From: Eric Leeds, NMSS
To: CHD1.CHP1.GEG, CHD1.CHP2.BLJ, ARD1.ARP1.DBS, ARD1.... B Jorgensen, R3
Date: 4/24/98 9:19am
Subject: VSC-24 UT Inspection Update -Forwarded -Forwarded

FYI. It looks like we have a workable solution path. We'll keep your people informed of our schedule and progress.

Eric

CC: CHD1.CHP2.RBL, ARD1.ARP1.JVE, WND2.WNP3.PMR, TWD2....

A/65

MEMORANDUM TO: Allen Howe, Welding Review Team Leader
Spent Fuel Technical Review Section, SFPO

FROM: Ronald Parkhill, Mechanical Engineer
Spent Fuel Technical Review Section, SFPO

Kenneth Battige, Materials Engineer
Spent Fuel Technical Review Section, SFPO

SUBJECT: FLAWTECH TRIP REPORT

On January 22, 1998, Messrs. Parkhill and Battige visited the FlawTech Division of PH Diversified, Inc., in Harrisburg, NC, to become more familiar with the methods for inserting flaws into metallic component specimens. FlawTech is currently under contract to Consumers Energy to implant flaws into the Palisades VSC-24 dry fuel storage mockup. Once the flaws are implanted, the mockup is to be shipped to ANO, where it will be used to evaluate the feasibility of performing UT on the structural lid closure weld. As a result of this visit, the following information was obtained:

a) Flaw Insertion Process-

Flaws are inserted into the desired location by excavating the specimen at the appropriate location, welding a lever arm to the area of the desired flaw, and then using fatigue to break the base metal at the end of the lever arm. Either mechanical or thermal fatigue can be used to cause the breakage. Once the metal is removed from the end of the lever arm, this results in a small piece of metal that fits exactly into its corresponding area of the component specimen. The size of the crack is controlled by machining the small piece of metal to the desired shape, reinserting it in its matching component location, and then seal welding its perimeter to the component. Once the seal welding of the flaw is completed, the excavated volume is welded to restore the component specimen to its original configuration. A UT examination of the excavated volume is performed to ensure that no other imperfections have been added during the welding process. Other types of flaws, such as slag inclusions and lack of fusion, may also be introduced.

b) Control of flaw size and location-

As described above the flaw size is controlled by measurement and machining of the small piece of fractured material prior to reattaching it to the component specimen via seal welding. The accuracy of this process was demonstrated via destructive examination of inserted flaws and documented in a report prepared for the Navy.

cc: F. Sturz, E. Hackett, G. Hornseth, C. Interrante, T. Kobetz, H. Lee, M. Vassilaros, D. Reid

A/68

c) Records and Documentation -

Drawings are prepared by FlawTech working in concert with their client to determine the size, location, and type of flaw to be inserted. These drawings control the fabrication process. Pictures are taken to provide a record of the flaw insertion process. A documentation package is provided to each client that includes the drawings and a pictorial record of the flaw insertion process. FlawTech also maintains a copy of the documentation package for their own records.

d) Shipping Considerations-

Due to the massiveness of the component specimens, FlawTech generally puts them on a flat bed truck, covered with a tarp. Since the flaws are well within the component specimen protected by the weld material of the excavated volume, no shipping damage is anticipated. For the Palisades mockup, Consumers Energy is planning to do a receipt inspection of the mockup at FlawTech's shop prior to shipping it to ANO.

e) Impact on UT inspectability-

At the time of the shop visit many of the flaws had already been inserted and FlawTech provided a demonstration of UT's ability to detect some of the flaws. Using a small portable, battery powered UT equipment with a 5-MHZ straight beam transducer, flaws # 13, 1, 2, 3 & 4 were readily identifiable when manually examined from the side of the mockup. It took only a couple of minutes to set up the UT equipment and perform an examination for these flaws. The EPRI representative stated that thin transducers (i.e., less than a 1/16th of an inch) were available for tight spaces like the area between the inside wall of the transport cask and the outside diameter of the canister. The EPRI representative also stated that an automated UT process could produce more accurate and timely examinations than a manual UT process.

f) Difference between the Palisades mockup flaws and those that would be produced for other calibration standards (ASME Section XI Appendices VII or VIII)-

FlawTech stated there was no difference between the flaws implanted in the VSC-24 mockup and Section XI, Appendix VII or VIII, qualification flaws.

g) Construction under FlawTech or Utility QA program-

FlawTech implanted flaws on the Palisades mockup under the utility's QA program since Consumer's Energy has visited FlawTech and performed audits. As mentioned above, CE will perform a receipt inspection of the finished product prior to shipping to ANO. FlawTech has its own QA program modeled after 10 CFR 50 Appendix B developed with the assistance of a utility.

h) Proprietary aspects-

FlawTech considered the physical details of the process by which they break the flaw specimen proprietary and we did not see this operation as part of our visit.

I) EPRI Involvement-

As identified in the Persons Contacted list, two representatives from EPRI's NDE center were present during our visit. They stated EPRI is assisting the SNC owners' group in the preparation of UT procedures for examination of the VSC-24 structural lid welds.

PERSONS CONTACTED:

George Pherigo, President FlawTech
Aaron Pherigo, Executive VP FlawTech and QA Manager
Kim Kietzman, EPRI NDE Center
Robert Zeh Bouck, EPRI NDE Center

February 3, 1998

Note To: Eric J. Leeds, Chief, Spent Fuel Licencing Section, SFPO, NMSS
Fritz C. Sturz, Chief, Spent Fuel Technical Review Section, SFPO, NMSS

From: Timothy J. Kobetz, Project Manager, SFLS, SFPO, NMSS
Allen G. Howe, Nuclear Engineer, SFTR, SFPO, NMSS

SUBJECT: MINUTES FROM THE JANUARY 28, 1998 WELD TEAM MEETING

The Weld Team met to review corrective actions associated with VSC-24 weld issues. Attendees were K. Battige, E. Hackett, G. Hornseth, A. Howe, C. Interrante, D. Jackson, T. Kobetz, H. Lee, S. Malik, R. Parkhill, and F. Sturz.

1. T. Kobetz discussed a proposed letter to SNC intended to reply to recent VSCOG submittals (e.g. weld samples, revised flaw calculations, and proposed schedules), the staff's expectations with regard to performing closeout inspections of Confirmatory Action Letters (CALs) issued to each member of the Owners Group, and the current status of SNC's response to requests for additional information (RAI). The RAIs were issued to SNC on August 26, 1997 and November 6, 1997 and pertain to the CALs.

   A. Howe discussed the technical issues regarding SNC calculation CPC-06Q-301, Revision 1, "Allowable Flaw Size Definition for VSC-24 Dry Storage Cask Structural Lid to Shell Weld" submitted December 17, 1997 and calculation WEP 109.002.73, "Analysis of a Hypothetical Crack in MSB-24 Shell and Bottom Plate,", Revision 1, dated October 24, 1997. **The weld team agreed to provide comments on the issues by 2/2/98.**

   After the technical issues are resolved, T. Kobetz will provide the draft letter to the team the week of 2/2/98.

2. H. Lee discussed the recent Addenda to the Sections III and XI of the ASME Code. These addenda provide guidance for the use of UT for preservice examinations and the section XI acceptance criteria. This is significant because, although the VSC-24 is not fully constructed to meet the Code, it parallels the approach agreed upon by the weld team to provide reasonable assurance that the welds are properly installed.

3. K. Battige and R. Parkhill discussed the results of their trip to FLAWTECH to observe the flaw insertion process in the VSC-24 mock-up. In addition to having a better understanding of the flaw insertion process, FLAWTECH demonstrated that a relatively simple, straight beam, UT scan of a flaw, readily detected the flaw. A trip report detailing this visit has been issued separately.

4. The weld team agreed that the pending inspection for the UT feasibility demonstration should focus on observing a "dress rehearsal" of the UT examination technique.

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72-1007

March 18, 1998
1952 Palisades Dr.
Appleton, WI 54915

3/25 Copies to: Leeds, SNRI, Bailey, Kokatz, Kokaj, NO, P Ray, NRR, Docket

Dear Mr. Haughney, NRC

I understand that the Palisades mock up of the VSC-24 was used in a MTC in Arkansas to do the dry run of the UT tests this week. I understand that the inspection report will be sent to me, but that it won't be completed for quite a while. Because I have had such a long term interest in the history of this cask development, I am, of course eager to know the results of the test. It is natural that you won't want to make any decision on the tests until the report is done, however, I really would appreciate being kept current on correspondence about this process that develops. So please send me anything you can to keep me current on the issues involved.

I noticed that there was a Nov 12, 1997 letter to Mr. Hal Austin (on flaw analysis input) included in SNC 97-125 of Dec 17, 1997. I am really surprised to see that in that Nov 12 letter Consumers is using the SAR Rev 0 of Oct 1991 as a reference. I really feel that all parties involved now need to be using the most current SAR, shouldn't they? Things have changed since 1991. I have repeatedly noted use of "the SAR" in many other documents with no reference date or letter at all. There is no "the SAR". My petition to keep documents current is still sitting on somebody's desk, I guess (It was for rulemaking.) How are the documents kept current at the plant? Do they change pages in a looseleaf notebook when parts are up dated or what? How is a check done

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to make sure everybody is referencing the most current changes? What is the SAR everybody should be using now? I really feel this is important — it could lead to misunderstandings to critical changes in analysis if documents aren't kept current at plant, by all those involved.

Also I guess I think that a test of these "knowns" is not as good as one with an "unknown". If you start with known flaws and then you evolve a test to reveal these flaws, you know what you are trying to reveal. SNC puts in the flaws, then makes the test reveal them. Now if NRC were to add their own flaws to this weld, unknown to SNC, and then use the UT method again and prove it could reveal these unknown flaws — that would certainly be a better proof in my mind. Can't you do it that way yet? (Its like going into an exam already knowing the questions to be asked, or going into an exam feeling you have to really know the material and being prepared to be asked anything in the course — I think, in the light of what has happened so far in this designs history, you need to be as careful as possible that this UT test really works — not in just a known set-up. I think this is reasonable.

As I understand it, a radiograph can't be done with fuel in the cask. Could a radiograph be done of the mock-up now though, to compare what it reveals to the UT testing? This might be of value too.

Questions:

1. What is the difference in size of the mockup and actual MSB?
2. Is the difference going to change the relationship in UT testing within a real MSB in MTC? — (its a tight space.)
3. In the mockup, was the shield lid in place? Shims? Was weight put in the MSB basket to represent the fuel and water? If not, how could the test represent real stresses?
4. In what ways did the dry run differentiate from the real thing? How were these accounted for?
5. Was the mockup structural lid actually welded in the 1st dry run at Palisades? If so, how was it cleaned or ground or cut? How did this affect its use for the UT test?
6. Was the minimum wall thickness of the MSB used in calculations? Shouldn't it?
7. Is the weld in the structural lid — MSB in the test a representation of all the weld configurations in the loaded casks? If not, will it represent all the welds to be done in the future — will they all be done exactly the same for this area?
8. How does the structural lid, MSB fit-up enter into the calculations. All casks are somewhat different I assume — and not perfect. If the structural lid is at "roundness" minimum or slightly "off-round" — Then the weld could be irregular in width couldn't it? Will UT work in this case for all irregularities?
9. Seems to me a structural lid "jammed" at Palisades in the dry run — how was that dealt with — maybe

it was the shield lid — In any case, the condition of the mock-up may be data needed to evaluate the process correctly.

10. Was the Palisades, or ANO, MTC used? Is there a difference at all? If so what? There were changes made in the MTC design.

11. Are the carbon steel materials for all casks the exact same thing? I thought there were some differences — (even if they do meet SAR requirements) — are these taken into account?

12. Was the width of a flaw revealed?

13 Were multiple flaws revealed?

14. Can these flaws be repaired? How?

15. If repaired, then how are the repairs checked?

16 Doses to workers for UT? repair? repair check? — time involved? — affect on drain down time?

17. Will NRC make a limit to flaw size, and then allow SNC to accept others on a case-to-case basis? Why? I don't think this should be allowed.

18. Some casks at Palisades were not Charpy tested correctly — how does that enter in to analysis for fracture toughness?

19. How do weld reinforcements enter in? I remember initially that they were not authorized, but done anyway. Am I wrong? Why was this done?

20. Is backing ring used in all casks?

21. How will UT be incorporated at each plant if feasible? What differences will there be at different sites?

22. Of course we are concerned with the loaded casks and feel no more should be loaded until those are tested. When will this be done? Thanks for any help on this, Karen Shillinglaw

SIERRA NUCLEAR CORP.

Copies to:
Leeds (letter only)
Kobetz
[redacted]
Lee
Parkhill
Battige
Intervale
Hornseth
Hackett(J)
Docket

December 17, 1997

SNC 97-125

Mr. Timothy Kobetz
U.S. Nuclear Regulatory Commission
11555 Rockville Pike
Rockville, MD 20852

Subject: Transmittal of Revised Calculation Package CPC-06Q-301 Rev. 1: Allowable Flaw Size Definition for VSC-24 Dry Storage Cask Structural Lid to Shell Weld

Reference: US NRC Request for Additional Information Concerning Confirmatory Action Letter 97-7-001 dated August 26, 1997

US NRC Letter to J. Massey, Sierra Nuclear Corporation, dated December 9, 1997; Subject: Commitments Made to the Nuclear Regulatory Commission by Sierra Nuclear Corporation and the VSC-24 Owners Group

Dear Mr. Kobetz

As part of the response to Question 4 of the US NRC Request for Additional Information Concerning Confirmatory Action Letter 97-7-001 dated August 26, 1997, and in response to Commitment 1 of the US NRC Letter to John Massey, Sierra Nuclear Corporation, dated December 9, 1997; titled: Commitments Made to the Nuclear Regulatory Commission by Sierra Nuclear Corporation and the VSC-24 Owners Group, Sierra Nuclear Corporation(SNC) and the VSC-24 Owners Group submit the updated and revised calculation package CPC-06Q-301 Rev. 1, titled: Allowable Flaw Size Definition for VSC-24 Dry Storage Cask Structural Lid to Shell Weld.

The revised calculation has been updated to incorporate the comments made during the technical review meeting held in Washington D.C. on December 4, 1997. In addition, the calculation has been revised to include a discussion on the postulated mockup defects (Section 7.0) and includes a complete description of these flaws in Appendix C.

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1 Victor Square • Scotts Valley, California 95066 • (408) 438-6444 • Fax (408) 438-5206

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Should you or the Commission have any additional questions please contact me at Sierra Nuclear Corporation(SNC); 408 - 438 - 6444.

Respectfully,

Kay Moeckel
Manager, Licensing

cc: G.Dixon, J.Massey; LicRile; f:\admin\ltrs\snc

STRUCTURAL INTEGRITY Associates, Inc.	# CALCULATION PACKAGE	FILE No: CPC-06Q-301 PROJECT No: CPC-06Q

PROJECT NAME: Analytical Support for Dry Spent Fuel Storage Activities

CLIENT: Consumers Energy (Palisades Nuclear Plant)

CALCULATION TITLE:
Allowable Flaw Size Definition for VSC-24 Dry Storage Cask Structural Lid to Shell Weld

PROBLEM STATEMENT OR OBJECTIVE OF THE CALCULATION:

Develop Weld Flaw Acceptance Criteria

Document Revision	Affected Pages	Revision Description	Project Mgr. Approval Signature & Date	Preparer(s) & Checker(s) Signatures & Date
0	1 - 24 Appendix A & B	Original Issue	H L Gustin 11/25/97	HLG 11/25/97 [illegible] 11/25/97
1	1 - 28 Appendices A, B, C	Incorporated Comments	H L Gustin 12/17/97	HLG 12/17/97 [illegible] 12/17/97

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1.0 INTRODUCTION

The purpose of this calculation is to develop acceptance criteria for flaws which may be detected in the structural lid to shell weld of spent fuel dry storage casks at Palisades, Point Beach, and ANO Nuclear Plants. The typical geometry of the structural lid to shell weld joint is illustrated in Figure 1 [1].

For the casks which are currently in service, nondestructive examination of these welds has included dye penetrant examination of the root and final welded layers. No volumetric examination of these welds has been performed in the past, but the plant owners are considering such examination as a result of discussions with the NRC.

2.0 CODE APPLICABILITY

In the present analysis, the methods of ASME Section XI, IWB-3600 and Appendix A [2] are used to determine allowable flaw sizes under the limiting loading conditions. IWB-3600 and Appendix A are directly applicable to Class 1 vessels (such as reactor vessels) and piping. Although the dry fuel storage casks are Class 2 (NC) vessels, Section IWC-3600 is still under development, and Section XI permits the use of IWB criteria for flaw evaluations.

Section XI flaw evaluation criteria are directly applicable for evaluation of flaw indications detected in the structural lid welds of casks which are already in service. Its applicability is less clear for examination results for new casks. However, for examinations of structural lid welds which are performed immediately upon completion prior to putting them in service, it is SI's opinion that the rules of Section XI should still be applied, in lieu of Section III rules. Although a loaded cask is not formally considered to be "in operation" until it is successfully transferred to the storage pad, the cask is performing its design function in a difficult to reverse manner once fuel is loaded and the shield lid and structural lid are in place. Section XI provides more extensive methods for the evaluation of defects detected by volumetric examination, and volumetric examination of the structural lid weld immediately following completion forms a baseline for any subsequent inservice inspections by similar methods.

3.0 LOAD DEFINITION

Table 1 [1] provides stress data for the structural lid weld under the horizontal drop accident. This event is considered to be an emergency/faulted class (service level C/D) event. Table 2 [1] presents stress data for normal operating events By comparing the Tables, it can be seen that at the structural lid weld, the normal operating stresses are significantly lower than the stresses which are predicted to result from the horizontal drop event. Therefore, the horizontal drop accident is judged to govern the critical flaw size determination.

As shown on Table 1, the horizontal drop event produces the following stresses in the structural lid-to-shell weld:

$$P_m = 7.2 \text{ ksi}$$

$$P_L + P_B = 43.3 \text{ ksi}$$

In the fracture mechanics analysis below, both of these stress components were included. These were conservatively modeled as a tensile membrane stress, with a magnitude of 43.3 ksi. This magnitude is appropriate for use in the vicinity of the structural lid-to-shell weld. The highest stress in the shell reported on Table 1 (73.0 ksi) occurs at a location which is approximately 12 inches from the bottom plate of the MSB [9], which is remote from this weld.

In addition to this applied stress, weld residual stress was included in the calculation. Because no measurements or calculations of weld residual stress were available, the weld residual stress was assumed to be represented by a distribution typical of a multipass groove weld such as is presented in Figure 7, which is taken from NUREG-0313, Revision 2 [8].

This typical distribution was scaled to reflect an assumed inside surface tensile stress of 40 ksi, corresponding to a typical yield stress for the A-516 Grade 70 material. The scaled distribution is shown as a dashed line on Figure 7. Appendix A of Section XI [2] requires the use of residual stresses in determination of allowable flaw sizes.

For normal operating conditions, the limiting applied stress intensity K_I (applied) is:

$$K_I(\text{applied}) < \frac{K_{ID}}{\sqrt{10}}$$

where K_{ID} calculated from the projected Charpy data is used as the critical stress intensity. The safety factor of $\sqrt{10}$ is as defined in Section IWB-3612. K_{ID} is equivalent to K_{Ia} as discussed above. For this case, the total applied stress intensity K_I (applied) is determined from the membrane, bending, and residual stresses as

$$K_I(\text{applied}) = K_I(\text{membrane}) + K_I(\text{bending}) + K_I(\text{residual})$$

where the *K_I (residual)* reflects the residual stress case.

For the emergency/faulted case (horizontal drop), it is still appropriate (and conservative) to use the calculated K_{ID} as the criterion, because of the dynamic nature of the loading, instead of the K_{IC} (which would be appropriate for static or slow loading rates). For this case (horizontal drop) the applied K_I is limited by

$$K_I(\text{applied}:\text{drop}) < \frac{K_{ID}}{\sqrt{2}}$$

The applied K_I using a safety factor of $\sqrt{2}$ on residual stresses as discussed above, is given

$$K_I\,(\text{applied}) = K_I\,(\text{membrane}) + K_I\,(\text{bending}) + K_I\,(\text{residual})$$

For this case, residual stresses are also conservatively treated as primary membrane stresses, using the full code safety margin of $\sqrt{2}$.

4.0 MATERIAL FRACTURE TOUGHNESS

The certified material test reports (CMTRs) [1,5,6] for the structural lid weld material were provided by the plant owners. The procedure qualification records (PQRs) were also provided. These documents contain Charpy V-Notch Impact data taken at -50°F (and some data at other temperatures). The PQRs also include Charpy results for base metal and heat affected zone (HAZ) as well as weld metal.

According to the "Certificate of Conformance for the VSC-24 System" [9] in Section 1.2.13. there are administrative limits which prevent moving of the storage casks when the temperature is less than 0°F. Consequently, a horizontal drop accident is judged not to be possible below this temperature.

Article A-4000 of Appendix A to Section XI [2] recommends that the material fracture toughness be determined from the actual material and product form in question. Therefore, to evaluate the fracture toughness of this material, use of the actual Charpy data at 0°F is appropriate. The Charpy data at 0°F is used to determine material fracture toughness (K_{Ic}) using the following equation for carbon steel in the transition temperature region [3]:

$$K_{ID} = \sqrt{5C_vE}$$

In this equation, E was assumed to be 29,000 ksi.

Judging from the % shear data, the material is in the transition region in the -50°F to 0°F temperature range, so use of this equation is appropriate [3]. Also, the Charpy correlation is for K_{ID} (dynamic) fracture toughness as well as K_{IC} (static), so it is applicable to a dynamic event like the drop accident.

As noted above, the material specifications for both base metal and weld metal require Charpy V-notch test results at -50°F, while the lowest temperature at which a horizontal drop could occur is 0°F, due to administrative limits [1]. All three plants (Palisades, Point Beach, ANO) provided CMTRs for weld material used (or proposed for use) in the structural lid welds [1,5,6] and these CMTRs included Charpy data at -50°F. All CMTRs include data for the as-welded condition, which is applicable to all three plants. Results for base metal and HAZ from PQRs were also considered.

The PQRs include -50° Charpy data for weld metal, HAZ, and base metal. In order to determine the limiting material condition, all such data was evaluated for toughness at 0°F as described in the following. All available data is presented in Table 3. Based on the data in Table 3 the HAZ is not the limiting location.

In order to determine allowable flaw sizes for each plant, it is appropriate to use the limiting material toughness at the limiting temperature of 0°F. Since such data is not available in most cases, it is necessary to extrapolate toughness at 0°F from the available -50°F data.

The data from all CMTRs and PQRs shows that the material is in the transition region (reported per cent shear of 20-80%) and so linear projection is appropriate. Referring to Figure 5 from [7],the slope of this curve is estimated as 0.55 ft-lb/°F for the high manganese curve, which describes a material similar to the A-516 Grade 70 base metal. This slope is more gradual than the 1% manganese curve, and therefore projection is more conservative using this slope. This slope was used to project all reported base metal, HAZ, and weld metal -50°F data [1,5,6] to 0°F. The results are shown in Table 3. Also, all available Charpy data from CMTRs [1,5,6] at 0°F is shown in Table 3 for comparison. The predicted 0°F Charpy data for weld metal is conservative compared to all available actual weld metal 0°F data. That is, the predicted Charpy results at 0°F (based on extrapolation of -50°data) are consistently lower than actual data at 0°F for weld metal, which is the only material for which 0°F data is available.

Each of the predicted Charpy absorbed energy results at 0°F were used to calculate a material toughness K_{ID} for use in allowable flaw size calculations.

The resulting fracture toughness at 0°F is greater than 75 ksi-$\sqrt{in.}$ for all cases. This value is shown in Figure 2 in comparison to ASME Section XI fracture toughness curves for carbon and low alloy steel reactor pressure vessel bounding materials. Figure 4 shows allowable flaw size (depth versus length) for a toughness of 78.4 ksi-$\sqrt{in}$, which results from extrapolation of the minimum specified Charpy V-notch absorbed energy of 15 ft-lb at -50°F. (This is the minimum specified for both weld metal and base metal). Allowable flaw size curves for the limiting material for each plant are also shown.

5.0 APPLICATION OF ASME CODE MARGINS

As discussed above, the limiting event for the structural lid weld is the horizontal drop accident, which is considered to be an emergency/faulted event. The stresses associated with this event are defined in Table 1 from [1].

Using the rules of IWB-3613(c) [2], the fracture toughness values determined above are reduced by a factor of $\sqrt{2}$ to define the limiting allowable K_I for flaws in the structural lid weld under emergency/faulted conditions. That is,

$$K_{I\ allowable} < \frac{K_{ID}}{\sqrt{2}}$$

For example, a limiting K_{ID} calculated from Charpy data of 78.8 ksi-$\sqrt{in}$ produces an allowable K_I of 55.4 ksi-$\sqrt{in}$. This value corresponds to the value obtained by extrapolating the minimum specified toughness (15 ft-lb at -50°F) to 0°F as discussed above.

6.0 ALLOWABLE FLAW CALCULATIONS

Using the above load definitions and fracture toughness, a series of allowable flaw size calculations were performed using the Structural Integrity Associates computer program **pc-CRACK™** [4], which has been developed and verified under the SI Quality Assurance program.

6.1 Surface Flaws

The structural lid weld was modeled as a plate with an elliptical surface crack subject to both membrane and bending stresses. This model is illustrated in Figure 3. Use of this flat plate model for flaws in the structural lid to shell weld is appropriate for flaws originating in the vicinity of the weld root and propagating through the weld material or weld-base metal interface. This model is conservative compared to the actual weld geometry, because the actual weld experiences significant hoop constraint due to the stiffness of the structural lid and cask shell. Such constraint will limit crack opening in the actual weld as compared to the model, and therefore a larger crack would be tolerable in the actual weld than is predicted by use of the flat plate model. These results are equally applicable to flaws originating on the outside surface and oriented inward.

The flaw aspect ratio (the ratio of flaw depth to length) was varied parametrically, to determine an allowable flaw depth versus length curve. The conservative fracture toughness including the emergency/faulted Code margins was used as the criterion for determining allowable flaw depth for each aspect ratio.

The results are shown in Figure 4, and the supporting **pc-CRACK** analyses are attached in Appendix A. There is no known mechanism for continued crack propagation of defects in these welds, so no crack growth calculations have been performed for the assumed defects. Limiting allowable flaw depths for each heat of weld material at each plant are shown in Table 3.

6.2 Subsurface Flaws

The above discussion addressed the determination of allowable flaw sizes for flaws which are connected to the surface of the weld, under a conservative set of assumptions. The weld could also contain subsurface defects as a result of the welding process for example. In general, the allowable flaw size for a subsurface defect will be larger (usually twice or greater) than for a surface defect under the same conditions.

Evaluation of allowable subsurface defects was performed using the same linear elastic fracture mechanics techniques as were described above for surface defects. For these cases, a center cracked plate model (Figure 6) was used to evaluate the infinite length flaw. This model is conservative for the actual cases, since it treats applied stresses as pure tension, while for the subsurface flaw cases, the drop load case has a significant through-wall bending component. Consequently, for a subsurface flaw the stresses due to the drop event will be significantly lower than the 43.3 ksi surface stress for this event (see page 3). The calculated allowable flaw sizes for subsurface flaws corresponding to the same assumptions presented in Table 3 for surface flaws are shown in Table 4. The allowable subsurface flaw results presented in Table 4 also require that the flaw be sufficiently embedded that treatment as a subsurface flaw is justified. ASME Section XI, Figures IWA-3310-1, -

3320-1, and -3330-1 provide criteria for evaluating proximity of flaws to the surface and to each other (in the case of multiple flaws). In general, if a flaw is closer to the surface than 0.4 of its half-depth, it must be considered to be a surface flaw.

7.0 RECOMMENDED MOCKUP DEFECTS

The above analysis shows that a family of significant sized flaws (Figure 4 a, b, c, d) can be accepted in the structural lid to shell weld, while maintaining Code margins, and under a conservative set of assumptions.

Ultrasonic examination of the final structural lid weld will be attempted using a mock-up which duplicates the final structural lid weld configuration.

In order to demonstrate the feasibility of the ultrasonic examination process, qualify the technique, and verify the capability for detecting and sizing any observed indications, the mockup will be implanted with flaws which represent the following conditions:

- Crack 0.05" to 0.25" deep and 0.5" long at the weld joint extremes to assure that the weld volume can be adequately examined - (Flaws 1-7, 8-13, 14-19 and 20-25).

- Cracks 0.3", 0.4", and 0.5" deep and 0.5" long at the weld centerline to provide confidence that large flaws can be detected and sized - (Flaws 28-30).

- Welding defects which represent slag (0.1" deep x 0.5" long) and lack of fusion including lack of fusion resulting from weld starts and stops (0.1" to 0.3" deep x 0.375" long) - (Flaws 26, 27 and 31-33).

Appendix C describes the flaws which will be implanted in the mockup for use in demonstrating the feasibility and performing the process qualification for ultrasonic examination of the final structural lid weld.

Appendix C identifies the defects (size, orientation, and location) which the Owners Group intends to incorporate in the Palisades mockup, for use in volumetric examinations, feasibility demonstrations and process qualification. Multiple flaw configurations (e.g., parallel flaws in either planar or laminar orientations) are not expressly included in the mock-up, because of the large number of such hypothetical combinations. For evaluation purposes, multiple flaws will be combined in accordance with Section XI proximity rules.

The allowable flaw sizes contained in Tables 3 and 4 are presented as circumferentially oriented defects. The allowable flaw depth are also conservatively applicable to flaws oriented transverse to the weld direction. Circumferentially oriented flaws are more significant with regard to structural adequacy and are not inherently limited in length, as are transverse flaws due to the structural constraints of the geometry. Flaws oriented radially into the shell will not degrade the integrity of the weld, and are not considered here.

8.0 CONCLUSIONS

This analysis has shown that flaws with depths greater than those which could have been missed during original weld examination can be accepted under the criteria of ASME Section XI, with a conservative set of assumptions. These results are generic and conservative in nature. Specific flaws exceeding the criteria developed in this calculation could potentially be accepted based upon more detailed analyses and less conservative materials properties on a case-by-case basis.

We recommend that the above results be used as the basis for establishing methods for qualifying volumetric examination techniques for these welds, and for initial screening of results of field examinations.

9.0 REFERENCES

1. Letter from Emil A. Zernick (Consumers Energy) to Hal Gustin (SI), "Flaw Analysis Inputs," dated November 12, 1997, transmitting design input information (letter attached as Appendix B). CPC-06Q-201

2. ASME Boiler and Pressure Vessel Code, Section XI (with Appendix A), 1989 Edition.

3. Rolfe, Stanley T., and Barsom, John, M., Fracture and Fatigue Control in Structures, Prentice-Hall, 1977.

4. Structural Integrity Associates, **pc-CRACK™** for Windows, Version 3.0, March 27, 1997.

5. Fax from Tom Burtard (Wisconsin Electric Power Company) to Hal Gustin (SI) dated 11/12/97 and 11/13/97 Charpy Test Results. CPC-06Q-203

6. Fax from Darrell Williams (ANO) to Hal Gustin (SI) dated 11/11/97: Weld Material CMTRs. CPC-06Q-202

7. ASM, The Metals Handbook, Vol 1, 10th Edition, 1990.

8. NUREG-0313 "Technical Report on Material Selection and Processing Guidelines for BWR Coolant Pressure Boundary Piping," Revision 2, 1988.

9. Letter from Kay Moeckel (Sierra Nuclear) to Hal Gustin (SI) dated 12/12/97. CPC-06Q-204

Table 1

TABLE 11.2-1

SUMMARY OF STRESSES (ksi) IN THE MSB RESULTING FROM THE HYPOTHETICAL HORIZONTAL DROP

Component		Drop	Dead Wt.*	Thermal	Pressure	Total	ASME Allowable
Bottom Plate	P_m	29.4	N/A	N/A	0.06	29.5	49.0
	$P_L + P_b$	44.6			1.7	46.3	73.5
Shell	P_m	25.9	N/A	N/A	0.1	26.0	49.0
	$P_L + P_b$	71.8			1.2	73.0	73.5
Structural Lid	P_m	2.6	N/A	N/A	0.0	2.6	49.0
	$P_L + P_b$	42.9			0.4	43.3	73.5
Shield Lid	P_m	2.4	N/A	N/A	0.0	2.4	49.0
	$P_L + P_b$	20.6			0.0	20.6	73.5
Bottom Weld	P_m	25.9	N/A	N/A	0.2	26.1	49.0
	$P_L + P_b$	44.6			1.7	46.3	73.5
Top Weld	P_m	7.1	N/A	N/A	0.06	7.2	36.8
	$P_L + P_b$	42.9			0.4	43.3	55.1
Shield Lid Weld	P_m	9.1	N/A	N/A	0.2	9.3	36.8
	$P_L + P_b$	20.6	N/A	N/A	0.8	21.4	55.1

* Dead weight is included in the drop load.

