GENTILLY-2 AND POINT LEPREAU DIVIDER PLATE REPLACEMENT

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ABSTRACT

The steam generators at Hydro Quebec's Gentilly-2 and New Brunswick Power's Point Lepreau Nuclear Plants have been in operation since 1983, and were built with primary divider plates of a bolted panel configuration.

During a routine outage inspection at Gentilly-2, it was noted that two bolts had dislodged from the divider plate and were located lying in the primary head. Subsequent inspections revealed erosion damage to a substantial number of divider plate bolts and to a lesser extent, to the divider plate itself. After further inspection and repair the units were returned to operation, however, it was determined that a permanent replacement of the primary divider plates was going to be necessary. Upon evaluation of various options, it was decided that the panel type divider plates would be replaced with a single piece floating design. The divider plate itself was to be of a one piece all-welded arrangement to be constructed from individual panels to be brought in through the manways. In view of the strength limitations of the bolted attachment of the upper seat bar to the tubesheet, a new welded seat bar was provided. To counteract erosion concerns, the new divider plate is fitted with erosion resistant inserts or weld buildup and with improved sealing features in order to minimize leakage and erosion.

At an advanced stage in the design and manufacture of the components, the issue of divider plate strength during loss of coolant accident (LOCA) conditions came into focus. Analysis was performed to determine the strength and/or failure characteristics of the divider plate to a variety of small and large LOCA conditions. Subsequently, Point Lepreau decided to replace their divider plates to address LOCA concerns.

The paper describes the diagnosis of the original divider plates and the design, manufacture, field mobilization, installation and subsequent operation of the replacement divider plates.

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INTRODUCTION

In September 1993, it was discovered at Gentilly-2 that the original primary side divider plates in operation in the steam generators since 1983 had experienced a degree of degradation. The units were inspected, the damage stabilized and returned to service. Over a period of months, the problem and various repair alternatives were evaluated and replacement divider plates were designed, developed and installed so that the units could be returned to service with new divider plates in June 1995 as described in this paper. The issue of divider plate strength during loss of coolant accident (LOCA) conditions came into focus at a later stage of the design phase. Analysis was performed to determine the strength and/or failure characteristics of the divider plate to a variety of small and large LOCA conditions. Subsequently, Point Lepreau decided to replace their divider plates to address LOCA concerns.

SEGMENTED DIVIDER PLATES

The original divider plate construction for the Gentilly-2 and Point Lepreau steam generators incorporated a number of 1½ inch thick vertical panels supported by peripheral seat bars, as shown in Figure 1. The divider plate assembly was of a floating configuration in which the segmented panels rested on the seat bars at their periphery in such a way that the dilation of the pressure vessel during changes in operating temperature and pressure were accommodated by sliding of the floating divider plate relative to the seat bars. The divider panels were attached to each other by a lap joint secured by a number of bolts. The lower edge of the floating divider plate was supported by a seat bar which was partial penetration welded to the primary head. The lap joint between the divider panels and the primary head seat bar was clamped by clamping blocks. The upper edges of the divider panels were bolted to a seat bar which was bolted to the tubesheet. At the outer corners of the divider plate a space exists bounded by the end of the tubesheet seat bar, the head seat bar, and the divider panels. This area is filled with an "ear" shaped filler block, affixed to the outer- most divider panels to help reduce cross flow leakage. The divider plates were designed as segmented panels in order to meet the specified requirement that they be removable. Their design function was to partition the steam generator primary head so that the primary flow was directed from the inlet side of the head, through the tubes to the outlet side. This process involves a pressure drop across the divider plate of approximately 35 psi.

During a routine inspection in September 1993 at Gentilly-2 , it was discovered that two of the divider panel joint bolts were missing. One was discovered lying in the head and the second some distance down the primary piping. It appeared that the bolts which tend to be held in place by the flow had simply popped out at some time during the shutdown or during the subsequent waterjet decontamination process. Further examination showed that a number of the divider panel joint bolts had experienced erosion to the underside of the bolt head, to the shank of the bolt and even to engaged threads. The divider plate components of all four steam generators experienced this type of damage to some degree. The divider panel to tubesheet seat bar bolts experienced a similar type of damage. The clamping block and tubesheet seat bar bolts were relatively unaffected. After further inspection, it was determined that 9, 12, 20, and 7 bolts had to be replaced on SG's #1, 2, 3 and 4, respectively. On return to operation, it was noted that surprisingly the performance of the steam generators improved by a small but significant amount, and that the amount of improvement happened to be consistent with the number of bolts which had been replaced in the respective steam generators. This reinforced the perception that divider plate cross flow leakage may have been more significant than previously assumed.

