VSC Weld Cracking Evaluation in Response to NRC CAL 97-7-001

Sierra Nuclear Corporation
(SNC)
Scotts Valley, California

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Executive Summary

Sierra Nuclear Corporation's VSC-24 system is certified by the United States Nuclear Regulatory Commission (NRC) for the storage of spent fuel at reactor sites. Currently, the VSC system is being used to store fuel at the Palisades, Point Beach, and Arkansas Nuclear One (ANO) sites. The VSC Multi-Assembly Sealed Basket (MSB) uses two closure lids, a shield lid and a structural lid, each of which is welded to the MSB shell to ensure that helium remains inside the MSB during fuel storage.

Some incidences of weld cracking have been identified during welding of the closure lids for the VSC MSB. Therefore, SNC and the users of the VSC system assembled an international team of welding and metallurgy experts to perform an evaluation of the issues associated with the lid weld cracking incidents. The evaluation included an assessment of the causes of the cracking incidents observed to-date, an evaluation of the potential for delayed cracking in MSBs that have been loaded, and development of actions to inhibit recurrence of cracking in welds for MSBs to be loaded in the future.

The root causes of the cracking were determined to be different for each site. The weld crack observed at Palisades was determined to have been caused by an existing condition in the shell material near the weld which opened up when the shield lid-to-shell weld was made. The Point Beach cracks were caused by fit-up problems with the structural lid and backing ring and by the presence of moisture near the shield lid-to structural lid seal weld. Two incidences of cracking were observed at ANO. The second crack at ANO was judged to have been hydrogen-induced, resulting from a combination of high residual stresses due to joint restraint, presence of hydrogen in the weld wire, and a shell material that is susceptible to heat affected zone (HAZ) hydrogen cracking. No direct physical evidence was available to evaluate the cause of the first crack at ANO, but the circumstances under which it occurred were similar to those of the second crack.

On the issue of delayed cracking, the review team concluded that, based on the parameters which affect the risk of hydrogen cracking, the lid welds for MSBs loaded to-date may be susceptible to the risk of hydrogen-induced cracking. Since hydrogen-induced cracking can be a delayed phenomenon, an evaluation was made of the delay times that would be expected for welds with characteristics similar to the lid welds. Research data on delay times were reviewed and temperature differences between the research welds and the lid welds were used to determine the maximum expected delay times associated with the welds for each MSB loaded to date. The time intervals from completion of welding to weld inspection of the final weld pass were reviewed for MSBs loaded to date. It was determined from this data that the expected maximum delay times associated with each weld are less than the time interval from completion of welding to inspection of the weld. It was therefore concluded that undetected hydrogen-induced cracking was highly unlikely in the welds made on MSBs loaded to-date. If hydrogen-induced cracking had occurred in the welds, it most likely would have occurred prior to the time that the weld inspections were performed and would therefore have been detected.

Recommended changes in welding processes and procedures were developed to address each of the identified causes of the weld cracking. These changes include the use of a 200°F preheat for all of the lid welds and the use of welding consumables with low hydrogen levels to provide reasonable assurance against hydrogen-induced cracking. The preheat temperature will be maintained for a minimum of 1 hour after completion of the final pass of the weld.

Acid etching of the top 4 inches of the inside surface of the MSB was initiated for MSBs already manufactured, but not yet loaded to detect the possible presence of undocumented welds in the area where the lid welds are to be made. Undocumented welds were found on the MSBs at ANO. An evaluation of these welds was performed and it was concluded that they will not adversely affect MSB performance.

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1.0 BACKGROUND

1.1 General

The Ventilated Storage Cask (VSC) system designed by Sierra Nuclear Corporation (SNC) is certified by the United States Nuclear Regulatory Commission (NRC) under Title 10 of the U.S. Code of Federal Regulations, Part 72 (10CFR72), under Docket No. 72-1007 for the storage of spent fuel at reactor sites. Currently, the VSC system is being used to store fuel at the Palisades, Point Beach, and Arkansas Nuclear One (ANO) plant sites. To date, 19 VSC casks have been loaded at the three sites, 13 at Palisades, 2 at Point Beach, and 4 at ANO.

The VSC system utilizes a multi-assembly sealed basket (MSB) to hold 24 pressurized water reactor (PWR) spent fuel assemblies. Closure of the MSB is accomplished using two closure lids, a shield lid and a structural lid, each of which is welded to the MSB shell to ensure that helium remains inside the MSB during fuel storage.

Some incidents of weld cracking have been encountered during welding of the MSB closure lids at the three sites where casks have been loaded. After cracking was discovered during the first cask loaded at ANO, the Nuclear Regulatory Commission (NRC) conducted a special inspection at SNC headquarters during the week of March 17-21, 1997 which focused primarily on the lid weld cracking that had occurred. The NRC identified several concerns associated with VSC lid weld cracking, including concerns that the causes of the cracking that had occurred were not well understood, and that the potential existed for cracking to have developed after inspections of the welds were performed.

Due to the possible generic nature of these weld failures, SNC and the users of the VSC-24 system initiated a complete evaluation of all issues associated with the VSC-24 lid weld cracking incidents. This evaluation was a joint effort led by SNC with participation by SNC's utility clients, partners and consultants. SNC met with the NRC on May 6, 1997 to describe the planned actions to address the weld lid cracking issue. The NRC subsequently issued a Confirmatory Action Letter to SNC on May 16, 1997 confirming the actions which SNC had committed to perform to address this issue.

An international team of welding and metallurgy experts, including some of the most prominent individuals in this field, was assembled to perform the lid weld evaluation. Several of the team members have specific expertise in weld cracking problems associated with carbon manganese steels such as the SA 516 Grade 70 steel used for the MSB shell and lids. The names and organizational affiliations of each of the team members are listed in Table 1. Resumes for each of the team members are provided in Appendix A.

The scope of the evaluation performed by the lid weld review team included the following:

- Review of Parameters Affecting Lid Welds

- ♦ Weld Joint Design/ Configuration
- ♦ Environment in Area of Weld
- ♦ Weld Processes/Procedures
- ♦ Properties of Base Materials and Weld Filler Materials

- Review of Variances Between Users

  - ♦ Weld Processes/Procedures Used
  - ♦ Material Properties
  - ♦ Other Factors

- Review of Data From Weld Cracking Incidences

- Determination of Root Cause(s) of Cracking Incidences (NRC CAL No. 97-7-001, item (1) covered in Section 2.0 of this report)

- Assessment of Potential for Delayed Cracking in Currently Loaded Casks (NRC CAL No. 97-7-001, item (2) covered in Section 3.0 of this report)

  - ♦ Structural Lid
  - ♦ Shield Lid

- Determination of Recommended Changes in Weld Process/Design to Inhibit Recurrence of Welding Problems in Casks Welded in the Future (NRC CAL No. 97-7-001, item (3) covered in Section 4.0 of this report)

The results of the evaluation described above are documented in this report.

1.2 VSC Closure Lid Weld Design

The VSC system utilizes two MSB closure lids, a shield lid and a structural lid. A schematic view of the MSB shield and structural lids and associated welds is shown in Figure 1. The function of the shield lid is to reduce radiation dose on the top of the MSB in order to limit exposure to site personnel during handling operations, including welding, and long term fuel storage. The structural lid ensures MSB integrity during normal operating and accident conditions.

The primary function of the lid welds is to ensure that the helium atmosphere is maintained within the MSB during storage. Helium is added to the MSB to prevent fuel cladding corrosion during storage over the 50 year design life of the cask. Redundant seal welds are required by the VSC Certificate of Compliance (C of C) to give high assurance that a helium atmosphere will remain in the MSB.

Fuel is loaded into the cask in the following manner, as depicted in Figure 2. An empty MSB is placed in the MSB Transfer Cask (MTC) and lowered into the spent fuel pool. Spent fuel is placed into the 24 sleeves of the MSB and the shield lid is lowered into place over the fuel. The loaded MSB is then raised to the spent fuel pool surface and the water inside the MSB is lowered to a point below the bottom of the shield lid. The MSB is placed in the decontamination area of the fuel building and the MSB exterior is decontaminated to allow welding of the shield lid.

Welding of the shield lid requires that steel shims be placed between the shield lid and the MSB shell to act as a backing ring for the shield lid-to-shell weld. These shims are custom fitted for each MSB. The shield lid is welded using ASME Code qualified welding procedures. The Gas Metal Arc Welding (GMAW) process is the primary process used, however, the Shielded Metal Arc Welding (SMAW) may be used as an alternate. The weld wire used in the GMAW process is either flux cored or metal cored depending on the preference of the site welding engineers. The weld is typically made using a machine process for GMAW, but can be completed manually using the SMAW process.

Following completion of the weld root, a liquid penetrant examination is conducted to ensure the integrity of the root. The remainder of the weld is completed in 3-6 passes. Following completion of the weld, the MSB is pressurized with helium and the weld is tested for leaks. A liquid penetrant examination of the finished weld is performed after the helium leak test is completed.

The structural lid is then placed on top of the shield lid after installation of a backing ring. The structural lid is welded to the shell in a similar manner as the shield lid except that significantly more passes are required (10-15) to complete the weld. Liquid penetrant examinations are performed following completion of the root and the final weld pass. The seal weld between the shield lid and structural lid around the perimeter of the port opening can be completed either prior to or following completion of the structural lid-to-shell weld. Water can be removed from the MSB during or after welding of the structural lid. After both lids have been welded and the seal weld between the two lids is completed, a vacuum pressure of 3 Torr is obtained and held for 30 minutes. The MSB is then back filled with helium and a helium leak test is completed to ensure weld integrity. A vacuum pressure of 3 Torr is obtained for a second time and held for 30 minutes to ensure that there is no leakage from the MSB. This also ensures that no moisture will remain in the MSB after the MSB has been sealed.

The MSB is then back filled with helium and the valve is closed. The valve cover plates are welded to seal the port opening and the loaded MSB is placed inside the concrete cask and moved to the concrete pad for storage.

1.3 Discussion of Observed Weld Cracks

The chronology and description of cracking encountered during welding of the shield lid and structural lid is as follows:

In March 1995, a crack was discovered during helium leak testing of the shield lid-to-shell weld for CMSB-05 (VSC No. 10) at Palisades. The crack was detected in the MSB shell base metal approximately 1/8 inch above the weld fusion line. The crack extended down into the shell side of the shield lid weld and was measured to be approximately 6" long x 1/8" in depth. Nondestructive Examination (NDE) of the crack revealed the presence of a material defect in the base metal along a line 4 to 6 inches long located 1 inch away from the toe of the weld. The cool down stresses from the welding process caused the defect to open resulting in the crack. The defect was removed by grinding and the weld was repaired using approved weld repair procedures. Remnants from removal of the defect were preserved by Consumers personnel and metallographic analyses were subsequently performed on these remnants.

In May 1996, cracks were discovered during a liquid penetrant examination of the root pass of the structural lid-to-shell weld on the second cask loaded at Point Beach. The cracks were located in the weld material along the center of the root pass. Three cracks were found, each having a length of less than 1 inch. The fit-up gap between the lid and the backing ring varied around the circumference of the lid and the cracking occurred at locations where the gap was widest. The cracks were removed by grinding and the weld was repaired using approved weld repair procedures. Cracking and weld porosity were also noted in the shield lid-to-structural lid seal weld on this MSB, apparently due to contamination of the weld by moisture. This weld was also repaired using approved procedures.

In December 1996, a crack was discovered during helium leak testing of the shield lid weld on the first cask loaded at ANO. Presence of the crack was confirmed by a subsequent liquid penetrant examination of the weld. The crack was located along the weld fusion line and was approximately 4" in length. The crack was considered by ANO personnel to have been caused by lamellar tearing, based on a visual examination of the crack prior to repair. The crack was ground out and repaired using approved weld repair procedures.

On March 25, 1997, a crack was identified during liquid penetrant examination of the root pass of the shield lid weld on the third cask loaded at ANO. This crack was also located along the weld fusion line. A section of weld 18" in length was ground out in attempting to remove the crack. Prior to repair of this crack, several modifications to the weld process were made to mitigate the potential for additional cracking. A staggered weld sequence was implemented to provide better distribution of the weld shrinkage stresses. Preheat was applied to the joint prior to the repair and during completion of the weld. In order to aid in the evaluation of the cause of the crack, an acetate film replica of the cracked area was prepared prior to repair of the crack. The crack was ground out and repaired using the modified weld procedure. After repair of the weld was completed, the weld was liquid penetrant tested. The liquid penetrant test was conducted approximately 48 hours after completion of the initial weld to ensure that any delayed cracking in the unrepaired area of the weld, should it occur, would be detected. No cracks were detected after the 48 hour period.

2.0 ROOT CAUSES OF CRACKING

The following discussions separately address the root causes of the weld cracking that occurred at each site, as the causes are different for each site.

2.1 Palisades

Evaluations of the cause of the crack in the shield lid-to-shell weld for Palisades CMSB-05 were performed by both Consumers and SNC. The crack was initially thought to have been caused by a subsurface lamination in the shell material which propagated to the shell material surface when subjected to the shrinkage stresses resulting from welding. On the basis of subsequently performed metallographic analyses, Consumers concluded that the shell material defect resulted from a weld of unknown origin rather than from a lamination in the shell.

The lid weld review team reviewed the data associated with the Palisades crack and the previous root cause evaluations. The team concluded that the weld failure 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. The metallographic analysis revealed a crack that propagated along prior austenitic grain boundaries of a pre-existing weld of unknown origin.

The lid weld review team also concluded that the cause of the weld crack at Palisades is different than the cause of the cracking observed at Point Beach or ANO.

2.2 Point Beach

Wisconsin Electric (WE) personnel performed an evaluation of the causes of the cracking discovered during welding of the structural lid on the second cask loaded at Point Beach. WE concluded that the cracks observed between weld beads on the root pass of the structural lid-to-shell weld were caused by the wide fit-up gaps which were not properly filled using the welding technique employed in the welding process. This resulted in a lack of fusion in the weld metal. WE personnel also evaluated the cause of the problems with the structural lid-to-shield lid seal weld and concluded that they were caused by contamination of the weld by moisture. The moisture resulted from water being forced up into the drain line during cask loading.

The lid weld review team concurred with the WE evaluation and concluded that the causes of the weld cracks at Point Beach were associated with welding technique and are not related to the causes of the cracking observed at Palisades or ANO.

2.3 ANO

2.3.1 Initial Evaluations

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 welding operators before the crack was repaired. No other data is available for use in evaluating the cause of this crack other than the observation by welders that the first crack was similar in appearance to the second crack which occurred during welding of the shield lid-to-shell weld for the third cask loaded at ANO.

A more detailed evaluation of the cause of the second crack was performed by ANO personnel and by an independent welding consultant. This evaluation concluded that the crack was primarily caused by mechanical tearing of the shell material due to weld shrinkage stresses associated with the highly constrained joint geometry of the weld. Hydrogen was not thought to be a significant factor in causing the cracks.

The conclusions from these initial evaluations were subsequently modified as a result of further investigations performed by the lid weld review team.

2.3.2 Lid Weld Review Team Evaluation

The lid weld review team performed a complete review of the data associated with the ANO cracks. The following activities were performed as a part of this review.

- The differences between ANO and the other sites were reviewed, since similar failures have not been observed at the other sites. A matrix containing the welding parameters, chemical composition, and other pertinent information for each lid closure weld at each site is contained in Table 2.

- The differences between ANO and other sites were evaluated with respect to how they may relate to the cause of the cracking.

- An evaluation was performed of the parameters which can contribute to the potential for hydrogen cracking, including:

    - Heat input of the weld
    - Hydrogen content of the weld wire
    - Temperature of the weld area before, during and after welding
    - Chemistry of the shell material which may influence the microstructure resulting from welding

- The replica of the weld crack in the third cask loaded at ANO was re-examined using light microscopy and scanning electron microscopy. The photomicrographs from the re-examination were evaluated by the review team.

- Tests were conducted using samples from the heat of weld wire used in welding the shield lid for the third cask loaded at ANO by The Welding Institute (TWI) to determine weld deposit hydrogen content.

- A through thickness tensile test was performed by TWI on a sample of the shell material from the same heat used for the third cask loaded at ANO. This test was used to evaluate the potential for lamellar tearing of the shell material.

2.3.3 Lid Weld Review Team Observations and Conclusions

The observations made and conclusions reached from the activities described in Section 2.3.2 are as follows:

- The differences between ANO and the other sites that were judged to have a possible influence on the cause of the cracks observed at ANO are:

  - The tack welds completed at Palisades and Point Beach were larger and more numerous than at ANO. These larger tack welds may have better stabilized the shield lid relative to the shell and provided a broader distribution of shrinkage strain than occurred at ANO.

  - The decay heat loads from the fuel loaded at ANO for the two MSBs that experienced shield lid cracking were lower than the heat loads for MSBs that did not crack, resulting in lower temperatures in the weld area for the MSBs that exhibited cracking. Also, at ANO the lids are welded while the MSB and transfer cask are still partially submerged in the spent fuel pool, which slows the heat-up rate of the MSB. The higher temperatures for MSBs where no cracking was observed constitute a degree of preheating that appears to have reduced the susceptibility for cracking in these MSBs. The higher heat loads also provided a small but beneficial degree of post-heat to enhance the escape of hydrogen from the weld.

  - The carbon equivalent values for MSB material used at ANO were slightly higher than those for material used at the other sites. Higher carbon equivalent values are associated with increased hardenability which in turn can lead to increased risk of hydrogen cracking .

- The parameters which affect the risk of hydrogen cracking, including hydrogen level, microstructure, and stress, when considered in combination, were in the range where hydrogen-induced cracking is of concern. The samples of ANO weld wire which were tested for hydrogen content showed an average level of 15.5 ml/H_2/STP/100g. It was the consensus of the review team that in this case the hydrogen content of the weld wire is the most significant factor in the amount of hydrogen introduced into the weld. Other factors such as the humidity of the surrounding air and hydrogen produced from the zinc-borated water reaction were judged to be much less significant in introducing hydrogen into the weld in comparison with the amount of hydrogen introduced via the weld wire.

- After reviewing the results of the re-analysis of the replica of the second crack at ANO, the review team concluded that the crack shown in the photomicrographs from the replica had the appearance of a hydrogen-induced crack based on the crack microstructure.

- To determine the susceptibility of the ANO shell material to lamellar tearing, through-thickness tensile tests were conducted on samples of the ANO shell material. The test results indicated a consistent 35% short transverse reduction of area (STRA). This is considerably higher than the 20% minimum acceptance standard contained in paragraph 5 of American Society of Mechanical Engineers (ASME) specification SA770 for the Through-Thickness Tension Testing of Steel Plates for Special Applications. The results of these tests indicate that the samples of the ANO shell material that were tested have excellent resistance to lamellar tearing.

On the basis of the observations listed above, the review team concluded that the second crack at ANO appears to have been hydrogen-induced. The review team also concluded that there is no evidence to indicate that other potential causes of cracking including lamellar tearing, undocumented welds discovered as a result of the team investigation, and small sulfur inclusions in unloaded MSBs found by additional testing at ANO, contributed to the cause of the cracking observed at ANO.

3.0 POTENTIAL FOR DELAYED CRACKING IN CURRENTLY LOADED CASKS

3.1 Evaluation of Delayed Cracking Mechanisms

The lid weld review team reviewed potential delayed cracking mechanisms and concluded that the only one of concern for the VSC closure lid welds is hydrogen-induced cracking. Although potential failures caused by plate laminations, pre-existing defective welds or lamellar tearing must be considered as possible failure mechanisms, they are not of concern with respect to delayed cracking. The consensus of the review team, based on their experience with lamellar tearing and on data they have seen, is that lamellar tearing, if it is to occur, takes place within minutes of the time that welding is completed. Likewise, weld failures caused by plate laminations or other defects such as pre-existing defective welds would take place at or close to the time of welding.

3.2 Evaluation of Susceptibility to Hydrogen-Induced Cracking

Hydrogen cracking can be a delayed phenomenon, the extent of the delay depending on a number of factors. For hydrogen cracking to occur, three conditions of sufficient combined severity must co-exist, namely a concentration of diffusible hydrogen in the weld area, a microstructure susceptible to embrittlement by hydrogen, and stress, as indicated schematically in Figure 3.

Data from the lid welds installed on previously loaded casks were reviewed to assess where the lid welds stand with respect to the three conditions mentioned above which must be present to some degree to cause hydrogen cracking.

3.2.1 Diffusible Hydrogen Level

During welding, hydrogen can be generated in the welding arc atmosphere and enter the liquid weld pool in its nascent state, to the limit of its solubility. During cooling of the weld metal from the superheat temperature of the weld pool to the freezing temperature, the hydrogen solubility decreases and hydrogen can be evolved as a gaseous species, escaping from the weld pool or forming porosity. Upon solidification, the solubility of hydrogen decreases abruptly and supersaturation of nascent hydrogen in the solid weld deposit can occur. This supersaturation is dissipated by diffusion into the surrounding steel and the escape of the hydrogen to the atmosphere.

Further relief of the saturation resulting from a decreasing solid solubility with temperature is also provided by the diffusion mechanism. Upon transformation of the higher temperature austenite constituent to lower temperature transformation products, another abrupt change in solubility occurs and concomitantly the diffusion rate increases in the lower temperature products because of the change in crystal structure upon transformation. The supersaturation of hydrogen in the weld deposit continues to be reduced by diffusion through the steel matrix. The effect of the reduction of hydrogen in the weld deposit by diffusion results in a time dependent increase (and then decrease) of hydrogen in the material surrounding the weld fusion zone (HAZ and base metal).