Table 2

TABLE 3.4-5

MSB MAXIMUM STRESS EVALUATION

Component	Stresses	CALCULATED VALUE, KSI*					
		DEAD WEIGHT	PRESSURE	THERMAL	HANDLING	TOTAL	ASME LIMIT
MSB Shell	P_m	0.1	0.1	N/A	0.9	1.1	20.5
	$P_L + P_b$	0.1	1.2	N/A	2.4	3.7	30.7
	$P + Q$	0.1	1.2	1.0	2.4	4.7	61.5
Bottom Plate	P_m	0.02	0.06	N/A	1.0	1.1	20.5
	$P_L + P_b$	0.02	1.7	N/A	1.5	3.2	30.7
	$P + Q$	0.02	1.7	19.4	1.5	22.6	61.5
Top Lid	P_m	0.0	0.0	N/A	0.1	0.1	20.5
	$P_L + P_b$	0.0	0.4	N/A	0.2	0.6	30.7
	$P + Q$	0.0	0.4	0.2	0.2	0.8	61.5
Bottom-to-Shell Junction	P_m	0.1	0.2	N/A	0.9	1.2	20.5
	$P_L + P_b$	0.1	1.7	N/A	1.5	3.3	30.7
	$P + Q$	0.1	1.7	1.5	1.5	4.8	61.5
Top-to-shell Junction	P_m	0.0	0.06	N/A	0.2	0.3	15.4
	$P_L + P_b$	0.0	0.4	N/A	0.2	0.6	23.1
	$P + Q$	0.0	0.4	0.4	0.2	1.0	46.1
Sleeve Assembly	P_m	0.05	N/A	N/A	1.8	1.9	20.5
	$P_L + P_b$	0.05	N/A	N/A	2.1	2.2	30.7
	$P + Q$	0.05	N/A	52.0	2.1	54.2	61.5
Shield Lid-to-Shell Weld	P_m	0.3	0.2	N/A	0.3	0.8	15.4
	$P_L + P_b$	0.3	0.8	N/A	0.4	1.5	23.1
	$P + Q$	0.3	0.8	1.3	0.4	2.8	46.1
Shield Lid Support Ring Weld	P_m	0.4	N/A	N/A	0.3	0.7	15.4
	$P_L + P_b$	0.4	N/A	N/A	0.3	0.7	23.1
	$P + Q$	0.4	N/A	0.0	0.3	0.7	46.1

* Values shown are maximums irrespective of location

Table 3

Projected Charpy Data and Allowable Surface Flaw Sizes

Plant	Identifier	Percent Shear	Charpy @-50°F Average	Charpy @ 0°F Predicted	Charpy @ 0°F Actual (If Available)	KID @ 0°F	Allowable Depth (360°) Surface
Point Beach	WP-18P4(18-8) (GMAW)						
	Weld	NA	28	55.4	NA	89.6	0.18
	Base 18-8	NA	41	68.4	NA	99.6	
	HAZ 18-8	NA	87	114.4	NA	128.8	
	PQR-WP-17 (SMAW)						
	Weld	NA	84	111.4	NA	127.1	
	Base	NA	40	67.4	NA	98.9	
	HAZ	NA	137	164.4	NA	154.4	
ANO	PQR-399 (FCAW)						
	Weld	58	55	82.4	NA	109.3	
	HAZ	70	80	107.4	NA	124.8	
	Base	13	33	60.4	NA	93.6	0.20
	PQR-398R1 (SMAW)						
	Weld	50	77	104.4	NA	123.0	
	HAZ	40	70	97.4	NA	118.8	
	Base	20	43	70.4	NA	101.0	
ANO	Weldstar 467H	NA	84	111.4	NA	127.1	
	ESAB 41323	40	60	87.4	117	112.6	
	ESAB 37962	27	55	82.4	96	109.3	
	ESAB 2A505A02	50	94	121.4	NA	132.7	
	ESAB 2H408A03	43	96	123.4	NA	133.8	
	ESAB 2E426G02	63	103	130.4	NA	137.5	
	ESAB 2K407H03	70	122	149.4	NA	147.2	

Table 3 (continued)

Plant	Identifier	Percent Shear	Charpy @-50°F Average	Charpy @ 0°F Predicted	Charpy @ 0°F Actual (If Available)	KID @ 0°F	Allowable Depth (360°) Surface
Palisades	Alloy Rods 32039	20	56	83.4	91	110.0	0.24
	ESAB 38380	56	99	126.4	135	135.4	
	ESAB 51122	60	82	109.4	115	125.9	
	PQR-SM-LID-D (SMAW)						
	Base	NA	60	87.4	NA	112.6	
	Weld	NA	130	157.4	NA	151.1	
	HAZ	NA	123	150.4	NA	147.7	
	PQR-SM-LID-C (SMAW)						
	Base	NA	70	97.4	NA	118.8	
	Weld	NA	92	119.4	NA	131.6	
	HAZ	NA	112	139.4	NA	142.2	
	PQR-FC-LID (FCAW)						
	Base	NA	58	85.4	NA	111.3	
	Weld	NA	69	96.4	NA	118.2	
	HAZ	NA	141	168.4	NA	156.3	
	PQR-FC-LID (FCAW)						
	Base	NA	64	91.4	NA	115.1	
	Weld	NA	91	118.4	NA	131.0	
	HAZ	NA	158	185.4	NA	164.0	
Min Specified	Base and Weld	NA	15	42.4	NA	78.4	0.15
	(15 ft-lb @ -50°F)						

Note: 1. The line labeled "Min Specified" represents calculation results based on 15 ft-lb absorbed energy at -50°F.

2. All Charpy data represents average results.

Table 4

Projected Charpy Data and Allowable Subsurface Flaw Sizes

Plant	Identifier	Percent Shear	Charpy @-50°F Average	Charpy @ 0°F Predicted	Charpy @ 0°F Actual (If Available)	KID @ 0°F	Allowable Depth (360°) Subsurface
Point Beach	WP-18P4(18-8) (GMAW)						
	Weld	NA	28	55.4	NA	89.6	0.30
	Base 18-8	NA	41	68.4	NA	99.6	
	HAZ 18-8	NA	87	114.4	NA	128.8	
	PQR-WP-17 (SMAW)						
	Weld	NA	84	111.4	NA	127.1	
	Base	NA	40	67.4	NA	98.9	
	HAZ	NA	137	164.4	NA	154.4	
ANO	PQR-399 (FCAW)						
	Weld	58	55	82.4	NA	109.3	
	HAZ	70	80	107.4	NA	124.8	
	Base	13	33	60.4	NA	93.6	0.30
	PQR-398R1 (SMAW)						
	Weld	50	77	104.4	NA	123.0	
	HAZ	40	70	97.4	NA	118.8	
	Base	20	43	70.4	NA	101.0	
ANO	Weldstar 467H	NA	84	111.4	NA	127.1	
	ESAB 41323	40	60	87.4	117	112.6	
	ESAB 37962	27	55	82.4	96	109.3	
	ESAB 2A505A02	50	94	121.4	NA	132.7	
	ESAB 2H408A03	43	96	123.4	NA	133.8	
	ESAB 2E426G02	63	103	130.4	NA	137.5	
	ESAB 2K407H03	70	122	149.4	NA	147.2	

Table 4 (continued)

Plant	Identifier	Percent Shear	Charpy @-50°F Average	Charpy @ 0°F Predicted	Charpy @ 0°F Actual (If Available)	KID @ 0°F	Allowable Depth (360°) Surface
Palisades	Alloy Rods 32039	20	56	83.4	91	110.0	
	ESAB 38380	56	99	126.4	135	135.4	
	ESAB 51122	60	82	109.4	115	125.9	
	PQR-SM-LID-D (SMAW)						
	Base	NA	60	87.4	NA	112.6	
	Weld	NA	130	157.4	NA	151.1	
	HAZ	NA	123	150.4	NA	147.7	
	PQR-SM-LID-C (SMAW)						
	Base	NA	70	97.4	NA	118.8	
	Weld	NA	92	119.4	NA	131.6	
	HAZ	NA	112	139.4	NA	142.2	
	PQR-FC-LID (FCAW)						
	Base	NA	58	85.4	NA	111.3	
	Weld	NA	69	96.4	NA	118.2	
	HAZ	NA	141	168.4	NA	156.3	
	PQR-FC-LID (FCAW)						
	Base	NA	64	91.4	NA	115.1	
	Weld	NA	91	118.4	NA	131.0	
	HAZ	NA	158	185.4	NA	164.0	
Min Specified	Base and Weld	NA	15	42.4	NA	78.4	0.24
	(15 ft-lb @ -50°F)						

Note: 1. For subsurface defects at weld mid wall depth, the allowable through-wall dimension of the defect is generally twice the allowable surface flaw dimension for the corresponding case.

2. The line labeled "Min Specified" represents calculation results based on 15 ft-lb absorbed energy at -50°F.

3. All Charpy data represents average results.

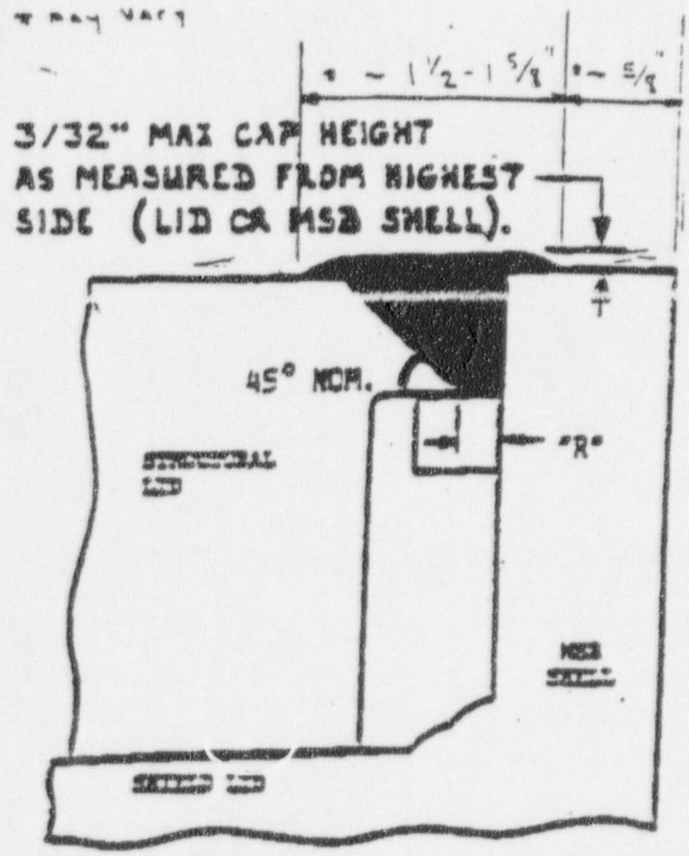

* may vary
* ~ 1 1/2 - 1 5/8"
* ~ 5/8"
3/32" MAX CAP HEIGHT
AS MEASURED FROM HIGHEST
SIDE (LID OR MSB SHELL).
45° NOM.
"R"

Figure 1

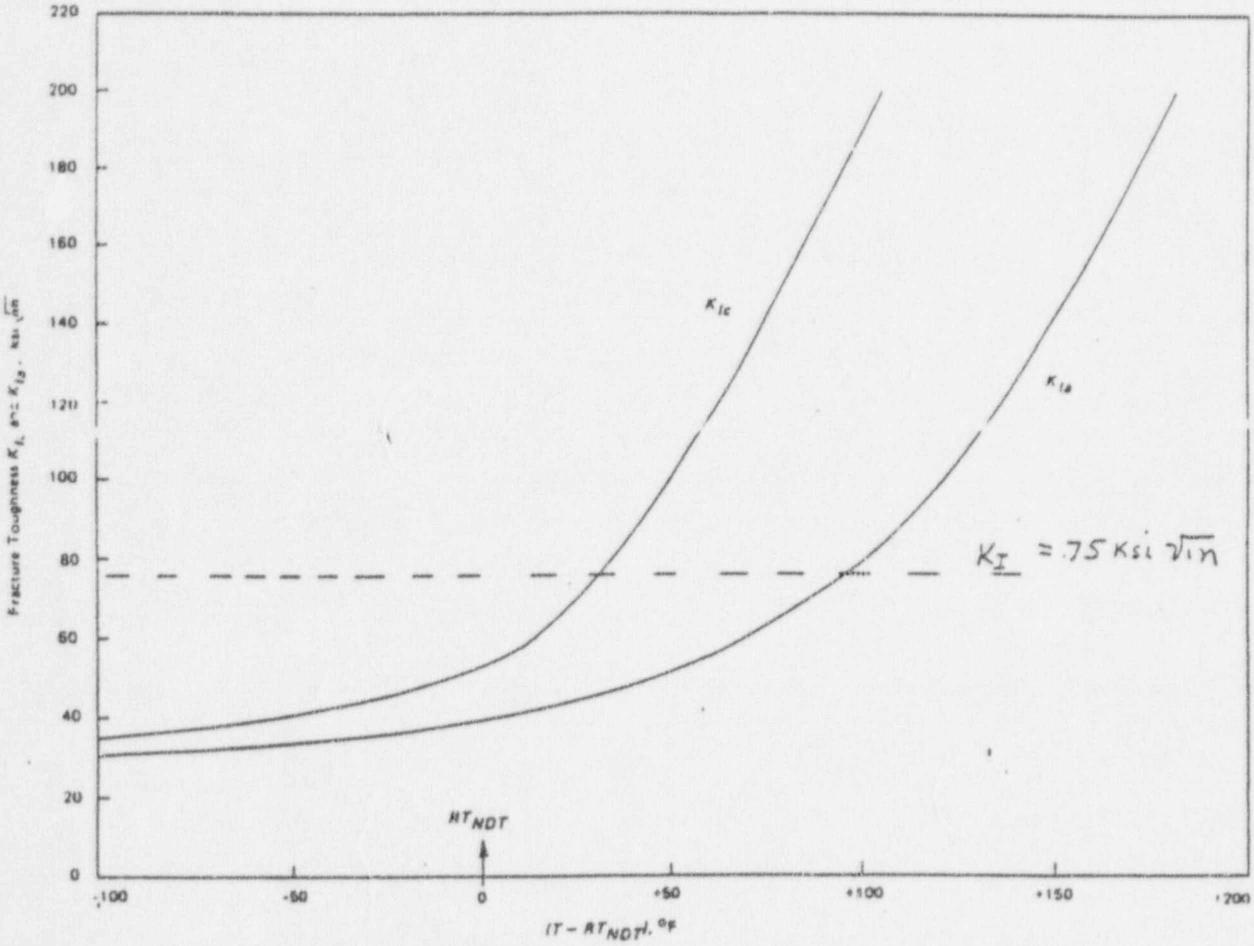


FIG. A-4200-1 LOWER BOUND K_{Ia} AND K_{Ic} VS TEMPERATURE CURVES FROM TESTS OF SA-533 GRADE B CLASS 1, SA-508 CLASS 2, AND SA-508 CLASS 3 STEELS

Figure 2

	Revision	1			
	Preparer/Date	HTS 12/17/97			
	Checker/Date	12/17/97			
	File No. CPC-06Q-301			Page 20 of 28	

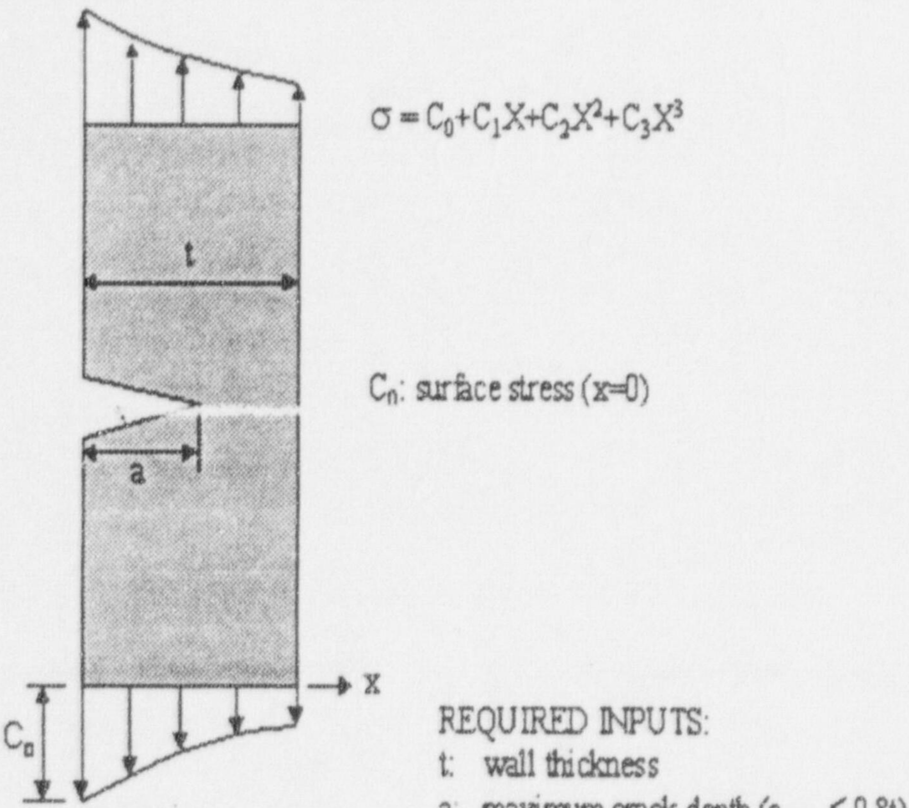


Figure 3: Single Edge Cracked Plate - LEFM Crack Model

ALLOWABLE SURFACE FLAW SIZE

FLAW DEPTH VERSUS LENGTH

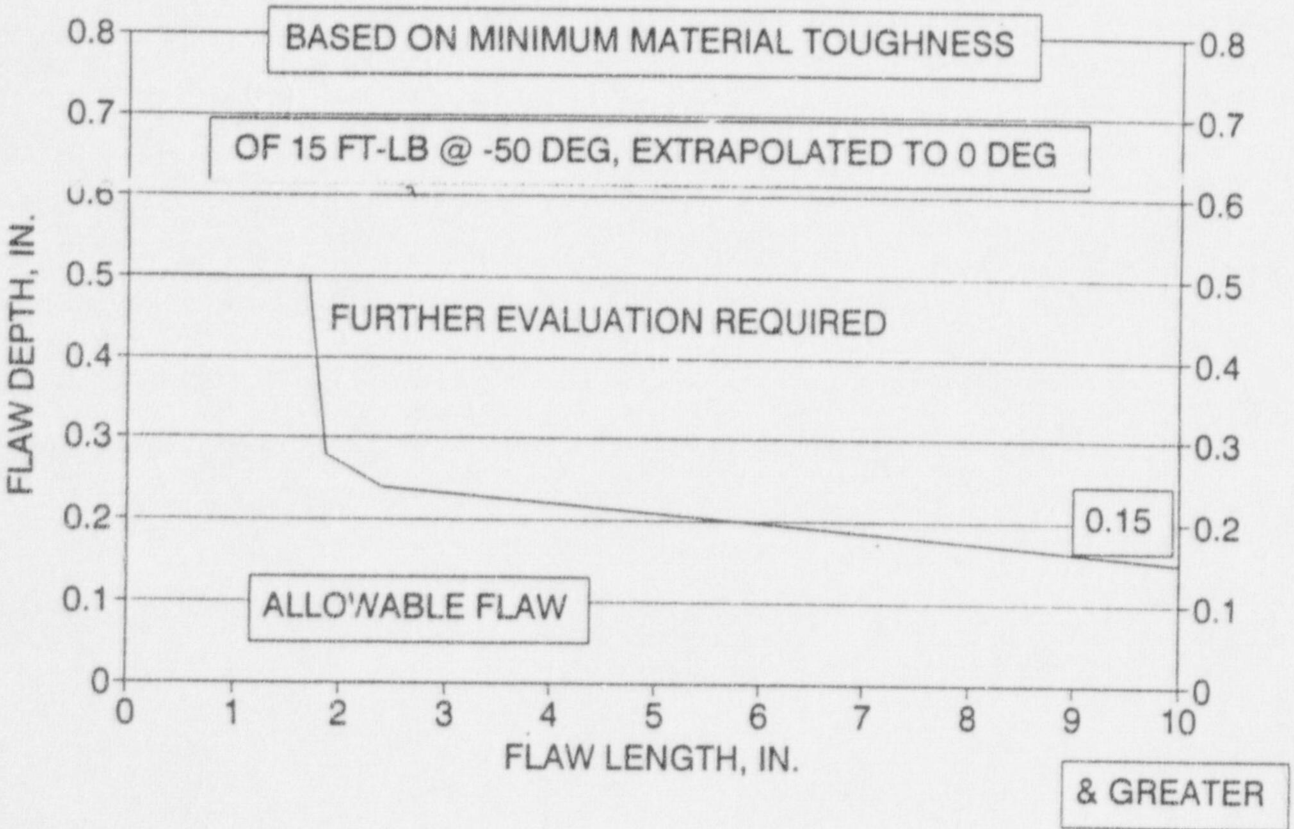


Figure 4a

	Revision	1			
	Preparer/Date	HJB 12/17/97			
	Checker/Date	12/17/97			
	File No. CPC-06Q-301			Page 22 of 28	

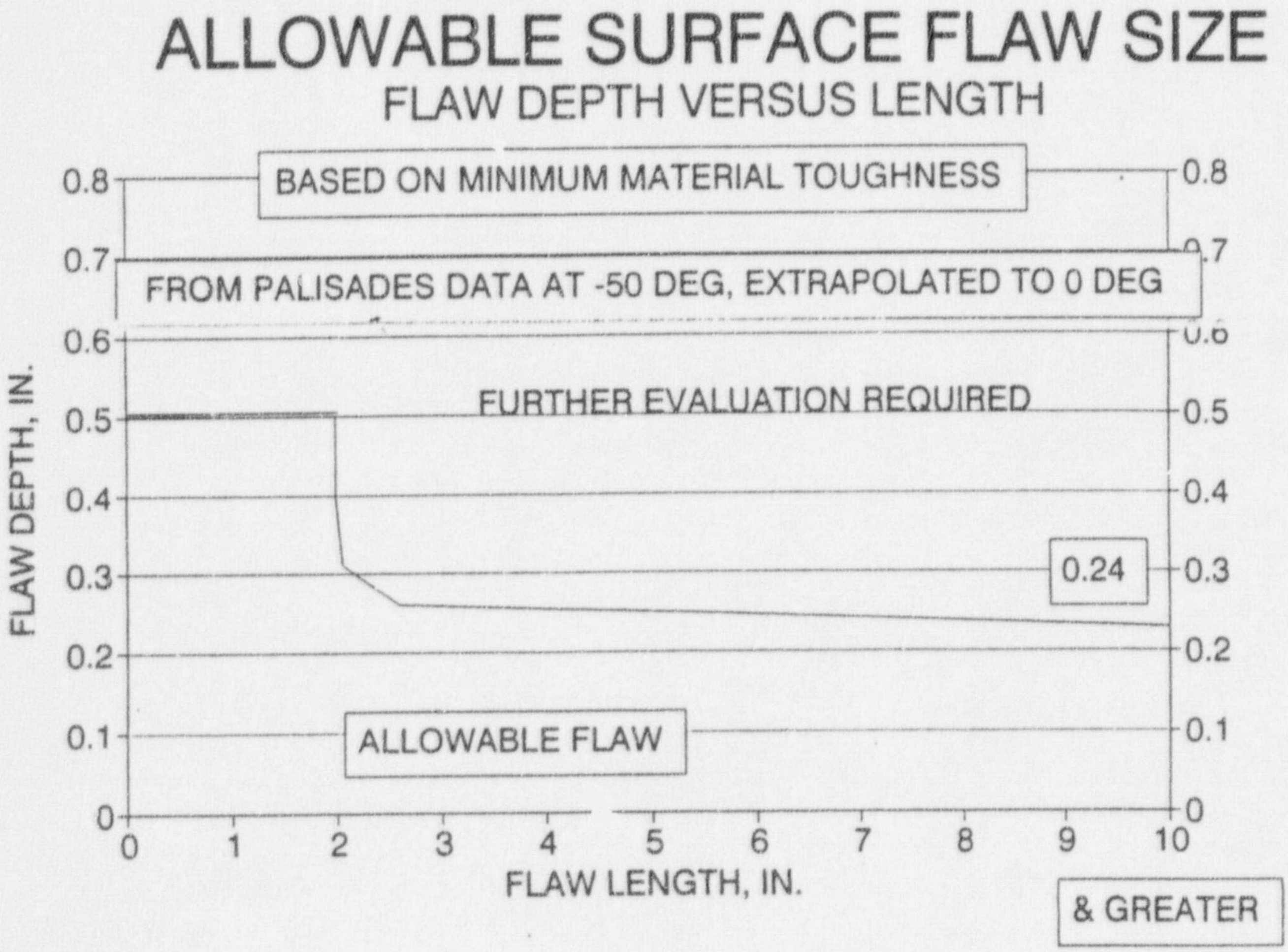

ALLOWABLE SURFACE FLAW SIZE
FLAW DEPTH VERSUS LENGTH
BASED ON MINIMUM MATERIAL TOUGHNESS
FROM PALISADES DATA AT -50 DEG, EXTRAPOLATED TO 0 DEG
FURTHER EVALUATION REQUIRED
0.24
ALLOWABLE FLAW
FLAW DEPTH, IN.
FLAW LENGTH, IN.
& GREATER
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
1
2
3
4
5
6
7
8
9
10

Figure 4b

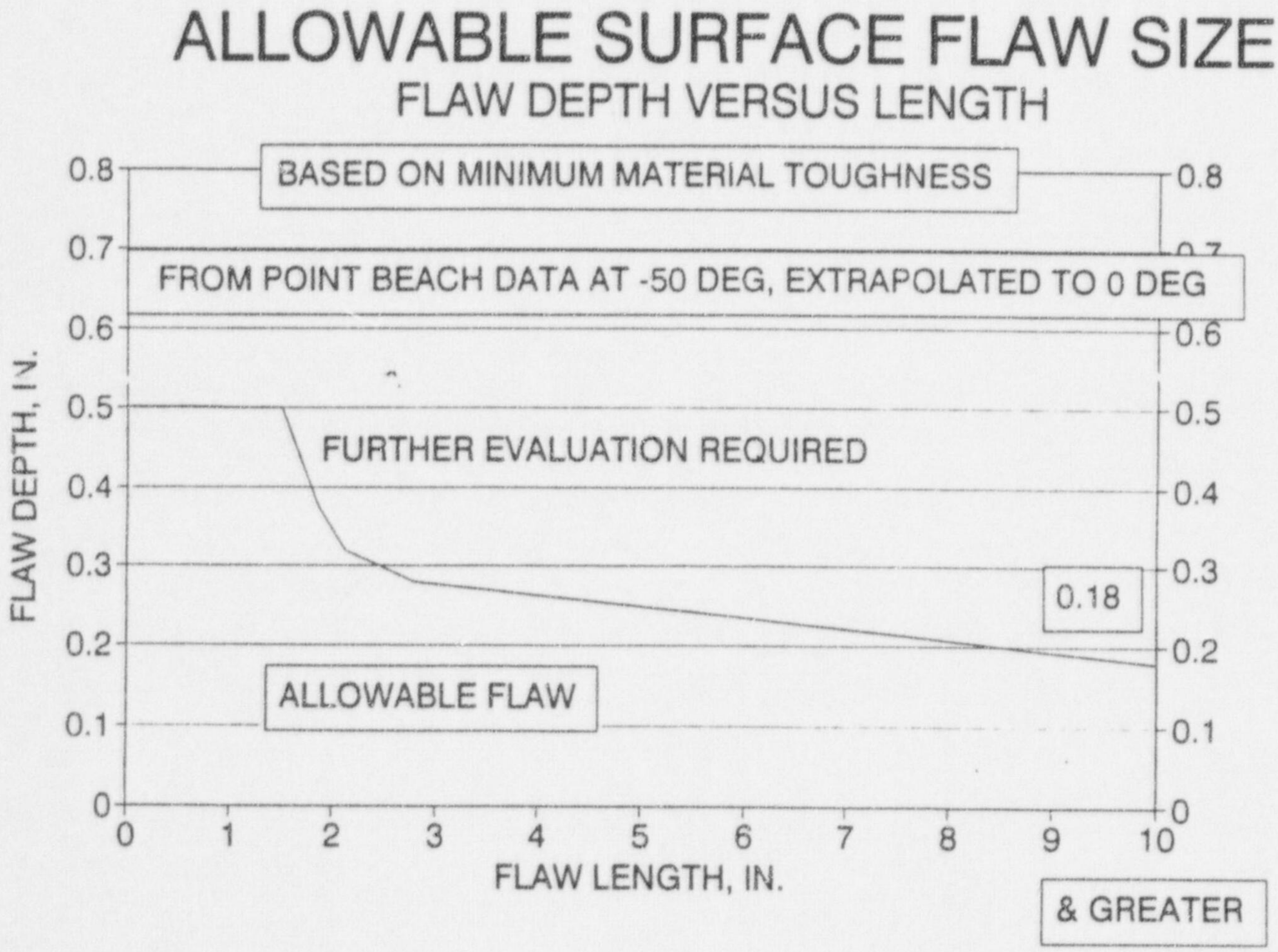


Figure 4c

	Revision	1			
	Preparer/Date	HJ 12/17/97			
	Checker/Date	12/17/97			
	File No. CPC-06Q-301			Page 24 of 28	

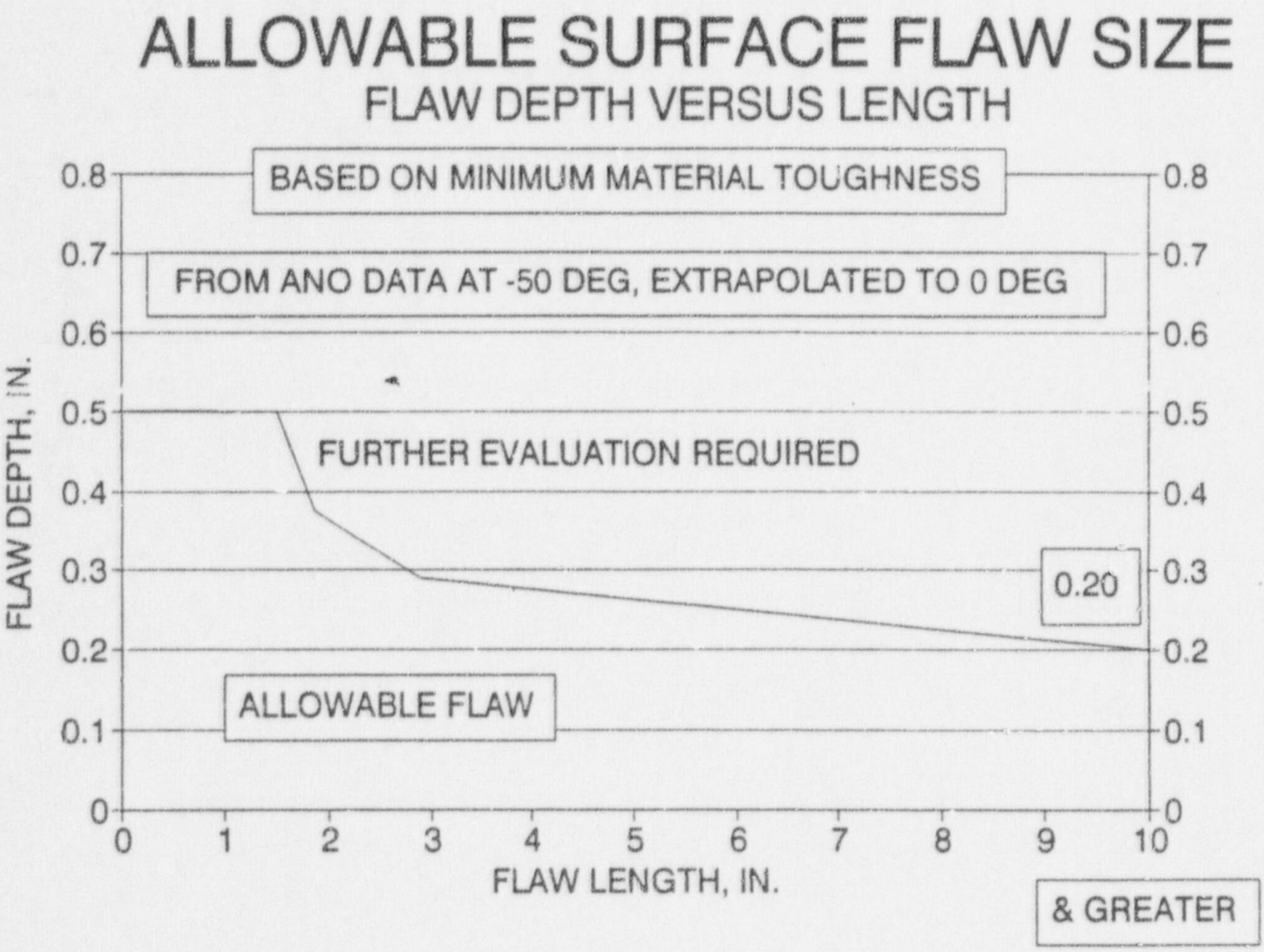


Figure 4d

	Revision	1			
	Preparer/Date	HLA 12/17/97			
	Checker/Date	[signature] 12/17/97			
	File No. CPC-06Q-301			Page 25 of 28	

