SF, for flaw propagation, is

SF = 138.8/K = 40.844

### 4.2.4 BASEPLATE

Because the depth of the baseplate is of the same order as the postulated flaw depth, we conservatively examine a single flaw with elliptical shape that spans 1", and has a depth of 0.5" in a 2.5" thick plate. The flaw is assumed to be oriented so that it is exposed to the maximum bending stress generated by the internal pressure. The stress intensity factor is generated by considering case 18 in [5, Table 7.1] with a plate width equal to the baseplate diameter (see Figure 4). Therefore, for analysis, a semi-elliptical surface flaw in a finite plate (width and thickness) under tension loading is considered, subject to a flaw opening stress equal to 21.921 ksi (from Table 2). Using the notation in [5] for case 18 (see Figure 4),

a = 0.5", 2c = 1", t = 2.5", and b=68.375".

Then,

$$K_I = \sigma\sqrt{\pi a}\, fF / E(k)$$

where f =1

F=F(a/t,a/c,b/c)=1.03

$k=1-(a/c)^2$

and E(k)=1

The calculated stress intensity factor is

K=28.241

so that the safety factor, SF, for flaw propagation, is

SF = 138.8/K = 4.915

# 5. SUMMARY OF RESULTS

The above analyses, using bounding flaw sizes for conservatism, proves the commonly acknowledged truism that flaw propagation in an austenitic stainless material is improbable. The potential for flaw propagation has been evaluated for the closure lid-to-canister shell weld, for the canister shell-to-baseplate weld, and for the central region of closure lid and the baseplate. The safety factors, SF, defined as the fracture toughness of the material divided by the calculated stress intensity factor for the specified flaw configuration, are summarized below.

| SUMMARY OF CALCULATED SAFETY FACTORS | |
|---|---|
| LOCATION | SAFETY FACTOR |
| Closure Lid-to-Canister Shell Weld | 34.42 (.75" weld); 45.14 (1.25" weld) |
| Canister Shell-to-Baseplate Weld | 4.25 |
| Center of Closure Lid | 40.84 |
| Center of Baseplate | 4.92 |

Based on the above results based on conservatively large assumed flaws, and on the mandated fabrication and inspection requirements, we consider that flaw propagation in the MPC confinement boundary is not a credible event under long-term storage loading; therefore, leak-tightness of the all welded stainless steel boundary is assured.

# 6. REFERENCES


[1] HI-941184, HI-STAR 100 TSAR, Docket 72-1008

[2] HI-951312, HI-STORM 100 TSAR, Docket 72-1014

[3] ASME Code, Section III, Subsection NB, 1998.

[4] "Handbook of Stainless Steels", D. Peckner and I.M. Bernstein McGraw-Hill, 1977, p.20-9.

[5] "Stress, Strain, and Structural Matrices", W.D. Pilkey, John Wiley, 1994

[6] "Spent Fuel Dry Cask Weld Crack Position Paper", NEI, October 9, 1998.

[7] V. Kumar et al., "An Engineering Approach for Elastic-Plastic Fracture", EPRI NP-1931, G.E., Schenectady, NY, July 1981.

[8] I.S. Raju, et al., "Stress Intensity Factor Solutions for Surface Cracks in Flat Plates Subjected to Non-Uniform Stresses", Fracture Mechanics: 24th Symposium, ASTM pp. 568-580 (1994).

