ATTACHMENT

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SAFETY EVALUATION REPORT

MATERIALS ENGINEERING BRANCH
MATERIALS APPLICATION SECTION

EVALUATION OF THE WNP-2 SACRIFICIAL SHIELD WALL STRUCTURAL DEFECTS AND THEIR REPAIRS

BACKGROUND

Purpose of Sacrificial Shield Wall

The sacrificial shield wall (SSW) is a cylindrical, double-walled steel shell, filled with concrete to form a structure surrounding the reactor pressure vessel (RPV). The SSW is approximately 2 feet thick, 30 feet in outside diameter and 48 feet high. It is anchored to the reactor support pedestal and forms an annulus with the RPV which is open to the drywell at the top. The SSW is classified as a Seismic Category I, Quality Class 1 structure.

The function of the SSW is to provide radiation shielding and structural support.

As a support structure it:

- o supports one end of a radial beam system, which in turn supports mechanical and electrical equipment,

- o supports the RPV in conjunction with the pedestal, stabilizer trusses and containment vessel, and

- o supports piping systems, (e.g., mainsteam, reactor feedwater, and reactor recirculation by hanger attachments) and minimizes pipe whip effects by supporting pipe whip restraints.

History of Events

In November of 1978, defects were found in the SSW which prevented a certificate of conformance being issued by the Major Mechanical Contractor (215 contractor). He recommended that a detailed review be performed by Burns & Roe (A/E) of the documents and work performed by the structural steel fabricator of the SSW (Leckenby).

The review by the applicant disclosed that two major nonconformances existed that could prevent the SSW from performing its required functions during normal and postulated accident conditions:

- The horizontal rings in the SSW, located above and below the interface at elevation 541'-5", are not welded together in accordance with the design requirements. As a result, the horizontal shear loads cannot be properly transmitted between the two rings.

- Concrete voids and shim gaps in the SSW have compromised the radiation shielding properties of the SSW.

As a consequence of these nonconformances, two specific corrective actions were identified by October 1979:

- A partial penetration groove weld was proposed to accommodate the shear loads.

- A comprehensive shielding repair program was prepared to restore the shielding properties of the SSW to a condition equal to or better than the original shielding design requirements.

The shielding aspect of the SSW will be discussed in correspondence by other Division of Engineering Branches. During the review process, former Leckenby workers made allegations concerning the SSW weld quality, material conditions and other defects. A stop work order was issued for the SSW on November 21, 1979. An in-depth broad scoped review to address the general concerns was initiated by the applicant.

The applicant had three problems to address at that time:

1. to determine the type and extent of flaws in the SSW, and to perform repairs as necessary,

2. to demonstrate that the SSW had adequate structural integrity, and

3. to ensure adequacy of shielding of the SSW.

Applicant's Approach

In February 1980, the applicant established a task force, which was asked to evaluate the SSW by:

- reviewing the SSW documentation for compliance to AWS Code, Quality Assurance and Design Specification requirement, to identify the non-conforming items and their implications for the as-built condition of the SSW,

- performing weld inspections and testing, as necessary, to determine the SSW as-built condition with respect to AWS Code requirements, Design Specification requirements, and defining the known and postulated defects and material conditions, and

- assessing the SSW in consideration of the above findings (1) to determine the SSW capabilities with respect to performing its design functions during operation, and (2) identify any necessary repairs.

An evaluation of the SSW radiation shielding properties was performed by Burns and Roe and is to be addressed by another Branch.

The investigation by the Task Force consisted of the following:

- review and evaluation of the welding procedures, welder qualifications, weld filler metal controls, nondestructive examination procedures, and inspector qualifications to identify documentation implications for the SSW weld quality,

- review and evaluation of documentation containing weld and base material defect/repair information to provide insight to related trends and relationships which might affect the quality of the SSW,

- performing additional visual and nondestructive examination to establish the weld quality of the SSW and to confirm or deny implications from the documentation reviews,

- evaluation of processes used on the SSW during fabrication for the effect on weld and material quality,

- review and evaluation of the material traceability system and material test reports to assist in establishing the material condition of the SSW, and

- assessing the as-built structural integrity of the SSW to perform its required functions considering the materials and processes used, the postulated accident loads on the SSW, and the known and postulated defects in the SSW.