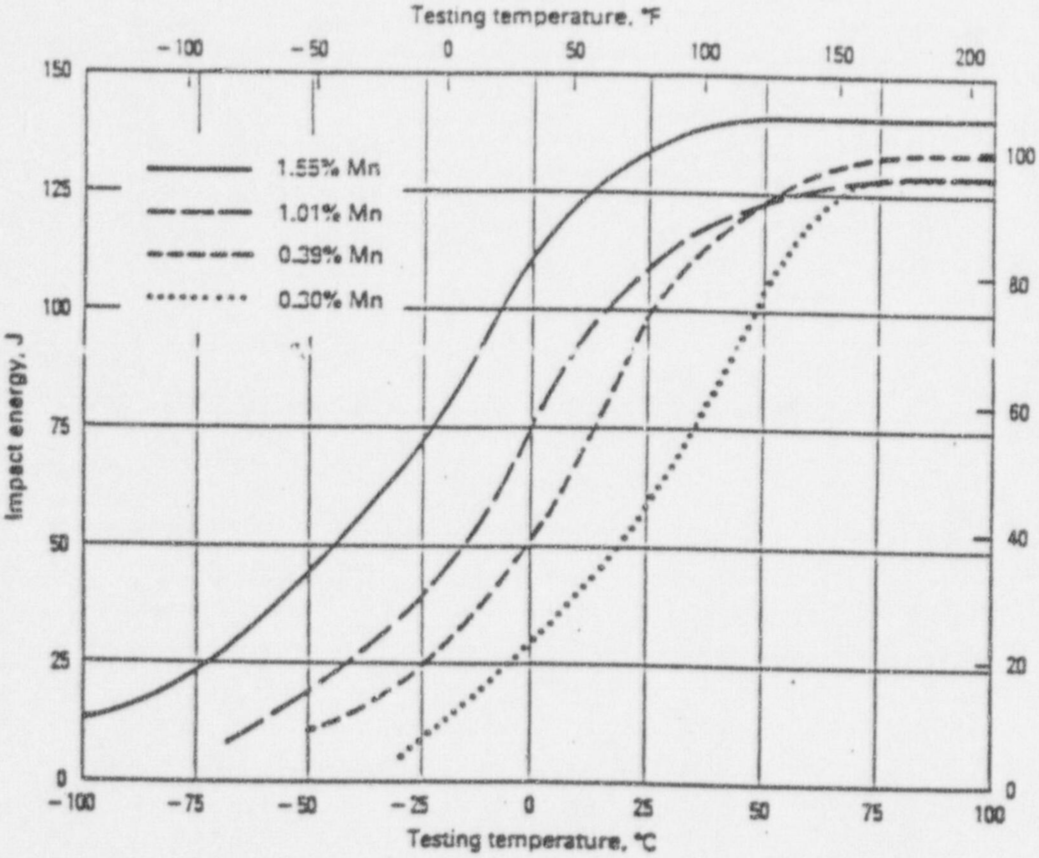
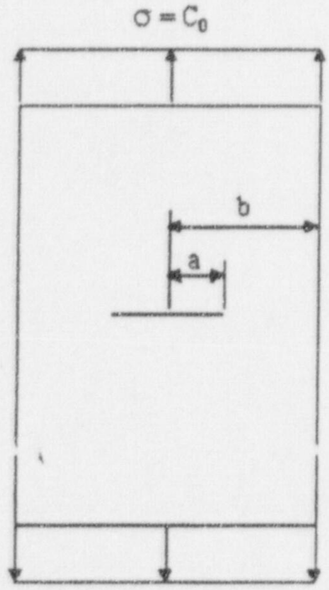


Fig. 11 Variation in Charpy V-notch impact energy with temperature for 0.30% C steels containing varying amounts of manganese. The specimens were austenitized at 900 °C (1650 °F) and cooled at approximately 14 °C/min (25 °F/min). The microstructures of these steels were pearlitic. Source: Ref 6

Figure 5

Revision	1			
Preparer/Date	HZ 12/17/97			
Checker/Date	[illegible] 12/17/97			
File No. CPC-06Q-301			Page 26 of 28	



REQUIRED INPUTS:
b: plate half width
a: maximum crack depth ($a_{max} \leq 0.9b$)

Figure 6: Center Cracked Plate under Remote Tension Stress - LEFM Crack Model

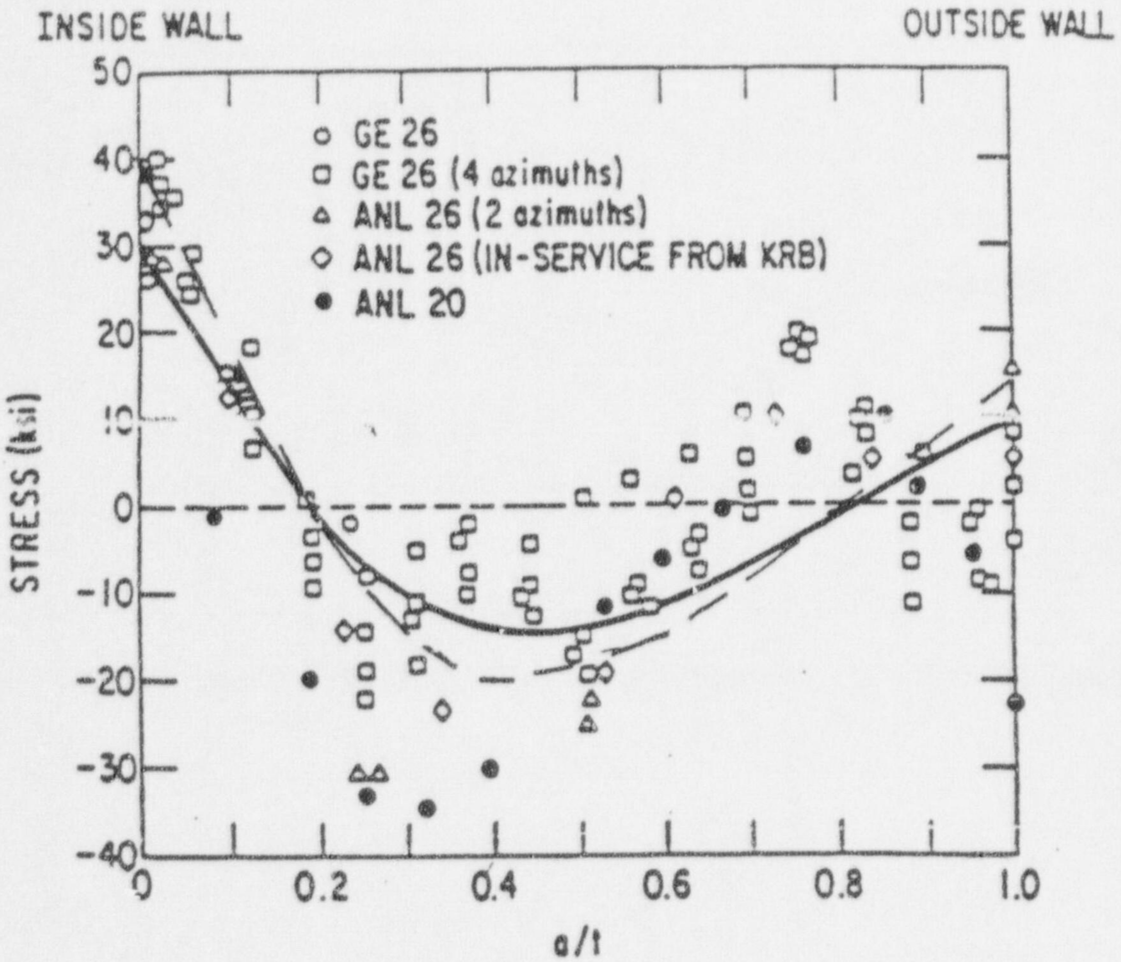


Figure 7
Axial Residual Stress Distribution for Multi-Pass Weld from [8].
(Dashed line represents scaling of distribution to produce inside surface tensile stress of 40 ksi.)

	Revision	1			
	Preparer/Date	HLD 12/17/97			
	Checker/Date	12/17/97			
	File No. CPC-06Q-301				Page 28 of 28

APPENDIX A

pc-CRACK Output

	Revision	1			
	Preparer/Date	HW 12/17/97			
	Checker/Date	[illegible] 12/17/97			
	File No. CPC-06Q-301			Page A1 of 33	

tm
pc-CRACK for Windows
Version 3.0, Mar. 27, 1997

Structural Integrity Associates, Inc.
3315 Almaden Expressway, Suite 24
San Jose, CA 95118-1557
Voice: 408-978-8200
Fax: 408-978-8964
E-mail: info@structint.com

Linear Elastic Fracture Mechanics

Date: Tue Dec 16 10:49:01 1997
File: SURFANO.LFM

Title: CPC-06Q: Allowable flaw size determination

Load Cases:

Case: residual --- Stress Distribution

Depth	Stress
0.0000	30.0000
0.1500	0.0000
0.3000	-15.0000
0.4500	-12.0000
0.6000	-2.0000
0.7500	10.0000

Stress Coefficients

Case ID	C0	C1	C2	C3	Type
normal	2	0	0	0	Coeff
drop	43.3	0	0	0	Coeff
residual	30.3653	-287.02	548.501	-268.861	StressDist

Crack Model: Single Edge Cracked Plate

Crack Parameters:
Plate width: 0.7500
Max. crack size: 0.5900

--------------------Stress Intensity Factor--------------------
Crack Case Case Case

CPC-06Q-301

A2/33

Size	normal	drop	residual
0.0118	0.4185	9.06053	5.92216
0.0236	0.598275	12.9526	7.87386
0.0354	0.740604	16.0341	9.04405
0.0472	0.864264	18.7113	9.76808
0.0590	0.976436	21.1398	10.1856
0.0708	1.08076	23.3985	10.3735
0.0826	1.19487	25.8688	10.5748
0.0944	1.31592	28.4897	10.7542
0.1062	1.43664	31.1033	10.827
0.1180	1.55746	33.719	10.8063
0.1298	1.67869	36.3436	10.7022
0.1416	1.80055	38.982	10.5229
0.1534	1.92952	41.7741	10.3067
0.1652	2.07603	44.9461	10.0972
0.1770	2.22516	48.1746	9.81596
0.1888	2.37689	51.4597	9.46745
0.2006	2.53123	54.8011	9.05601
0.2124	2.68815	58.1985	8.58594
0.2242	2.84764	61.6514	8.0615
0.2360	3.04756	65.9797	7.56107
0.2478	3.2547	70.4642	6.97506
0.2596	3.46627	75.0447	6.2977
0.2714	3.68219	79.7194	5.53033
0.2832	3.90237	84.4862	4.67451
0.2950	4.12673	89.3436	3.73199
0.3068	4.4086	95.4461	3.13246
0.3186	4.73656	102.546	2.78244
0.3304	5.07193	109.807	2.37727
0.3422	5.41456	117.225	1.92303
0.3540	5.76429	124.797	1.42617
0.3658	6.12101	132.52	0.893474
0.3776	6.51287	141.004	0.402307
0.3894	7.0141	151.855	0.106159
0.4012	7.52584	162.934	-0.256648
0.4130	8.0479	174.237	-0.6781
0.4248	8.5801	185.759	-1.14987
0.4366	9.12225	197.497	-1.66333
0.4484	9.6742	209.446	-2.20947
0.4602	10.5138	227.623	-2.82647
0.4720	11.4141	247.114	-3.62191
0.4838	12.3317	266.982	-4.59183
0.4956	13.2665	287.219	-5.72798
0.5074	14.218	307.821	-7.02199
0.5192	15.1862	328.781	-8.46527
0.5310	16.6666	360.831	-10.603
0.5428	18.6587	403.961	-13.5771
0.5546	20.688	447.895	-16.8[illegible]18

CPC-CGG-301

0.5664	22.7538	492.62	-20.4879
0.5782	24.8556	538.125	-24.3654
0.5900	26.993	584.397	-28.4845

Material fracture toughness:

Material ID: ANO-min

Depth	K1c
0.0000	66.0000
0.3750	66.0000
0.7500	66.0000

Load combination for critical crack size:

Load Case	Scale Factor
drop	1.0000
residual	1.3300

Crack Size	Total K	K1c
0.0118	16.937	66
0.0236	23.4249	66
0.0354	28.0627	66
0.0472	31.7029	66
0.059	34.6867	66
0.0708	37.1953	66
0.0826	39.9333	66
0.0944	42.7928	66
0.1062	45.5032	66
0.118	48.0913	66
0.1298	50.5775	66
0.1416	52.9774	66
0.1534	55.482	66
0.1652	58.3753	66
0.177	61.2298	66
0.1888	64.0514	66
0.2006	66.8456	66
0.2124	69.6178	66
0.2242	72.3732	66
0.236	76.0359	66
0.2478	79.741	66
0.2596	83.4207	66
0.2714	87.0747	66
0.2832	90.7033	66
0.295	94.3072	66

0.3068	99.6123	66
0.3186	106.247	66
0.3304	112.969	66
0.3422	119.783	66
0.354	126.694	66
0.3658	133.708	66
0.3776	141.539	66
0.3894	151.996	66
0.4012	162.593	66
0.413	173.335	66
0.4248	184.23	66
0.4366	195.285	66
0.4484	206.508	66
0.4602	223.864	66
0.472	242.297	66
0.4838	260.874	66
0.4956	279.601	66
0.5074	298.481	66
0.5192	317.522	66
0.531	346.729	66
0.5428	385.904	66
0.5546	425.443	66
0.5664	465.371	66
0.5782	505.719	66
0.59	546.513	66

Critical crack size = 0.1969

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pc-CRACK for Windows
Version 3.0, Mar. 27, 1997

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Linear Elastic Fracture Mechanics

Date: Tue Dec 16 10:50:55 1997
File: SURFPB.LFM

Title: CPC-06Q: Allowable flaw size determination

Load Cases:

Case: residual --- Stress Distribution

Depth	Stress
0.0000	30.0000
0.1500	0.0000
0.3000	-15.0000
0.4500	-12.0000
0.6000	-2.0000
0.7500	10.0000

Case ID	Stress Coefficients C0	C1	C2	C3	Type
normal	2	0	0	0	Coeff
drop	43.3	0	0	0	Coeff
residual	30.3653	-287.02	548.501	-268.861	StressDist

Crack Model: Single Edge Cracked Plate

Crack Parameters:
Plate width: 0.7500
Max. crack size: 0.5900

--------------------Stress Intensity Factor--------------------

Crack	Case	Case	Case

CPC-06Q-301

A6/33

Size	normal	drop	residual
0.0118	0.4185	9.06053	5.92216
0.0236	0.598275	12.9526	7.87386
0.0354	0.740604	16.0341	9.04405
0.0472	0.864264	18.7113	9.76808
0.0590	0.976436	21.1398	10.1856
0.0708	1.08076	23.3985	10.3735
0.0826	1.19487	25.8688	10.5748
0.0944	1.31592	28.4897	10.7542
0.1062	1.43664	31.1033	10.827
0.1180	1.55746	33.719	10.8063
0.1298	1.67869	36.3436	10.7022
0.1416	1.80055	38.982	10.5229
0.1534	1.92952	41.7741	10.3067
0.1652	2.07603	44.9461	10.0972
0.1770	2.22516	48.1746	9.81596
0.1888	2.37689	51.4597	9.46745
0.2006	2.53123	54.8011	9.05601
0.2124	2.68815	58.1985	8.58594
0.2242	2.84764	61.6514	8.0615
0.2360	3.04756	65.9797	7.56107
0.2478	3.2547	70.4642	6.97506
0.2596	3.46627	75.0447	6.2977
0.2714	3.68219	79.7194	5.53033
0.2832	3.90237	84.4862	4.67451
0.2950	4.12673	89.3436	3.73199
0.3068	4.4086	95.4461	3.13246
0.3186	4.73656	102.546	2.78244
0.3304	5.07193	109.807	2.37727
0.3422	5.41456	117.225	1.92303
0.3540	5.76429	124.797	1.42617
0.3658	6.12101	132.52	0.893474
0.3776	6.51287	141.004	0.402307
0.3894	7.0141	151.855	0.106159
0.4012	7.52584	162.934	-0.256648
0.4130	8.0479	174.237	-0.6781
0.4248	8.5801	185.759	-1.14987
0.4366	9.12225	197.497	-1.66333
0.4484	9.6742	209.446	-2.20947
0.4602	10.5138	227.623	-2.82647
0.4720	11.4141	247.114	-3.62191
0.4838	12.3317	266.982	-4.59183
0.4956	13.2665	287.219	-5.72798
0.5074	14.218	307.821	-7.02199
0.5192	15.1862	328.781	-8.46527
0.5310	16.6666	360.831	-10.603
0.5428	18.6587	403.961	-13.5771
0.5546	20.688	447.895	-16.8818

CFC-CGG-301

0.5664	22.7538	492.62	-20.4879
0.5782	24.8556	538.125	-24.3654
0.5900	26.993	584.397	-28.4845

Material fracture toughness:

Material ID: PB-min

Depth	K1c
0.0000	63.0000
0.3750	63.0000
0.7500	63.0000

Load combination for critical crack size:

Load Case	Scale Factor
drop	1.0000
residual	1.3300

Crack Size	Total K	K1c
0.0118	16.937	63
0.0236	23.4249	63
0.0354	28.0627	63
0.0472	31.7029	63
0.059	34.6867	63
0.0708	37.1953	63
0.0826	39.9333	63
0.0944	42.7928	63
0.1062	45.5032	63
0.118	48.0913	63
0.1298	50.5775	63
0.1416	52.9774	63
0.1534	55.482	63
0.1652	58.3753	63
0.177	61.2298	63
0.1888	64.0514	63
0.2006	66.8456	63
0.2124	69.6178	63
0.2242	72.3732	63
0.236	76.0359	63
0.2478	79.741	63
0.2596	83.4207	63
0.2714	87.0747	63
0.2832	90.7033	63
0.295	94.3072	63

0.3068	99.6123	63
0.3186	106.247	63
0.3304	112.969	63
0.3422	119.783	63
0.354	126.694	63
0.3658	133.708	63
0.3776	141.539	63
0.3894	151.996	63
0.4012	162.593	63
0.413	173.335	63
0.4248	184.23	63
0.4366	195.285	63
0.4484	206.508	63
0.4602	223.864	63
0.472	242.297	63
0.4838	260.874	63
0.4956	279.601	63
0.5074	298.481	63
0.5192	317.522	63
0.531	346.729	63
0.5428	385.904	63
0.5546	425.443	63
0.5664	465.371	63
0.5782	505.719	63
0.59	546.513	63

Critical crack size = 0.1843

CPC-06Q-301

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Version 3.0, Mar. 27, 1997

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Linear Elastic Fracture Mechanics

Date: Tue Dec 16 10:52:09 1997
File: SURFSPEC.LFM

Title: CPC-06Q: Allowable flaw size determination

Load Cases:

Case: residual --- Stress Distribution

Depth	Stress
0.0000	30.0000
0.1500	0.0000
0.3000	-15.0000
0.4500	-12.0000
0.6000	-2.0000
0.7500	10.0000

	Stress Coefficients				
Case ID	C0	C1	C2	C3	Type
normal	2	0	0	0	Coeff
drop	43.3	0	0	0	Coeff
residual	30.3653	-287.02	548.501	-268.861	StressDist

Crack Model: Single Edge Cracked Plate

Crack Parameters:
Plate width: 0.7500
Max. crack size: 0.5900

--------------------Stress Intensity Factor--------------------
Crack Case Case Case

CPC-06Q-301

Size	normal	drop	residual
0.0118	0.4185	9.06053	5.92216
0.0236	0.598275	12.9526	7.87386
0.0354	0.740604	16.0341	9.04405
0.0472	0.864264	18.7113	9.76808
0.0590	0.976436	21.1398	10.1856
0.0708	1.08076	23.3985	10.3735
0.0826	1.19487	25.8688	10.5748
0.0944	1.31592	28.4897	10.7542
0.1062	1.43664	31.1033	10.827
0.1180	1.55746	33.719	10.8063
0.1298	1.67869	36.3436	10.7022
0.1416	1.80055	38.982	10.5229
0.1534	1.92952	41.7741	10.3067
0.1652	2.07603	44.9461	10.0972
0.1770	2.22516	48.1746	9.81596
0.1888	2.37689	51.4597	9.46745
0.2006	2.53123	54.8011	9.05601
0.2124	2.68815	58.1985	8.58594
0.2242	2.84764	61.6514	8.0615
0.2360	3.04756	65.9797	7.56107
0.2478	3.2547	70.4642	6.97506
0.2596	3.46627	75.0447	6.2977
0.2714	3.68219	79.7194	5.53033
0.2832	3.90237	84.4862	4.67451
0.2950	4.12673	89.3436	3.73199
0.3068	4.4086	95.4461	3.13246
0.3186	4.73656	102.546	2.78244
0.3304	5.07193	109.807	2.37727
0.3422	5.41456	117.225	1.92303
0.3540	5.76429	124.797	1.42617
0.3658	6.12101	132.52	0.893474
0.3776	6.51287	141.004	0.402307
0.3894	7.0141	151.855	0.106159
0.4012	7.52584	162.934	-0.256648
0.4130	8.0479	174.237	-0.6781
0.4248	8.5801	185.759	-1.14987
0.4366	9.12225	197.497	-1.66333
0.4484	9.6742	209.446	-2.20947
0.4602	10.5138	227.623	-2.82647
0.4720	11.4141	247.114	-3.62191
0.4838	12.3317	266.982	-4.59183
0.4956	13.2665	287.219	-5.72798
0.5074	14.218	307.821	-7.02199
0.5192	15.1862	328.781	-8.46527
0.5310	16.6666	360.831	-10.603
0.5428	18.6587	403.961	-13.5771
0.5546	20.688	447.895	-16.8818

CPC-060-301

0.5664	22.7538	492.62	-20.4879
0.5782	24.8556	538.125	-24.3654
0.5900	26.993	584.397	-28.4845

Material fracture toughness:

Material ID: SPEC-min

Depth	K1c
0.0000	55.0000
0.3750	55.0000
0.7500	55.0000

Load combination for critical crack size:

Load Case	Scale Factor
drop	1.0000
residual	1.3300

Crack Size	Total K	K1c
0.0118	16.937	55
0.0236	23.4249	55
0.0354	28.0627	55
0.0472	31.7029	55
0.059	34.6867	55
0.0708	37.1953	55
0.0826	39.9333	55
0.0944	42.7928	55
0.1062	45.5032	55
0.118	48.0913	55
0.1298	50.5775	55
0.1416	52.9774	55
0.1534	55.482	55
0.1652	58.3753	55
0.177	61.2298	55
0.1888	64.0514	55
0.2006	66.8456	55
0.2124	69.6178	55
0.2242	72.3732	55
0.236	76.0359	55
0.2478	79.741	55
0.2596	83.4207	55
0.2714	87.0747	55
0.2832	90.7033	55
0.295	94.3072	55

0.3068	99.6123	55
0.3186	106.247	55
0.3304	112.969	55
0.3422	119.783	55
0.354	126.694	55
0.3658	133.708	55
0.3776	141.539	55
0.3894	151.996	55
0.4012	162.593	55
0.413	173.335	55
0.4248	184.23	55
0.4366	195.285	55
0.4484	206.508	55
0.4602	223.864	55
0.472	242.297	55
0.4838	260.874	55
0.4956	279.601	55
0.5074	298.481	55
0.5192	317.522	55
0.531	346.729	55
0.5428	385.904	55
0.5546	425.443	55
0.5664	465.371	55
0.5782	505.719	55
0.59	546.513	55

Critical crack size = 0.1515

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pc-CRACK for Windows
Version 3.0, Mar. 27, 1997

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Linear Elastic Fracture Mechanics

Date: Tue Dec 16 10:52:56 1997
File: SURFPAL.LFM

Title: CPC-06Q: Allowable flaw size determination

Load Cases:

Case: residual --- Stress Distribution

Depth	Stress
0.0000	30.0000
0.1500	0.0000
0.3000	-15.0000
0.4500	-12.0000
0.6000	-2.0000
0.7500	10.0000

Stress Coefficients

Case ID	C0	C1	C2	C3	Type
normal	2	0	0	0	Coeff
drop	43.3	0	0	0	Coeff
residual	30.3653	-287.02	548.501	-268.861	StressDist

Crack Model: Single Edge Cracked Plate

Crack Parameters:
Plate width: 0.7500
Max. crack size: 0.5900

--------------------Stress Intensity Factor--------------------
Crack Case Case Case

CPC-06Q-301

A14/33

Size	normal	drop	residual
0.0118	0.4185	9.06053	5.92216
0.0236	0.598275	12.9526	7.87386
0.0354	0.740604	16.0341	9.04405
0.0472	0.864264	18.7113	9.76808
0.0590	0.976436	21.1398	10.1856
0.0708	1.08076	23.3985	10.3735
0.0826	1.19487	25.8688	10.5748
0.0944	1.31592	28.4897	10.7542
0.1062	1.43664	31.1033	10.827
0.1180	1.55746	33.719	10.8063
0.1298	1.67869	36.3436	10.7022
0.1416	1.80055	38.982	10.5229
0.1534	1.92952	41.7741	10.3067
0.1652	2.07603	44.9461	10.0972
0.1770	2.22516	48.1746	9.81596
0.1888	2.37689	51.4597	9.46745
0.2006	2.53123	54.8011	9.05601
0.2124	2.68815	58.1985	8.58594
0.2242	2.84764	61.6514	8.0615
0.2360	3.04756	65.9797	7.56107
0.2478	3.2547	70.4642	6.97506
0.2596	3.46627	75.0447	6.2977
0.2714	3.68219	79.7194	5.53033
0.2832	3.90237	84.4862	4.67451
0.2950	4.12673	89.3436	3.73199
0.3068	4.4086	95.4461	3.13246
0.3186	4.73656	102.546	2.78244
0.3304	5.07193	109.807	2.37727
0.3422	5.41456	117.225	1.92303
0.3540	5.76429	124.797	1.42617
0.3658	6.12101	132.52	0.893474
0.3776	6.51287	141.004	0.402307
0.3894	7.0141	151.855	0.106159
0.4012	7.52584	162.934	-0.256648
0.4130	8.0479	174.237	-0.6781
0.4248	8.5801	185.759	-1.14987
C.4366	9.12225	197.497	-1.66333
0.4484	9.6742	209.446	-2.20947
0.4602	10.5138	227.623	-2.82647
0.4720	11.4141	247.114	-3.62191
0.4838	12.3317	266.982	-4.59183
0.4956	13.2665	287.219	-5.72798
0.5074	14.218	307.821	-7.02199
0.5192	15.1862	328.781	-8.46527
0.5310	16.6666	360.831	-10.603
0.5428	18.6587	403.961	-13.5771
0.5546	20.688	447.895	-16.8818

CPC-06Q-301

A15/33

0.5664	22.7538	492.62	-20.4879
0.5782	24.8556	538.125	-24.3654
0.5900	26.993	584.397	-28.4845

Material fracture toughness:

Material ID: PAL-min

Depth	Klc
0.0000	78.0000
0.3750	78.0000
0.7500	78.0000

Load combination for critical crack size:

Load Case	Scale Factor
drop	1.0000
residual	1.0000

Crack Size	Total K	Klc
0.0118	16.937	78
0.0236	23.4249	78
0.0354	28.0627	78
0.0472	31.7029	78
0.059	34.6867	78
0.0708	37.1953	78
0.0826	39.9333	78
0.0944	42.7928	78
0.1062	45.5032	78
0.118	48.0913	78
0.1298	50.5775	78
0.1416	52.9774	78
0.1534	55.482	78
0.1652	58.3753	78
0.177	61.2298	78
0.1888	64.0514	78
0.2006	66.8456	78
0.2124	69.6178	78
0.2242	72.3732	78
0.236	76.0359	78
0.2478	79.741	78
0.2596	83.4207	78
0.2714	87.0747	78
0.2832	90.7033	78
0.295	94.3072	78

0.3068	99.6123	78
0.3186	106.247	78
0.3304	112.969	78
0.3422	119.783	78
0.354	126.694	78
0.3658	133.708	78
0.3776	141.539	78
0.3894	151.996	78
0.4012	162.593	78
0.413	173.335	78
0.4248	184.23	78
0.4366	195.285	78
0.4484	206.508	78
0.4602	223.864	78
0.472	242.297	78
0.4838	260.874	78
0.4956	279.601	78
0.5074	298.481	78
0.5192	317.522	78
0.531	346.729	78
0.5428	385.904	78
0.5546	425.443	78
0.5664	465.371	78
0.5782	505.719	78
0.59	546.513	78

Critical crack size = 0.2423

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pc-CRACK for Windows
Version 3.0, Mar. 27, 1997

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Linear Elastic Fracture Mechanics

Date: Tue Dec 16 14:00:51 1997
File: SUBPAL.LFM

Title: CPC-06Q: Allowable flaw size determination

Load Cases:

Case: residual --- Stress Distribution

Depth	Stress
0.0000	30.0000
0.1500	0.0000
0.3000	-15.0000
0.4500	-12.0000
0.6000	-2.0000
0.7500	10.0000

Stress Coefficients

Case ID	C0	C1	C2	C3	Type
normal	2	0	0	0	Coeff
drop	43.3	0	0	0	Coeff
residual	30.3653	-287.02	548.501	-268.861	StressDist

Crack Model: Center Cracked Plate Under Remote Tension Stress

Crack Parameters:
Plate Half Width: 0.3750
Crack depth: 0.3375

--------------------Stress Intensity Factor--------------------

Crack	Case	Case	Case

CPC-C6Q-3C1

4 of 33

Size	normal	drop	residual
0.0067	0.2913	6.30664	4.4227
0.0135	0.412197	8.92407	6.25825
0.0202	0.505322	10.9402	7.67213
0.0270	0.584283	12.6497	8.87096
0.0337	0.654384	14.1674	9.93529
0.0405	0.718372	15.5527	10.9068
0.0472	0.777895	16.8414	11.8105
0.0540	0.834048	18.0571	12.6631
0.0607	0.887603	19.2166	13.4762
0.0675	0.93514	20.3324	14.2586
0.0742	0.989108	21.4142	15.0173
0.0810	1.03787	22.4699	15.7576
0.0877	1.08573	23.5061	16.4843
0.0945	1.13295	24.5284	17.2012
0.1012	1.17976	25.5418	17.9119
0.1080	1.22636	26.5506	18.6194
0.1147	1.27294	27.5591	19.3266
0.1215	1.31968	28.571	20.0362
0.1282	1.36675	29.59	20.7508
0.1350	1.41431	30.6199	21.473
0.1417	1.46255	31.6642	22.2054
0.1485	1.51162	32.7265	22.9503
0.1552	1.56169	33.8106	23.7106
0.1620	1.61296	34.9206	24.489
0.1687	1.66561	36.0604	25.2883
0.1755	1.71984	37.2345	26.1117
0.1822	1.77587	38.4477	26.9625
0.1890	1.83395	39.7051	27.8443
0.1957	1.89434	41.0125	28.7611
0.2025	1.95732	42.3761	29.7174
0.2092	2.02323	43.803	30.7181
0.2160	2.09244	45.3013	31.7687
0.2227	2.16535	46.8798	32.8757
0.2295	2.24245	48.5491	34.0464
0.2362	2.32429	50.321	35.289
0.2430	2.41152	52.2095	36.6133
0.2497	2.5049	54.231	38.031
0.2565	2.60531	56.405	39.5556
0.2632	2.71385	58.7549	41.2035
0.2700	2.83183	61.309	42.9946
0.2767	2.96084	64.1022	44.9534
0.2835	3.10291	67.1781	47.1105
0.2902	3.26058	70.5916	49.5043
0.2970	3.43714	74.4141	52.1849
0.3037	3.63692	78.7393	55.2181
0.3105	3.86578	83.6942	58.6929
0.3172	4.13189	89.4555	62.7331

0.3240	4.44704	96.2784	67.5179
0.3307	4.82904	104.549	73.3176
0.3375	5.30639	114.883	80.5651

Material fracture toughness:

Material ID: PAL-min

Depth	Klc
0.0000	78.0000
0.3750	78.0000
0.7500	78.0000

Load combination for critical crack size:

Load Case	Scale Factor
drop	1.0000
residual	1.3300

Crack Size	Total K	Klc
0.00675	12.1888	78
0.0135	17.2475	78
0.02025	21.1441	78
0.027	24.4481	78
0.03375	27.3814	78
0.0405	30.0588	78
0.04725	32.5494	78
0.054	34.899	78
0.06075	37.1399	78
0.0675	39.2964	78
0.07425	41.3872	78
0.081	43.4276	78
0.08775	45.4303	78
0.0945	47.4061	78
0.10125	49.3646	78
0.108	51.3144	78
0.11475	53.2634	78
0.1215	55.2191	78
0.12825	57.1886	78
0.135	59.179	78
0.14175	61.1973	78
0.1485	63.2504	78
0.15525	65.3458	78
0.162	67.491	78
0.16875	69.6939	78

0.1755	71.9631	78
0.18225	74.3078	78
0.189	76.738	78
0.19575	79.2647	78
0.2025	81.9002	78
0.20925	84.6581	78
0.216	87.5537	78
0.22275	90.6046	78
0.2295	93.8307	78
0.23625	97.2553	78
0.243	100.905	78
0.24975	104.812	78
0.2565	109.014	78
0.26325	113.556	78
0.27	118.492	78
0.27675	123.89	78
0.2835	129.835	78
0.29025	136.432	78
0.297	143.82	78
0.30375	152.179	78
0.3105	161.756	78
0.31725	172.891	78
0.324	186.077	78
0.33075	202.061	78
0.3375	222.035	78

Critical crack size = 0.1925

tm
pc-CRACK for Windows
Version 3.0, Mar. 27, 1997

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Linear Elastic Fracture Mec anics

Date: Tue Dec 16 14:01:43 1997
File: SUBANO.LFM

Title: CPC-06Q: Allowable flaw size determination

Load Cases:

Case: residual --- Stress Distribution

Depth	Stress
0.0000	30.0000
0.1500	0.0000
0.3000	-15.0000
0.4500	-12.0000
0.6000	-2.0000
0.7500	10.0000

	Stress Coefficients				
Case ID	C0	C1	C2	C3	Type
normal	2	0	0	0	Coeff
drop	43.3	0	0	0	Coeff
residual	30.3653	-287.02	548.501	-268.861	StressDist

Crack Model: Center Cracked Plate Under Remote Tension Stress

Crack Parameters:
Plate Half Width: 0.3750
Crack depth: 0.3375

--------------------Stress Intensity Factor--------------------

Crack	Case	Case	Case

CPC-06Q-301

Size	normal	drop	residual
0.0067	0.2913	6.30664	4.4227
0.0135	0.412197	8.92407	6.25825
0.0202	0.505322	10.9402	7.67213
0.0270	0.584283	12.6497	8.87096
0.0337	0.654384	14.1674	9.93529
0.0405	0.718372	15.5527	10.9068
0.0472	0.777895	16.8414	11.8105
0.0540	0.834048	18.0571	12.6631
0.0607	0.887603	19.2166	13.4762
0.0675	0.93914	20.3324	14.2586
0.0742	0.989108	21.4142	15.0173
0.0810	1.03787	22.4699	15.7576
0.0877	1.08573	23.5061	16.4843
0.0945	1.13295	24.5284	17.2012
0.1012	1.17976	25.5418	17.9119
0.1080	1.22636	26.5506	18.6194
0.1147	1.27294	27.5591	19.3266
0.1215	1.31968	28.571	20.0362
0.1282	1.36675	29.59	20.7508
0.1350	1.41431	30.6199	21.473
0.1417	1.46255	31.6642	22.2054
0.1485	1.51162	32.7265	22.9503
0.1552	1.56169	33.8106	23.7106
0.1620	1.61296	34.9206	24.489
0.1687	1.66561	36.0604	25.2883
0.1755	1.71984	37.2345	26.1117
0.1822	1.77587	38.4477	26.9625
0.1890	1.83395	39.7051	27.8443
0.1957	1.89434	41.0125	28.7611
0.2025	1.95732	42.3761	29.7174
0.2092	2.02323	43.803	30.7181
0.2160	2.09244	45.3013	31.7687
0.2227	2.16535	46.8798	32.8757
0.2295	2.24245	48.5491	34.0464
0.2362	2.32429	50.321	35.289
0.2430	2.41152	52.2095	36.6133
0.2497	2.5049	54.231	38.031
0.2565	2.60531	56.405	39.5556
0.2632	2.71385	58.7549	41.2035
0.2700	2.83183	61.309	42.9946
0.2767	2.96084	64.1022	44.9534
0.2835	3.10291	67.1781	47.1105
0.2902	3.26058	70.5916	49.5043
0.2970	3.43714	74.4141	52.1849
0.3037	3.63692	78.7393	55.2181
0.3105	3.86578	83.6942	58.6928
0.3172	4.13189	89.4555	62.7331