# 7. TABLES

Table 1
LIST OF ASME CODE EXCEPTIONS MPC ENCLOSURE VESSEL

| Component | Reference ASME Code Section/Article | Code Requirement | Exception, Justification & Compensatory Measures |
|---|---|---|---|
| MPC | NB-1100 | Statement of requirements for Code stamping of components. | MPC enclosure vessel is designed and will be fabricated in accordance with ASME Code, Section III, Subsection NB to the maximum practical extent, but Code stamping is not required. |
| MPC | NB-2000 | Requires materials to be supplied by ASME-approved material supplier. | Materials will be supplied by Holtec approved suppliers with Certified Material Test Reports (CMTRs) in accordance with NB-2000 requirements. |
| MPC Lid and Closure Ring Welds | NB-4243 | Full penetration welds required for Category C Joints (flat head to main shell per NB-3352.3) | MPC lid and closure ring are not full penetration welds. They are welded independently to provide a redundant seal. Additionally, a weld efficiency factor of 0.45 has been applied to the analyses of these welds. |
| MPC Closure Ring, Vent and Drain Cover Plate Welds | NB-5230 | Radiographic (RT) or ultrasonic (UT) examination required. | Root (if more than one weld pass is required) and final liquid penetrant examination to be performed in accordance with NB-5245. The MPC vent and drain cover plate welds are leak tested. The closure ring provides independent redundant closure for vent and drain cover plates. |

| | | | |
|---|---|---|---|
| MPC Lid Weld | NB-5230 | Radiographic (RT) or ultrasonic (UT) examination required. | Only UT or multi-layer liquid penetrant (PT) examination is permitted. If PT examination alone is used, at a minimum, it will include the root and final weld layers and each approx. 3/8" of weld depth. |
| MPC Enclosure Vessel and Lid | NB-6111 | All completed pressure retaining systems shall be pressure tested. | The MPC vessel is seal welded in the field following fuel assembly loading. The MPC vessel shall then be hydrostatically tested as defined in Chapter 8. Accessibility for leakage inspections preclude a Code compliant hydrostatic test. All MPC vessel welds (except closure ring and vent/drain cover plate) are inspected by RT or UT. The vent/drain cover plate welds are confirmed by helium leakage testing and liquid penetrant examination and the closure ring weld is confirmed by liquid penetrant. |
| MPC Enclosure Vessel | NB-7000 | Vessels are required to have overpressure protection. | No overpressure protection is provided. Function of MPC enclosure vessel is to contain radioactive contents under normal, off-normal, and accident conditions of storage. MPC vessel is designed to withstand maximum internal pressure considering 100% fuel rod failure and maximum accident temperatures. |
| MPC Enclosure Vessel | NB-8000 | States requirements for nameplates, stamping and reports per NCA-8000. | System to be marked and identified in accordance with 10CFR71 and 10CFR72 requirements. Code stamping is not required. QA data package to be in accordance with Holtec approved QA program. |

Table 2

SUMMARY OF KEY STRESS ANALYSIS RESULTS FOR MPC CONFINEMENT BOUNDARY FOR LONG-TERM STORAGE (FROM TSAR DOCUMENTATION)

| LOCATION | ANALYSIS | CALCULATED VALUE (ksi) | ALLOWABLE VALUE (ksi) | SAFETY FACTOR |
|---|---|---|---|---|
| Closure Lid | Internal Pressure, Primary Bending | 2.960 | 30.0 | 10.1 |
| Closure Lid | Internal Pressure + Temperature, Primary + Secondary Bending | 3.517 | 60.0 | 17.1 |
| Baseplate | Internal Pressure, Primary Bending | 20.528 | 30.0 | 1.46 |
| Baseplate | Internal Pressure + Temperature, Primary +Secondary Bending | 21.921 | 60 | 2.7 |
| Canister Shell | Internal Pressure, Primary Membrane | 6.86 | 18.7 | 2.72 |
| Canister Shell | Internal Pressure, Primary + Secondary Bending | 43.986 | 60.0 | 1.36 |
| Canister Shell | Internal Pressure + Temperature, Primary + Secondary Bending | 39.929 | 60.0 | 1.5 |

