U.S. NUCLEAR REGULATORY COMMISSION
Office of Nuclear Material Safety and Safeguards
Spent Fuel Project Office

CONFIRMATORY ACTION LETTER 97-7-001 TECHNICAL EVALUATION

Docket No: 72-1007

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EXECUTIVE SUMMARY

This technical evaluation provides the staff's assessment of Sierra Nuclear Corporation's (SNC) response to Confirmatory Action Letter (CAL) 97-7-001. The U.S. Nuclear Regulatory Commission (NRC) issued the CAL on May 16, 1997, to confirm SNC's commitments to resolve welding problems associated with the Ventilated Storage Cask Model No. 24 (VSC-24). On four occasions during loading operations at the utilities using the VSC-24, cracks occurred in either the weld between the shield lid and the multi-assembly sealed basket (MSB) shell or the weld between the structural lid and the MSB shell. In each case, the welds were repaired and reexamined using approved procedures to provide a sound boundary. The MSB shell, shield lid, structural lid, and their closure welds form part of the confinement boundary for the VSC-24 dry spent fuel storage system and are classified as important to safety. CALs regarding resolution of the welding issues were also sent to each utility using the VSC-24 and recognizing their commitments not to load additional casks until the welding problems were resolved.

In June 1997, during its investigation into the welding problems, SNC and the VSC-24 owners identified weld repairs that had been made to numerous MSB shells during fabrication and had not been documented in accordance with VSC-24 licensing commitments and regulatory requirements. As a result, on September 5, 1997, NRC supplemented the CALs issued to the utilities using the VSC-24. The supplements documented each utility's commitment that, in addition to resolving the welding problems, they would certify that all unloaded casks intended for use were fabricated in accordance with the VSC-24 licensing basis and regulatory requirements.

SNC and the VSC-24 owners responded to the CAL and proposed corrective actions in numerous correspondence between July 30, 1997, and July 17, 1998. A significant part of those responses involved development of a process to volumetrically examine the structural lid closure weld using ultrasonic testing (UT) and acceptance criteria to disposition the flaw indications that may be located by the UT.

The staff concluded that the root causes presented by SNC for each of the weld cracking events were credible and accepted SNC's assessment on the susceptibility of the welds, on previously loaded casks, to hydrogen-induced cracking. However, the staff also concluded that SNC did not accurately assess the length of time in which delayed cracking of the shield and structural lid welds may have occurred. In response to this concern, as discussed in the Technical Evaluation, the utilities that currently have VSC-24s in use, have committed to perform ultrasonic testing (UT) of previously loaded casks. The UT data will be used to evaluate whether the casks meet the design basis for the VSC-24 structural lid weld.

For casks to be loaded in the future, the staff has concluded that SNC has developed adequate corrective actions to prevent the recurrence of the root causes of the identified welding defects. UT examination of the structural lid-to-shell weld joint will provide reasonable assurance to confirm the presence of a structurally sound weld for future MSB loadings. The methodology to address flaw indications identified by UT requires that if unacceptable conditions are identified, they are required to be evaluated and/or repaired in accordance with the licensee's quality assurance program.

The staff concluded that SNC's proposed revisions to licensing documents as described in Appendices C and D were acceptable.

PURPOSE

This technical evaluation provides the staff's assessment of Sierra Nuclear Corporation's (SNC) response to Confirmatory Action Letter (CAL) 97-7-001. The CAL was issued to SNC to confirm its commitments to resolve welding problems associated with the Ventilated Storage Cask Model No. 24 (VSC-24) dry storage system. Specifically, the CAL documented SNC's commitments to:

(1) Determine the root cause(s) of the weld problems;
(2) Assess the potential for delayed cracking in the shield and structural lid welds in the 19 VSC-24 casks presently in use; and
(3) Determine appropriate corrective actions to inhibit recurrence of weld problems.
(4) On completion of this action, submit a written description of the evaluations described in Items 1, 2 and 3.

SNC received assistance in responding to the CAL from the VSC-24 Owners Group. The VSC-24 Owners Group (Owners Group) includes Sierra Nuclear Corporation, and licensees using the VSC-24 system: Consumers Energy at Palisades Nuclear Plant (Palisades), Entergy Operations, Inc., at Arkansas Nuclear One (ANO), and Wisconsin Electric Power Company (WE) at Point Beach Nuclear Plant (Point Beach).

The staff's review contained in this technical evaluation addresses all technical issues related to the CAL except those related to potential undocumented welds on previously loaded multi-assembly sealed baskets (MSBs) which were identified during resolution of the concerns described in the CAL. This issue will be addressed in supplements to CAL 97-7-002, CAL 97-07-003, and CAL 97-07-004 issued for ANO, Palisades, and Point Beach, respectively.

BACKGROUND

On May 3, 1993, the U.S. Nuclear Regulatory Commission (NRC) issued Certificate of Compliance (CoC) No. 1007 to SNC certifying that the VSC-24 may be used to store spent nuclear fuel under a general license in accordance with 10 CFR Part 72. Since that time, 19 VSC-24s have been loaded with spent fuel by three utilities: Consumers Energy Company at Palisades, Wisconsin Electric Power Company at Point Beach, and Entergy Operations, Inc. at ANO.

Between March 1995 and March 1997, the utilities using the VSC-24 experienced four incidents in which cracks occurred in either the weld between the shield lid and the MSB shell or the weld between the structural lid and the MSB shell. This cracking was identified by either helium leak test or dye penetrant examination required to be performed during cask loading. Table 1 summarizes the weld crack events. The MSB shell, shield lid, structural lid, and their closure welds form part of the confinement boundary for the VSC-24 dry spent fuel storage system and are classified as important to safety.

In March 1997, NRC performed an inspection at SNC after learning of the cracking events at Palisades (March 1995) and ANO (December 1996). As part of the inspection, NRC evaluated possible root causes but did not positively confirm a root cause. However, NRC concluded that neither SNC nor utilities using the VSC-24 had performed a comprehensive analysis to identify the root cause(s) of the welding problems nor implemented sufficient corrective actions to preclude recurrence of the problems. On March 26, 1997, shortly after the inspection, another crack occurred during loading at ANO.

Table 1 - Weld Cracking Events Summary

Facility	Date	Detection	Location	Description
Palisades	3/95	helium leak test	shield lid-to-shell weld	about 6 inches long by 1/8 inch deep that extended from about 1/8 inch above the shield lid-to-shell weld fusion line into the shell base metal
Point Beach	5/96	liquid penetrant test	structural lid-to-shell weld structural lid-to-shield lid weld	- three cracks, each less than 1 inch long, located along the center of the root pass at locations where the fit-up gap between the lid and the backing ring was widest - in addition, cracking and weld porosity were found in the structural lid-to-shield lid seal weld (fillet weld associated with the vent port covers)
ANO	12/96	helium leak test	shield lid-to-shell weld	about 4-inches long located along the weld fusion line
ANO	3/97	liquid penetrant test	shield lid-to-shell weld	about 18-inches long located along the weld fusion line of the root pass

On May 16, 1997, NRC issued CALs, to SNC and the three utilities using the VSC-24, that documented their commitments to resolve the welding problems. In response to the CALs, the utilities using the VSC-24 and SNC formed the Owners Group to collectively identify the root cause(s) and develop corrective actions.

The Owners Group assembled a team to evaluate the welding problems. The team consisted of industry experts in metallurgy, welding, and non-destructive examination. This evaluation included an assessment of the information gathered during the initial evaluations performed by the individual licensees and additional testing and evaluation to determine the root causes of the four observed cracking incidents. To ensure that the Owners Group's proposed corrective actions received the appropriate technical and regulatory attention, NRC also assembled a team of staff experts in the areas of metallurgy, welding, and non-destructive examination.

In June 1997, during its investigation into the welding problems, the Owners Group identified weld repairs that had been made to numerous MSB shells during fabrication that were not documented in accordance with VSC-24 licensing commitments and regulatory requirements. As a result, on September 5, 1997, NRC supplemented the CALs issued to the utilities. The supplements documented each utility's commitment that, in addition to resolving the welding problems, they would certify that all unloaded casks intended for use were fabricated in accordance with the VSC-24 licensing basis and regulatory requirements.

On July 30, 1997, and September 18, 1997, the Owners Group submitted to NRC the results of its review and proposed corrective actions to the welding process to inhibit the cracking. On November 6, 1997, NRC notified the Owners Group that the staff agreed with the VSC-24 Owners Group's corrective actions associated with the welding process. However, NRC staff required that the Owners Group develop testing, surveillance, or monitoring to confirm that the corrective actions were effective. The NRC identified volumetric inspection of the structural lid-to-shell weld as an acceptable confirmation method. This type of inspection has the capability to examine the entire volume of the weld. The American Society of Mechanical Engineers (ASME) Code has recognized two techniques for volumetric inspection: radiography and ultrasonic testing (UT). Because of physical limitations in accessing the examination area, the Owners Group determined radiography inspection of the weld was impractical. Therefore, the Owners Group pursued UT inspection of the structural lid weld.

Development of the UT process involved two major tasks: (1) demonstration of a UT technique on a full diameter MSB mockup containing imbedded flaws; and (2) development of a methodology to disposition flaw indications located by UT. The Owners Group successfully demonstrated a UT technique in April 1998. NRC review of the UT demonstration was documented in NRC Inspection Report (IR) 72-1007/98-202. In June and July 1998, the Owners Group submitted its responses to complete actions associated with loading of future MSBs. Those included flaw screening criteria, UT examination guidelines, and plans for revising licensing documents. Appendix F to this Technical Evaluation lists related correspondence regarding this CAL.