CPC-060-301

0.3240	4.44704	96.2784	67.5179
0.3307	4.82904	104.549	73.3176
0.3375	5.30639	114.883	80.5651

Material fracture toughness:

Material ID: ANO-min

Depth	K1c
0.0000	66.0000
0.3750	66.0000
0.7500	66.0000

Load combination for critical crack size:

Load Case	Scale Factor
drop	1.0000
residual	1.3300

Crack Size	Total K	K1c
0.00675	12.1888	66
0.0135	17.2475	66
0.02025	21.1441	66
0.027	24.4481	66
0.03375	27.3814	66
0.0405	30.0588	66
0.04725	32.5494	66
0.054	34.899	66
0.06075	37.1399	66
0.0675	39.2964	66
0.07425	41.3872	66
0.081	43.4276	66
0.08775	45.4303	66
0.0945	47.4061	66
0.10125	49.3646	66
0.108	51.3144	66
0.11475	53.2634	66
0.1215	55.2191	66
0.12825	57.1886	66
0.135	59.179	66
0.14175	61.1973	66
0.1485	63.2504	66
0.15525	65.3458	66
0.162	67.491	66
0.16875	69.6939	66

CPC-CGG-3ci

0.1755	71.9631	66
0.18225	74.3078	66
0.189	76.738	66
0.19575	79.2647	66
0.2025	81.9002	66
0.20925	84.6581	66
0.216	87.5537	66
0.22275	90.6046	66
0.2295	93.8307	66
0.23625	97.2553	66
0.243	100.905	66
0.24975	104.812	66
0.2565	109.014	66
0.26325	113.556	66
0.27	118.492	66
0.27675	123.89	66
0.2835	129.835	66
0.29025	136.432	66
0.297	143.82	66
0.30375	152.179	66
0.3105	161.756	66
0.31725	172.891	66
0.324	186.077	66
0.33075	202.061	66
0.3375	222.035	66

Critical crack size = 0.1574

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Version 3.0, Mar. 27, 1997

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Linear Elastic Fracture Mechanics

Date: Tue Dec 16 14:02:59 1997
File: SUBPB.LFM

Title: CPC-06Q: Allowable flaw size determination

Load Cases:

Case: residual --- Stress Distribution

Depth	Stress
0.0000	30.0000
0.1500	0.0000
0.3000	-15.0000
0.4500	-12.0000
0.6000	-2.0000
0.7500	10.0000

Stress Coefficients

Case ID	C0	C1	C2	C3	Type
normal	2	0	0	0	Coeff
drop	43.3	0	0	0	Coeff
residual	30.3653	-287.02	548.501	-268.861	StressDist

Crack Model: Center Cracked Plate Under Remote Tension Stress

Crack Parameters:
Plate Half Width: 0.3750
Crack depth: 0.3375

--------------------Stress Intensity Factor--------------------

Crack	Case	Case	Case

CPC-06Q-301

A26/33

Size	normal	drop	residual
0.0067	0.2913	6.30664	4.4227
0.0135	0.412197	8.92407	6.25825
0.0202	0.505322	10.9402	7.67213
0.0270	0.584283	12.6497	8.87096
0.0337	0.654384	14.1674	9.93529
0.0405	0.718372	15.5527	10.9068
0.0472	0.777895	16.8414	11.8105
0.0540	0.834048	18.0571	12.6631
0.0607	0.887603	19.2166	13.4762
0.0675	0.93914	20.3324	14.2586
0.0742	0.989108	21.4142	15.0173
0.0810	1.03787	22.4699	15.7576
0.0877	1.08573	23.5061	16.4843
0.0945	1.13295	24.5284	17.2012
0.1012	1.17976	25.5418	17.9119
0.1080	1.22636	26.5506	18.6194
0.1147	1.27294	27.5591	19.3266
0.1215	1.31968	28.571	20.0362
0.1282	1.36675	29.59	20.7508
0.1350	1.41431	30.6199	21.473
0.1417	1.46255	31.6642	22.2054
0.1485	1.51162	32.7265	22.9503
0.1552	1.56169	33.8106	23.7106
0.1620	1.61296	34.9206	24.489
0.1687	1.66561	36.0604	25.2883
0.1755	1.71984	37.2345	26.1117
0.1822	1.77587	38.4477	26.9625
0.1890	1.83395	39.7051	27.8443
0.1957	1.89434	41.0125	28.7611
0.2025	1.95732	42.3761	29.7174
0.2092	2.02323	43.803	30.7181
0.2160	2.09244	45.3013	31.7687
0.2227	2.16535	46.8798	32.8757
0.2295	2.24245	48.5491	34.0464
0.2362	2.32429	50.321	35.289
0.2430	2.41152	52.2095	36.6133
0.2497	2.5049	54.231	38.031
0.2565	2.60531	56.405	39.5556
0.2632	2.71385	58.7549	41.2035
0.2700	2.83183	61.309	42.9946
0.2767	2.96084	64.1022	44.9534
0.2835	3.10291	67.1781	47.1105
0.2902	3.26058	70.5916	49.5043
0.2970	3.43714	74.4141	52.1849
0.3037	3.63692	78.7393	55.2181
0.3105	3.86578	83.6942	58.6928
0.3172	4.13189	89.4555	62.7331

CPC-CGQ-3-1

0.3240	4.44704	96.2784	67.5179
0.3307	4.82904	104.549	73.3176
0.3375	5.30632	114.883	80.5651

Material fracture toughness:

Material ID: PB-min

Depth	K1c
0.0000	63.0000
0.3750	63.0000
0.7500	63.0000

Load combination for critical crack size:

Load Case	Scale Factor
drop	1.0000
residual	1.3300

Crack Size	Total K	K1c
0.00675	12.1888	63
0.0135	17.2475	63
0.02025	21.1441	63
0.027	24.4481	63
0.03375	27.3814	63
0.0405	30.0588	63
0.04725	32.5494	63
0.054	34.899	63
0.06075	37.1399	63
0.0675	39.2964	63
0.07425	41.3872	63
0.081	43.4276	63
0.08775	45.4303	63
0.0945	47.4061	63
0.10125	49.3646	63
0.108	51.3144	63
0.11475	53.2634	63
0.1215	55.2191	63
0.12825	57.1886	63
0.135	59.179	63
0.14175	61.1973	63
0.1485	63.2504	63
0.15525	65.3458	63
0.162	67.491	63
0.16875	69.6939	63

0.1755	71.9631	63
0.18225	74.3078	63
0.189	76.738	63
0.19575	79.2647	63
0.2025	81.9002	63
0.20925	84.6581	63
0.216	87.5537	63
0.22275	90.6046	63
0.2295	93.8307	63
0.23625	97.2553	63
0.243	100.905	63
0.24975	104.812	63
0.2565	109.014	63
0.26325	113.556	63
0.27	118.492	63
0.27675	123.89	63
0.2835	129.835	63
0.29025	136.432	63
0.297	143.82	63
0.30375	152.179	63
0.3105	161.756	63
0.31725	172.891	63
0.324	186.077	63
0.33075	202.061	63
0.3375	222.035	63

Critical crack size = 0.1478

EPC-06G-301

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Linear Elastic Fracture Mechanics

Date: Tue Dec 16 14:03:52 1997
File: SUBSPEC.LFM

Title: CPC-06Q: Allowable flaw size determination

Load Cases:

Case: residual --- Stress Distribution

Depth	Stress
0.0000	30.0000
0.1500	0.0000
0.3000	-15.0000
0.4500	-12.0000
0.6000	-2.0000
0.7500	10.0000

Stress Coefficients

Case ID	C0	C1	C2	C3	Type
normal	2	0	0	0	Coeff
drop	43.3	0	0	0	Coeff
residual	30.3653	-287.02	548.501	-268.861	StressDist

Crack Model: Center Cracked Plate Under Remote Tension Stress

Crack Parameters:
Plate Half Width: 0.3750
Crack depth: 0.3375

--------------------Stress Intensity Factor--------------------

Crack	Case	Case	Case

CPC-06Q-301

130/33

Size	normal	drop	residual
0.0067	0.2913	6.30664	4.4227
0.0135	0.412197	8.92407	6.25825
0.0202	0.505322	10.9402	7.67213
0.0270	0.584283	12.6497	8.87096
0.0337	0.654384	14.1674	9.93529
0.0405	0.718372	15.5527	10.9068
0.0472	0.777895	16.8414	11.8105
0.0540	0.834048	18.0571	12.6631
0.0607	0.887603	19.2166	13.4762
0.0675	0.93914	20.3324	14.2586
0.0742	0.989108	21.4142	15.0173
0.0810	1.03787	22.4699	15.7576
0.0877	1.08573	23.5061	16.4843
0.0945	1.13295	24.5284	17.2012
0.1012	1.17976	25.5418	17.9119
0.1080	1.22636	26.5506	18.6194
0.1147	1.27294	27.5591	19.3266
0.1215	1.31968	28.571	20.0362
0.1282	1.36675	29.59	20.7508
0.1350	1.41431	30.6199	21.473
0.1417	1.46255	31.6642	22.2054
0.1485	1.51162	32.7265	22.9503
0.1552	1.56169	33.8106	23.7106
0.1620	1.61296	34.9206	24.489
0.1687	1.66561	36.0604	25.2883
0.1755	1.71984	37.2345	26.1117
0.1822	1.77587	38.4477	26.9625
0.1890	1.83395	39.7051	27.8443
0.1957	1.89434	41.0125	28.7611
0.2025	1.95732	42.3761	29.7174
0.2092	2.02323	43.803	30.7181
0.2160	2.09244	45.3013	31.7687
0.2227	2.16535	46.8798	32.8757
0.2295	2.24245	48.5491	34.0464
0.2362	2.32429	50.321	35.289
0.2430	2.41152	52.2095	36.6133
0.2497	2.5049	54.231	38.031
0.2565	2.60531	56.405	39.5556
0.2632	2.71385	58.7549	41.2035
0.2700	2.83183	61.309	42.9946
0.2767	2.96084	64.1022	44.9534
0.2835	3.10291	67.1781	47.1105
0.2902	3.26058	70.5916	49.5043
0.2970	3.43714	74.4141	52.1849
0.3037	3.63692	78.7393	55.2181
0.3105	3.86578	83.6942	58.6928
0.3172	4.13189	89.4555	62.7331

CPC-OSQ-301

0.3240	4.44704	96.2784	67.5179
0.3307	4.82904	104.549	73.3176
0.3375	5.30639	114.883	80.5651

Material fracture toughness:

Material ID: SPEC-min

Depth	Klc
0.0000	55.0000
0.3750	55.0000
0.7500	55.0000

Load combination for critical crack size:

Load Case	Scale Factor
drop	1.0000
residual	1.3300

Crack Size	Total K	Klc
0.00675	12.1888	55
0.0135	17.2475	55
0.02025	21.1441	55
0.027	24.4481	55
0.03375	27.3814	55
0.0405	30.0588	55
0.04725	32.5494	55
0.054	34.899	55
0.06075	37.1399	55
0.0675	39.2964	55
0.07425	41.3872	55
0.081	43.4276	55
0.08775	45.4303	55
0.0945	47.4061	55
0.10125	49.3646	55
0.108	51.3144	55
0.11475	53.2634	55
0.1215	55.2191	55
0.12825	57.1886	55
0.135	59.179	55
0.14175	61.1973	55
0.1485	63.2504	55
0.15525	65.3458	55
0.162	6[illegible].491	55
0.16875	69.6939	55

CFC-CGG-30

A32/33

0.1755	71.9631	55
0.18225	74.3078	55
0.189	76.738	55
0.19575	79.2647	55
0.2025	81.9002	55
0.20925	84.6581	55
0.216	87.5537	55
0.22275	90.6046	55
0.2295	93.8307	55
0.23625	97.2553	55
0.243	100.905	55
0.24975	104.812	55
0.2565	109.014	55
0.26325	113.556	55
0.27	118.492	55
0.27675	123.89	55
0.2835	129.835	55
0.29025	136.432	55
0.297	143.82	55
0.30375	152.179	55
0.3105	161.756	55
0.31725	172.891	55
0.324	186.077	55
0.33075	202.061	55
0.3375	222.035	55

Critical crack size = 0.1208

CFC-06Q-301

APPENDIX B

Design Input from Consumers Energy

CPC-06Q-201

Consumers Energy

A CMS Energy Company

Palisades Nuclear Plant
27780 Blue Star Memorial Highway
Covert, MI 49043

November 12, 1997

Mr. Hal Gustin
Structural Integrity Associates, Inc.
3315 Almaden Expressway, Suite 24
San Jose, CA 95118-1557

SUBJECT: Flaw Analysis Inputs

Dear Hal:

This letter transmits design inputs for use in the flaw analysis being provided under purchase order C0025456. The specific design inputs shown below are enclosed.

- Safety Analysis Report for the Ventilated Storage System, PSN-91-001, Rev 0, dated October 1991, Table 11.2-1, Summary of Stresses(ksi) in the MSB Resulting from the Hypothetical Horizontal Drop. The limiting event for the structural lid weld is the horizontal drop accident, which is considered to be an emergency/faulted event.
- Safety Analysis Report for the Ventilated Storage System, PSN-91-001, Rev 0, dated October 1991, Table 3.4-5, MSB Maximum Stress Evaluation.
- Certificate of Compliance (C of C) for Dry Spent Fuel Storage Casks (No. 1007), effective May 7, 1993, Section 1.2.13, Minimum Temperature for Moving the MSB.
- Certificate of Compliance (C of C) for Dry Spent Fuel Storage Casks (No. 1007), effective May 7, 1993, Section 1.2.14, Minimum Temperature for Lifting the MTC.

Certified Material Test Reports (Lot No. 32039 and 38380) for the weld material used on the structural lid welds in MSB's 1-13 are enclosed. The CMTR (Lot No. 51122) for the weld material to be used on future structural lid welds is also enclosed. The cask structural lid welds will remain in the as welded condition following welding.

Please give me a call if you have any questions.

Sincerely,

EA Zernick

Emil A. Zernick
Engineering Lead -Dry Fuel Storage

B 2/11

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CPC-06Q-30

TABLE 3.4-5

MSB MAXIMUM STRESS EVALUATION

Component	Stresses	CALCULATED VALUE, KSI*					
		DEAD WEIGHT	PRESSURE	THERMAL	HANDLING	TOTAL	ASME LIMIT
MSB Shell	P_m	0.1	0.1	N/A	0.9	1.1	20.5
	$P_L + P_b$	0.1	1.2	N/A	2.4	3.7	30.7
	$P + Q$	0.1	1.2	1.0	2.4	4.7	61.5
Bottom Plate	P_m	0.02	0.06	N/A	1.0	1.1	20.5
	$P_L + P_b$	0.02	1.7	N/A	1.5	3.2	30.7
	$P + Q$	0.02	1.7	19.4	1.5	22.6	61.5
Top Lid	P_m	0.0	0.0	N/A	0.1	0.1	20.5
	$P_L + P_b$	0.0	0.4	N/A	0.2	0.6	30.7
	$P + Q$	0.0	0.4	0.2	0.2	0.8	61.5
Bottom-to-Shell Junction	P_m	0.1	0.2	N/A	0.9	1.2	20.5
	$P_L + P_b$	0.1	1.7	N/A	1.5	3.3	30.7
	$P + Q$	0.1	1.7	1.5	1.5	4.8	61.5
Top-to-shell Junction	P_m	0.0	0.06	N/A	0.2	0.3	15.4
	$P_L + P_b$	0.0	0.4	N/A	0.2	0.6	23.1
	$P + Q$	0.0	0.4	0.4	0.2	1.0	46.1
Sleeve Assembly	P_m	0.05	N/A	N/A	1.8	1.9	20.5
	$P_L + P_b$	0.05	N/A	N/A	2.1	2.2	30.7
	$P + Q$	0.05	N/A	52.0	2.1	54.2	61.5
Shield Lid-to-Shell Weld	P_m	0.3	0.2	N/A	0.3	0.8	15.4
	$P_L + P_b$	0.3	0.8	N/A	0.4	1.5	23.1
	$P + Q$	0.3	0.8	1.3	0.4	2.8	46.1
Shield Lid Support Ring Weld	P_m	0.4	N/A	N/A	0.3	0.7	15.4
	$P_L + P_b$	0.4	N/A	N/A	0.3	0.7	23.1
	$P + Q$	0.4	N/A	0.0	0.3	0.7	46.1

* Values shown are maximums irrespective of location

TABLE 11.2-1

SUMMARY OF STRESSES (ksi) IN THE MSB RESULTING FROM THE HYPOTHETICAL HORIZONTAL DROP

Component		Drop	Dead Wt.*	Thermal	Pressure	Total	ASME Allowable
Bottom Plate	P_m	29.4	N/A	N/A	0.06	29.5	49.0
	$P_L + P_b$	44.6			1 7	46.3	73.5
Shell	P_m	25.9	N/A	N/A	0.1	26.0	49.0
	$P_L + P_b$	71.8			1.2	73.0	73.5
Structural Lid	P_m	2.6	N/A	N/A	0.0	2.6	49.0
	$P_L + P_b$	42.9			0.4	43.3	73.5
Shield Lid	P_m	2.4	N/A	N/A	0.0	2.4	49.0
	$P_L + P_b$	20.6			0.0	20.6	73.5
Bottom Weld	P_m	25.9	N/A	N/A	0.2	26.1	49.0
	$P_L + P_b$	44.6			.7	46.3	73.5
Top Weld	P_m	7.1	N/A	N/A	0.06	7.2	36.8
	$P_L + P_b$	42.9			0.4	43.3	55.1
Shield Lid Weld	P_m	9.1	N/A	N/A	0.2	9.3	36.8
	$P_L + P_b$	20.6	N/A	N/A	0.8	21.4	55.1

* Dead weight is included in the drop load.

1.2.13 Minimum Temperature for Moving the MSB

Limit/Specification:

Movement of the MSB inside the VCC will only be allowed at ambient temperatures of 0^0 F or above.

Objective: To avoid the potential for brittle failure.

Action: Confirm that the ambient temperature is above 0^0 F immediately before moving the MSB, while inside the VCC.

Surveillance: The ambient temperatures shall be measured before movement of the MSB.

Basis: Each MSB shell material will have shown, during fabrication, by Charpy test (per ASTM A370) that it has 15 ft-lb of absorbed energy at -50^0 F; and, therefore, movement of the MSB at temperatures above 0^0 F will avoid the potential for brittle fracture. Calculations show that the MSB shell minimum temperature will be substantially above the ambient temperature (e.g., 20 ^{0}F for 25-year-old fuel). However, for conservatism and simplicity, it is recommended that the ambient be selected as the minimum MSB movement temperature. It is highly unlikely that any MSB movement activity would take place at temperatures below zero. Nevertheless, if movement at a temperature below that specified is necessary, calculations (similar to those presented in Chapter 4 of the SAR) may be used to estimate the minimum MSB shell temperature for any particular ambient condition.

CPC-06Q-301 B5

1.2.14 Minimum Temperature for Lifting the MTC

Limit/Specification:

The MTC shall be allowed to be used to move the MSB if the ambient temperature is 40^0 F or above.

Objective: To avoid the potential for brittle failure.

Action: Confirm that the ambient temperature is above 40^0 F before moving the MSB inside the MTC.

Surveillance: The MTC ambient temperature shall be determined before movement of the MSB in the MTC.

Basis: The MTC material will have shown, during fabrication, that it has 15 ft-lb of absorbed energy at 0^0 F. Having Charpy test results, at 0^0 F, which show ductility (or other appropriate test to show that the Nil Ductility Temperature is lower than 0^0 F), will avoid the potential for brittle failure when the cask is moved at 40^0 F or higher. The MTC shell will have a temperature higher than ambient due to the heat source from the irradiated fuel. However, for conservatism and simplicity, it is recommended that the ambient temperature be used as the minimum shell temperature. If movement at lower temperatures is ever required, additional specific analysis or other actions that meet the approval of the NRC must be provided.

CPC-SUG-[illegible] B6/

WELDSTAR COVERS [illegible] PORTER [illegible] G0032319; WELDSTAR NUCLEAR SHIPPING TICKET N911411

ALLOY RODS CORPORATION

CERTIFICATE OF ANALYSIS

P.O. BOX 517/1500 KAREN LANE
HANOVER, PA 17331
(717) 637-8911

CERTIFIED MATERIALS TEST REPORT

WELDSTAR COMPANY
1750 MITCHELL ROAD
AURORA, IL 60504

Customer Order No.: 2244A-A
Order No.: 144017-1

This Material Conforms to Specification:
ASME SFA 5.20 SEC II PART C & ASME SEC III SUBSEC NB FOR CLASS 1 MATERIAL 1989 ED., 1990 ADD. ASME SFA 5.01, CLASS T2, SCH. K, 10 CFR PART 21 APPLIES

Trade Name or Trademark: Dual Shield II 70
Diameter Size: .045" x 25# Spool — Type: E71T-1
Weight: 7,200 lbs. — Test No.: 2-19406-00
Lot Number: 32039 — X-Rays Satisfactory
Carbon: .06 — Type Steel A-285

		Full	Split	Triple	Quad	Volts	Amps
Manganese:	1.24						
Chromium:	.04						
Nickel:	<.01		5	3		26	250 DC+
Silicon:	.47						

		Test Results:	As Welded	Stress Relieved 8 Hrs. @ 1150°F
Columbium:				
Tantalum:				
Molybdenum:	.01			
Tungsten:		Yield	80,400	72,900
Copper:	.02	Tensile	88,400	84,400
Titanium:		Elongation (2") %	28.0	28.0
Phosphorus:	.009	Red. of Area	70.7	69.5
Sulphur:	.013			
Vanadium:	.02	Charpy V-Notch Impacts Tested @ 0°F		
Cobalt:		Ft. Lbs.	90-92-91	79-72-76
		Lat. Exp.	69-71-78	66-60-62
		% Shear	40-30-40	30-30-30
Preheat:	70°F			
Interpass:	300°F	Charpy V-Notch Impacts Tested @ -20°F		
		Ft. Lbs.	81-82-74	54-50-51
Shielding		Lat. Exp.	66-62-56	46-44-43
Gas:	75% AR/25% CO_2	% Shear	40-30-30	30-20-30
Cool Rate:	100°F	Charpy V-Notch Impacts Tested @ -50°F		
max/hr. above 600°F		Ft. Lbs.	53-59-56	33-30-36
		Lat. Exp.	46-47-46	30-42-31
Tensile Specimen	.505"	% Shear	20-20-20	20-30-20
Impact Specimen	.394" x .394"			

Fillets: OK Vertical-Up/Overhead

This material is certified to be free of any mercury contamination.

Location & Orientation of Charpy-V-Notch/Tensile Specimens is I/A/W ASME NB-2322 and/or AWS/SFA specifications as applicable.

Quality Systems Certificate No. QSC-221
Expiration Date: September 8, 1993

The undersigned certifies that the contents of this report are accurate and that all operations performed by the undersigned or sub-contractors are in compliance with requirements of the material specification and ASME Boiler and Pressure Vessel Code, Section III, Division I, Subsection NCA-3800.

State of Pennsylvania
ss:
County of York

Subscribed and sworn to before me this 12th day of June, 1992.

ALLOY RODS CORPORATION

SEAL: Linda C. Myers — Notary Public

BY: D. A. Smith — D. A. Smith, Supervisor, Q. A. Services

NOTARIAL SEAL
LINDA C. MYERS, Notary Public
Penn Township, York County
My Commission Expires April 13, 1996.

WELDSTAR COMPANY QUALITY SYSTEM CERT (MATERIALS) EXPIRATION DATE

Certs reviewed by [illegible] 1/03/9[illegible]

THE C.T.R. COVERS CONSUMERS POWER P.O. / G0109204, WELDSTAR NUCLEAR SHIPPING TICKET / 891299

THE ESAB GROUP

CERTIFICATE OF ANALYSIS

CERTIFIED MATERIALS TEST REPORT

WELDSTAR COMPANY
1750 MITCHELL ROAD
AURORA IL 60504

Customer Order No.: 907122
Order No.: [illegible]
This Material Conforms to Specification:
ASME SFA 5.20 SEC II PART C & ASME SEC
III SUBSEC NB FOR CLASS 1 MATERIAL 1992
ED. 1992 ADD. ASME SFA 5.01 LOT CLASS
T2 SCHED "L" 10 CFR PART 21 APPLIES

Trade Name or Trademark: Alloy Rods Dual Shield II 70T12
Diameter Size: .045 x 25 Spool
Weight: [illegible],000 lbs.
Lot Number: 38380

Type: E71T-[illegible]
Test No.: 2-22961-00
X-Ray: Satisfactory

Carbon	.06		Type Steel A-285						
Manganese	1.30		Full	Split	Triple	Quad	Volts	Amps	
[illegible]	.0[illegible]								
Nickel	.01			6			28	260	DC
Silicon	.38								
Columbium			Test			As		Stress	
Tantalum			Results:			Welded		Relieved	
Molybdenum	.01						8 Hrs.	@ 1150°F	
Tungsten			Yield			75,000		68,700	
Copper	.0[illegible]		Tensile			83,700		80,500	
Titanium			Elongation (2") %			27.0		29.0	
Phosphorus	.012		Red. of Area			73.6		7[illegible]	
Sulphur	.012								
Vanadium	.02		Charpy V-Notch Impact Tested [illegible]						
Cobalt			Ft. Lbs.		[illegible]		[illegible]		
Cool Rate	[illegible]		Lat. Exp.		90-90-85		96-87-8[illegible]		
Max/Int. above 600°F			% Shear		70-70-60		80-70-70		
Preheat	[illegible]								
Interpass	[illegible]		Charpy V-Notch Impact Tested @ -50°F						
			Ft. Lbs.		[illegible]		93-10[illegible]		
			Lat. Exp.		[illegible]		70-79-[illegible]		
Shielding			% Shear		60-50-60		50-50-70		
Gas [illegible]									
			Welded Specimen [illegible]						
Diffusible [illegible]			Impact Specimen [illegible]						

This material is certified to be free of any mercury contamination.

WELDSTAR COMPANY'S QUALITY SYSTEM CERTIFICATE MATERIALS QSC 290 EXPIRATION DATE JAN. 5, 1997

[illegible] Notch/Tensile Specimen [illegible] Specification [illegible]

Quality Systems Certificate No. QSC-2[illegible]
Expiration Date: September [illegible] 199[illegible]

State of Pennsylvania)
) ss.
[illegible]   )

The undersigned certifies that the contents of this report are accurate and that all operations performed by the undersigned or sub-contractors are in compliance with the requirements of the material specification and ASME Boiler and Pressure Vessel Code Section III Division 1 Subsection NCA-3800

[illegible]

By: [signature]
Notary Public

By: [signature]
[illegible] Supervisor, [illegible]

The Esab Group, Inc.
1500 KAREN LANE
P.O. BOX 517
HANOVER, PA 17331-0066
(717) 637-8911
FAX (800) 222-89[illegible]

NOTARIAL SEAL
LINDA C. MYERS, Notary Public
Penn Township, York County
My Commission Expires April 13, 1996

OLD VALUES...NEW IDEAS

WELDSTAR®

1936 **60** 1996
Years

P.O. BOX 1150 • AURORA, IL 60507-1150 • PHONE (630) 859-3100

CERTIFICATE OF COMPLIANCE

ISSUED: August 22, 1997

CUSTOMER: Consumers Energy

CUSTOMER PO#: G0238240

SHIP TICKET #: N917296

DESCRIPTION: 495 lbs. spooled wire (33# spools) ESAB
.045" E71T01/E71T-12MJ/E71T-12MH8
Lot #51122

The attached CMTR(s), one copy per item, covers the material shipped against the above referenced purchase order number.

The above material will meet code requirements of ASME Section II, Part C and Section III 1986 Edition through 1988 Addenda, NB2400 for Class 1 material, with special impact properties of 15 ft/lbs minimum absorbed energy at -50° F, and the requirements of ASME Boiler and Pressure Vessel Code current edition and addenda for Section II, C, SFA 5.20, and is in compliance with the above referenced purchase order number. We certify that the material shipped has been handled in compliance with our identification and verification program.

All vendors on Weldstar's approved vendors list have been audited by Weldstar.

Weldstar's Quality Assurance Program Revision K, dated November 12, 1996 meets the requirements of ASME Section III, NCA-3800, 1995 Edition.

The provisions of NRC 10CFR Part 21 apply to this order.