REPAIR & REPLACEMENT CONCEPT

On return to operation, work began immediately at Babcock & Wilcox (B&W) to develop a more permanent repair or replacement for the existing temporarily repaired divider plate. An initial concept for a flat floating divider plate somewhat like that used on the later CANDU 6 steam generators was quickly conceived. It was realized that it should be possible to install the very large divider plate into the primary head in only 4 pieces. This was a very important consideration in minimizing the amount of in-head fit up and welding. In response to questions, suggestions and feedback from Hydro Quebec and New Brunswick Power, numerous variations and fixes were evaluated. At some point the variations included - replacement of the existing divider plate bolts only, doubling the number of bolts, replacement of the existing divider plate bolts and seating clamps, seal welding of the divider plate panels and replacement of bolts, replacement of the entire divider plate with a similar assembly, replacement of the divider plate with a one piece floating design with bolted joints, robotic installation of the divider plate replacement components, application of a seal panel over the face of the divider plate to preclude leakage, adding a seal panel and repairing bolts as well - and other variations too numerous to mention. Many of the alternatives were developed to the point of having a worked-out design concept, feasibility and cost.

Assessment of the individual options indicated that many of the quick and cheap options were in fact not quick and not particularly cheap, often costing a large fraction of the full replacement cost and taking as long. It was also determined that the divider plates had to satisfy a wide range of requirements which were not met by any of the "quick fix" options. The selected option had to - correct the loose parts problem, sustain normal operating pressure differentials, accommodate vessel thermal motions, reduce divider plate leakage to an absolute minimum, preclude on-going erosion damage, accommodate various forward and reverse LOCA loads in an acceptable manner, be installed in a short period of time with a minimum radiation uptake, minimize in-head work including welding and be of a reliability consistent with this critical application.

After evaluation of many concepts and performing many cost and feasibility assessments, it was determined that a replacement divider plate of a dish shaped, welded one piece, floating configuration was the only concept which adequately addressed all of the requirements.

WELDED FLOATING DIVIDER PLATE

A unique 3/4 inch thick curved divider plate concept was developed in order to address the problems associated with field welding a 1-1/2 inch thick flat replacement divider plate. The curved portion of the replacement divider plate is supported by a robust peripheral rim that enables it to carry the load in both membrane and bending. This permits a thinner, lighter divider plate which provides greater strength than the original 1-1/2 inch flat divider plate. A 3/4 inch thick curved divider plate requires only about 33% of the field weld volume of a flat 1-1/2 inch thick divider plate. Since the field welding of the divider plate is performed manually this results in significantly less radiation exposure to installation personnel. It is important that weld distortion be minimized so that the supporting seat bars do not bind but permit the divider plate to float freely. The robust rim of the replacement divider plate is effective in restraining the relatively thin divider plate during welding thereby reducing distortion from the field welding process. A replacement tubesheet seat bar is provided to increase resistance to erosion and to provide increased strength over the original seat bar. It is a two-piece design and welded onto the tubesheet overlay with partial penetration welds.

In summary, the features of the replacement divider plate shown in Figure 2 include:

- strong, light weight, welded one-piece construction designed to minimize both field welding and associated distortion
- fabricated in four segments that are manipulated into position in the primary head via the manway openings
- floating tongue and groove support
- tight fit up tolerances at sealing surfaces to minimize leakage

- erosion resistant material at all sealing surfaces to preclude erosion
- new, higher strength tubesheet seat bar welded to tubesheet overlay
- ears integral with the new tubesheet seat bar which fill the corners and create an essentially continuous seat bar around the entire periphery of the divider plate

FUNCTIONAL DESIGN

The primary function of a steam generator divider plate is to divert the flow arriving from the reactor outlet header into the tube bundle so that heat can be rejected into the secondary side fluid and steam generated. The divider plate is designed to float freely so that it will not restrain the tubesheet and primary head as they dilate under pressure and thermal loading. Because of the severe thermal transient loading experienced under normal operation, this is a very desirable feature. The tongue and groove design of Figure 2 provides this feature with a minimum of divider plate bypass leakage.