TABLE 3 – MPC NDE REQUIREMENTS

| Weld Location | NDE Requirement | Acceptance Criteria (Applicable Code) |
|---|---|---|
| Shell longitudinal seam | RT<br><br><br>PT (surface) | RT: ASME Section III, Subsection NB, Article NB-5320<br>PT: ASME Section III, Subsection NB, Article NB-5350 |
| Shell circumferential seam | RT<br><br><br>PT (surface) | RT: ASME Section III, Subsection NB, Article NB-5320<br>PT: ASME Section III, Subsection NB, Article NB-5350 |
| Baseplate-to-shell | RT<br>or UT<br><br><br><br><br><br>PT (surface) | RT: ASME Section III, Subsection NB, Article NB-5320<br>UT: ASME Section III, Subsection NB, Article NB-5330<br>PT: ASME Section III, Subsection NB, Article NB-5350 |
| Lid-to-shell | PT (root and final pass) and multi-layer PT (if UT is not performed).<br>PT (surface following hydrostatic test)<br><br>UT (if multi-layer PT is not performed) | =PT: ASME Section III, Subsection NB, Article NB-5350<br><br><br><br><br>UT: ASME Section III, Subsection NB, Article NB-5332 |
| Closure ring-to-shell | PT (final pass) | PT: ASME Section III, Subsection NB, Article NB-5350 |
| Closure ring-to-lid | PT (final pass) | PT: ASME Section III, Subsection NB, Article NB-5350 |
| Closure ring radial welds | PT (final pass) | PT: ASME Section III, Subsection NB, Article NB-5350 |
| Port cover plates-to-lid | PT (root and final pass) | PT: ASME Section III, Subsection NB, Article NB-5350 |

| Table 4<br><br>WEIGHT AND PRESSURE DATA | | |
|---|---|---|
| Item | Symbol | Value |
| MPC Internal Design Pressure (psi) | p | 100 |
| MPC Lid Weight (lb) | $W_L$ | 10,400 |
| MPC Shell and Bottom Plate Weight (lb) | $W_s$ | 8,900 |
| Bounding Weight of SNF and<br>Fuel Basket and<br>Miscellaneous MPC Internals | $W_F$ | 70,700 |