Asst QUALITY ASSURANCE MANAGER

CPC-CGQ-301

B7/1

TEST NO.: 2-27679-00
Page 2

Charpy V-Notch Impacts Tested @ -50°F. (As-Welded)

Ft. Lbs.	77-84-85
Lat. Exp.	59-66-66
% Shear	50-50-70

GLYCERINE METHOD
HYDROGEN ANALYSIS

1. 3.1 ML/100 G OF WELD METAL

2. 3.1

3. 2.2

4. 3.1

2.9 AVERAGE

ARC VOLTAGE 26

AMPERES 230 DC+

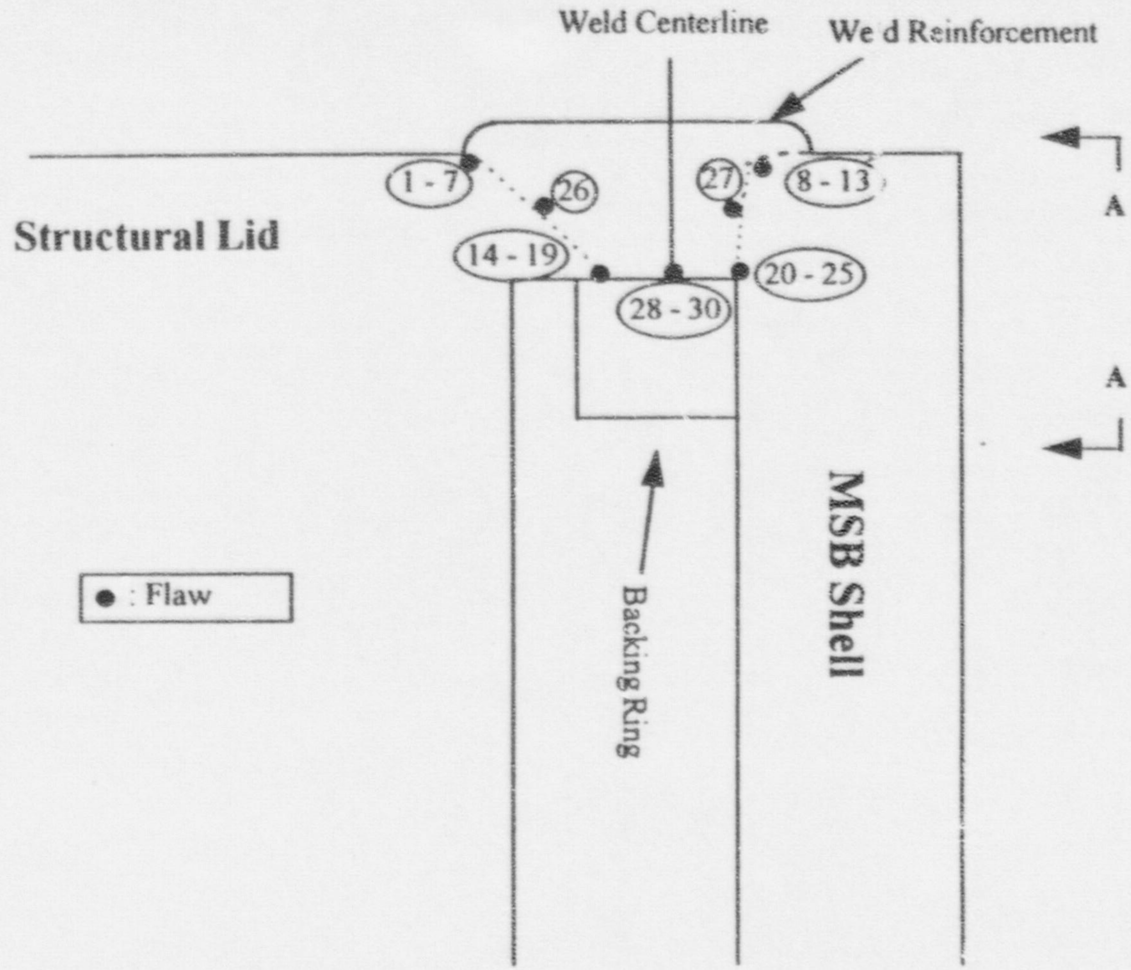
CFC-CGG-301

BH/11

APPENDIX C

Mockup Flaw Details

Palisades DFS Mock-up

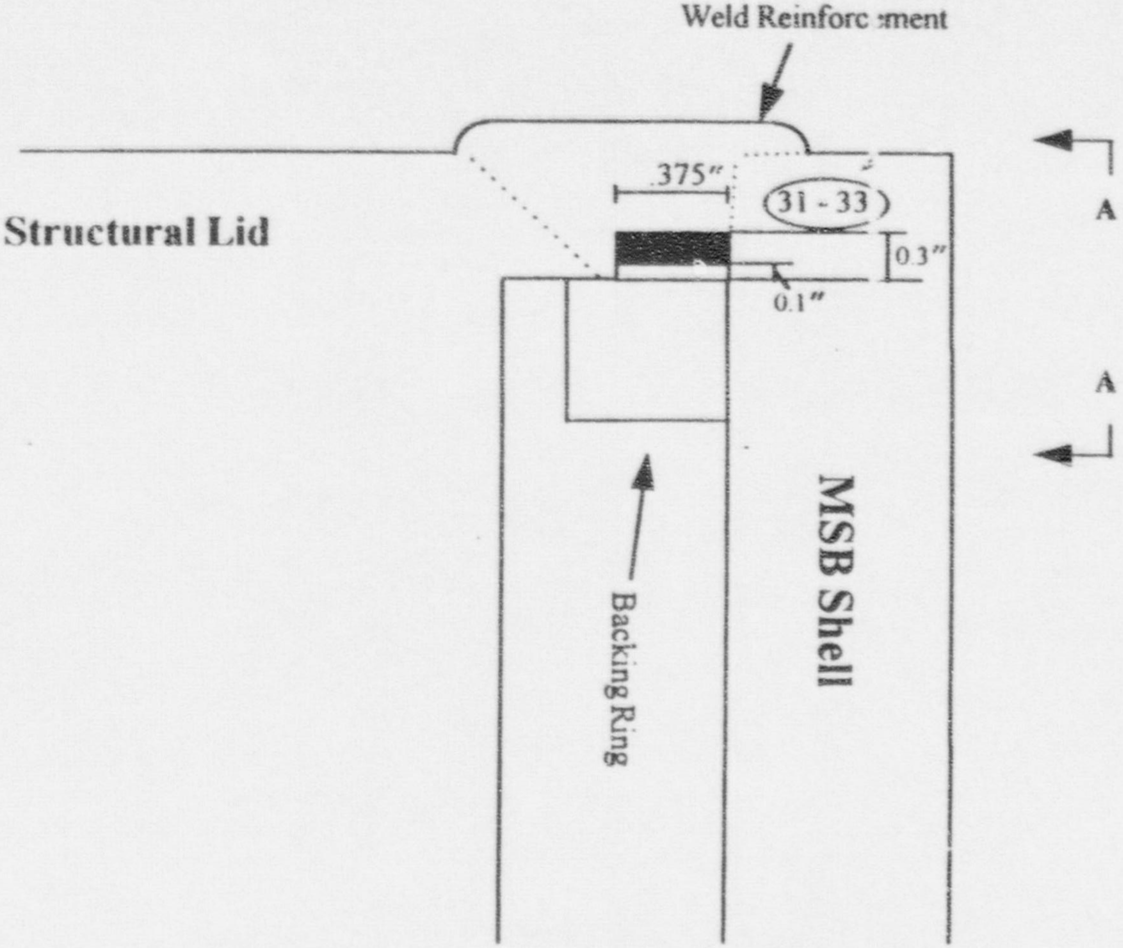


CIRCUMFERENTIAL FLAWS

CPC-CGQ-301

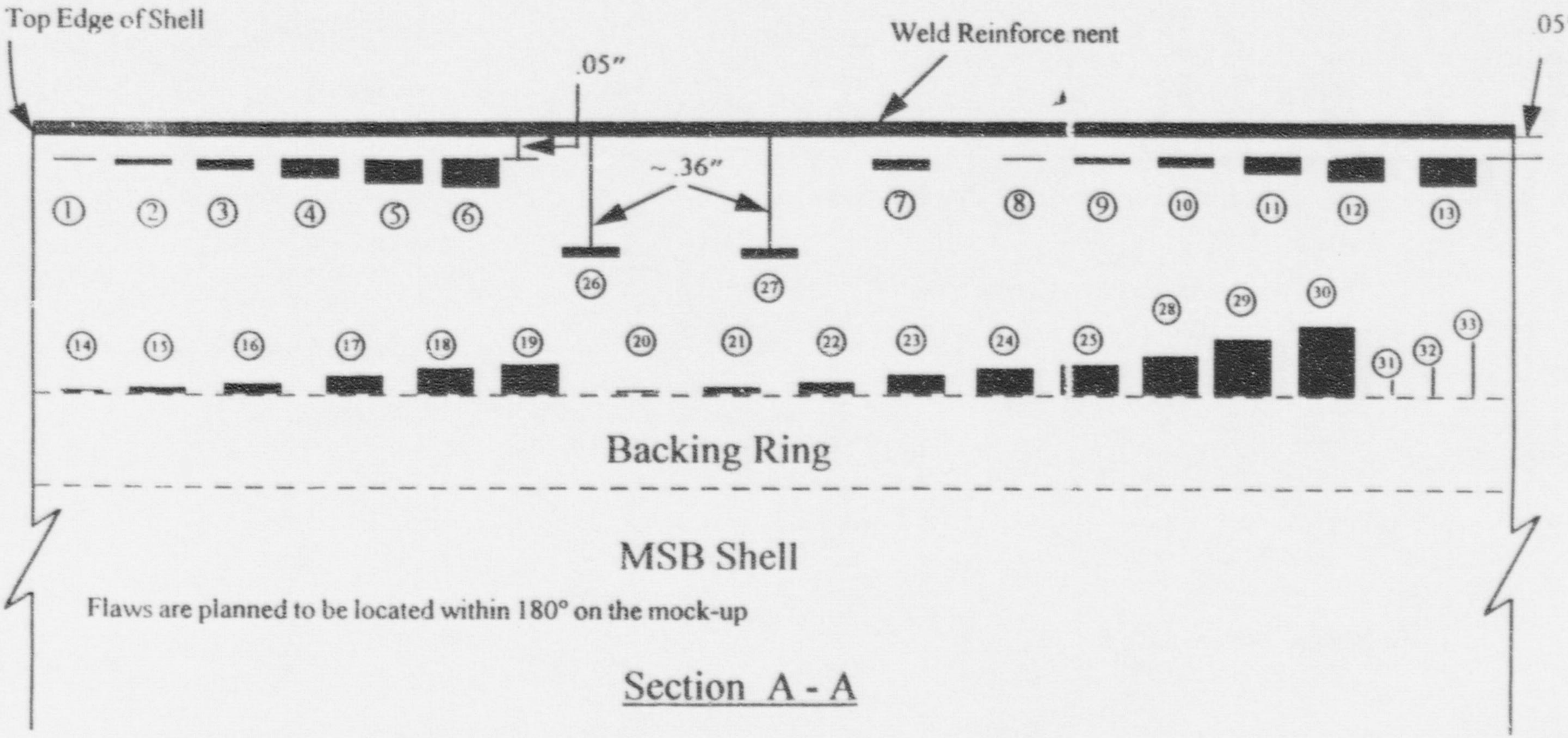
C2/5

Palisades DFS Mock-up



TRANSVERSE FLAWS

Palisades DFS Mock-up



Flaws are planned to be located within 180° on the mock-up

Section A - A

CPC-062-701

C4/5

CPC-16G-301

FLAW DETAILS

Flaw	Location	Type	Orientation	Height
1.	Top, lid side weld HAZ, .05" below lid surface	Crack	Circumferential	.05"
2.	Top, lid side weld HAZ, .05" below lid surface	Crack	Circumferential	.075"
3.	Top, lid side weld HAZ, .05" below lid surface	Crack	Circumferential	.1"
4.	Top, lid side weld HAZ, .05" below lid surface	Crack	Circumferential	.15"
5.	Top, lid side weld HAZ, .05" below lid surface	Crack	Circumferential	.2"
6.	Top, lid side weld HAZ, .05" below lid surface	Crack	Circumferential	.25"
7.	Top, lid side weld HAZ, .05" below lid surface (near valve access hole)	Crack	Circumferential	.1"
8.	Top, shell side weld HAZ, .05" below lid surface	Crack	Circumferential	.05"
9.	Top, shell side weld HAZ, .05" below lid surface	Crack	Circumferential	.075"
10.	Top, shell side weld HAZ, .05" below lid surface	Crack	Circumferential	.1"
11.	Top, shell side weld HAZ, .05 below lid surface	Crack	Circumferential	.15"
12.	Top, shell side weld HAZ, .05" below lid surface	Crack	Circumferential	.2"
13	Top, shell side weld HAZ, .05" below lid surface	Crack	Circumferential	.25"
14.	Bottom, lid side weld HAZ, surface breaking	Crack	Circumferential	.05"
15.	Bottom, lid side weld HAZ, surface breaking	Crack	Circumferential	.075"
16.	Bottom, lid side weld HAZ, surface breaking	Crack	Circumferential	.1"
17.	Bottom, lid side weld HAZ, surface breaking	Crack	Circumferential	.15"
18.	Bottom, lid side weld HAZ, surface breaking	Crack	Circumferential	.2"
19.	Bottom, lid side weld HAZ, surface breaking	Crack	Circumferential	.25"
20.	Bottom, shell side weld HAZ, surface breaking	Crack	Circumferential	.05"
21.	Bottom, shell side weld HAZ, surface breaking	Crack	Circumferential	.075"
22.	Bottom, shell side weld HAZ, surface breaking	Crack	Circumferential	.1"
23.	Bottom, shell side weld HAZ, surface breaking	Crack	Circumferential	.15"
24.	Bottom, shell side weld HAZ, surface breaking	Crack	Circumferential	.2"
25.	Bottom, shell side weld HAZ, surface breaking	Crack	Circumferential	.25"
26	Middle, lid side of weld	Slag	Circumferential	.1"
27.	Middle, shell side of weld	LOF	Circumferential	.1"
28.	Bottom, weld centerline, surface breaking	Crack	Circumferential	.3"
29.	Bottom, weld centerline, surface breaking	Crack	Circumferential	.4"
30.	Bottom, weld centerline, surface breaking	Crack	Circumferential	.5"
31.	Bottom, weld	LOF	Transverse(Radial)	.1"
32.	Bottom, weld	LOF	Transverse(Radial)	.2"
33.	Bottom, weld	LOF	Transverse(Radial)	.3"

Flaws 1 - 30 should be approximately .5" long
Flaws 31 - 33 should be approximately .375" long

12-1001

SIERRA NUCLEAR CORP.

12/1 Copies to
Leeds
Sturz
Kobetz
Reid
Howe
Weld Team (10)
Docket

November 26, 1997

SNC 97-121

Mr. Timothy Kobetz
U.S. Nuclear Regulatory Commission
11555 Rockville Pike
Rockville, MD 20852

Subject: Hardcopy Transmittal of Calculation Package CPC-06Q-301; Attachment to Response to Question 4 of Request for Additional Information Concerning CAL 97-7-001

Dear Mr. Kobetz

Sierra Nuclear Corporation(SNC) submits the attached hardcopy of calculation package CPC-06Q-301; as part of the response to Question 4 of Request for Additional Information concerning CAL 97-7-001. Should you or the Commission have any additional questions please contact me at Sierra Nuclear Corporation(SNC); 408 - 438 - 6444.

Respectfully,

Kay Moeckel
Manager, Licensing

cc: G.Dixon, J.Massey; LicRile; c:\ltr\nrcrai4

A170

9712030011 1p.

STRUCTURAL INTEGRITY Associates, Inc.	CALCULATION PACKAGE	FILE No: CPC-06Q-301 PROJECT No: CPC-06Q

PROJECT NAME: Analytical Support for Dry Spent Fuel Storage Activities

CLIENT: Consumers Energy (Palisades Nuclear Plant)

CALCULATION TITLE:
Allowable Flaw Size Definition for VSC-24 Dry Storage Cask Structural Lid to Shell Weld

PROBLEM STATEMENT OR OBJECTIVE OF THE CALCULATION:

Develop Weld Flaw Acceptance Criteria

Document Revision	Affected Pages	Revision Description	Project Mgr. Approval Signature & Date	Preparer(s) & Checker(s) Signatures & Date
0	1 - 24 Appendix A & B	Original Issue	[signature] 11/25/97	[signature] 11/25/97 [signature] 11/25/97

SIC-97-039

9712030012 80 pp.

1.0 INTRODUCTION

The purpose of this calculation is to develop acceptance criteria for flaws which may be detected in the structural lid to shell welds of spent fuel dry storage casks at Palisades, Point Beach, and ANO Nuclear Plants. The geometry of the structural lid to shell joint is illustrated in Figure 1 [1].

For the casks which are currently in service, nondestructive examination of these welds has included dye penetrant examination of the root and final welded layers. No volumetric examination of these welds has been performed in the past, but the plant owners are considering such examination as a result of discussions with the NRC.

2.0 CODE APPLICABILITY

In the present analysis, the methods of ASME Section XI, IWB-3600 and Appendix A [2] are used to determine allowable flaw sizes under the limiting loading conditions. IWB-3600 and Appendix A are directly applicable to Class 1 vessels (such as reactor vessels) and piping. Although the dry fuel storage casks are Class 2 (NC) vessels, Section IWC-3600 is still under development, and Section XI permits the use of IWB criteria for flaw evaluations.

Section XI flaw evaluation criteria are directly applicable for evaluation of flaw indications detected in the structural lid welds of casks which are already in service. Its applicability is less clear for examination results for new casks. However, for examinations of structural lid welds which are performed immediately upon completion prior to putting them in service, it is SI's opinion that the rules of Section XI should still be applied, in lieu of Section III rules. Although a loaded cask is not formally considered to be "in operation" until it is successfully transferred to the storage pad, the cask is performing its design function in a difficult to reverse manner once fuel is loaded and the shield lid and structural lid are in place. Section XI provides more extensive methods for the evaluation of defects detected by volumetric examination, and volumetric examination of the structural lid weld immediately following completion forms a baseline for any subsequent inservice inspections by similar methods.

3.0 LOAD DEFINITION

Table 1 [1] provides stress data for the structural lid weld under the horizontal drop accident. This event is considered to be an emergency/faulted class (service level C/D) event. Table 2 [1] presents stress data for normal operating events. By comparing the Tables, it can be seen that at the structural lid weld, the normal operating stresses are significantly lower than the stresses which are predicted to result from the horizontal drop event. Therefore, the horizontal drop accident is judged to govern the critical flaw size determination.

As shown on Table 1, the horizontal drop event produces the following stresses in the structural lid-to-shell weld:

$$P_m = 7.2 \text{ ksi}$$

$$P_L + P_B = 43.3 \text{ ksi}$$

In the fracture mechanics analysis below, both of these stress components were included. The second (bending) component was modeled as linear through weld bending, with the 43.3 ksi applied as tension on the inside surface (root) of the weld, which is assumed to be the origin of any observed cracks.

In addition to these two load components, weld residual stress was included in the calculation. Because no measurements or calculations of weld residual stress were available, the weld residual stress was assumed to be represented by a constant tensile stress through the weld thickness.

Appendix A of Section XI [2] requires the use of residual stresses in determination of allowable flaw sizes. However, it is overly conservative to treat such steady state secondary stresses equally with primary stresses resulting from normal operation (e.g. pressure) or accidents (such as the horizontal drop event). Appendix H of Section XI defines treatment of residual stresses in a manner which is judged to be appropriate for evaluation of flaws in the structural lid weld. This appendix requires that residual stresses be included, but with a safety factor of 1, rather than the Section XI specified factors for code-limited types of stress.

For normal operating conditions, the limiting applied stress intensity K_I (applied) is:

$$K_I(\,applied\,) < \frac{K_{ID}}{\sqrt{10}}$$

where K_{ID} calculated from the projected Charpy data is used as the critical stress intensity. The safety factor of $\sqrt{10}$ is as defined in Section IWB-3612. K_{ID} is equivalent to K_{Ia} as discussed above. For this case, the total applied stress intensity K_I (applied) is determined from the membrane, bending, and residual stresses as

$$K_I\,(applied) = K_I\,(membrane) + K_I\,(bending) + \frac{K_I(\,residual\,)}{\sqrt{10}}$$

where the $\frac{K_I(\,residual\,)}{\sqrt{10}}$ reflects the safety factor of 1 for the residual stress case.

For the emergency/faulted case (horizontal drop), it is still appropriate (and conservative) to use the calculated K_{ID} as the criterion, because of the dynamic nature of the loading, instead of the K_{IC} (which would be appropriate for static or slow loading rates). For this case (horizontal drop) the applied K_I is limited by

$$K_I(applied - drop) < \frac{K_{ID}}{\sqrt{2}}$$

The applied K_I using a safety factor of 1.0 on residual stresses as discussed above, would be given by:

$$K_I(applied) = K_I(membrane) + K_I(bending) + \frac{K_I(residual)}{\sqrt{2}}$$

However, because the horizontal drop case is a dynamic loading case with a very high loading rate (impact), residual stresses may not be able to redistribute during the horizontal drop case as they would during slower or static cases. In fact, for the initial horizontal drop impact, residual stresses may in fact behave more like primary stresses over the short interval of the drop impact. Consequently, for this case, residual stresses are conservatively treated as primary membrane stresses, using the full code safety margin of $\sqrt{2}$.

The magnitude of the residual stress is assumed to be a constant 30 ksi tensile value through the weld thickness. This value was selected based upon consideration of the base material yield stress, with consideration of anticipated reduction of residual stresses in the inner (near root) layers of the weld due to application of subsequent welded layers.

4.0 MATERIAL FRACTURE TOUGHNESS

The certified material test reports (CMTRs) [1,5,6] for the structural lid weld material were provided by the plant owners. These documents contain Charpy V-Notch Impact data taken at -50°F (and some data at other temperatures). According to the "Certificate of Conformance for the

VSC-24 System" [9] in Section 1.2.13, there are administrative limits which prevent moving of the storage casks when the temperature is less than 0°F. Consequently, a horizontal drop accident is judged not to be possible below this temperature.

Article A-4000 of Appendix A to Section XI [2] recommends that the material fracture toughness be determined from the actual material and product form in question. Therefore, to evaluate the fracture toughness of this material, use of the actual Charpy data at 0°F is appropriate. The Charpy data at 0°F is used to determine material fracture toughness (K_{Ic}) using the following equation for carbon steel in the transition temperature region [3]:

$$K_{ID}=\sqrt{5C_v E}$$

In this equation, E was assumed to be 29,000 ksi.

Judging from the % shear data, the material is in the transition region in the -50°F to 0°F temperature range, so use of this equation is appropriate [3]. Also, the Charpy correlation is for K_{ID} (dynamic) fracture toughness as well as K_{IC} (static), so it is applicable to a dynamic event like the drop accident.

As noted above, the material specifications require Charpy V-notch test results at -50°F, while the lowest temperature at which a horizontal drop could occur is 0°F, due to administrative limits [1]. All three plants (Palisades, Point Beach, ANO) provided CMTRs for weld material used (or proposed for use) in the structural lid welds [1,5,6] and these CMTRs included Charpy data at -50°F. Although all CMTRs include data for both as-welded and stress relieved conditions, the as-welded condition is applicable to all three plants, so that data will be used.

In order to determine allowable flaw sizes for each plant, it is appropriate to use material toughness at the limiting temperature of 0°F. Since such data is not available in most cases, it is necessary to extrapolate toughness at 0°F from the available -50°F data.

The data from all CMTRs shows that the material is in the transition region (reported per cent shear of 20-80%) and so linear projection is appropriate. Referring to Figure 5 from [7],the slope of this curve is estimated as 0.55 ft-lb/°F for the high manganese curve, which describes a material similar to the 516 Grade 70 base metal. This slope was used to project all reported weld metal -50°F data [1,5,6] to 0°F. The results are shown in Table 3. Also, all available Charpy data from CMTRs [1,5,6] at 0°F is shown in Table 3 for comparison. The predicted 0°F Charpy data for weld metal is conservative compared to all available actual 0°F data. That is, the predicted Charpy results at 0°F (based on extrapolation of -50°data) are consistently lower than actual data at 0°F.

Each of predicted Charpy absorbed energy results at 0°F were used to calculate a material toughness K_{ID} for use in allowable flaw size calculations.

The resulting fracture toughness 0°F is generally greater than 75 ksi-$\sqrt{in.}$. This is shown in Figure 2 in comparison to ASME Section XI fracture toughness curves for carbon and low alloy steel reactor pressure vessel bounding materials. Figure 4 shows allowable flaw size (depth versus length) for a toughness of 78.4 ksi-$\sqrt{in}$, which results from extrapolation of the minimum specified Charpy V-notch absorbed energy of 15 ft-lb at -50°F.

5.0 APPLICATION OF ASME CODE MARGINS

As discussed above, the limiting event for the structural lid weld is the horizontal drop accident, which is considered to be an emergency/faulted event. The stresses associated with this event are defined in Table 1 from [1].

Using the rules of IWB-3613(c) [2], the fracture toughness values determined above are reduced by a factor of $\sqrt{2}$ to define the limiting allowable K_I for flaws in the structural lid weld under emergency/faulted conditions. That is,

$$K_{I\ allowable} < \frac{K_{ID}}{\sqrt{2}}$$

For example, a limiting K_{ID} calculated from Charpy data of 78.8 ksi-$\sqrt{in}$ produces an allowable K_I of 55.4 ksi-$\sqrt{in}$. This value corresponds to the value obtained by extrapolating the minimum specified toughness (15 ft-lb at -50°F) to 0°F as discussed above.

6.0 ALLOWABLE FLAW CALCULATIONS

Using the above load definitions and fracture toughness, a series of allowable flaw size calculations were performed using the Structural Integrity Associates computer program **pc-CRACK™** [4], which has been developed and verified under the SI Quality Assurance program.

6.1 Surface Flaws

The structural lid weld was modeled as a plate with an elliptical surface crack subject to both membrane and bending stresses. This model is illustrated in Figure 3. Use of this flat plate model for flaws in the structural lid to shell weld is appropriate for flaws originating in the vicinity of the weld root and propagating through the weld material or weld-base metal interface. This model is conservative compared to the actual weld geometry, because the actual weld experiences significant hoop constraint due to the stiffness of the structural lid and cask shell. Such constraint will limit crack opening in the actual weld as compared to the model, and therefore a larger crack would be tolerable in the actual weld than is predicted by use of the flat plate model. These results are equally applicable to flaws originating on the outside surface and oriented inward.

The flaw aspect ratio (the ratio of flaw depth to length) was varied parametrically, to determine an allowable flaw depth versus length curve. The conservative fracture toughness including the emergency/faulted Code margins was used as the criterion for determining allowable flaw depth for each aspect ratio.

The results are shown in Figure 4, and the supporting **pc-CRACK** analyses are attached in Appendix A. There is no known mechanism for continued crack propagation of defects in these welds, so no crack growth calculations have been performed for the assumed defects. Limiting allowable flaw depths for each heat of weld material at each plant are shown in Table 3.

6.2 Subsurface Flaws

The above discussion addressed the determination of allowable flaw sizes for flaws which are connected to the surface of the weld, under a conservative set of assumptions. The weld could also contain subsurface defects as a result of the welding process for example. In general, the allowable flaw size for a subsurface defect will be larger (usually twice or greater) than for a surface defect under the same conditions.

Evaluation of allowable subsurface defects was performed using the same linear elastic fracture mechanics techniques as were described above for surface defects. For these cases, a center cracked plate model (Figure 6) was used to evaluate the infinite length flaw. This model is conservative for the actual cases, since it treats applied stresses as pure tension, while for the subsurface flaw cases, the drop load case has a significant through-wall bending component. Consequently, for a subsurface flaw the stresses due to the drop event will be significantly lower than the 43.3 ksi surface stress for this event (see page 3). The calculated allowable flaw sizes for subsurface flaws corresponding to the same assumptions presented in Table 3 for surface flaws are shown in Table 4. The allowable subsurface flaw results presented in Table 4 also require that the flaw be sufficiently embedded that treatment as a subsurface flaw is justified. ASME Section XI, Figures IWA-3310-1, -3320-1, and -3330-1 provide criteria for evaluating proximity of flaws to the surface and to each other (in the case of multiple flaws). In general, if a flaw is closer to the surface than 0.4 of its half-depth, it must be considered to be a surface flaw.

7.0 RECOMMENDED MOCKUP DEFECTS

The above analysis shows that a family of significant sized flaws (Figure 4) can be accepted in the structural lid to shell weld, while maintaining Code margins, and under a conservative set of assumptions.

For the existing operating casks, the nondestructive examination performed as a part of accepting these welds included dye penetrant examination of the root pass. Such an examination would have detected defects which had penetrated the root pass surface. Consequently, it is concluded that the most likely defects in these welds are limited in size to less than the root pass thickness. The root pass is assumed to be about 0.1 inch in thickness. Therefore, we recommend that a mockup to be used for qualification of volumetric examination techniques include indications in the root of the weld which are equal to the root pass thickness (e.g., 0.1 inch deep), to test detection capability. To test defect sizing capability, we suggest that a range of flaws with depths from 0.05 inch to perhaps 0.25 inch be included, with orientations along and normal to the weld direction, and directed through the weld metal, along the lid to weld interface, and along the shell to weld interface. Indications of various aspect ratios in the range of 0.1 to 0.5 should be considered. Implanted flaws will give results which are most representative of those to be expected in actual casks.

With regard to embedded defects representative of welding defects, the most likely defects are interbead lack of fusion and lack of penetration at both weld metal-base metal interfaces. Where the weld was made with a flux shielded process (such as is the case at Palisades and ANO), slag inclusions could also occur. Representative defects of these types should also be included in the mockups, with sizes in the same range as the above root defects.

8.0 CONCLUSIONS

This analysis has shown that flaws with depths greater than those which could have been missed during original weld examination can be accepted under the criteria of ASME Section XI, with a conservative set of assumptions. These results are generic and conservative in nature. Specific flaws exceeding the criteria developed in this calculation could potentially be accepted based upon more detailed analyses and less conservative materials properties on a case-by-case basis.

We recommend that the above results be used as the basis for establishing methods for qualifying volumetric examination techniques for these welds, and for initial screening of results of field examinations.

9.0 REFERENCES

1. Letter from Emil A. Zernick (Consumers Energy) to Hal Gustin (SI), "Flaw Analysis Inputs", dated November 12, 1997, transmitting design input information (letter attached as Appendix B).
2. ASME Boiler and Pressure Vessel Code, Section XI (with Appendix A), 1989 Edition.
3. Rolfe, Stanley T., and Barsom, John, M., Fracture and Fatigue Control in Structures, Prentice-Hall, 1977.
4. Structural Integrity Associates, **pc-CRACK™** for Windows, Version 3.0, March 27, 1997.
5. Fax from Tom Burtard (Wisconsin Electric Power Company) to Hal Gustin (SI) dated 11/12/97 and 11/13/97 Charpy Test Results.
6. Fax from Darrell Williams (ANO) to Hal Gustin (SI) dated 11/11/97: Weld Material CMTRs.
7. ASM, The Metals Handbook, Vol 1, 10th Edition, 1990.

Table 1

TABLE 11.2-1

SUMMARY OF STRESSES (ksi) IN THE MSB RESULTING FROM THE HYPOTHETICAL HORIZONTAL DROP

Component		Drop	Dead Wt.*	Thermal	Pressure	Total	ASME Allowable
Bottom Plate	P_m	29.4	N/A	N/A	0.06	29.5	49.0
	$P_L + P_b$	44.6			1.7	46.3	73.5
Shell	P_m	25.9	N/A	N/A	0.1	26.0	49.0
	$P_L + P_b$	71.8			1.2	73.0	73.5
Structural Lid	P_m	2.6	N/A	N/A	0.0	2.6	49.0
	$P_L + P_b$	42.9			0.4	43.3	73.5
Shield Lid	P_m	2.4	N/A	N/A	0.0	2.4	49.0
	$P_L + P_b$	20.6			0.0	20.6	73.5
Bottom Weld	P_m	25.9	N/A	N/A	0.2	26.1	49.0
	$P_L + P_b$	44.6			1.7	46.3	73.5
Top Weld	P_m	7.1	N/A	N/A	0.06	7.2	36.8
	$P_L + P_b$	42.9			0.4	43.3	55.1
Shield Lid Weld	P_m	9.1	N/A	N/A	0.2	9.3	36.8
	$P_L + P_b$	20.6	N/A	N/A	0.8	21.4	55.1

* Dead weight is included in the drop load.

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Table 2

TABLE 3.4-5

MSB MAXIMUM STRESS EVALUATION

Component	Stresses	CALCULATED VALUE, KSI*					
		DEAD WEIGHT	PRESSURE	THERMAL	HANDLING	TOTAL	ASME LIMIT
MSB Shell	P_m	0.1	0.1	N/A	0.9	1.1	20.5
	$P_L + P_b$	0.1	1.2	N/A	2.4	3.7	30.7
	$P + Q$	0.1	1.2	1.0	2.4	4.7	61.5
Bottom Plate	P_m	0.02	0.06	N/A	1.0	1.1	20.5
	$P_L + P_b$	0.02	1.7	N/A	1.5	3.2	30.7
	$P + Q$	0.02	1.7	[illegible]	1.5	[illegible]	61.5
Top Lid	P_m	0.0	0.0	N/A	0.1	0.1	20.5
	$P_L + P_b$	0.0	0.4	N/A	0.2	0.6	30.7
	$P + Q$	0.0	0.4	0.2	0.2	0.8	61.5
Bottom-to-Shell Junction	P_m	0.1	0.2	N/A	0.9	1.2	20.5
	$P_L + P_b$	0.1	1.7	N/A	1.5	3.3	30.7
	$P + Q$	0.1	1.7	1.5	1.5	4.8	61.5
Top-to-shell Junction	P_m	0.0	0.06	N/A	0.2	0.3	15.4
	$P_L + P_b$	0.0	0.4	N/A	0.2	0.6	23.1
	$P + Q$	0.0	0.4	0.4	0.2	1.0	46.1
Sleeve Assembly	P_m	0.05	N/A	N/A	1.8	1.9	20.5
	$P_L + P_b$	0.05	N/A	N/A	2.1	2.2	30.7
	$P + Q$	0.05	N/A	52.0	2.1	54.2	61.5
Shield Lid-to-Shell Weld	P_m	0.3	0.2	N/A	0.3	0.8	15.4
	$P_L + P_b$	0.3	0.8	N/A	0.4	1.5	23.1
	$P + Q$	0.3	0.8	1.3	0.4	2.8	46.1
Shield Lid Support Ring Weld	P_m	0.4	N/A	N/A	0.3	0.7	15.4
	$P_L + P_b$	0.4	N/A	N/A	0.3	0.7	23.1
	$P + Q$	0.4	N/A	0.0	0.3	0.7	46.1

* Values shown are maximums irrespective of location

Table 3
Projected Charpy Data and Allowable Flaw Sizes

Plant	Identifier	Percent Shear	Charpy @-50°F Average (or Min)	Charpy @ 0°F Predicted	Charpy @ 0°F Actual (If Available)	KID @ 0°F	Allowable Depth (360°) Surface
Point Beach	WP-18P4(18-8) Weld	NA	28	55.4	NA	89.6	0.14
	Base 18-8	NA	41	68.4	NA	99.6	0.17
	Haz 18-8	NA	87	114.4	NA	128.8	0.22
ANO PQR AS-030	Weld Zone Min	40	17	44.4	NA	80.2	0.13
	Weld Zone Avg	58	55	82.4	NA	109.3	0.17
	HAZ Avg	70	80	107.4	NA	124.8	0.20
	Base Long Avg	13	33	60.4	NA	93.6	0.14
ANO	Weldstar 467H Av	NA	84	111.4	NA	127.1	0.20
	Min Spec 467H	NA	20	47.4	NA	82.9	0.13
	ESAB 41323	40	60	87.4	117	112.6	0.17
	ESAB 37962	27	55	82.4	96	109.3	0.17
	ESAB 2A505A02	50	94	121.4	NA	132.7	0.22
	ESAB 2H408A03	43	96	123.4	NA	133.8	0.22
	ESAB 2E426G02	63	103	130.4	NA	137.5	0.22
	ESAB 2K407H03	70	122	149.4	NA	147.2	0.25
Palisades	Alloy Rods 32039	20	56	83.4	91	110.0	0.17
	ESAB 38380	56	99	126.4	135	135.4	0.22
	ESAB 51122	60	82	109.4	115	125.9	0.20
Min Specified	NA	NA	15	42.4	NA	78.4	0.13

Note: For subsurface defects at weld mid wall depth, the allowable through-wall dimension of the defect is generally twice the allowable surface flaw dimension for the corresponding case.

Table 4
Projected Charpy Data and Allowable Flaw Sizes

Plant	Identifier	Percent Shear	Charpy @-50°F Average (or Min)	Charpy @ 0°F Predicted	Charpy @ 0°F Actual (If Available)	KID @ 0°F	Allowable Depth (360°) Subsurface
Point Beach	WP-18P4(18-8) Weld	NA	28	55.4	NA	89.6	0.32
	Base 18-8	NA	41	68.4	NA	99.6	0.38
	Haz 18-8	NA	87	114.4	NA	128.8	0.48
ANO PQR AS-030							
	Weld Zone Min	40	17	44.4	NA	80.2	0.28
	Weld Zone Avg	58	55	82.4	NA	109.3	0.38
	HAZ Avg	70	80	107.4	NA	124.8	0.44
	Base Long Avg	13	33	60.4	NA	93.6	0.32
ANO							
	Weldstar 467H Av	NA	84	111.4	NA	127.1	0.44
	Min Spec 467H	NA	20	47.4	NA	82.9	0.28
	ESAB 41323	40	60	87.4	117	112.6	0.38
	ESAB 37962	27	55	82.4	96	109.3	0.38
	ESAB 2A505A02	50	94	121.4	NA	132.7	0.48
	ESAB 2H408A03	43	96	123.4	NA	133.8	0.48
	ESAB 2E426G02	63	103	130.4	NA	137.5	0.48
	ESAB 2K407H03	70	122	149.4	NA	147.2	0.52
Palisades	Alloy Rods 32039	20	56	83.4	91	110.0	0.38
	ESAB 38380	56	99	126.4	135	135.4	0.48
	ESAB 51122	60	82	109.4	115	125.9	0.44
Min Specified	NA	NA	15	42.4	NA	78.4	0.28

Note: For subsurface defects at weld mid wall depth, the allowable through-wall dimension of the defect is generally twice the allowable surface flaw dimension for the corresponding case.