The specified leakage for the replacement divider plate is 1% maximum. By tolerance control at the seat bars and the corner filler 'ears', the calculated leakage during normal operation is 0.6%. Because the material at sealing surfaces is erosion resistant this leakage rate is expected to remain constant throughout the life of the steam generator.

STRUCTURAL DESIGN

The normal operating pressure drop is approximately 35 psi, however a static design pressure differential of +/-60 psi has been specified. This is the same as that previously used to evaluate the original divider plate. Because the divider plate, under positive pressure differential, is put into compression there is the potential for geometric instability (buckling). In addition, the stress levels are higher than the material yield strength at a pressure differential (120 psi) that provides an appropriate margin of safety. This precludes elastic analysis methods. A non-linear elastic-plastic buckling analysis was carried out in order to satisfactorily demonstrate the curved divider plate's load carrying capacity. This analysis shows that as the load is increased, the curved portion of the divider plate tends to flatten and becomes more flexible and eventually pushes through to assume a reverse curvature with increasing stiffness. The divider plate does not become disengaged nor does it take on a significant permanent set as a result of a pressure of 120 psi. Therefore the replacement divider plate design provides ample margin of safety for a design pressure differential of +/-60 psi.

As a means of demonstrating adequate strength during a small LOCA, the divider plate was designed to sustain a static pressure differential of 130 psi. At this load the divider plate deflects to the point where it has assumed a degree of reverse curvature having pushed through slightly. However, it remains fully engaged with the supporting seat bars around the entire periphery of the divider plate and the seat bars and welds remain intact.

LOCA LOADS

In December 1994, at a point where the divider plate concept and design had been fully detailed and where materials procurement and manufacture of components were underway, the need to design for LOCA loads suddenly changed from a consideration to a major requirement. LOCA load requirements were developed by Hydro Quebec in conjunction with New Brunswick Power who were simultaneously considering the need for divider plate replacement. It thus became necessary to show that the divider plate would sustain a range of small LOCA loads without collapse or disengagement and to show that during very large LOCA loads the divider plate would be released without generating any loose parts outside the steam generator.

To address the LOCA loads, a large number of pipe break/divider plate condition cases were identified and modelled by Hydro Quebec. Response to the divider plate to small LOCA and a large LOCA was evaluated for B&W by Ontario Hydro using a dynamic, elastic-plastic finite element analysis. The results of the analysis have shown that the divider plate is able to sustain small breaks (5% and 7-1/2% break sizes) with significant distortion but without any disengagement of the divider plate from the seat bar. For the purpose of modelling LOCA flow conditions, this allows the divider plate to be considered totally intact. The response of the divider plate to a small break LOCA is shown in Figure 3.

For the very large LOCA loads, the dynamic elastic-plastic analysis shows that the divider plate fully disengages from the seat bars. The central portion of the divider plate first pushes through and dishes in the downstream direction, next the upper rim pulls downward and begins to disengage from the tubesheet seat bar and finally the entire peripheral rim pulls away and disengages from the seat bar and moves toward the outlet nozzle. Further finite element analysis for the remaining intermediate LOCA loading is planned that will couple together the response of the primary fluid during the LOCA event with that of the divider plate. That is, as the divider plate becomes partially disengaged and bypass flow area develops, full credit will be taken for the reduction in pressure loading caused from by-pass flow.

In the large LOCA case, analysis has shown that the divider plate is totally intact after disengaging though severely distorted and that the new tubesheet seat bars and welds remain totally intact. The new U-shaped liner which is applied over the primary head seat bar by double strength welds does experience severe distortion during the disengagement of the divider plate. It may shear through at a corner but the remaining pieces would remain attached to the seat bar because of the strength welds. Verification of this will be carried out by employing detailed computer modelling. Since there exists the possibility that a fully disengaged divider plate could partially block the outlet flow and effect the response of other system components, further detailed finite element analysis is planned to confirm the percentage blockage of the outlet nozzle.