# 8. FIGURES

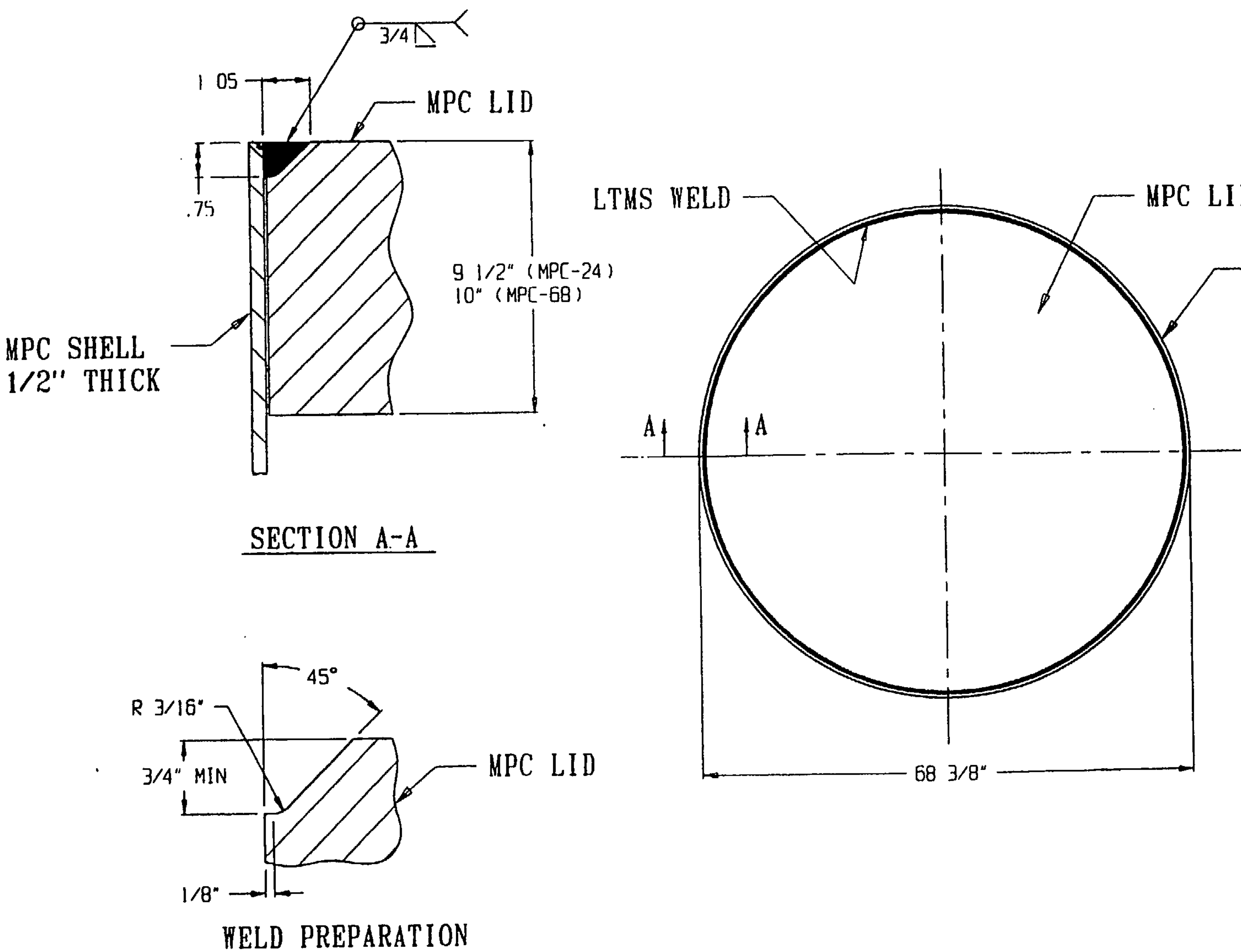


FIGURE 1; LTMS WELD GEOMETRY

5014/POSITION/DS-213/

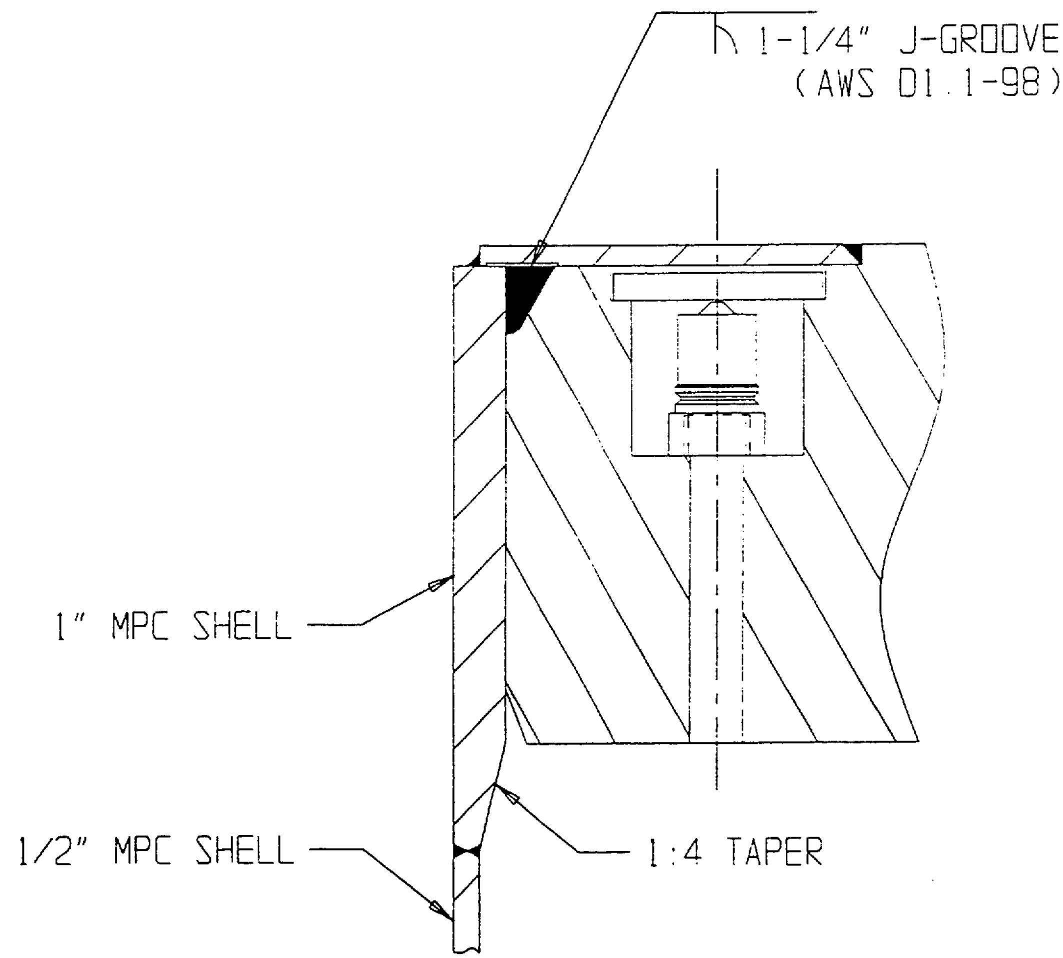