EVALUATION

CAL 97-7-001 FIRST COMMITMENT: **Determine the root cause(s) of the weld problems**

<u>Owners Group Response</u>

The Owners Group lid weld review team (the team), composed of industry experts in metallurgy, welding, and non-destructive examination, evaluated each of the four weld cracking events to identify the root cause(s). This evaluation included a reassessment of the initial evaluations performed by the individual licensees, additional evaluation by the team, and testing. The team identified separate root causes for each of the four weld cracking events.

The team reviewed information regarding the Palisades crack and concluded that the weld crack was caused by an existing condition in the rolling plane of the shell material which was opened

up by the process of making the shield lid weld. Metallographic analysis revealed a crack that propagated along prior austenitic grain boundaries of a pre-existing weld of unknown origin.

The team reviewed the data associated with the Point Beach crack and concurred with the WE evaluation. WE determined that the cracks on the root pass of the structural lid-to-shell weld were caused by wide fit-up gaps that were not properly filled by the welding technique. This resulted in a lack of fusion in the weld metal. WE personnel also concluded that the cracking and weld porosity found in the structural lid-to-shield lid seal weld were caused by moisture contamination of the weld. The moisture came from water forced out of the drain line during cask loading. The team concluded that the causes of the weld cracks at Point Beach were associated with the welding technique and were not related to the causes of the cracking observed at Palisades or ANO.

The crack in the shield lid-to-shell weld for the first cask loaded at ANO was initially considered to have been caused by lamellar tearing based on visual observations of the crack by the welders before the crack was repaired. No other data were available other than the observation that this crack was similar in appearance to the second crack observed during welding of the shield lid-to-shell weld for the third cask loaded at ANO.

The team performed a complete review of the data associated with both weld crack events at ANO. The team (1) observed differences between the welding conditions at ANO and those at Point Beach and Palisades that were judged to have a possible influence on the cause of the cracks observed at ANO; (2) evaluated parameters which affect the risk of hydrogen induced cracking (HIC), including hydrogen level, microstructure, and stress; (3) tested samples of the ANO shell material and determined that they had excellent resistance to lamellar tearing; and (4) reexamined a replica of the second weld crack using light microscopy and scanning electron microscopy and concluded that the crack had the appearance of a HIC.

The team concluded that the second crack at ANO appeared to have been HIC. The team also concluded that there was no evidence to indicate that other potential causes of cracking, including lamellar tearing, undocumented welds discovered as a result of the team investigation, or small sulfur inclusions found in MSB shell material at ANO, contributed to the cause of the cracking observed at ANO.

NRC Staff Evaluation

The staff reviewed information submitted by the Owners Group regarding the Palisades crack and additional information gathered during a site visit. The additional information included a condition report evaluation, C-PAL-95-0192, which provided a description of the crack and the results of examinations performed by Consumers Energy. In addition, the staff reviewed photomicrographs of metallurgical samples taken from the area excavated to remove the crack. The Owners Group concluded that the weld crack propagated along prior austenite grain boundaries of a pre-existing weld of unknown origin (the welds had not been documented during fabrication). The existence of undocumented welds observed on several MSB shells was confirmed as discussed in NRC IR 72-1007/97-212 and IR 72-0013/97-215. The staff accepted

the Owners Group conclusion that there was evidence of a pre-existing weld of unknown origin and that the weld crack may have propagated along prior austenite grain boundaries of that pre-existing weld.

For the second cask loaded at Point Beach, the staff reviewed the evaluation of the causes of the cracking discovered during welding of the structural lid. Based on this information and the staff's experience, the staff found that the wide fit-up gaps and a resulting lack of fusion in the weld metal were a reasonable explanation for the cracks observed between weld beads on the root pass of the structural lid-to-shell weld. The staff also concluded that a probable cause for the cracking and porosity found in the structural lid-to-shield lid seal weld was contamination of the weld by moisture.

The staff reviewed the information submitted by the Owners Group regarding the two cracks observed on MSBs at ANO and additional information gathered by NRC during inspection. The results of the inspections are documented in NRC IR 50-368/97-12; 72-13/97-01 and IR 72-1007/97-204. Data reviewed included a photograph of the first crack observed in December 1996, photomicrographs of the second crack observed in March 1997, and root cause analysis reports, prepared by two separate consultants. Based on the information reviewed and professional experience, the staff concluded that the second crack at ANO appears to have been HIC. The staff also concluded that there are insufficient data to further evaluate the cause of the first crack at ANO, but believes that this crack may have been HIC.

<u>Staff Conclusions on Root Cause</u>

The staff concluded that the root causes presented by the Owners Group for the weld cracking events were credible.

CAL 97-7-001 SECOND COMMITMENT: Assess the potential for delayed cracking in the shield and structural lid welds in the 19 VSC-24 casks presently in use

<u>Owners Group Response</u>

The Owners Group determined that HIC of the MSB closure welds was possible whenever a sufficient combined severity of the following three conditions were present during welding: (1) a concentration of diffusible hydrogen in the weld area; (2) a microstructure susceptible to embrittlement by hydrogen; and (3) high constraint (stresses) in the weld area. These conditions may have existed during the welding of previously loaded casks and, therefore, previously loaded casks may have been susceptible to HIC. The Owners Group based its conclusion on the following:

- The hydrogen content of the welding consumables, particularly for ANO and Palisades, was high enough to cause these welds to be susceptible to HIC. Diffusible hydrogen levels, in units of ml H_2 STP/100g (milliliters of hydrogen at standard temperature and pressure per 100 grams of weld metal), were measured to be at levels of 15.0 to 15.9 for ANO and Palisades and levels of 9.0 for Point Beach. The weld consumables were regarded to be the predominant source of the hydrogen in these weldments.

- The microstructures of the selected steels welded for previously loaded VSC-24s were judged to have been in the susceptible range and likely to contain martensite. This assessment was based upon carbon equivalent (CE) values, as calculated by the International Institute of Welding formula, in the range of 0.40% to 0.49% CE.

- The joint configuration for these weldments is recognized as being highly constrained so that residual stresses are expected to be at, or near, the yield level.

The Owners Group estimated the maximum expected delay times for HIC of SA516, Grade 70 steel, at 3 hours. The delay time is the time between completion of the weld and the onset of cracking. Their computed estimates considered: (1) data gathered from a literature review of delay times associated with HIC; (2) an understanding of factors that affect the onset and continuation of cracking such as the influence of temperature and alloy content on hydrogen diffusion rates; (3) the material/weld strength; and (4) volume of the weld -- the time for escape (loss of a given fraction of the hydrogen to the environs) increases as the square of the hydrogen diffusion path.

The Owners Group compared the estimated maximum expected delay times with the elapsed times between completion of a weld pass and inspection of that pass and concluded that it was unlikely that delay times would have exceeded the actual inspection time intervals. The Owners Group further supported its conclusion with the observation that cracking was detected at ANO within an elapsed time of 30 minutes after welding.

<u>NRC Staff Evaluation</u>

The staff reviewed literature provided by the Owners Group and independently reviewed additional literature regarding HIC. The staff accepted the three principal factors that promote HIC discussed by the VSC-24 Owners Group. Specifically, the staff accepted:

- The hydrogen content of the welding consumables, particularly for ANO and Palisades, was high enough to cause tnese welds to be susceptible to HIC.

- The microstructure and the chemical compositions, especially those for steel plates with the higher computed values of CE, are within the range of compositions for which cracking could likely occur at the expected hydrogen levels.

- Moderately-high to high restraint in the weld joints could have promoted cracking in these weldments.

The staff identified additional factors that may increase or decrease the potential for HIC of the MSB closure welds:

- The level of sulfur in the steels may affect the potential for HIC. Many of the lid closure weldments involved low-sulfur steels. These low-sulfur steels, especially those with shape controlled sulfides, have superior fracture toughness and may have a decreased

susceptibility to HIC, when compared with that for steels of higher sulfur content but at the same value of CE.

- The hydrogen content may vary widely in weldments made without strict controls on selected weld parameters. As indicated previously, welds with high hydrogen content may be susceptible to HIC.

- Poor fit-up can lead to increases in local notch effects and higher local stresses.

- Welding processes differ in cooling rates and therefore in heat affected zone (HAZ) microstructures. The local maximum levels of hardness can be decreased by tempering in multi-pass weldments and this can decrease the susceptibility of cracking by hydrogen.

- A lower temperature of the weldments could increase the propensity for HIC. Factors that would have decreased temperatures of weldments include lower temperatures in the spent fuel pool and lower decay heat from the spent fuel. The staff noted that initial temperatures of the welds at Point Beach may have been lower than at the other two sites, due to lower pool temperatures at this site.

The staff concluded that conditions that promote HIC may have existed during the welding of previously loaded casks and, therefore, weldments of both the structural lid and the shield lid on those casks may have been susceptible to HIC. VSC-24 closure welds on MSBs with low sulfur content in the steel may be less susceptible to HIC than steels of higher sulfur content.

Regarding delay times for HIC of SA-516, Grade 70 steels, the staff accepts many of the factors that affect delay times described by the Owners Group. However, the staff does not accept the Owners Group estimate of 3 hours as the maximum delay time for cracking. While the staff concluded that the initiation of cracks of significant size would most probably have been within the 3-hour delay time estimated by the VSC-24 Owners Group, the staff determined that cracking may have occurred over longer time periods. Specifically, the staff took exception with the following:

- The staff concluded that field observations from surface inspections conducted after the first and final weld passes do not fully confirm the delay times for cracking of multi-pass closure weldments. Hydrogen-induced cracks, except in the most severe cases, are subsurface cracks that would not be detected by a surface examination. Hence, the absence of indications of surface cracking is not a definitive indicator for the absence of cracking at subsurface locations, either at short elapsed times or at longer times.