COMPONENT MANUFACTURE

The replacement divider plate components are a unique and novel design and therefore required the development of unique and novel manufacturing procedures. The divider plate was manufactured by a vessel fabricator as a heavy peripheral "window frame" into which was welded the curved central portion. Subsequently the 4 segments were prepared for field assembly by breaking the divider plate assembly into 4 pieces and adding the edge weld preparations. The complex shape of the tubesheet seat bar was machined from a solid forging by an aircraft component manufacturer using sophisticated NC machines to deal with the complexities of the 7° divider plate slope and the ear profile.

INSTALLATION

Two criteria were established for the design of tooling and processes for installation of the replacement divider plates; minimize radiation exposure and assure worker safety. These were sizable challenges. The upper and lower centre plates each weighed 300 lbs, and the radiation fields in the primary head at Gentilly-2 were expected to be in the range of 250 mRem/hour. These factors were compounded by the fact that the primary head is a confined space only 34 inches high.

Initial installation concepts included using a manipulator(s) to remove the existing plates and to install and weld the replacement plates. Various manipulator systems were investigated including COBRA (Framatome Technologies), SCOMPI, and AECL manipulators. Some of these manipulators could perform multiple functions while others were looked at as single function arms. All of the robotic systems were rejected because they provided minimal schedule and dose savings, and added significant cost to the project. As a result of this study, divider plate replacement became a labour intensive process.

Computer modelling was performed to define the motions required to move the replacement plates into the primary head, and to lift them into position. It became obvious from this study that the safety of a man working in the primary head could not be assured during plate handling operations. Therefore, rigging and lifting systems were developed to allow remote installation and positioning of the plates.

ALARA objectives were met by providing shielding within the primary head. Shielding the tubesheet was determined to provide the maximum dose reduction. A system consisting of a structural frame which reacted off of the primary head and supported a plastic coated lead plate was developed.

A full scale mockup of the 600 MW primary head was built to test the installation processes, and train the craft labour needed to perform the modification. Walls and obstructions were built outside of the mockup to simulate the boiler cabinet. The tube sheet shielding system and all prototypical tools were used in the mockup. Initial process verification tests were performed using full size replacement hardware constructed from Lexan. The light weight plates allowed engineers and technicians to enter the mockup during plate installation to observe the operation of the lifting devices, and the motions of the plates. After the processes were proven, the Lexan plates were replaced by steel plates which were the same weight as the prototype plates. These plates were used to qualify the process, and to train the craft labour. All supervisory personnel were trained on the mockup at B&W in Cambridge. The mockup and a set of clean tools were shipped to site where the mockup was used to train the craft labour hired to perform the modification.

Extensive welding tests were performed in parallel with the removal/installation work. The resulting welding process for the 3/4 inch full penetration weld required simultaneously welding from both sides of the plate to minimize distortion due to welding.

Replacement one piece floating divider plates were installed at Gentilly-2 beginning in April 1995, and at Point Lepreau beginning in June 1995. Significant management and technical challenges were encountered at each site. Figure 4 shows the access constraints for the field installation.

Gentilly-2

Divider plate replacement was performed in two steam generators in parallel, working two 12-hour shifts per day.

The dose rates in the steam generator primary heads at Gentilly-2 averaged 1.5 to 2 Rem/hour without shield, and 600 mRem/hour with the tubesheet shielding installed. The dose rates on the steam generator platforms were 300 mRem/hr. These fields were more than double the anticipated dose rates. As a result, increased numbers of craft labour were required to perform the task. Recruiting, training, and badging these personnel became a larger task than the replacement of the divider plates.

B&W set up an off-site mock-up facility where craft labour were trained, and welders were qualified. This facility was staffed 24 hours a day, seven days per week. A 4 day craft personnel training cycle was established. The cycle consisted of one day for ARW medical examination, two days of mockup training, and one day for orange badge training. All personnel were required to dress in a plastic suit, and work inside the mockup. Training was limited to the tasks which would be in progress when the craft reached site. Once on site, the craft personnel on average worked for two days. A total of 223 craft personnel were required to replace the four divider plates.