FIGURE 1A: CLOSURE REGION FOR MPC CARRYING DAMAGED FUEL

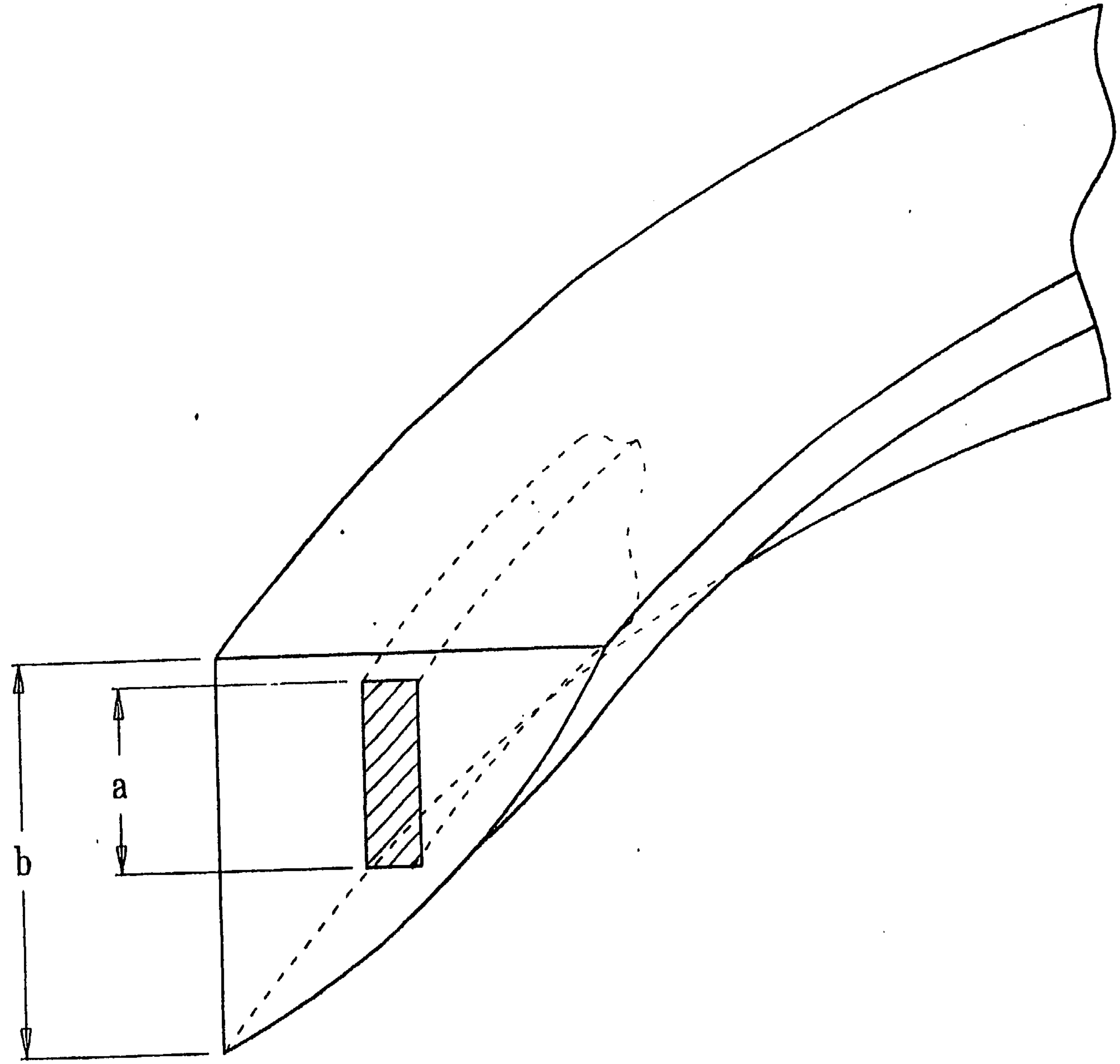


FIGURE 2; ASSUMED (CIRCUMFERENCIALLY