If the HAZ has undergone an on-cooling transformation from austenite to a martensitic constituent (hard and brittle) the hydrogen diffusing from the weld deposit can cause further embrittlement and cracking depending on the hardness (ductility) of the martensitic region of the HAZ and the stress state. Since the level of hydrogen attained in the HAZ by diffusion is time dependent, the embrittlement of the martensitic constituent, if present in the HAZ, may reach its potential critical hydrogen level at some time after welding is completed.

Hydrogen also tends to diffuse to regions of higher stress in addition to regions of lower concentration, thus the time for attaining a hydrogen level critical for cracking of the hardened HAZ is dependent upon the global stress state and discontinuities which can cause stress concentration. Depending on the initial steel temperature and the welding conditions, the weldment may cool to ambient temperature before the total hydrogen concentration has diminished to a level below which cracking can occur and thus the occurrence of cracking may be delayed by the reduced rate of diffusion (the diffusion rate is temperature dependent) at ambient temperature.

As mentioned in Section 2.3.3, tests performed on samples of the weld wire used at ANO showed an average diffusible hydrogen level of 15.5 ml/H_2/STP/100g. Samples of the wire used at Palisades and Point Beach were also tested. The Palisades wire showed levels of 15.0 to 15.9 ml/H_2/STP/100g. Tests on the Point Beach wire showed a level of 9.0 ml/H_2/STP/100g. The hydrogen content of the welding consumables, particularly for ANO and Palisades, is high enough to cause these welds to be susceptible to hydrogen-induced cracking.

Weld hydrogen levels can also be affected by the humidity of the surrounding environment. This has been extensively reported in the open literature for shielded metal arc welds, and a nomogram has been published by Dikehut and Hotz (Reference19) for this process (Figure 4). Less extensive work has been published for other processes, but it is apparent that gas shielded flux cored arc welding is less susceptible to hydrogen pick-up from the surrounding atmosphere than shielded metal arc (References 20 and 21) (Figure 5). Data for extremely low hydrogen rutile and basic cored wires compared with basic coated electrodes are presented in Figure 6 from Reference 21.

Although humidity can contribute to the hydrogen level in welds, it is apparent that for the lid welds, the predominant source of hydrogen introduced into the welds comes from the hydrogen content of the welding consumables.

3.2.2 Microstructure

During welding the temperature of the HAZ surrounding the fusion zone is increased over a range of temperatures from ambient to the melting temperature. Adjacent to the fusion boundary the temperature increase causes transformation to higher temperature products such as austenite.

As the weld progresses, the temperature in the HAZ decreases and transformation to lower temperature transformation products occurs. If the cooling rate (dependent on the material thickness and welding conditions as well as preheat) is sufficient, for a given material composition, a hard microconstituent called martensite can form. This martensitic constituent is sensitive to the presence of hydrogen which causes further embrittlement. The sensitivity of the steel to the formation of a martensitic constituent in the HAZ is often characterized by a formula which combines all of the alloying elements into a single numerical index known as the Carbon Equivalent.

Various formulas have been developed for determining Carbon Equivalent values. One such formula is that published by the International Institute of Welding (IIW), which is %Carbon + (%Manganese)/6 + (%Chromium + %Molybdenum + %Vanadium)/5 + (%Nickel + %Copper)/15. The Carbon Equivalent values based on this formula are shown in Table 2 for the shell materials used on MSBs loaded to date.

The carbon equivalent values for the shell material used at the various sites range from below 0.40 to just under 0.50. Carbon equivalent values above 0.40 are judged to be in the range where development of hard microstructures is of concern. The weld cooling rate also affects the likelihood for formation of hard microstructures. The cooling rate is primarily affected by the heat input of the weld and the surrounding heat sink, with low heat input and large heat sinks leading to harder HAZ microstructures. The heat input applied in the deposition of each weld bead ranges from 32,800 to 40,800 Joules/inch using the GMAW process, which is judged to be in the low to medium range.

3.2.3 Stress

Although no specific calculations of residual stresses in the joint were attempted, it was recognized that the joint configuration for these welds is highly constrained and residual stresses are at or near the yield level.

3.2.4 Conclusions

Based on the information discussed above, the weld review team concluded that the lid welds made on previously loaded casks may be susceptible to hydrogen-induced cracking.

3.3 Evaluation of Delay Times Associated with Hydrogen-Induced Cracking

Having concluded that lid welds for previously loaded casks may be susceptible to hydrogen-induced cracking, an evaluation was made of the time between completion of the weld and formation of cracking, referred to as delay time, which would be expected for welds having the characteristics of the lid welds.

3.3.1 Factors Affecting Delay Times

The extent of the delay times associated with hydrogen-induced cracking depends on conditions similar to those which cause hydrogen cracking to occur. These include the concentration of diffusible hydrogen in the steel, the diffusivity of hydrogen in the alloy of interest, the degree of susceptibility of the microstructure to embrittlement by hydrogen, and stress. The embrittling effect of hydrogen is a function of temperature, and is greatest at about normal ambient temperature. The onset of cracking may be delayed if conditions upon completion of welding are not sufficient to cause cracks to initiate immediately. Such delays result from the ability of hydrogen to diffuse within steel, not only from regions of higher to regions of lower hydrogen concentration, but also up stress gradients from regions of lower to higher concentration. Cracking may require an accumulation of hydrogen which can occur locally after the development of residual stresses. Some limit to the time period over which cracking can continue is, however, set by the overall loss of hydrogen from the weld area. Although hydrogen may accumulate locally to start with, this will eventually be overtaken by general hydrogen escape.

Delay time between completion of welding and initiation and cessation of cracking is a complicated subject, and generalized statements, unsupported by definitive data, should be treated with caution. To assess the present situation quantitatively, published data have been reviewed, and some diffusion calculations have been performed.

3.3.2 Review of Research Data on Delay Times

A special computerized database (Weldasearch), which covers journals, conference proceedings, books, patents, standards and theses from any nationality since 1967, was used to search for references to measurement of delay time following hydrogen cracking. Copies of papers identified as being relevant from examination of the abstracts were obtained and reviewed, along with some earlier references already known to TWI. The following paragraphs explain how data relevant to the present situation have been selected.

3.3.2.1 Effect of Composition and Strength

Interrante and Stout (1) found increasing delays on moving from A302 to HY80 to T-1 steels (Figure 7), and Alcantara et al (2) similarly found increasing delays when welding C-Mn pipe with increasing strength consumables between 7018 and 13018. This suggests that material/weld strength may influence delay times. The data considered, therefore, have been restricted to C and C-Mn steels.

3.3.2.2 Effect of Overall Weld Volume

The growth of a hydrogen crack is a discontinuous process, which depends on hydrogen collecting at each new crack tip position to once again create suitable combined conditions for cracking. The time period over which cracking can continue is thus dependent on overall hydrogen loss rates. Beyond a certain time, there is insufficient hydrogen generally available to concentrate to a critical level at the crack tip. In a large weld, time for overall hydrogen loss is longer than in a small weld, due to greater distances that bulk hydrogen has to diffuse in order to cause cracking. The effect of weld size on time for hydrogen evolution can be seen in Figure 9. Whereas it would take over 1200 hours for a weld of ~30mm (1 - 3/16 inch) diameter to lose ~90% of its hydrogen at 20°C (68°F), it would only take 89 hours for a ~8mm (¼ inch) diameter weld. Thus, continued acoustic emission activity for up to about 90 hours for 30mm deep groove welds reported by Samman may be taken as unrepresentative of the welds of present concern.

3.3.2.3 Review of Relevant Data

The remaining data in the first section of Table 3 have to be considered as valid measures of potential delay times. This shows that the vast majority of the data give delay times not exceeding about 3 hours. However, there are two data points at significantly longer times of 9.45 and 12.8 hours, and one outlier at 96 hours. The 9.45 and 12.8 hour results were for a single steel with a carbon content a little above the values for the MSB shell steel and this might be expected to lead to slightly slower diffusivity and hence longer delay times. The 96 hour result was obtained using self-shielded consumables which may, because of their very different deposit composition (this deposit contained 1.5% Al and 1% Ni) have a slower diffusivity. It should be noted that the same authors determined maximum delays of only 3 hours when using SMAW. Finally, there is one reference to crack growth activity for up to 48 hours. This value should also be treated with caution since it is nearly an order of magnitude greater than the typical time to onset of cracking reported by Lundin from implant testing (Reference 22).

Thus, the available data for welds similar to the lid welds of concern provides reasonable assurance that delay times will not exceed 12.8 hours. Indeed, considering data for steels of closely similar composition, the evidence is that delays are unlikely to exceed 3 hours.

It should be noted, however, that an effect of temperature may be expected. Because of decay heat from the fuel assemblies, the lid welds cooled to temperatures between about 100°F to 150°F after welding, whereas the test welds (in the literature) cooled to normal ambient temperature, typically 70°F. The higher temperatures for the lid welds cause higher hydrogen diffusion rates, which has a dual effect. First, it will accelerate any local concentration of hydrogen necessary to induce crack initiation, and second, it will accelerate overall hydrogen loss. The effect of temperature on hydrogen diffusion is shown in Figure 10. The effect of temperature on calculated time for hydrogen loss is indicated in Figure 11. Figure 12 shows the factor by which time for hydrogen diffusion (which covers both time for hydrogen loss, and/or local accumulation) is reduced at elevated temperature by comparison with normal ambient temperature.

This is based on a median value of diffusivity (D), taken from Figure 10. The time is reduced by a factor of between 2 to 8, over the range 100-150°F. This would be expected to give a corresponding reduction in delay time. The maximum anticipated delay times as a function of temperature, based on these considerations and values reported in the literature, are presented in Fig.13.

3.3.3 Lid Weld Inspection Timeframes

A time interval between completion of welding and initiation of weld inspection is inherent in the process used to install the lid welds. The cask loading experience at Palisades, Point Beach and ANO was reviewed to determine what this interval was. The review indicated that the time interval varies from a minimum period of approximately one hour to a maximum period of 54 hours: the latter was purposely implemented to check for the presence of delayed cracking on the structural lid-to-shell weld for the third MSB after cracking was detected in the shield lid-to shell weld. The minimum time interval was approximately 1.8 hours for the shield lid-to-shell welds and approximately 1 hour for the structural lid-to-shell welds. The actual time intervals for each lid weld on casks loaded to date are shown in Tables 4 and 5.

3.3.4 Conclusions on the Potential for Delayed Cracking in VSC Welds

The probable maximum delay time for cracking to occur in any given MSB weld can be determined on the basis of published information, from a knowledge of the temperature of that MSB, as outlined above. The maximum likely delay time has been plotted in Figure 13 as a function of temperature, and in Figure 14, data points from the actual MSB welds have been included. Maximum expected delay times derived from Figure 13 have been included in Tables 4 and 5. It can be seen that, on the basis of the majority of the data, and in particular that from most closely similar steel compositions, it is unlikely that delay times will have exceeded the actual inspection time intervals.

The literature on delay times is consistent with the experience gained in welding of the lids on the 19 casks loaded to-date. For the two casks (at ANO) where it was concluded that the cracking was hydrogen-induced, the cracks were discovered less than 30 minutes after welding, indicating that delay times, if any, were very short. If longer delay times were feasible for the lid welds, it is expected that some additional cracking would have been discovered over the range of time intervals that existed between completion of welding and completion of weld inspection for the other 17 casks that have been loaded. The fact that no cracking was detected in over 6,000 linear inches of weld over this range of time intervals is consistent with the expectations derived from the literature on delay times, which are that delay times are short for hydrogen-induced cracking under the circumstances present during welding of the lids.

4.0 MEASURES TO INHIBIT RECURRENCE OF WELD CRACKING

The root causes of each of the weld failures detected to-date were reviewed and actions were developed to address each cause and prevent recurrence of the failure. The recommended measures are described below.

4.1 Measures to Address Cause of Palisades Cracking

The crack discovered near the shield lid-to-shell weld for Palisades CMSB-05 was caused by a defect in the shell material which was not detected during the manufacturing process. In order to prevent recurrence of this failure, an acid etch of the top 4 inches of the inside surface of the shell will be performed for unloaded MSBs that have been manufactured to-date. The top 4 inches of the shell corresponds to the area where the lid welds will be made. The etching process was initiated to detect the presence of any welds that have been made in this area.

Etching of already-manufactured MSBs has been completed by ANO (10 units) and Point Beach (2 units). As a result of this process, evidence of undocumented welds was found on all of the ANO units. No evidence of undocumented welds was found on the Point Beach units. An evaluation of the undocumented welds found on the ANO MSBs was initiated following their detection. The description, results, and conclusions of this evaluation are presented in Appendix B.

Ultrasonic testing (UT) of the top 4 inches of the shell will be also be performed to detect the presence of laminations near the inside shell surface. The UT examination will be performed in accordance with the criteria and requirements of ASTM A 435. Although there is no evidence to indicate that laminations contributed to the cause of weld cracking seen to date and failures caused by laminations are not a concern with respect to delayed cracking, this action will be implemented as an added measure of protection against the possibility of cracking. This measure will be implemented on already manufactured MSBs. For MSBs manufactured in the future, low sulfur material will be used.

These measures are being implemented because of the desire to avoid any additional instances where material defects could cause cracking in the welding of the VSC lids. However, were a similar incidence of cracking to occur, the inspections of the welds that are performed would be able to detect the presence of the crack, as they did in the crack found on Palisades CMSB-05.

4.2 Measures to Address Causes of Point Beach Cracking

The cause of the crack in the structural lid-to-shell weld on the second cask loaded at Point Beach was determined to be improper fit-up of the lid and backing ring. Wisconsin Electric (WE) will implement the following measures to address this:

- The lid components will be pre-fit as an assembly to ensure a tighter fit-up of the backing ring.

- If gaps greater than 1/16" are identified during fit-up, manual welding will be performed to bridge these gaps prior to initiation of the machine GMAW process.

The cause of the crack in the structural lid-to-shield lid seal weld on the second cask loaded at Point Beach was determined to be contamination of the weld by moisture which was present in the area of the weld. WE will implement the following measures to address this:

- Water in the MSB will be drained down to a level corresponding to removal of approximately 40 gallons to protect against water being forced up the drain line. Venting of the airspace beneath the shield lid will also help to prevent water from being forced up into the weld area.

- The area to be welded will be preheated to 200°F as discussed in Section 4.3.

Similar measures are already in-place or will be implemented at ANO and Palisades to prevent cracking of the type encountered at Point Beach.

4.3 Measures to Address Cause of ANO Cracking

It was concluded by the review team that the crack discovered in the shield lid-to-shell weld for the third cask loaded at ANO was hydrogen-induced. In developing recommended measures to prevent recurrence of hydrogen-induced cracking, the review team noted that the lid welding experience gained for the casks loaded to-date indicates that the welding practices currently employed are close to the threshold of what is required to prevent hydrogen-induced cracking for these welds. This is based on the fact that cracking was observed on only 2 of the 19 shield lids welded to-date and on none of the structural lids welded. The slight differences in temperatures and stress for the two casks where cracking was observed appear to have been sufficient to move the combination of factors which cause hydrogen-induced cracking over the threshold.

Based on this observation, it was concluded that relatively minor changes in the weld procedure would be enough to prevent the occurrence of hydrogen-induced cracking during the welding of lids on future MSBs. However, recommended changes to the weld process were developed which were intended to provide ample margin above the threshold condition.

The most significant measure is implementation of a 200°F preheat for all future lid welds. The preheat temperature of 200°F will be held for a minimum period of one hour after welding is completed on the shield lid and structural lid welds to accelerate the diffusion of hydrogen out of the weld and HAZ. A minimum time interval of 2 hours will be implemented between completion of welding and initiation of inspection of the shield lid and structural lid welds. Although no hydrogen-induced cracking is expected when these measures are implemented, the time interval will provide sufficient time for any delayed cracking, should it occur, to be detected. Similar precautions will be applied to the lid-to-lid and valve cover fillet welds.

An evaluation was performed to assess the potential impact of the 200°F preheat on the time to drain down. The results of this evaluation indicate the effect is negligible.

A 200°F preheat will meet the requirements and recommendations of ASME Section III Subsection NC. In addition, it is supported by AWS Structural Welding Code D1.1-96 Table 3.2 Category B, and by Stout and Doty in Weldability of Steels. AWS Structural Welding Code D1.1 recommends a 150°F preheat for A516 Grade 70 material, for thicknesses up to 2.5 inches. In Weldability of Steels, Stout and Doty recommend a 200°F preheat for A516 Grade 70 in the thickness range from 2 to 4 inches.

Possibly the best illustration of the adequacy of the 200°F preheat is provided by the experience gained in welding of the lids on casks loaded to date. The occurrence of only very occasional instances of cracking indicates that conditions are close to threshold with a preheat of around 100°F (due to decay heat from the fuel assemblies). The imposition of a 200°F preheat provides a 100°F margin above threshold conditions.

The lids will be secured to prevent movement during welding by a combination of large tack welds and/or implementation of a balanced weld sequence. This will better distribute the shrinkage forces that result from cooling of the weld.

Further protection against hydrogen-induced cracking will be provided by using welding consumables with low hydrogen levels (less than 10 ml/H_2/STP/100g).

In the longer term, shell and lid materials with lower carbon equivalent values will be used for MSBs manufactured in the future to further mitigate the potential for hydrogen-induced cracking.

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Table 1
Lid Weld Review Team Members

Bill Baker	NDE Level III, Portland General Electric
Thomas Burtard	Welding Engineer, Wisconsin Electric
Domenic Canonico	Vice President/Technology, ABB Combustion Engineering, Inc.
Tony Ciapanno	Welding Engineer, Portland General Electric
Stephen Fisher	Senior Welding Engineer, British Nuclear Fuels
Hal Gustin	Associate, Structural Integrity Associates
Peter Hart	Head, Materials Department, The Welding Institute, United Kingdom
Bill Heinsohn	Welding Engineer, Wisconsin Electric
Brian Kruse	Consulting Engineer, Duke Power Company
Carl Lundin	Professor, University of Tennessee
Jim Nestell	Executive Engineer, MPR Associates
Richard Pargeter	Section Manager, Ferrous Section, Materials Department, The Welding Institute, United Kingdom
Bill Pavlichko	Lead Senior Metallurgical Engineer, Consumers Energy
Walt Sperko	President, Sperko Engineering
Dan Spond	Senior Welding Engineer, ANO

Table 2
Lid Weld Parameters

Plant	**ANO**	**ANO**	**ANO**	**ANO**
Parameter/Cask	1(MSB-01)	2(MSB-03)	3(MSB-05)	4(MSB-06)
Fuel Load (Kw)	5.1 kw	10.6 kw	4.2	6.4 kw
Shell Chemistry				
Carbon Equivalent	0.46	0.47	0.46	0.47
Carbon Content	0.22	0.22	0.22	0.22
Sulfur Content	0.017	0.012	0.017	0.014
Heat Number	C 5051 - 03DA	C-4964 - 39AB	C-5051 - 4CA	C-2500 - 1M
Tensile Strength	77.9 ksi	80.6 ksi	76.5 ksi	83.2 ksi
Ductility SEE NOTE	44-56 ft lb@-50 °F	36-42 ft lb@-50 °F	35-42 ft lb @-50 °F	40-56 ft lb @-50 °F
Manufacturer	Lukens	Lukens	Lukens	Lukens
Shield Lid Weld				
Weld Process	GMAW	GMAW	GMAW	GMAW
Weld Wire Type	E71T-1	E71T-1	E71T-1	E71T-1
Voltage (Volts)	28-30	28 - 30	28 - 30	28 - 30
Current (Amps)	250-310	250-310	250-310	250-310
Heat Input (kJ/in)	40.8 (max)	40.8 (max)	40.8 (max)	40.8 (max)
Number of Passes	4	4	4	3
Head Speed (in/min)	12.7 - 14.3	12.7 - 14.3	12.7 - 14.3	12.7 - 14.3
Structural Lid Weld				
Weld Process	Same as Shield Lid	Same as Shield Lid	Same as Shield Lid	Same as Shield Lid
Weld Wire Type	Same as Shield Lid	Same as Shield Lid	Same as Shield Lid	Same as Shield Lid
Voltage	Same as Shield Lid	Same as Shield Lid	Same as Shield Lid	Same as Shield Lid
Current	Same as Shield Lid	Same as Shield Lid	Same as Shield Lid	Same as Shield Lid
Heat Input	Same as Shield Lid	Same as Shield Lid	Same as Shield Lid	Same as Shield Lid
Number of Passes	13	13	14	16
Head Speed	Same as Shield Lid	Same as Shield Lid	Same as Shield Lid	Same as Shield Lid