In the field, the old divider plates were quickly removed. After the old divider plates were removed from the first steam generator, B&W discovered that the primary head seat bar was eroded. The condition was found in all four steam generators with approximately 1/3 of the arc length having significant erosion. Weld repair was performed on each seatbar, which was ground smooth prior to installation of the liner. No major technical problems were encountered during the installation of the replacement hardware.

The replacement of the divider plates in the first pair of steam generators required 15 days. Replacement of the divider plates in the second pair of steam generators required 9 days. The average dose uptake for the project was 1.2 Rem/man.

Point Lepreau

Divider Plate Replacement at Point Lepreau was performed in parallel with SLAR operations. During SLAR operations access to steam generators 1 and 3 was stopped due to the radiation fields originating from the fuel in the fuelling machines. Access was possible during the period of time when maintenance was performed on the SLAR tool. The SLAR maintenance outages were defined as the windows where maintenance could be performed in steam generators 1 and 3. The start date for these windows were not fixed in time, and the duration was variable.

B&W and New Brunswick Power established a three window plan for replacing divider plates in steam generators 1 and 3. During window 1, the existing divider plates were removed. During window 2, the tubesheet seatbar was replaced, and the liner was installed on the primary head seat bar. During window 3, the new plates were installed. The replacement of the divider plates in steam generators 2 and 4 was scheduled to be performed after the completion of boilers 1 and 3 without the access restrictions due to SLAR.

The three window plan resulted in increased numbers of personnel, increased site time, increased dose, and increased cost. These factors were compounded by changes in the schedule. However, there were benefits from these windows.

After the old plates were removed, the seat bar erosion was found to be much worse than seen at Gentilly-2. The erosion spanned the full arc length of the seatbar, and was evident on both the hot leg and cold leg sides. The time between windows 1 and 2 was used to design and fabricate a fixture to recondition the seatbars.

As anticipated, the dose rates at Point Lepreau were significantly lower than at Gentilly-2. The primary head dose rates were 100 mRem/hour. Because of these low rates, the tubesheet shielding was not used. This improved access to the tubesheet and corner seal bar welds, resulting in improved production schedule and lower accumulated dose.

A total of 98 people were on site as a result of the 3 window plan (56 craft were on site to perform the window 3 work on steam generators 1 and 3 and to perform the replacement on steam generators 2 and 4). The average personnel exposure was 700 mRem per man. The average time to complete the replacement of a divider plate was 5 days.

RETURN TO OPERATION

In operation the divider plates at Gentilly-2 and Point Lepreau have been performing very well. Prior to the divider plate replacements, the steam generators at both plants had been experiencing a continuous degradation of performance in the form of an increase of the reactor inlet header (RIH) temperature. On re-start Gentilly-2 and Point Lepreau were observed to have very large RIH temperature reductions, averaging 5.2°C and 3.6°C, respectively.

At Gentilly-2 the divider plate replacement was the only relevant change, other than ID cleaning of a very small number of tubes on one generator. Point Lepreau performed primary and secondary side chemical cleaning in parallel to the divider plate replacement to gain RIH temperature improvement.

This type of RIH temperature improvement will indefinitely avoid the need for plant derating at Gentilly-2 which had been anticipated prior to the outage. Similar benefits will also be realized at Point Lepreau.

CONCLUSION

The replacement of the segmented original divider plates at Gentilly-2 and Point Lepreau with a welded floating one-piece design has been completed as a unique first-of-a-kind operation. The result has been a very satisfactory installation of a design which is better able to meet the various loading requirements and which has had the effect of substantially improving plant performance.