SYMMETRIC) RECTANGULAR LONGITUDINAL FLAW IN LTMS WELD

5014/POSITION/DS-213/

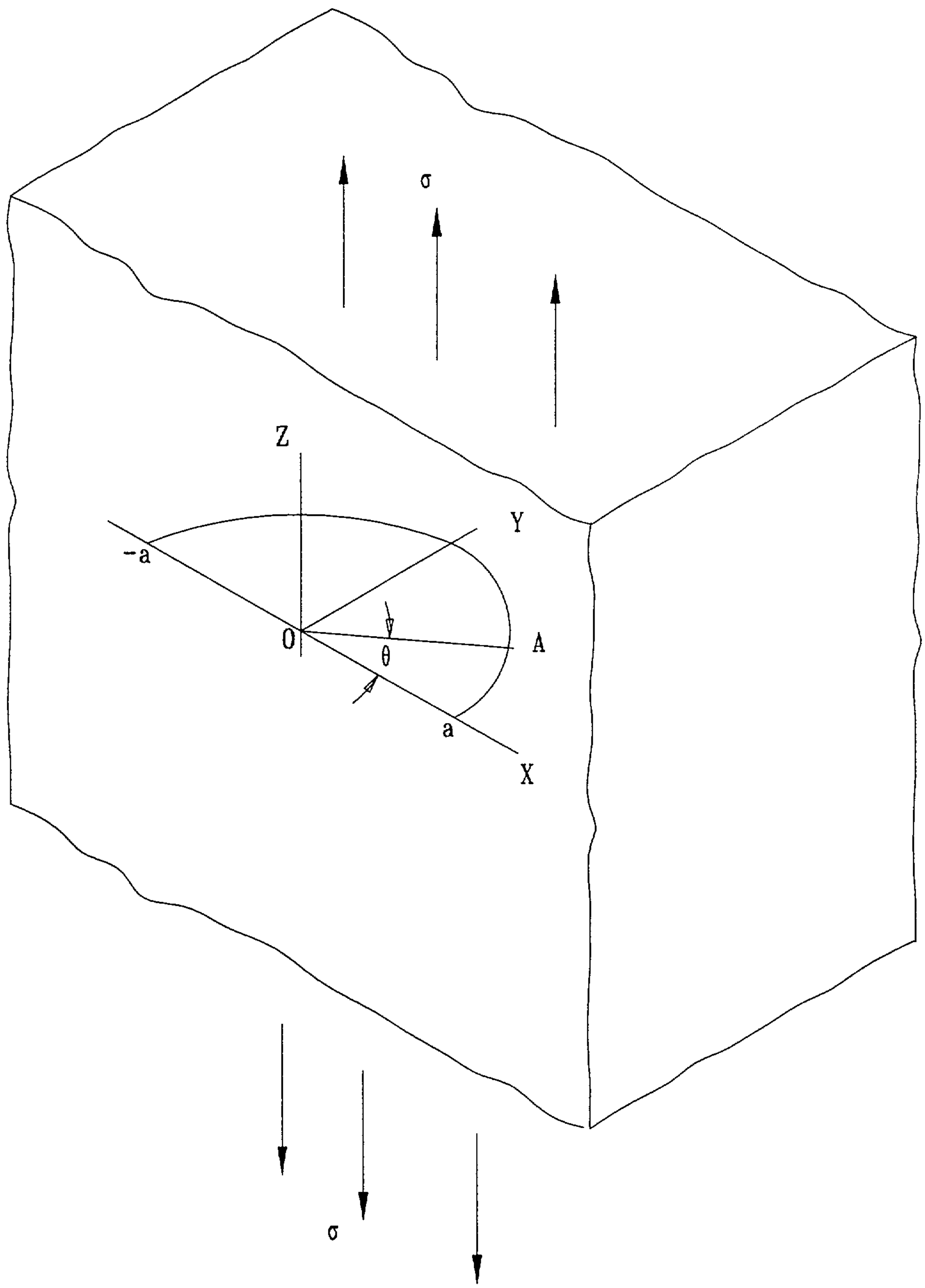


FIGURE 3; SEMI-INFINITE BODY WITH SEMI-CIRCULAR