NOTE: Mill Charpy V Impacts

Table 2 (Continued)
Lid Weld Parameters

Plant	**Palisades**	**Palisades**	**Palisades**	**Palisades**
Parameter/Cask	1(CMSB-01)	2(CMSB-02)	3(CMSB-03)	4(CMSB-04)
Fuel Load (Kw)	11.9	11.9	9.3	9.4
Shell Chemistry				
Carbon Equivalent	.39	.44	.42	.417
Carbon Content (%)	.20	.193	.23	.22
Sulfur Content (%)	.002	.01	.006	.003
Heat Number	492521	327136	67720	610066
Tensile Strength	77.0 ksi	76.9 ksi	83.1 ksi	79.7 ksi
Ductility SEE NOTE	79.3 ft lbs @-50°F	51 ft lbs @-50°F	48.3 ft lbs @-50°F	67 ft lbs @-50°F
Manufacturer	Oxelosund	Oregon Steel	Peine-Salzgitter	Rautarukki
Shield Lid Weld				
Weld Process	GMAW	GMAW	GMAW	GMAW
Weld Wire Type	E71T-1	E71T-1	E71T-1	E71T-1
Voltage (Volts)	30	30	30	30
Current (Amps)	215-230	215-230	215-230	215-230
Heat Input (kJ/in)	33-34	33-34	33-34	33-34
Number of Passes	5-6	5-6	5-6	5-6
Head Speed (in/min)	12.5-14	12.5-14	12.5-14	12.5-14
Structural Lid Weld				
Weld Process	Same as Shield Lid	Same as Shield Lid	Same as Shield Lid	Same as Shield Lid
Weld Wire Type	Same as Shield Lid	Same as Shield Lid	Same as Shield Lid	Same as Shield Lid
Voltage	Same as Shield Lid	Same as Shield Lid	Same as Shield Lid	Same as Shield Lid
Current	Same as Shield Lid	Same as Shield Lid	Same as Shield Lid	Same as Shield Lid
Heat Input	Same as Shield Lid	Same as Shield Lid	Same as Shield Lid	Same as Shield Lid
Number of Passes	22-26	22-26	22-26	22-26
Head Speed	Same as Shield Lid	Same as Shield Lid	Same as Shield Lid	Same as Shield Lid

NOTE: **Mill Charpy V Impacts**

Table 2 (Continued)
Lid Weld Parameters

Plant		**Palisades**		**Palisades**		**Palisades**
Parameter/Cask		5(CMSB-05)		6(CMSB-06)		7(CMSB-07)
Fuel Load (Kw)		9.6		9.5		9.6
Shell Chemistry						
Carbon Equivalent		.46		.46		.46
Carbon Content (%)		.22		.22		.22
Sulfur Content (%)		.011		.011		.011
Heat Number		C5056		C5056		C5056
Tensile Strength		77.6 ksi		81.2 ksi		79.1 ksi
Ductility SEE NOTE		42.7 ft lbs @-50°F		62.0 ft lbs @-50°F		32.7 ft lbs @-50°F
Manufacturer		Lukens		Lukens		Lukens
Shield Lid Weld						
Weld Process		GMAW		GMAW		GMAW
Weld Wire Type		E71T-1		E71T-1		E71T-1
Voltage (Volts)		30		30		30
Current (Amps)		215-230		215-230		215-230
Heat Input (kJ/in)		33-34		33-34		33-34
Number of Passes		5-6		5-6		5-6
Head Speed (in/min)		12.5-14		12.5-14		12.5-14
Structural Lid Weld						
Weld Process		Same as Shield Lid		Same as Shield Lid		Same as Shield Lid
Weld Wire Type		Same as Shield Lid		Same as Shield Lid		Same as Shield Lid
Voltage		Same as Shield Lid		Same as Shield Lid		Same as Shield Lid
Current		Same as Shield Lid		Same as Shield Lid		Same as Shield Lid
Heat Input		Same as Shield Lid		Same as Shield Lid		Same as Shield Lid
Number of Passes		22-26		22-26		22-26
Head Speed		Same as Shield Lid		Same as Shield Lid		Same as Shield Lid

NOTE: Mill Charpy V Impacts

Table 2 (Continued)
Lid Weld Parameters

Plant		**Palisades**		**Palisades**		**Palisades**
Parameter/Cask		8(CMSB-08)		9(CMSB-09)		10(CMSB-10)
Fuel Load (Kw)		8.9		9.6		9.9
Shell Chemistry						
Carbon Equivalent		.46		.46		.46
Carbon Content (%)		.22		.22		.22
Sulfur Content (%)		.011		.011		.011
Heat Number		C5056		C5056		C5056
Tensile Strength		82.4 ksi		81.7 ksi		75.6 ksi
Ductility SEE NOTE		58.7 ft lbs @-50°F		63.3 ft lbs @-50°F		65.7 ft lbs @-50°F
Manufacturer		Lukens		Lukens		Lukens
Shield Lid Weld						
Weld Process		GMAW		GMAW		GMAW
Weld Wire Type		E71T-1		E71T-1		E71T-1
Voltage (Volts)		30		30		30
Current (Amps)		215-230		215-230		215-230
Heat Input (kJ/in)		33-34		33-34		33-34
Number of Passes		5-6		5-6		5-6
Head Speed (in/min)		12.5-14		12.5-14		12.5-14
Structural Lid Weld						
Weld Process		Same as Shield Lid		Same as Shield Lid		Same as Shield Lid
Weld Wire Type		Same as Shield Lid		Same as Shield Lid		Same as Shield Lid
Voltage		Same as Shield Lid		Same as Shield Lid		Same as Shield Lid
Current		Same as Shield Lid		Same as Shield Lid		Same as Shield Lid
Heat Input		Same as Shield Lid		Same as Shield Lid		Same as Shield Lid
Number of Passes		22-26		22-26		22-26
Head Speed		Same as Shield Lid		Same as Shield Lid		Same as Shield Lid

NOTE: Mill Charpy V Impacts

Table 2 (Continued)
Lid Weld Parameters

Plant	**Palisades**	**Palisades**	**Palisades**
Parameter/Cask	11(CMSB-11)	12(CMSB-12)	13(CMSB-13)
Fuel Load (Kw)	9.9	10.0	10.0
Shell Chemistry			
Carbon Equivalent	.41	.42	.42
Carbon Content (%)	.17	.19	.19
Sulfur Content (%)	.011	.008	.008
Heat Number	357986	359288	359288
Tensile Strength	76.0 ksi	79.0 ksi	79.0 ksi
Ductility SEE NOTE	61.7 ft lbs @-50°F	45.7 ft lbs @-50°F	45.7 ft lbs @-50°F
Manufacturer	Oregon Steel	Oregon Steel	Oregon Steel
Shield Lid Weld			
Weld Process	GMAW	GMAW	GMAW
Weld Wire Type	E71T-1	E71T-1	E71T-1
Voltage (Volts)	30	30	30
Current (Amps)	215-230	215-230	215-230
Heat Input (kJ/in)	33-34	33-34	33-34
Number of Passes	5-6	5-6	5-6
Head Speed (in/min)	12.5-14	12.5-14	12.5-14
Structural Lid Weld			
Weld Process	Same as Shield Lid	Same as Shield Lid	Same as Shield Lid
Weld Wire Type	Same as Shield Lid	Same as Shield Lid	Same as Shield Lid
Voltage	Same as Shield Lid	Same as Shield Lid	Same as Shield Lid
Current	Same as Shield Lid	Same as Shield Lid	Same as Shield Lid
Heat Input	Same as Shield Lid	Same as Shield Lid	Same as Shield Lid
Number of Passes	22-26	22-26	22-26
Head Speed	Same as Shield Lid	Same as Shield Lid	Same as Shield Lid

NOTE: Mill Charpy V Impacts

Table 2 (Continued)
Lid Weld Parameters

Plant		Point Beach		Point Beach
Parameter/Cask		1(MSB-01)		2(MSB-03)
Fuel Load (Kw)		9.7		9.2
Shell Chemistry				
Carbon Equivalent		0.37		0.43
Carbon Content (%)		0.19		0.23
Sulfur Content (%)		0.009		0.001
Heat Number		24975		U2099
Tensile Strength		75.4 ksi		75.3 ksi
Ductility SEE NOTE		51-75 J @-40°C		82-92 ft lbs@-50°F
Manufacturer		Vitkovice		Lukens
Shield Lid Weld				
Weld Process		GMAW		GMAW
Weld Wire Type		E70C-6M		E70C-6M
Voltage (Volts)		30.3-31.8		30.3-31.8
Current (Amps)		311-350		311-350
Heat Input (kJ/in)		32.8		32.8
Number of Passes		4		4
Head Speed (in/min)		19.5-27		19.5-27
Structural Lid Weld				
Weld Process		Same as Shield Lid		Same as Shield Lid
Weld Wire Type		Same as Shield Lid		Same as Shield Lid
Voltage		Same as Shield Lid		Same as Shield Lid
Current		Same as Shield Lid		Same as Shield Lid
Heat Input		Same as Shield Lid		Same as Shield Lid
Number of Passes		14		14
Head Speed		Same as Shield Lid		Same as Shield Lid

NOTE: Mill Charpy V Impacts

Table 3
Summary of references giving measurements of delay times for hydrogen cracking

Reference	Type of Test	Steel	Process	H_2 Level (ml/100g)	Max Delay (start-finish)	Comments
Relevant data						
Beachum et al 1961 (3)	Lehigh Restraint	AISI 1020	GMAW	2.5%C_3H_8	1.9 hrs	Cracking detected by relaxation of welded groove.
	Lehigh Restraint	ASTM A212	GMAW	7.5%H_2	9.45 hrs	0.32C steel
Interrante and Stout 1964 (1)	Lehigh Restraint	ASTM A 302	SMAW+GMAW	Not reported	0.5 hrs	Cracking detected by relaxation of welded groove.
	Lehigh Restraint	ASTM A 212	GMAW	1% H_2	12.8 hrs	0.32C steel
Nakayama et al 1974 (4)	Single and double bevel Y groove	CMn	SMAW	2-37	3-48 hrs	From sectioning a series of nominally identical samples at different times.
Nakayama et al 1975 (5)	Single bevel Y groove	CMn	Self Shielded FCAW (1.5%Al, 1%Ni)	4	96 hrs	From sectioning a series of nominally identical samples at different times.
Stout et al 1976 (6)	Slot weld	Linepipe steels	SMAW	Cellulosic	0.3-15 hrs	Linepipe welding
Vasudevan et al 1980 (7)	Slot weld				0.3 hrs	
Lazor, 1984 (8)	High restraint cracking test	X65	SMAW	37	550s(~9 mins)	
Steffens and Killing, 1985 (9)	Stressed butt weld	StE460	SMAW	5.5	~1.5-3 mins	Acoustic Emission data. Slightly shorter time for 11.9ml/100g.
Bohme et al 1980 (10)	Longitudinally and self stressed bead in groove	StE51/StE 70	SAW	Not reported	<3-~7 hrs	Some activity, which could only be related to <200 micron microcracks, up to 40hrs. Not clear which steel used for acoustic emission.
Thick, multipass weld						
Samman, 1976 (11)	Longitudinally stressed 30mm thick multipass bead in groove	1%Mn steel	SMAW	Not reported	~5-70 hrs	Acoustic Emission measurements
High strength steels						
Beachum et al 1961 (3)	Lehigh Restraint	HY80	GMAW	5%H_2	34.4 hrs	Cracking detected by relaxation of welded groove.
		AISI 4140	GMAW	Low	7.75 hrs	
		HY80	SMAW+GMAW	7016 low H_2	7.9-14.3 hrs	Cracking detected by relaxation of welded groove.
Interrante and Stout 1964 (1)	Lehigh Restraint	CMn pipe	SMAW,E10018	<5	45 mins	Cracking detected by relaxation of welded groove.
Alcantara et al 1984 (2)	Double bevel Y groove (Tekken)	CMn pipe	SMAW, E14018	<5	7 hrs	Acoustic Emission
	Double bevel Y groove (Tekken)	HY180	SMAW, E14018	Not reported	13 days	Acoustic Emission
Juers 1982 (12)	Trough weld test	25KhN3MFA	SMAW	Not reported	~4-20 hrs	MPI and Radiography
Pronin et al 1989 (13)	Externally loaded	780&400MPa yield	FCW, >650 MPa yield	~4	~18 mins	Acoustic Emission used but no raw data
Panov et al 1991 (14)	Externally loaded					Acoustic Emission used but no raw data
		2.25Cr1Mo	SAW	Not reported	96 hrs	
Nishio et al 1975 (15)	Narrow groove, self stressed					WM cracking in multipass welds (45-200mm thickness).
		AISI 4340	GMAW		~2 days	
Fang et al 1995 (16)	Machined slot, stressed by welding					Acoustic Emission

Table 4
Calculated Maximum Expected Delay Times and Time Intervals Between Completion of Welding and Weld Inspection For Shield Lid Welds Made To Date

Plant	MSB No.	Temperature After Welding (°F)	Maximum Expected Delay Time (Hours)	Inspection Time Interval (Hours-See Note)
Palisades	CMSB-01	104	1.4	3.0
	CMSB-02	108	1.2	3.0
	CMSB-03	105	1.4	3.0
	CMSB-04	103	1.4	3.0
	CMSB-05	96	1.6	3.0
	CMSB-06	108	1.2	3.0
	CMSB-07	95	1.7	3.0
	CMSB-08	102	1.5	3.0
	CMSB-09	98	1.6	3.0
	CMSB-10	96	1.6	3.0
	CMSB-11	97	1.6	3.0
	CMSB-12	107	1.3	3.0
	CMSB-13	103	1.4	3.0
Point Beach	MSB-01	88	1.9	2.0
	MSB-03	89	1.9	2.0
ANO	MSB-001	93	1.8	3.8
	MSB-003	104	1.4	1.8
	MSB-005 Unrepaired Area	90	1.8	48.0
	MSB-005 Repaired Area	165	0.2	4.0
	MSB-006	155	0.3	2.8

NOTE: **Inspection time interval is the time between completion of welding and start of inspection of final weld pass**

Table 5
Calculated Maximum Expected Delay Times and Time Intervals Between Completion of Welding and Weld Inspection For Structural Lid Welds Made To Date

Plant	MSB No.	Temperature After Welding (°F)	Maximum Expected Delay Time (Hours)	Inspection Time Interval (Hours- See Note)
Palisades	CMSB-01	148	0.4	1.0
	CMSB-02	141	0.5	1.0
	CMSB-03	147	0.4	1.0
	CMSB-04	156	0.3	1.0
	CMSB-05	132	0.6	1.0
	CMSB-06	154	0.4	1.0
	CMSB-07	132	0.6	1.0
	CMSB-08	153	0.4	1.0
	CMSB-09	129	0.6	1.0
	CMSB-10	131	0.6	1.0
	CMSB-11	134	0.6	1.0
	CMSB-12	138	0.5	1.0
	CMSB-13	143	0.4	1.0
Point Beach	MSB-01	98	1.6	2.0
	MSB-03	96	1.6	2.0
ANO	MSB-001	130	0.7	1.7
	MSB-003	140	0.5	3.1
	MSB-005	100	1.5	54.0
	MSB-006	170	0.2	1.0

NOTE: **Inspection time interval is the time between completion of welding and start of inspection of final weld pass**