- The effects of multi-pass welding are complex and more difficult to evaluate than single-pass cases. Literature information used in the delay time estimates was taken from experiments on single-pass welds rather than multi-pass welds. Empirical methods and additional data may be needed to obtain reliable estimates of times over which cracking is likely to occur in multi-pass weldments.

- Delay times reported in the literature are not derived on a consistent basis. They represent observed times for a fixed (usually very small) level of crack propagation that is measurable in laboratory specimens. Cracking begins before, and continues after, the reported "cracking time." Further, the length of crack propagation is not the same among the experimental data, as there is no standard criterion on the crack length that corresponds with the reported time to cracking.

- The Owners Group did not adequately support its basis for excluding literature data from the delay time estimates. For example, a slightly higher carbon content of one steel (0.3 vs. 0.2 wt %) was considered a sufficient reason to believe that the delay times from this steel would not typify those expected in the SA516, Grade 70 steel. For ferritic steels, the staff view is that the greatest effect of chemical composition on delay times is likely to be its effect on diffusivity. This small change in chemical composition was not considered to be large enough to warrant the exclusion of otherwise representative data.

Therefore, the staff did not agree with the estimates for the maximum delay times on previously loaded MSBs. For those MSBs, the staff concluded that hydrogen-induced delayed cracking behavior could have occurred both before and after completion of weld inspections required by VSC-24 CoC No. 1007.

In addition, the staff concluded that cracking through the full weld depth would only occur in the most severe cases of HIC. Further, as discussed in the corrective actions portion of this evaluation, the VSC-24 owners will volumetrically inspect, using UT, the structural lid welds of previously loaded (and future) casks to confirm the integrity of the welds.

Staff Conclusions on Delayed Cracking

On previously loaded casks, the staff concluded that (1) conditions that promote HIC may have existed during welding, (2) weldments of both the structural lid and the shield lid may have been susceptible to HIC, (3) and therefore, that HIC may have occurred in those welds. In addition, the staff concluded that delayed HIC behavior could have occurred both before and after completion of weld inspections performed on previously loaded MSBs.

CAL 97-7-001 THIRD COMMITMENT: Determine appropriate corrective actions to inhibit recurrence of weld problems

Owners Group Response

The Owners Group developed corrective actions to address each root cause and prevent recurrence in the future. In general, those actions involved modifications to weld processes, non-destructive examinations, and other quality or operational changes. From review of correspondence regarding the corrective actions, the NRC staff developed Table 2, a composite summary of the Owners Group corrective actions that address welding for unloaded MSBs.

To provide reasonable assurance that the proposed corrective actions summarized in Table 2 were effective and to verify the presence of a structurally sound weld, the Owners Group

committed to volumetric examination, using UT, of the structural lid-to-shell closure weld during future loadings. For previously loaded casks, the Owners Group also committed to volumetric examination of the structural lid-to-shell closure weld. Development of the UT process included the following major steps:

- Development of flaw size screening criteria, CPC-06Q-301, "Allowable Flaw Size Definition for VSC-24 Dry Storage Cask Structural Lid to Shell Weld," and methodology for dispositioning flaw indications identified by UT;
- Performance of material fracture toughness testing of weld metal, HAZ, and base metal at 0°F to determine the physical properties of base metal, weld metal, and HAZ for both the manual and semi-automatic welding techniques used at each site;
- Submission of weld coupons, to NRC, for independent material testing;
- Construction of an MSB mockup with implanted flaws of various known sizes, orientations, and locations within the structural lid-to-shell weld;
- Development of VMSB 98-001, "Guideline Requirements for the Time-of-Flight Diffraction Ultrasonic Examination of the VSC-24 Structural Lid to Shell Weld;" and
- Demonstration of the UT technique during NRC inspection.

Table 2. Owners Group Corrective Actions for Unloaded MSBs and MSBs to be Manufactured In the Future		
Root Cause	**Corrective Action**	**Applicability**
Defect in shell material; undocumented welds	1. Acid etch top 4 inches of cask 2. UT per ASTM A435 [a] 3. Certification that MSBs meet the design and terms and conditions of the CoC and are in conformance with the Safety Analysis Report and Safety Evaluation Report including any referenced standards, criteria, or requirements [b] 4. Use of low sulfur, calcium-treated, vacuum-degassed steel	1 - 2. Unloaded MSBs already manufactured 3. Unloaded MSBs 4. MSBs manufactured in the future
Improper fit-up of lid and backing ring	5. Proper fit-up of assembly 6. Manual welding to fill-in unacceptable gaps before automated welding	5 - 6. All future lid welding
Moisture contamination of weld	7. Ensure water level in MSB is adequately below the shield lid via partial drain of MSB 8. Vent or inert airspace beneath shield lid 9. Preheat weld area to 200°F	7 - 9. All future shield and structural lid welding, including lid-to-lid and valve cover fillet welds
Hydrogen induced cracking	10. Addition of 200 °F [c, d] preheat 11. Addition of 200 °F postheat, 1 hour 12. Low hydrogen welding electrodes (<10 ml H_2 / 100g deposited weld metal) 13. Large tack welds/balanced weld sequence to prevent movement of lids and better distribute shrinkage forces from cooling of weld 14. 2-hour delay before inspection 15. Use of materials with lower carbon equivalent values	10 - 14. All future shield and structural lid welding, including lid-to-lid and valve cover fillet welds 15. MSBs manufactured in the future

Notes: a. Palisades indicated an alternate, ASME Section III, NB-2532.1

b. NRC CAL Supplements 97-7-002, 97-7-003, and 97-7-004

c. SNC evaluation indicated the effect on time to drain down (VSC-24 Technical Specification 1.2.10) is negligible

d. Meets requirements of ASME Section III, Sub-Section NC

In addition, the Owners Group evaluated the impact that the 200°F preheat and postheat of the MSB shell and closure lids would have on CoC Technical Specification (TS) 1.2.10, "Time Limit for Draining the MSB." The objective of TS 1.2.10 is to provide added assurance that significant changes in moderator density cannot occur during loading or unloading operations and to support the double contingency criteria for criticality safety.

The Owners Group also evaluated the impact of a spent fuel pool (SFP) temperature of greater than 70°F would have on the time to drain limit. The second evaluation was required because in 1993 the utilities identified that SNC Calculation 109.003.13, Revision 0, non-conservatively assumed an SFP temperature of 70°F when in practice the temperature may vary by utility from approximately 70°F to 100°F.

Entergy and SNC performed independent calculations to define the effect of preheat and post heat on TS 1.2.10. Entergy concluded in Calculation 95-E-0083-05, Revision 1 that the preheat and post heat of the MSB would only decrease the drain time, as calculated by TS 1.2.10, by 5 minutes. SNC concluded in Calculation WEP 109.003.20 that preheat and post heat of the MSB would decrease the drain time, as calculated by TS 1.2.10, by 1 hour. In response to the increased heat-up rate due to preheating of the MSB and to respond to an initial SFP temperature greater than 70°F, SNC proposed to modify TS 1.2.10 (see Appendix D). The modification relied on actual temperature measurements to determine the heat-up rate and derive the time at which water would begin to boil inside the MSB.

On September 18, 1997, and June 26, July 9, and July 17, 1998, SNC submitted the following proposed actions to update the VSC-24 SAR and CoC to: (1) revise weld procedures to prevent recurrence of the shield lid to MSB shell and structural lid to MSB shell welding problems; (2) volumetrically inspect the structural lid to MSB shell weld; (3) implement a revised time limit for draining the MS; and (4) implement a revised minimum ambient air temperature at which the MSB may be moved. These proposals are summarized in Appendix C and Appendix D.

NRC Staff Evaluation

The staff reviewed the information provided by the Owners Group and independently evaluated the proposed corrective actions related to the weld cracking. The corrective actions described in Table 2 are based on the root causes identified for the known instances of cracking.

The four corrective actions for the first root cause, defects in shell material and undocumented welds, are based on identifying defects present in the MSB wall or preventing undocumented welds. Referencing the Corrective Actions (CA) in Table 2, CA 1 (acid etching) will identify undocumented welds and CA 2 (UT examination of the base material) will identify material defects and thus allow them to be dispositioned or removed and repaired before MSB loading. The staff noted that Palisades alternate UT standard, ASME Section III, NB-2532.1, was equivalent to ASTM A435, and therefore, acceptable. CA 3 (certification of MSBs) ensures an added level of oversight to verify the MSB fabrication process met requirements and commitments. CA 4 (use of low sulfur, calcium-treated, vacuum-degassed steel) is a preventive measure to improve; (1) the through-thickness mechanical properties of the steel, important for the residual stress loading during closure welding, and (2) fracture toughness properties of the steel, important for the hypothetical drop accident. The staff concluded that the proposed

corrective actions for the first root cause provide adequate measures to detect and properly address potential base metal defects or undocumented welds in existing unloaded MSBs. For MSBs fabricated in the future, the proposed corrective actions should minimize the potential for base metal defects and undocumented welds.

The two corrective actions for the second root cause, improper fit-up of lid and backing ring, are intended to check proper fit-up (CA 5), and if required, repair by welding to fill in unacceptable gaps (CA 6). These measures serve to reduce the residual stresses generated during cooling of the weld. High residual stresses can distort the structure, exacerbate an existing welding flaw, e.g., propagate a crack, and make a weld more susceptible to HIC. Poor fit-up may also cause weld metal cracking; CA 6 (reducing the root opening by building up the edges with weld metal) is an acceptable remedy for unacceptable gaps. The staff concluded that the proposed corrective actions for the second root cause should adequately prevent poor fit-up conditions during future closure lid welding.