CRACK, TENSION LOADING.

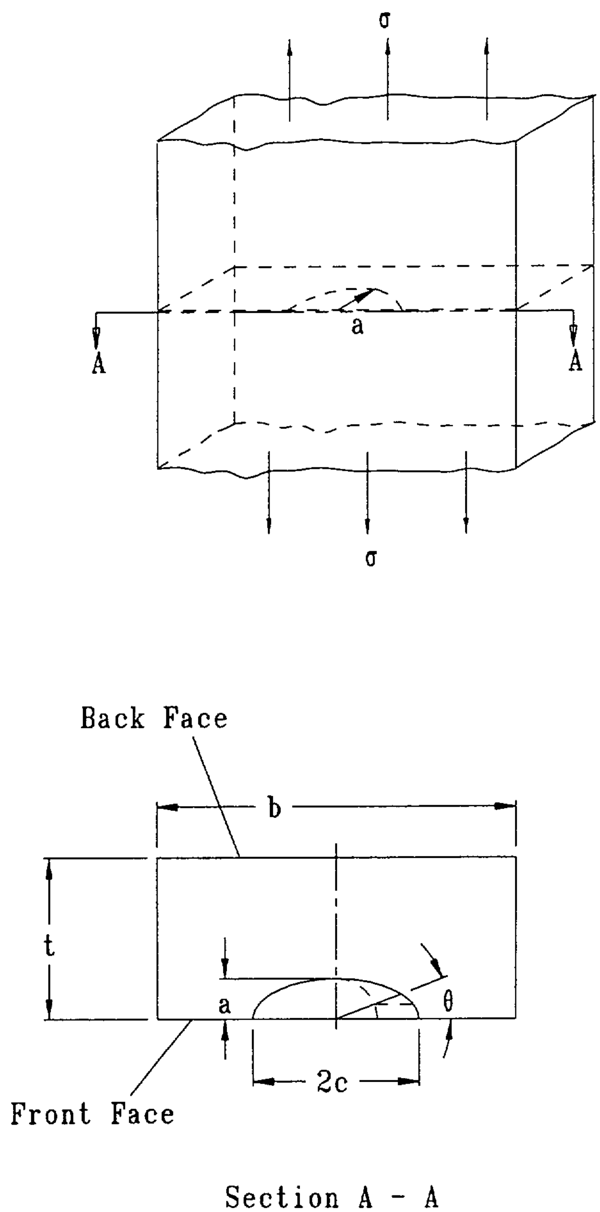


FIGURE 4; SEMIELLIPTICAL SURFACE CRACK IN INFINITE PLATE,
TENSION LOADING.