DISCUSSION

Weld Quality

The initial causes for concern about the weld quality of the SSW were:

- o irregularities observed in Leckenby documentation,
- o weld and base material defects (including cracks and crack-like indications) discovered during site construction contractor magnetic particle examinations of SSW attachment locations,
- o visual observation of SSW weld defects not within AWS D1.1 visual inspection acceptance criteria (the governing welding code), and
- o numerous defects identified by UT in electroslag welds on pipe whip restraints (PWR) previously fabricated by Luckenby under a separate contract.

During the beginning stages of the Task Force review, additional concerns associated with the SSW weld quality were identified. These concerns were as follows:

- o A review of the Leckenby records indicated that Leckenby experienced difficulty with the electroslag welding process. Specifically, both cracks and the lack of fusion were detected by visual inspection and repaired.
- o The visual inspection required by specification may not have identified all the cracks and planar lack of fusion defects, and as such, these type of defects may exist in the SSW.

Plan of Action

The as-built weld quality of the SSW was determined by the following:

- an evaluation of the potential for and nature of defects in the SSW due to nonconformances in documentation,

- an evaluation of the potential for and nature of defects in the SSW based on the weld fabrication history and known defects identified and repaired by site construction contractors since the completion of fabrication, and

- additional visual inspections and nondestructive examinations.

Inspections

1. Leckenby Visual Inspection

In order to gain perspective on the weld quality of the SSW, knowledge of the weld defect and repair history was reviewed. This information was then integrated with results from other inspections and evaluations of procedures affecting weld quality to establish the as-built quality of SSW welds.

A visual inspection of the SSW welds by Leckenby was documented on the Leckenby weld maps. Weld defects were reported on shop Incomplete/ Rejection Tags, Field Inspection Reports and noted in the remarks column of the shop weld maps. The defects recorded by Leckenby were repaired. The repair verification consisted of:

- o the applicant's ultrasonic testing of welds recorded as repaired found no defects, and

- o no previously recorded defects documented by Leckenby were reidentified during the applicant's visual inspection.

As mentioned earlier, and substantiated by the high weld rejection rate during fabrication, the electroslag weld defect history was originally the cause for concern. There are 1273 electroslag welds (ESW) in the SSW. A total of 388 ESWs had recorded defects for a defect percentage of 30.5%. Lack of fusion (LOF) and undercut comprise the majority of weld defects.

Based upon comments in the defect related Leckenby documentation, it is clear that Leckenby was experiencing difficulty with the electroslag process, but relied upon inspection and repair as the resolution.

When large excesses of flux exist during welding with steel backing, slag entrapment may occur in the weld. The steel backing was used for welding joints which results in inaccessibility to the backside of the joint. Based on review of the Leckenby weld maps, steel backing was used on less than 10% of the ESWs. The applicant UT inspected numerous ESWs; 17 of these welds had steel backing, confirmed by UT depth readings. None of the 17 welds contained defects based on the UT examinations.

Based on the extensive documented repair of the welds and the good results from UT performed in May and June, 1980 (one potential defect in 73 welds), the task force concluded that the quality of the ESWs in the SSW was acceptable.

Flux cored arc welding (FCAW) and shielded metal arc welding (SMAW) surface defects were likewise recorded and repaired during fabrication. Cracks or crack-like defects were very few in number. Undercut comprised by far the majority of defects and the occurrence of this type defect is usually due to welder technique.

2. Leckenby Ultrasonic Testing

The 215 Contract specification was modified to require UT of ESW tee-joints for lamellar tearing per ASTM A435-74. The Leckenby lamellar tearing UT, however, was performed prior to this contract modification requirement. This UT was primarily performed due to concern for lamellar tearing at tee-joints where buttering, an original preventive measure, had not been used. The UT was performed per Leckenby Quality Control Procedure (QCP) - 8.0. The defect repair criteria in QCP-8.0 are substantially more stringent than the 215 contract specification or the ASTM A435 three-inch diameter circle criteria.