The corrective actions for the third root cause, moisture contamination of weld, should preclude and remove water in the area surrounding the weld joint to keep it from becoming entrained into the closure welds. Water in the weld joint may cause welding flaws, including porosity. CAs 7 and 8 are intended to remove the source of water in the weld, while CA 9 (preheat) should remove water already there. The staff concluded the proposed corrective actions for the third root cause are adequate to prevent future moisture contamination of welds.

The corrective actions for the fourth root cause, HIC, are preventive measures. The staff evaluated the changes to the welding procedures proposed by the Owners Group to address HIC and concluded that these changes will:

- allow hydrogen to diffuse out of base metal before and after welding to reduce susceptibility to HIC (CAs 10[1] and 11)
- reduce the cooling rate and thus hardness, which reduces susceptibility to HIC (CAs 10 and 11)
- improve fracture and notch toughness (CAs 10 and 11)
- reduce hydrogen introduction into weld metal from electrodes to reduce susceptibility to HIC (CA 12)
- reduce residual stresses to reduce susceptibility to HIC (CAs 10, 11, and 13)

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[1]The 200°F preheat temperature described in CA 10 meets the requirements of ASME Section III, Subarticle NC-4600, (1989) Heat Treatment, which references Section III, Appendix D, Nonmandatory Preheat Procedures, for the SA-516, Grade 70, material used in the VSC-24.

If, despite the above corrective actions, HIC still occurs, a hold period of 2 hours between the completion of the weld and inspection (CA 14) will allow time for delayed HIC to develop such that it will be detectable by the various non-destructive examination methods used on the VSC-24 closure welds. For future casks, steels with a lower carbon equivalent, which are less susceptible to HIC, will be used (CA 15).

Relative to concerns with delay times for HIC as previously discussed, the staff found that the 2-hour hold period prior to performing the final weld inspection for future MSB loading is an acceptable practice. The revised welding procedures ensure that temperatures are maintained at or above 200°F during welding. At these temperatures, the diffusivity of hydrogen is increased, leading to the escape of hydrogen from the weldment to the surrounding metal and to the ambient air. This decreases the available hydrogen and thereby decreases the likelihood of cracking. However, it also leads to a decrease in the delay time for any cracks that might form. Nevertheless, the detection of any significant cracks that may have formed is ensured by the fact that the UT inspection of the structural lid closure weld is not to be conducted until 2 hours after the completion of the final pass. As the root pass is regarded to be the most likely pass to crack, the beneficial effects of elevated temperatures will have been present for many hours from the time that this pass is completed to the time of the inspection. This gives high confidence that sufficient time has been allowed for the initiation of cracks (that may form) prior to conduct of the UT inspection. The staff concluded that CAs 10 through 15 for the fourth root cause, HIC, should effectively reduce the susceptibility of future welds to HIC[2] and allow for detection, should they occur.

On the basis of concerns with the weld cracking events and experience that has shown that welding processes are not always reliable, NRC staff sought reasonable assurance to confirm that the MSB closure has sufficient integrity to meet the requirements of 10 CFR 72.236 (:). To address this issue, the Owners Group developed a UT technique to volumetrically examine the structural lid-to-shell weld and committed to perform UT examination of all currently loaded MSBs and MSBs to be loaded in the future. The UT technique will confirm the integrity of the welded joint through detection of subsurface flaws such as cracking and weld process-induced flaws, e.g., slag inclusions, incomplete fusion, incomplete joint penetration. ASME Section III recognizes UT for volumetric examination of welds. The Owners Group successfully demonstrated its UT technique during an NRC inspection. The staff documented its findings on the acceptability of UT to examine the structural lid-to-shell welds for both future MSB loadings and previously loaded MSBs in NRC IR 72-1007/98-202.

The staff evaluated the methodology for dispositioning flaw indications found during UT described in VMSB 98-001, "Guideline Requirements for the Time-of-Flight Diffraction Ultrasonic Examination of the VSC-24 Structural Lid to Shell Weld." Flaw indications will be characterized, evaluated for flaw proximity per the criteria of ASME Section XI, IWA-3300 (1989), and compared to screening criteria. Flaws within the screening limits are acceptable. If a flaw is larger than these screening limits, a flaw specific evaluation, using the methodology of ASME Section XI, IWB-3600 (1989), may be performed to assess acceptability. Flaws that are

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[2]Cieslak, M. J., *Cracking Phenomena Associated with Welding*, article in the *ASM Handbook: Welding, Brazing, and Soldering*, Vol. 6, ASM International, 1993, pp. 88-96.

unacceptable will be removed or reduced to acceptable limits, the area repaired in accordance with a qualified welding procedure, and the area reexamined to determine acceptability. These actions will be performed in accordance with the site quality assurance program. The staff concluded that this approach provided reasonable assurance to ensure the adequacy of the structural lid closure weld.

The staff performed a detailed evaluation of the flaw screening criteria for the UT examination. These criteria were calculated in CPC-06Q-301, "Allowable Flaw Size Definition for VSC-24 Dry Storage Cask Structural Lid to Shell Weld." The screening criteria are applicable to both currently loaded MSBs and those that will be loaded in the future. On the basis of its review, the staff identified, to the Owners Group, the following positions:

- The screening criteria shall be based on a lower bound fracture toughness value derived from the completed fracture toughness testing data. A lower bound fracture toughness value can be established from the existing material fracture toughness test data by:; (1) reducing quasi-static fracture toughness measurements by a factor of 0.6 to adjust for the dynamic load condition (this reduction is consistent with the fracture toughness curves in ASME Section XI, Appendix A, Figure A-4200-1 (1989); (2) calculating the mean of the adjusted values; and (3) reducing the mean of the calculated dynamic data by twice the standard deviation.

- The residual stress value used in calculating the screening criteria shall be an upper bound value at the yield stress level (38 ksi) for the material.

- The screening criteria shall be reduced to account for surface flaws where the limiting stress intensity factor is at the surface-tip rather than the depth-tip. These flaws include postulated semi-elliptical surface cracks with a depth-to-surface-length aspect ratio of 0.5.

- Calculation of the screening criteria to ensure that the primary stress limits of NB-3000, as required by ASME Section XI, IWB-3610(d)(2), are not exceeded for allowable flaw sizes calculated by IWB-3611 or IWB-3612.

- Establishing a minimum structural lid weld temperature requirement applicable to cask movement operations would provide larger flaw screening criteria, maintain an adequate margin of safety, and have minimal operational impact for cask movement.

A summary of the staff's detailed material fracture toughness evaluation is enclosed as Appendix A to this report. Appendix A incorporates the results of the independent materials analysis conducted by an NRC contractor as confirmatory research. The staff's VSC-24 structural lid-to-shell weld fracture mechanics evaluation is enclosed as Appendix B to this report. At the revised weld service temperature of 30°F, the staff's independent calculations given in Appendix B corroborate those proposed by the Owners Group after incorporation of the above stated staff positions.

On the basis of: (1) NRC staff review of the calculational approach, input parameters, safety factors, assumptions, and their basis; (2) independent material testing by NRC; and (3) staff independent confirmatory analysis that corroborates the Owners Group analysis, the staff accepted the Owners Group proposed analytical approach in its methodology for dispositioning flaws.

The staff reviewed the calculations regarding the time limit for draining the MSB performed by Entergy and SNC and the staff performed independent calculations. The staff determined that Calculation 95-E-0083, Revision 1, performed by Entergy is non-conservative in that the methodology used by Entergy assumes the heat transfer is at steady-state-conditions. However, the staff also determined that the Calculation WEP.109.003.20, performed by SNC, is conservative and provides adequate assurance that reducing the time in CoC TS 1.2.10, "Time to Drain the MSB," by 1 hour will prevent water inside the MSB from boiling. On July 9, 1998, SNC submitted a proposed revision to CoC TS 1.2.10. The revision relied on periodic temperature measurements of water inside the MSB to determine the heat-up rate and to calculate when the MSB should be drained to avoid boiling. The staff concluded that the temperature measurements provided the utilities with a better methodology to ensure that boiling did not occur in the MSB. Therefore, the staff further concluded that the time to drain the MSB, as stated in Appendix D, must be implemented by utilities using the VSC-24 under a general license until a CoC amendment is approved.

Staff Conclusions on Corrective Actions

The staff concluded that the VSC-24 Owners Group proposed corrective actions, including modifications to the welding procedures, nondestructive examinations, and other material, quality, and operational changes, were adequate to prevent recurrence of the root causes of the identified welding defects. In addition, volumetric examination of the structural lid-to-shell weld joint will provide reasonable assurance to confirm the presence of a structurally sound weld for both future MSB loadings and previously loaded MSBs. The methodology to address flaws identified by UT requires that if unacceptable conditions are identified, the flaws are required to be evaluated and/or repaired in accordance with the licensee's quality assurance program and Owners Group commitments.

The staff accepted calculations regarding the time limit for draining the MSB performed by SNC that show a 1-hour reduction in the allowable time to drain the MSB required by CoC TS 1.2.10, "Time to Drain the MSB."

The staff concluded that SNC's proposed revision to licensing documents as described in Appendices C and D were acceptable. The staff further concluded that utilities, that are currently using the VSC-24 under a general license, must implement the corrective actions contained in Appendices C and D until the affected licensing documents can be updated.