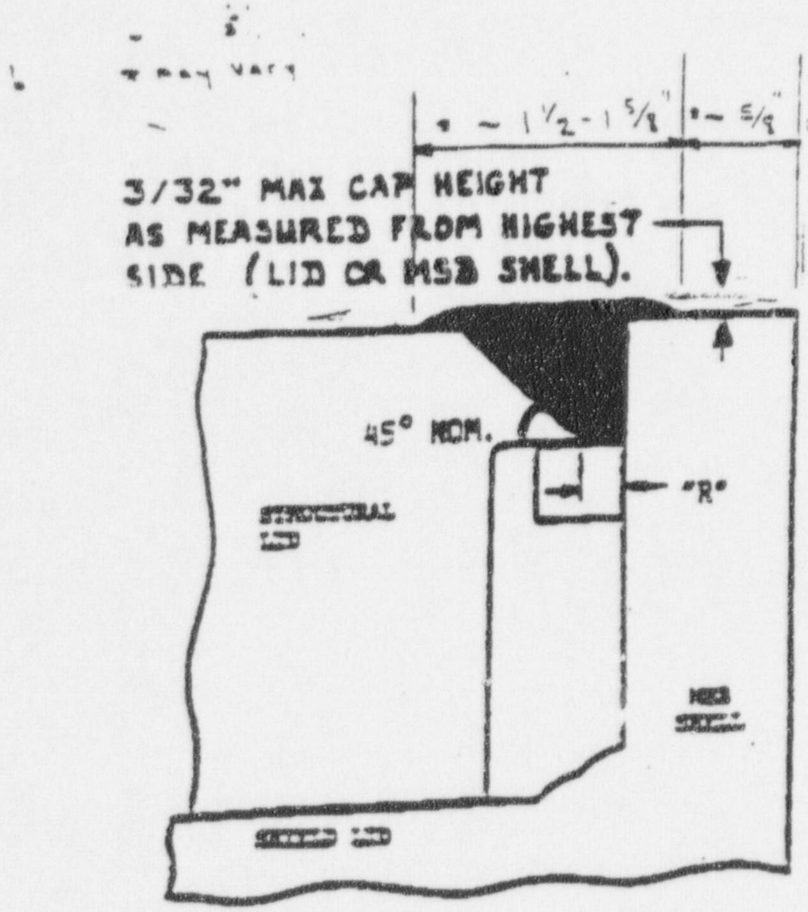

Figure 1

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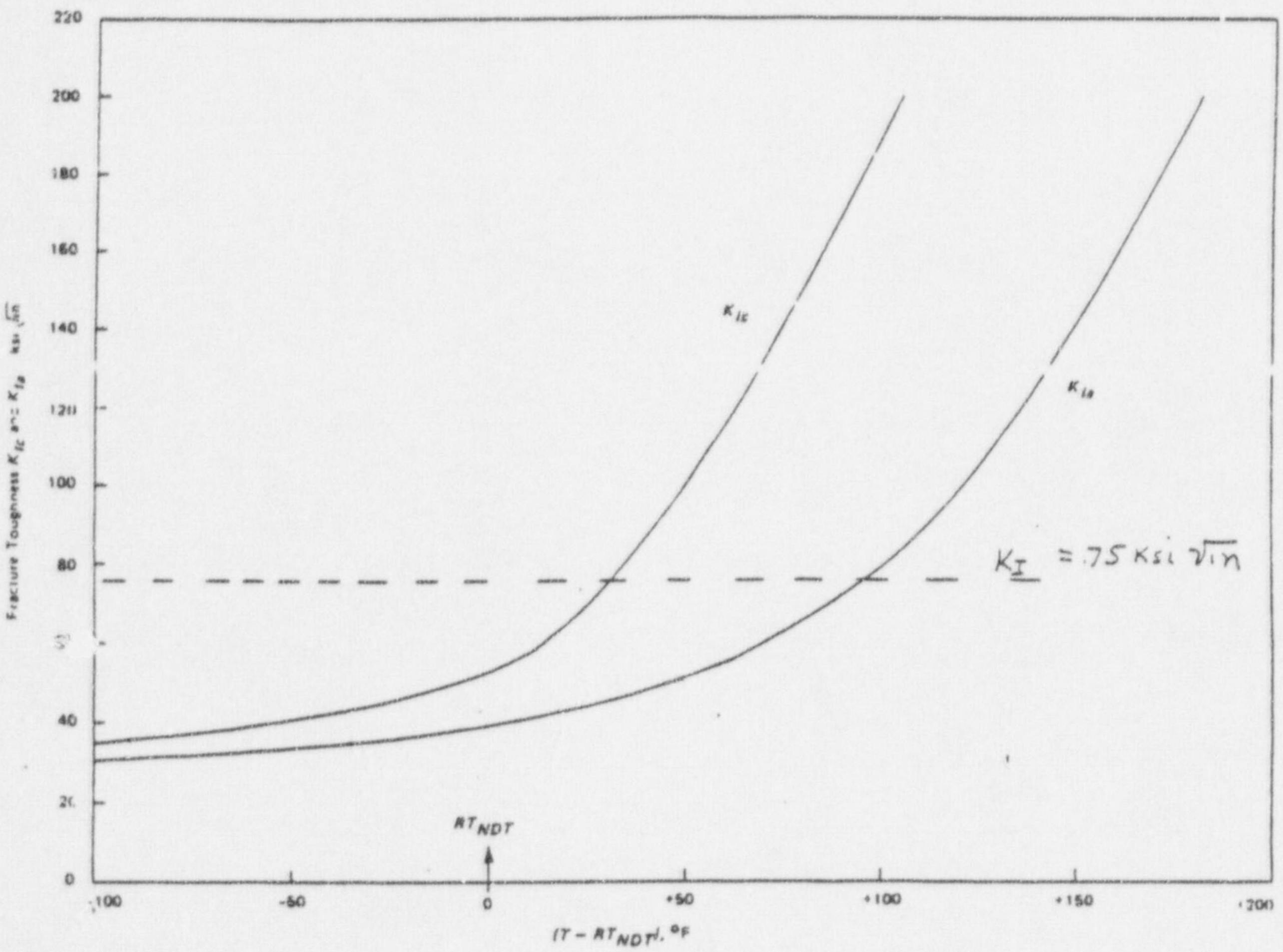

FIG. A-4200-1 LOWER BOUND K_{Ic} AND K_{Ia} VS TEMPERATURE CURVES FROM TESTS OF SA-533 GRADE B CLASS 1, SA-508 CLASS 2, AND SA-508 CLASS 3 STEELS

Figure 2

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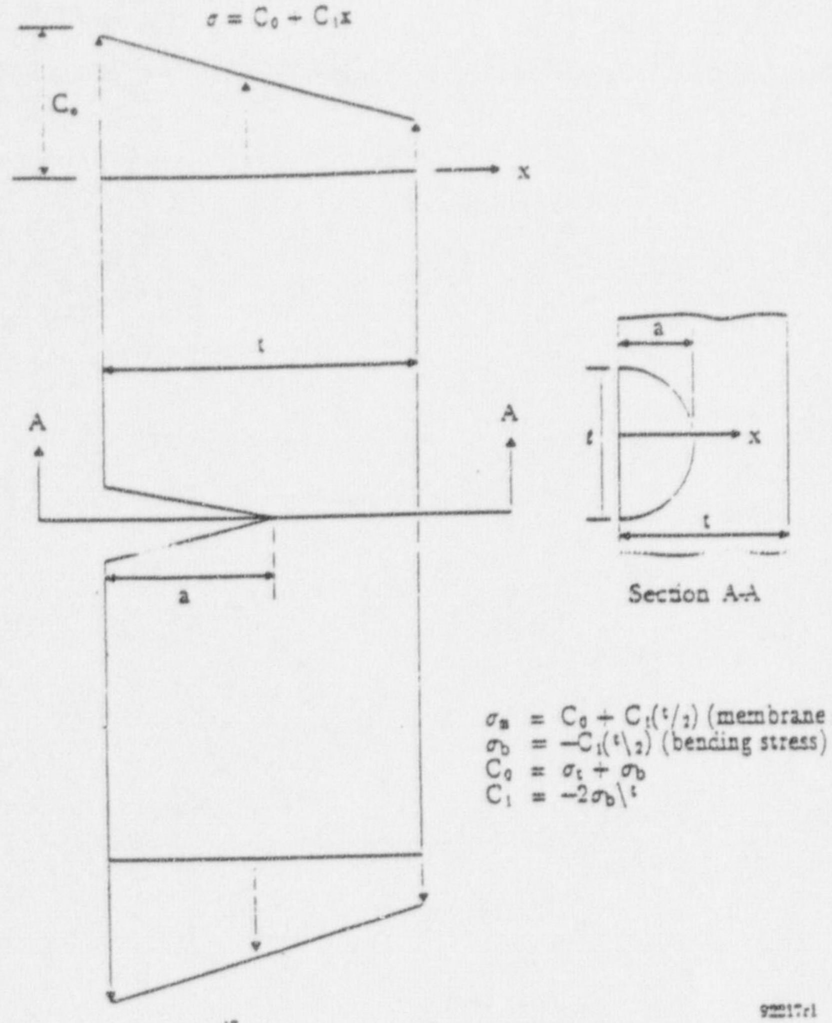

$\sigma_m = C_0 + C_1(t/2)$ (membrane stress)
$\sigma_b = -C_1(t\backslash 2)$ (bending stress)
$C_0 = \sigma_t + \sigma_b$
$C_1 = -2\sigma_b\backslash t$

REQUIRED INPUTS:

t:	wall thickness
a:	crack depth ($a_{max} \leq 0.5t$)
σ_{ys}:	material yield stress
a/ℓ:	crack aspect ratio

Figure 3–2[illegible]. LEFM Crack Model A, Page 2 – Elliptical Surface Crack Plate under Membrane and Bending Stresses

Figure 3

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Figure 4a

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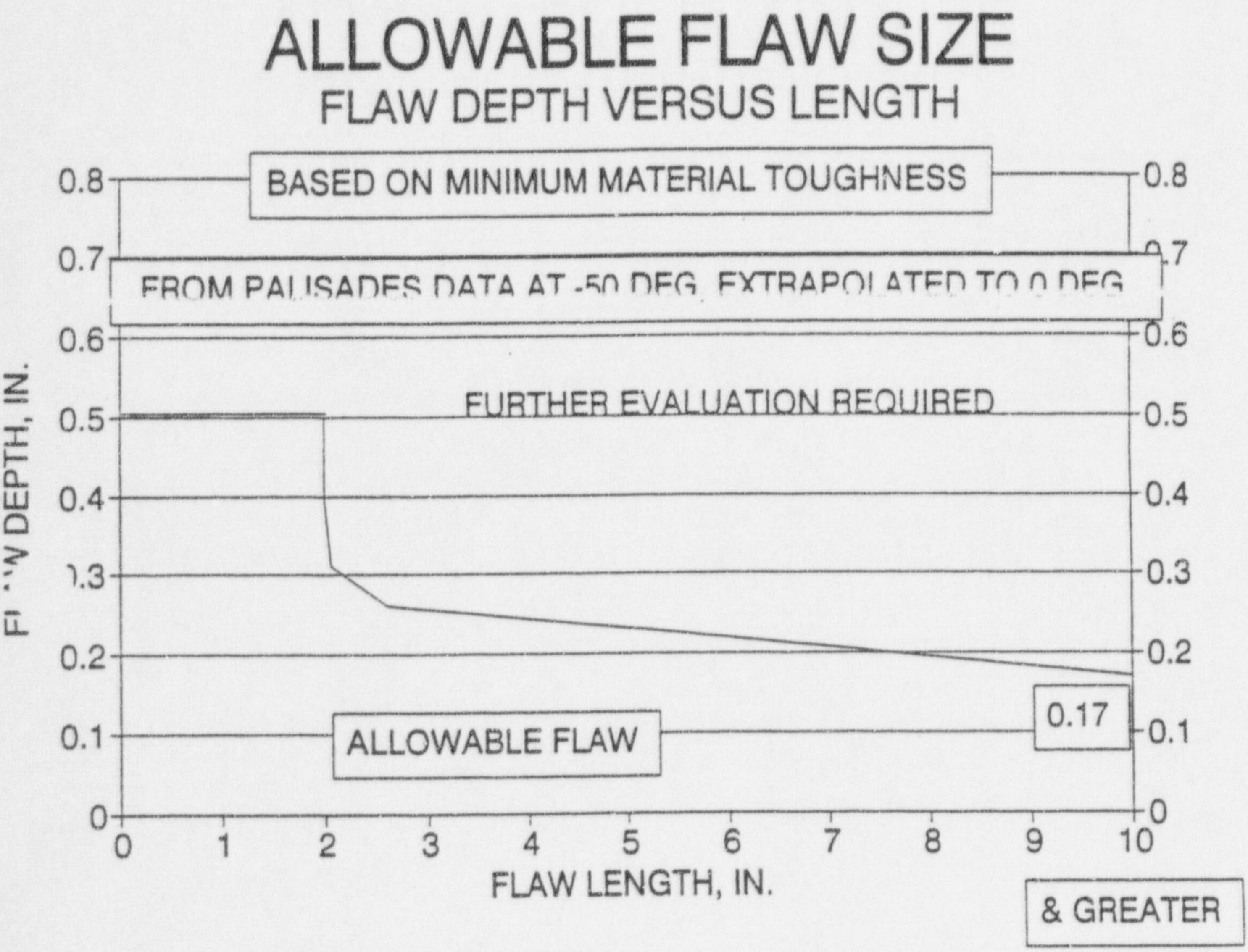

Figure 4b

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ALLOWABLE FLAW SIZE
FLAW DEPTH VERSUS LENGTH

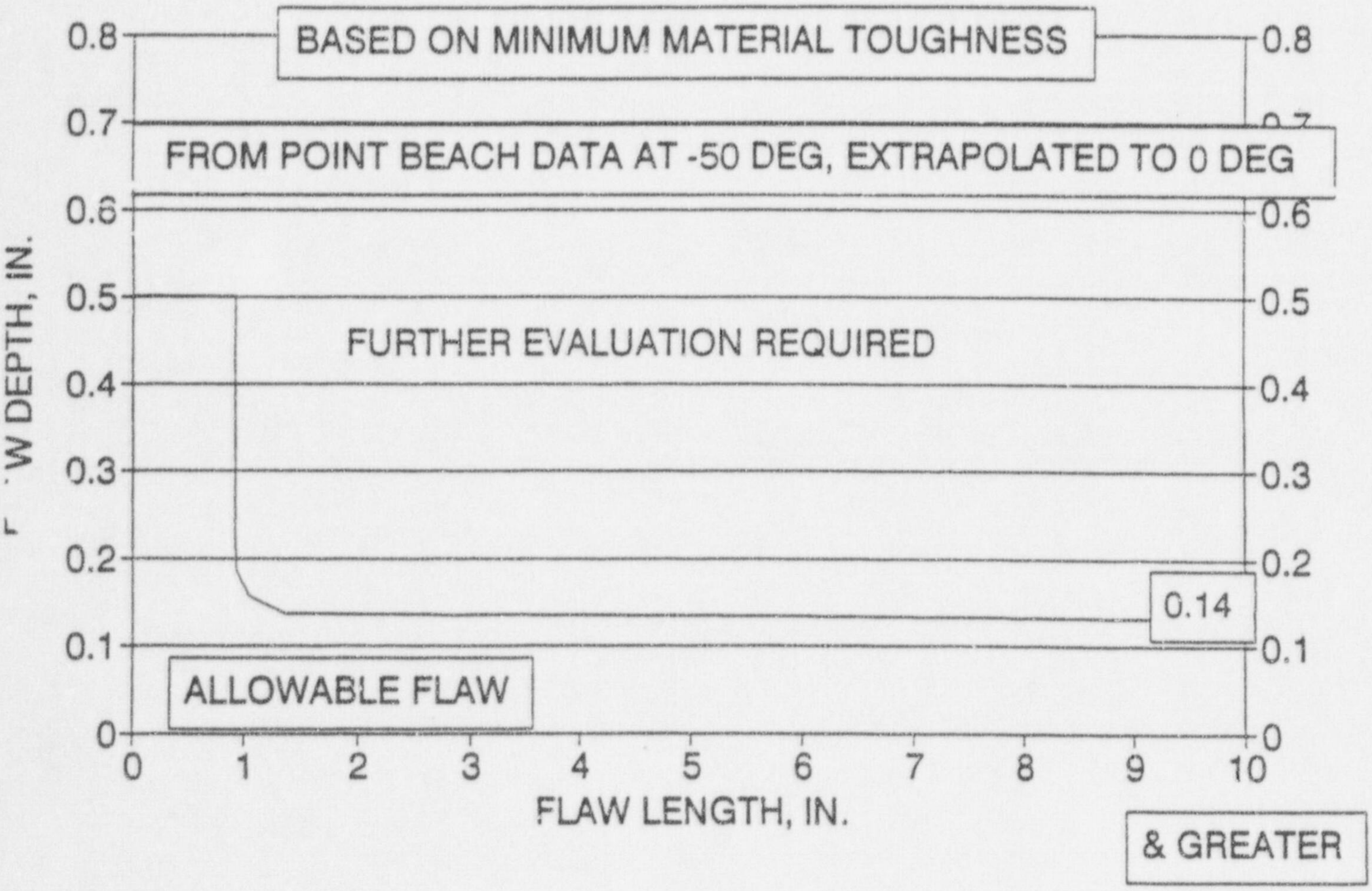

Figure 4c

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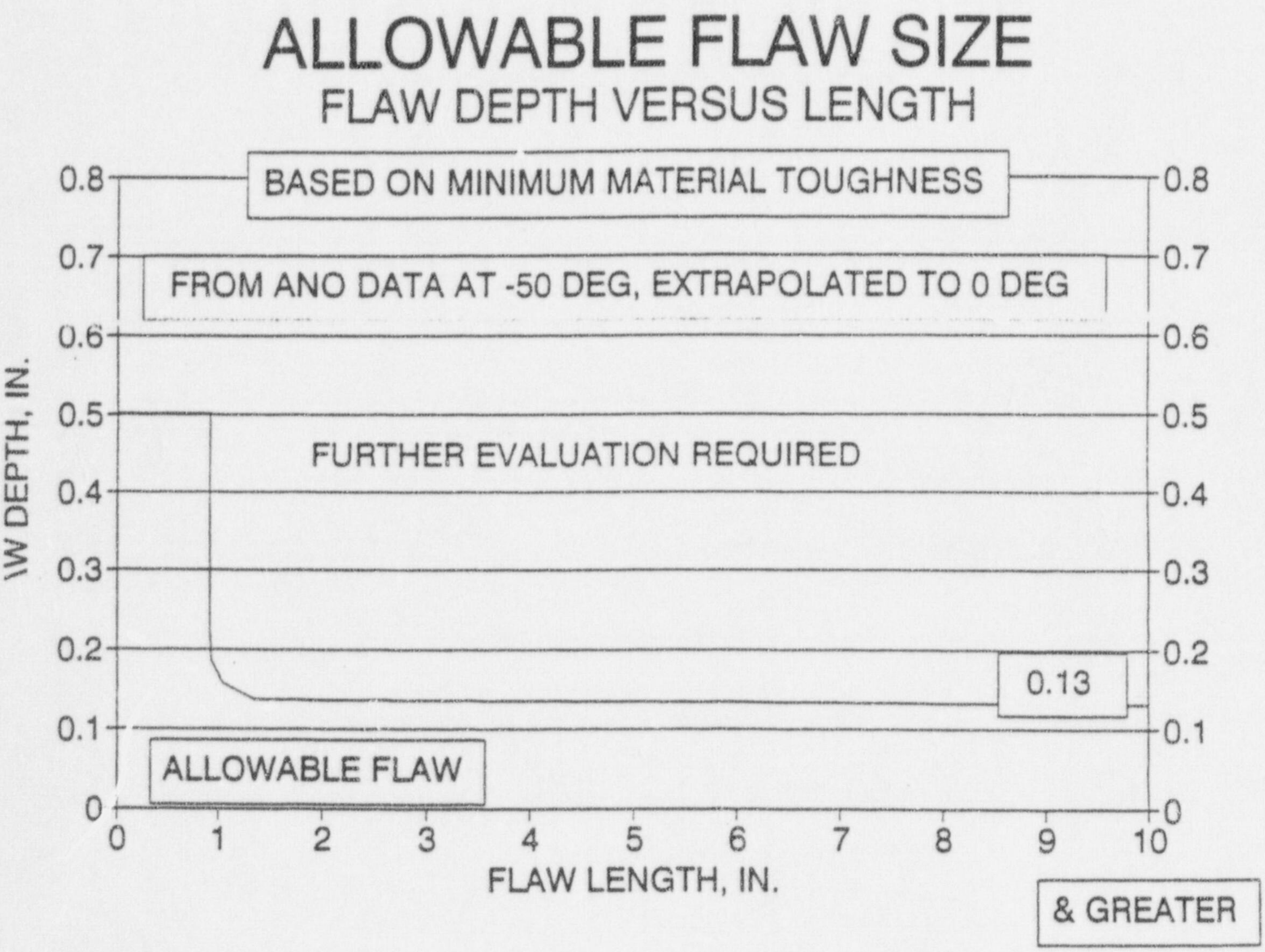

Figure 4d

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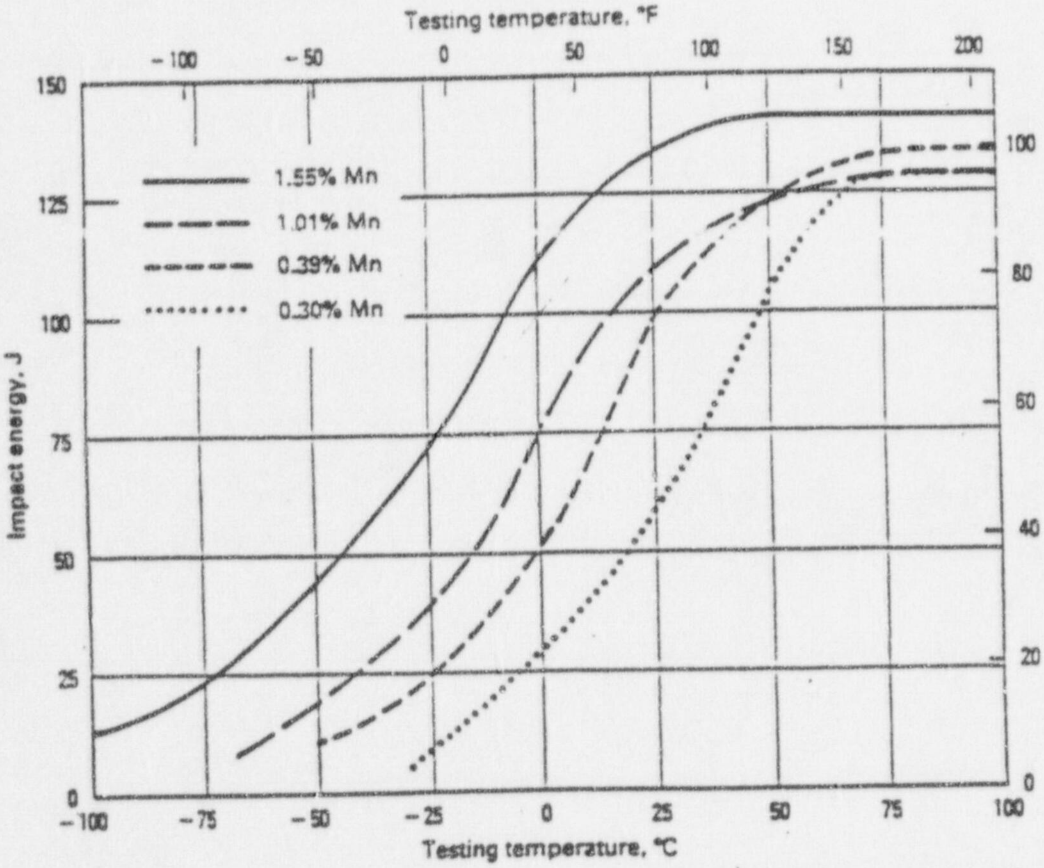

Fig. 11 Variation in Charpy V-notch impact energy with temperature for 0.30% C steels containing varying amounts of manganese. The specimens were austenitized at 900 °C (1650 °F) and cooled at approximately 14 °C/min (25 °F/min). The microstructures of these steels were pearlitic. Source: Ref 6

Figure 5

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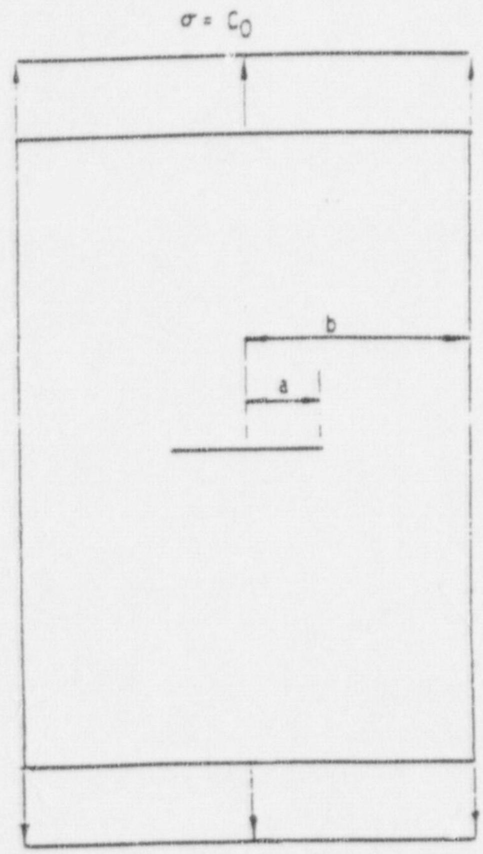

REQUIRED INPUTS:

b: plate width
a: crack depth ($a_{max} \leq 0.9b$)

Figure 3–22. LEFM Crack Model C, Page 2 – Center Crack Plate under Remote Tension Stress

Figure 6

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	Checker/Date	[illegible]			

APPENDIX A

pc-CRACK Output

tm
pc-CRACK for Windows
Version 3.0, Mar. 27, 1997

Structural Integrity Associates, Inc.
3315 Almaden Expressway, Suite 24
San Jose, CA 95118-1557
Voice: 408-978-8200
Fax: 408-978-8964
E-mail: info@structint.com

Linear Elastic Fracture Mechanics

Date: Thu Nov 20 10:56:27 1997
File: 55.LFM

Title: CPC-06Q: LIMITING ZERO DEGREE FLAWS

Load Cases:

Case: DROP2 --- Stress Distribution

Depth	Stress
0.0000	43.3000
0.3750	7.2000
0.7500	-28.9000

Case ID	Stress Coefficients C0	C1	C2	C3	Type
RESIDUAL	30	0	0	0	Coeff
MEMBRANE	7.2	0	0	0	Coeff
DROP2	43.3001	-96.2668	0	0	StressDist

Crack Model: Single Edge Cracked Plate

Crack Parameters:
Plate width: 0.7500
Max. crack size: 0.3750

Crack Size	--------------------Stress Intensity Factor-------------------- Case RESIDUAL	Case MEMBRANE	Case DROP2

0.0075	4.98488	1.19637	7.12042
0.0150	7.09853	1.70365	10.034
0.0225	8.75371	2.10089	12.2441
0.0300	10.177	2.44248	14.0849
0.0375	11.4554	2.74931	15.6861
0.0450	12.6334	3.03202	17.1144
0.0525	13.737	3.29688	18.4094
0.0600	14.7832	3.54796	19.5969
0.0675	15.7835	3.78805	20.695
0.0750	16.7465	4.01917	21.7166
0.0825	17.9075	4.29781	22.9894
0.0900	19.0627	4.57506	24.2291
0.0975	20.2147	4.85153	25.4397
0.1050	21.3655	5.12771	26.6243
0.1125	22.5167	5.404	27.7854
0.1200	23.6695	5.68069	28.9252
0.1275	24.8252	5.95805	30.0451
0.1350	25.9845	6.23629	31.1465
0.1425	27.1482	6.51557	32.2305
0.1500	28.3168	6.79604	33.298
0.1575	29.7019	7.12847	34.5864
0.1650	31.1029	7.46469	35.8642
0.1725	32.5197	7.80472	37.1309
0.1800	33.9523	8.14855	38.3864
0.1875	35.4007	8.49617	39.63
0.1950	36.8649	8.84758	40.8616
0.2025	38.3448	9.20276	42.0805
0.2100	39.8404	9.56169	43.2863
0.2175	41.3515	9.92437	44.4787
0.2250	42.8782	10.2908	45.6571
0.2325	44.8048	10.7532	47.2543
0.2400	46.7591	11.2222	48.8424
0.2475	48.7407	11.6978	50.4204
0.2550	50.7491	12.1798	51.9869
0.2625	52.784	12.6682	53.5409
0.2700	54.8452	13.1628	55.0813
0.2775	56.9322	13.6637	56.607
0.2850	59.0448	14.1708	58.117
0.2925	61.1827	14.6838	59.6102
0.3000	63.3455	15.2029	61.0856
0.3075	66.4177	15.9402	63.5413
0.3150	69.5356	16.6886	65.9877
0.3225	72.6988	17.4477	68.423
0.3300	75.9066	18.2176	70.8454
0.3375	79.1584	18.998	73.2532
0.3450	82.4536	19.7889	75.6445
0.3525	85.7917	20.59	78.0178
0.3600	89.1722	21.4013	80.3714
0.3675	92.5944	22.2227	82.7036
0.3750	96.0581	23.0539	85.0129

Material fracture toughness:

erial ID: A516_55

Depth	Klc
0.0000	55.4000
0.3750	55.4000
0.7500	55.4000

Load combination for critical crack size:

Load Case	Scale Factor
RESIDUAL	1.0000
DROP2	1.0000

Crack Size	Total K	Klc
0.0075	12.1053	55.4
0.015	17.1326	55.4
0.0225	20.9978	55.4
0.03	24.2618	55.4
0.0375	27.1415	55.4
0.045	29.7478	55.4
0.0525	32.1464	55.4
0.06	34.3801	55.4
0.0675	36.4785	55.4
0.075	38.4631	55.4
0.0825	40.897	55.4
0.09	43.2918	55.4
0.0975	45.6544	55.4
0.105	47.9897	55.4
0.1125	50.3021	55.4
0.12	52.5947	55.4
0.1275	54.8703	55.4
0.135	57.131	55.4
0.1425	59.3787	55.4
0.15	61.6148	55.4
0.1575	64.2884	55.4
0.165	66.9671	55.4
0.1725	69.6506	55.4
0.18	72.3386	55.4
0.1875	75.0308	55.4
0.195	77.7265	55.4
0.2025	80.4253	55.4
0.21	83.1267	55.4

0.2175	85.8302	55.4
0.225	88.5352	55.4
0.2325	92.0591	55.4
0.24	95.6015	55.4
0.2475	99.161	55.4
0.255	102.736	55.4
0.2625	106.325	55.4
0.27	109.926	55.4
0.2775	113.539	55.4
0.285	117.162	55.4
0.2925	120.793	55.4
0.3	124.431	55.4
0.3075	129.959	55.4
0.315	135.523	55.4
0.3225	141.122	55.4
0.33	146.752	55.4
0.3375	152.412	55.4
0.345	158.098	55.4
0.3525	163.81	55.4
0.36	169.544	55.4
0.3675	175.298	55.4
0.375	181.071	55.4

Critical crack size = 0.1292

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Linear Elastic Fracture Mechanics

Date: Thu Nov 20 10:58:23 1997
File: 60.LFM

Title: CPC-06Q: LIMITING ZERO DEGREE FLAWS

Load Cases:

Case: DROP2 --- Stress Distribution

Depth	Stress
0.0000	43.3000
0.3750	7.2000
0.7500	-28.9000

Stress Coefficients

..se ID	C0	C1	C2	C3	Type
RESIDUAL	30	0	0	0	Coeff
MEMBRANE	7.2	0	0	0	Coeff
DROP2	43.3001	-96.2668	0	0	StressDist

Crack Model: Single Edge Cracked Plate

Crack Parameters:
Plate width: 0.7500
Max. crack size: 0.3750

--------------------Stress Intensity Factor--------------------

Crack Size	Case RESIDUAL	Case MEMBRANE	Case DROP2

A6

0.0075	4.98488	1.19637	7.12042
0.0150	7.09853	1.70365	10.034
0.0225	8.75371	2.10089	12.2441
0.0300	10.177	2.44248	14.0849
0.0375	11.4554	2.74931	15.6861
0.0450	12.6334	3.03202	17.1144
0.0525	13.737	3.29688	18.4094
0.0600	14.7832	3.54796	19.5969
0.0675	15.7835	3.78805	20.695
0.0750	16.7465	4.01917	21.7166
0.0825	17.9075	4.29781	22.9894
0.0900	19.0627	4.57506	24.2291
0.0975	20.2147	4.85153	25.4397
0.1050	21.3655	5.12771	26.6243
0.1125	22.5167	5.404	27.7854
0.1200	23.6695	5.68069	28.9252
0.1275	24.8252	5.95805	30.0451
0.1350	25.9845	6.23629	31.1465
0.1425	27.1482	6.51557	32.2305
0.1500	[illegible]	[illegible]	[illegible]
0.1575	29.7019	7.12847	34.5864
0.1650	31.1029	7.46469	35.8642
0.1725	32.5197	7.80472	37.1309
0.1800	33.9523	8.14855	38.3864
0.1875	35.4007	8.49617	39.63
0.1950	36.8649	8.84758	40.8616
0.2025	38.3448	9.20276	42.0805
0.2100	39.8404	9.56169	43.2863
0.2175	41.3515	9.92437	44.4787
0.2250	42.8782	10.2908	45.6571
0.2325	44.8048	10.7532	47.2543
0.2400	46.7591	11.2222	48.8424
0.2475	48.7407	11.6978	50.4204
0.2550	50.7491	12.1798	51.9869
0.2625	52.784	12.6682	53.5409
0.2700	54.8452	13.1628	55.0813
0.2775	56.9322	13.6637	56.607
0.2850	59.0448	14.1708	58.117
0.2925	61.1827	14.6838	59.6102
0.3000	63.3455	15.2029	61.0856
0.3075	66.4177	15.9402	63.5413
0.3150	69.5356	16.6886	65.9877
0.3225	72.6988	17.4477	68.423
0.3300	75.9066	18.2176	70.8454
0.3375	79.1584	18.998	73.2532
0.3450	82.4536	19.7889	75.6445
0.3525	85.7917	20.59	78.0178
0.3600	89.1722	21.4013	80.3714
0.3675	92.5944	22.2227	82.7036
0.3750	96.0581	23.0539	85.0129