The Leckenby UT sampling may be represented as follows:

o ESW tee-joints	81 straight beam
o ESW tee-joints	2 angle beam
o FCAW tee-joints,	48 straight beam
o Other SMAW and FCAW joints	68 angle beam

In addition, the number of lamellar tearing UT examinations performed by Leckenby exceeded the 215 contract specification requirements and no indications of lamellar tearing were found. UT inspection for lamellar tearing is not required by AWS D1.1.

3. Site Construction Contractor Visual and Magnetic Particle (MT) Examinations

Other reported defects which created concern for the SSW weld quality were found during site construction contractor visual and MT examinations. The examination requirement for the fabrication of the SSW was visual. However, due to past lamellar tearing experienced while making attachments to the containment vessel, MT inspection of SSW attachment areas was required. The MT examinations used the DC prod method. Magnetic particle examination was an upgrading of the original SSW visual inspection requirements. The 11.6% MT rejection rate (726 total examinations) is not considered abnormal for a structure requiring only visual inspection during fabrication (excluding lamellar tearing UT). The available defect information in many cases lacks good definition with respect to type, size and location.

Defects found by site construction contractor visual inspection and MT have been repaired.

The detection of these SSW defects creates concern for the quality of inaccessible welds, one contributing factor being the lack of definitive information. This negative factor is overcome, however, when considering the results of the recently performed visual inspection and nondestructive examinations, the Leckenby defect repair history, and the structural assessment, which envelopes all known and postulated defects.

4. Burns and Roe Visual Inspection

From December 1979 through April 1980, a detailed, documented visual inspection was performed by Burns & Roe of SSW exterior accessible welds. Over 90% of the accessible welds which were made with the FCAW and SMAW processes. The inspection was performed to AWS D1.1 requirements. The identified defects, primarily associated with weld profile, have been repaired or determined to be acceptable for service as is. Defects in 12% of the welds are indicative of a lack of attention to some detail or in some cases the judgment of inspection personnel, but not gross negligence in Leckenby's visual inspection.

Also, the Burns and Roe inspection results make a comparatively positive statement about the Leckenby inspector and welder performance. The 1170 evaluated welds were almost equally distributed to shop and field work. Based on a review of the visual inspection results with respect to the Leckenby inspectors and welders, no specific trends or relationships were established. This indicates that no gross ineffectiveness can be attributed to specific Leckenby inspectors or welders and welding was not out of control.

Based on the design margins available in the SSW, the only defects found in this inspection which are structurally significant are undersized fillet welds. These defects were analyzed for plastic collapse and found acceptable or repaired by weld buildup.

5. Task Force MT Examination

Magnetic particle examination was performed on five FCAW and eighteen SMAW fillet welds. The MT was performed for two reasons: to obtain general fillet weld condition information to assist in the SSW evaluation and to provide information relative to undersized fillet welds. The MT examinations used the yoke AC method. The 23 MT examinations found no cracks or lack of fusion.

6. Task Force UT Examination

As discussed earlier, additional UT was performed at the request of the Task Force to determine the SSW weld quality. In total, 90 welds were examined by UT. Specifically,

- 73 ESWs were examined per AWS D1.1 (69 were acceptable, 3 had questionable discontinuities 1/, and 1 was recorded as rejectable 2/),

- 9 tee-joints were examined for lamellar tearing (7 FCAW double-bevel welds and 2 ESW joints, no lamellar tearing was observed),

- 2 FCAW single-bevel welds were examined per AWS D1.1 in conjunction with the plastic collapse assessment, (both welds were reported to have incomplete penetration), and

- 6 SMAW welds were examined per AWS D1.1 for general information about the SMAW process (2 welds were acceptable with no indications, 3 welds were acceptable with minor indications, and 1 weld was rejectable).

1/ Reflector location strongly indicates them to be associated with backside geometry of the welds.

2/ Categorized as a large reflector. Design drawing weld thickness indicates the reflector should be in a fused steel backing shoe which was not specified by design. This specific weld is not structurally significant, in that the other immediate welds had the design function to handle the local loads.

UT of the 73 accessible electroslag welds was performed in January, May, and June 1980. An L-wave examination was performed of each general weld area (six inches each side of the weld) to locate interfering reflectors prior to performing the 70° angle beam examination. No lamellar tearing was observed in any of 23 tee-joints of a particularly susceptible joint design configuration and laminations were located in only one of the 73 welds.