Appendix A

Material Fracture Toughness Evaluation

Owners Group Response

The Owners Group initially proposed a flaw tolerance assessment for the VSC-24 structural lid weld that was based on fracture toughness determined from a fracture toughness - Charpy V-Notch (CVN) correlation attributed to Barsom and Rolfe[1]. The Owners Group originally proposed three different fracture toughness values based on this correlation and CVN testing. Subsequently, the Owners Group performed actual fracture toughness tests on a "typical" VSC-24 structural lid weldment. Samples of this weld were provided to the NRC for independent testing and confirmatory evaluation of the fracture toughness properties. Results from the Owners Group fracture toughness evaluation were documented in CPC-06Q-301, "Allowable Flaw Size Definition for VSC-24 Dry Storage Cask Structural Lid to Shell Weld." However, in this calculation, the Owners Group continued to rely on the use of the CVN correlation approach to establish the limiting fracture toughness of 55.1 ksi$\sqrt{in}$ (kilo-pounds per square inch -- root inch) at 0°F.

NRC Staff Evaluation

The staff conducted an independent assessment of the methodology used by the Owners Group to determine the fracture toughness for the VSC-24 materials and also conducted independent fracture toughness testing of the materials provided by the Owners Group. This independent testing was performed for the NRC by the Carderock Division of the Naval Surface Warfare Center (NSWC) and is documented in a letter dated June 24, 1998, from P. W. Holsberg NSWC to the Chief, Electrical, Materials and Mechanical Engineering Branch, Office of Nuclear Regulatory Research.

The staff plotted the data for fracture toughness and CVN provided by the Owners Group (Figure A1). The staff did not observe any relationship between K_{IC} and CVN in the data presented and concluded that the Barsom-Rolfe correlation for the MSB material was inappropriate. This staff position was documented in the May 21, 1998, letter from NRC to SNC.

In its independent evaluation, the NRC staff considered fracture toughness data generated by both the Owners Group and NSWC and used the following approach to arrive at a limiting fracture toughness of 53 ksi$\sqrt{in}$ for a temperature of 0°F:

(1) Assumption of relative independence of fracture toughness on CVN energy level based on evaluation of available data;

[1]Barsom, J. and Rolfe, S., *Fracture and Fatigue Control in Structures*, Prentice-Hall, 1977, pp. 179-185.

(2) Adjustment of all fracture toughness data for effects of dynamic loading by reduction in accordance with the difference between the ASME Section XI K_{IC} and K_{Ia} curves for T - RT_{NDT} = +50°F (test temperature (T) = 0°F, RT_{NDT} = -50°F. [2] This resulted in the fracture toughness data being reduced by multiplying the values by 0.59, where:

T	=	test temperature;
RT_{NDT}	=	the reference temperature for indexing the fracture toughness behavior as defined by ASME, Section III, NB-2331;
K_{IC}	=	quasi-static fracture toughness;
K_{Ia}	=	dynamic fracture toughness;

Lower bound K_{IC} and K_{Ia} curves for reactor pressure vessel materials are described in the fracture toughness curves in ASME Section XI, Appendix A, Figure A-4200-1 (1989).

(3) A lower bound for the adjusted data set was established at 75 ksi$\sqrt{in}$. A lower bound fracture toughness value can be established calculating the mean of the adjusted values and reducing the mean of the calculated dynamic data by twice the standard deviation.

(4) This lower bound of the data set was then reduced by the ASME Section XI safety factor for the faulted condition ($\sqrt{2}$) resulting in the lower bound fracture toughness of 53 ksi$\sqrt{in}$ at 0°F.

Although the VSC-24 Owners Group and staff used different methods, the approaches yield very similar lower bound estimates for fracture toughness. However, the staff considers the above approach more technically sound due to a lack of dependence on the K_{IC}-CVN correlation. The Owners Group adopted the NRC staff approach as the basis for development of revised flaw size inspection screening criteria as described in the June 11, 1998, letter from SNC to NRC.

[2]Lundin, C.D., et al, "Metallurgical Characterization of the HAZ in SA516-70 and Evaluation of Fracture Toughness Specimens," WRC Bulletin 403, July 1995, Welding Research Council, page 2.

The staff performed an additional iteration on the above approach to evaluate adjustment of the lower bound fracture toughness for increases in the minimum allowable service temperature above 0°F. The lower bound fracture toughness was increased by the differential amount of fracture toughness represented on the ASME Section XI, K_{Ia} curve indexed to the appropriate T - RT_{NDT}. Table A1 presents the lower bound estimates:

Table A1. Variation in Material Fracture Toughness with Temperature

Temperature (°F)	Fracture Toughness with √2 Safety Factor (ksi√in)
0	53.0
20	61.5
30	67.4
40	73.0

The fracture analysis, described in Appendix B, "VSC-24 Structural Lid-to-Shell Weld Fracture Mechanics Evaluation," shows a family of flaw tolerance curves which depend on the minimum service temperature and the fracture toughness values shown above. Due to the classic transition region and variation of the fracture response of the cask material and weldments, over the above-described temperature range, significant enhancement of the fracture toughness properties result when the temperature is increased. This is due to initiation of a fundamental progressive change in the failure mode from predominantly cleavage fracture at lower temperatures, to a mixture of cleavage and higher energy ductile tearing at higher temperatures

K vs. CVN

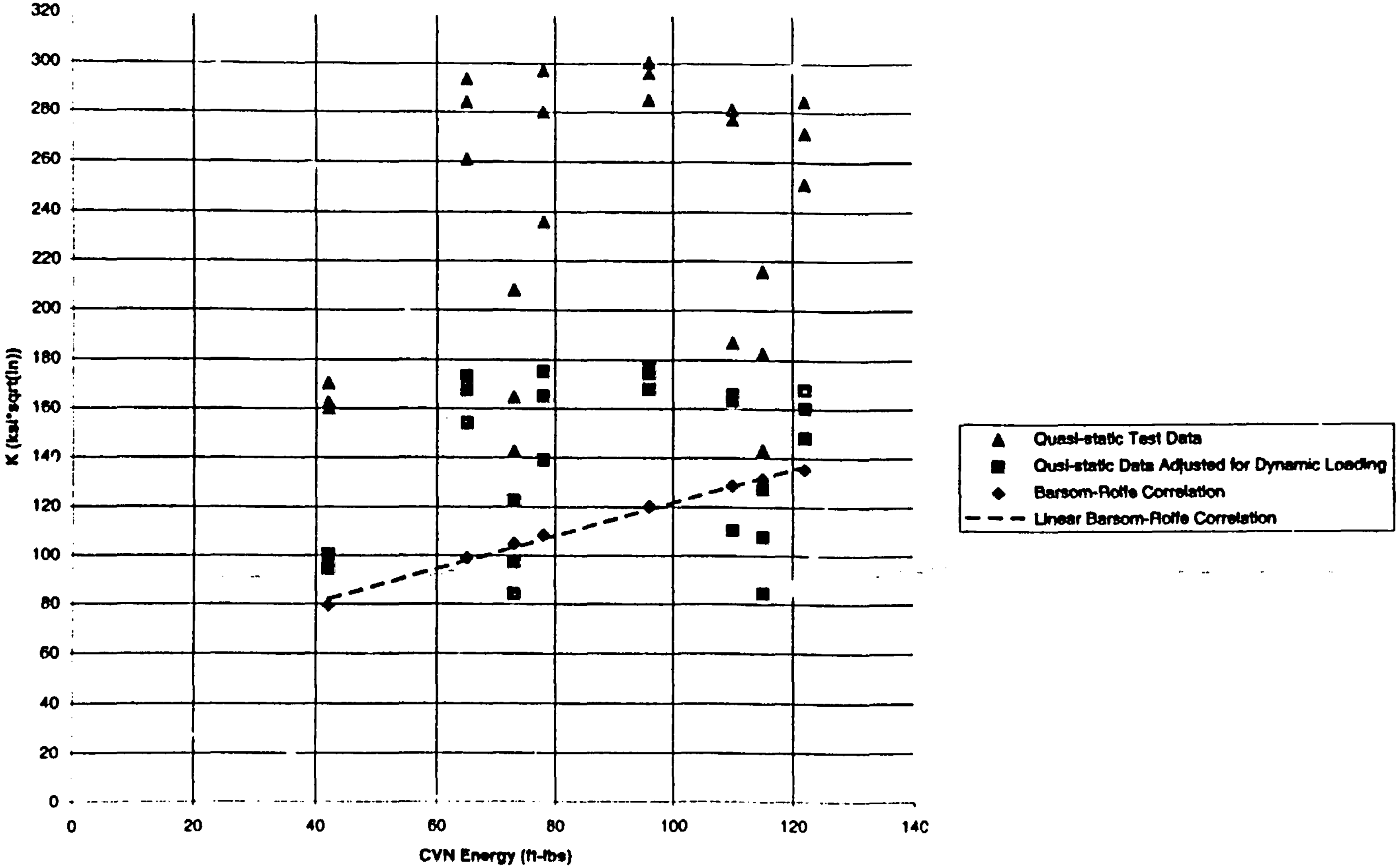

Figure A1

Appendix B

VSC-24 Structural Lid-to-Shell Weld Fracture Mechanics Evaluation

NRC staff independently performed a fracture mechanics evaluation to assess the structural integrity of the closure weld between the structural lid and MSB wall. It is assumed that a hypothetical crack is formed at the closure weld, and this crack is subjected to stresses perpendicular to the plane of orientation. The maximum permissible size of the hypothetical crack is determined to assure structural integrity of the weld under all potential loading conditions.