Material fracture toughness:

Material ID: A516_60

Depth	Klc
0.0000	60.0000
0.3750	60.0000
0.7500	60.0000

Load combination for critical crack size:

Load Case	Scale Factor
RESIDUAL	1.0000
DROP2	1.0000

Crack Size	Total K	Klc
0.0075	12.1053	60
0.015	17.1326	60
0.0225	20.9978	60
0.03	24.2618	60
0.0375	27.1415	60
0.045	29.7478	60
0.0525	32.1464	60
0.06	34.3801	60
0.0675	36.4785	60
0.075	38.4631	60
0.0825	40.897	60
0.09	43.2918	60
0.0975	45.6544	60
0.105	47.9897	60
0.1125	50.3021	60
0.12	52.5947	60
0.1275	54.8703	60
0.135	57.131	60
0.1425	59.3787	60
0.15	61.6148	60
0.1575	64.2884	60
0.165	66.9671	60
0.1725	69.6506	60
0.18	72.3386	60
0.1875	75.0308	60
0.195	77.7265	60
0.2025	80.4253	60
0.21	83.1267	60

0.2175	85.8302	60
0.225	88.5352	60
0.2325	92.0591	60
0.24	95.6015	60
0.2475	99.161	60
0.255	102.736	60
0.2625	106.325	60
0.27	109.926	60
0.2775	113.539	60
0.285	117.162	60
0.2925	120.793	60
0.3	124.431	60
0.3075	129.959	60
0.315	135.523	60
0.3225	141.122	60
0.33	146.752	60
0.3375	152.412	60
0.345	158.098	60
0.3525	163.81	60
0.36	169.544	60
0.3675	175.298	60
0.375	181.071	60

Critical crack size = 0.1446

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Linear Elastic Fracture Mechanics

Date: Thu Nov 20 10:59:25 1997
File: 70.LFM

Title: CPC-06Q: LIMITING ZERO DEGREE FLAWS

Load Cases:

Case: DROP2 --- Stress Distribution

Depth	Stress
0.0000	43.3000
0.3750	7.2000
0.7500	-28.9000

Stress Coefficients

Case ID	C0	C1	C2	C3	Type
RESIDUAL	30	0	0	0	Coeff
MEMBRANE	7.2	0	0	0	Coeff
DROP2	43.3001	-96.2668	0	0	StressDist

Crack Model: Single Edge Cracked Plate

Crack Parameters:
Plate width: 0.7500
Max. crack size: 0.3750

--------------------Stress Intensity Factor--------------------

Crack Size	Case RESIDUAL	Case MEMBRANE	Case DROP2

Ala

0.0075	4.98488	1.19637	7.12042
0.0150	7.09853	1.70365	10.034
0.0225	8.75371	2.10089	12.2441
0.0300	10.177	2.44248	14.0849
0.0375	11.4554	2.74931	15.6861
0.0450	12.6334	3.03202	17.1144
0.0525	13.737	3.29688	18.4094
0.0600	14.7832	3.54796	19.5969
0.0675	15.7835	3.78805	20.695
0.0750	16.7465	4.01917	21.7166
0.0825	17.9075	4.29781	22.9894
0.0900	19.0627	4.57506	24.2291
0.0975	20.2147	4.85153	25.4397
0.1050	21.3655	5.12771	26.6243
0.1125	22.5167	5.404	27.7854
0.1200	23.6695	5.68069	28.9252
0.1275	24.8252	5.95805	30.0451
0.1350	25.9845	6.23629	31.1465
0.1425	27.1482	6.51557	32.2305
0.1500	28.3168	6.79604	33.298
0.1575	29.7019	7.12847	34.5864
0.1650	31.1029	7.46469	35.8642
0.1725	32.5197	7.80472	37.1309
0.1800	33.9523	8.14855	38.3864
0.1875	35.4007	8.49617	39.63
0.1950	36.8649	8.84758	40.8616
0.2025	38.3448	9.20276	42.0805
0.2100	39.8404	9.56169	43.2863
0.2175	41.3515	9.92437	44.4787
0.2250	42.8782	10.2908	45.6571
0.2325	44.8048	10.7532	47.2543
0.2400	46.7591	11.2222	48.8424
0.2475	48.7407	11.6978	50.4204
0.2550	50.7491	12.1798	51.9869
0.2625	52.784	12.6682	53.5409
0.2700	54.8452	13.1628	55.0813
0.2775	56.9322	13.6637	56.607
0.2850	59.0448	14.1708	58.117
0.2925	61.1827	14.6838	59.6102
0.3000	63.3455	15.2029	61.0856
0.3075	66.4177	15.9402	63.5413
0.3150	69.5356	16.6886	65.9877
0.3225	72.6988	17.4477	68.423
0.3300	75.9066	18.2176	70.8454
0.3375	79.1584	18.998	73.2532
0.3450	82.4536	19.7889	75.6445
0.3525	85.7917	20.59	78.0178
0.3600	89.1722	21.4013	80.3714
0.3675	92.5944	22.2227	82.7036
0.3750	96.0581	23.0539	85.0129

Material fracture toughness:

Material ID: A516_70

Depth	K1c
0.0000	70.0000
0.3750	70.0000
0.7500	70.0000

Load combination for critical crack size:

Load Case	Scale Factor
RESIDUAL	1.0000
DROP2	1.0000

Crack Size	Total K	K1c
0.0075	12.1053	70
0.015	17.1326	70
0.0225	20.9978	70
0.03	24.2618	70
0.0375	27.1415	70
0.045	29.7478	70
0.0525	32.1464	70
0.06	34.3801	70
0.0675	36.4785	70
0.075	38.4631	70
0.0825	40.897	70
0.09	43.2918	70
0.0975	45.6544	70
0.105	47.9897	70
0.1125	50.3021	70
0.12	52.5947	70
0.1275	54.8703	70
0.135	57.131	70
0.1425	59.3787	70
0.15	61.6148	70
0.1575	64.2884	70
0.165	66.9671	70
0.1725	69.6506	70
0.18	72.3386	70
0.1875	75.0308	70
0.195	77.7265	70
0.2025	80.4253	70
0.21	83.1267	70

0.174	62.585	90
0.18	64.3934	90
0.186	66.2586	90
0.192	68.1871	90
0.198	70.186	90
0.204	72.2631	90
0.21	74.4272	90
0.216	76.6879	90
0.222	79.056	90
0.228	81.5437	90
0.234	84.1649	90
0.24	86.9355	90
0.246	89.8738	90
0.252	93.0009	90
0.258	96.3416	90
0.264	99.9252	90
0.27	103.787	90
0.276	107.968	90
0.282	112.519	90
0.288	117.504	90
0.294	123.001	90
0.3	129.109	90

Critical crack size = 0.2463

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Linear Elastic Fracture Mechanics

Date: Mon Nov 24 12:18:54 1997
File: CCP100.LFM

Title: CPC-06Q: SUBSURFACE DEFECT, KID=100

Load Cases:

Case: DROP2 --- Stress Distribution

Depth	Stress
0.0000	43.3000
0.3750	7.2000
0.7500	-28.9000

	Stress Coefficients				
Case ID	C0	C1	C2	C3	Type
RESIDUAL	30	0	0	0	Coeff
MEMBRANE	7.2	0	0	0	Coeff
DROP2	43.3001	-96.2668	0	0	StressDist

Crack Model: Center Cracked Plate Under Remote Tension Stress

Crack Parameters:
Plate Half Width: 0.3750
Crack depth: 0.3000

	--------------------Stress Intensity Factor--------------------		
Crack Size	Case RESIDUAL	Case MEMBRANE	Case DROP2

A42

0.0060	4.11943	0.988664	5.94572
0.0120	5.82841	1.39882	8.41235
0.0180	7.14374	1.7145	10.3108
0.0240	8.25766	1.98184	11.9186
0.0300	9.24501	2.2188	13.3437
0.0360	10.1444	2.43466	14.6418
0.0420	10.9791	2.63498	15.8465
0.0480	11.7643	2.82342	16.9798
0.0540	12.5107	3.00257	18.0572
0.0600	13.2264	3.17434	19.0902
0.0660	13.9176	3.34021	20.0877
0.0720	14.589	3.50137	21.0569
0.0780	15.2449	3.65878	22.0035
0.0840	15.8886	3.81326	22.9326
0.0900	16.523	3.96552	23.8482
0.0960	17.1508	4.11618	24.7543
0.1020	17.7742	4.2658	25.6541
0.1080	18.3954	4.41489	26.5507
0.1140	19.0164	4.56392	27.447
0.1200	19.639	4.71336	28.3457
0.1260	20.2651	4.86363	29.2494
0.1320	20.8965	5.01516	30.1607
0.1380	21.5349	5.16837	31.0821
0.1440	22.182	5.32369	32.0161
0.1500	22.8398	5.48154	32.9655
0.1560	23.5099	5.64238	33.9327
0.1620	24.1944	5.80665	34.9206
0.1680	24.8952	5.97486	35.9322
0.1740	25.6146	6.1475	36.9705
0.1800	26.3547	6.32513	38.0387
0.1860	27.1181	6.50834	39.1405
0.1920	27.9074	6.69777	40.2797
0.1980	28.7255	6.89411	41.4605
0.2040	29.5756	7.09814	42.6875
0.2100	30.4613	7.31071	43.9659
0.2160	31.3866	7.53277	45.3013
0.2220	32.3558	7.76538	46.7002
0.2280	33.3739	8.00974	48.1698
0.2340	34.4467	8.26722	49.7182
0.2400	35.5807	8.53936	51.3549
0.2460	36.7832	8.82798	53.0906
0.2520	38.0631	9.13514	54.9378
0.2580	39.4304	9.46328	56.9112
0.2640	40.897	9.81529	59.0282
0.2700	42.4774	10.1946	61.3092
0.2760	44.1886	10.6053	63.7789
0.2820	46.0514	11.0523	66.4677
0.2880	48.0916	11.542	69.4124
0.2940	50.3414	12.0819	72.6595
0.3000	52.8414	12.6819	76.2679

Material fracture toughness:

Material ID: a516-100

Depth	K1c
0.0000	100.0000
0.3750	100.0000
0.7500	100.0000

Load combination for critical crack size:

Load Case	Scale Factor
RESIDUAL	1.0000
DROP2	1.0000

Crack Size	Total K	K1c
0.006	10.0652	100
0.012	14.2408	100
0.018	17.4545	100
0.024	20.1762	100
0.03	22.5887	100
0.036	24.7863	100
0.042	26.8256	100
0.048	28.7441	100
0.054	30.5679	100
0.06	32.3166	100
0.066	34.0053	100
0.072	35.6459	100
0.078	37.2484	100
0.084	38.8211	100
0.09	40.3712	100
0.096	41.905	100
0.102	43.4283	100
0.108	44.9461	100
0.114	46.4633	100
0.12	47.9847	100
0.126	49.5145	100
0.132	51.0572	100
0.138	52.617	100
0.144	54.1982	100
0.15	55.8052	100
0.156	57.4426	100
0.162	59.115	100
0.168	60.8274	100

0.174	62.585	100
0.18	64.3934	100
0.186	66.2586	100
0.192	68.1871	100
0.198	70.186	100
0.204	72.2631	100
0.21	74.4272	100
0.216	76.6879	100
0.222	79.056	100
0.228	81.5437	100
0.234	84.1649	100
0.24	86.9355	100
0.246	89.8738	100
0.252	93.0009	100
0.258	96.3416	100
0.264	99.9252	100
0.27	103.787	100
0.276	107.968	100
0.282	112.519	100
0.288	117.504	100
0.294	123.001	100
0.3	129.109	100

Critical crack size = 0.2641

APPENDIX B

Design Input from Consumers Energy

Consumers Energy

A CMS Energy Company

Palisades Nuclear Plant
27780 Blue Star Memorial Highway
Covert, MI 49043

November 12, 1997

Mr. Hal Gustin
Structural Integrity Associates, Inc.
3315 Almaden Expressway, Suite 24
San Jose, CA 95118-1557

SUBJECT: Flaw Analysis Inputs

Dear Hal:

This letter transmits design inputs for use in the flaw analysis being provided under purchase order C0025456. The specific design inputs shown below are enclosed.

- Safety Analysis Report for the Ventilated Storage System, PSN-91-001, Rev 0, dated October 1991, Table 11.2-1, Summary of Stresses(ksi) in the MSB Resulting from the Hypothetical Horizontal Drop. The limiting event for the structural lid weld is the horizontal drop accident, which is considered to be an emergency/faulted event.
- Safety Analysis Report for the Ventilated Storage System, PSN-91-001, Rev 0, dated October 1991, Table 3.4-5, MSB Maximum Stress Evaluation.
- Certificate of Compliance (C of C) for Dry Spent Fuel Storage Casks (No. 1007), effective May 7, 1993, Section 1.2.13, Minimum Temperature for Moving the MSB.
- Certificate of Compliance (C of C) for Dry Spent Fuel Storage Casks (No. 1007), effective May 7, 1993, Section 1.2.14, Minimum Temperature for Lifting the MTC.

Certified Material Test Reports (Lot No. 32039 and 38380) for the weld material used on the structural lid welds in MSB's 1-13 are enclosed. The CMTR (Lot No. 51122) for the weld material to be used on future structural lid welds is also enclosed. The cask structural lid welds will remain in the as welded condition following welding.

Please give me a call if you have any questions.

Sincerely,

E A Zernick

Emil A. Zernick
Engineering Lead -Dry Fuel Storage

B2

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TABLE 3.4-5

MSB MAXIMUM STRESS EVALUATION

Component	Stresses	CALCULATED VALUE, KSI*					
		DEAD WEIGHT	PRESSURE	THERMAL	HANDLING	TOTAL	ASME LIMIT
MSB Shell	P_m	0.1	0.1	N/A	0.9	1.1	20.5
	$P_L + P_b$	0.1	1.2	N/A	2.4	3.7	30.7
	$P + Q$	0.1	1.2	1.0	2.4	4.7	61.5
Bottom Plate	P_m	0.02	0.06	N/A	1.0	1.1	20.5
	$P_L + P_b$	0.02	1.7	N/A	1.5	3.2	30.7
	$P + Q$	0.02	1.7	19.4	1.5	22.6	61.5
Top Lid	P_m	0.0	0.0	N/A	0.1	0.1	20.5
	$P_L + P_b$	0.0	0.4	N/A	0.2	0.6	30.7
	$P + Q$	0.0	0.4	0.2	0.2	0.8	61.5
Bottom-to-Shell Junction	P_m	0.1	0.2	N/A	0.9	1.2	20.5
	$P_L + P_b$	0.1	1.7	N/A	1.5	3.3	30.7
	$P + Q$	0.1	1.7	1.5	1.5	4.8	61.5
Top-to-shell Junction	P_m	0.0	0.06	N/A	0.2	0.3	15.4
	$P_L + P_b$	0.0	0.4	N/A	0.2	0.6	23.1
	$P + Q$	0.0	0.4	0.4	0.2	1.0	46.1
Sleeve Assembly	P_m	0.05	N/A	N/A	1.8	1.9	20.5
	$P_L + P_b$	0.05	N/A	N/A	2.1	2.2	30.7
	$P + Q$	0.05	N/A	52.0	2.1	54.2	61.5
Shield Lid-to-Shell Weld	P_m	0.3	0.2	N/A	0.3	0.8	15.4
	$P_L + P_b$	0.3	0.8	N/A	0.4	1.5	23.1
	$P + Q$	0.3	0.8	1.3	0.4	2.8	46.1
Shield Lid Support Ring Weld	P_m	0.4	N/A	N/A	0.3	0.7	15.4
	$P_L + P_b$	0.4	N/A	N/A	0.3	0.7	23.1
	$P + Q$	0.4	N/A	0.0	0.3	0.7	46.1

* Values shown are maximums irrespective of location

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TABLE 11.2-1

SUMMARY OF STRESSES (ksi) IN THE MSB RESULTING FROM THE HYPOTHETICAL HORIZONTAL DROP

Component		Drop	Dead Wt.*	Thermal	Pressure	Total	ASME Allowable
Bottom Plate	P_m	29.4	N/A	N/A	0.06	29.5	49.0
	$P_L + P_b$	44.6			1.7	46.3	73.5
Shell	P_m	25.9	N/A	N/A	0.1	26.0	49.0
	$P_L + P_b$	71.8			1.2	73.0	73.5
Structural Lid	P_m	2.6	N/A	N/A	0.0	2.6	49.0
	$P_L + P_b$	42.9			0.4	43.3	73.5
Shield Lid	P_m	2.4	N/A	N/A	0.0	2.4	49.0
	$P_L + P_b$	20.6			0.0	20.6	73.5
Bottom Weld	P_m	25.9	N/A	N/A	0.2	26.1	49.0
	$P_L + P_b$	44.6			1.7	46.3	73.5
Top Weld	P_m	7.1	N/A	N/A	0.06	7.2	36.8
	$P_L + P_b$	42.9			0.4	43.3	55.1
Shield Lid Weld	P_m	9.1	N/A	N/A	0.2	9.3	36.8
	$P_L + P_b$	20.6	N/A	N/A	0.8	21.4	55.1

- Dead weight is included in the drop load.

1.2.13 Minimum Temperature for Moving the MSB

Limit/Specification:

Movement of the MSB inside the VCC will only be allowed at ambient temperatures of 0^0 F or above.

Objective: To avoid the potential for brittle failure.

Action: Confirm that the ambient temperature is above 0^0 F immediately before moving the MSB, while inside the VCC.

Surveillance: The ambient temperatures shall be measured before movement of the MSB.

Basis: Each MSB shell material will have shown, during fabrication, by Charpy test (per ASTM A370) that it has 15 ft-lb of absorbed energy at -50^0 F; and, therefore, movement of the MSB at temperatures above 0^0 F will avoid the potential for brittle fracture. Calculations show that the MSB shell minimum temperature will be substantially above the ambient temperature (e.g., 20 ^{0}F for 25-year-old fuel). However, for conservatism and simplicity, it is recommended that the ambient be selected as the minimum MSB movement temperature. It is highly unlikely that any MSB movement activity would take place at temperatures below zero. Nevertheless, if movement at a temperature below that specified is necessary, calculations (similar to those presented in Chapter 4 of the SAR) may be used to estimate the minimum MSB shell temperature for any particular ambient condition.

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1.2.14 Minimum Temperature for Lifting the MTC

Limit/Specification:

The MTC shall be allowed to be used to move the MSB if the ambient temperature is 40^0 F or above.

Objective: To avoid the potential for brittle failure.

Action: Confirm that the ambient temperature is above 40^0 F before moving the MSB inside the MTC.

Surveillance: The MTC ambient temperature shall be determined before movement of the MSB in the MTC.

Basis: The MTC material will have shown, during fabrication, that it has 15 ft-lb of absorbed energy at 0^0 F. Having Charpy test results, at 0^0 F, which show ductility (or other appropriate test to show that the Nil Ductility Temperature is lower than 0^0 F), will avoid the potential for brittle failure when the cask is moved at 40^0 F or higher. The MTC shell will have a temperature higher than ambient due to the heat source from the irradiated fuel. However, for conservatism and simplicity, it is recommended that the ambient temperature be used as the minimum shell temperature. If movement at lower temperatures is ever required, additional specific analysis or other actions that meet the approval of the NRC must be provided.

Bt

THIS DATA COVERS [illegible] PO# G0032319; WELDSTAR NUCLEAR SHIPPING TICKET N911411

ALLOY RODS CORPORATION

CERTIFICATE OF ANALYSIS

P.O. BOX 517/1500 KAREN LANE
HANOVER, PA 17331
(717) 637-8911

CERTIFIED MATERIALS TEST REPORT

WELDSTAR COMPANY
1750 MITCHELL ROAD
AURORA, IL 60504

Customer Order No.: 2244A-A
Order No.: 144017-1

This Material Conforms to Specification:
ASME SFA 5.20 SEC II PART C & ASME SEC III SUBSEC NB FOR CLASS 1 MATERIAL 1989 ED., 1990 ADD. ASME SFA 5.01, CLASS T2, SCH. K, 10 CFR PART 21 APPLIES

Trade Name or Trademark: Dual Shield II 70
Diameter Size: .045" x 25# Spool
Type: E71T-1
Weight: 7,200 lbs.
Test No.: 2-19406-00
Lot Number: 32039
X-Rays Satisfactory
Type Steel A-285

Carbon:	.06
Manganese:	1.24
Chromium:	.04
Nickel:	.01
Silicon:	.47
Columbium:	
Tantalum:	
Molybdenum:	.01
Tungsten:	
Copper:	.02
Titanium:	
Phosphorus:	.009
Sulphur:	.013
Vanadium:	.02
Cobalt:	

Full Split Triple Quad. Volts Amps

Test Results:	As Welded	Stress Relieved 8 Hrs. @ 1150°F
Yield	80,400	72,900
Tensile	88,400	84,400
Elongation (2") %	28.0	28.0
Red. of Area	70.7	69.5
Charpy V-Notch Impacts Tested @ 0°F		
Ft. Lbs.	90-92-91	79-72-76
Lat. Exp.	69-71-78	66-[illegible]
% Shear	40-30-40	30-30-30
Charpy V-Notch Impacts Tested @ -20°F		
Ft. Lbs.	81-82-74	54-50-51
Lat. Exp.	66-62-56	46-44-43
% Shear	40-30-30	30-20-30
Charpy V-Notch Impacts Tested @ -50°F		
Ft. Lbs.	53-59-56	33-50-36
Lat. Exp.	46-47-46	30-42-31
% Shear	20-20-20	20-30-20

Preheat: 70°F
Interpass: 300°F

Shielding Gas: 75% AR/25% CO2

Cool Rate: 100°F max/hr. above 600°F

Tensile Specimen .505"
Impact Specimen .394" x .394"

Fillets: OK Vertical-Up/Overhead

This material is certified to be free of any mercury contamination.

WELDSTAR COMPANY QUALITY SYSTEM CERT. (MATERIALS) EXPIRATION DATE [illegible]

Certs Reviewed by [illegible] 6/03/92

Location & Orientation of Charpy V-Notch/Tensile Specimens is [illegible] ASME NB-2322 and/or AWS/SFA specifications as applicable.

Quality Systems Certificate No. QSC-221
Expiration Date: September [illegible] 1993

The undersigned certifies that the contents of this report are accurate and that all operations performed by the undersigned or sub-contractors are in compliance with requirements of the material specification and ASME Boiler and Pressure Vessel Code, Section III, Division I, Subsection NCA-3800.

State of Pennsylvania
ss:
County of York

Subscribed and sworn to before me this 12th day of June 1992.

ALLOY RODS CORPORATION

SEAL Linda C. Myers
Notary Public

BY: [signature]
D. A. Smith, Supervisor, Q.A. Services

NOTARIAL SEAL
LINDA C. MYERS, Notary Public
Penn Township, York County
My Commission Expires April 13, 1996

[illegible] (GO 09204), [illegible] SHIPPING TICKET [illegible]

THE ESAB GROUP

CERTIFICATE OF ANALYSIS

CERTIFIED MATERIALS TEST REPORT

[illegible] COMPANY
[illegible] MITCHELL ROAD
AURORA [illegible] 60501

Customer Order No.: 907122
Order No.: [illegible]

This Material Conforms to Specification:
ASME SFA 5.20 [illegible] PART [illegible] ASME SEC
[illegible] SUBSEC [illegible] CLASS [illegible] MATERIAL [illegible] 1992
[illegible] 1992 ADD. [illegible] LOT CLASS
[illegible] SCHED [illegible] PART [illegible] APP [illegible]

Trade Name or Trademark	Alloy Rods Dual Shield [illegible] 70T [illegible]		
Diameter Size	.045 x 25 Spool	Type	E71T- [illegible]
Weight	[illegible] 000 lbs.	Test No.	[illegible] 2961-00
Lot Number	38380	X-Ray	Satisfactory

Type Steel A-285

Carbon	.06							
Manganese	1.30	Full	Split	Triple	Quad	Volts	Amps	
Chromium	.03							
Nickel	.01	[illegible]	[illegible]	[illegible]	[illegible]	28	260	DC
Silicon	.3 [illegible]							
Columbium								
Tantalum								
Molybdenum	.01							
Tungsten								
Copper	.0 [illegible]							
Titanium								
Phosphorus	.016							
Sulphur	.012							
Vanadium	.01							
Cobalt								
Coo. [illegible]	[illegible]							
max/ [illegible]	[illegible]							
[illegible]	[illegible]							
[illegible]	[illegible]							
[illegible]								

Test Results	As Welded	Stress Relieved
		[illegible] Hrs. @ [illegible] 50
Yield	[illegible] ,000	68,700
Tensile	8 [illegible] ,700	80,500
Elongation (2")	2 [illegible]	29 [illegible]
Red. of Area	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
Charpy [illegible] Impacts Tested @ [illegible] 50 [illegible]		
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]

[illegible]

[illegible] Specimen [illegible]
[illegible] Specimen [illegible]

[illegible] free of any mercury contamination.

Quality System Certificate No. [illegible]
Expiration Date September [illegible]

WELDSTAR COMPANY
QUALITY SYSTEM CERTIFICATE
MATERIALS [illegible]
EXPIRATION DATE JAN [illegible]

[illegible]

The undersigned certifies that the contents of this report are accurate and that all operations performed by the undersigned or [illegible] subcontractors are in compliance with the requirements of the [illegible] specification [illegible]

[illegible]

[illegible]

[illegible] Linda [illegible] (signature)

By [illegible] (signature)

[illegible]

The Esab Group, Inc.
1500 Karen Lane
P.O. Box [illegible]
Hanover, PA [illegible]
[illegible] 637-[illegible]
FAX [illegible] 800 [illegible]

NOTARIAL SEAL
LINDA [illegible] MYERS, Notary Public
Penn Township, York County
My Commission Expires April 13, 1996

OLD VALUES...NEW IDEAS

WELDSTAR®

1936 60 Years 1996

P.O. BOX 1150 • AURORA, IL 60507-1150 • PHONE (630) 859-3100

CERTIFICATE OF COMPLIANCE

ISSUED: August 22, 1997

CUSTOMER: Consumers Energy

CUSTOMER PO#: G0238240

SHIP TICKET #: N917296

DESCRIPTION: 495 lbs. spooled wire (33# spools) ESAB
.045" [illegible]
Lot #51122

The attached CMTR(s), one copy per item, covers the material shipped against the above referenced purchase order number.

The above material will meet code requirements of ASME Section II, Part C and Section III 1986 Edition through 1988 Addenda, NB2400 for Class 1 material, with special impact properties of 15 ft/lbs minimum absorbed energy at -50° F, and the requirements of ASME Boiler and Pressure Vessel Code current edition and addenda for Section II, C, SFA 5.20, and is in compliance with the above referenced purchase order number. We certify that the material shipped has been handled in compliance with our identification and verification program.

All vendors on Weldstar's approved vendors list have been audited by Weldstar.

Weldstar's Quality Assurance Program Revision K, dated November 12, 1996 meets the requirements of ASME Section III, NCA-3800, 1995 Edition.

The provisions of NRC 10CFR Part 21 apply to this order.

Asst. QUALITY ASSURANCE MANAGER

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THE ESAB GROUP

CERTIFICATE OF ANALYSIS

CERTIFIED MATERIALS TEST REPORT

WELDSTAR COMPANY
1750 MITCHELL ROAD
AURORA, IL 60504

Customer Order No.: 901556
Order No.: 68953/RMA 3798

This Material Conforms to Specification:
ASME SFA 5.20 SEC II PART C AND ASME SEC III, SUBSEC NB FOR CLASS 1 MATERIAL 1995 ED., 1995 ADD., ASME SFA 5.01, CLASS T3, SCHEDULE K, 10 CFR PART 21 APPLIES

Trade Name or Trademark: Dual Shield II 70T12
Diameter Size: .045" x 33# Spool
Weight: 4,752 lbs.
Lot Number: 51122

Type: E71T-1 / 71T-12MJ / 71T-12MJH8
Test No.: 2-27679-00
Shielding Gas: 75% AR / 25% CO_2
X-Rays Satisfactory
Type Steel A-285

Carbon:	.07
Manganese:	1.30
Chromium:	.02
Nickel:	<.01
Silicon:	.39
Columbium+:	
Tantalum:	
Molybdenum:	.01
Tungsten:	
Copper:	<.01
Titanium:	
Phosphorus:	.013
Sulphur:	.007
Vanadium:	.01
Cobalt:	

Full	Split	Triple	Quad	Volts	Amps
--	*	--	--	27	250 DC+

Test Results:	As Welded	Stress Relieved 8 Hrs. @ 1150°F.
Yield	81,000	73,500
Tensile	88,000	85,500
Elongation (2"), %	28.0	27.0
Red. of Area	72.4	73.4

Charpy V-Notch Impacts Tested @ 0°F.

	As Welded	Stress Relieved
Ft. Lbs.	109-117-120	90-84-92
Lat. Exp.	83-76-80	71-61-67
% Shear	70-70-70	60-70-70

Charpy V-Notch Impacts Tested @ -20°F.

	As Welded	Stress Relieved
Ft Lbs.	112-96-107	41-73-50
Lat. Exp.	83-69-70	33-57-39
% Shear	70-70-70	30-40-30

Charpy V-Notch Impacts Tested @ -40°F.

Ft. Lbs.	99-78-109-102-102
Lat. Exp.	69-56-78-74-70
% Shear	70-70-70-50-50

Cool Rate: 100°F. max/hr. above 600°F.
Preheat: 65°F.
Interpass: 325°F.

Fillets: OK Vertical-Up/ Overhead

Tensile Specimen .505"
Impact Specimen .394" x .394"

Quality Systems Program Issue No. 5, Rev. 4, dated 07/10/96.

Location & Orientation of Charpy-V-Notch/Tensile Specimens is I/A/W ASME NX-2323 and/or AWS/SFA specifications as applicable.

This material is certified to be free of any mercury contamination.

Quality Systems Certificate No. QSC-221
Expiration Date: September 8, 1999.

State of Pennsylvania)
) SS:
County of York)

Subscribed and sworn to before me this 22nd day of August, 1997.

SEAL: Linda C. Myers
Notary Public

The undersigned certifies that the contents of this report are accurate and that all operations performed by the undersigned or sub-contractors are in compliance with requirements of the material specification and ASME Boiler and Pressure Vessel Code, Section III, Division I, Subsection NCA-3800.