The nine tee-joint welds of another design configuration examined for lamellar tearing indicated incomplete penetration (IP) in 6 of the 7 FCAW double bevel welds. The IP, located in the root, was determined to be a maximum of 5/32 inch in the through-thickness dimension (considerably less in the majority of cases) by comparison to a specially made test block. The UT indications and reject associated with the SMAW single bevel welds were also characterized as incomplete penetration in the root.

The structural impact of the IP was assessed by the applicant. Since the IP did not appear unique, a number of FCAW and SMAW welds in the SSW were identified which were limiting in terms of design stress for the structural integrity evaluation. The minimum static stress design margin in consideration of the defined IP, 5/32 inch, for all FCAW and SMAW welds was determined to be 1.25. For this particular case, the minimum design margin is defined as the ratio of the capacity tensile stress of the weld to the design normal stress. In determining the design margin, a conservative static analysis was used. The use of dynamic analysis or consideration of plastic collapse would have produced greater margins. The flaw sizes used in the structural integrity evaluations were in excess of these flaws.

To ensure that the IP indications were not cracks in the heat-affected zone of the outer skin plate, UT examinations were performed to accurately measure the distance from the front of the skin plate to the indication. No indications were found at distances less than the thickness of the skin plate.

Aside from the exceptions noted above, the UT results have been acceptable. The electroslag weld UT results confirm the effectiveness of the Leckenby inspection and repair program on electroslag welds. Additionally, the UT increases confidence in the performance of the Leckenby welders and inspectors, the Task Force UT confirmed the lamellar tearing UT inspection results of Leckenby. Welds with rejectable indications were evaluated on a case-by-case basis. They were repaired or allowed to remain as is becasue stresses were low and weld repair would not have increased structural integrity.

7. Pipe Whip Restraint UT

It is known that the ongoing electroslag weld UT of Leckenby fabricated pipe whip restraints (PWR) has a high reject rate (62%) based on data available through April 30, 1980. A review of differences in materials, welders, or welding procedures has provided no insight to explain the difference with respect to the SSW UT results.

The PWR electroslag weld defects recently identified are recorded as "shrink" and lack of fusion. The "shrink" defect has been excavated and repaired on several PWRs and was found to be cracks in the center of the weld. These cracks are typically caused by operating at an abnormally high amperage level when using consumable guide tubes. This creates an undesirable weld form with horizontal grain growth which results in cracking at the center of the weld. No PWR recorded lack of fusion defect has been excavated to date; hence, a description of this type defect does not currently exist.

The PWR were fabricated in a different Leckenby shop than the SSW. Differences in shop foreman, production emphasis, attitudes and/or supervision competancy may explain the SSW/PWR UT results.

8. Leckenby SSW Weld Map Design Review

Burns and Roe performed a review of 166 Leckenby weld maps. All SSW structural members and associated welds illustrated on the Contract drawings were shown and documented on the Leckenby drawings. Six design related concerns were identified in the detailed review of 20 Leckenby weld maps, but none proved to be structurally significant.

Applicant's Conclusions Concerning Weld Quality

a. Based on a complete review of the weld related Leckenby quality records and other visual inspection and nondestructive examinations, it is concluded that Leckenby performed the visual inspections on the SSW required by the specification and repaired the identified defects.

b. The recently performed UT results verified that the inspection and repair of the SSW electroslag welds by Leckenby was adequate, even though Leckenby did not assess and correct their electroslag fabrication difficulties.

c. Leckenby records indicate that they performed more UT for lamellar tearing on the SSW than was required by specification. The examination recorded no lamellar tearing or unacceptable indications. The UT defect repair criteria were more restrictive than what the specification required. The recently performed UT provided no results to indicate that Leckenby overlooked lamellar tearing or laminations.