B.1 Applied Stresses Acting on the Hypothetical Crack

The Owners Group calculation[1] provides information about the maximum stresses in the structural lid-to-shell closure weld under a hypothetical drop accident, which is assumed to be an emergency and faulted condition (service levels C and D events). The primary membrane (P_m) and secondary "local plus bending" ($P_L + P_B$), stresses are:

$$P_m = 7.2 \text{ ksi}$$
$$P_L + P_B = 43.3 \text{ ksi}$$

The ASME allowable stresses are:

$$P_m \leq 36.8 \text{ ksi}$$
$$P_L + P_B \leq 55.1 \text{ ksi}$$

The stresses during the drop accident are conservatively bound by considering a membrane stress (P_m) to be:

$$\text{Bounding } P_m = 43.3 \text{ ksi}$$

The weld residual stresses ($P_{residual}$) at the interface between the structural lid and the MSB shell wall, are conservatively assumed to be equal to the minimum specified yield stress for the material, SA-516, Grade 70, steel. This residual stress is conservatively assumed to be a tensile membrane stress, i.e.,

$$P_{residual} = 38 \text{ ksi}$$

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[1]Table 1, Calculation Package CPC-06Q-301, "Allowable Flaw Size Definition for VSC-24 Storage Cask Structural Lid to Shell Weld," Analytical Support for Dry Spent Fuel Storage Activities for Client: Consumers Energy (Palisades Nuclear Plant), Structural Integrity Associates, Inc., Report SIC-97-039, Rev. 2, April 20, 1998.

B.2 Geometry of the Hypothetical Crack

For conservatism, it is assumed that the potential crack, oriented along the closure weld, is a semi-elliptical surface crack with a crack depth (a) and a surface length (c). The aspect ratio, a/c, of the assumed surface crack can range from 1 to 0 for crack shapes ranging from "semi-circular to that of "infinite length" crack. Fully-elliptical embedded cracks could also form within the closure weld, but the resulting stress intensity factors for embedded, full-elliptical cracks are bounded by those for surface-breaking semi-elliptical cracks of the same aspect ratio.

B.3 Stress Intensity Factors for the Hypothetical Crack

In accordance with Paragraph H-7300[2], for the emergency and faulted condition (the horizontal drop), the stress intensity factor due to applied loading ($K_I^{Applied}$) has a safety factor of $\sqrt{2}$ for the applied loading, and a safety factor of 1 for the weld residual stress. The condition for non-propagation of the assumed crack in a catastrophic cleavage-fracture mode, under the applied and the residual stress induced loadings, is given as:

$$K_I^{Applied} = [K_I^{membrane} + K_I^{residual}/\sqrt{2}] \leq (K_{ID}/\sqrt{2})$$

where K_{ID} is the material fracture toughness under dynamic loading condition, such as during a drop/impact loading of the storage cask. The dynamic fracture toughness (K_{ID}) of a material is a test-temperature and strain-rate dependent property. It is preferable to determine K_{ID} experimentally at the desired temperature and strain-rates reached by the cask material during the drop accident, which would require considerable time and effort to carry out the tests. It could also conservatively be estimated from statically determined fracture toughness (K_{IC}), as presented in Appendix A of this report.

The computer code pc-CRACK[3] was used for determining the stress intensity factors (K_I) for semi-elliptical surface cracks with aspect ratios of 0.2, 0.1 and a continuous single edge crack plate (SECP, i.e., a surface crack with an aspect ratio, a/c, of 0). For the cracks with aspect ratios of 0.2 and 0.1, the depth tip has a higher K_I value than the free-surface tip of the semi-elliptical crack. For semi-elliptical cracks with an aspect ratio, a/c, of 0.5, the present version of pc-CRACK does not determine the highest value of K_I, which occurs at the free-surface tip of the

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[2]ASME Boiler and Pressure Vessel Code, Section XI, Appendix H, 1989 Edition.

[3]pc-CRACK Version 2.0, "Fracture Mechanics Software for Personal Computers," Structural Integrity Associates, Inc., San Jose, California, 1989.

crack. Therefore, for an a/c ratio of 0.5, the K_I values were determined from the influence functions presented in Tables A-3320-1 and A-3329-2 of the 1995 version of ASME Appendix A[4]. Paragraphs A-3300 (b) and (c) in 1989 version of ASME Appendix A[5] have cautionary notes to check for the maximum value of K_I, should the K_I value vary around the crack periphery.

Figure B1 shows the maximum stress intensity factors (K_I) for the semi-elliptical cracks with aspect ratios, a/c, of 0.5, 0.2, 0.1 and 0 SECP, as a function of the crack depth. It can be seen that as the aspect ratio, a/c, value decreases from 0.5 to 0, the crack driving force (K_I) values increase with the SECP (i.e., for a/c = 0) being the highest value for any given crack depth.

B.4 Flaw Screening Criteria

Flaw screening criteria to prevent cleavage crack propagation were determined on the basis of bounding estimates of dynamic fracture toughness (K_{ID}) values at assumed minimum closure weld service temperatures, as shown in Appendix A, Table A1. The flaw screening criteria (depths and surface lengths) criteria for semi-elliptical surface-breaking flaws are shown in Figure B2. For flaw lengths that are 18 inches or less (i.e., about 10% of the MSB shell circumference), the primary stress limits of NB-3000 are not exceeded, per Paragraph IWB-3610 (d) (2) of Section XI to the ASME Code (1989).

[4]ASME Boiler and Pressure Vessel Code, Section XI, Appendix A, 1995 Edition.

[5]ASME Boiler and Pressure Vessel Code, Section XI, Appendix A, 1989 Edition.

Applied K versus Crack Depth for (Horizontal Drop + 0.707*Weld Residual Stress) Loading