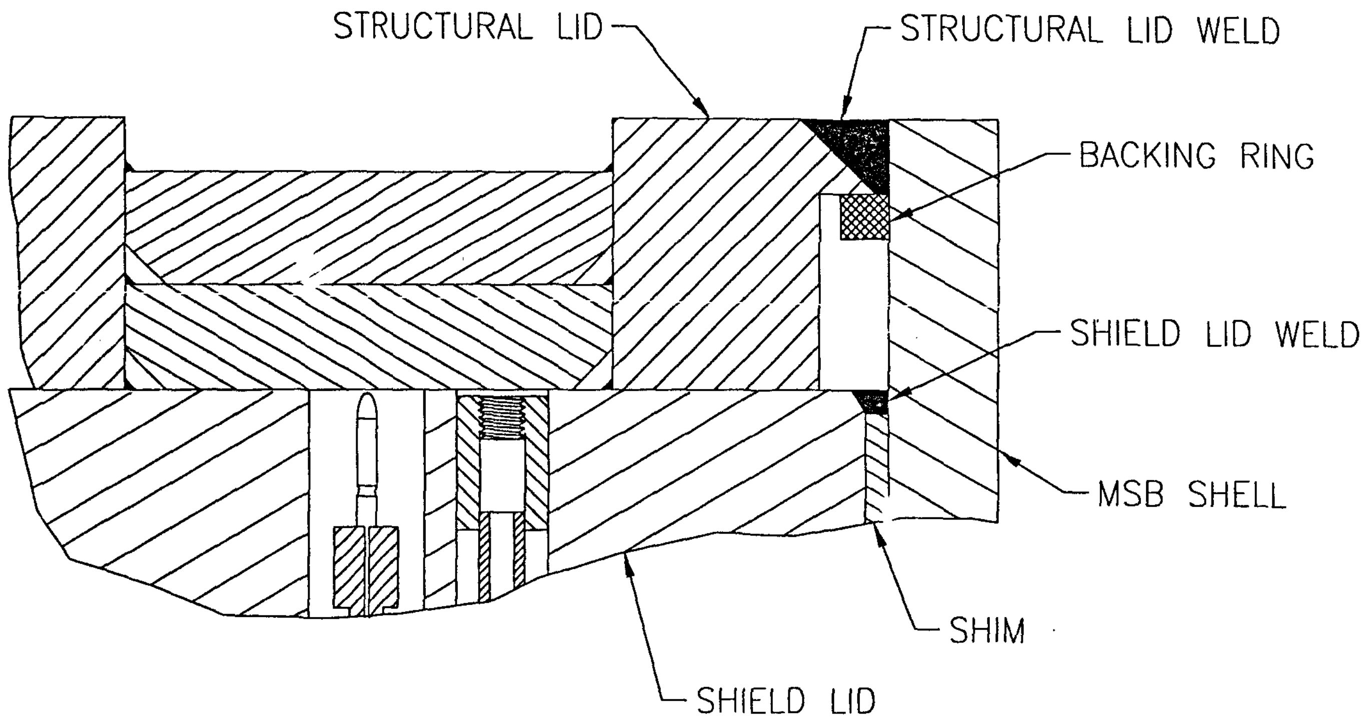


Figure 1
VSC 24 MSB Lid Configuration

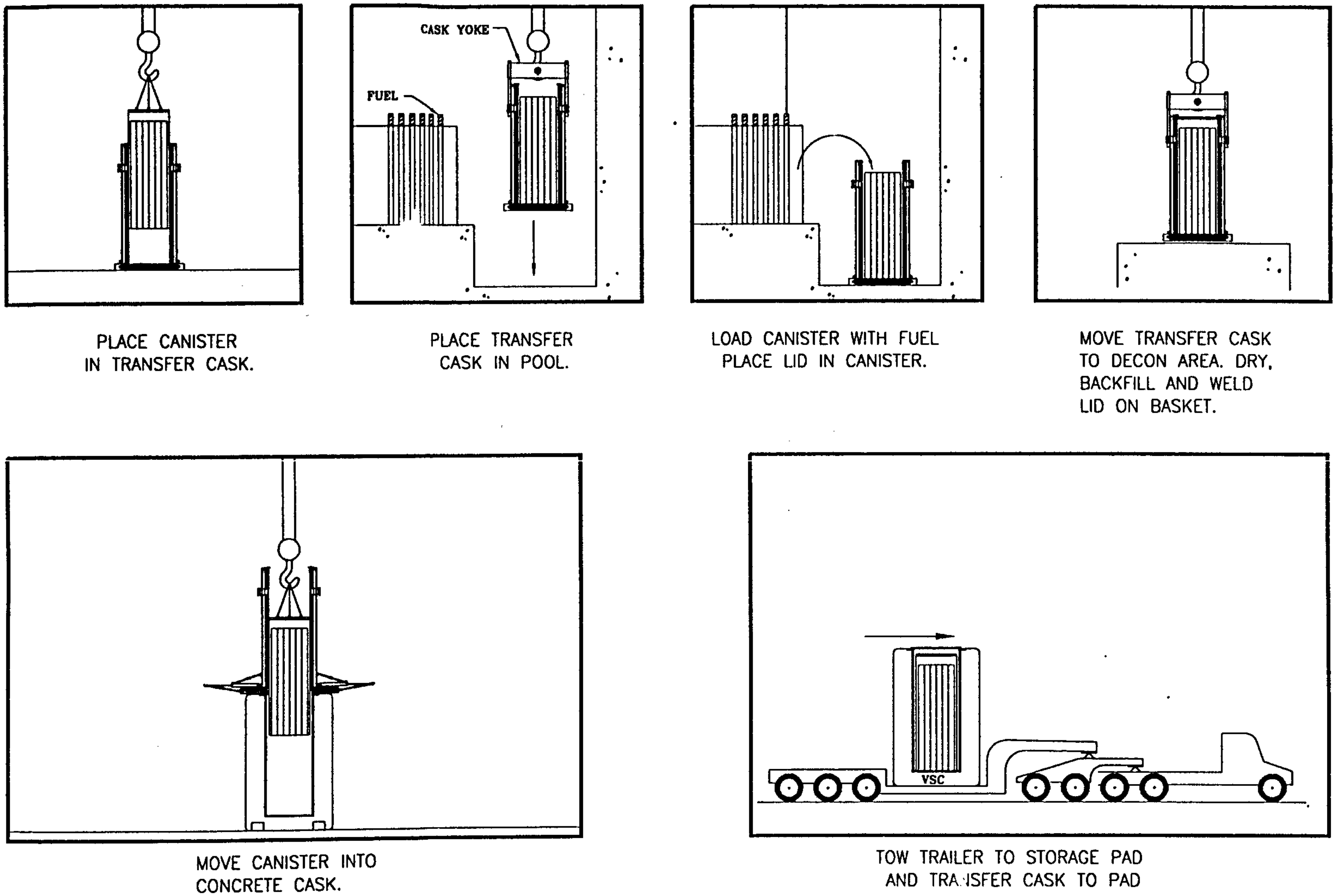


Figure 2
Cask Loading Operations

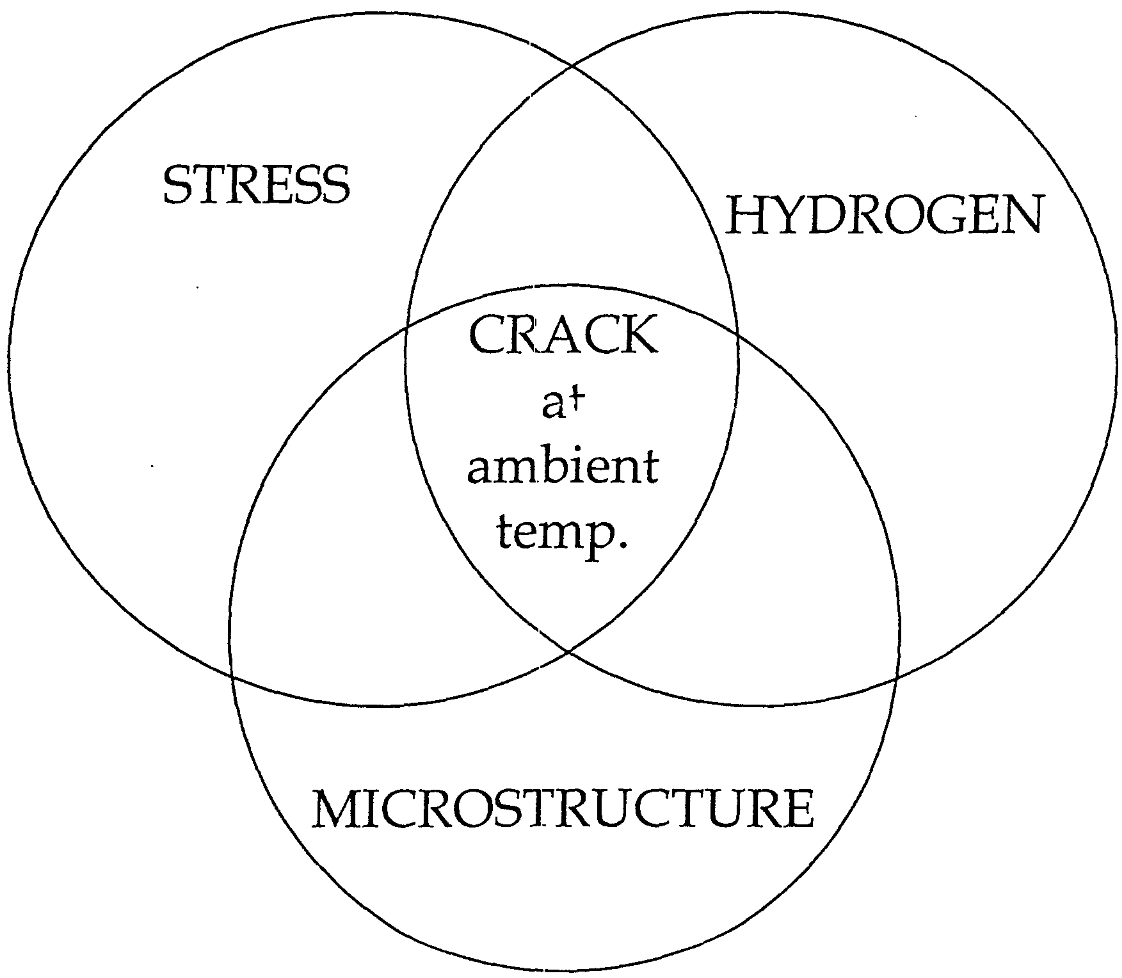


Figure 3
Schematic Representation of the Requirement For a Sufficient Combination of Three Conditions For Hydrogen Cracking to Occur

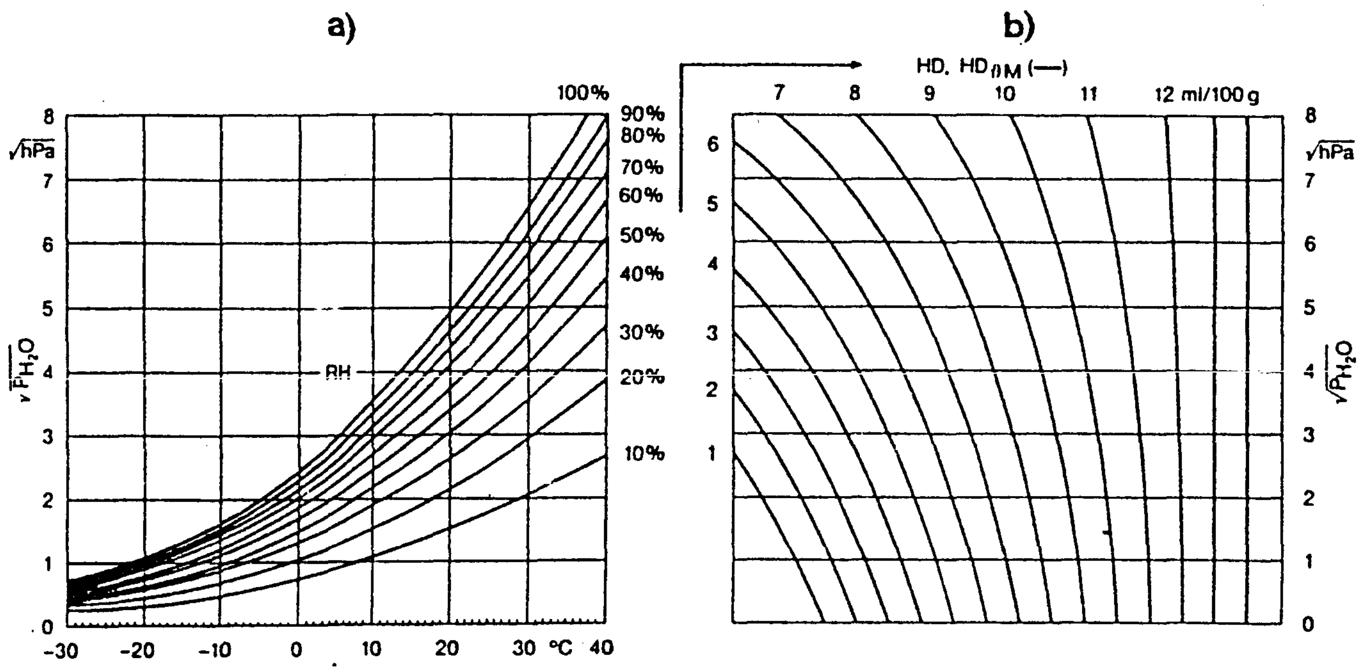
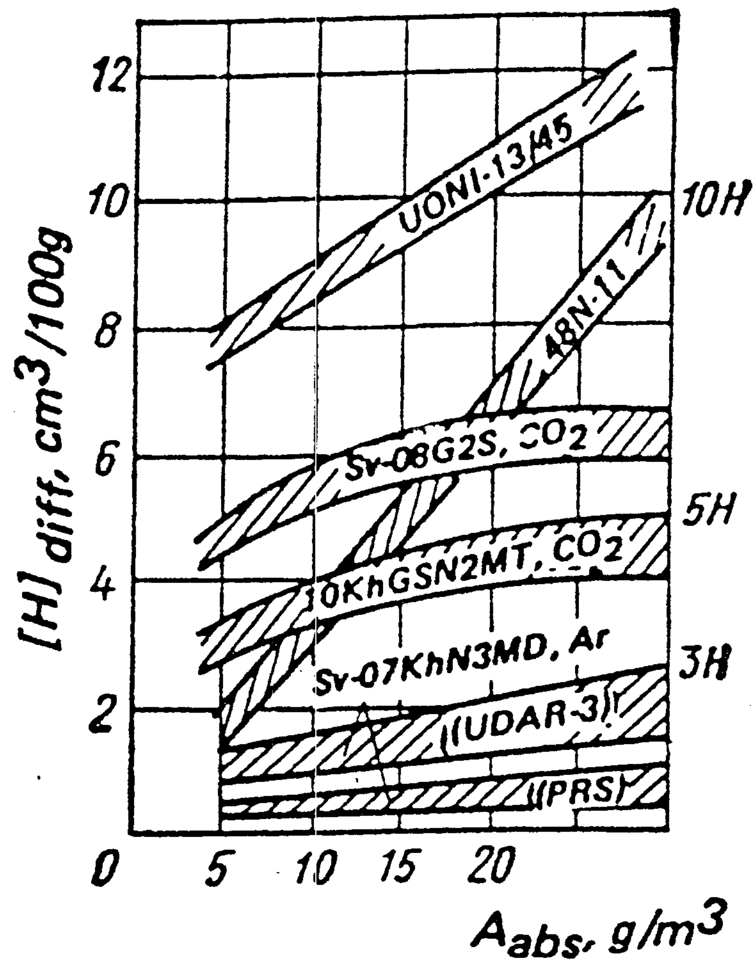


Figure 4
Nomogram For the Prediction of the Effect of Climate on Diffusible Hydrogen Content in Manual Arc Weld Metal (Dikehut & Hotz, Reference 19)



NOTE: SMAW consumables are UON1-13/45 and 48N-11, others are GMAW and GTAW

Figure 5
Comparison of the Effect of Atmospheric Humidity on Hydrogen Content for Different Welding Processes (Levchenko et al., Reference 20)

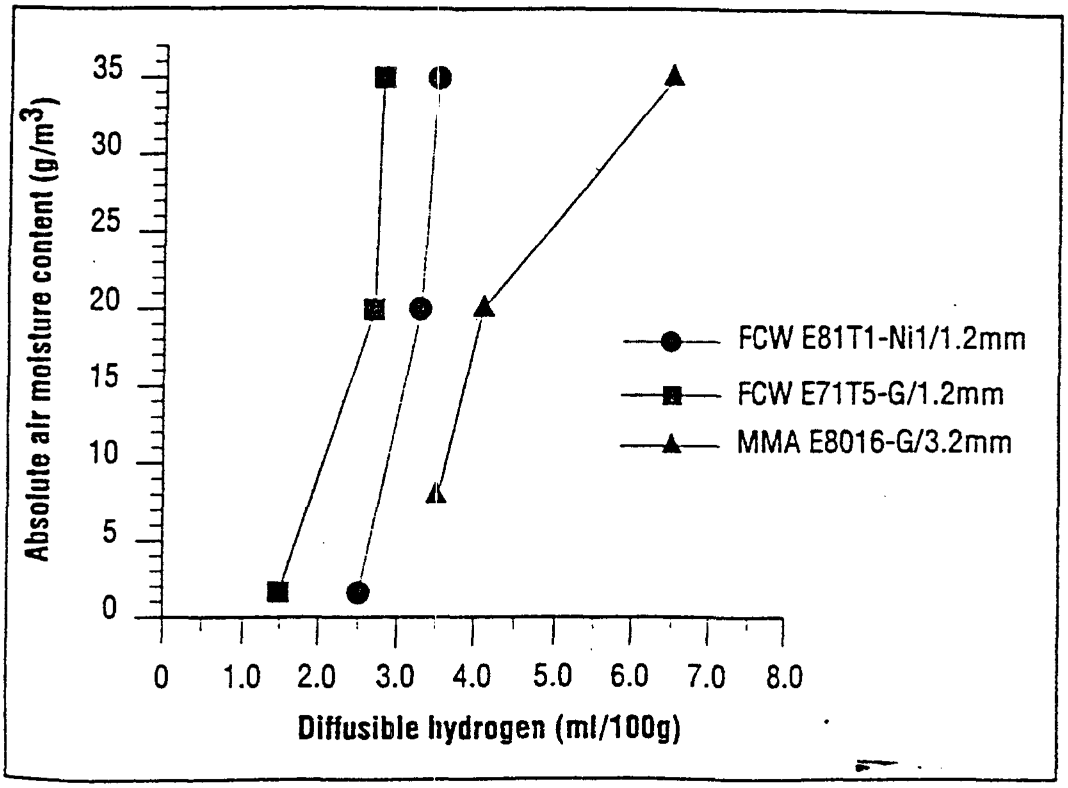


Figure 6
Influence of Absolute Air Moisture Content on Weld Metal Hydrogen Levels for Two Cored Wires and an SMAW Consumable (Nilhn et al., Reference 21)

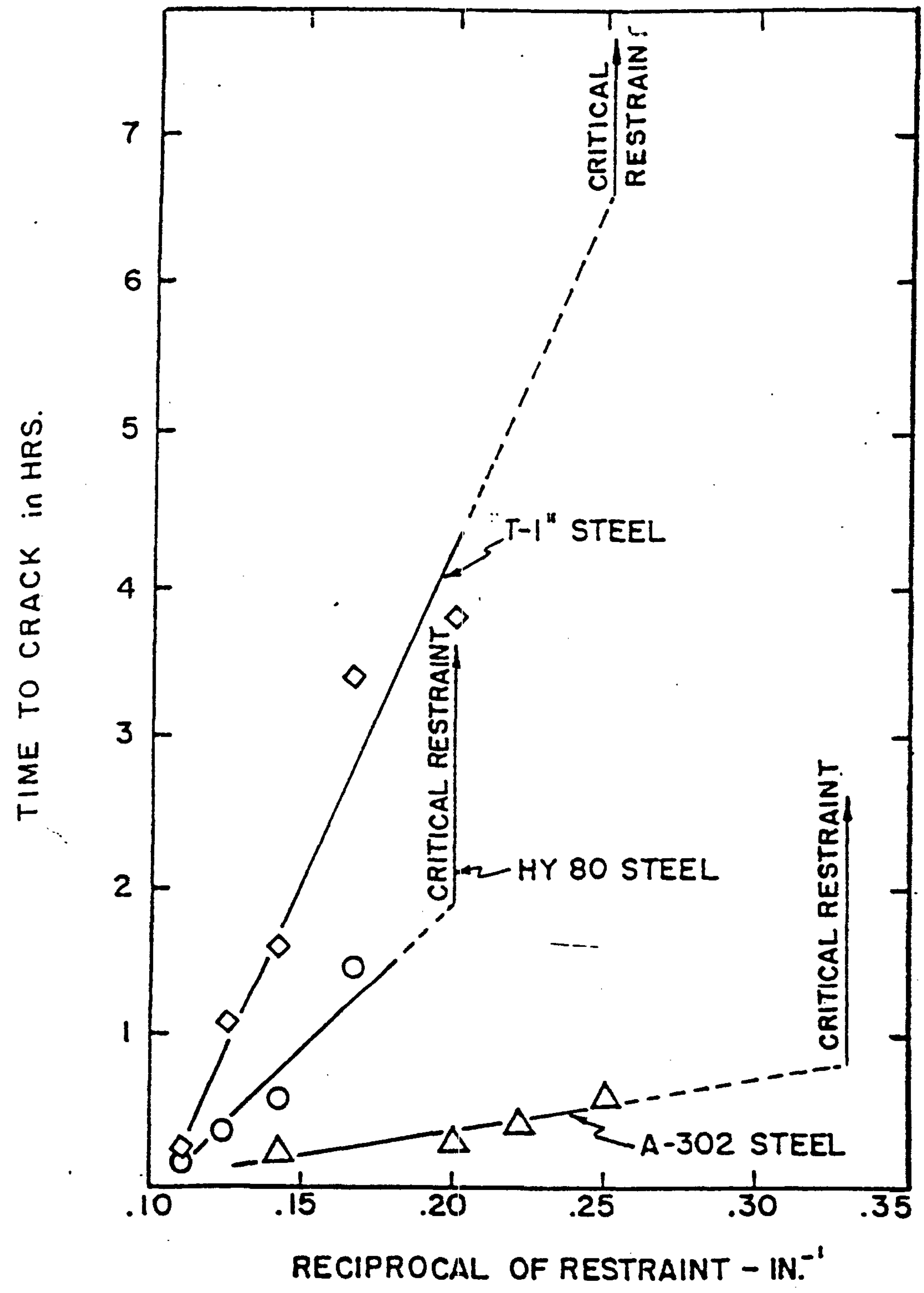


Figure 7
Influence of Restraint Level and Steel on Delay Before Hydrogen Crack Inititiation (Interrante & Stout, Reference 1)

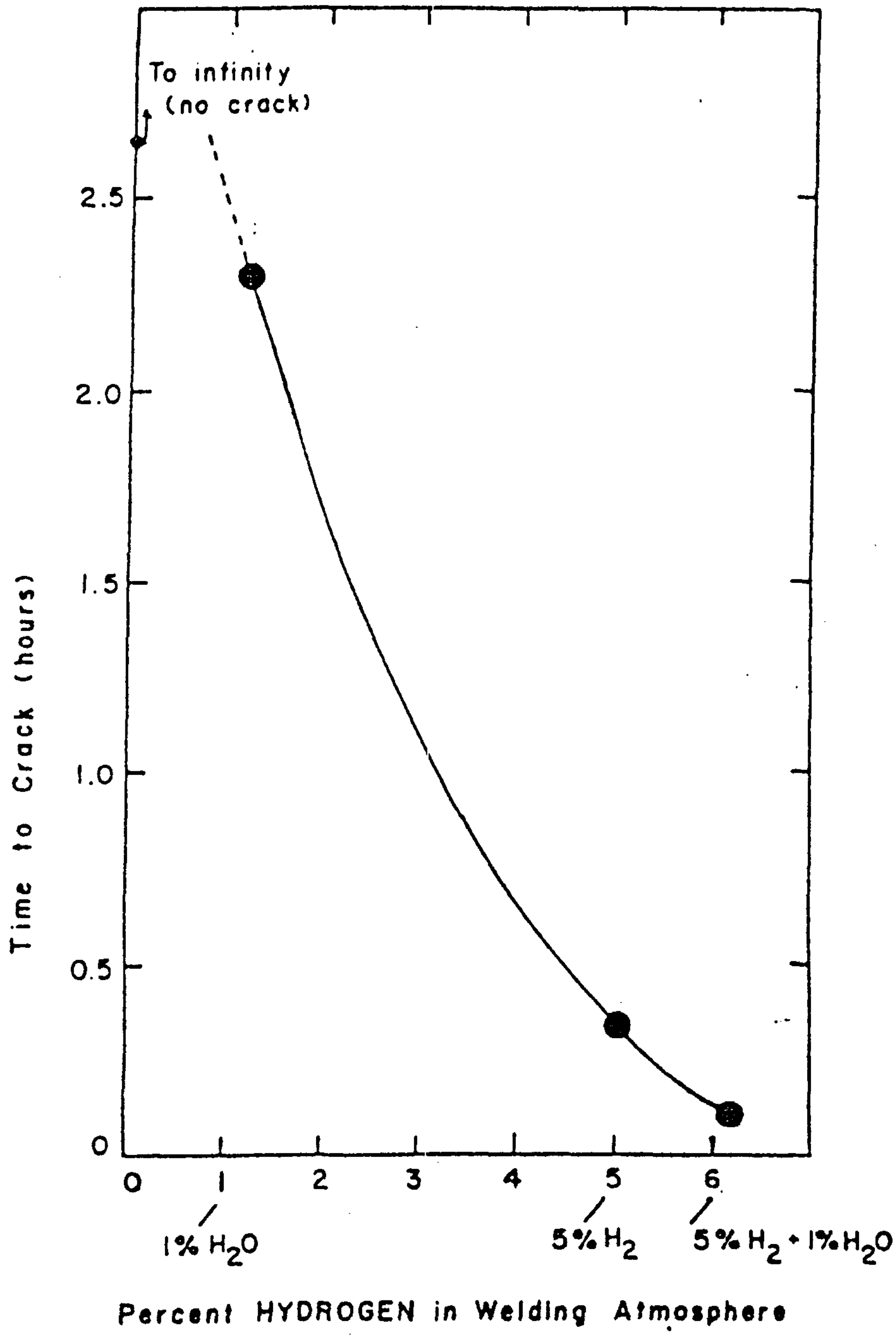


Figure 8
Influence of Hydrogen on Delay Before Hydrogen Crack Initiation
(Interrante & Stout, Reference 1)