d. The Burns and Roe visual inspection of the SSW only identified defects in 12% of the accessible welds. These defects, with exception to undersized and convex fillet welds, affect only a short part of the individual weld lengths. The defects are mainly associated with weld profile and workmansip. Most of these defects and their projections to inaccessible welds will not be detrimental to the performance of the SSW. Included are porosity, undercut, crater fill, arc strikes, and postulated slag inclusions. This conclusion is based upon the limited extent of the defects, the design loads based on the conservative static analysis and their minor significance for structures which do not experience cyclic loading. The undersized fillet welds were evaluated for plastic collapse and found acceptable for service considering the design loads and projected occurrence of critical defects of this type.

e. The visually identified defects by site construction contractors were few in number. The MT they performed resulted in a 11.6% rejection rate, not considered abnormal for a structure fabricated with only visual inspection required (excepting the lamellar tearing UT). These defects have been repaired.

f. The recently performed MT on undersized fillet welds found no cracks or lack of fusion. These results in conjunction with the Burns and Roe visual inspection provide confidence in the general soundness of the fillet welds and the low probability for cracking of those that are undersized.

g. The recently performed UT identified root defects, characterized as incomplete penetration, in welds associated with the FCAW and SMAW processes. These defects were analyzed in a generic manner and found acceptable. In addition, UT examinations showed that the type of defects anticipated due to unqualified welding procedures were not present.

h. A preliminary review of the initial concerns for weld quality raised the possibility of existing cracks and lack of fusion defects throughout the SSW. Careful exam'nation of each concern, together findings of the Burns and Roe visual inspection and additional MT and UT establish that this is not the case. In general, as discussed above, the weld quality was found to be acceptable. Based on the Task Force investigation, it is concluded that there is not a major problem with the as-built weld quality of the SSW.

i. By extrapolation of the previous site construction contractors' visual and MT findings, it could be postulated that there are cracks and crack-like defects present in the SSW. In addition, it is recognized that defects similar to those recorded and repaired could be assumed to exist in the inaccessible welds of the SSW. Accordingly, an evaluation of the structural integrity of the SSW was performed.

EVALUATION

Structural Integrity

An assessment of the structural significance of known and postulated defects in the SSW was made by the Welding Institute under contract to the applicant. The investigation of weld quality characterized the nature and extent of the flaws in accessible welds. The SSW was built using visual inspection for acceptance of welds. Visual inspection does not provide a high confidence of freedom from internal weld defects in a welded structure of this type. In addition, the information presented previously leads to the conclusion that defects and deficiencies are in the SSW. The primary aim of the structural integrity assessment was to determine the effect of postulated defects on the performance of the SSW under normal and design loadings.

Only two mechanisms of failure were considered to be relevant to the SSW in this situation; brittle fracture and plastic collapse. Other failure modes such as fatigue, corrosion and stress corrosion are not applicable.

Brittle Fracture Evaluation

Evaluation of the fracture safe design of the SSW was performed using the crack arrest/failure analysis diagram approach developed by Pellini and co-workers at the U. S. Naval Research Laboratories. This approach is based upon a structure operating at a sufficient margin above the nil-ductility transition temperature (NDT), such that unstable fractures which initiate from preexisting defects in weld joints will arrest in the base material or weld metal Thus, structural failure is prevented.

The margin above the NDT required to satisfy this arrest criterion is dependent on both thickness and applied stress. This approach avoids the need to predict conditions for initiation of unstable failure in the weld zone. Thus, if the crack arrest criterion is met during operation, then structural failure by brittle, elastic fracture will not occur even though defects, both crack-like and non-cracklike, are assumed to be in the weld joints. Using this approach, the size of the defects is not critical as large through-thickness flaws will arrest.

The philosophy behind the crack arrest approach is to assume that cracks can initiate at defects, at locally embrittled regions and at regions of high local stress and to demonstrate that fracture will be arrested by surrounding material. The details of the initiating defect and its immediate environment need not be considered. The simplest approach is based on the drop weight test (DWT) which measures the nil-ductility transition (NDT) temperature. From a knowledge of the NDT temperature, crack arrest can be assumed at a temperature of NDT + x, where x depends on nominal stress level, section thickness and size of initial defect. For initial defects of comparable or smaller size than the plate thickness, and for nominal stresses of around yield, the crack arrest temperature will be obtained from Pellini's Fracture Analysis Diagram (FAD) for 1" thick material. By applying a recommended 30°F temperature shift, allowance is made for the extra constraint in 3" thick material.