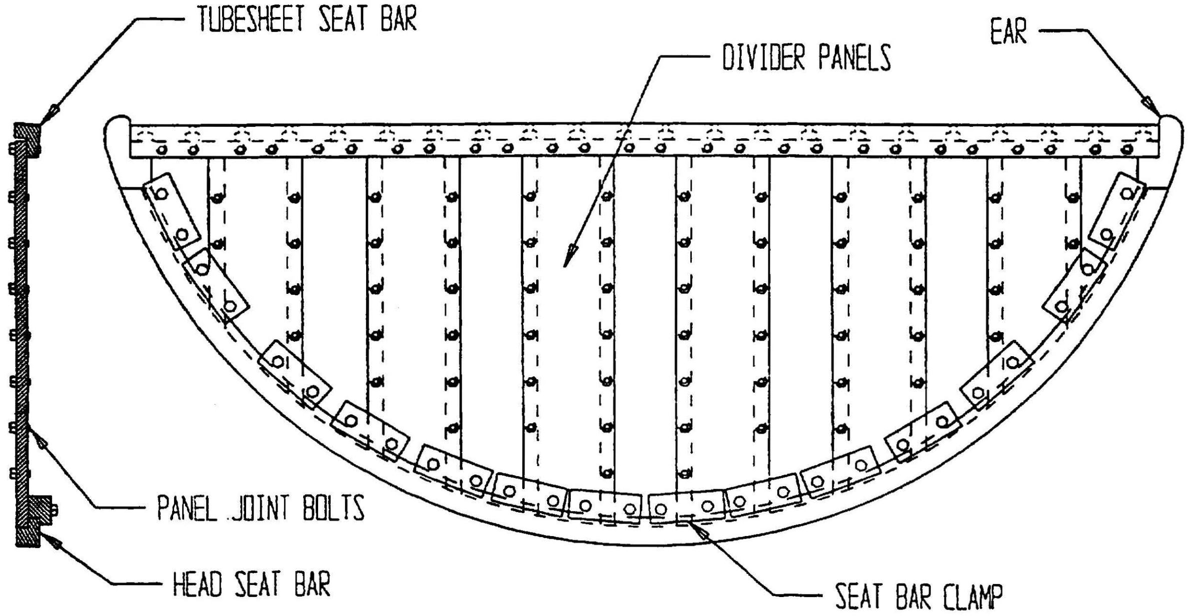

FIGURE 1: SEGMENTED DIVIDER PLATE

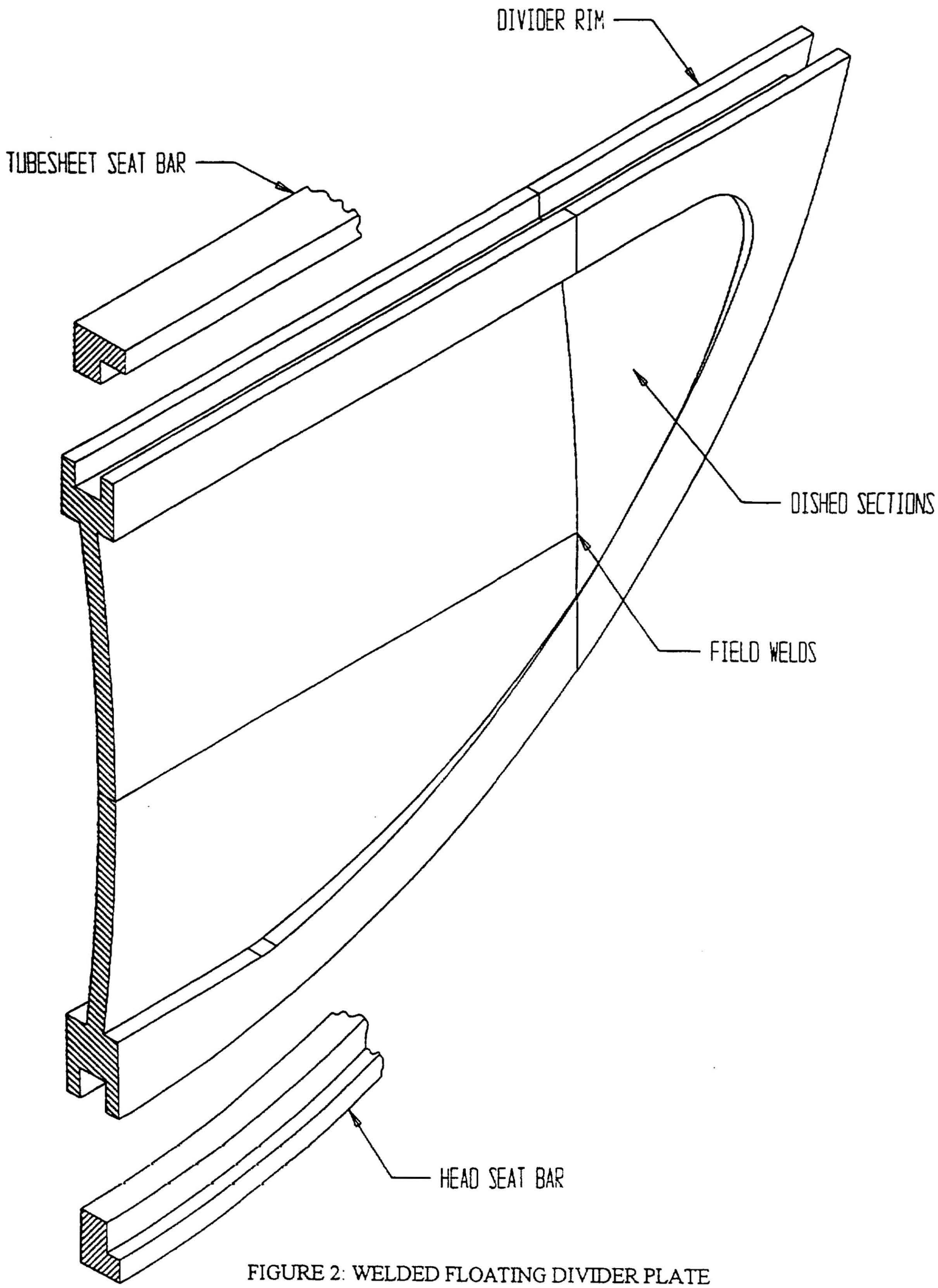

FIGURE 2: WELDED FLOATING DIVIDER PLATE

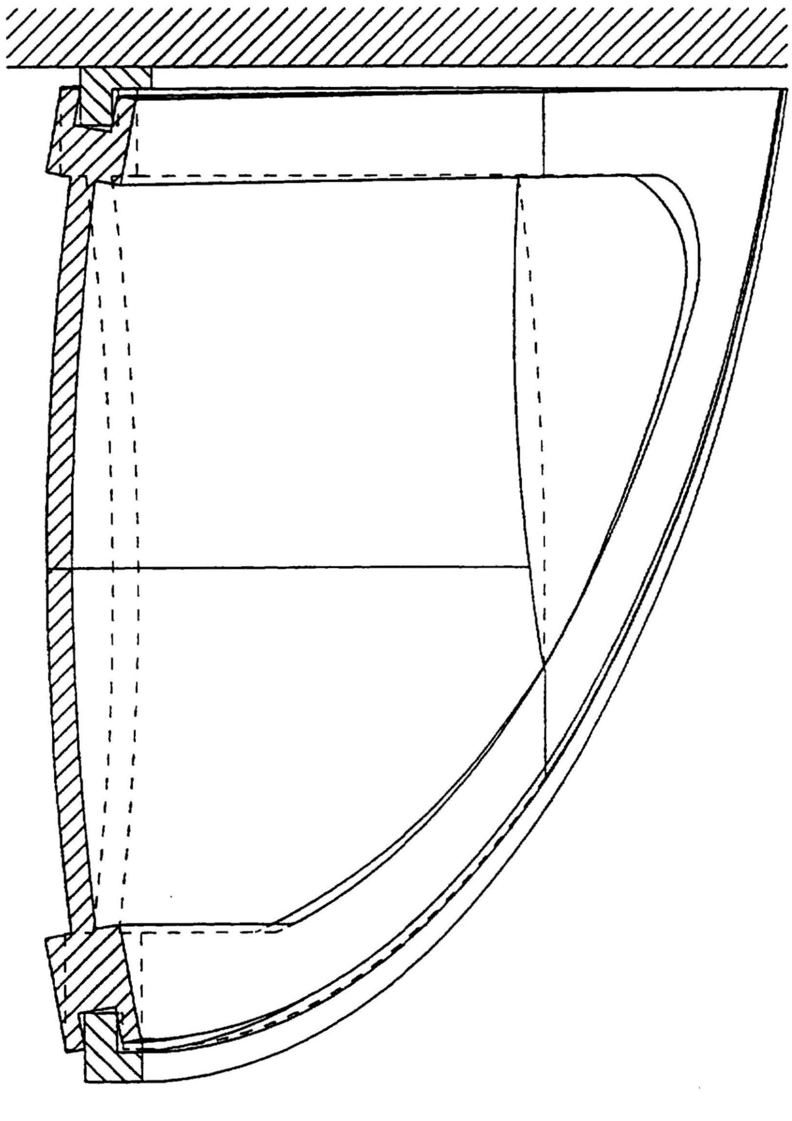