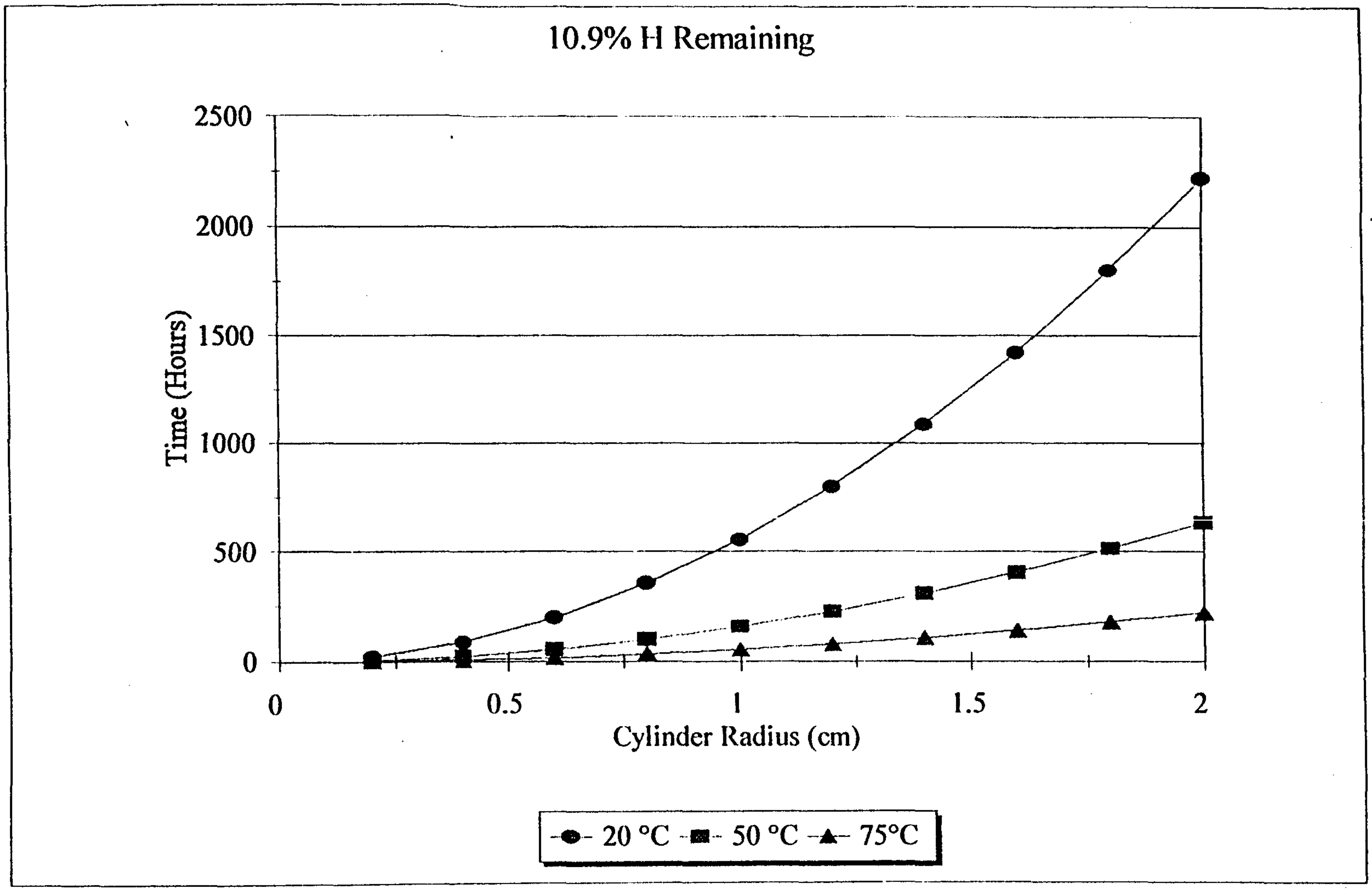


Figure 9

Effect of Temperature and Size (Cylinder Radius) on Time for Hydrogen Loss to 10.9% of Original Value at the Center of an Infinite Cylinder Based on a Mid-Range Value of Diffusivity

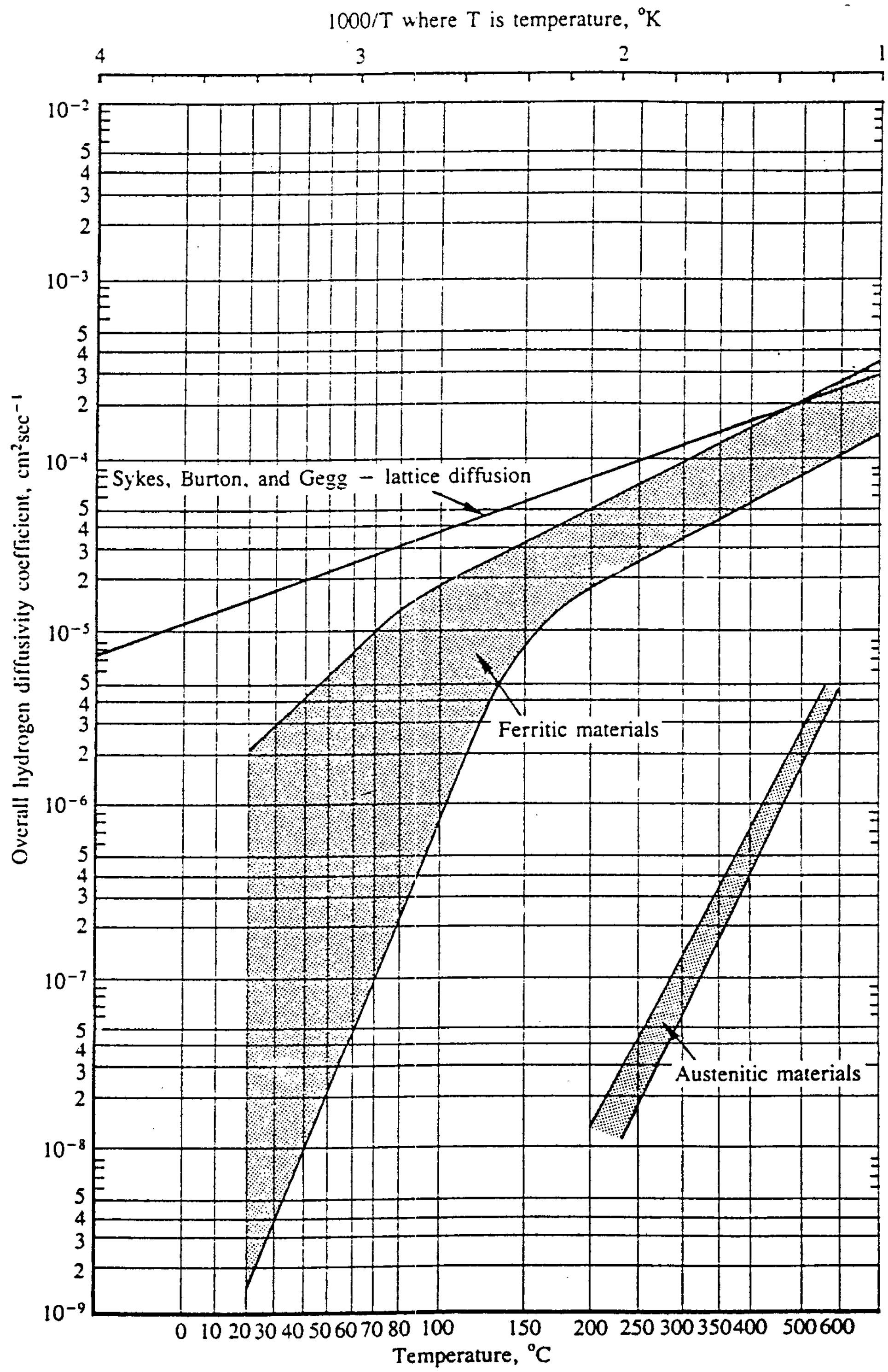
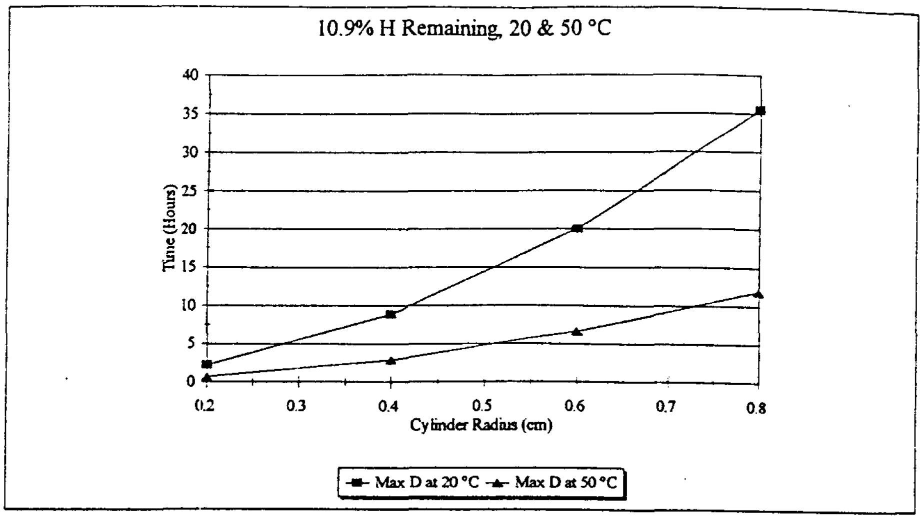
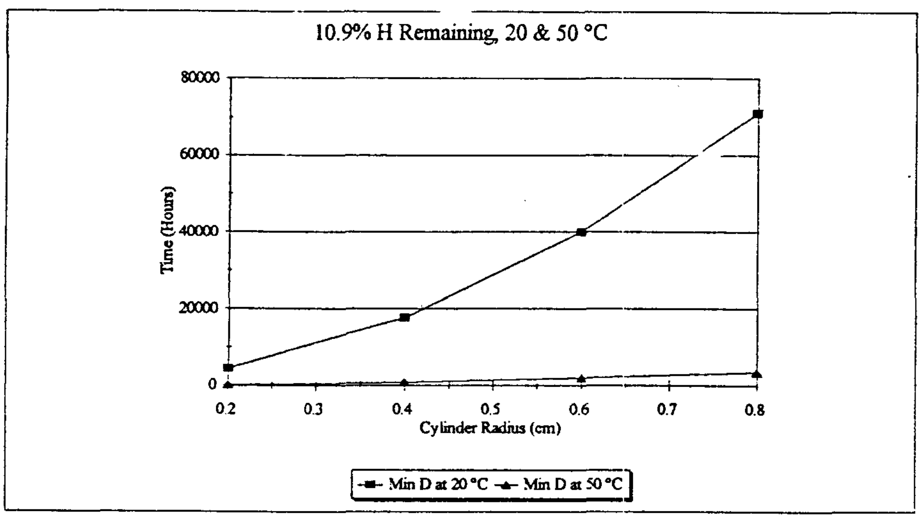


Figure 10
Influence of Temperature on Hydrogen Diffusivity Coefficient

Maximum D for ferritic steels



Minimum D for ferritic steels



Mid range D for ferritic steels

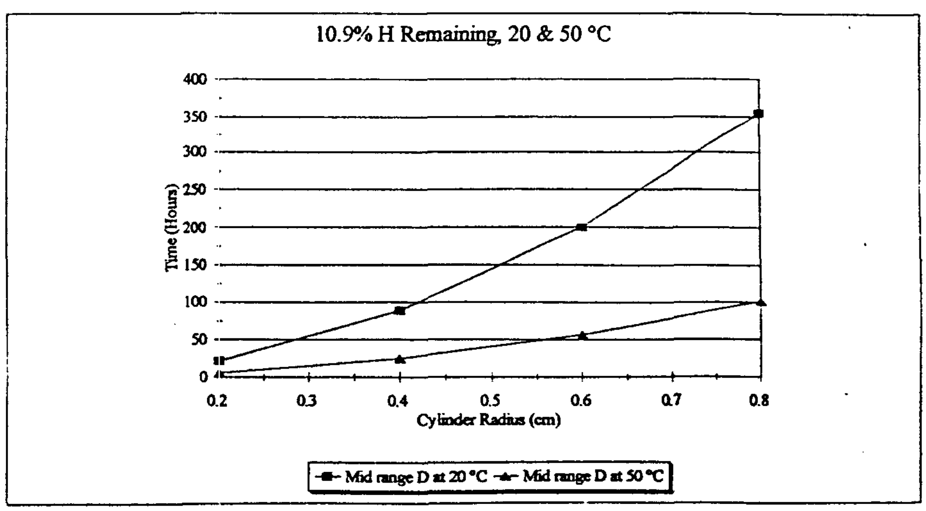


Figure 11
Effect of Temperature on Time For Hydrogen Loss to 10.9% of Original Value at the Center of Infinite Cylinder

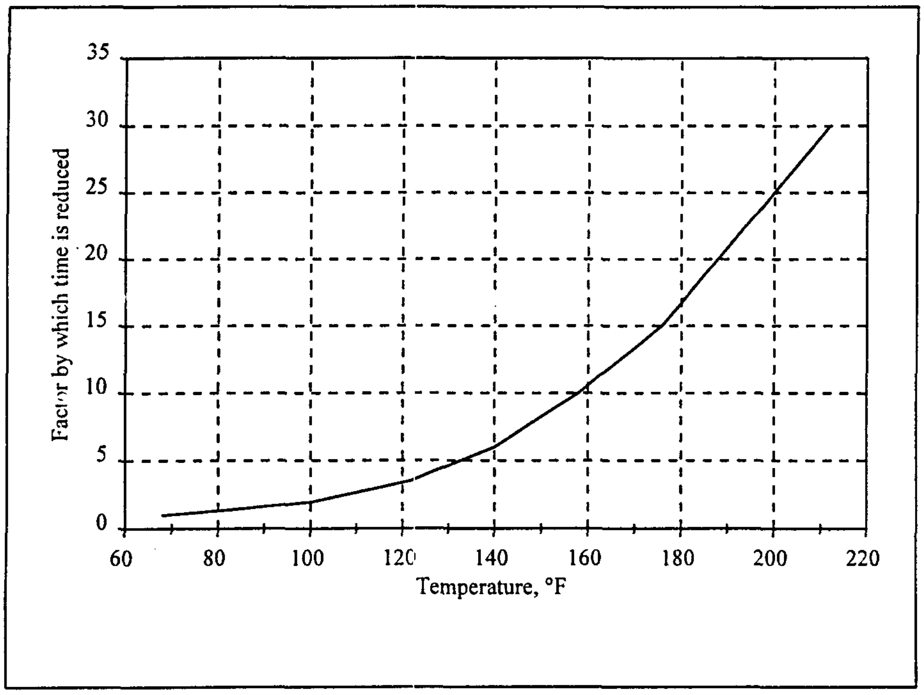


Figure 12
Factor By Which Time For Hydrogen Diffusion Is Reduced At Elevated Temperature By Comparison With Normal Ambient Temperature (20 °C, ~ 70 °F)

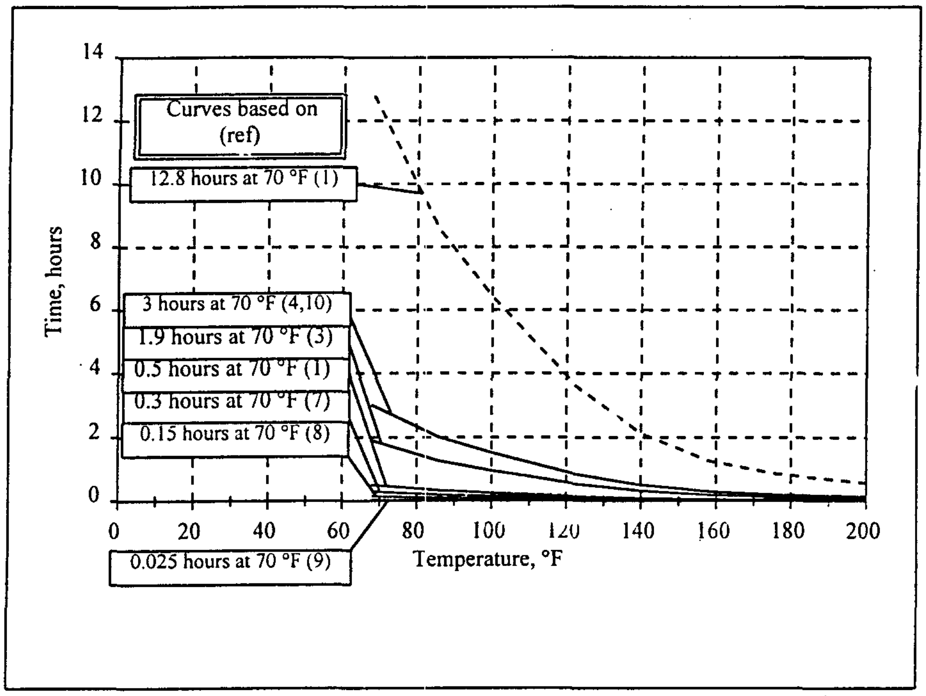


Figure 13
Effect Of Temperature On Maximum Expected Delay Time Before Hydrogen Cracking, Based On Different Reported Delays At Ambient Temperature (See Table 3)

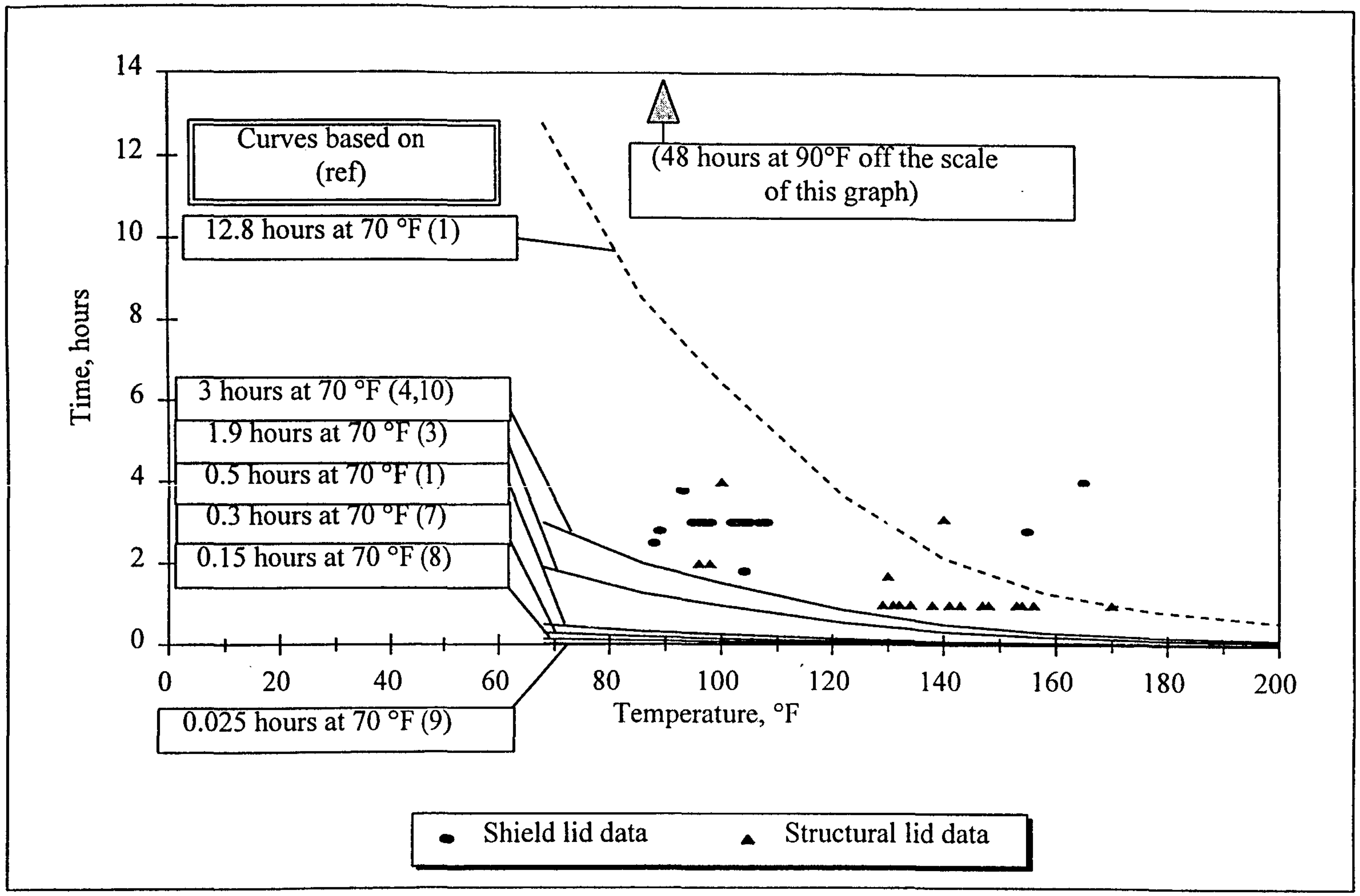


Figure 14
Data For Lid Welds Superimposed On Figure 13, Indicating That Actual Delay Times Exceed Maximum Expected Values Based On Most Relevant Published Data (See Table 3)

Appendix A

Resumes of Lid Weld Review Team

PROFESSIONAL PROFILE

Bill L. Baker
69913 Nick Thomas Road
Rainier, OR 97048
3-556-2214 or 7570

EDUCATION:
Bachelor of Science in Applied Science and Technology
Major: Non-Destructive Evaluation (NDE)
Minor: Metallurgy

NATIONAL CERTIFICATIONS
ASNT: NDE Level III - MT, PT, UT, RT, LT
EPRI: NDE Level III VT 1-4; UT IGSCC Sizing and Detection
AWS: Certified Welding Inspector #82120211
ICBO: Certified Special Inspector - Structural Steel and Welding #89087

WORK EXPERIENCE:

1/95 to Present — ***Baker*** Consulting Company

As owner of ***Baker*** Consulting Company, provide Nondestructive Examination Level III consulting, Quality Assurance/Quality Control/Surveillance and Welding Inspection services to most industries worldwide. Specialize in examination problem solution, NDE program development, training, personnel qualification, and rformance of examinations using most conventional NDE methods. Provide Quality Assurance/Control ogram development. Perform Internal and Vendor Quality Assurance Audits, Quality Control Inspections and Surveillance of project activities. Perform Welding Inspection and Welder and Welding Procedure Qualification. Utilize most Microsoft products, and Word Perfect.

1/89 to Present — **Portland General Electric**

Progressed to Quality Control Supervisor responsible for twelve person Quality Control/NDE inspection staff supporting Pressurized Water Reactor Nuclear Power Plant operations and maintenance prior. Develop and maintain administrative, personnel qualification and inspection activity procedures. Certified to ASME and SNT-TC-1A as Level III in VT 1-4, MT, PT, UT, RT and LT NDE methods. Received 80 hours eddy current theory and examination training from ZETEC, Inc., and certified as SNT-TC-1A Level II ET examiner. Monitored activities of Steam Generator Tube ET Examination contractor. Certified and performed inspections as ANSI Level III Mechanical, Welding and Civil Inspector; ANSI Level II Electrical, Instrumentation & Control Systems and Receiving Inspection. Received award for project coordination, equipment purchase/installation and procedure development for X-ray system to examine welder qualification coupons. Additionally, as Quality Assurance Specialist and certified as Lead Auditor to ANSI N45.2.23, perform Internal and Vendor Quality Audits and Source Surveillances.

sently perform the above NDE, Quality Assurance and Quality Control responsibilities during the Trojan Nuclear Plant decommissioning and Independent Spent Fuel Storage Installation (ISFSI). Decommissioning activities include major component removal and radioactive waste packaging and shipment. ISFSI activities include pad installation, Transtor cask vendor surveillance, cask loading surveillance, cask weld NDE and Fuel Debris processing equipment vendor surveillance.