In applying this approach, all possible crack propagation paths are considered, fracture in parent materials, weld metals, and HAZs.

The fracture safe design evaluation requires knowledge of an upper bound NDT temperature for each type of material. For some materials this data is available. For others, correlations based upon Charpy impact data were used.

It was concluded that the upper bound NDT of A36 plate, A36 rolled sections and all weld deposits, except the electroslag weld deposits, could be adequately defined. The assumed NDT values for the A36 and A588 plate are based upon the as-rolled condition. Some plates have been cold bent to the radius of the SSW. Experiments were performed which showed the increase in NDT due to cold forming to the SSW radius is inconsequential and does not need to be considered.

For A588 plate steel, industry sources indicated a range of NDT values from 10-80°F. Because of this wide range, and the limited number of heats of A588 in the SSW, test samples of material from the SSW were taken to determine their NDTs. For the electroslag weld deposits, the data available was insufficient to confirm an upper bound NDT value with high confidence. Samples of weld material were removed from the SSW and weld procedure qualification tests were also run to get more data. In this new data, the highest NDT found was +60°F for an electroslag weld in the structure.

A study was performed to predict the SSW temperature during operations. The predicted range of normal operating temperature is +100°F to 135°F, with the outer surfaces being coolest. The most conservative situation is lowest normal operating temperature being at least 40°F above the highest known material NDT of 60°F.

Plastic Collapse Evaluation

Plastic collapse occurs when the net section is insufficient to support the load on it. This could be a problem where extended defects result in a significant reduction in net sectional area. Consideration of this possibility involves the assessment of the likely maximum size of defects at the various levels of section size and nominal stress present in the structure (residual stresses, which are self-balancing and are relieved by plastic flow, do not affect the tendency towards plastic collapse). If plastic collapse cannot be ruled out in certain details, the effect of loss of load-bearing capacity in these details must be examined.

The possibility of plastic collapse was assessed in terms of the nominal design stresses, the likely defect sizes and the estimated flow stresses of the materials (based on generic data).

The inspections performed to characterize weld quality were the basis for establishing the type and maximum size flaws in the structure. The maximum size flaw to cause the flow stress to be reached in the reduced net sectional area, while under nominal yield stress, was determined by calculation. This approach predicts rather large flaws, at least 12% of thickness for the full width of the member in the material with the lowest flow strength/yield strength ratio.

This approach is very conservative. Dynamic loadings increase the flow strength of these materials. The design of the SSW is such that nominal stresses under the worst conditions are only about half of yield in the highest loaded members. The inspections conducted have not found any defects approaching the maximum calculated flaw size for stresses of yield strength magnitude.

The vast majority of welds in the SSW will be limited in the strain they can undergo, because of the redundancy inherent in a system with multiple load paths, and because of the large mass of concrete which would provide some restraint. While it is probable that any region with critical defects will reach yield on the net section, in order to reach the flow stress considerable plastic deformation will need to take place. This could only be possible if all the members in parallel had defects of the critical dimension. This is extremely unlikely because, although many welds probably contain defects, it is only the large, extended ones which are critical, and the chances of these existing in all parallel welds is very remote.

Girth Weld Repair

During the girth weld repair, other defects were found and repaired. The defects were typical of a structure built to visual standards, i.e., in accordance with AWS D1.1. The size and nature of the defects found were bounded by the brittle fracture and plastic collapse.

Hence, they would not affect the results of these analyses. Repairs and the girth weld were completed to AWS D1.1 requirements.

CONCLUSIONS

Considering the low stresses under the highest loads (30% of yield), and a minimum operating temperature which is 40°F above NDT, the staff concludes the structure is not subject to brittle fracture. The through-thickness flaws will not propagate by the brittle fracture mechanism.

The staff considers plastic collapse of the SSW under design conditions as not being a credible failure mode. It would require loads much greater than were considered in the design of the structure.

Accordingly, the staff concludes that the applicant has demonstrated that the structural integrity of the SSW will meet its design requirements with known and postulated flaws. The public health and safety are adequately protected in that this structure, as repaired, will perform satisfactorily within the design limits established.