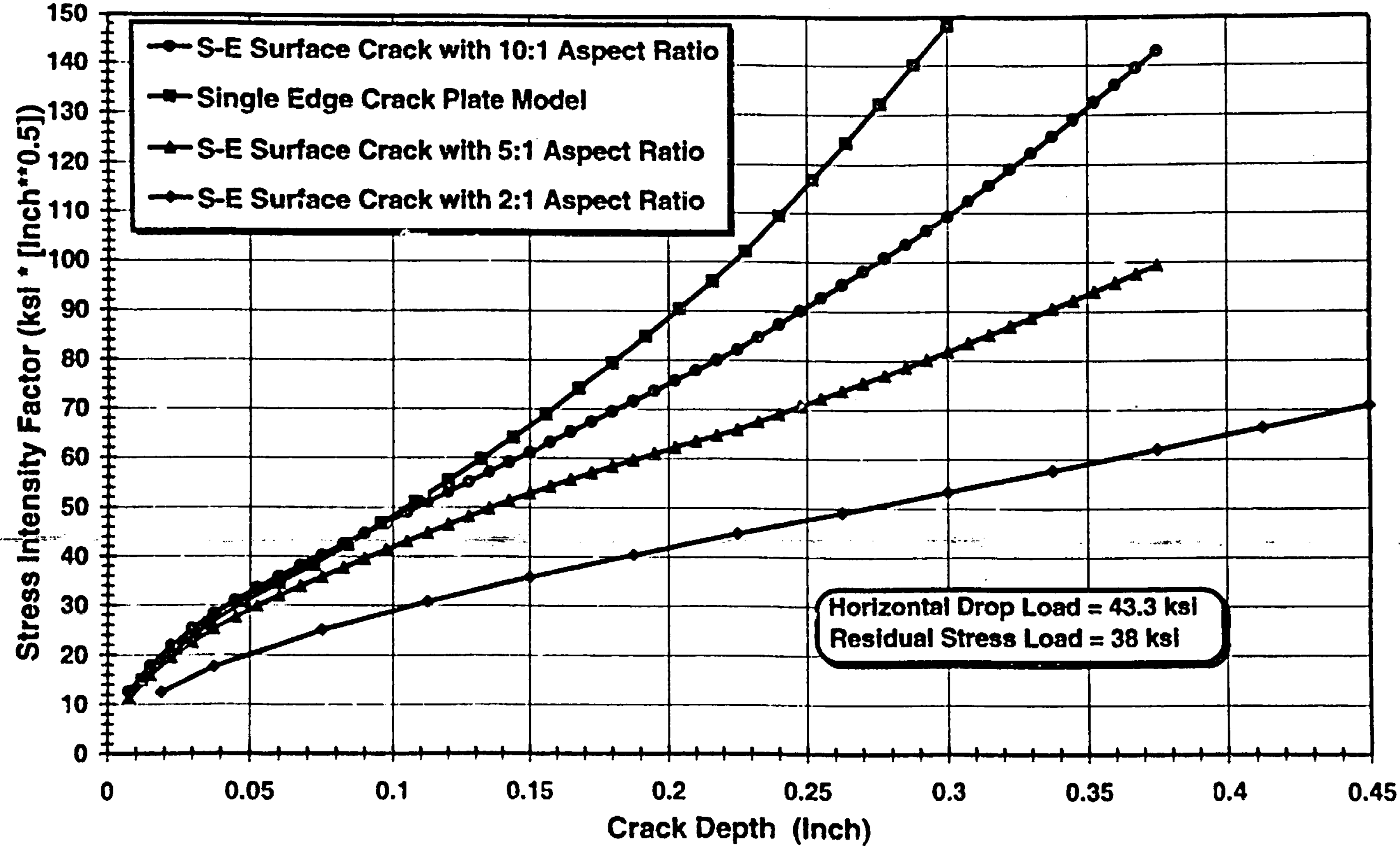

Figure B1

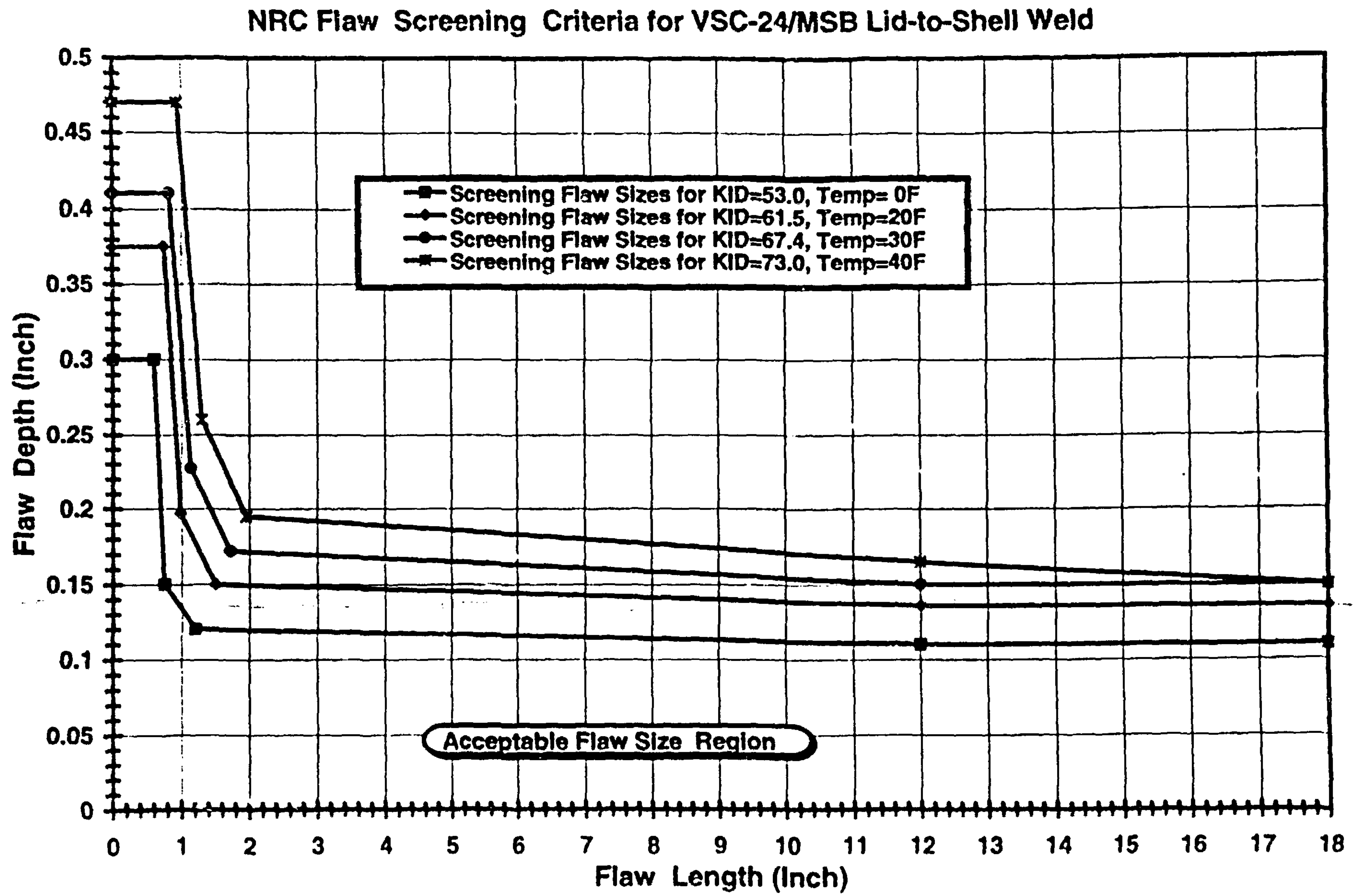
NRC Flaw Screening Criteria for VSC-24/MSB Lid-to-Shell Weld
Screening Flaw Sizes for KID=53.0, Temp= 0F
Screening Flaw Sizes for KID=61.5, Temp=20F
Screening Flaw Sizes for KID=67.4, Temp=30F
Screening Flaw Sizes for KID=73.0, Temp=40F
Acceptable Flaw Size Region
Flaw Depth (Inch)
Flaw Length (Inch)
0.5
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18

Figure B2

Appendix C

Required Changes to the VSC-24 Safety Analysis Report

SNC must update the VSC-24 Safety Analysis Report to contain the following information:

1 In addition to the material specifications currently described in the SAR, the MSBs will be fabricated from low carbon, low sulfur, calcium-treated, vacuum-degassed steel. If material has already been purchased which does not meet those specifications, the top 4 inches of the MSB must be inspected for flaws and defects by acid etching, and the top 4 inches of the MSB must be UT inspected in accordance with ASTM A435.

2. The shield lid and structural lid should be fit up properly. Both lids must be tack welded in place using large tack welds or a balanced weld sequence to prevent movement of the lids and better distribute shrinkage forces from cooling of the weld. Manual welding should be used to fill in unacceptable gaps before automated welding.

3. The water level inside the MSB should be drained to a level sufficiently below the shield lid to prevent water contamination of the weld.

4. Air spaces must be vented in accordance with commitments made by utilities and SNC in response to Bulletin 96-04, "Chemical, Galvanic, or Other Reactions in Spent Fuel Storage and Transportation Casks."

5. The shield and structural lid welds must be preheated to 200°F.

6. The shield and structural lid welds must be made using weld consumables with low hydrogen levels (less than 10ml/H_2/STP/100g).

7. The preheat temperature must be maintained for a minimum of 1 hour after completion of the final weld pass. The 1-hour minimum is measured in the aggregate and is not required to be continuous.

8. In addition to the currently required post weld inspection of CoC TS 1.2.9, "Non-Destructive Examination of MSB Shield and Structural Lid Welds," a UT inspection will be performed of the structural lid weld in accordance with SNC Document No. VMSB-98-001, latest revision, "Guideline Requirements for the Time-Of-Flight Diffraction Ultrasonic Examination of the VSC-24 Structural Lid to Shell Weld." A minimum of 2 hours must have expired between completing welding and performing any welding inspections.

9. During MSB loading operations the drain time will be controlled by revised CoC TS 1.2.10, "Time for Draining the MSB," contained in Appendix D.

10. The UT acceptance criteria contained in SNC Document No. VMSB-98-001, Revision 4, is based on a minimum temperature of 30°F to move the MSB. Therefore, CoC TS 1.2.13, "Minimum Temperature for Moving the MSB," will be changed to revise the minimum temperature from 0°F to 30°F, as described in Appendix D.

Appendix D

Required Changes to the VSC-24 Certificate of Compliance No. 1007

A. The following guidelines will be incorporated into the VSC-24 SAR section 12.2.2.4 and the CoC as Section 1.2.9.

Title: Non-Destructive Examination of MSB Shield and Structural Lid Welds

Specification: The MSB pressure boundary shield lid, structural lid and valve cover plate closure welds shall be liquid penetrant tested (PT) in accordance with the requirements of the ASME Boiler and Pressure Vessel Code Section III, Division I, Article NC-5000 (1986 edition, 1988 addenda). The PT acceptance standards shall be as described in NC-5350.

In addition, the MSB structural lid-to-shell weld shall be examined by ultrasonic testing (UT) in accordance with the criteria defined in the "Guideline Requirements for the Time-of-Flight Diffraction Ultrasonic Examination of the VSC-24 Structural Lid to Shell Weld", VMSB-98-001, latest revision.

The initiation of the specified PT and UT examinations on the completed welds must be delayed for a minimum of two hours after completion of the weld to be examined.

Applicability: The PT examination is applicable to the root and final weld surface on the shield lid-to-shell weld and the structural lid-to-shell weld. The PT examination is also applicable to the final weld surface on the structural lid-to-shield lid weld and the valve cover plate-to-structural lid welds for all MSBs.

The confirmatory UT examination is applicable to the completed MSB structural lid-to-shell weld.

Objective: To ensure that the MSB is adequately sealed, leak tight, and to confirm the structural adequacy of the structural lid-to-shell weld.

Action: If the PT examination indicates that a weld is unacceptable:

1) The weld shall be repaired in accordance with Article NC-4000 Fabrication and Installation, ASME Boiler and Pressure Vessel Code, Section III - Division I, Sub-Section NC (1986 edition, 1988 addenda)

2) The repaired weld shall be re-examined in accordance with the requirements of this specification.

If indications are found as a result of the UT examination:

1) Evaluate the flaw proximity per ASME Section XI, IWA-3300 (1989 edition)

2) Compare each flaw to the flaw screening criteria provided below:

Flaw Depth (L $\leq$ 0.7 in.)	Flaw Depth (L > 0.7 in.)
0.37 in	0.16 in

3) If a flaw is unacceptable, perform further flaw specific evaluation (LEFM or EPFM) per VMSB-98-001, latest revision, to show that the flaw is acceptable for continued operation, or repair the weld in accordance with Article NC-4000 Fabrication and Installation, ASME Boiler and Pressure Vessel Code, Section III - Division I, Sub-Section NC (1986 edition, 1933 addenda) to reduce the flaw to an acceptable size.

4) The repaired weld shall be re-examined in accordance with the requirements of this specification.

Surveillance: During MSB closure operations.

Bases: Article NC-5000 Examination, ASME Boiler and Pressure Vessel Code, Section III - Division I, Sub-Section NC (1986 edition, 1988 addenda).