4/88 to 12/88

MK-Ferguson Company
NDE Supervisor

Responsible for fifteen person NDE group supporting Pressurized Water Reactor Nuclear Power Plant Steam Generator replacement project. Developed and maintained administrative, personnel qualification and NDE procedures. Planned and scheduled work activities. Interpreted all radiographic film, and reviewed all NDE reports prior to issue. Certified to ASME and SNT-TC-1A as Level III in VT, MT, PT, UT, and RT NDE methods. As Radiation Safety Officer was responsible for radiation safety training, personnel exposure records and various radiographic sources. Trained and certified NDE personnel. Additionally, was certified as Lead Auditor to ANSI N45.23 to perform Internal Quality Audits.

2/86 to 4/88

Westinghouse Hanford Co.
Inspection Supervisor

Supervised Inspection personnel supporting N-Reactor and various chemical processing and tank farm facilities. Certified to SNT-TC-1A as Level III in VT, MT, PT, UT, RT, and LT NDE methods. Performed NDE, erosion/corrosion monitoring, inservice and new construction inspection of metal and concrete tanks, radioactive waste containers, structures, piping systems, and lifting equipment. Performed examination of radioactive waste containers using automated Real Time system. Trained and certified Inspection personnel. Performed Vendor audits and Source Surveillance of Nondestructive Examination companies who performed NDE on equipment supplied to DOE site.

9/83 to 2/86

Bechtel National, Inc.
Senior Engineer/Corporate NDE Level III

Consulted with project groups regarding NDE and Metallurgical problem solution. Established and managed field group (Level III, Level II's and support personnel) performing ASME Section XI Preservice Inspection activities. Trained and certified examination personnel. Certified to SNT-TC-1A as Level III in VT, MT, PT, UT, and RT NDE methods. Provided Nuclear Regulatory Inspector and Authorized Nuclear Inservice Inspector liaison, code interpretation, flaw and failure analysis. Received award for developing computer software for the ASME Section XI classification of flaws detected and sized using Ultrasonic examination techniques during Pre and Inservice examination of piping welds. Team member performing life assessment inspections and metallurgical analysis of electric power plant, chemical plant and refinery structures, systems and components. Successfully completed Ultrasonic detection and sizing of IGSCC training at the EPRI NDE Center.

6/81 to 9/83

MK/ESI/Lord
NDE Level III

NDE staff Lead during construction of Pressurized Water Reactor Nuclear Power Plant. Developed and qualified NDE procedures. Reviewed all examination documentation and radiographic film prior to client turnover. Certified to SNT-TC-1A as Level III in MT, PT, UT, and RT NDE methods, performed ASME Section III and AWS NDE examinations of piping and structural systems.

Thomas Burtard

EDUCATION BSME University of Wisconsin-Madison 1974

EMPLOYMENT

1974-77 Babcock & Wilcox

- Supervisor of automated welding
- Welding Engineer process development

1977-present Wisconsin Electric Power

Welding Engineer

Responsibilities include:

- Procedure development for repairs to Fossil and Nuclear Power components.

- Develop run/repair programs to manage creep/fatigue/FAC damage to Fossil Power components.

- Develop special process techniques and equipment for repair of Power Plant equipment.

- Train and qualify welders to AWS and ASME Codes.

- Develop State of Wisconsin required Quality Control program to manage ASME Sec 1 repairs.

- Perform root cause failure analysis of equipment.

PROFESSIONAL AWS Certified Weld Inspector
Registered Professional Engineer Wisconsin
EEI Metallurgy and Piping Task Force

PUBLICATIONS EPRI/ASME Power Conference -- L-1 Turbine Bucket Refurbishment

RESUME

DR. DOMENIC A. CANONICO

Domenic A. Canonico is Vice President, Technology for ABB CE Power Products Manufacturing. He is Chairman of the ASME Council on Codes and Standards. He has over 40 years experience in metal joining, fracture toughness, pressure vessel technology and physical metallurgy. His experience and expertise traverses both non-nuclear and nuclear pressure vessel fabrication.

Dr. Canonico's previous experience was in welding and brazing at Armour Research Foundation (currently Illinois Institute of Technology Research Institute), Bethlehem Steel Company and Oak Ridge National Laboratory. He was Director of Combustion Engineering's Metallurgical and Materials Laboratory from 1981 to 1990. He is currently associated with fabrication in ABB CE Power Products Manufacturing facilities. At the Oak Ridge National Laboratory Dr. Canonico was responsible for Pressure Vessel Technology and was the materials expert assigned to the Nuclear Regulatory Commission Heavy Section Steel Technology Program.

Dr. Canonico received his B.S. degree from Michigan Technological University and his M.S. and Ph.D. from Lehigh University. His research activities at Lehigh included welding and materials properties of pressure vessel steels. Domenic's technical contributions have been recognized by his peers through his election to Fellow in three major technical societies; the American Welding Society, the American Society for Metals and the American Society for Mechanical Engineers. He has been particularly cited by the American Welding Society, he was the 1983 Adams Lecturer, was awarded the William H. Hobart Memorial Medal in 1985, the James F. Lincoln Gold Metal in 1979 and the Dr. Rene Wasserman Award in 1978. He is the 1994 recipient of the ASME J. Hall Taylor Metal. Dr. Canonico's outstanding contributions to ASME Codes and Standards were recognized when he was awarded the 1996 Dedicated Service Award. He has written over 100 technical papers and given numerous talks before technical organizations in the U.S., Mexico, Europe and Asia. He is named in Who's Who in Engineering and Men and Women of Science.

Dr. Canonico is an Adjunct Professor at the University of Tennessee - Knoxville and on the Advisory Committee to the School of Engineering at the University of Tennessee - Chattanooga. He is Chairman of the Board of Directors of The Welding Research Council and a member of The Board of Directors of The Materials Properties Council. Domenic is a member of Sigma XI. Dr. Canonico is a member of the Tennessee State Board of Boiler Rules.

ANTHONY J. CIAPANNO
56635 Country Villa Lane
Warren, Oregon 97053
(503) 397-5046

PROFFESIONAL PROFILE

Welding Engineering & Code Specialist
Welding Program Implementation

INDUSTRY EXPERIENCE AND RESPONSIBILITIES

25⁺years of Integrated Experiences and ***Direct Responsibilities*** in the welding industry.

Areas of experience are in Welding Engineering, evaluating technical problems and finding solutions; ***Interpretation and Application*** of construction code requirements, training, procurement of materials, *QA/QC* activities, including ***Project Management and Contract Administration***.

Responsible for fabrication, construction, and installation of boilers, pressure vessels, and piping systems including the ***repair/replacement and maintenance*** of such components.

A broad background consisting of: Nuclear, Fossil-Fuel, Petro-Chemical, Electronics, and Marine Industries all of which involved the application of ***various welding processes*** of which require a *comprehensive understanding* of materials and their ***behavior in specific environments***.

Developed diversified and ***intensive training programs*** for qualification of welders, welding instructors and welding inspection personnel, reducing costs, increasing both ***Quality*** and ***Production capabilities***.

Obtained thorough ***knowledge of codes*** applicable to power plants, welding procedure development and qualification with the ***Ability to Interpret and Implement*** regulatory changes and requirements. Understanding ***budgetary concerns, operating costs, and schedules.***

Overseen the application of ***various mechanical and non-destructive testing*** methods including ***interpretation/assessment of results,*** providing ***qualitative data*** required to determine that a specific design basis or a code ***acceptance criteria has been met.*** and **Implemented**

Developed unique welding ***programs with specific controls***, utilizing specialized welding procedures, setting variables for insuring that WPS-specifications are being met for code and non-code welding related applications. ***Developed multiple Computer data base*** programs for welder qualification, documentation, tracking and updating current qualification status of individuals, including WPS and PQR applications this included field Quality assurance activities related to weld records and inspections.

Contributed to specific *research* and *development* programs involving contributions to **improving technical changes to existing repair code requirements**.

Able to work with managers, engineer's supervisors, craft foreman and personnel with different levels of understanding of the ***implied requirements***. Thus providing and developing a mutual understanding of the ***responsibilities and relationship*** between all associated parties.

Familiar with state and federal OSHA requirements for Safety and Health, repair and maintenance of equipment thus **understanding liability issues or concerns.**

Contributed to specific Research and development programs involving welding technology intended for improving technical changes to existing repair code requirements as applicable to ASME and NBIC.

Obtained a comfortable *skill and knowledge level* with using computers, various *software programs*, intended for meeting the ***Managerial needs of today's working environment.***

ANTHONY J. CIAPANNO
56635 Country Villa Lane
Warren, Oregon 97053
(503) 397-5046

EMPLOYMENT HISTORY

Portland General Electric Company - Corporate - Generation & Transmission Engineering
Welding Engineering & Code Specialist V Portland , Oregon 92-Present

Developed and ***implemented*** PGE Corporate Welding Program, endorsing all applicable codes, standards and regulations as required by State and Federal regulatory agencies and insurance requirements. ***Administration of the program*** requirements apply to Nuclear, Fossil Fuel, Hydro-Electric, Power Generation and Transmission Facilities. This requires finding ***cost effective solutions*** to many diversified problems. Presently involved with the ***research and development*** of ***Specialized Welding Procedures*** for meeting the newly ***revised rules*** of NBIC. This as applicable to ***Post weld heat treat*** exemptions. for ***Repair of in-service components***. This is in conjunction with the ***Edison Welding institute*** and the ASME ***Pressure vessel Research Council and the International Institute of Welding***. **Developed** -corporate ***computer Program & data base*** for the tracking and documentation of welder qualifications , including the maintenance and updating of such qualifications. The functional relationships of the data base include WPS & PQR form based viewing, report generation, usable network viewing and applications.

Portland General Electric Company Trojan Nuclear Power Plant
Welding Engineering & Code Specialist V Rainier, Oregon 1986/1992

Administer craft welder qualifications, organize and control activities of ***multiple welding engineers/specialists***. Develop welding procedures, training programs; perform safety and ***suitability evaluations***; provide expert ***technical input*** to support event review teams in determining ***root cause analysis and solutions*** to welding related ***failures or unacceptable weld joints***. Reviewed welding / code documentation; reviewed and ***approved purchase specifications*** for ***technical content***. Administered/approved contract specifications for personnel services requiring testing, inspection, material acceptance applicable to vendors/contractors and suppliers. The position of ***"Senior/Lead"*** Welding Engineering ***Code*** Specialist required ***functional organization*** skills, utilizing effective communication methods and ***directing*** other engineers / specialists / craft personnel / supervisors related to welding tasks. ***Developed Specialized*** welding procedures and integrated ***updated*** welding ***technological improvements*** into the applications of maintenance welding activities. Meeting , interpreting and implementing intended ***Quality Assurance*** and **Quality Control** requirements where part of the overall ***intent***. This included activities of ***auditing vendors*** and ***performing surveillance activities***. The activities brought forth a more complete understanding of ***Design Engineering requirements*** and how to ***insure*** they are being meet correctly.

Steam fitters Local 290 Training/Testing Center 1981 - 1986
Senior Welding Instructor/Engineering Specialist Portland Oregon

Provided ***support*** for all signatory contractors involved in the ***piping industry***. Instructor duties included ***training*** of personnel, ***curriculum development***, coordinating activities with other instructors and management. Welding Engineering ***duties*** where qualifying welders, developing and writing welding procedures and acting as a ***technical representative*** for the Portland area mechanical contractors. Provided ***code interpretation*** for implementation and development of programs meeting State of Oregon regulations. Responsible for projection budgets including projection of yearly operating costs and established fees for testing welders and qualification of welding procedures. Developed electronics industry welding inspection criteria.

Hoffman Construction **1978 - 1980**

National Contractor/Fabricator Welding Superintendent QA /QC +Specialist 1975 - 1976

Responsible for qualifying welders, implemented welding program and code requirements for construction fabrication of piping, components, vessels, structural supports. Supervised craft, coordinated activities with management, engineering, QA/QC personnel. Assisted in bid/contract proposals, interfaced with fabrication personnel to meet delivery dates and budget restraints. Maintained large pool of qualified welders establishing high productivity with low ***(3-7%)*** weld rejection rates. Certified and Performed various NDE methods of inspection interpreted radiographs for code acceptance criteria under QA Program. Helped develop and implement ASME Code Stamp Programs R, PP, U and N.

Marine and Pipeline Industries Various contractors: Nuclear, Fossil-Fuel, Petro-Chemical, 1970-1975

Craft Welder, Supervisor, Inspection Technician, Welding Engineering Technician

Worked with various types of piping/pressure vessel installations and repairs. Performed inspection of weld joints and materials of fabricated components, VT MT PT RT

Welding Industry & Community Accomplishments - Awards

95 **Portland Chapter of the American Welding Society** Outstanding Contributions and Achievements to the Portland Section and the National Organization Development and implementation of Lectures, courses, seminars for the welding industry. With specific involvement and Responsibilities in the National AWS QC-1 Welding Inspection Certification Program. Provided and developed example test questions, review of testing materials, methods, topics and areas of need. Thus intended to provide a basis for establishing the minimum levels of knowledge, experience and training for welding inspectors. Overall promotion of the Society.

93 **Factory Mutual Engineering** Received award and recognition of outstanding contributions to the development and ***training of ASME authorized Inspectors*** of their employ. This covered code concerns, inspection, interpretation, welding, pwht requirements, welding procedure qualification and welder qualifications as applied to specific conditions.

90 **Nuclear / Fossil Fuel Industry** Qualified welding procedures for Carbon steel / Stainless steel clad piping materials. High Pressure Feed water applications where abnormal erosion / corrosion rates occur. Material is designed to have high resistance to ***Stress Corrosion Cracking and Erosion phenomena.***

87-89 **Nuclear Industry** Developed and Qualified Specialized Welding Procedures for Trojan Nuclear Plant. ASME section XI Repair & Replacement Code , ***Half Bead /Temper Bead Repair Procedure*** for ASME P-1 and P-3 material groups with the exemption of Post Weld Heat Treatment. These procedures are intended for repairing nuclear components (steam generator vessel walls, main steam outlet nozzles and feed water inlet nozzles). Therefor as welded mechanical properties ***(notch Toughness)*** as required by the code where meet. This was accomplished using both manual (SMAW and GTAW) and (GTAW) machine welding.

84 **Electronics industry -** Implemented the ***first formal Training programs*** for individuals on the usage, and necessity of ***Automatic Orbital Welding equipment*** and the applications in the state of Oregon. This was implemented to meet the needed changes in the industry and providing support for the contractors. Assisted in the development of weld joint acceptance criteria for visual acceptance of fabricated components and weld joint fitness for purpose concepts. Evaluation and testing the strength of weld joints with known defects or discontinuities related to normal fabrication problems or concerns.

81-83 **Gas transmission project** invoking American Pe*oleum Institute- API- 1104 Code requirements for welding where ***CTOD Crack Tip Opening Displacement testing*** was required to be meet. Developed Welding procedure qualification essential variables to meet the requirements of the intended material types for sub-zero environment or temperatures. This was for Shielded Metal Arc Welding (SMAW) and Flux Cored Arc Welding (FCAW) of High Strength Low Alloy pipeline materials intended for the Alaska Pipeline Projects. These requirements of the code imposed strict adherence to controlling; preheat, interpass temperatures, Heat input (joules) which where variables effected by travel speeds, amperage, and voltage. Included was deposit thickness (per layer) and weld bead size, and time in between passes. E71-T1 and E8010/ E9010 filler metal classifications where used and qualified to meet the needed requirements.

81 & 86 **Steam fitters Training Center** developed and implemented a Welding certification and Procedure development program for all signatory contractors. This provided a method to help correctly qualify welders and programmatically improve the quality within the individuals employed by the contractors. At the same time assisted in meeting the requirements of the state of Oregon Boiler & Pressure vessel law. **86-** Award for Commitment and contributions to the training of apprentices and journeyman for the organization.

EDUCATION

Oregon Graduate Institute of Material Science & Engineering: 93-present Failure Analysis. Metallurgy of ferrous materials, Welding metallurgy, and applications of welding processes (current course instructor).

Oregon Institute of Technology : 1992-93 Engineering Management, Industrial psychology , Accounting

Clackamas Community College: 1985, Welding Metallurgy of Ferrous Materials,
Portland State University: 1983-1985,Various Courses of Material Science, Physical and Chemical Metallurgy of ferrous and non-ferrous materials in conjunction with the American Society of Metals.

Purdue University: **1981-1985,** ***Material Technology BSMSE Program certificate,*** Major: ***Joining of Materials Consisting of;*** ferrous and non-ferrous metallurgy, process metallurgy, welding metallurgy, properties of ma :r.als, strength of materials, metalographic preparation and interpretation of ferrous materials, material testing /methods/application/interpretation, crystalline/polycrystalline structures, general principals of failure analysis. Material joining methods (arc welding types and processes), brazing, soldering, thermal setting processes and joining of nonmetallic materials. Nondestructive testing methods and evaluation of results.

Vocational Education / Teaching U.A. Instructors Training Program.
Development of test questions, examinations, interpretation of results, test content, qualitative value.
Evaluating test scores, data, and quantifying the results. Instructional aides, equipment. Developing lesson plans and objectives. Course content assessment, development, and review plans. Instructor (personal) development needs. Psychology, cognizant learning and awareness, personality problems. Instructional objectives, methods, and techniques. Classroom lectures, demonstrations, format and arrangement of classroom presentations to promote functional interactions between individuals. Effective and diversified teaching methods . Learning objectives and observational skill development.

Reliant Heating and Cooling, Inc.: 1981, General Heat Treating; Post-Weld Heat Treatment and Stress-Relieving of Welds and Materials.

American Welding Society: 1977-1988, Safety and Health of Welding Environments ; Welding Metallurgy and Destructive Testing; Welding Imperfections and Discontinuities; Fitness for Duty, Welding Inspection and Quality Control, Failure analysis. AWS QC-1 certification 1977 and 1982

American Society of Non-Destructive Testing: 1977-1980, Introduction to the Application of N.D.T. with certification courses in MT, PT, UT, LT and RT. 1993-95 Eddy Current examination

Portland Community College: 1972-1974, Major: **Welding Technology,** processes and applications, Basic welding Metallurgy (introductory), with supplemental courses in Mathematics.

PERSONAL

Educational Chairman , Chairman of the Portland Chapter of A.W.S. in the 1983-1984 and 1984-1985 terms etc. Currently still involved as an ***executive board member*** and have served as a Proctor for the **A.W.S. QC1 Certified Welding Inspector's examination** at the Portland test site for the past 14 years.

Currently A.W.S. Chapter Certification and Qualification Chairman.
I have ***taught*** many courses on ***welding technology subjects*** and ***inspection*** for the Portland chapter of the American Welding Society. Presently serve as an **Advisory Board Member** for **Portland Community College** "Welding Technology"-10 years **"Chairman 90-94"** and also serve on **Vancouver-" Clark College"** Welding Technology Advisory Board 4-years.
Started Private Consulting Business in 1983: As a secondary method of income and professional interests. Services are conducive to construction and fabrication codes, with a broad base knowledge of ***diversified material types*** and their ***weldability*** concerns. Training, direct inspection, program development and implementation are the prime areas of expertise. Quality Assurance development and improvement methods have been provided to contractors and owners. ***Auditing*** of vendors or Sub-contractors, providing ***surveillance activities*** and providing functional documentation is also part of the available services.

curriculum vitae

STEPHEN FISHER

'Arkle', 31 Frith Ave, Delamere, Northwich, Cheshire CW8 2JB UK

Tel No (Home) 01606 888277
(Business) 01925 834926

PROFILE

Dedicated and enthusiastic senior engineer with over 20 years experience in welding and fabrication experience associated with structural steels and high integrity chemical process plant.

KEY SKILLS AND ATTRIBUTES

* Professional qualified welding engineer and metallurgist with chartered engineer status.
* Extensive knowledge of welding engineering and fabrication from project design stage through plant construction and commissioning.
* R & D project management responsibility
* Familiar with QA and Inspection principles
* Good communication skills
* Self motivated and reliable

SPECIALIST KNOWLEDGE

- Experience in all aspects of welding technology, in particular;
- welding design, welding processes and fabrication practices.
- welding metallurgy, in particular of carbon and stainless steels.

PROFESSIONAL MEMBERSHIP

1974 - Corporate member Institute of Materials (MIM)

1977 - Chartered Engineer (CEng)

1981 - Corporate member The Welding Institute (Sen MWeldI)

1991 - Member of the American Welding Society (AWS)

1995 - European Welding Engineer (EWE)

BRIEF CAREER DETAILS

1988 - present
Currently responsible for welding engineering section of small specialist consultancy group within British Nuclear Fuels plc.
Engaged on the provision of welding technical support to major capital investment projects both in UK and overseas.

Responsibilities include;

- Control of £100k R&D projects on welding and fabrication.
- Provision of technical input to Company welding and fabrication specifications.
- Technical assessments of new Companies.
- Review and approval of Contractors welding procedures.
- Welding consultancy to design offices and outside Companies.