# APPENDIX A – J-INTEGRAL CALCULATION

This alternate, confirmatory calculation follows the approach espoused by NEI [6]. The NEI approach consists of the following steps:

Define the lower bound elastic-plastic fracture toughness for the austenitic stainless steel weld material.

Assume that the postulated flow is located in the closure weld at the lid/shell interface and is oriented in the axial/circumferential plane.

Require that the elastic-plastic crack driving force be less than the weld material elastic-plastic resistance curve at a crack extension of 0.1 inch (akin to the evaluation criterion in Section XI, Appendix K, paragraph K-4220).

Reference [7] provides the lower bound value of J-R resistance curve value at 0.1" crack extension as 1430 in-lb/inch$^2$. Since fracture toughness $K_I$ is related to J by

$$J = K^2/E'; \; E' = E/(1-\nu^2)$$

where E is Young's Modulus of the weld material; $\nu$ = Poisson's ratio.

Using E = 25.55 x 10$^6$ psi, corresponding to Alloy X at 550°F, we obtain

$$K = 200.4 \; ksi \sqrt{inch}$$

It should be noted that K calculated from the J-R curve is considerably greater than the value used in the elastic fracture calculation in the preceding section.

For determining the crack driving potential, P, the simplified approach utilized by NEI is adopted for this bounding evaluation. The geometry of the crack is defined by Figure 1 of [6]. In the following sub-sections, the analysis is performed for the two weld sizes.

Analysis for 0.75" Groove Weld

Consistent with previous assumptions, we have

$t = 0.75"$

$a = 0.375"$

$w = \pi\ (68.375) = 214.8"$

$2c = w\ (360° \text{ flaw}) = 214.8"$

Using the solution proposed by Raju, et al. [8], we have

$$P = \sigma\ F \sqrt{\pi \frac{a}{Q}}$$

where

$$Q = 1 + 0.464\ (\frac{a}{c})^{1.65}$$

$$= 1.000041 \approx 1.0$$

$\sigma =$ Reference remote tensile stress. We again conservatively assume it to be equal to 2.215 ksi since the stress concentration factor is part of the solution.

F is the stress concentration factor. From the data provided in Reference [8], we can conclude that F = 3 will bound the actual value.

Substituting, we have

$$P = 7.27\ ksi\ \sqrt{inch}$$

We note that

P < K and the safety factor, "SF", defined here as K/P, is

SF=27.56

Therefore, the crack resistance ability of the weld is shown to be greater than the potential acting to grow it.

Analysis for 1.25" Groove Weld

Consistent with previous assumptions, we have

t = 1.25"
a = 0.625"
w = π (67.375) = 211.7"
2c = w (360° flaw) = 211.7"

Using the solution proposed by Raju, et al. [8], we have

$$P = \sigma\ F \sqrt{\pi\ \frac{a}{Q}}$$

where

$$Q = 1 + 0.464\ (\frac{a}{c})^{1.65}$$

$= 1.000031 \approx 1.0$

$\sigma =$ Reference remote tensile stress. We will conservatively assume it to be equal to 1.308 ksi.

F is the stress concentration factor. From the data provided in Reference [7], we can conclude that F = 3 will bound the actual value.

Substituting, we have

$$P = 5.5\ ksi\ \sqrt{inch}$$

We note again that

P < K and the safety factor, SF, is

SF = 36.44

Therefore, the crack resistance ability of the weld is shown to be greater than the potential acting to grow it.