By: D. A. Smith
D. A. Smith, Supervisor, Q. A. Services

B10

NOTARIAL SEAL
LINDA C. MYERS, Notary Public
Penn Township, York County
My Commission Expires April 13, 2000

The Esab Group, Inc.
1500 KAREN LANE
P.O. BOX 517
HANOVER, PA 17331-1058
(717) 637-8911
FAX 800-444-8911

EST NO.: 2-27679-00
age 2

harpy V-Notch Impacts Tested @ -50°F. (As-Welded)

t. Lbs.	77-84-85
at. Exp.	59-66-66
Shear	50-60-70

GLYCERINE METHOD
HYDROGEN ANALYSIS

1. 3.1 ML/100 G OF WELD METAL

2. 3.1

3. 2.2

4. 3.1

2.9 AVERAGE

ARC VOLTAGE 26

AMPERES 230 DC+

B11

0.2175	85.8302	70
0.225	88.5352	70
0.2325	92.0591	70
0.24	95.6015	70
0.2475	99.161	70
0.255	102.736	70
0.2625	106.325	70
0.27	109.926	70
0.2775	113.539	70
0.285	117.162	70
0.2925	120.793	70
0.3	124.431	70
0.3075	129.959	70
0.315	135.523	70
0.3225	141.122	70
0.33	146.752	70
0.3375	152.412	70
0.345	158.098	70
0.3525	163.81	70
0.36	169.544	70
0.3675	175.298	70
0.375	181.071	70

Critical crack size = 0.1735

tm
pc-CRACK for Windows
Version 3.0, Mar. 27, 1997

Structural Integrity Associates, Inc.
3315 Almaden Expressway, Suite 24
San Jose, CA 95118-1557
Voice: 408-978-8200
Fax: 408-978-8964
E-mail: info@structint.com

Linear Elastic Fracture Mechanics

Date: Thu Nov 20 11:00:13 1997
File: 80.LFM

Title: CPC-06Q: LIMITING ZERO DEGREE FLAWS

Load Cases:

Case: DROP2 --- Stress Distribution

Depth	Stress
0.0000	43.3000
0.3750	7.2000
0.7500	-28.9000

Case ID	Stress Coefficients C0	C1	C2	C3	Type
RESIDUAL	30	0	0	0	Coeff
MEMBRANE	7.2	0	0	0	Coeff
DROP2	43.3001	-96.2668	0	0	StressDist

Crack Model: Single Edge Cracked Plate

Crack Parameters:
Plate width: 0.7500
Max. crack size: 0.3750

Crack Size	Stress Intensity Factor: Case RESIDUAL	Case MEMBRANE	Case DROP2

0.0075	4.98468	1.19637	7.12042
0.0150	7.09853	1.70365	10.034
0.0225	8.75371	2.10089	12.2441
0.0300	10.177	2.44248	14.0849
0.0375	11.4554	2.74931	15.6861
0.0450	12.6334	3.03202	17.1144
0.0525	13.737	3.29688	18.4094
0.0600	14.7832	3.54796	19.5969
0.0675	15.7835	3.78805	20.695
0.0750	16.7465	4.01917	21.7166
0.0825	17.9075	4.29781	22.9894
0.0900	19.0627	4.57506	24.2291
0.0975	20.2147	4.85153	25.4397
0.1050	21.3655	5.12771	26.6243
0.1125	22.5167	5.404	27.7854
0.1200	23.6695	5.68069	28.9252
0.1275	24.8252	5.95805	30.0451
0.1350	25.9845	6.23629	31.1465
0.1425	27.1482	6.51557	32.2305
0.1500	28.3168	6.79604	33.298
0.1575	29.7019	7.12847	34.5864
0.1650	31.1029	7.46469	35.8642
0.1725	32.5197	7.80472	37.1309
0.1800	33.9523	8.14855	38.3864
0.1875	35.4007	8.49617	39.63
0.1950	36.8649	8.84758	40.8616
0.2025	38.3448	9.20276	42.0805
0.2100	39.8404	9.56169	43.2863
0.2175	41.3515	9.92437	44.4787
0.2250	42.8782	10.2908	45.6571
0.2325	44.8048	10.7532	47.2543
0.2400	46.7591	11.2222	48.8424
0.2475	48.7407	11.6978	50.4204
0.2550	50.7491	12.1798	51.9869
0.2625	52.784	12.6682	53.5409
0.2700	54.8452	13.1628	55.0813
0.2775	56.9322	13.6637	56.607
0.2850	59.0448	14.1708	58.117
0.2925	61.1827	14.6838	59.6102
0.3000	63.3455	15.2029	61.0856
0.3075	66.4177	15.9402	63.5413
0.3150	69.5356	16.6886	65.9877
0.3225	72.6988	17.4477	68.423
0.3300	75.9066	18.2176	70.8454
0.3375	79.1584	18.998	73.2532
0.3450	82.4536	19.7889	75.6445
0.3525	85.7917	20.59	78.0178
0.3600	89.1722	21.4013	80.3714
0.3675	92.5944	22.2227	82.7036
0.3750	96.0581	23.0539	85.0129

"-terial fracture toughness:

.cerial ID: A516_80

Depth	K1c
0.0000	80.0000
0.3750	80.0000
0.7500	80.0000

Load combination for critical crack size:

Load Case	Scale Factor
RESIDUAL	1.0000
DROP2	1.0000

Crack Size	Total K	K1c
0.0075	12.1053	80
0.015	17.1326	80
0.0225	20.9978	80
0.03	24.2618	80
0.0375	27.1415	80
0.045	29.7478	80
0.0525	32.1464	80
0.06	34.3801	80
0.0675	36.4785	80
0.075	38.4631	80
0.0825	40.897	80
0.09	43.2918	80
0.0975	45.6544	80
0.105	47.9897	80
0.1125	50.3021	80
0.12	52.5947	80
0.1275	54.8703	80
0.135	57.131	80
0.1425	59.3787	80
0.15	61.6148	80
0.1575	64.2884	80
0.165	66.9671	80
0.1725	69.6506	80
0.18	72.3386	80
0.1875	75.0308	80
0.195	77.7265	80
0.2025	80.4253	80
0.21	83.1267	80

0.2175	85.8302	80
0.225	88.5352	80
0.2325	92.0591	80
0.24	95.6015	80
0.2475	99.161	80
0.255	102.736	80
0.2625	106.325	80
0.27	109.926	80
0.2775	113.539	80
0.285	117.162	80
0.2925	120.793	80
0.3	124.431	80
0.3075	129.959	80
0.315	135.523	80
0.3225	141.122	80
0.33	146.752	80
0.3375	152.412	80
0.345	158.098	80
0.3525	163.81	80
0.36	169.544	80
0.3675	175.298	80
0.375	181.071	80

Critical crack size = 0.2013

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pc-CRACK for Windows
Version 3.0, Mar. 27, 1997

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Linear Elastic Fracture Mechanics

Date: Thu Nov 20 11:00:51 1997
File: 90.LFM

Title: CPC-06Q: LIMITING ZERO DEGREE FLAWS

Load Cases:

Case: DROP2 --- Stress Distribution

Depth	Stress
0.0000	43.3000
0.3750	7.2000
0.7500	-28.9000

	Stress Coefficients				
Case ID	C0	C1	C2	C3	Type
RESIDUAL	30	0	0	0	Coeff
MEMBRANE	7.2	0	0	0	Coeff
DROP2	43.3001	-96.2668	0	0	StressDist

Crack Model: Single Edge Cracked Plate

Crack Parameters:
Plate width: 0.7500
Max. crack size: 0.3750

	--------------------Stress Intensity Factor--------------------		
Crack Size	Case RESIDUAL	Case MEMBRANE	Case DROP2

A18

0.0075	4.98488	1.19637	7.12042
0.0150	7.09853	1.70365	10.034
0.0225	8.75371	2.10089	12.2441
0.0300	10.177	2.44248	14.0849
0.0375	11.4554	2.74931	15.6861
0.0450	12.6334	3.03202	17.1144
0.0525	13.737	3.29688	18.4094
0.0600	14.7832	3.54796	19.5969
0.0675	15.7835	3.78805	20.695
0.0750	16.7465	4.01917	21.7166
0.0825	17.9075	4.29781	22.9894
0.0900	19.0627	4.57506	24.2291
0.0975	20.2147	4.85153	25.4397
0.1050	21.3655	5.12771	26.6243
0.1125	22.5167	5.404	27.7854
0.1200	23.6695	5.68069	28.9252
0.1275	24.8252	5.95805	30.0451
0.1350	25.9845	6.23629	31.1465
0.1425	27.1482	6.51557	32.2305
0.1500	28.3168	6.79604	33.298
0.1575	29.7019	7.12647	34.5864
0.1650	31.1029	7.46469	35.8642
0.1725	32.5197	7.80472	37.1309
0.1800	33.9523	8.14855	38.3864
0.1875	35.4007	8.49617	39.63
0.1950	36.8649	8.84758	40.8616
0.2025	38.3448	9.20276	42.0805
0.2100	39.8404	9.56169	43.2863
0.2175	41.3515	9.92437	44.4787
0.2250	42.8782	10.2908	45.6571
0.2325	44.8048	10.7532	47.2543
0.2400	46.7591	11.2222	48.8424
0.2475	48.7407	11.6978	50.4204
0.2550	50.7491	12.1798	51.9869
0.2625	52.784	12.6682	53.5409
0.2700	54.8452	13.1628	55.0813
0.2775	56.9322	13.6637	56.607
0.2850	59.0448	14.1708	58.117
0.2925	61.1827	14.6838	59.6102
0.3000	63.3455	15.2029	61.0856
0.3075	66.4177	15.9402	63.5413
0.3150	69.5356	16.6886	65.9877
0.3225	72.6988	17.4477	68.423
0.3300	75.9066	18.2176	70.8454
0.3375	79.1584	18.998	73.2532
0.3450	82.4536	19.7889	75.6445
0.3525	85.7917	20.59	78.0178
0.3600	89.1722	21.4013	80.3714
0.3675	92.5944	22.2227	82.7036
0.3750	96.0581	23.0539	85.0129

Material fracture toughness:

Material ID: A516_90

Depth	K1c
0.0000	90.0000
0.3750	90.0000
0.7500	90.0000

Load combination for critical crack size:

Load Case	Scale Factor
RESIDUAL	1.0000
DROP2	1.0000

Crack Size	Total K	K1c
0.0075	12.1053	90
0.015	17.1326	90
0.0225	20.9978	90
0.03	24.2618	90
0.0375	27.1415	90
0.045	29.7478	90
0.0525	32.1464	90
0.06	34.3801	90
0.0675	36.4785	90
0.075	38.4631	90
0.0825	40.897	90
0.09	43.2918	90
0.0975	45.6544	90
0.105	47.9897	90
0.1125	50.3021	90
0.12	52.5947	90
0.1275	54.8703	90
0.135	57.131	90
0.1425	59.3787	90
0.15	61.6148	90
0.1575	64.2884	90
0.165	66.9671	90
0.1725	69.6506	90
0.18	72.3386	90
0.1875	75.0308	90
0.195	77.7265	90
0.2025	80.4253	90
0.21	83.1267	90

0.2175	85.8302	90
0.225	88.5352	90
0.2325	92.0591	90
0.24	95.6015	90
0.2475	99.161	90
0.255	102.736	90
0.2625	106.325	90
0.27	109.926	90
0.2775	113.539	90
0.285	117.162	90
0.2925	120.793	90
0.3	124.431	90
0.3075	129.959	90
0.315	135.523	90
0.3225	141.122	90
0.33	146.752	90
0.3375	152.412	90
0.345	158.098	90
0.3525	163.81	90
0.36	169.544	90
0.3675	175.298	90
0.375	181.071	90

Critical crack size = 0.2291

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Linear Elastic Fracture Mechanics

Date: Thu Nov 20 11:01:34 1997
File: 100.LFM

Title: CPC-06Q: LIMITING ZERO DEGREE FLAWS

Load Cases:

Case: DROP2 --- Stress Distribution

Depth	Stress
0.0000	43.3000
0.3750	7.2000
0.7500	-28.9000

Stress Coefficients

Case ID	C0	C1	C2	C3	Type
RESIDUAL	30	0	0	0	Coeff
MEMBRANE	7.2	0	0	0	Coeff
DROP2	43.3001	-96.2668	0	0	StressDist

Crack Model: Single Edge Cracked Plate

Crack Parameters:
Plate width: 0.7500
Max. crack size: 0.3750

--------------------Stress Intensity Factor--------------------

Crack Size	Case RESIDUAL	Case MEMBRANE	Case DROP2

A22

0.0075	4.98488	1.19637	7.12042
0.0150	7.09853	1.70365	10.034
0.0225	8.75371	2.10089	12.2441
0.0300	10.177	2.44246	14.0849
0.0375	11.4554	2.74931	15.6861
0.0450	12.6334	3.03202	17.1144
0.0525	13.737	3.29688	18.4094
0.0600	14.7832	3.54796	19.5969
0.0675	15.7835	3.78805	20.695
0.0750	16.7465	4.01917	21.7166
0.0825	17.9075	4.29781	22.9894
0.0900	19.0627	4.57506	24.2291
0.0975	20.2147	4.85153	25.4397
0.1050	21.3655	5.12771	26.6243
0.1125	22.5167	5.404	27.7854
0.1200	23.6695	5.68069	28.9252
0.1275	24.8252	5.95805	30.0451
0.1350	25.9845	6.23629	31.1465
0.1425	27.1482	6.51557	32.2305
0.1500	28.3168	6.79604	33.298
0.1575	29.7019	7.12847	34.5864
0.1650	31.1029	7.46469	35.8642
0.1725	32.5197	7.80472	37.1309
0.1800	33.9523	8.14855	38.3864
0.1875	35.4007	8.49617	39.63
0.1950	36.8649	8.84758	40.8616
0.2025	38.3448	9.20276	42.0805
0.2100	39.8404	9.56169	43.2863
0.2175	41.3515	9.92437	44.4787
0.2250	42.8782	10.2908	45.6571
0.2325	44.8048	10.7532	47.2543
0.2400	46.7591	11.2222	48.8424
0.2475	48.7407	11.6978	50.4204
0.2550	50.7491	12.1798	51.9869
0.2625	52.784	12.6682	53.5409
0.2700	54.8452	13.1628	55.0813
0.2775	56.9322	13.6637	56.607
0.2850	59.0448	14.1708	58.117
0.2925	61.1827	14.6838	59.6102
0.3000	63.3455	15.2029	61.0856
0.3075	66.4177	15.9402	63.5413
0.3150	69.5356	16.6886	65.9877
0.3225	72.6988	17.4477	68.423
0.3300	75.9066	18.2176	70.8454
0.3375	79.1584	18.998	73.2532
0.3450	82.4536	19.7899	75.6445
0.3525	85.7917	20.59	78.0178
0.3600	89.1722	21.4013	80.3714
0.3675	92.5944	22.2227	82.7036
0.3750	96.0581	23.0539	85.0129

"aterial fracture toughness:

-terial ID: A516_100

Depth	K1c
0.0000	100.0000
0.3750	100.0000
0.7500	100.0000

Load combination for critical crack size:

Load Case	Scale Factor
RESIDUAL	1.0000
DROP2	1.0000

Crack Size	Total K	K1c
0.0075	12.1053	100
0.015	17.1326	100
0.0225	20.9978	100
0.03	24.2618	100
0.0375	27.1415	100
0.045	29.7478	100
0.0525	32.1464	100
0.06	34.3801	100
0.0675	36.4785	100
0.075	38.4631	100
0.0825	40.897	100
0.09	43.2918	100
0.0975	45.6544	100
0.105	47.9897	100
0.1125	50.3021	100
0.12	52.5947	100
0.1275	54.8703	100
0.135	57.131	100
0.1425	59.3787	100
0.15	61.6148	100
0.1575	64.2884	100
0.165	66.9671	100
0.1725	69.6506	100
0.18	72.3386	100
0.1875	75.0308	100
0.195	77.7265	100
0.2025	80.4253	100
0.21	83.1267	100

0.2175	85.8302	100
0.225	88.5352	100
0.2325	92.0591	100
0.24	95.6015	100
0.2475	99.161	100
0.255	102.736	100
0.2625	106.325	100
0.27	109.926	100
0.2775	113.539	100
0.285	117.162	100
0.2925	120.793	100
0.3	124.431	100
0.3075	129.959	100
0.315	135.523	100
0.3225	141.122	100
0.33	146.752	100
0.3375	152.412	100
0.345	158.098	100
0.3525	163.81	100
0.36	169.544	100
0.3675	175.298	100
0.375	181.071	100

Critical crack size = 0.2493

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Version 3.0, Mar. 27, 1997

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Linear Elastic Fracture Mechanics

Date: Mon Nov 24 12:13:59 1997
File: CCP60A.LFM

Title: CPC-06Q: SUBSURFACE DEFECT, KID=60

Load Cases:

Case: DROP2 --- Stress Distribution

Depth	Stress
0.0000	43.3000
0.3750	7.2000
0.7500	-28.9000

Case ID	Stress Coefficients C0	C1	C2	C3	Type
RESIDUAL	30	0	0	0	Coeff
MEMBRANE	7.2	0	0	0	Coeff
DROP2	43.3001	-96.2668	0	0	StressDist

Crack Model: Center Cracked Plate Under Remote Tension Stress

Crack Parameters:
Plate Half Width: 0.3750
Crack depth: 0.3000

--------------------Stress Intensity Factor--------------------

Crack Size	Case RESIDUAL	Case MEMBRANE	Case DROP2

A26

0.0060	4.11943	0.988664	5.94573
0.0120	5.82841	1.39882	8.41235
0.0180	7.14374	1.7145	10.3108
0.0240	8.25766	1.98184	11.9186
0.0300	9.24501	2.2188	13.3437
0.0360	10.1444	2.43466	14.6418
0.0420	10.9791	2.63498	15.8465
0.0480	11.7643	2.82342	16.9798
0.0540	12.5107	3.00257	18.0572
0.0600	13.2264	3.17434	19.0902
0.0660	13.9176	3.34021	20.0877
0.0720	14.589	3.50137	21.0569
0.0780	15.2449	3.65878	22.0035
0.0840	15.8886	3.81326	22.9326
0.0900	16.523	3.96552	23.8482
0.0960	17.1508	4.11618	24.7543
0.1020	17.7742	4.2658	25.6541
0.1080	18.3954	4.41489	26.5507
0.1140	19.0164	4.56392	27.447
0.1200	19.639	4.71336	28.3457
0.1260	20.2651	4.86363	29.2494
0.1320	20.8965	5.01516	30.1607
0.1380	21.5349	5.16837	31.0821
0.1440	22.182	5.32369	32.0161
0.1500	22.8398	5.48154	32.9655
0.1560	23.5099	5.64238	33.9327
0.1620	24.1944	5.80665	34.9206
0.1680	24.8952	5.97486	35.9322
0.1740	25.6146	6.1475	36.9705
0.1800	26.3547	6.32513	38.0387
0.1860	27.1181	6.50834	39.1405
0.1920	27.9074	6.69777	40.2797
0.1980	28.7255	6.89411	41.4605
0.2040	29.5756	7.09814	42.6875
0.2100	30.4613	7.31071	43.9659
0.2160	31.3866	7.53277	45.3013
0.2220	32.3558	7.76538	46.7002
0.2280	33.3739	8.00974	48.1698
0.2340	34.4467	8.26722	49.7182
0.2400	35.5807	8.53936	51.3549
0.2460	36.7832	8.82798	53.0906
0.2520	38.0631	9.13514	54.9378
0.2580	39.4304	9.46328	56.9112
0.2640	40.897	9.81529	59.0282
0.2700	42.4774	10.1946	61.3092
0.2760	44.1886	10.6053	63.7789
0.2820	46.0514	11.0523	66.4677
0.2880	48.0916	11.542	69.4124
0.2940	50.3414	12.0819	72.6595
0.3000	52.8414	12.6819	76.2679

Material fracture toughness:

Material ID: a516-60

Depth	K1c
0.0000	60.0000
0.3750	60.0000
0.7500	60.0000

Load combination for critical crack size:

Load Case	Scale Factor
RESIDUAL	1.0000
DROP2	1.0000

Crack Size	Total K	K1c
0.006	10.0652	60
0.012	14.2408	60
0.018	17.4545	60
0.024	20.1762	60
0.03	22.5887	60
0.036	24.7863	60
0.042	26.8256	60
0.048	28.7441	60
0.054	30.5679	60
0.06	32.3166	60
0.066	34.0053	60
0.072	35.6459	60
0.078	37.2484	60
0.084	38.8211	60
0.09	40.3712	60
0.096	41.905	60
0.102	43.4283	60
0.108	44.9461	60
0.114	46.4633	60
0.12	47.9847	60
0.126	49.5145	60
0.132	51.0572	60
0.138	52.617	60
0.144	54.1982	60
0.15	55.8052	60
0.156	57.4426	60
0.162	59.115	60
0.168	60.8274	60

0.174	62.585	60
0.18	64.3934	60
0.186	66.2586	60
0.192	68.1871	60
0.198	70.186	60
0.204	72.2631	60
0.21	74.4272	60
0.216	76.6879	60
0.222	79.056	60
0.228	81.5437	60
0.234	84.1649	60
0.24	86.9355	60
0.246	89.8738	60
0.252	93.0009	60
0.258	96.3416	60
0.264	99.9252	60
0.27	103.787	60
0.276	107.968	60
0.282	112.519	60
0.288	117.504	60
0.294	123.001	60
0.3	129.109	60

Critical crack size = 0.1652

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pc-CRACK for Windows
Version 3.0, Mar. 27, 1997

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Linear Elastic Fracture Mechanics

Date: Mon Nov 24 12:15:34 1997
File: CCP70.LFM

Title: CPC-06Q: SUBSURFACE DEFECT, KID=70

Load Cases:

Case: DROP2 --- Stress Distribution

Depth	Stress
0.0000	43.3000
0.3750	7.2000
0.7500	-28.9000

Stress Coefficients

Case ID	C0	C1	C2	C3	Type
RESIDUAL	30	0	0	0	Coeff
MEMBRANE	7.2	0	0	0	Coeff
DROP2	43.3001	-96.2668	0	0	StressDist

Crack Model: Center Cracked Plate Under Remote Tension Stress

Crack Parameters:
Plate Half Width: 0.3750
Crack depth: 0.3000

--------------------Stress Intensity Factor--------------------

Crack Size	Case RESIDUAL	Case MEMBRANE	Case DROP2

0.0060	4.11943	0.988664	5.94573
0.0120	5.82841	1.39882	8.41235
0.0180	7.14374	1.7145	10.3108
0.0240	8.25766	1.98184	11.9186
0.0300	9.24501	2.2188	13.3437
0.0360	10.1444	2.43466	14.6418
0.0420	10.9791	2.63498	15.8465
0.0480	11.7643	2.82342	16.9798
0.0540	12.5107	3.00257	18.0572
0.0600	13.2264	3.17434	19.0902
0.0660	13.9176	3.34021	20.0877
0.0720	14.589	3.50137	21.0569
0.0780	15.2449	3.65878	22.0035
0.0840	15.8886	3.81326	22.9326
0.0900	16.523	3.96552	23.8482
0.0960	17.1508	4.11618	24.7543
0.1020	17.7742	4.2658	25.6541
0.1080	18.3954	4.41489	26.5507
0.1140	19.0164	4.56392	27.447
0.1200	19.639	4.71336	28.3457
0.1260	20.2651	4.86363	29.2494
0.1320	20.8965	5.01516	30.1607
0.1380	21.5349	5.16837	31.0821
0.1440	22.182	5.32369	32.0161
0.1500	22.8398	5.48154	32.9655
0.1560	23.5099	5.64238	33.9327
0.1620	24.1944	5.80665	34.9206
0.1680	24.8952	5.97486	35.9322
0.1740	25.6146	6.1475	36.9705
0.1800	26.3547	6.32513	38.0387
0.1860	27.1181	6.50834	39.1405
0.1920	27.9074	6.69777	40.2797
0.1980	28.7255	6.89411	41.4605
0.2040	29.5756	7.09814	42.6875
0.2100	30.4613	7.31071	43.9659
0.2160	31.3866	7.53277	45.3013
0.2220	32.3558	7.76538	46.7002
0.2280	33.3739	8.00974	48.1698
0.2340	34.4467	8.26722	49.7182
0.2400	35.5807	8.53936	51.3549
0.2460	36.7832	8.82798	53.0906
0.2520	38.0631	9.13514	54.9378
0.2580	39.4304	9.46328	56.9112
0.2640	40.897	9.81529	59.0282
0.2700	42.4774	10.1946	61.3092
0.2760	44.1886	10.6053	63.7789
0.2820	46.0514	11.0523	66.4677
0.2880	48.0916	11.542	69.4124
0.2940	50.3414	12.0819	72.6595
0.3000	52.8414	12.6819	76.2679

Material fracture toughness:

Material ID: a516-70

Depth	K1c
0.0000	70.0000
0.3750	70.0000
0.7500	70.0000

Load combination for critical crack size:

Load Case	Scale Factor
RESIDUAL	1.0000
DROP2	1.0000

Crack Size	Total K	K1c
0.006	10.0652	70
0.012	14.2408	70
0.018	17.4545	70
0.024	20.1762	70
0.03	22.5887	70
0.036	24.7863	70
0.042	26.8256	70
0.048	28.7441	70
0.054	30.5679	70
0.06	32.3166	70
0.066	34.0053	70
0.072	35.6459	70
0.078	37.2484	70
0.084	38.8211	70
0.09	40.3712	70
0.096	41.905	70
0.102	43.4283	70
0.108	44.9461	70
0.114	46.4633	70
0.12	47.9847	70
0.126	49.5145	70
0.132	51.0572	70
0.138	52.617	70
0.144	54.1982	70
0.15	55.8052	70
0.156	57.4426	70
0.162	59.115	70
0.168	60.8274	70

0.174	62.585	70
0.18	64.3934	70
0.186	66.2586	70
0.192	[illegible]	70
0.198	70.186	70
0.204	72.2631	70
0.21	74.4272	70
0.216	76.6879	70
0.222	79.056	70
0.228	81.5437	70
0.234	84.1649	70
0.24	86.9355	70
0.246	89.8738	70
0.252	93.0009	70
0.258	96.3416	70
0.264	99.9252	70
0.27	103.787	70
0.276	107.968	70
0.282	112.519	70
0.288	117.504	70
0.294	123.001	70
0.3	129.109	70

Critical crack size = 0.1976

tm
pc-CRACK for Windows
Version 3.0, Mar. 27, 1997

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Linear Elastic Fracture Mechanics

Date: Mon Nov 24 12:16:49 1997
File: CCP80.LFM

Title: CPC-06Q: SUBSURFACE DEFECT, KID=80

Load Cases:

Case: DROP2 --- Stress Distribution

Depth	Stress
0.0000	43.3000
0.3750	7.2000
0.7500	-28.9000

Case ID	Stress Coefficients C0	C1	C2	C3	Type
RESIDUAL	30	0	0	0	Coeff
MEMBRANE	7.2	0	0	0	Coeff
DROP2	43.3001	-96.2668	0	0	StressDist

Crack Model: Center Cracked Plate Under Remote Tension Stress

Crack Parameters:
Plate Half Width: 0.3750
Crack depth: 0.3000

--------------------Stress Intensity Factor--------------------

Crack Size	Case RESIDUAL	Case MEMBRANE	Case DROP2

A34

0.0060	4.11943	0.988664	5.94573
0.0120	5.82841	1.39882	8.41235
0.0180	7.14374	1.7145	10.3108
0.0240	8.25766	1.98184	11.9186
0.0300	9.24501	2.2188	13.3437
0.0360	10.1444	2.43466	14.6418
0.0420	10.9791	2.63498	15.8465
0.0480	11.7643	2.82342	16.9798
0.0540	12.5107	3.00257	18.0572
0.0600	13.2264	3.17434	19.0902
0.0660	13.9176	3.34021	20.0877
0.0720	14.589	3.50137	21.0569
0.0780	15.2449	3.65878	22.0035
0.0840	15.8886	3.81326	22.9326
0.0900	16.523	3.96552	23.8482
0.0960	17.1508	4.11618	24.7543
0.1020	17.7742	4.2658	25.6541
0.1080	18.3954	4.41489	26.5507
0.1140	19.0164	4.56392	27.447
0.1200	19.639	4.71336	28.3457
0.1260	20.2651	4.86363	29.2494
0.1320	20.8965	5.01516	30.1607
0.1380	21.5349	5.16837	31.0821
0.1440	22.182	5.32369	32.0161
0.1500	22.8398	5.48154	32.9655
0.1560	23.5099	5.64238	33.9327
0.1620	24.1944	5.80665	34.9206
0.1680	24.8952	5.97486	35.9322
0.1740	25.6146	6.1475	36.9705
0.1800	26.3547	6.32513	38.0387
0.1860	27.1181	6.50834	39.1405
0.1920	27.9074	6.69777	40.2797
0.1980	28.7255	6.89411	41.4605
0.2040	29.5756	7.09814	42.6875
0.2100	30.4613	7.31071	43.9659
0.2160	31.3866	7.53277	45.3013
0.2220	32.3558	7.76538	46.7002
0.2280	33.3739	8.00974	48.1698
0.2340	34.4467	8.26722	49.7182
0.2400	35.5807	8.53936	51.3549
0.2460	36.7832	8.82798	53.0906
0.2520	38.0631	9.13514	54.9378
0.2580	39.4304	9.46328	56.9112
0.2640	40.897	9.81529	59.0282
0.2700	42.4774	10.1946	61.3092
0.2760	44.1886	10.6053	63.7789
0.2820	46.0514	11.0523	66.4677
0.2880	48.0916	11.542	69.4124
0.2940	50.3414	12.0819	72.6595
0.3000	52.8414	12.6819	76.2679

Material fracture toughness:

aterial ID: a516-80

Depth	K1c
0.0000	80.0000
0.3750	80.0000
0.7500	80.0000

Load combination for critical crack size:

Load Case	Scale Factor
RESIDUAL	1.0000
DROP2	1.0000

Crack Size	Total K	K1c
0.006	10.0652	80
0.012	14.2408	80
0.018	17.4545	80
0.024	20.1762	80
0.03	22.5887	80
0.036	24.7863	80
0.042	26.8256	80
0.048	28.7441	80
0.054	30.5679	80
0.06	32.3166	80
0.066	34.0053	80
0.072	35.6459	80
0.078	37.2484	80
0.084	38.8211	80
0.09	40.3712	80
0.096	41.905	80
0.102	43.4283	80
0.108	44.9461	80
0.114	46.4633	80
0.12	47.9847	80
0.126	49.5145	80
0.132	51.0572	80
0.138	52.617	80
0.144	54.1982	80
0.15	55.8052	80
0.156	57.4426	80
0.162	59.115	80
0.168	60.8274	80

0.174	62.585	80
0.18	64.3934	80
0.186	66.2586	80
0.192	68.1871	80
0.198	70.186	80
0.204	72.2631	80
0.21	74.4272	80
0.216	76.6879	80
0.222	79.056	80
0.228	81.5437	80
0.234	84.1649	80
0.24	86.9355	80
0.246	89.8738	80
0.252	93.0009	80
0.258	96.3416	80
0.264	99.9252	80
0.27	103.787	80
0.276	107.968	80
0.282	112.519	80
0.288	117.5[illegible]4	80
0.294	123.001	80
0.3	129.109	80

Critical crack size = 0.2244

tm
pc-CRACK for Windows
Version 3.0, Mar. 27, 1997

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Linear Elastic Fracture Mechanics

Date: Mon Nov 24 12:17:52 1997
File: CCP90.LFM

Title: CPC-06Q: SUBSURFACE DEFECT, KID=90

Load Cases:

Case: DROP2 --- Stress Distribution

Depth	Stress
0.0000	43.3000
0.3750	7.2000
0.7500	-28.9000

Stress Coefficients

Case ID	C0	C1	C2	C3	Type
RESIDUAL	30	0	0	0	Coeff
MEMBRANE	7.2	0	0	0	Coeff
DROP2	43.3001	-96.2668	0	0	StressDist

Crack Model: Center Cracked Plate Under Remote Tension Stress

Crack Parameters:
Plate Half Width: 0.3750
Crack depth: 0.3000

--------------------Stress Intensity Factor--------------------

Crack Size	Case RESIDUAL	Case MEMBRANE	Case DROP2

0.0060	4.11943	0.988664	5.94573
0.0120	5.82841	1.39882	8.41235
0.0180	7.14374	1.7145	10.3108
0.0240	8.25766	1.98184	11.9186
0.0300	9.24501	2.2188	13.3437
0.0360	10.1444	2.43466	14.6418
0.0420	10.9791	2.63498	15.8465
0.0480	11.7643	2.82342	16.9798
0.0540	12.5107	3.00257	18.0572
0.0600	13.2264	3.17434	19.0902
0.0660	13.9176	3.34021	20.0877
0.0720	14.589	3.50137	21.0569
0.0780	15.2449	3.65878	22.0035
0.0840	15.8886	3.81326	22.9326
0.0900	16.523	3.96552	23.8482
0.0960	17.1508	4.11618	24.7543
0.1020	17.7742	4.2658	25.6541
0.1080	18.3954	4.41489	26.5507
0.1140	19.0164	4.56392	27.447
0.1200	19.639	4.71336	28.3457
0.1260	20.2651	4.86363	29.2494
0.1320	20.8965	5.01516	30.1607
0.1380	21.5349	5.16837	31.0821
0.1440	22.182	5.32369	32.0161
0.1500	22.8398	5.48154	32.9655
0.1560	23.5099	5.64238	33.9327
0.1620	24.1944	5.80665	34.9206
0.1680	24.8952	5.97486	35.9322
0.1740	25.6146	6.1475	36.9705
0.1800	26.3547	6.32513	38.0387
0.1860	27.1181	6.50834	39.1405
0.1920	27.9074	6.69777	40.2797
0.1980	28.7255	6.89411	41.4605
0.2040	29.5756	7.09814	42.6875
0.2100	30.4613	7.31071	43.9659
0.2160	31.3866	7.53277	45.3013
0.2220	32.3558	7.76538	46.7002
0.2280	33.3739	8.00974	48.1698
0.2340	34.4467	8.26722	49.7182
0.2400	35.5807	8.53936	51.3549
0.2460	36.7832	8.82798	53.0906
0.2520	38.0631	9.13514	54.9378
0.2580	39.4304	9.46328	56.9112
0.2640	40.897	9.81529	59.0282
0.2700	42.4774	10.1946	61.3092
0.2760	44.1886	10.6053	63.7789
0.2820	46.0514	11.0523	66.4677
0.2880	48.0916	11.542	69.4124
0.2940	50.3414	12.0819	72.6595
0.3000	52.8414	12.6819	76.2679

Material fracture toughness:

.terial ID: a516-90

Depth	K1c
0.0000	90.0000
0.3750	90.0000
0.7500	90.0000

Load combination for critical crack size:

Load Case	Scale Factor
RESIDUAL	1.0000
DROP2	1.0000

Crack Size	Total K	K1c
0.006	10.0652	90
0.012	14.2408	90
0.018	17.4545	90
0.024	20.1762	90
0.03	22.5887	90
0.036	24.7863	90
0.042	26.8256	90
0.048	28.7441	90
0.054	30.5679	90
0.06	32.3166	90
0.066	34.0053	90
0.072	35.6459	90
0.078	37.2484	90
0.084	38.8211	90
0.09	40.3712	90
0.096	41.905	90
0.102	43.4283	90
0.108	44.9461	90
0.114	46.4633	90
0.12	47.9847	90
0.126	49.5145	90
0.132	51.0572	90
0.138	52.617	90
0.144	54.1982	90
0.15	55.8052	90
0.156	57.4426	90
0.162	59.115	90
0.168	60.8274	90

Material fracture toughness:

.terial ID: a516-90

Depth	Klc
0.0000	90.0000
0.3750	90.0000
0.7500	90.0000

Load combination for critical crack size:

Load Case	Scale Factor
RESIDUAL	1.0000
DROP2	1.0000

Crack Size	Total K	Klc
0.006	10.0652	90
0.012	14.2408	90
0.018	17.4545	90
0.024	20.1762	90
0.03	22.5887	90
0.036	24.7863	90
0.042	26.8256	90
0.048	28.7441	90
0.054	30.5679	90
0.06	32.3166	90
0.066	34.0053	90
0.072	35.6459	90
0.078	37.2484	90
0.084	38.8211	90
0.09	40.3712	90
0.096	41.905	90
0.102	43.4283	90
0.108	44.9461	90
0.114	46.4633	90
0.12	47.9847	90
0.126	49.5145	90
0.132	51.0572	90
0.138	52.617	90
0.144	54.1982	90
0.15	55.8052	90
0.156	57.4426	90
0.162	59.115	90
0.168	60.8274	90