1980-1988
Welding Engineer with British Nuclear Fuels plc.

1975-80
Metallurgist with National Nuclear Corporation.

1972-75
Research Scientist with MOD at The Royal Military College of Science.

MAJOR ACHIEVEMENTS

Successful management of welding engineering section staff.
Promoted use of FCAW for stainless steel plant construction to demonstrate caost and quality benefits.
Significant technical contribution to Company fabrication specifications.
Successful implementation of orbital welding process for Pipework installation on THJORP-Uks major construction project in the 1980's.
Representation on BSI committee's for European welding standards.

TECHNICAL EDUCATION AND TRAINING

Date	Institution	Subject	Award
1970	University of Loughborough	Metallurgy	MSc
1969	University of Surrey	Metallurgy	A..Met
1966	Manchester Polytechnic	Metallurgy	HND
1963	Bolton Institute of Technology	Metallurgy	ONC

RECENT TRAINING/COURSES (since 1990)

1994 - Joint author and presenter at 5th International conference on Computer in Welding of paper 'The development of advanced image based sensors for automated TIG welding'.
1993 - Radiological protection course (BNFL in-house)
1992 - CSWIP Welding Inspector, TWI Abington (1 week)
1991 - BS5750 Lead Assessors Course, Preston (1 week)

OTHER INFORMATION

Car owner - clean driving license
Hobbies; diy, amaeur radio (licensed operator), computers

Harry L. Gustin, P.E.

Associate

Education

BS, Mechanical Engineering, Massachusetts Institute of Technology
MS, Mechanical Engineering, Massachusetts Institute of Technology

Professional Associations

American Society of Mechanical Engineers
American Society for Nondestructive Testing
Registered Professional Engineer: Illinois, Minnesota, New Jersey, North Carolina, Wisconsin

Professional Experience

1985 to Present	Structural Integrity Associates, San Jose, California Associate
1982 to 1985	NUTECH, San Jose, California Principal Engineer and Technical Leader
1980 to 1982	Massachusetts Institute of Technology Research Assistant
1975 to 1980	Commonwealth Edison Company, Chicago, Illinois General Engineer

Summary

Mr. Gustin has over 20 years of technical and supervisory experience related to the nuclear energy field. This experience includes the areas of fracture mechanics, welding engineering, power plant system operation, modification, and repair design, ASME Boiler and Pressure Vessel Code requirements, licensing and regulatory compliance, and nuclear and software quality assurance.

At Structural Integrity, Mr. Gustin has performed failure analyses, flaw evaluations, and stress analyses for PWR and BWR reactor vessel components and PWR steam generators, and performed leak-before-break (LBB) analyses. He has also developed welded repair designs for carbon steel, stainless steel, and nickel based alloy piping systems and components. Mr. Gustin was a principal investigator for the recent BWRVIP-sponsored project which developed underwater welded repairs for reactor internal core spray piping.

While at NUTECH, Mr. Gustin served as Technical Leader of the Applied Mechanics Group, where he directed the activities of engineers and analysts responsible for stress, fatigue, and fracture mechanics analyses of nuclear power plant components.

At MIT, he developed a highly simplified class of automatic welding machines as part of an undersea welding program.

At Commonwealth Edison, Mr. Gustin was a member of the engineering group which supported operating nuclear power plants. He managed the implementation of several of the containment modifications associated with the BWR Mark I program, and designed modifications to plant circulating water systems, nuclear off-gas treatment systems, and reactor water cleanup systems.

PETER H M HART, BSc, ARSM, CEng, MIM, SenMWeldI

Peter Hart is currently Head of TWI's Materials Department. He is a member of the Institute of Materials and of The Welding Institute, and obtained a degree in Metallurgy from the Royal School of Mines at the Imperial College, London. He was a joint winner of The 1985 Larke medal, which was awarded for a paper on submerged arc weld metal toughness.

After initially working on non-ferrous materials, he has spent most of his career working on ferritic material, particularly C:Mn and low alloy steels, and has been involved with almost all aspects of their weldability. He has led and managed numerous projects into all aspects of weld metal and heat affected zone hydrogen cracking, while also being involved with weld metal and heat affected zone toughness, with special emphasis on factors controlling microstructure development. He has also led and been involved in several large failure investigations. During his career he has had extensive involvement with the metallurgical aspects of pipe welding, particularly with respect to hydrogen cracking and toughness behaviour of girth welds, but also in relation to seam welding of line pipe.

Peter Hart has written numerous reports and published over 60 papers, both nationally and internationally, on most aspects of weldability but particularly on hydrogen cracking and weld toughness. He has also been a Technical Director for seminars and International conferences on weldability and pipe welding. He is a member of several Committees on welding, including British Standard, European and ISO, and of IIW Sub-Commission IX-B, and is currently Chair of BSI Committee WEE/21/7 on field welding of pipelines.

WILLIAM W. HEINSOHN

EDUCATION:

BSME, University of Minnesota, Institute of Technology, 1985

EMPLOYMENT:

1991 - Present

Wisconsin Electric Power Company, Point Beach Nuclear Plant,
Senior Engineer/Welding Engineer

1986 - 1991

General Electric, Knolls Atomic Power Laboratory,
Shift Supervisor/Nuclear Plant Engineer, S3G Prototype

Responsibilities in Welding Include:

- Develop and maintain the welding program at Point Beach Nuclear Plant
- Procedure Development for repairs to plant components
- Train and qualify welders to AWS and ASME codes

RESUME

BRIAN JOHN KRUSE
Manager, Hydro Maintenance Section
Duke Energy Corporation
5562 Pendergrass Blvd.
Great Falls, South Carolina 29055

FORMAL EDUCATION

Master of Science, Metallurgical Engineering, The University of Tennessee, August 1980.
(Thesis topic: Lamellar Tearing Susceptibility Evaluation).
Bachelor of Science (Honors), Metallurgical Engineering, The University of Tennessee, June, 1979.

PROFESSIONAL REGISTRATION and HONORS

Registered Professional Engineer, North Carolina. (# 12999)
Registered Professional Engineer, South Carolina. (# 11296)
Member, Tau Beta Pi Engineering Honor Society

PUBLICATIONS

High Temperature Properties of 2¼ Cr-1 Mo Weld Metal, WRC Bulletin 277, May 1982 (with C D Lundin and M R Pendley).
Lamellar Tearing Susceptibility Evaluation, M S Thesis, University of Tennessee, August 1980.
Phase Transformation in the HAZ and Weld Metal, Proceedings, Trends in Welding Research in the US, ASM 1981 (with J L Wen and C D Lundin).
Fatigue Behavior of HY-130 Weldments Containing Fabrication Discontinuities, April, 1985 NRL M. Report 5520 (with S J Gill, J A Hauser, T W Crooker, R Menon, C D Lundin).
Influence of the Crack Starter Bead Technique on the Nil-Ductility Transition Temperature of ASTM A572 Grade 55 Hot Rolled Plate, ASTM STP No.919 December, 1986. (with E A Merrick and C D Lundin).
In-Situ Metallography - A Economical Technique for Making Metallurgical Determinations in The Field. Power Engineering, Sept. 1987. (with S E Ferdon).
Remote Video Welding System for Dry Storage Canisters Proceedings, Maintenance and Repair Welding in Power Plants, AWS, 1991. (with D G Smith and J C Jenkins).
MPC Closure Weld Model Study Proceedings, Fifth Annual Int'l Conf.,High Level Radioactive Waste Mgmt., ASCE, May, 1994 (with J B Stringer and G G Childress).
Bonding Problem with Babbitt-To-Copper At Bad Creek Pumped Storage Station Proceedings, ASME Joint Int'l Power Gen. Conf., October, 1994 94-JPGC-PWR-8 (with R A King, E G Duncan, G Turner).

EXPERIENCE

Management and eupervisory experience, engineers, technicians and craft workers. Project management, design and build welding systems. ASME Codes. Metallurgical failure analysis. Member of the Duke Nuclear Safety Review Board, assessing nuclear safety issues for operating nuclear stations. Welding procedure development. Welding research and development. Experience with dry storage systems for spent nuclear fuel (see publications above). Writing and oral communication skills. Knowledgeable of personal computers; Windows, word processing, CAD, spreadsheet, and data bases.

BRIAN JOHN KRUSE
WORK HISTORY

6/97 to present Manager, Hydro Maintenance Section. Leader of 8 supervisors and technical specialists in the hydro maintenance section. Section size is 40. Responsible for the maintenance and overhaul of approximately 100 hydro units on the Duke system.

6/94 to 6/97, Team Leader, Predictive Maintenance and Technologies, Duke Power Company.

Supervisor of a team of twelve engineers and technicians. The team employs predictive maintenance technologies such as vibration measurement and thermography to determine condition of large rotating machinery in power plants. The team also performs other advanced diagnostics and machine alignments. Member of the Duke Corporate Nuclear Safety Review Board, analyzing plant events and technical specification changes. Consultant to the Duke Engineering and Services Subsidiary of Duke Power for metallurgy and welding engineering. Awarded the division Team Leader of the Year for 1996.

7/90 to 6/94, Engineering Consultant, Duke Power Company.

Responsible for conducting and reviewing metallurgical failure analyses. Managed the Duke Corporate Welding Program. Served on the ASME Special Working Group for Underwater Welding in Nuclear Facilities. Member of the Duke Corporate Nuclear Safety Review Board, analyzing plant events and technical specification changes. Section Quality Steering Committee chairman, rolling out the corporate quality improvement process to the section. Provided consultation in the selection of materials for design and modification activities. Author of technical papers in the area of Welding Engineering.

6/85 to 7/90, Staff Engineer, Duke Power Company.

Responsible for maintaining the Duke Power Corporate Welding program to ensure continued compliance with applicable codes. Established corporate policy on implementation of the welding program. Assessed field fabrication problems. Monitored project compliance with the welding program and fabrication procedures. Identified new technology and application to construction activities. Served as Welding/Metallurgical Consultant to the Design and Construction Departments in codes, standards and specifications. Initiated analysis of failed components, to determine the cause of the failure and prescribe corrective action. Reviewed proposed changes to codes and standards for code committee members and provided recommendations for the position of the company on new issues in the welding and metallurgy areas.

10/84 to 6/85, Associate Field Engineer, Duke Power Company.

Responsible for resolving problems encountered with piping and mechanical components during construction. Completed documentation required for the N-5 data report. Provided consultation on material selection for other construction groups and provide interpretation of ASME and ANSI codes and ANSI and ASTM specifications to other groups in construction. Reviewed construction drawings for correctness. Revised and developed construction procedures and served as instructor for construction and QA procedures. Overall responsibility for fire protection systems, insured installation was correct and met regulatory requirements.

11/83 to 10/84, Assistant Field Engineer, Welding Group Supervisor, Duke Power Company.

Responsible for resolving welding and material related problems associated with construction and insuring welding activities compiled with applicable codes and regulations. In the supervisory capacity, responsible for four engineering technicians and their resolution of problems, issuance of routing and special welding instructions, and the revising and reviewing of engineering drawings. During this time, the Welder B issue arose as an employee concern of construction quality. In a team effort with an engineer from the Design Department developed a non destructive metallographic technique to assess the metallurgical condition of welds made by welders assigned to the crew identified by Welder B. Provided testimony operation license hearings of the results of the technique on Catawba welds. The technique was also used to determine the metallurgical condition of the 1B Diesel Generator Engine Block.

8/80 to 10/83, Research Associate, University of Tennessee.

The primary responsibility was supervising graduate students (M.S. and PhD candidates) in their research projects. The topics of the projects varied, but in general were related to the metallurgical response of metals to welding. This involved establishing the initial direction of the project, defining milestones, and insuring commitments to funding agencies were met. All the projects were funded by outside agencies so in addition to supervising the daily activities of graduate students, new topics of research had to be identified and new funding solicited on a continuing basis, as the Research Associate salary and graduate student stipends came exclusively from research funds solicited. Projects ranged from analyzing glass bottle fractures to large pressure vessel failures. Expert consultation was provided to legal counsel for both criminal cases and product liability cases.

12/75 to 8/80 Student, University of Tennessee.

Undergraduate then graduate student in the metallurgical engineering department. Worked as a part time employee at a local welding supply company, repairing and installing welding systems. Also worked part time as a laboratory assistant in the metallurgy laboratory.

6/72 to 12/75 Technician, R&R Welding Supply and Mon-Arc Welding Supply.

Repaired and installed welding systems in factories and welding repair shops. Performed electrical and mechanical troubleshooting of motors, generators and hydraulic systems. Overhauled diesel and gasoline engines used to power pumps and generators. Installed emergency power generators at hospitals and poultry farms.

MILITARY SERVICE

U S Navy, 1966-1972. Obtained rate of E5, Honorable Discharge. Attended and passed Gunners mate A and C schools. Maintained shipboard guided missile launching systems. Served 4 years aboard the USS Columbus, CG-12.

Curriculum Vita

Dr. Carl D. Lundin
Professor of Metallurgy
Magnavox Professor of Engineering
Tennessee Tomorrow Professor

Materials Joining Group
Materials Science and Engineering
The University of Tennessee
Knoxville, Tennessee 37996-2200

Dr. Carl Lundin is the Magnavox Professor of Engineering in Metallurgical Engineering, College of Engineering of the University of Tennessee, Knoxville, Tennessee, and is also Director of the Materials Joining Research and Engineering Group at UTK. Dr. Lundin came to The University of Tennessee from Rensselaer Polytechnic Institute, Troy, New York, in 1968 and established a welding research laboratory at UT where none had existed before. The materials joining laboratory facilities at the University are valued at over $800,000.

Dr. Lundin obtained his Bachelor of Metallurgical Engineering Degree from RPI in 1957, attending college on a U.S. Navy scholarship. After receiving his bachelor's degree, Dr. Lundin served for three years in the U.S. Navy in both engineering and operations capacities. After completion of the U.S. Navy tour of duty in 1960, he returned to graduate school and became involved in welding research and development.

In 1960 he was appointed a Research Assistant in the Metallurgy Department and became actively involved in the welding programs at RPI. In 1962 he was appointed an Instructor and also became Supervisor of Welding Research. He obtained his Ph.D. in 1966 from RPI. The title of his dissertation was, "A New Approach to the Study of Hot Cracking in Welds." This research led to the development of the Varestraint Hot Cracking Evaluation Method, a technique which is now the most widely used on a world-wide basis. He was appointed an Assistant Professor in the Materials Division in 1966, and continued as Supervisor of Welding Research.

In 1968, Dr. Lundin left RPI to join the Metallurgical Group at the University of Tennessee, Knoxville and establish a welding research laboratory. Except for one year, 1976, Dr. Lundin has taught Welding, Metallurgy and Materials at UTK. During 1976, Dr. Lundin was Section Manager of the Welding Group of the Babcock and Wilcox Company in Alliance, Ohio. In this capacity he managed research programs of $750,000 and worked on solving production problems in Babcock and Wilcox production plants. Dr. Lundin was appointed Full Professor of Metallurgy at UTK in 1975; a position he now holds.

Dr. Lundin's activities have expanded into the technical community on the local and national scene. Dr. Lundin is a member of several Pressure Vessel Research committees, Welding Research Council committees and The Materials Properties Council. He currently is Project Director for the Weld Metal and Welding Procedures Subcommittee and the Failure Modes Subcommittee. He chairs The Welding and Fabrication Subcommittee of The Materials Properties Council.

Dr. Lundin has been active at both the local and national level of the American Welding Society. He has served on the Educational Activities Committee and was the AWS representative to the National Academy of Engineering for three years. He has held all offices in the Northeast Tennessee Section of AWS and for many years conducted educational courses for welding inspectors and seminars on welding metallurgy. Dr. Lundin is also a member of the International Institute of Welding.

Dr. Lundin is a member of the Joining Council of the American Society for Metals. He is also an adjunct faculty member for the Academy of the American Society for Metals. Dr. Lundin has taught many of the American Society for Materials courses on materials joining and developed a course in welding metallurgy for ASM.

Dr. Lundin participates in Tennessee Industries Week, which serves the industrial engineering community in Tennessee and the Southeast. In this regard, a Welding and Metallurgy course is taught by Dr. Lundin. This course has attracted over 190 engineers in past years for a one week exposure to welding and joining. This has been one of the more successful of the many courses offered by UTK to practicing engineers.

In the research area, Dr. Lundin has authored or co-authored over 150 technical articles and many research reports. Dr. Lundin's interests have been in the metallurgical aspects of joining and most recently in the origin, nature and effect of discontinuities in welds. He has headed-up a task for the Welding Research Council on the definitions of welding defects and discontinuities and has published a review of the literature on the subject of the "Significance of Discontinuities in Welds," in Welding Research Council Bulletin #222. His most recent Welding Research Council work on weld discontinuities includes; "Annotated Bibliography on the "Significance of Origin and Nature of Discontinuities in Welds 1975-80," Bulletin #263, "Review of Worldwide Weld Discontinuity Acceptance Standards," Bulletin #268, "Hot Cracking Susceptibility of Austenitic Stainless Steel Weld Metals," Bulletin #289, "Fundamentals of Weld Discontinuities and their Significance," #295 and Postweld Heat Treatment Cracking in Chromium-Molybdenum Steels, Postweld. Heat Treatment Cracking in High Strength Low Alloy Steels," #349. Dr. Lundin has conducted the majority of the Pressure Vessel Research Committee work on the elevated temperature behavior of Cr-Mo Steels. The initial work has been published in WRC Bulletins 277, 315, 348 and 354. There are several bulletins in preparation for publication in the Cr-Mo weldment behavior area. He has also contributed to the 7th Ed. Of the Welding Handbook in the significance of discontinuities area. Major efforts have been undertaken and significant work has been published in the joining of austenitic stainless steels and high alloy cast materials. In addition, Dr. Lundin has worked extensively on the corrosion of cast and wrought austenitic stainless steels.

The research now in progress at The University of Tennessee involves seven graduate engineers, visiting professors and research assistants with a budget of over $300,000. The programs deal with joining, defects, heavy section weld properties for energy systems, stainless steel welding & corrosion cracking problems, the influence of welding on nuclear pressure vessel steels, elevated temperature properties of Cr-Mo welds, the weldability of HSLA Steel, joining of carbon-carbon composites and aluminum metal matrix composite fabrication.

Since 1962, Dr. Lundin has been a consultant to industry on welding, failure analysis and materials behavior problems. He has dealt with welding of high strength quench and tempered low allow steels, HSLA steels, carbon steels, Cr-Mo steels, stainless steels, aluminum, uranium and other alloys. A partial list of companies which Dr. Lundin has consulted are:

Aladdin Industries
Arkansas Power & Light
Bechtel
Caterpillar Tractor
Chicago Bridge & Iron (CBI Ind.)
Corrugating Roll
Department of Energy
EG & G Idaho
Ebasco Services
Hallen Construction Co.
Huyck Formex
Ingersol Rand
Kamyr Inc.
Oak Ridge National Laboratories
Potomac Electric Company
Rosenblad Corporation
Shelby Williams Inc.
Southern California Edison
Tennessee Valley Authority
Tera Corporation
Texas Instruments
Union Carbide Nuclear/Martin Marietta
United States Justice Department
United States Steel
West Virginia Highway Department

In his consulting activities, Dr. Lundin is involved in solving production problems, failure analysis, materials selection and testing of welds and weldments in accordance with various codes. Dr. Lundin is an AWS Certified Welding Inspector.

Dr. Lundin has been involved in welding research for 34 years and since the establishment of a joining facility at the University in 1968, his students have entered the industrial world with experience and background in welding and welding metallurgy. Dr. Lundin has been recognized by his peers in the welding community. In 1968, he was awarded the Adams Memorial Membership in the American Welding Society for his teaching activities in "Advancing the Knowledge of Welding Technology." In 1978, he received the AWS William Sparagen Award for "The Best Research Paper in the Welding Journal". Dr. Lundin delivered the Adams Memorial Lecture the American Welding Society at its 1981 meeting. This is the highest award granted by the American Welding Society and is given for "Expertise Above and Beyond the Normal in the area of Science and Engineering." He was presented with the McKay-Helm award in 1981 by AWS for the Outstanding Research Paper on Stainless Steel Welding. In 1989 he received the W.F. Savage Award for the Paper Judged The Greatest Contribution To The Understanding Of Welding Metallurgy.

In April of 1980, Dr. Lundin was named a "Tennessee Tomorrow Professor" by The University of Tennessee for "his many contributions to the excellence of the UTK College of Engineering." He was named Magnavox Professor of Engineering in May, 1981 for his "excellence in engineering teaching and research." Dr. Lundin received the "Eminent Engineer" award from Tau Beta Pi in 1981. In April of 1985, Dr. Lundin received the M.E. Brooks Award of The University of Tennessee for "distinction in engineering practice." Dr. Lundin was named a Fellow of the American Society for Materials in 1986. Dr. Lundin was elected a Fellow of the American Welding Society in 1991, (Elected to the first class of 13 Fellows inducted by AWS out of 30 authorized). Dr. Lundin was presented with The University of Tennessee Chancellor's Research and Creative Achievement Award in April 1992 for his development of the Materials Joining Research Laboratory and the Internationally recognized research program in Materials Joining at The University of Tennessee. He received the International Metallographic Societies' Best Paper Award in August 1992 for the work presented at the IMS 1991 Conference, entitled "Microstructural Investigation of the Heat-Affected Zone in Newly Developed Advanced Austenitic Stainless Steel". Dr. Lundin is a life member of the American Society for Materials.

MPR
ASSOCIATES INC.
ENGINEERS

JAMES E. NESTELL, JR., PH.D.