Delayed initiation of the specified PT and UT examinations ensures that closure welds will be inspected after any potential delayed hydrogen induced cracking.

The safety analysis of leak tightness of the MSB is based on a weld being leak tight to 10^{-4} scc/sec. These examinations are performed to ensure compliance with the leak tightness design criteria, and to confirm the structural adequacy of the structural lid-to-shell weld.

B. The following guidelines will be incorporated into the VSC-24 SAR as Section 12.2.2.6 and the CoC as Section 1.2.10.

Title: Time Limit for Draining the MSB

Specification: The water inside the MSB shall be drained or the MSB returned to the Spent Fuel Pool prior to reaching a bulk temperature of 212°F. The allowed drain down time shall be calculated as follows:

$$Y\ (\text{hrs}) = \frac{(212 - T_i)\ °\text{F}}{X\ (°\text{F/hr})}$$

where:

Y = allowed draindown time limit (hrs) determined within 12 hours following emergence of the MSB from the spent fuel pool

T_i = spent fuel pool water temperature as measured upon emergence of MSB from the spent fuel pool (°F)

X = actual heatup rate of an isolated MSB based on comparing MSB sample temperatures to initial spent fuel pool temperature, over time (°F/hr),

where:

$$X = (T_s - T_i)\ °\text{F} / (t_s - t_i)\ \text{hr}$$

or

$$X = 3°\text{F/hr times } (x\ \text{kW})/(24\ \text{kW})$$

whichever is greater

x = total spent fuel decay heat load (kW) in the MSB

T_s = MSB water temperature at time of sampling (°F)

t_s = time of sampling MSB

t_i = time of measuring T_i

Applicability: This specification is applicable to all MSBs.

Objective: To provide added assurance that significant changes in moderator density cannot occur and to support the double contingency criteria for criticality safety.

Action: If the water cannot be drained within the allowed drain down time, the MSB must be placed back into the fuel pool before the drain down time expires, and allowed to cool.

Surveillance: The water temperature inside the MSB shall be measured at least every 6 hours following determination of the draindown time (Y) until the MSB is drained or returned to the pool. The user must determine after each measurement (based on the heat-up rate X) whether the allowable temperature of 212°F could be exceeded before the next measurement.

Basis: Periodic MSB water temperature monitoring is the most reliable method of temperature control to prevent boiling. Using the greater of a factored 3°F/hr or the calculated heat-up rate is conservative because the heat-up rate could only decrease as the system moves toward the steady-state condition.

The heat-up rate value of 3°F/hr was determined assuming an adiabatic heat-up of a fully loaded cask with the maximum allowable heat load of 24 kW.

The 12 hour window for calculation of the drain down time affords sufficient time to establish a reliable heat-up rate. It remains early enough in a conservative heat-up cycle to allow for the development and initiation of corrective actions, if required.

The 6 hour interval for surveillance of the MSB water temperature is conservative because it ensures that timely temperature measurements are taken and heat-up projections are made.

C. The following guidelines will be incorporated into the VSC-24 SAR as Section 12.2.2.9 and the CoC as Section 1.2.13.

Title: Minimum Temperature for Moving the Loaded MSB

Specification: Movement of the loaded MSB while inside the VCC will only be allowed at ambient temperatures of 0°F or above, coincident with a closure weld temperature of 30°F or above.

Objective: To mitigate the potential for brittle failure.

Action: Confirm before moving the loaded MSB, while inside the VCC, that the ambient temperature is at 30°F or above.

If the ambient is less than 30°F but 0°F or greater, confirm that the structural lid-to-shell weld is at 30°F or above. Physical measurement should be used to determine the structural lid-to-shell weld temperature. Alternatively, calculations similar to those presented in Chapter 4 of the SAR may be used for the specific fuel to determine the minimum MSB shell temperature for any particular ambient condition.

Surveillance: The temperatures shall be determined prior to movement of the VSC.

Basis: Movement of the loaded MSB at a 30°F ambient temperature or above conservatively satisfies this specification.

Restricting movement of the loaded MSB below the temperatures specified will mitigate the potential for brittle failure.

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°F; and, therefore, movement of the loaded MSB at temperatures 0°F or above will mitigate the potential for brittle fracture.

The temperature limit for the structural lid-to-shell weld effectively increases material toughness, and permits allowable flaw size in the weld to be governed by primary stress criteria rather than by brittle fracture limits.

Specifications for future procurement and fabrication of pressure retaining materials, including base materials and weld metal, shall specify a minimum Charpy V-notch impact absorbed energy value of 15 ft-lbs at -50°F for the MSB pressure retaining materials, with the additional requirement of a minimum of 45 ft-lbs at 0°F for the shell, lid and weld materials associated with the structural lid-to-shell weld. These requirements define minimum values for material toughness and produce adequate margins of safety relative to the potential for brittle fracture under the most severe handling conditions.

Appendix E

Acronyms

ANO	Arkansas Nuclear One
ASME	American Society of Mechanical Engineers
ASTM	American Society of Testing and Materials
CE	carbon equivalent
CA	Corrective Action
CAL	Confirmatory Action Letter
CoC	Certificate of Compliance
CVN	Charpy V-Notch
°F	degrees Fahrenheit
g	gram
HAZ	heat affected zone
HIC	hydrogen induced cracking
IR	inspection report
ksi	kilo-pounds per square inch
kW	kilo-watts
ml	milliliter
MSB	multi-assembly sealed basket
NRC	U.S. Nuclear Regulatory Commission
NSWC	Naval Surface Warfare Center
RAI	request for additional information
RES	Office of Nuclear Regulatory Research
SAR	safety analysis report
SECP	single edge crack plate
SFP	spent fuel pool
SFPO	Spent Fuel Project Office
SNC	Sierra Nuclear Corporation
STP	standard temperature and pressure
TS	Technical Specification
UT	ultrasonic testing
VSC-24	Ventilated Storage Cask Model No. 24
WE	Wisconsin Electric Power Company
wt%	weight percent

Appendix F

List of Related Correspondence

I. NRC correspondence to SNC

A. Commitments Made to NRC by British Nuclear Fuels, Ltd., Sierra Nuclear Corporation, and the VSC-24 Owners Group - June 24, 1998
B. NRC Inspection Report 72-1007/98-202 - June 18, 1998
C. Staff Review of Acceptance Criteria - May 21, 1998
D. Status of Welding Problems - February 12, 1998
E. Commitments Made to NRC by Owners Group at December 4, 1997, Meeting - December 9, 1997
F. CAL 97-7-001 Request for Additional Information - October 24, 1997
G. NRC Inspection Report 72-1007/97-212 - August 29, 1997
H. CAL 97-7-001 Request for Additional Information August 26, 1997
I. CAL 97-7-001 - May 16, 1997
J. NRC Inspection Report 72-1007/97-204 - April 15, 1997

II. Correspondence from SNC to NRC

A. Clarification to the Proposed Technical Specifications for NDE - July 17, 1998
B. Revised Response to November 6, 1997, Request for Additional Information - July 9, 1998
C. Owners Group UT Guidelines, Revision 4 - June 26, 1998
D. Response to November 6, 1997, Request for Additional Information - June 26, 1998
E. Transmittal of Hypothetical Flaw Analysis - June 26, 1998
F. Revised Owners Group UT Guidelines - June 11, 1998
G. SNC Response to May 21, 1998, Letter - June 11, 1998
H. Owners Group Milestone Schedule - May 5, 1998
I Owners Group UT Guidelines - May 1, 1998
J. Allowable Flaw Size Calculation, Rev. 2 - April 20, 1998
K. Mock-Up Flaw Size Location - January 14, 1998
L. Owners Group Testing Commitments - December 23, 1997
M. Allowable Flaw Size Calculation, Rev. 1 - December 17, 1997
N. Response to Question 4 - RAI Concerning CAL 97-7-001 - November 25, 1997
O. Response to Questions 2 and 3 - RAI Concerning CAL 97-7-001 - October 24, 1997
P. SNC Response to Nonconformances in Inspection Report 72-1007/97-212 - September 29, 1997
Q. SNC Response to August 26, 1997 RAI - September 18, 1997
R. SNC Response to CAL 97-7-001 - July 30, 1997
S. Fax Transmittal from T. Wenner: Identification of Undocumented Welds - July 10, 1997
T. SNC Response to CAL - June 27, 1997
U. SNC Response to Inspection Report 72-1007/97-204 - May 15, 1997

III. NRC correspondence to Arkansas Nuclear One, Point Beach, & Palisades

A. Arkansas Nuclear One
1. NRC Inspection Report 72-13/97-215 - December 2, 1997
2. CAL 97-7-002 (Supplement) - September 2, 1997
3. NRC Inspection Report 50-368/97-12, 72-13/97-10 - May 21, 1997
4. CAL 97-7-002 - May 16, 1997

B. Palisades
1. CAL 97-7-003 (Supplement) - September 5, 1997
2. CAL 97-7-003 - May 16, 1997

C. Point Beach
1. CAL 97-7-004 (Supplement) - September 5, 1997
2. CAL 97-7-004 - May 16, 1997

IV. Correspondence from Arkansas Nuclear One, Point Beach, & Palisades

A. Arkansas Nuclear One
1. ANO CAL Response - March 12, 1998
2. ANO CAL Response - August 11, 1997

B. Point Beach
1. Point Beach CAL Response - September 22, 1997
2. Point Beach CAL Response - August 9, 1997

C. Palisades
1. Palisades CAL Response - September 19, 1997
2. Palisades CAL Response - August 5, 1997