FIGURE 3: DIVIDER PLATE UNDER SMALL BREAK LOCA LOADS

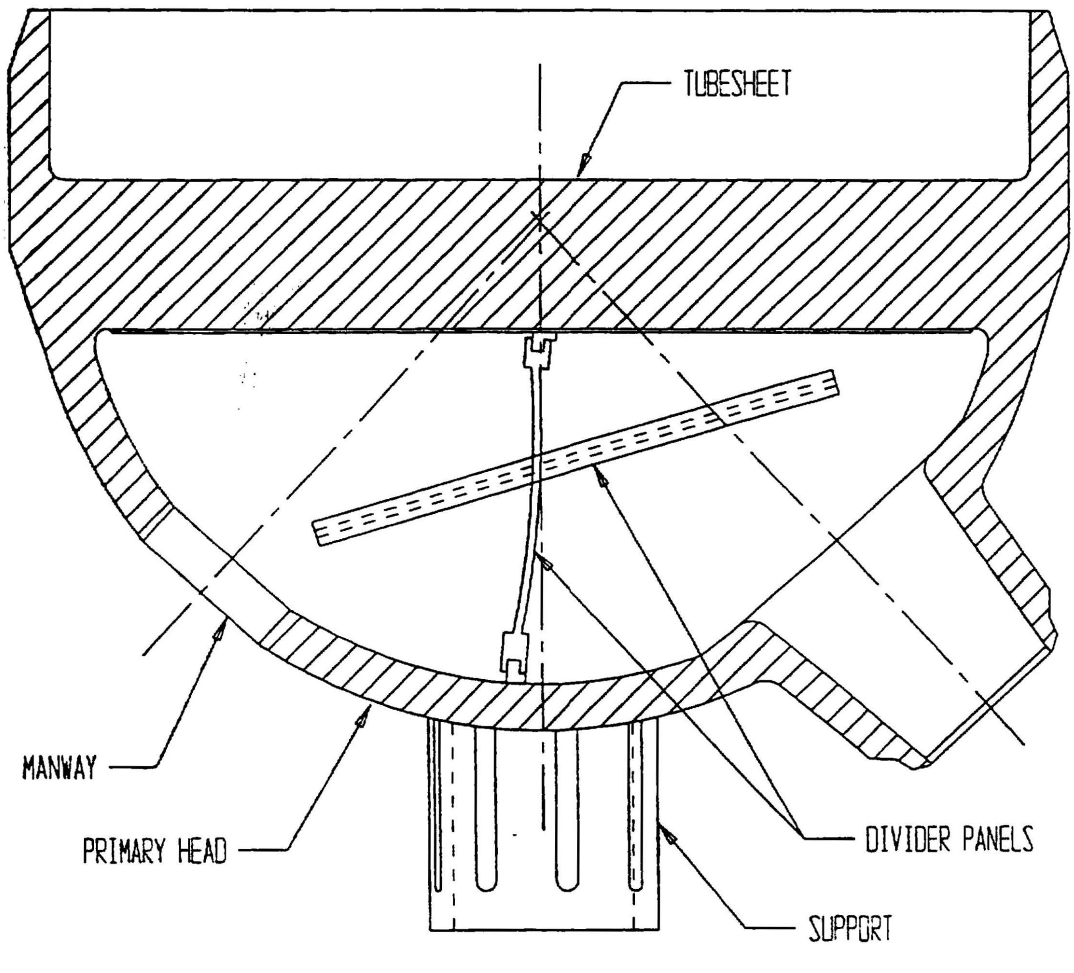

FIGURE 4: DIVIDER PLATE REPLACEMENT

POINT LEPREAU GENERATING STATION

INFORMATION REPORT

STEAM GENERATORS SECONDARY SIDE CHEMICAL CLEANING AT POINT LEPREAU G.S. USING THE SIEMEN'S HIGH TEMPERATURE PROCESS

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