EDUCATION

Dartmouth College, Ph.D. Physics, 1979
Bettis Reactor Engineering School, Certificate in Nuclear Engineering (Westinghouse), 1971
Dartmouth College, M.A. Physics, 1970
Stanford University, B.S. Physics, 1968

PROFESSIONAL HISTORY

1970 - 1975	Department of the Navy, Nuclear Propulsion Directorate
1978 - 1979	IBM Thomas J. Watson Research Laboratory
1979 - present	MPR Associates, Inc.

MPR EXPERIENCE

Since joining MPR in 1979, Dr. Nestell has been the primary engineer for materials and corrosion problems. He has been involved with solving intergranular stress corrosion cracking problems with stainless steel piping in boiling water reactors, corrosion in steam generators and steam generator chemical cleaning, and corrosion in circulating water and service water systems. He has recently conducted a state-of-the-art evaluation of the effectiveness of hydrogen water chemistry control in a boiling water reactor.

Current activities include lead engineering efforts for fossil-fired boiler materials problems, including waterwall corrosion, pipe and header creep problems, and gas turbine blade cracking problems. He is the lead engineer for nuclear and fossil plant service water system corrosion problems and has developed service water material condition evaluation methodologies, corrosion test programs, and new replacement materials evaluation programs at two plants.

Dr. Nestell has also been active in the area of fracture mechanics and has developed the pressure/temperature operating limits for two nuclear plants to prevent brittle fracture of the reactor vessel. He has also taken the lead at MPR for the development of elastic-plastic fracture evaluation methods, and has applied these methods in the leak-before-break analyses of multiple piping systems at three nuclear power plants.

Finally, Dr. Nestell has extensive experience in the area of failure analyses and for the evaluation and disposition of material defects found in service. His knowledge of many aspects of corrosion as well as of most fatigue and fracture mechanics methodologies has allowed him to take the lead in the failure analyses of major components, including main coolant pumps and pressure vessels. He has also helped develop justification to leave in place defects found in service, as well as efficient methods for repair, when repair is required.

At the Watson Research Lab, Dr. Nestell developed a system for the vacuum deposition of thin superconducting films of lead alloys and niobium using electron beam techniques.

With the Department of the Navy, Dr. Nestell was responsible for the government supervision of a $1 million/annum reactor plant materials research and development test program involving 40 materials scientists and engineers at the Bettis and Knolls Atomic Power Laboratories.

PUBLICATIONS

"Optics of Thin Metal Films," American Journal of Physics, Volume 39/3, 313-320, March 1971.

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RICHARD J PARGETER

Richard Pargeter has been working in the Materials Department of The Welding Institute since 1976. He gained a BA (honours) from the University of Cambridge in 1976 having specialised in Metallurgy and Materials Science, and this was converted to MA in 1980. He was accepted as a Member of the Institution of Metallurgists in 1980 and given Chartered Engineer status shortly afterwards, and was appointed Section leader of the Ferrous section within the Materials department in 1988. He is also a Fellow of the Welding Institute.

Mr Pargeter worked principally on ferritic steels. Major research and development projects have included work on sour service, fabrication hydrogen cracking, weldability of high strength steels, properties of electric resistance welded pipe, weld metal microstructural development, and weld and HAZ microstructure/property relationships. Consultancy and failure investigation have covered virtually every form of failure, both during fabrication and during service, and have involved travel to sites in the UK, continental Europe, Egypt, SE Asia and the USA.

Mr Pargeter has published a number of papers, both in the UK and internationally, especially on structure/property relationships for ferritic weld metal, sour service, and hydrogen cracking. He serves on BSI Committees on testing of welds and on corrosion of metals and alloys, and on IIW sub commissions IIA and IXJ.

WILLIAM R. PAVLICHKO

William R. Pavlichko is a Senior Engineer for Consumers Energy Company, a CMS subsidiary. He provides metallurgical expertise for all aspects of electric and gas utility operations. Backed by a fully staffed metallurgical laboratory, including scanning electron microscopy, metallography, and material property testing, Dr. Pavlichko analyzes and provides recommendations to minimize such items as boiler tube failures, fan blade failures, pump failures, turbine blade failures, and piping erosion/corrosion.

Dr. Pavlichko is a long-time member of Edison Electric Institute's Materials and Properties Task Force. He has written numerous papers on the failure and analysis of boilers, turbine-generators and other power plant equipment for Edison Electric Institute and other forums.

Dr. Pavlichko is presently active in the Materials Property Council High Energy Piping Committee.

Prior to joining Consumers, Dr. Pavlichko had a post-doctoral appointment at Ohio State University's Fontana Corrosion Research Laboratories from 1974-1977.

Dr. Pavlichko received a PhD - Metallurgical Engineering from Penn State University in 1974. He is a Registered Professional Engineer in the State of Michigan. Dr. Pavlichko is a member of the National Association of the Corrosion Engineers and ASM International.

Walter J. Sperko, P.E.

1981 to present
President, Sperko Engineering Services, Inc.
Greensboro, North Carolina 274069795 USA
(910) 674-0600 FAX: (910) 6740202

Mr. Sperko provides engineering consulting services to customers in the metal fabrication industries in the technical areas of welding, metallurgy, manufacturing processes, piping and pressure vessel design, inspection and quality assurance. He also prepares and conducts training programs in piping, welding and metallurgy for The National Board, the Center for Professional Advancement and ASME, as well as custom-tailored programs related to metal fabrication. Mr. Sperko is an instructor for the National Board of Boiler and Pressure Vessel Inspectors, and he is the Technical Consultant to the National Certified Pipe Welding Bureau.

1981 to 1979
Quality Control Manager, RECO North Carolina, Inc.
Division of Richmond Engineering Company
Colfax, North Carolina 27235

Responsible for directing the technical and quality control programs for RECO North Carolina and two other division facilities and for technical support in design, code compliance, welding, metallurgy and steel fabrication methods for all divisions of Richmond Engineering in the construction of ASME pressure vessels, piping and storage tanks.

1974 to 1979
ITT Grinnell Industrial Piping, Inc.
Manager, Research and Development
Kernersville, North Carolina 27284

Wrote and qualified all welding, fabrication, heat treating, and quality control procedures and provided technical support for the fabrication and erection of nuclear and conventional power piping and petroleum and chemical piping. Provided interface between customers and manufacturing by interpreting customer specifications and Codes and preparing procedures and standards accordingly.

1969 to 1974
Materials Engineer, Ebasco Services Inc.
New York, New York

Performed various failure analyses of components, evaluated materials for compatibility with environment and for suitability for intended service for use in conventional and nuclear power generation systems. Provided metallurgical and welding support to piping and pressure vessel design group. Wrote materials, NDT and Quality Assurance Specifications. Conducted QA audits of vendor facilities and QA programs. Member of Ebasco Corporate QA Committee.

PROFESSIONAL LICENSE STATUS

Professional Engineer registered in North Carolina, South Carolina and Ohio

PATENTS

US Patent 4932160, QuickOpening Pressure Vessel Closure
US Patent 5072960, Loading Cart Method

CODE COMMITTEE MEMBERSHIP

ASME Boiler and Pressure Vessel Code
Subcommittee IX (Welding and Brazing), ViceChairman
Subcommittee IX, various Subgroups
Subcommittee II, Subgroup on Strength of Weldments
Subcommittee III (Nuclear) Materials, Fabrication and Examination Subgroup
ASME B31.9, Building Services Piping
Advisory Committee to the National Board of Boiler and Pressure Vessel Inspectors

American Welding Society
Committee D-10, Piping and Tubing, Chairman

LECTURING and TRAINING

Course Director since 1983 for a highlysuccessful three day course, Welding and Brazing per ASME Section IX under the sponsorship of ASME.

Course Director since 1978 for a highly successful threeday course Piping Design, Analysis and Fabrication under the sponsorship of the Center for Professional Advancement, East Brunswick, New Jersey. The course is held several times each year in North and South America, Europe and in the Middle East.

Instructor in welding for the National Board of Boiler and Pressure Vessels in their training programs for National Board Inspectors and Supervisors.

PUBLICATIONS

Publishes articles regularly in Welding Design and Fabrication and the Welding Journal regarding piping fabrication and ASME Section IX changes. Coauthor of piping design section of the Standard Handbook of Plant Engineering.

EDUCATION

University of Notre Dame, Notre Dame, Indiana
B.A. 1968 - Engineering
B.S. 1969 - Metallurgical Engineering and Materials Science

RESUME
DANIEL F. SPOND

EDUCATION

BS - Metallurgical Engineering - 1969 - Vanderbilt University
MS - Metallurgical Engineering - 1975 - University of Tennessee

OTHER TRAINING/
EXPERIENCE

U. S. Marine Corps Officer Candidate School, ASME Section IX Code Training

CERTIFICATION/
LICENSES

Professional Engineer (Arkansas), AWS Certified Welding Inspector

WORK EXPERIENCE

EOI - April 1991 to Present
Senior Lead Engineer - Metallurgical Engineering assignments, welding procedure development, BWOG Materials Committee (Chairman 1994-95), CEOG Reactor Vessel Working Group, and CEOG Materials Working Group

AP&L - January 1988 to April 1991
Senior Lead Engineer (fossil and hydro plants) - Metallurgical Engineering assignments, metallurgical failure analysis, project construction management

AP&L - June 1984 to January 1988
Senior Lead Engineer (nuclear, fossil and hydro plants) - Metallurgical Engineering assignments, metallurgical failure analysis, welding procedure development, BWOG Materials Committee

AP&L - January 1979 to June 1984
Engineer Level II (nuclear, fossil and hydro plants) - Metallurgical Engineering assignments, metallurgical failure analysis, welding procedure development, BWOG Materials Committee

AP&L - April 1977 to December 1978
Quality Assurance Engineer - engineering audits, vendor audits

AFCO Steel Co. - October 1975 to March 1977
Welding Engineer - welding procedure development, nondestructive testing (UT Level I, MT Level II, PT Level II)

University of Tennessee - September 1973 to October 1975
Graduate Research Assistant - laboratory assignments

U.S. Marine Corps - June 1969 to August 1973
Commissioned Officer - domestic and foreign assignments

Appendix B

Evaluation of Undocumented Welds

B.1 Background

As part of the actions to address the root cause of the Palisades weld failure, an acid etch of the top 4 inches of the inside surface of the shell is being performed for unloaded MSBs that have been manufactured to-date. The top 4 inches of the shell corresponds to the area where the lid welds will be made. The etching process was initiated to detect the presence of any shell welds that may have been made in this area.

Etching of already-manufactured MSBs by ANO revealed evidence of undocumented welds on the 10 ANO units which have not yet been loaded with spent fuel. An evaluation of the undocumented welds found on the ANO MSBs was initiated following their detection. The description, results, and conclusions of this evaluation are presented in this Appendix.

The following actions were initiated to address the possible impact of undocumented welds in casks that were manufactured by March Metalfab Inc (MMI).

1. Gather information from MMI on circumstances and extent of undocumented welds

2. Assess quality of undocumented welds

3. Assess potential for defects in undocumented welds

4. Assess potential adverse effects of an assumed material defect in an undocumented weld

In addition, an evaluation was done to determine if MMI operated outside the requirements of its Quality Assurance Program in making the undocumented welds. Further, a review was performed to determine if other MSB fabricators made similar undocumented welds.

B.2 Circumstances and Extent of Undocumented Welds

Discussions were conducted with MMI personnel to determine the circumstances and extent of any undocumented welds made during fabrication of MSBs. Information received as a result of these discussions is as follows:

1. Undocumented welds were made on MSBs fabricated by MMI prior to and during the first half of 1995. The MSBs potentially affected include the 14 fabricated for ANO and MSBs 5-10 fabricated for Consumers Energy. The 8 MSBs currently being fabricated by MMI for Consumers are not affected as all temporary attachment welds and weld repairs made during fabrication of these MSBs have been documented.

2. The undocumented welds were made under the following circumstances:

   a. Temporary attachments were welded to the MSB shell to hold it in position during various fabrication operations. After the operation was completed and the temporary attachment was no longer needed, it was removed and the attachment weld was ground to match the adjacent shell surface. Non-destructive examination (NDE) of the area where the attachment was removed was not performed, since the ASME Code version referenced by the MSB fabrication specification (ASME Boiler and Pressure Vessel Code, Section III, 1986 Edition, 1988 Addenda) did not require NDE of the base material after removal of temporary attachments. This was subsequently identified as an inadvertent omission from this version of the Code. The requirement for performing NDE of temporary attachment sites was restored in a later code version and was subsequently added to the SNC MSB Fabrication Specification.

b. Repairs to the shell base material by welding were made in some instances where fabrication activities caused a surface imperfection that was less than 0.050 inches in depth. The ASME Code specifies conditions for which a repair to the base material is required, e.g. for surface defects whose depth would encroach upon the minimum required wall thickness of the shell, repairs must be performed and documented. MMI complied with this Code requirement by documenting repairs by welding in cases where the depth of the defect encroached upon the minimum required wall thickness of the shell. The criteria used to determine the minimum required wall thickness was to apply the drawing block tolerance to the nominal thickness resulting in a minimum required thickness of 0.050 inches less than the nominal thickness. For a surface imperfection that does not encroach upon the minimum required wall thickness, the ASME Code does not require repair by welding. However, MMI also repaired some of these imperfections by welding, instead of grinding to blend the imperfection with the surrounding area, as specifically allowed by the Code. The MMI interpretation of the ASME Code requirements regarding a repair that does not encroach upon the minimum required wall thickness is that documentation of the repair is not required.

3. The locations of the undocumented welds were as follows:

a. Temporary attachment welds were made at various locations on the shell. Bracing members or "spiders" were welded to the shell typically near the top, center and bottom to maintain roundness while the longitudinal seam weld was made. Alignment fixtures were sometimes welded near seams to maintain alignment of plates at the seam location. These fixtures were located within approximately 5/8 inch of the seam. The area where the fixtures were attached was encompassed by the area covered by NDE of the seam weld, thus NDE of the attachment sites was covered by NDE of the seam weld itself.

b. Surface imperfections caused by fabrication activities primarily consisted of imperfections located along the edges of plate sections which were caused by the clamping devices used to lift plate sections. As mentioned previously, repair of these imperfections was not documented if the repair depth was less than 0.050 inch.

3. MMI has stated that all repairs were performed by qualified personnel using qualified welding procedures and certified materials. The repairs were made using either a shielded metal arc welding (SMAW) or gas tungsten arc welding (GTAW) process.

B.3 Assessment of Quality of Undocumented Welds

A series of activities was initiated to assess the quality of the undocumented welds that have been performed on MSBs and to confirm information received from MMI that repairs were made using qualified procedures and certified materials.

At ANO, liquid penetrant (PT) and ultrasonic (UT) examinations were performed of all welds (approximately 28 welds) detected as a result of acid etching. These examinations showed no evidence of unacceptable indications for any of the areas where welds had been detected.

Samples of material were extracted from several areas where the welds were detected. These samples were sent to an independent laboratory for chemical analyses of the material, hardness testing and evaluation of the microstructure. The results of the chemical analyses indicate that the chemical composition of the weld material is carbon manganese steel, which is consistent with that certified for use in fabrication of the MSBs. Hardness testing results indicate that hardness levels of the base material and heat-affected zone are as expected for attachment and shallow repair welds. Likewise, examination of the microstructure of the material in the area of the repair indicates that it is consistent with the microstructure that would be expected for weld attachments or shallow repairs made using qualified procedures and certified materials.

Examination of the extracted material samples also indicates that the depth of the welds is very shallow, i.e. less than 0.050 inches, which is consistent with the information provided by MMI on the criteria they used to determine whether or not to document repairs.

B.4 Assessment of Potential Defects In Undocumented Welds

An evaluation was conducted to identify the potential adverse effects on the MSBs that could result from the presence of undocumented welds. The following effects were considered and evaluated:

1. The potential for hydrogen-induced cracking was considered. In order to have hydrogen-induced cracking, a sufficiently severe combination of stress, hydrogen, and a susceptible microstructure must be present. Residual stress levels in the area of shallow repair welds are expected to be small since the weld itself is very small and the weld configuration provides little restraint. The weld processes used to make the repairs, when properly implemented, result in low levels of hydrogen being introduced into the weld. The low stresses and low hydrogen level in the consumables are expected to result in a low risk of hydrogen-induced cracking in shallow repair welds. For temporary attachment welds, the joint configuration may provide more restraint, causing higher residual stress levels and a greater risk of hydrogen cracking. Nevertheless, the ANO NDE results indicate that this

higher level of restraint associated with the temporary attachment welds is still not sufficient to cause hydrogen cracking.

It should be noted that the incidence of cracking of the shield lid weld for CMSB-05 appears to be inconsistent with the conclusion that there is a low risk of hydrogen-induced cracking associated with the undocumented welds that were made by MMI. However, the characteristics of the shell defect at Palisades which caused the shield lid weld to crack differ from those of the undocumented welds detected on the ANO MSBs. The crack size at Palisades was approximately 1/8 inch deep by 6 inches long, which is significantly greater in length and depth than the size of any of the undocumented welds found in the ANO MSBs. The origin of the apparent defect which caused the crack in Palisades CMSB-05 remains unknown, as its characteristics do not match those of the undocumented welds found on the ANO MSBs.

2. Since the welds were not inspected after their completion, the potential for undetected weld defects may exist in other areas of the shell. Inspection of the ANO welds found no evidence of defects, indicating that the likelihood that imperfections do exist is small. An evaluation is performed in Section B.5 to address the effect of an undetected defect in an undocumented weld.

B.5 Assessment of Potential Adverse Effects of an Assumed Material Defect in an Undocumented Weld

Although the results of the evaluation described above indicate that the presence of a defect in the areas where undocumented welds were made is highly unlikely, an evaluation was performed of the potential impact that such a postulated defect would have on the ability of the MSB to perform its intended design function. The approach used to perform this evaluation was to assume the presence of a defect in the MSB shell and perform a fracture mechanics analysis to determine if the defect would propagate when subjected to the maximum stress conditions that could be present during normal, off-normal, and accident conditions. The evaluation was performed using the analytical methodology contained in Section XI of the ASME Code, which provides guidelines for evaluation and disposition of material flaws in nuclear components. The rules of Subsection IWB, which apply to reactor vessels, are conservatively used in this evaluation.

In performing this evaluation, a defect having a depth of 0.100 inch was assumed. This bounds the depth of any undocumented welds identified on MSBs by a factor of 2.0. Guidance in selecting the profile of the assumed flaw was taken from Appendix G of Section XI of the ASME Code.

The results of the evaluation show that no propagation of the assumed flaw will occur under the maximum stress conditions present in the shell during normal, off-normal, and accident conditions. Since the assumed flaw would not propagate, no failure of the shell will occur nor will any distortion of the shell occur which would inhibit its ability to perform its intended design function. The details of the hypothetical flaw evaluation are provided in calculation No. WEP 109.002.73, Revision 0, which is included with this submittal.

B.6 Conclusion

It is concluded from the above evaluation that the undocumented welds have no impact on safety or the ability of the MSB to carry out its intended design function.

B.7 Evaluation of MMI Compliance With Its Quality Assurance Program With Respect to Undocumented Welds

The investigation into undocumented welds made by MMI determined that undocumented welds to the MSB shell were made when using temporary attachments during fabrication and when repairing defects in the shell caused by fabrication activities that were less than 0.050 inches in depth.

In making undocumented temporary attachment welds MMI did not operate outside of its quality assurance program or outside of ASME or SNC specification requirements which were in place at the time that the work was performed. As mentioned previously, the ASME Code version referenced by the MSB fabrication specification did not require NDE of the base material after removal of temporary attachments. Thus NDE was not performed and the locations of the temporary attachment welds were not documented.

In making repairs of surface defects that are less than 0.05 inches in depth, MMI judged that documentation of such repairs is not required by the ASME Code. While the ASME Code is explicit in requiring that defects whose depth encroaches on the minimum required thickness be repaired and documented, the noted Code edition does not specifically address repairs of defects that are less than the minimum required thickness. SNC believes that it is the intent of the ASME Code that all welds to the shell be documented. However, SNC acknowledges that the ASME Code is not explicit in the application of the requirement to document repair of defects that do not encroach on the minimum required thickness. Thus, there is basis for the MMI interpretation of ASME Code requirements as they pertain to this circumstance. For this reason, SNC believes that MMI was not operating outside of their Quality Assurance program, given their interpretation of the ASME Code requirements, and that there was not a deviation from requirements of 10CFR72 or VSC SAR commitments.

B.8 Evaluation to Determine if Other MSB Fabricators Made Similar Undocumented Welds

MSBs manufactured to date have been built by three separate fabricators. Richmond Rhodes Enterprises in Salinas, California fabricated 8 MSBs for use at the Palisades plant. Seven of these MSBs have been loaded with spent fuel and one unit is currently available for loading. PCC has fabricated 4 MSBs for use at the Point Beach plant. Two of these units have been loaded with spent fuel and 2 units are currently available for loading. Acid etching of the two already-manufactured MSBs available for loading at Point Beach showed no evidence of undocumented welds.

A review of fabrication practices at Richmond Rhodes and PCC was conducted and it was determined that the use of temporary attachment welds was not documented for the first 4 MSBs fabricated by Richmond Rhodes, since this was not required by the ASME Code version referenced by the MSB fabrication specification at the time that these units were fabricated. For subsequent units fabricated by Richmond Rhodes, and for all units fabricated by PCC, NDE of areas where temporary attachments were removed was performed and documented. No undocumented repairs of shell defects were performed at any of these facilities, regardless of the depth of the defect.